INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

Vol. 17 No. 3 (2025) 212-222
https://publisher.uthm.edu.my/ojs/index.php/ijie

IJIE

Development of Ranking Criteria to Determine The Emergency Auxiliary Spillway for Dam Overtopping Failure

R. S. Muda[1]*, N. S. Kamal[1], F. F. Norkhairi[1], M. N. Ismail[1]

[1] *Civil Engineering and Geoinformatics,*
TNB Research Sdn Bhd, Kajang 43000, Selangor, MALAYSIA

*Corresponding Author: rashidism@gmail.com

DOI: https://doi.org/10.30880/ijie.2025.17.03.023

Article Info

Received: 6 August 2024
Accepted: 15 June 2025
Available online: 19 September 2025

Keywords

Dam failure, saddle dam, auxiliary spillway, ranking assessment, site selection

Abstract

Dams are critical infrastructure for sustaining human life by serving various purposes, including irrigation and water supply, power generation, flood mitigation, and other essential needs. In the event of a dam failure, the sudden release of stored reservoir water can have catastrophic consequences to downstream communities and the environment. Dam failure is often caused by overtopping, which happens when the water level in the reservoir exceeds the dam's capacity. In preventing overtopping, considering an auxiliary spillway as an additional passage for releasing surplus water from the dam or reservoir during periods of high water flow or flooding emerges as a viable option. This study focuses on developing comprehensive ranking criteria for systematically determining emergency auxiliary spillways, explicitly addressing the potential threat of dam overtopping failures. It employs a structured methodology to establish robust criteria for evaluating and prioritizing potential sites. The study applied a multidisciplinary approach in assessing topography, geology, geotechnical aspects, river capacity, feasibility, technical intricacies, accessibility, construction limitations, site seismic activity, environmental ramifications, and the population at risk. The study employed multi-criterion analysis (MCA) to establish ranking criteria, enabling the prioritization of the most suitable saddle dams for selection as emergency auxiliary spillways. The study chose a Hydropower scheme situated in the Eastern region of Peninsular Malaysia for a case study. This scheme comprises a main dam and eight saddle dams within its infrastructure. The outcomes of this study contribute significantly to the advancement of methodologies for selecting emergency auxiliary spillways, thereby enhancing dam safety measures and minimizing the potential risks associated with overtopping incidents.

1. Introduction

The water body retained by a barrier known as a reservoir, either naturally occurring or man-made, that is utilized to store, regulate, and distribute water for a variety of purposes, such as for drinking water supply, irrigation, hydroelectric power generation, flood control, recreation, wildlife conservation, and industrial applications [1]-[3]. Reservoirs can be created by constructing dams across rivers or streams, or may occur naturally in geological formations, such as underground aquifers [4]. These water bodies can range in size, from small ponds to large lakes spanning thousands of square kilometers. In Malaysia, reservoirs are primarily utilized for domestic water supply, industrial, and agricultural purposes. Despite Malaysia's tropical climate, water resources are distributed unevenly throughout the region. In response to this concern, the Malaysian government has built multiple reservoirs aimed at capturing and storing water during periods of rainfall to ensure its availability during drier seasons. Amongst the largest reservoirs in Malaysia are located in the central region of the country which used for hydropower generation and flood mitigation, such as Kenyir Lake in Terengganu and Temengor Lake in Perak [5]. In Northern part of Peninsular Malaysia, Pedu Lake is the biggest lake used for irrigation and water supply to nearby towns and cities, support industrial and agricultural activities in Kedah. Fig. 1 shows reservoirs in Malaysia are sparsely distributed throughout the country.

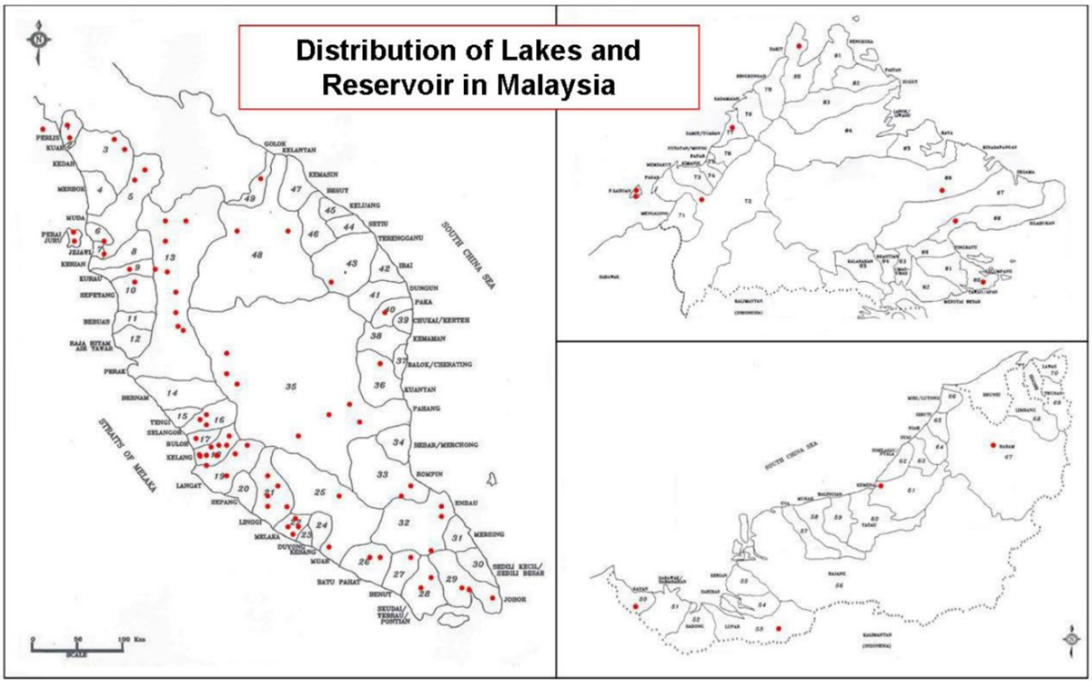

Fig. 1 *Distribution of lakes and reservoirs in Malaysia [5]*

Due to their diverse roles beyond water supply, certain reservoirs in Malaysia have become well-known tourist attractions despite primarily functioning as water resources. Due to of their scenic beauty of landscapes and opportunities for leisure activities such as fishing, boating, and camping, reservoirs like Chini Lake in Pahang, Kenyir Lake in Terengganu and Banding Lake in Perak stand as prime examples of these kinds of destinations. Another significant use of reservoirs is for hydropower generation[6]. Hydropower plants are typically situated in proximity to expansive rivers or reservoirs, allowing for the storage and controlled release of water to propel turbines and generators [7]. The operation encompasses storing water behind a dam and subsequently releasing it through tunnels and pipelines to rotate turbines, ultimately producing electricity that operates generators [8]. The amount of electricity produced depends on various factors like the height of the dam, water volume, and the rate at which water flows through the turbines. Reservoirs provide a means of storing water that can be released to match changes in electricity demand, enabling hydropower plants to run efficiently and provide a reliable source of renewable energy. There are 16 Dams in Malaysia used to store water for for hydropower generation, amongst the biggest dams for hydropower are Bakun Dam in Sarawak, Kenyir Dan in Terengganu and Temengor Dam in Perak [7]. These three dams have generated a significant amount of electricity supply, contributing to sustainable development and renewable energy for the country.

2. Saddle Dam and Spillway Structure

Saddle dams and spillways are crucial components of dam infrastructure. It plays an essential role in managing water flow, preventing flooding, and ensuring the structural integrity of dams. Both serve distinct yet complementary functions in regulating and controlling water within reservoirs and dam systems.

2.1 Saddle Dam

Most dams worldwide are built with saddle dams as their additional supporting structures. A saddle dam is a relatively smaller embankment constructed adjacent to the primary dam of a reservoir. The purpose of a saddle dam is to augment the reservoir's water level, enhance the main dam's stability, and amplify its storage capacity. The saddle dam is typically built perpendicular to the primary dam, thus creating a saddle-shaped configuration. The USBR [8] has stated that this configuration supports the primary dam, strengthening its ability to withstand water pressure. The construction of a saddle dam is a common practice in the design of reservoirs, and it plays a crucial role in the safe and efficient management of water resources. When selecting a site for a dam, multiple factors must be considered, such as water availability, topography, geology, environmental impact, land availability, transmission infrastructure, social considerations, economic viability, regulatory requirements, climate considerations, and security [9]. Evaluating the site's water source, elevation changes, stability, environmental impact, land availability, and proximity to other related infrastructures is essential. Social and economic factors and regulatory compliance should also be assessed to make an informed decision.

2.2 Guideline for Spillway and Dam Safety

Despite the importance of spillways in ensuring the safety and functionality of dams, the need for specific guidelines tailored to Malaysian conditions complicates the decision-making process for engineers and project stakeholders. Malaysia's diverse geography and climate present unique challenges for dam construction, including varying rainfall patterns, tropical storms, and geological considerations. Spillway selection must account for these factors to ensure optimal performance and resilience. While specific guidelines for Malaysian conditions are still lacking, MyDAMS stands as the sole guideline available in Malaysia to provide some direction; there remains a crucial need for comprehensive references to inform spillway selection effectively. Adaptation of International standards and guidelines developed by international organizations such as The Federal Emergency Management Agency (FEMA), the American Society of Civil Engineers (ASCE), the International Commission on Large Dams (ICOLD) and the US National Research Council (USNRC) can provide valuable insights that can be adapted to local contexts [9]. These guidelines included numerous recommendations supporting deterministic and risk-based approaches to spillway design and modifications. The Federal Energy Regulatory Commission (FERC) documents state that the beginning of the year 2000 can be considered the period of risk-informed decision-making; several advances and publications prior to the year 2000 paved the way for introducing risk into Spillway Design Flood (SDF) selection. The earliest reference of using risk-based analyses to determine the SDF appears in the 1964 manual prepared by the American Water Works Association (AWWA). The AWWA guidelines presented that for water supply dams, in which the selection of a spillway capacity less than the maximum probable flood is a grave decision for the designer for dam management, and recommends the use of thorough cost study to evaluate the variable costs of; (i) repairs to the dam and spillway; (ii) lost water during periods of repairs; (iii) damages caused by insufficient spillway; and (iv) construction of spillways of specific capacity [10].

2.3 Spillway Design and Its Functions

According to FEMA [10], a spillway is a hydraulic structure designed to pass expected flood flows while protecting the dam or dike's structural integrity. It was sized to handle floods equal to or less than the Intensity Duration Frequency (IDF), which is equal to or less than the current critical Probable Maximum Flood (PMF). Spillways are structures that release excess floodwater when other outlets are unable to handle it. They're located within a reservoir in a customary position to ensure sufficient passage for extreme floods to prevent the main dam from being overtopped. Spillways also play a vital role in regulating water supply by releasing controlled amounts of excess water during periods of heightened inflow. In addition, spillways are important for preserving natural water courses and mitigating harm to people and the environment downstream. Spillways are crucial for mitigating the risks of dam overtopping and failures. They come in two types; controlled and uncontrolled. A controlled spillway consists of a control structure such as gates, control channels or terminal structures, while an uncontrolled spillway is usually an open channel. Safely releasing excess water from dams and reservoirs will reduce the risk of overtopping and prevent catastrophic consequences of dam failure [11]. It is vital to prioritize the development of spillways as part of a comprehensive dam safety strategy.

Another spillway is called an Auxiliary or Emergency spillway. An auxiliary spillway is infrequently used and always be a secondary spillway, usually used for augmenting a service spillway discharge capacity. During operation, structural damage or erosion to the auxiliary spillway could occur due to excessive releases, including the maximum design discharge. Auxiliary spillways may be less robust, erosion-resistant structures consisting of some cast-in-place reinforced concrete, riprap channel protection and unarmored excavated channels [12]. An emergency spillway is designed to provide additional protection against the overtopping of a dam and is intended for use under unusual or extreme conditions, such as missed operation or malfunction of the service spillway or outlet works during large and remote floods such as the PMF or other emergency conditions. Fig. 2 is an example of the auxiliary and emergency spillway at New Waddel Dam.

The guidance for managing and controlling the spillway can be found in Section 4-2 of EM 1110-2 3600, which addresses the overall of water control systems for spillway design and management [13]. The EM 1110-2-1603, Hydraulic Design of Spillways, describes the technical aspects of design for the hydraulic features of spillways and

ER 1110-8-2, Inflow Design Floods for Dams and Reservoirs, sets forth requirements for selecting and accommodating IDFs [14]. According to Shicheng Li [15], spillways serve as a crucial component in ensuring the integrity and reliability of dams. These structures play an essential role in the management of water resources, safeguarding infrastructure, and preserving the delicate ecological balance. Spillways facilitate the release of excess water from dams and prevent the catastrophic consequences that may result from overtopping. By enabling a controlled and safe flow of water, spillways ensure the smooth and effective operation of dams while also mitigating the risks associated with floods and other natural disasters.

As specified in MyDAMS [7], spillway size should be established on the basis of accepted guidelines and requirements given the capacity and locality. The hydraulic, hydrological and meteorological input should be appropriately designed and considered. As stated in USO and FERC [16], when assessing spillway adequacy, independent designer must evaluate the potential for disoperation, failure to operate, blockage, or debilitating damage to a spillway, and the resulting effects on the maximum reservoir level and the potential for overtopping.

Fig. 2 *An emergency spillway with fuse plug (bottom) and an auxiliary ogee spillway (top) at New Waddell Dam [12]*

3. Methodology

3.1 Engineering Assessment of The Dam

The hydropower scheme located in the Eastern region of Peninsular Malaysia was selected for a case study. The hydropower scheme consists of 3 stations cascading from the northwest to the east, allowing water flow from the northwest hydropower stations to flow and accumulate in the lake of the lowest power station. When these two upstream lakes overflow or during PMF (Probable Maximum Flood), all the water will flow downstream and gather in the lake of the lowest hydropower station. To avoid the main dam overflow, the excess water needs to be channeled out through the spillway.

The lowest hydropower station has a main dam and eight additional saddle dams. The catchment area of the dam is about 2,600 km^2. The main dam is called Dam A, and the eight saddle dams are referred to as; saddle dam 1 (SD1), saddle dam 2 (SD2), saddle dam 3 (SD3), saddle dam 4 (SD4), saddle dam 5 (SD5), saddle dam 6 (SD6), saddle dam 7 (SD7), and saddle dam 8 (SD8). As recorded by TNBR [17], the saddle dams are strategically placed at the lowest points of a ridge that forms the northeastern boundary of the reservoir. Fig. 3 shows the location of all saddle dams in the study area. These dams are constructed in different locations within the reservoir vicinity and vary in length and height to best suit their respective locations. The bedrock in the area where the saddle dams are located is predominantly composed of granite that has been intruded by intermediate to basic dikes. The bedrock is mainly covered with residual granitic soil that varies in depth. The dam body is typically founded on completely weathered granitic rock, providing a sturdy foundation for the structure [17].

The main dam is built to withstand the hydrostatic forces of the reservoir and prevent seepage and erosion [18]. It is constructed using impervious materials and has two distinct zones, each with a slightly different layer thickness which is crucial for proper placement and compaction. The upstream zone is made up of a thicker layer of earth fill and is compacted thoroughly to ensure it is strong and stable. The downstream zone, on the other hand, has a thinner layer but is still compacted to the same degree. These zones work together to provide the required strength and stability to the dam, enabling it to withstand natural forces and provide reliable water storage for its intended purposes.

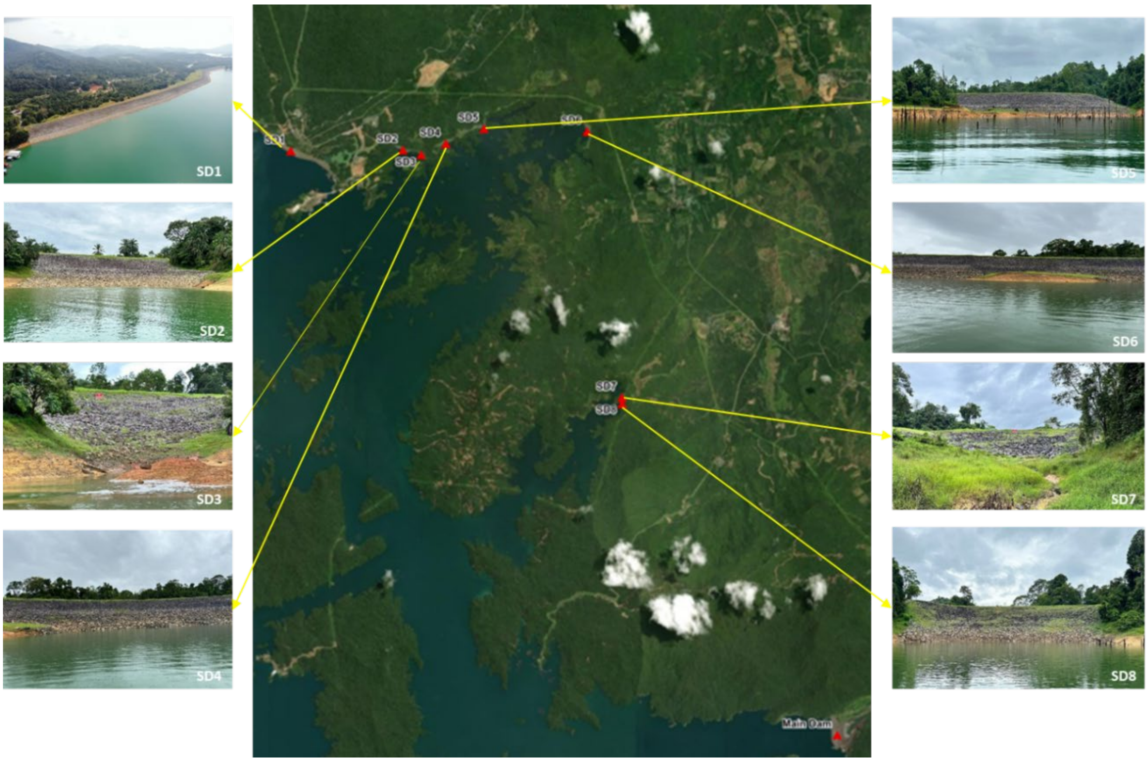

Fig. 3 *Location of saddle dams [17]*

3.2 Consideration to Select Auxiliary Spillway

During selection of an auxiliary spillway, it is crucial to consider the discharge capacity. This is significant because even a slight rise in the reservoir water surface (RWS) can result in a substantial flow release from the spillway. When selecting the type and size of a new auxiliary spillway, certain factors should be considered. These factors include frequency and duration of operation, flood control requirements, dam type such as concrete, embankment, composite, site conditions, topography, geology, and climate, hydrologic and seismic loading requirements, and diversion during construction requirements. Others important considerations includes assessing the downstream impacts, evaluating and mitigating erosion potential both upstream and downstream due to reservoir wave actions.

The proposed location for an auxiliary spillway has been made from the eight (8) saddle dams that have been identified, which cover the reservoir. All saddle dams are constructed of earth fill and have the same crest elevation of EL-155 m. The lowest hydropower station consists of a primary dam and eight additional saddle dams. The catchment area of the dam is about 2,600 km^2.

The saddle dams have been ranked according to the technical viability and complexity of the options available. The best one was selected and then evaluated for financial feasibility. Table 1 provides a brief overview of the dimensions of the eight saddle dams.

Table 1 *Saddle dam dimensions [17]*

Saddle Dam	Height (m)	Length (m)
1	52	2,240
2/3	24	765
4	21	420
5	20	480
6	39	747
7/8	18	300

A decision matrix with multiple criteria is used to determine the best location for selecting the auxiliary spillway. Bosnjak & Jajac [18] has highlighted that this decision-making tool provides a comprehensive and systematic approach to evaluate various options based on multiple criteria and objectives. The evaluation process involves five steps, starting with determining criteria or parameters, assigning weights to each criterion, scoring given to each criterion, calculating the given score for each saddle dam, and finally ranking the saddle dam. Each option is based on the assigned weights, which are determined based on previous project experiences, engineering judgment, international guidelines, and research papers [18],[19]. To ensure that all relevant factors are considered and given appropriate weightage, various criteria are typically taken into account. These criteria include factors like safety, cost, construction time, environmental impact, and social impact. Once the numerical scores are calculated based on these criteria, the options are ranked from best to worst in terms of total score. The option with the highest score is usually recommended for implementation, while the ones with lower scores are not recommended. It is important to assign weightage to each criteria in the decision-making process.

The proposed criteria for ranking auxiliary spillways are based on several factors. These include topography (15%), geology, and geotechnical aspects (15%), the capacity of the river to contain floods (15%), feasibility and technical complexity (15%), accessibility and construction constraints (10%), site seismicity (10%), environment (10%), and downstream population at risk (10%). The weightage assigned to each factor was based on site conditions during field visits and assessments, selected parameters, and engineering practicality judgment. Table 2 displays the criteria used for ranking the spillways with their respective weightages.

Table 2 *Weightage distribution for the factor affecting the site selection for the new auxiliary spillway*

Criteria	Description	Weightage (%)
1	Topography	15
2	Geology and Geotechnical	15
3	River Downstream	15
4	Feasibility and Technical Complexity	15
5	Accessibility and Construction Constraints	10
6	Site Seismicity	10
7	Environmental Impact	10
8	Downstream Population Risk	10
	Total Score	100

The average scoring system proposed for the criteria is set as a five-point system. The points given are based on the effectiveness of the approach as referred to in Table 3.

Table 3 *Points given based on effectiveness of the approach*

Points	Effectiveness Remarks
5	Excellent effectiveness
4	Very effective
3	Moderately effective
2	Fairly effective
1	Not effective

4. Data Analysis

4.1 Scenario Analyzed

A Multi-Criteria Analysis (MCA) was performed to prioritize saddle dams based on inspection and review results. Bosnjak et al. [18] and Mckenzie et al. [20] established an infrastructure management-based MCA process that involved an engineering assessment, data processing, map digitization, profile and section sketching, identification of negative lineaments, cross-checking digitized maps with geo-referenced satellite imagery, and analysis of both field and digitized data. The ArcGIS Geographic Information System (GIS) was used for digitizing. The digitized geological terrain maps were manually verified against the field maps to ensure that the boundaries and terrain attributes were accurately represented. Seven different scenarios were tested at each saddle dam during the analysis. The auxiliary spillways were placed at specific points on each saddle dam and ranked accordingly based on the MCA results. Table 4 shows the scenario for the analysis.

The study considered two scenarios for managing flood discharge and release in a cascading dam system. Scenario A assumed that the main dam spillway would handle all excessive flood discharge without the need for an auxiliary spillway. However, the study found that this scenario had the highest hazard and risk likelihood during a large flood event, as overtopping of the crest and internal erosion of the main dam and saddle dams were the most critical failure modes. In Scenario B-G, the site suitability for constructing an auxiliary spillway at each saddle dam, namely 1, 2/3, 4, 5, 6, and 7/8, was tested and ranked. This analysis aimed to identify the most practical and effective measures for mitigating risks and hazards associated with different scenarios.

Table 4 *Scenario of auxiliary analysis*

Scenario	Tested location of auxiliary spillway
A	No auxiliary spillway
B	Saddle Dam 1
C	Saddle Dam 2/3
D	Saddle Dam 4
E	Saddle Dam 5
F	Saddle Dam 6
G	Saddle Dam 7/8

5. Results and Discussion

The summary of the technical scoring for each scenario assessed is shown in Table 5. The results are ranked according to the score attained. Based on the data presented in Table 5, scenario A has the highest score in terms of topography criteria. This indicates that a large flood may potentially occur downstream of the service spillway, posing a severe risk to human life and causing significant property damages. It is also worth noting that scenario A has the lowest score for geotechnical and geological criteria. On the other hand, other scenarios have the same score for topography, geotechnical, and geological criteria.

Table 5 *Summary of score for all saddle dam for 'topography' and 'geology and geotechnical' criteria*

		Technical Score			
Scenario	Description	Topography	Score	Geology and Geotechnical	Score
		15		15	
A	No auxiliary spillway	5	0.15	3	0.09
B	Saddle Dam 1	3	0.09	4	0.12
C	Saddle Dam 2/3	3	0.09	4	0.12
D	Saddle Dam 4	3	0.09	4	0.12
E	Saddle Dam 5	3	0.09	4	0.12
F	Saddle Dam 6	3	0.09	4	0.12
G	Saddle Dam 7/8	3	0.09	4	0.12

Table 6 indicates that in scenario A, the river downstream criteria received the lowest score, implying that it could be the main source of a severe flood downstream. However, scenarios D and E received low scores in terms of technical complexity and practicality, primarily due to the existence of an uncontrolled spillway that could result in a significant flood with no downstream area control.

Table 6 *Summary of score for all saddle dam for 'river downstream' and 'feasibility and technical complexity' criteria*

		Technical Score			
Scenario	Description	River Downstream	Score	Feasibility and Technical Complexity	Score
		15		15	
A	No auxiliary spillway	1	0.03	3	0.09
B	Saddle Dam 1	2	0.06	4	0.12
C	Saddle Dam 2/3	3	0.09	4	0.12
D	Saddle Dam 4	3	0.09	2	0.06
E	Saddle Dam 5	3	0.09	2	0.06
F	Saddle Dam 6	3	0.09	3	0.09
G	Saddle Dam 7/8	3	0.09	3	0.09

Table 7 shows that in scenario A, the lowest score was received by the criteria related to construction constraints and accessibility. This happens because floods can enter the reservoir and overflow from the spillway, cutting off access roads and upstream reservoirs due to high water levels. There is also a high risk for personnel to access the upstream part of the reservoir during extreme flood events. Scenarios B to E obtained the same scores for both access and construction constraints. However, scenarios F and G received the lowest scores for accessibility and construction constraints. The seismicity of the site is assumed to be the same for the entire reservoir and dam area. This result suggests that Saddle Dam 1 presents fewer options for site accessibility and has higher construction constraints when compared to other saddle dams.

Table 7 *Summary of score for all saddle dam for 'accessibility and construction constraints' and 'site seismicity' criteria*

Technical Score					
Scenario	Description	Accessibility and Construction Constraints	Score	Site seismicity	Score
		10		10	
A	No auxiliary spillway	1	0.02	4	0.08
B	Saddle Dam 1	4	0.08	4	0.08
C	Saddle Dam 2/3	4	0.08	4	0.08
D	Saddle Dam 4	4	0.08	4	0.08
E	Saddle Dam 5	4	0.08	4	0.08
F	Saddle Dam 6	3	0.06	4	0.08
G	Saddle Dam 7/8	3	0.06	4	0.08

In Table 8, it is shown that scenario A has the lowest score for the environment and downstream population at risk categories. This means that flood flows in scenario A would carry excessive sediments and debris towards the downstream river. This could cause log jams and river erosion at various locations. Extreme flood flows in downstream river activities like water intake, fishery, boating, and navigation would also be affected by this scenario. Other scenarios have almost the same scores for environment and downstream population impact.

Table 8 *Summary of score for all saddle dam for 'environment' and 'downstream population risk' criteria*

Technical Score					
Scenario	Description	Environment	Score	Downstream population risk	Score
		10		10	
A	No auxiliary spillway	1	0.02	1	0.02
B	Saddle Dam 1	3	0.06	2	0.04
C	Saddle Dam 2/3	3	0.06	3	0.06
D	Saddle Dam 4	3	0.06	3	0.06
E	Saddle Dam 5	3	0.06	3	0.06
F	Saddle Dam 6	3	0.06	3	0.06
G	Saddle Dam 7/8	3	0.06	3	0.06

Table 9 and Fig. 4 summarize the overall scores for each scenario and saddle dam. The result suggests the installation of an auxiliary spillway at Saddle Dam 2/3 in Scenario C. Scenario A has the lowest score by leaving the saddle dam without an auxiliary spillway. Scenario C has the highest score among all the scenarios. This indicates that scenario C is the most suitable saddle dam for the proposed auxiliary spillway. It is important to note that the slight total score difference of 0.05 between each scenario is due to numerous parameters that were analyzed during MCA. Despite the similarities in the differences for each scenario, each parameter holds a different weightage that contributes to this percentage. This highlights the need to analyze each parameter thoroughly when making crucial decisions. The consideration was applied according to weightage distribution for the factor affecting the site selection for the proposed auxiliary spillway, as described in Table 2.

The construction of the auxiliary spillway could impact the downstream river morphology, downstream flooding, sedimentation transport and erosion. Since the auxiliary spillways are designed for extreme flood discharges, the estimated discharge is expected to impact the downstream riverine should an extreme flood event occur. The construction of an auxiliary spillway has the potential to cause significant changes in the downstream river morphology, downstream flooding, sedimentation transport, and erosion. This is particularly true in the event of extreme flood discharges. Such discharges can have serious impacts on the downstream riverine, which is why it is important to evaluate the potential effects on river hydrology during the planning and implementation of any spillway construction project.

Table 9 *Summary of total score for all scenarios and saddle dam*

Scenario	Description	Score	
		Total Score	Rank
A	No auxiliary	0.50	7
B	spillway	0.65	4
C	Saddle Dam 1	0.70	1
D	Saddle Dam 2/3	0.64	5
E	Saddle Dam 4	0.64	6
F	Saddle Dam 5	0.65	3
G	Saddle Dam 6	0.65	2
	Saddle Dam 7/8		

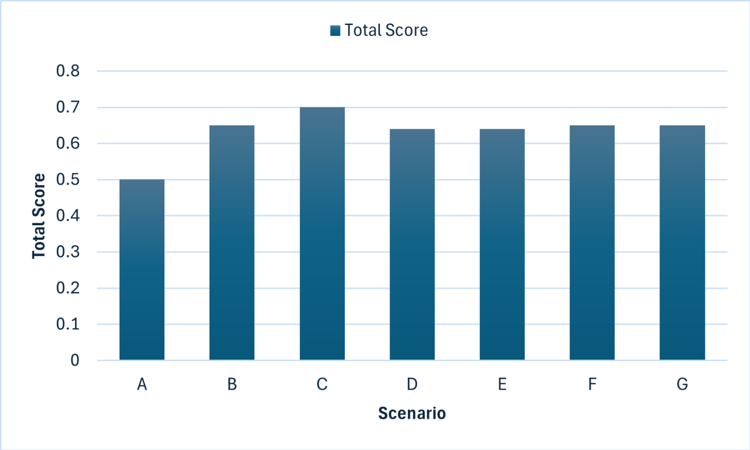

Fig. 4 *Summary of total weightage for all scenario*

The effects of spillway construction on river morphology vary depending on a number of factors, including the amount and type of impounded sediments during the construction activities. A detailed feasibility study is required to determine the specific parameters associated with river morphology, including stream channel hydrogeometry, slope, hydrology, and sediment basin. It is important to consider these factors because the construction of an auxiliary spillway and related structures can modify the localized hydrologic regime of a natural river.

In addition to the impacts on river morphology, the construction of an auxiliary spillway can also have an impact on water quality conditions downstream of the structure. It is important to take this into account during the planning and implementation of any spillway construction project to minimize any negative impacts on the environment. Hydrologic effects of spillway construction typically depend on factors, including the construction activities and the size of the structure. Since the location is site-specific, the construction activities would have minimum impact on the downstream river hydrology. These potential impacts should be evaluated when planning and implementing the Project. The effects on river morphology vary based on the quantity and composition of impounded sediments during the earthworks and construction work activities. A detailed feasibility study would need to be carried out further for specific parameters associated with river morphology, including stream channel hydrogeometry, slope, hydrology, and sediment basin. Generally, constructing the auxiliary spillway and appurtenant structures would modify the localised hydrologic regime of a natural river. As a result of these construction activities, there would be an impact on the water quality conditions downstream of the structure.

6. Conclusion

A study has been conducted to identify the best position for an auxiliary spillway and its modification. Saddle dam 2/3 has been found to be the most suitable location based on a technical scoring system that assesses eight criteria. However, more detailed assessments such as site investigation, topography survey, and engineering design are required to complement this proposed location. Selecting a suitable site for an auxiliary spillway is a complex process that involves a thorough assessment of engineering and non-engineering aspects with multiple technical considerations. Factors such as river channel downstream, topography, environmental impact, downstream population, and infrastructure are crucial. During the field visit, downstream population and infrastructure such as roads, bridges, and transmission lines at Saddle Dam 2/3 have been identified as high-risk areas that may require compensation, relocation, or modification should the extreme flood waters pass. The study shows that while engineering and socio-impact assessments have been given due importance, Environmental Impact Assessment (EIA) has not received the same level of attention. To ensure a comprehensive analysis during the design stage, a detailed study on EIA is essential in the future. This would help identify any potential environmental risks and hazards, leading to better decision-making and more sustainable outcomes. Selecting an auxiliary spillway requires engaging with experts, conducting feasibility studies, and consulting with stakeholders. It demands high professionalism, expertise, and comprehensive deliberation of all relevant factors. Ultimately, determining the most suitable and secure saddle dam for constructing an auxiliary spillway is a crucial and challenging task.

Acknowledgement

The author wishes to express gratitude to Tenaga Nasional Berhad and TNB Research Sdn Bhd for their ongoing support throughout this study. A special acknowledgement is dedicated to the Civil & GIS team for their consistent dedication and effort in completing the project.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contributions to the paper as follows: ***The study conception and design*** *were carried out by Rashidi Sabri Muda and Nor Syafiqah Kamal.* ***Data collection and case study development*** *were performed by Nor Syafiqah Kamal.* ***Methodology development and analysis*** *were conducted by Rashidi Sabri Muda, Nor Syafiqah Kamal and Fatin Faiqa Norkhairi.* ***The initial draft of the manuscript*** *was prepared by Nor Syafiqah Kamal and Fatin Faiqa Norkhairi. Rashidi Sabri Muda and Mohd Nadzari Ismail provided* ***technical review and critical revisions****. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Akademi Sains Malaysia (2009). Strategies for the Sustainable Development and Management of Lakes and Reservoirs in Malaysia. Kuala Lumpur.

[2] Sharip, Z., & Zakaria, S. (2008). Lakes and reservoir in Malaysia: Management and research challenges. Proceeding of the 12th World Lake Conference, pp. 1349–1355.

[3] Lempérière, F. (2003). Design and Construction of Dams, Reservoirs and Balancing Lakes. Paris.

[4] Oyekanmi, M. O., & Mbossoh, E. R. (2018). Dams and sustainable development goals: a vital interplay for sustainability. Journal of Environmental Earth Sciences, 8, 1–11.

[5] Sharip, Z., & Zakaria, S. (2008). Lakes and reservoir in Malaysia: Management and research challenges. Proceeding of the 12th World Lake Conference, pp. 1349–1355.

[6] Mariapan, M., Lin, E. L. A., Isa, S. S., Karim, M. S., & Hakeem, K. R. (2017). Ecotourism Potentials in Malaysia. 2017. Universiti Putra Malaysia.

[7] DID (2017). Malaysia Dam Safety Management Guidelines (MyDAMS). Kuala Lumpur.

[8] USBR (2012). Design of Small Dam. A Water Resources Technical Publication. United States Department of the Interior.

[9] FERC (2015). Chapter II - Selecting and Accommodating Inflow Design Floods. Engineering Guidelines for the Evaluation of Hydropower Projects. Federal Energy Regulatory Commission.

[10] FEMA (2012). Summary of Existing Guidelines for Hydrologic Safety of Dams. Federal Emergency Management Agency.

[11] Jamal, H. (2017). Spillway - Definition, Types of Spillways and Classification. https://www.aboutcivil.org/spillway-definition-types-classification.html

[12] USBR (2022). Design Standards No. 14 Appurtenant Structures for Dams: Spillways and Outlet Works Design Standard. U.S. Department of the Interior Bureau of Reclamation.

[13] USACE (1987). Engineer Manual U.S. Army Corps of Engineers Management of Water Control Systems. Washington DC.

[14] U.S. Army Corps of Engineers (1997). Hydrologic Engineering Requirements for Reservoirs. Manual No. 110-2-1420. Washington DC.

[15] Li, S. (2023). CFD and Data-Driven Modeling for Safe Spillway Discharge. KTH Royal Institute of Technology,

[16] Fearon, K., Boyer, D., & DiJohn, T. (2012). Safety of Water Power Projects and Project Works. Washington, DC.

[17] TNBR (2022). Saddle Dam Risk Assessment and Engineering Mitigation. Bangi, Selangor.

[18] Bosnjak, A., & Jajac, N. (2023). Determining priorities in infrastructure management using multicriteria decision analysis. Sustainability, 15, 14953. https://doi.org/10.3390/su152014953

[19] TNBR (2022). Final Report Hulu Terengganu Dam Break. Bangi, Selangor.

[20] Mckenzie, R., & Gala, T. (2022). GIS-based analytical hierarchy process (AHP) for flood hazards and risks assessment: A case study of the Port City of Montego Bay and the surrounding St. James Parish, Jamaica. Research Square. https://doi.org/10.21203/rs.3.rs-2285275/v1