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ENVIRONMENTAL FLOW ASSESSMENT MODEL ON SUSTAINABILITY PLANNING STRATEGIES, KENYIR LAKE BASIN, MALAYSIA

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Abstract

The study presents the Environmental Flow Assessment (EFA) model on sustainability planning strategies to reduce damage in the main area of Kenyir Lake Basin. The XPSWMM model have been used to simulate the EFA in this study. Based on simulation in the Terengganu River, which has a most effective discharge of 42.78 m^3/s with depth on 3.94 m and a water velocity of 0.54 m/s, which are expected to meet the development needs of fish species, the analysis for both study rivers found the minimum river discharge values with the frequency probability in the period of 20 years needs to be maintained. While, based to the simulation in the Petuang River, the maximum discharge is only 0.08 m^3/s, the maximum depth is 0.4 m, and the maximum water speed is 0.04 m/s, which is adequate for a small number of small-sized fish species. With output deficiency of less than 20% from an actual situation, the two lowest values later obtained were adopted as input in low flow analysis. A more effective management approach ensures the ecosystem's sustainability and maintains an optimal equilibrium among the many uses. Environmental flows aren't considered a luxury but instead an integral component of contemporary water management given the global misuse of water resources and the resulting degradation of ecosystems and their functions. It is a strategy that requires widespread adoption.

Keywords: Environmental Flow Assessment (EFA), Sustainability planning, Mitigation Strategies, Kenyir Lake Basin, XPSWMM

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INTRODUCTION

The peak discharge, the amount of time it takes for the flood to reach its height, and runoff all appear to be increased by logging or other land uses that alter the natural ecosystem within the context of development, such as a forest reserve or a planting area inside a drainage basin. Although forestry is a significant source of livelihood it also contributes to the degradation of river basins by increasing sedimentation issues along river basins due to high soil erosion caused by increased surface runoff and contamination of the lake alongside chemicals and fertilizer. There is an indirect rise in the concentration of chemicals in the water and sediment throughout the river basin (Pokhrel et al., 2018; Mustaffa et al., 2023). According to Kamarudin et al. (2019), the hydrological processes and the causes of floods are significantly impacted by changes in land use in urbanising watersheds. These floods occur more frequently, and increasing flood volumes may adversely affect the public more severely. Therefore, the planning, design, and construction of roads, stormwater drains, and other structures must take these distinctive river or drainage systems into consideration. Poor drainage planning is frequently a factor in property failure or significant damage, including to stormwater drainage systems that can remove water. Considering that it reduces surface erosion, the approach of increasing forest canopy density was a very effective means of reducing erosion and higher flow, which contribute to the sedimentation and flood phenomenon (Al-Ghadi et al., 2020).

The "Act of Nature" and "Act of Human" determine the fate of the river ecosystem sustainability, known as the source of disruptions and alteration resulting in deleterious and degradation effects on the environmental ecosystem. The ecological integrity of the river will be compromised if a change is made to a component of the flow regime. Almost all the users dependent on the flow are affected by a change in the flow regime and significant changes in the flow may have negative effects, notably for the permanent change (Vigiak et al., 2018). This is also evident in other sectors such as tourism where the ecological integrity of the river-based destination for instance, might be compromised and thus degrading the place sustainability and economic performance (Azinuddin et al., 2022). Based on this premise, the flow regime has been viewed by many aqualogists as a key component of the ecosystems of the river and the floodplain. There are four key principles to highlight the necessary of mechanisms in the integrated of hydrology and aquatic biodiversity components affected by the alteration of flow regimes characteristics. The first principle is "Flow and habitat preferences" as flow is a major element of physical habitat in streams, which affect the habitat complexity and change the biotic diversity. Secondly is "Adaptation to disturbance" as the temporary or permanent disturbance effects during the critical stage and its depends on the species's survival strategies. Then, the third principle is "Connectivity" as the water abstraction or regulating structure limits the free moving ability (natural patterns of longitudinal and lateral connectivity) and affect the migratory and recruitment success of species. Lastly, the fourth principle is “Exotic species succession” as the modified of flow regime characteristics favored by the exotic and introduced species in rivers (Bunn and Arthington, 2002) (Refer Figure 1).

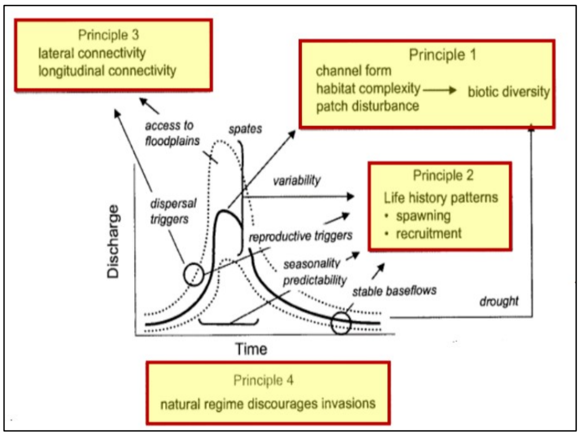

Figure 1: Flow Regime Components Play Different Role in Sustaining the Equilibrium State of Ecological Integrity
Source: Bunn and Arthington, 2002

The hydrological and hydraulic models provide thorough analysis for hydraulic transports, flood resilience projects, and hydraulic structures like dams and reservoirs. It must be constructed to a high standard and suitable for the intended use. It is possible to simulate how precipitation moves from the surface through structures and facilities to the water receipt using the important, complicated urban stormwater model known as XPSWMM. The floods, water resources, and water quality scenarios have all been simulated using this software, which was created by MWH Soft Ltd. in Australia. The model can replicate either a single occurrence or a series of events. Storm water management systems' hydraulic and hydrologic components are represented using a 1-dimensional model. The drainage system was represented using XPSWMM using a node-link concept based on the cross-sectional data that was gathered. Similar to connections, nodes represent the system's hydraulic flow components, and the model offered a variety of additional conduit types for modelling, including sewer pipes, the channel reaches, or culverts, and nodes, which could represent lakes, ponds, junctions, or other physical transition sites along the links. The river was modelled as a network of conduits with a weir added, creating numerous links (Dao et al., 2022).This study was conducted in Terengganu River (outlet river of Kenyir Lake) and Petuang River (inlet river of Kenyir Lake). It is located within latitude (between 5o01’57.3”N until 5°14’149.9”N) and longitude (between

102°55’37.6”E until 102°39’37.4”T). In order to facilitate the analysis of the E-Flow, these two study areas will be divided into three sampling sub stations, namely Terengganu River I, Terengganu River II, Terengganu River III, Petuang River I, Petuang River II and Petuang River III. Besides that, the study was conducted for two seasons as September 2018 (covering the dry season as Low Flow Scenario Model) and July 2019 (covering the normal season as Basic Scenario Model). Figure 2 showed the specific coordinate and map location of each sampling station.

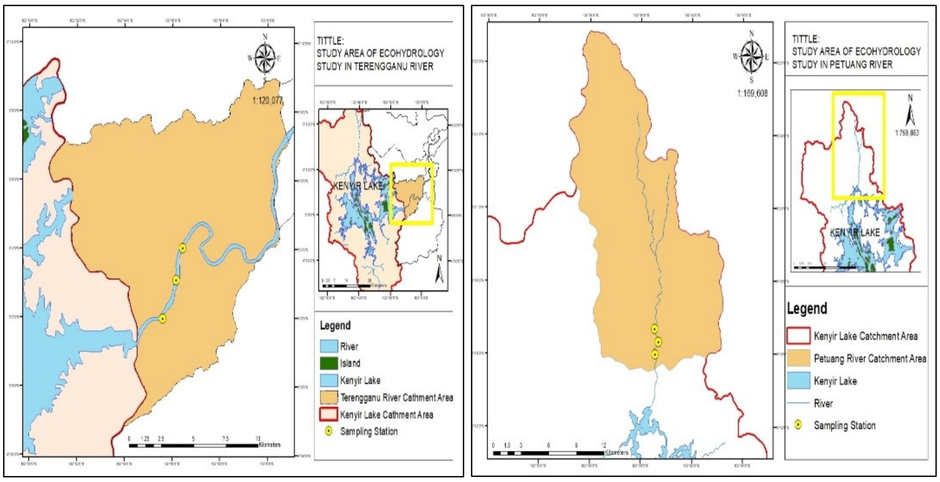

Figure 2: Sampling Location in Terengganu River (oulet of Kenyir Lake) and Petuang River (inlet of Kenyir Lake)

RESEARCH METHODOLOGY

This investigation applies flood modelling that combines hydrology with hydraulic modelling using XPSWMM to two major river systems in the study areas: the Terengganu River (the lake basin's outlet) and the Petuang River (the lake basin's inlet). The monsoon flood, which can occur multiple times annually, is the type of flooding that is regularly encountered in the study region. The hydrodynamic modelling of the water level and discharge in this study incorporates the river geometry system and flood plain zones. The upstream inflow hydrograph produced by Runoff Mode is used in hydrology hydraulic modelling to carry out hydraulic routing of flood flow in the network of rivers at research regions. The area that is most vulnerable to flooding under different scenarios (both present and future) will be determined by the simulated water surface profile and discharge. The three model simulations' modelling scenarios will encompass the research area's present and future conditions as well as any existing and proposed future mitigation measures.

The average recurrence interval (ARI) design peak Q will be used as the basis for the model scenario. According to Hassan et al. (2019), the Rational Method is the most popular technique for calculating flow peaks. Utilising Average Recurrence Interval (ARI), one of these experimental approaches may enhance flash flood forecasting by adding another way to describe flash flood events as they take place. According to numerous studies, rainfall ARIs can be calculated in real-time to more effectively convey the severity of a flood as it develops. These initiatives have made it possible for the NWS weather forecast office to operate with real-time rainfall ARI estimations. On the best way to apply this new knowledge, however, there hasn't been much research. A hydrological hydraulic projection model with the proposed development of projects without mitigation strategies has been simulated to reflect the worst-case scenario in the proposed project locations. This model is based on 100-year average recurrence interval (ARI) design peaks Q and current geometric river survey data. It should be noted that the model simulates both low and high flows, which were accurately calibrated earlier. The flow value at the time of sampling was chosen as the basic scenario for the simulation. The low flow analysis produced by the ARI computation was the extra base scenario that was chosen. It is a fundamental tenet that other variable elements, such as river upstream moisture, have an impact on the ARI of the flow. It is advised that drainage system performance be evaluated to ensure satisfactory performance, regardless of the design foundation (Bayat et al., 2019). The on-site drainage system for the areas undergoing redevelopment must be planned so that the predicted peak flow rate from the site for the design ARI of the acquiring minor system is no higher than what would be anticipated from the current construction (Bayat et al., 2019). Figure 3 showed the *node* and *link* of each sampling station in Terengganu River and Petuang River in simulation modelling of all stations at Kenyir Lake Basin. Thera are three *link* which are represent the classification of four location stations such as *link* 1 (*node* Terengganu River (ST)/ Petuang River (SP) 1 until *node* ST/SP 2), *link* 2 (*node* ST/SP 2 until *node* ST/SP 3), *link* 3 (*node* ST/SP 3 until *node* ST/SP 4).

Figure 3: *node* and *link* of each sampling station in Terengganu River and Petuang River

RESULT AND DISCUSSION

Table 1(a) and Table 1(b) showed the information data of *Conduit Profile* for *link* along the river channel of Terengganu River and Petuang River. There are required information data such as *Upstream Invert Elevation*, *Downstream Invert Elevation*, *Length* dan *Roughness*. This data input applied in XPSWMM software automatically to identify the percentage values of slope (gradient) based on calibration of each *node*. Then the *link conduit* dialog box and the *Conduit Profile* information entry registration process that covers three segments for each study river channel such as *link* ST 1, *link* ST 2, *link* ST 3 for Terengganu River and *link* SP 1, *link* SP 2 dan *link* SP 3 for Petuang River.

Table 1(a): The Information Data of *Conduit Profile* for *link* in Terengganu River I (ST 1), Terengganu River II (ST 2) and Terengganu River III (ST III)

link	**Upstream Invert Elevation (m)**	**Downstream Invert Elevation (m)**	**Length (m)**	**Roughness**	**Shape**
***link* ST 1**	151.26	141.26	2978	0.014	Natural
***link* ST 2**	141.26	135.560	2199	0.014	Natural
***link* ST 3**	135.560	135.560	2199	0.014	Natural

Table 1(b): The Information Data of *Conduit Profile* for *link* in Petuang River I (SP 1), Petuang River II (SP 2) and Petuang River III (SP III)

link	**Upstream Invert Elevation (m)**	**Downstream Invert Elevation (m)**	**Length (m)**	**Roughness**	**Shape**
***link* SP 1**	158.60	151.90	425	0.014	Natural
***link* SP 2**	151.90	151.0	2065	0.014	Natural
***link* SP 3**	151.0	151.0	2065	0.014	Natural

Figure 4(a) shows an illustration of the view of normal simulation for *links* ST1, ST2, and ST3. Based on the simulation results of normal flow in the Terengganu River, the maximum depth reached by each station in the normal season is in the range between 3.74 m and 4.94 m, where ST 1 (upstream) recorded the lowest depth (3.74 m) and discharge values of 184.196 m^3/s compared to other stations and a maximum flow speed of 1.91 m/s. It was found that the speed of the river flow affects the flow rate in each section of the *link conduit*, where even though the stations located in the middle (ST 2 and ST 3) have a higher depth than the stations in the upstream part, the flow rate of the river in that section is directly proportional to the flow trends (Bayat et al., 2019; Budhathoki et al., 2021). This is due to the flow becoming slower when it reaches the downstream part due to the presence of a dam structure in the area before entering the Terengganu River Basin. The structure acts as a barrier to the flow of water, where the flow is controlled by the overflow bank at a rate of 1.43 m/s in the normal season to control the water depth so that it is not less than 1.0 m (refer to Figure 4(b) and Table 2). Figure 5(a) shows an illustration of the view of low flow simulation for *links* ST1, ST2, and ST3. Based on the results of this simulation, the maximum depth reached by each station in the dry season is in the range of 3.64 m to 3.94 m (ST 1 upstream recorded the lowest depth (3.64 m) and discharge values of 14.26 m^3/s compared to the other stations and a maximum flow speed of 0.79 m/s). It was found that the speed of the river flow affects the discharge rate in each section of the *link conduit*, where although the stations located in the middle and downstream (ST 2 and ST 3) have a higher depth, the river discharge rate in the section in question is directly proportional to the flow rate. This is because the flow becomes slower when it reaches the downstream side compared to the upstream side due to the presence of a dam that acts as a structure that releases water periodically in the dry season (Saad et al., 2023). The structure acts as a barrier to the flow of water, where the flow is controlled by the banks of the overflow channel at a rate of 0.54 m/s in the dry season to control the water depth so that it is not less than 1.0m (refer to Figure 5(b) and Table 3). It can be concluded that the maximum depth of 3.94 m with a rate of 42.78 m^3/s in the downstream part can only accommodate medium-sized fish individuals compared to the normal season. Compared to the normal season, a lower discharge rate was recorded in Sungai Terengganu during the dry season, with a maximum discharge rate not exceeding 42.78 m^3/s (simulation) and 8.52 m^3/s (observation) recorded.

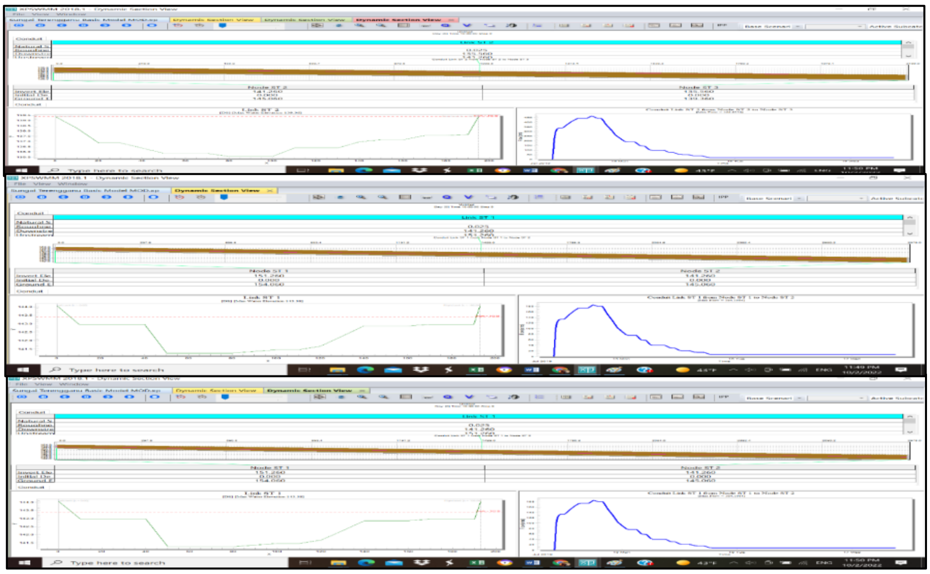

Figure 4(a): Dynamic View of Normal Simulation for link ST 1, link ST 2 and link ST 3

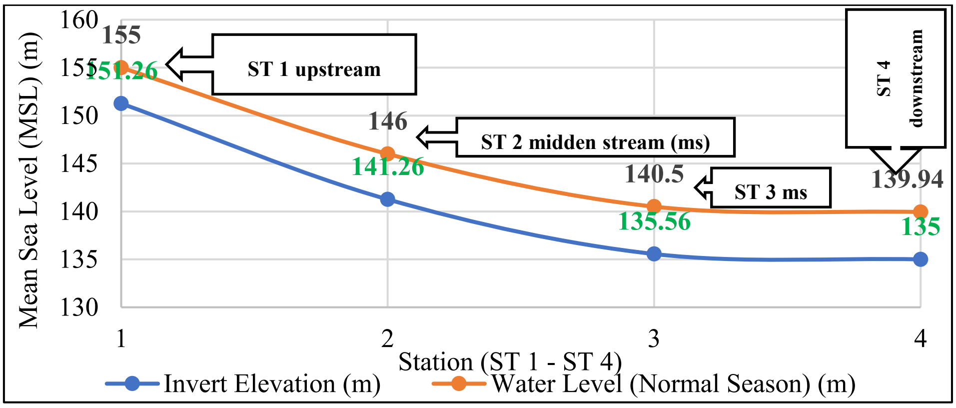

Figure 4(b): The Longitudinal View of *node* dan *link* in Terengganu River During Nomal Simulation

Table 2: The Longitudinal Characteristics of *node* dan *link* in Terengganu River During Nomal Simulation

Station	**ST 1**	**ST 2**	**ST 3**	**ST 4**
Invert Elevation (m)	151.26	141.26	135.56	135.00
Water Level (Normal Season) (m)	155.00	146.00	140.50	139.94
Maximum Velocity (m/s)	1.91	1.97	1.43	
Maximum Discharge (m^3/s)	184.1964	466.8354	505.7206	
Maximum Depth (m)	3.74	4.74	4.94	

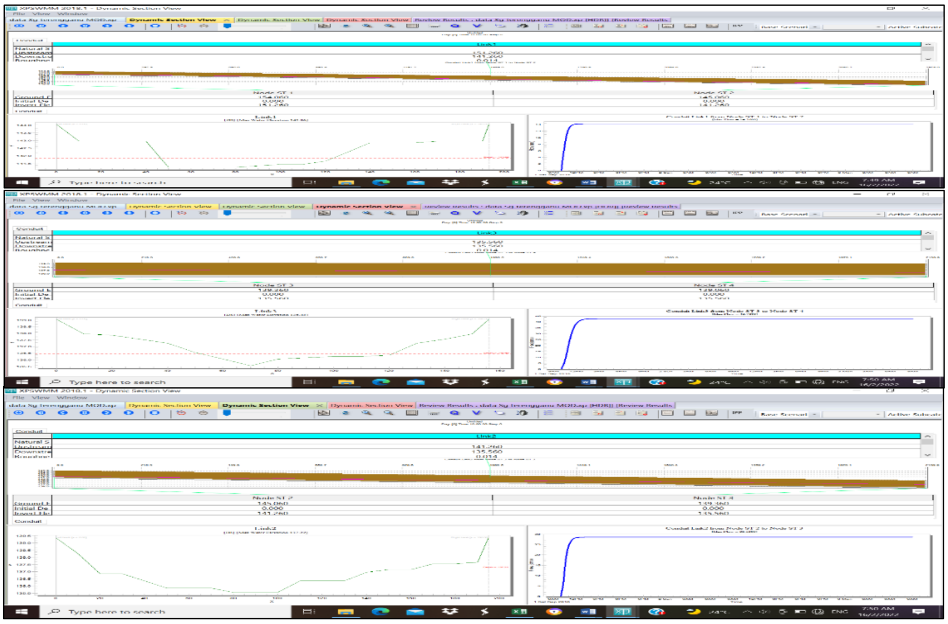

Figure 5(a): Dynamic View of Low Flow Simulation for *link* ST 1, *link* ST 2 and *link* ST 3

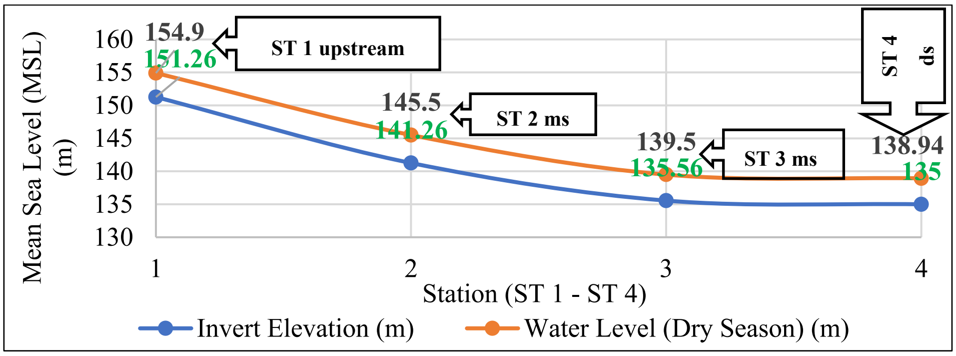

Figure 5(b): The Longitudinal View of *node* dan *link* in Terengganu River During Low Flow Simulation

Table 3: The Longitudinal Characteristics of *node* dan *link* in Terengganu River During Low Flow Simulation

Station	**ST 1**	**ST 2**	**ST 3**	**ST 4**
Invert Elevation (m)	151.26	141.26	135.56	135.00
Water Level (Normal Season) (m)	154.90	145.50	139.50	138.94
Maximum Velocity (m/s)	0.79	0.80	0.54	
Maximum Discharge (m^3/s)	14.260	28.52	42.78	
Maximum Depth (m)	3.64	4.24	3.94	

Figure 6(a) shows an illustration of the view of normal simulation for *links* SP1, SP2, and SP3. It was found that the speed of the river flow affects the discharge rate in each section of the *link conduit*, where the stations located in the middle and downstream (SP 2 and SP 3) have a higher depth (over 0.5 m), but the river discharge rate in the section in question is directly proportional to the flow rate. The base invert height of SP 2 and SP 3 from sea level is lower than that of SP 1, causing the downstream part of the river to receive more water than the capacity of the drainage section. At the end of the simulation, the maximum value of discharge magnitude in the downstream part of the river (SP 4) received discharge at a rate of 0.91 m^3/s, which is at a depth of about 0.9 m from the river bed. At that depth, it was found that a large number of medium-sized and small fish species are still able to inhabit the drainage habitat in small numbers (refer to Figure 6(b) and Table 4) (Raman et al., 2020). This is because the flow becomes faster when it reaches the downstream part due to the outflow factor from the river drainage in the upstream part of the lake basin towards the lake outlet, which is also near the dam structure. Figure 8(a) shows an illustration of the view of low flow simulation for *links* SP 1, SP 2, and SP 3. Based on the results of this simulation, the maximum depth that can be reached by each station in the dry season is in the range of 0.1 to 0.4 m, where the upstream station SP 1 recorded the lowest depth (0.1 m) and has a maximum discharge value of 0.1063

m^3/s compared to the other station and a maximum flow speed of 0.56 m/s. It was found that the speed of the river flow affects the flow rate in each section of the link conduit, where, although the stations located in the middle (SP 2 and SP 3) have a higher depth, the river flow rate in the section in question is not directly proportional to the flow rate, especially in the downstream part, due to the effects of external environmental factors such as anthropogenic and climatological factors. It can be observed that the speed of the flow is deteriorating when it reaches the downstream part of the river, with the maximum value of the speed of the flow at the last station (SP 4) being only 0.04 m/s. This proves that the highest depth was recorded in the downstream part of the river, giving a higher area of wet perimeter. However, the water level does not pass the level of the overflow bank of the dam structure in the upstream part of the river, causing the flow speed to be very slow (Kamarudin et al., 2017). This is contrary to the original purpose of the construction of the structure, which was to prevent the water level from being lower than the 1.0 m depth level. Figure 8(b) and Table 5 show the longitudinal display of all nodes and links in Sungai Petuang for the lowest discharge simulation. It can be concluded that at the end of the simulation, the maximum value of the discharge magnitude in the downstream part of the river receives discharge at a rate of 0.886 m^3/s and a maximum depth of 0.40 m.

Figure 6(a): Dynamic View of Normal Simulation for *link* SP 1, *link* SP 2 and *link* SP 3

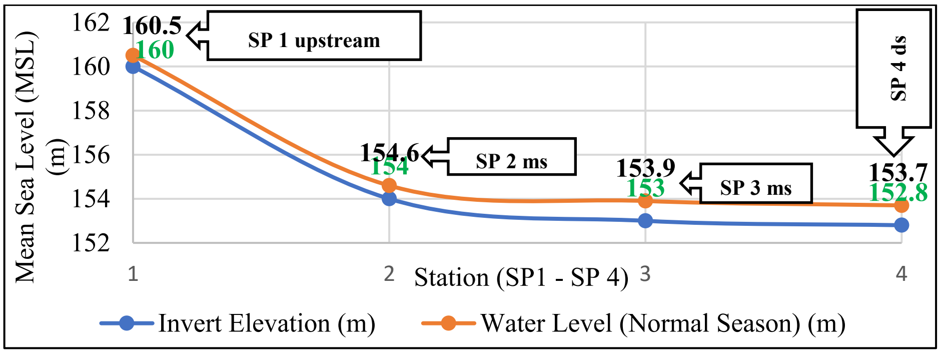

Figure 6(b): The Longitudinal View of *node* dan *link* in Petuang River During Normal Simulation

Table 4: The Longitudinal Characteristics of *node* dan *link* in Petuang River During Normal Simulation

Station	**SP 1**	**SP 2**	**SP 3**	**SP 4**
Invert Elevation (m)	160.00	154.00	153.00	152.80
Water Level (Normal Season) (m)	160.50	154.60	153.90	153.70
Maximum Velocity (m/s)	2.09	1.06	0.91	
Maximum Discharge (m^3/s)	55.7640	122.5366	124.623	
Maximum Depth (m)	0.5	0.6	0.9	

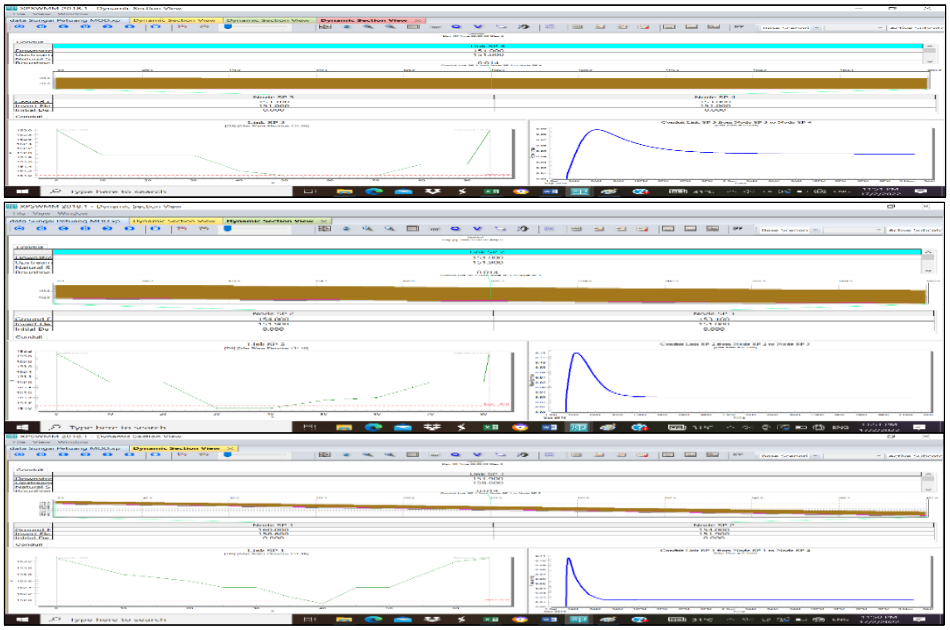

Figure 7(a): Dynamic View of Low Flow Simulation for *link* SP 1, *link* SP 2 and *link* SP 3

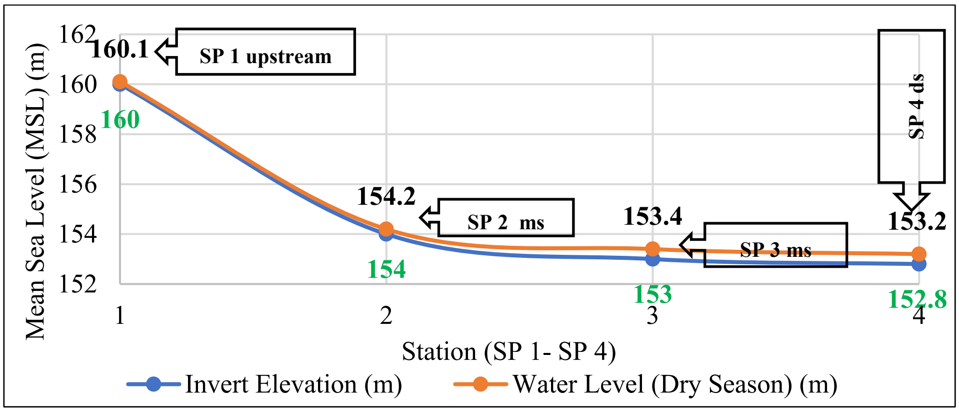

Figure 7(b): The Longitudinal View of *node* dan *link* in Petuang River During Low Flow Simulation

Table 5: The Longitudinal Characteristics of *node* dan *link* in Petuang River During Low Flow Simulation

Station	SP 1	SP 2	SP 3	SP 4
Invert Elevation (m)	160.00	154.00	153.00	152.80
Water Level (Normal Season) (m)	160.10	154.20	153.40	153.20
Maximum Velocity (m/s)	0.56	0.13	0.04	
Maximum Discharge (m^3/s)	0.1063	0.1198	0.0886	
Maximum Depth (m)	0.1	0.20	0.40	

HYDROLOGY HYDRAULIC MODEL DEVELOPMENT WITH SUSTAINABILITY PLANNING (MITIGATION MEASURES)

The strategy for mitigation actions can be taken in a variety of ways, including choosing appropriate technologies for the construction, selecting a standard design, using the code of ethics of the construction, adhering to the recommendations for the implementation of security, and complying with all requirements of the regulation. Both the development and operating phases should employ these procedures.

Soil Erosion and Sedimentation Management

It is strongly advised that erosion and sedimentation control measures be built in the proper places before any development activity is started (Abdul Maulud et al., 2021). The following are the major components of the suggested soil erosion and sediment management measures:

a) Scheduling and Staging of Development

Scheduling and arranging all of the actions will protect the soil's top layer and any vegetation that is already present and is not directly impacted by the land's transformation. During the rainy season, land-clearing activities are prohibited.

b) Implementation of Land Disturbing Prevention Pollution and Mitigation Measures (LDP2M2)

Through comprehensive and methodical preparation, execution, monitoring, and inspection of mitigation strategies for soil erosion and sedimentation, LDP2M2's primary goal is to protect, restore, and further improve the quality of the environment at the project site and its adjacent areas. Before beginning any development activities, the LDP2M2 for the project advancement must be provided for approval by the DOE. The following diagram illustrates the control strategies that target soil erosion and sedimentation. There are seven components that make up the LDP2M2 (Guideline for Erosion and Sediment Control in Malaysia, DID 2010);

i. Minimizing soil erosion
ii. Preserving top soil & other assets
iii. Access route & site management
iv. Runoff control & management
v. Earthwork & erosion control
vi. Sediment prevention control
vii. Site maintenance

c) Inspection and Maintenance during the Construction

Application of applicable compliance BMPs proposed mitigation measures for land development activities and its control. Table 6 showed the inspection and maintenance during the construction will be applied for development along the Kenyir Lake Basin.

Table 6: The Inspection and Maintenance During the Construction

ESCP	Development Period	Maintenance Required
Sediment Basins	Initial Stage before grading works.	Weekly inspection and after a rainfall event or rainfall reading equal to or greater than 12.5 mm. Remove trapped sediment when one-third full.
Earth Drain Channels	Initial Stage before grading works.	Weekly inspection and after a rainfall event or rainfall reading equal to or greater than 12.5 mm
Check Dams	Initial Stage before grading works but after development activity of temporary diversion channels.	Weekly inspection and after a rainfall event or rainfall reading equal to or greater than 12.5 mm. Remove trapped sediment when one-third full.
Silt Fence	Initial Stage before grading works.	Weekly inspection and after a rainfall event or rainfall reading equal to or greater than 12.5 mm.

d) River Buffer Zone

The Forestry Department created *Manual Perhutanan Jilid III, 2005*, to serve as a manual for logging operations and as a criterion for issuing logging licences to loggers. The ideal width of the river reserve for the river bank created by the forestry department. When a development damages a river that is not on the *Warta Rezab Sungai Negeri* list, the rule will be enforced. The fundamental tenets of measures to prevent soil erosion are to shield the soil surface from precipitation and direct runoff away from exposed areas, while the fundamental tenets of measures to prevent sedimentation are to preserve the quality of discharged runoff by removing eroded soil particles from the site before they enter water courses.

CONCLUSION

This strategy must be used to improve the requirements for the river by utilising the most effective practises currently available, maximising environmental monitoring techniques or the most effective management practises for river basin management, particularly in areas close to anthropogenic development processes, and acting as a controller for the high-level runoff intensity flows out into the lake basin. These mitigation techniques are used in the study areas to reduce flow in small temporary channels that are currently degrading, where permanent stabilisation is impractical due to the transient nature of the problem, and to reduce flow in small eroding channels where construction delays or weather conditions prevent timely installation of non-erosive liners. This is due to the effectiveness and suitability of all mitigation methods employing simulation modelling for the system of Kenyir Lake Basin.

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