

Integration of Nature-Based Solutions into Flood Defence for Sungai Damansara using Info Works Integrated Catchment Modelling

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ABSTRACT

In Malaysia, intense floods such as flash floods are characterized by rapidly rising water levels and sudden onset, often overwhelming flood defences and evacuation routes. The Sungai Damansara catchment in Selangor has experienced frequent and severe flooding despite conventional structural mitigation measures, including flood walls and detention ponds. Rapid urbanization in the region has reduced natural infiltration, increasing peak runoff and surface discharge. This study explores the use of Nature-Based Solutions (NBS), specifically Floodplain and Riparian Zone Restoration (Flood Resilient Redevelopment), to mitigate flooding. Critical factors such as water level and flow rate were assessed for their influence on flood severity and associated risks. A coupled 1D–2D hydrodynamic model was developed using InfoWorks Integrated Catchment Modelling (ICM) software to simulate flood behaviour under existing conditions and scenarios enhanced with NBS, flood walls, and pond modifications. Design storms with a 200-year Annual Recurrence Interval (ARI) were used to evaluate extreme flood impacts. Simulation results indicated that NBS reduced water levels by up to 12% and peak flow by up to 78% for a 200-year ARI event compared to existing conditions. In contrast, flood walls had minimal hydrologic impact, while pond modifications reduced water levels by only 4% and peak flow by 10%. These findings demonstrate that NBS can outperform conventional measures in flood attenuation while enhancing ecological resilience. The study highlights the potential of NBS to complement or even replace traditional hard infrastructure, supporting integrated and sustainable flood risk management strategies in rapidly urbanizing catchments.

Keywords: Nature-based solutions; Integrated Catchment Modelling; flood defences

INTRODUCTION

The emergence of new flood cases that severely affected Sungai Damansara catchment could be narrowed down to the inefficient flood mitigation that was already in place along the river (JPS 2021). Besides that, high tide, backwater effect from Sungai Klang and clogged drains also contributed to the flooding of Sungai Damansara catchment as reported by the Department of Irrigation and Drainage (DID). DID also mentioned that among the causes of floods are bund and flood wall breaches like the one in TTDI Jaya during the 2021 flood event (DID 2021). This indicates that grey-engineering solutions, such as those mentioned, carry inherent risks, particularly when structural failure occurs, potentially endangering the very

areas they are designed to protect. Furthermore, the increasing intensity and unpredictability of rainfall due to climate change have exacerbated flood occurrences in low-lying urban areas (Mohd et al. 2023). Besides physical damage, flood disasters also produce wide-ranging social and economic consequences that are often difficult to quantify, as they affect livelihoods, community well-being, and public perception over both short- and long-term periods (Mohamed et al. 2024). The discharge of untreated industrial wastewater containing high levels of heavy metals is highly toxic even at low concentrations, making effective removal essential (Lokman et al. 2023). In the event of flooding, the release of untreated industrial wastewater may worsen, thus it is crucial to implement initiatives that can reduce or prevent flooding from occurring. Hence, the aim of this research is to introduce

and study the effectiveness of a nature-prominent flood mitigation for Sungai Damansara catchment, namely the Nature-based Solution (NBS) using Infoworks ICM. NBS is a flood mitigation method that incorporates the idea of returning the flood plain back to its natural course, which has less urbanization and promotes plenty of greenery, or termed as 'intermittent areas' that will reduce surface runoff and relatively decreasing the curve number (CN) thus improving soil infiltration of the catchment.

In this research, the effectiveness of nature-based solutions would be tested using hydrological and hydrodynamic modelling. Findings suggest that NBS effectively reduces flood risks by lowering runoff and controlling soil erosion. Increased vegetation cover, as evidenced by Peng et al. (2022), improves soil stability and reduces sediment discharge. The integration of multi-functional floodplains enhances community resilience and aligns with national water management policies Malaysian Water Partnership, (MWP) and the Malaysian National Committee for Irrigation and Drainage (MANCID). NBS offers a promising alternative to conventional flood mitigation methods by enhancing ecological resilience and promoting sustainable water management. The limitations of conventional flood engineering necessitate alternative approaches. This research explores NBS as a viable long-term flood mitigation strategy, addressing sustainability and multifunctional benefits. Although hard engineering measures like bunds and flood walls are effective for low Annual Recurrence Interval (ARI) rainfall, they often fail under extreme conditions, as seen in the 18 December 2021 flood event. NBS offers an adaptive and resilient alternative, integrating flood management with ecological and social benefits. NBS also supports sustainable approaches that enhance flood resilience while improving biodiversity, air and water quality, and overall community well-being. They support vital ecological processes and offer multiple co-benefits, making them a superior strategy for climate adaptation and disaster risk reduction (Esra-Ul-Zannat et al. 2024).

Additionally, this study promotes the Living with Flood (LwF) concept, advocating for the coexistence with river systems rather than rigid suppression of natural watercourses. Despite Malaysia's comprehensive flood management framework and significant investments, the implementation of NBS and innovative approaches like the LwF concept remains difficult. The LwF, which promotes coexistence with natural river systems and has shown success in countries like the Netherlands by enhancing biodiversity, water quality, and climate resilience (Costa et al. 2021), is still underutilized in Malaysia. This is largely due to fragmented coordination between federal and local governments, where weak intergovernmental cooperation and delayed responses

hinder the effective integration of NBS into national flood mitigation strategies. The institutional disconnect continues to obstruct the shift from traditional structural controls to more adaptive, nature-based approaches (Rosmadi et al. 2024). For the Sungai Damansara basin, this research highlights NBS as a transformative approach, enhancing flood resilience while improving urban planning, green spaces, and overall quality of life. By demonstrating NBS feasibility, the study aims to shift local flood management paradigms towards sustainable, long-term solutions.

METHODOLOGY

STUDY AREA

The district of Damansara is located in Kuala Lumpur, under the jurisdiction of Majlis Bandaraya Petaling Jaya (MBPJ), and situated at 3°8'45.6" latitude and 101°32'27.24" longitude. The catchment area is approximately 151km². The main river that courses through the Damansara district is the Sungai Damansara. The location of the river along with the catchment boundary can be seen in Figure 1.

Sungai Damansara is a tributary of the main Sungai Klang, and it runs its course from Kampung Melayu Subang and merges back downstream at the confluence of Sungai Damansara and Sungai Klang, near the Taman Sri Muda area. The river itself has its own major tributaries which are the Sungai Ayer Kuning, Sungai Kayu Ara and Sungai Rumpit. The total length of the river is 42.1 km. There are three main ponds along Sungai Damansara that served as a flood mitigation measure, namely the Rubber Research Institute of Malaysia (RRIM) Pond, Subang Airport South (SAS) Pond and Eko Ara Damansara (EAD) Pond.

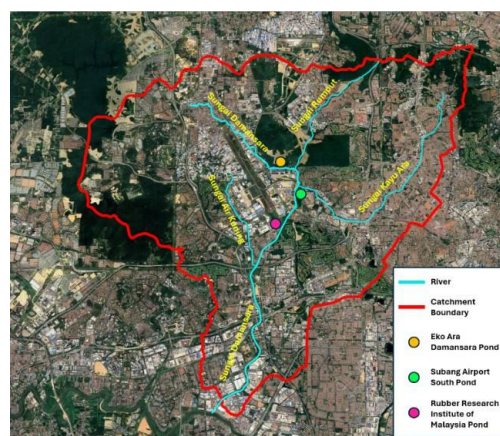


FIGURE 1. Catchment boundary for Sungai Damansara

DATA COLLECTION

The development of the Sungai Damansara hydrologic and hydrodynamic model required extensive data acquisition, categorized into key datasets, including hydrology and historical flood data, engineering river survey drawings, existing river conditions, land use information, and streamline, contour, and digital terrain models (DTM). These datasets were crucial in ensuring an accurate representation of the catchment's behavior under different hydrological conditions, showing that one of the cores of this study is data gathering. Lack of data would lead to inaccurate results, errors and the failure of the software to execute simulations. Catchment delineation is a fundamental step in hydrological modeling, as it defines the area where all surface runoff converges toward a single outlet, forming the basic spatial unit for analyzing rainfall–runoff processes and flood behavior (Ping et al. 2024). One of the most important data to be fed into the model is the rainfall data. Without rainfall data, it can be said that the model would be useless in generating results with the exception that the model only uses base-flow from the delineated catchment. There are two types of rainfall data to be considered in this model. Firstly, historical rainfall data that was obtained from DID and for the design rainfall, data was collected from DID Hydrological Procedure 1 (HP1), where the nearest rainfall stations to the study area were considered. The design data were interpolated through Thiessen Polygon. In this research, 200-year ARI representing extreme design storms would be used for the flood mitigation design of Sungai Damansara.

The contour data was processed to determine the time of concentration (T_c) for each sub-catchment. The contour information was used to define slope gradients, which were then applied in calculating flow paths and travel times. Land use data was acquired from Department of Survey and Mapping Malaysia (JUPEM) to generate curve number (CN) values for the delineated sub-catchments. Each land use type was assigned an appropriate CN value based on the US Soil Conservation Service (SCS) method, enabling the generation of realistic catchment hydrographs using InfoWorks ICM. Survey data was also incorporated to represent the actual river and structural conditions, including bridges, drains, and tidal control gates. These datasets were integrated into the model to ensure accurate representation of flow resistance, conveyance, and storage capacity.

Altogether, these datasets formed the basis for hydrological and hydraulic simulations in InfoWorks ICM, supporting accurate flood risk assessment and mitigation scenario development.

MODEL DEVELOPMENT

Flood prediction models are essential tools for understanding hydrological behavior and improving flood management strategies. By integrating hydrological data, these models provide an effective means to analyze flood dynamics, assess hazards, and guide flood mitigation planning. Their strength lies in enabling comprehensive evaluations of rainfall–runoff processes to enhance preparedness and resilience (Ehsan et al. 2024). In this study, a comprehensive hydrological and hydrodynamic model for Sungai Damansara was developed using InfoWorks ICM, integrating 1D and 2D modeling approaches. The 1D hydrological analysis, focusing on rainfall–runoff modeling, employed the SCS Unit Hydrograph method.

The catchment of Sungai Damansara was delineated into smaller sub-catchments as seen in Figure 2 that would give a better representative of soil conditions when it was subjected to individual land use data. Catchment delineation was performed by defining boundaries based on contour data and subdividing the catchment into smaller and more precise sub-catchments. Sub-catchment parameters, including CN and T_c values, were assigned for accurate runoff modeling. Then, excess rainfall from sub-catchments was routed using the Unit Hydrograph method. The 1D model represented the hydrological flow in the river system, focusing on the main river reaches and omitting floodplain spillovers. Simulations were carried out for various storm durations to determine the critical storm duration. The model was calibrated with real rainfall and water level data.

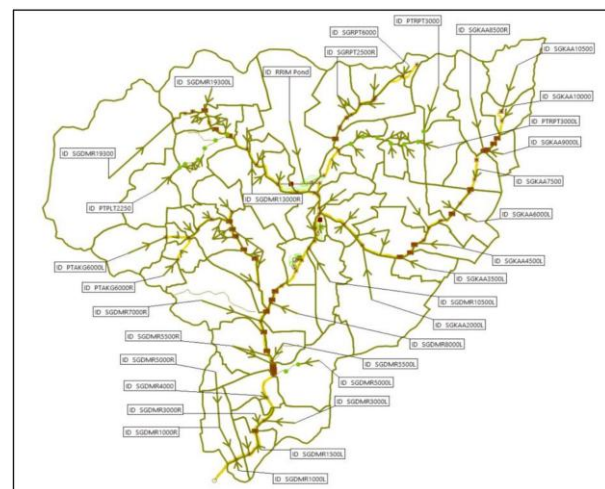


FIGURE 2. The existing river model of Sungai Damansara along with delineated sub-catchments

After completing the 1D model, it was then converted into a 2D model. After creating a model with river reach and bank lines, a connection between the bank lines and the ground model had to be created in order to simulate an overspill. That is where the 2D mesh was utilized. In simple terms, the 2D mesh can be likened to a representation of a floodplain. A 2D mesh is a mesh of triangles and elements that when generated, its vertices will give heights that are calculated through interpolation from the ground model. The 2D mesh was generated using the Shewchuk Triangle meshing functionality. The maximum area of triangles, the number of elements, and the roughness of the mesh can be user-defined. This allows for efficient model performance, as the mesh resolution can be adjusted using a smaller mesh for detailed representation around key features and a coarser mesh for less critical areas. A two-dimensional (2D) triangular mesh was generated to represent the Sungai Damansara floodplain based on the digital terrain model (DTM) that was obtained from DID in the form of LiDAR. The 2D mesh is generated using the Shewchuk Triangle meshing functionality. Heights at the vertices of the generated mesh elements are calculated by interpolation from the DTM. The maximum triangle area was set to 1000 m², while the minimum element area is 500 m². While the mesh sizes can be adjusted to be finer, it may disrupt the stability of the meshing and lead to model failure. However, in InfoWorks ICM, the terrain-sensitive meshing is activated, meaning that the mesh will increase the resolution of mesh in areas that have a large variation in height like hilly areas or areas with buildings, and maintain normal resolution of mesh in flat areas. For the overland flow roughness value, the Manning's n value was set as 0.1 to account for the roughness from various factors such as buildings, cars, trees which is lumped in one sub-catchment. According to Chow (1988), floodplains with dense vegetation exhibit high Manning's roughness value of 0.1, where this can be paralleled to modern urban floodplains with dense structures and obstructions that hinder flow.

After completing the 2D mesh generation, the riverbanks were connected to the 1D river network to ensure proper interaction between channel flow and overbank flooding. This configuration allowed the model to simulate both in-channel and floodplain hydraulics effectively. The riverbanks were linked to the adjacent 2D mesh using the weir equation, allowing water levels exceeding riverbank elevation to spill onto the 2D floodplain.

CALIBRATION

After the development of the 2D model, the model was calibrated. The term calibration can be defined as trying to fine tune the river model, i.e., the sub-catchments and other parameters, so better results can be generated. The river model is suitable to be calibrated using water level data. Hence, for this river model, the calibration is based on the flood event of December 2020 in the Sungai Damansara catchment. The calibration as shown in Figure 3 yielded a Pearson Correlation Coefficient of 0.85. After calibration, the addition of flood mitigation measures like wall, ponds and Nature-Based Solutions (NBS) were simulated to assess their effectiveness in reducing flood extents, flow, and water levels at selected locations.

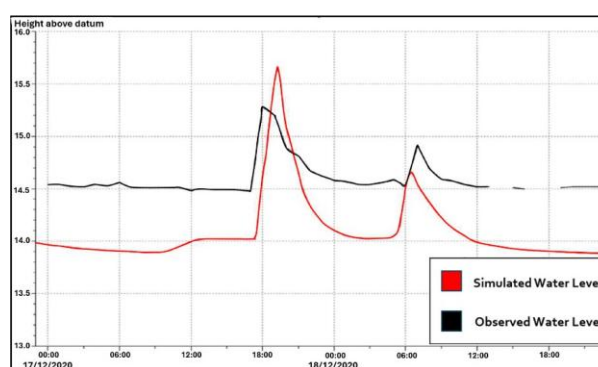


FIGURE 3. Calibration for December 2020 flood event for Sungai Damansara at Kampung Melayu Subang Water Level Station

Figure 4 illustrates the simulated discharge for various storm durations ranging from 1 to 24 hours under a 200-year ARI event. The results show that the critical storm duration at the downstream of Sungai Damansara is 6 hours. The analysis focused on locations where NBS could be implemented, while also incorporating backwater effects from Sungai Klang, which influenced water levels in Sungai Damansara. Meanwhile, Figure 5 presents the flood map for existing conditions under the 200-year ARI, revealing extensive flooding with depths exceeding 2 meters, particularly near the confluence with Sungai Klang. As previously mentioned, this is primarily due to the backwater effect from Sungai Klang. These findings served as a benchmark for evaluating flood mitigation options, including flood walls, pond improvements, and NBS aimed at reducing flood depth and discharge.

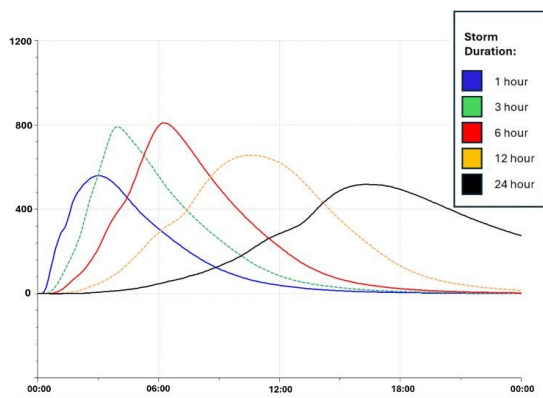


FIGURE 4. Discharge for various storm durations at Sungai Damansara downstream



FIGURE 5. 200-Year ARI flood map for existing river conditions

APPLICATION OF NBS

Figure 6 illustrates the seven selected locations for the implementation of Nature-based Solutions (NBS), distributed from the upstream to the downstream reaches of Sungai Damansara. These sites were identified as the primary areas affected by flooding (refer the Figure 5). Furthermore, implementing flood mitigation measures in these flood-prone areas is socially logical, since redevelopment efforts in unaffected zones would likely face resistance from residents. With the assumption of catchment rehabilitation through NBS, the Curve Number (CN) for these areas was recalculated using the weighted CN method. Table 1 presents the updated CN values for the NBS locations. The reduction in CN indicates that the existing conditions were previously impervious, with poor soil infiltration capacity.

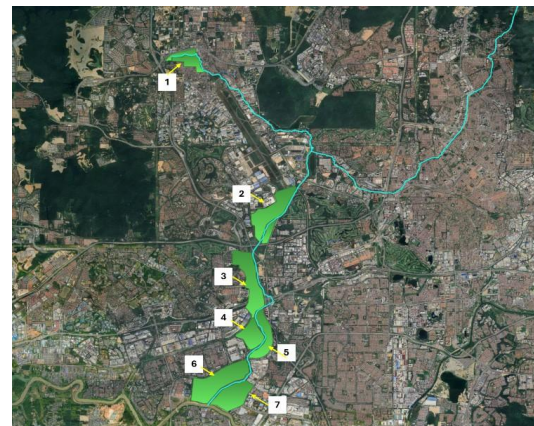


FIGURE 6. Selected locations of NBS in the catchment

TABLE 1. Provision of new CN value using weighted CN method

Type	%	CN	Weighted CN
Water Body	20	98	19.6
Open Spaces	40	61	24.4
Paved Pavement	20	98	19.6
Residential	20	68	13.6
Total	100		77.2

Figure 7 illustrates the typical cross-section of the Nature-Based Solutions (NBS), showing the wet, intermittent, and dry areas. These three zones can be differentiated based on their platform level values. The Wet Area consists of a wet pond that will be connected to the main river and would also cater to internal flooding. The Intermittent Area consists of a green space rich in vegetation, which helps increase the rate of infiltration. This transformation improves the land use, shifting it from a previously dense industrial and residential area to a more nature-friendly environment. The Dry Area features an elevated platform designed to withstand floods of up to a 200-year ARI. This ensures that such flood events will not overflow into nearby residential areas, thereby preventing further flood-related issues. The total area will be divided into three categories: 20% will be allocated to the Wet Area, 40% to the Intermittent Area, and the remaining 40% to the Dry Area. Amongst the criterion for selection of NBS areas are:

1. Based on 200-ARI flood map
2. Flood Hotspots or locations prone to flooding based on previous flood reports from DID
3. Residential areas with economic and development potential

Within the ICM modelling framework, the designated NBS solution was represented using a weir structure that

served as the diversion inlet from the main river into a pond, which was designed based on the specified NBS cross section. An outlet weir was then configured from the pond back to the main river and set at the 200-year ARI level, ensuring that only water levels exceeding this threshold would discharge from the pond. Additionally, an orifice positioned at the river invert level was incorporated to facilitate low-flow conveyance and allow gradual release of retained water from the pond back into the main river. Besides that, a void zone was incorporated to hydraulically isolate the NBS areas from the surrounding 2D mesh, thereby preventing external floodwaters from entering the designated NBS domain. Conceptually, the NBS dry zones were elevated to the 200-year ARI level, rendering them flood-free under design conditions. However, since the 2D mesh adopts the existing ground elevation from the terrain model, the use of void sections was necessary to ensure accurate hydraulic representation and to avoid the misinterpretation of the NBS areas as inundated zones within the simulation.

Meanwhile, Table 2 presents detailed design specifications of NBS across the seven locations, showing how each area is divided into the three zones with corresponding sizes and elevation levels. Each NBS site varies in total area but consistently follows the conceptual areal division of 20 % for Wet, 40 % for Intermittent, and 40 % for Dry areas. The invert, ground, and platform levels indicate the vertical design elevations, which are crucial for ensuring water flow, infiltration, and flood protection during events up to a 200-year ARI. The variation in the elevation of the NBS platforms across the selected locations was determined based on existing topography and ground levels, with adjustments made to incorporate the 200-year ARI flood level. For instance, NBS 1 is in a naturally hilly upstream area, resulting in a higher platform elevation compared to the flatter downstream sites. Specifically, NBS 1 is designed with a platform level of 21.0 m, whereas NBS 7 has lower elevation of 6.3 m. These variations reflect the site-specific design considerations made to address local topographic conditions and flood risks.

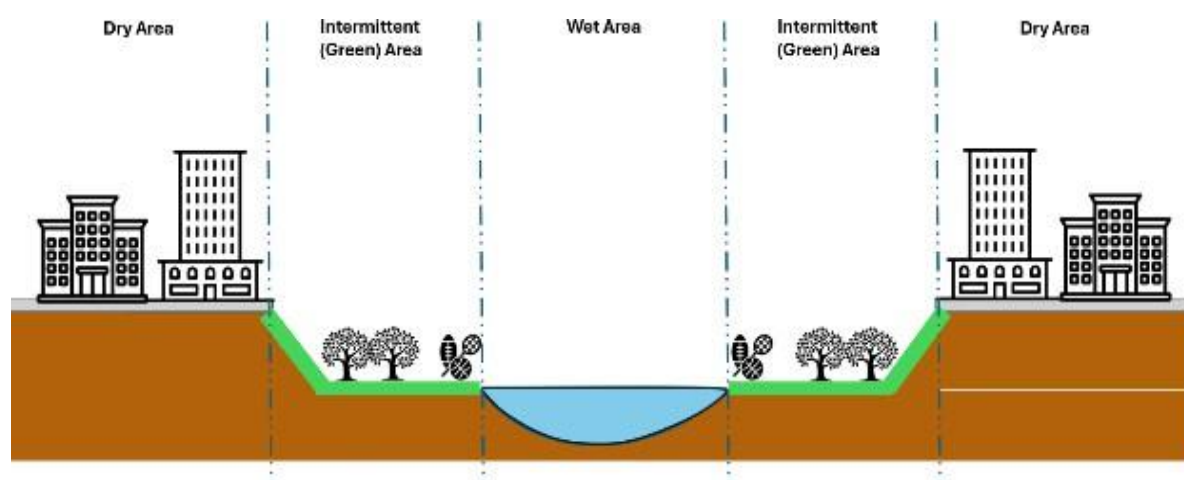


FIGURE 7. Longitudinal view of NBS concept

TABLE 2. Details of the NBS

Location of NBS	Total Area (ha)	Area Type	Area Division (ha)	Invert Level (m LSD)	Ground Level (m LSD)	Platform Level (m LSD)
1	49.0	Wet	9.8	18.0	20.0	21.0
		Intermittent	19.6			
		Dry	19.6			
2	128.0	Wet	26	3.4	6.9	9.8
		Intermittent	51			
		Dry	51			
3	121.0	Wet	24	2.9	5.4	8.5
		Intermittent	48.5			
		Dry	48.5			

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		Wet	12			
4	60.0	Intermittent	24	0.1	3.6	7.1
		Dry	24			
		Wet	12.2			
5	61.0	Intermittent	24.4	0.1	3.6	7.3
		Dry	24.4			
		Wet	30			
6	150.0	Intermittent	60	0.5	4.0	6.4
		Dry	60			
		Wet	19			
7	95.0	Intermittent	38	0.5	4.0	6.3
		Dry	38			

APPLICATION OF OTHER FLOOD MITIGATION MEASURES

Besides the application of NBS, other flood mitigation options were also proposed to be incorporated into the model, such as the installation of flood walls and the modification of existing ponds. Table 3 presents a summary of pond modifications for the existing ponds along Sungai Damansara, namely the Eko Ara Damansara (EAD) Pond, Subang Airport South (SAS) Pond, and the Rubber Research Institute of Malaysia (RRIM) Pond. The locations of these ponds are shown in Figure 1. Pond modifications were determined based on site-specific factors, including the feasibility of enlarging the pond and adjusting the inlet width and levels. Where pond enlargement is constrained by the site, lowering the weir level is proposed to increase inflow; however, excessive lowering could cause the pond to receive normal flows

instead of only flood flows, disrupting runoff conveyance and reducing flood storage capacity. The EAD Pond on site has already undergone volume enlargement and thus requires no further adjustments to its weir level or width. In contrast, due to limited space for volume expansion, the SAS Pond and RRIM Pond were modified by enlarging the weir width and reducing the weir level by 1 m, ensuring they capture flood flows without receiving normal flows. For width modifications, the weir was increased to 100 m—the maximum feasible within the site boundary compared to the current widths of approximately 80 m (SAS Pond) and 70 m (RRIM Pond). This increase allows higher inflow rates during storm events, improving hydraulic performance without altering storage volume. It is important to note that land acquisition requirements and associated costs were not included in the evaluation of these supplementary flood mitigation measures.

TABLE 3. Summary of Pond Modifications

Pond Name	Pond Volume Increment	Original Inlet Weir Level (m)	Original Inlet Width (m)	Modified Inlet Weir Level (m)	Modified Inlet Width (m)
EAD Pond	50%	10.5	8.6	No Modification	No Modification
SAS Pond	No Increment	8.7	80	-1	+ 20
RRIM Pond	No Increment	8	70	-1	+ 30

RESULTS AND DISCUSSION

WATER LEVEL COMPARISON

In evaluating the effectiveness of NBS in comparison to other flood mitigation options for Sungai Damansara which are implementation of flood walls and modification of existing ponds, the hydraulic parameters such as the water level, flow and flood map for each option should be analyzed and compared against the existing conditions.

Table 4 shows the water level simulation results for each flood mitigation measure for 200 ARI. The NBS approach achieves the highest percentage of water level reduction. The significant reduction observed with NBS is attributed to its design, which incorporates dedicated wet and intermittent areas that function as temporary storage zones for excess runoff. These features effectively retain stormwater, thereby easing the pressure on the main river channel and lowering overall water levels. This demonstrates the capacity of NBS to manage floodwaters more sustainably than rigid structural measures. Besides that,

the reduced CN value due to the improvement of soil infiltration by provision of intermittent and wet areas also affected the amount of runoff generation which ultimately affects the discharge and water level of the river (Shazmin et al. 2021).

Flood walls are vertical structures built primarily from reinforced concrete or steel to act as barriers against rising floodwaters. They are commonly used in urban areas where space is limited, and earthen levees are not practical. Flood wall was proposed along the flooded areas along Sungai Damansara. In contrast to the NBS, the implementation of flood walls has resulted in increased water levels within the river channel, with a peak rise of 19% at the midstream segment compared to existing conditions. While flood walls provide localized protection, Wyżga et al. (2016) note that such structures can exacerbate downstream flood risks by restricting natural floodplain storage, leading to elevated water stages and intensified hydraulic pressure in protected areas.

During extreme flood events, this can produce deeper water levels that increase the risk of floodwall failure. Meanwhile, pond improvements have proven to be the least effective option, particularly under 200-year ARI flood conditions. With only a 4% reduction in water level at the midstream and negligible effects upstream and downstream, it is evident that pond modifications contribute minimally to overall flood level reduction compared to NBS and flood walls. This limited effectiveness can be attributed to the scope of modifications implemented, as summarized in Table 3, where most adjustments involved only minor changes to weir level, inlet width, or pond volume due to site constraints. Consequently, the combined impact of these measures across the catchment resulted in only marginal reductions in simulated water levels, as shown in Table 4. Lockwood et al. (2022) also suggested that pond structures must be optimally designed to effectively manage inflow and outflow dynamics, ensuring they perform as intended during flood events.

TABLE 4. Summary of water level reduction for the selected flood mitigation measures

Location	Flood Mitigation Option						
	Existing Conditions	NBS		Flood Wall		Pond Modification	
	Water Level (m)	Water Level (m)	% Reduction compared to Existing	Water Level (m)	% Reduction compared to Existing	Water Level (m)	% Reduction compared to Existing
1	20.5	18.9	8%	20.9	-2%	20.5	0%
2	11.1	9.8	12%	11.9	-7%	10.9	2%
3	9	8.5	6%	10.6	-18%	9	0%
4	8	7.4	8%	9.5	-19%	7.7	4%
5	7.4	7	5%	8.8	-19%	7.3	1%
6	6.2	6.4	-3%	7.1	-15%	6.2	0%
7	6	6.3	-5%	6.7	-12%	6	0%

FLOW COMPARISON

Table 5 presents the flow reduction simulation results for each flood mitigation measure under the 200-year Average Recurrence Interval (ARI) scenario. The most notable flow reduction recorded is 78% for the 200 ARI event at the upstream section of the river. The peak flow reduction achieved through the implementation of NBS aligns with findings by Sciuto et al. (2024), who reported a reduction of up to 12.02% in peak flow, further emphasizing the potential of NBS in managing high-ARI flood events. The significant reduction observed in this study can be attributed to the redirection of water that would otherwise cause flooding due to overspill from Sungai Damansara into the wet and intermittent zones of the NBS system. These zones function as temporary storage and retention areas, thereby reducing flow velocity and lowering the water level within the river.

In contrast, the flood wall option produced the highest flow values among all mitigation strategies. Flow along Sungai Damansara increased progressively from upstream to downstream when flood walls were applied, as they prevented any overflow or lateral water losses and confined runoff within the river channel. Consequently, flow accumulation occurred along the river with no dissipation, ultimately discharging entirely into Sungai Klang. This demonstrates that while flood walls provide effective localized protection, they can also intensify downstream flow volumes due to the absence of floodplain storage. For the pond modification option, the overall flow reduction achieved was relatively low. Similar to the water level results, this limited effectiveness is primarily due to the modest structural adjustments implemented, as summarized in Table 3.

TABLE 5. Summary of flow reduction for the selected flood mitigation measures

Location	Flood Mitigation Option						
	Existing Conditions	NBS		Flood Wall		Pond Modification	
	Flow (m ³ /s)	Flow (m ³ /s)	% Reduction compared to Existing	Flow (m ³ /s)	% Reduction compared to Existing	Flow (m ³ /s)	% Reduction compared to Existing
1	76.6	17.1	78%	89	-16%	76.6	0%
2	572.2	245.3	57%	572	0%	523	9%
3	589.7	314.9	47%	647.7	-10%	557.5	5%
4	439.2	275	37%	693.1	-58%	419.5	4%
5	265.5	164.6	38%	694.6	-162%	260.7	2%
6	476.0	372.7	22%	708.3	-49%	464.3	2%
7	457.2	296.6	35%	713.3	-56%	455.8	0%

As a result, the ponds' capacity to attenuate peak flows remained constrained, yielding flow reductions of only 9% at selected upstream locations with negligible improvements elsewhere. Consequently, the cumulative impact of pond modifications contributed only minor reductions in simulated flood flows compared to existing conditions.

FLOOD MAP COMPARISON

To further evaluate the effectiveness of different flood mitigation strategies, a comparative analysis of flood maps generated under the three flood mitigation measures were generated.

As demonstrated by Sidek et al. (2021), the generation of flood maps is one of the ways of assessing the performance of flood mitigation measures. Each flood map reflects their effectiveness in managing surface runoff and reducing flood extent along Sungai Damansara. The flood maps illustrate spatial differences in inundation areas along the Sungai Damansara catchment. By comparing these maps with the existing flood map shown previously in Figure 5, it is possible to visualize which strategy effectively reduces flood. The flood maps for Sungai Damansara after pond modifications, NBS and flood wall implementation can be seen in Figure 8, Figure 9 and Figure 10, respectively. From the flood maps presented, it is evident that only the implementation of NBS and flood walls offer effective protection against a 200-year ARI flood.



FIGURE 8. Flood map of Sungai Damansara after pond improvement for 200-Year ARI



FIGURE 9. Flood map of Sungai Damansara after implementation of NBS for 200-Year ARI



FIGURE 10. Flood map of Sungai Damansara after construction of flood wall for 200-Year ARI

NBS achieve this by enhancing soil infiltration and increasing water retention through strategically designed wet and intermittent areas. These green infrastructures slow down runoff and reduce surface water accumulation, thereby minimizing flood extent. On the other hand, flood walls function by rapidly directing water flow downstream, preventing overflow along protected sections of the river channel. While this provides localized protection, it may shift flood risks further downstream if not managed holistically. In contrast, pond modifications appear to be the least effective intervention. As shown in TABLE 4 and Table 5, the flood extent under the pond improvement scenario remains largely unchanged from the existing condition. This is likely due to the limited storage capacity and suboptimal design of the modified ponds, which are insufficient to manage large volumes of floodwater during extreme events.

The flood maps visually reinforce this, showing minimal spatial reduction in inundated areas. Overall, the comparison highlights that both NBS and flood walls outperform pond modifications in mitigating severe flood risks, with NBS offering additional long-term ecological and hydrological benefits.

CONCLUSION

This study assessed the effectiveness of three flood mitigation strategies known as Nature-Based Solutions (NBS), flood walls, and pond modifications for the Sungai Damansara catchment under a 200-year ARI design storm. Based on 1D–2D hydrodynamic modelling using InfoWorks ICM, NBS emerged as the most effective

solution, reducing water levels by up to 12%, and peak flow by as much as 78% at the upstream section. Furthermore, the flood map comparison showed that NBS significantly reduced flood extent, especially in critical residential areas, through the use of wet and intermittent zones that temporarily stores runoff, while also promoting improved soil infiltration through change of land use from impermeable to permeable. This demonstrates the role of NBS in not only decreasing hydraulic loading but also expanding retention across the landscape. Conversely, the flood wall scenario, despite offering localized structural protection, led to a 19% increase in midstream water level and a 162% rise in downstream discharge due to flow confinement and the elimination of natural floodplain buffering. While structural measures such as floodwalls can provide localized protection, they may also increase water levels behind the structure, consequently amplifying residual flood risk.

Therefore, as emphasized by Yusof et al. (2023), effective flood risk management should prioritize and integrate risk reduction strategies into any chosen flood mitigation option that minimize both the possibilities and severity of losses. Pond modifications showed minimal impact, with only 4% water level reduction at midstream and a maximum of 10% flow reduction downstream, performing the least effectively overall. The limited capacity and areal constraints of the modified ponds hindered their ability to manage peak stormwater volumes. In contrast, the NBS flood map clearly displayed the greatest spatial reduction in inundated zones compared to existing and other mitigation conditions. These results underline the superior hydrological and ecological performance of NBS, supporting its adoption as a core strategy in future flood risk management planning for urban catchments like Sungai Damansara.

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DECLARATION OF COMPETING INTEREST

None.

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