Heriot-Watt University
Research Gateway

Flood Hydrograph Generation for Kenyir Dam Using Hydrological Modeling System

Citation for published version:
Mohd Sidek, L, Razali, J, Marufuzzaman, M, Yalit, MR, Radzi, MRBM & Hossain, MS 2020, Flood Hydrograph Generation for Kenyir Dam Using Hydrological Modeling System. in *ICDSME 2019: Proceedings of the 1st International Conference on Dam Safety Management and Engineering.* Water Resources Development and Management, Springer, pp. 64-75. https://doi.org/10.1007/978-981-15-1971-0_7

Digital Object Identifier (DOI):
10.1007/978-981-15-1971-0_7

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Peer reviewed version

Published In:
ICDSME 2019

Publisher Rights Statement:
This is a post-peer-review, pre-copyedit version of an article published in ICDSME 2019. ICDSME 2019. Water Resources Development and Management. The final authenticated version is available online at: https://doi.org/10.1007/978-981-15-1971-0_7

General rights
Copyright for the publications made accessible via Heriot-Watt Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
Heriot-Watt University has made every reasonable effort to ensure that the content in Heriot-Watt Research Portal complies with UK legislation. If you believe that the public display of this file breaches copyright please contact open.access@hw.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 21. Sep. 2021

Flood hydrograph generation for Kenyir Dam using Hydrological Modeling System

Lariyah Mohd Sidek[1,2], Juliana Razali[1], Mohammad Marufuzzaman[2], Mohd Ruzaimie Yalit[3], Mohd Rashid bin Mohd Radzi[3], Md. Shabbir Hossain[4]

[1] Civil Engineering Department, College of Engineering, Universiti Tenaga Nasional, Selangor, Malaysia
[2] Institute of Energy Infrastructure, Universiti Tenaga Nasional, Selangor, Malaysia
[3] Asset management department, Tenaga Nasional Berhad, 59200, Kuala Lumpur, Malaysia
[4] School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Malaysia

julianarazalee27@gmail.com
Lariyah@uniten.edu.my
marufsust@gmail.com
ruzjemz86@gmail.com
rashidshah92@gmail.com
m.hossain@hw.ac.uk

Abstract. Among various dams owned by Tenaga Nasional Berhad (TNB) Malaysia, some were constructed in the early 1930s. Hence, these dams might be affected by severe storms after completion. Climate change affects the availability and distribution of water resources in space and time and the frequency of extreme rainfall events (PMP). Moreover, the probable maximum flood (PMF) designed before has increased and currently, some dams would be overtopped and caused floods in the downstream area. Thus, it is important to revise the PMP and the PMF values by using the notable storms of climate change as well as to generate flood hydrographs for water dams. In this research, Kenyir Lake is considered for sampling sites. The long record of rainfall and other meteorological data for all stations have been identified, collected, assembled, processed and used in the analyses to determine the PMP values and generation of PMF using HEC-HMS. The results showed that the inflow value for Kenyir is 23,923.1 m^3/s, whereas the outflow is 5,563.2 m^3/s. Finally, 5, 10, 50 and 100-year flood hydrographs for Kenyir dam are proved that it is expected to be safe from overtopping under the PMF condition founded by this research.

Keywords: Flood Hydrograph; PMP-PMF; HEC-HMS; Kenyir Dam.

1 Introduction

Dams have played an important role in sustaining people's lives [1-5]. Most of the dams are single-purpose dams, but now a number of multipurpose dams are being built. According to the World Register of Dams, about 48% of the world's large dams were built primarily for irrigation, and some 17% for hydropower (production of electricity), 13% for water supply, 10% for flood control, 5% for recreation and less than 1% for navigation and fish farming [6]. Earlier dams have been designed and operated under the assumption of stationary of a design storm value, known as Probable Maximum Precipitation (PMP) for deriving the Probable Maximum Flood (PMF) in spillways of large dams where no risk of failure can be accepted [7-9]. These estimates have also been used in defining the extent of floodplain areas at risk in extreme flood conditions. The main purpose of designing spillways using the PMP-PMF is to avoid the loss of life and damage to property due to the overtopping and failure of the dam wall.

There are some dams owned by TNB, which were constructed in the early 1930s. It is expected that severe storms might have occurred few times after the completion of the dams. There are also indications that global climate change has a potential influence on the regional climate and more specifically the rainfall and temperature [10-12]. As the saturation vapor pressure increases with temperature, the rainfall producing cycle could have more availability of moisture to precipitate. Moreover, in the moisture maximization method, there are possibilities that the values of PMP will increase [13]. Climate change affects the availability and distribution of water resources in space and time and the frequency of extreme rainfall events. Moreover, the PMF designed before has increased and currently some dams would be overtopped and caused floods in downstream area. Thus, it is important to revise the PMP-PMF values by using notable storms as well as to consider potential effects of climate change on estimates of PMP and PMF. It is worth to mention at the stage that if future alterations in the meteorological elements had been known, then it would have received the necessary attention to PMP estimation.

The PMP is the greatest depth of precipitation for a given duration that is meteorologically possible for a watershed or an area at a particular time of year, with no allowance made for long-term climatic trends [14]. While PMF is the flood that may be expected from, the most severe combination of critical meteorological and hydrologic conditions [15]. The PMF also has physical meaning, which provides an upper limit of the interval within which the engineer must operate and design the dam. Due to the risks to human life, the adequacy of a spillway of a dam upstream of a population center must be catering to the PMF. The method used to determine the PMF is a deterministic approach, which uses PMP as the meteorological input. The deterministic method of calculation of PMF consists of the transformation of the PMP with a rainfall-runoff deterministic model into a runoff hydrograph.

As a responsible dam owner for assuring the safety of dams Tenaga Nasional Berhad jointly with TNB Research Sdn Bhd has embarked on a comprehensive research program to study a dam break analysis with a view to assess the impact downstream in terms of hydrological assessment, social, economic and environmental from all of its operating dams since year 2003. The program began with Sungai Perak Hydroelectric Scheme in 2003, followed by Kenyir Hydroelectric Scheme in 2006 and Pergau Hydroelectric in 2013. However, the methods of PMP estimation carried out did not consider the effects of climate change on estimates of PMP. Since dams are long-lived structures with lifespans exceeding 100 years or more, it is vital to consider the potential effects of climate change on estimates of PMP. With the climate change impacts on rainfall and the long life age of the dams, a study is necessary to revise estimates of PMP and PMF values for TNB`s Dam using the latest recorded rainfall data. The purpose of the study is to check the adequacy of the existing spillway capacities of dams using revised PMP and PMF values.

An increased concentration of greenhouse gases also substantially changes the global hydrological cycle and consequently the variability and strength of Malaysian rainfall. Climate change affects the availability and distribution of water resources in space and time as well as the frequency of extreme rainfall events [16]. In the long term, climate change can cause significant impacts on every aspect of life, the environment and facilities that support living life. This includes the performance of existing infrastructures such as dams that were installed to benefit the public. The impact of climate change on these infrastructures can be positive or negative and, for either outcome, it may or may not be significant. These impacts need to be evaluated especially for those constructed and operated for public safety and security.

In this research, PMP and PMF for Kenyir and Pergau Hydro Stations will be calculated using the Hydrologic Engineering Center- Hydrological Modeling System (HEC-HMS) model, which is a product of the US Army Corps of Engineers' research and development program and is produced by the HEC. The program simulates precipitation-runoff and routing processes, both natural and controlled. The program improves upon the capabilities of HEC-1 and provides additional capabilities for distributed modeling and continuous simulation. The 5, 10, 50 and 100-year flood hydrographs for both dams will be calculated and thus help to develop the flood hazard maps and save thousands of lives in that area.

2 Study Area

The Kenyir dam is located in the central portion of Terengganu State on the east coast of Peninsular Malaysia. Kenyir Hydro Scheme is mainly designed for hydroelectric power generation, and flood mitigation purposes owned by TNB. The details of the Kenyir Dam are shown in Table 1. The Kenyir dam is a rockfill dam standing 155 m tall from its foundation. It is currently the largest operational dam in Malaysia in terms of three features. First, the dam structure is made up of the largest volume of fill. Secondly, the Kenyir reservoir is the largest synthetic lake by a surface area approximately 369 km^2 at FSL and thirdly, Kenyir reservoir has the largest gross storage volume, which is about 13.6 billion m^3 at FSL.

Table 1. Details of Kenyir Dam.

General		
Date of construction		1980-1985
Full supply level (FSL)	[m]	145.00
Maximum flood level	[m]	153.00
Dam crest level	[m]	155.00
Normal minimum operation level	[m]	135.40
Absolute minimum operating level	[m]	120.00
Reservoir volume at FSL	[m^3]	13.6 x 10^9

Live storage	[m^3]	7.4 x 10^9
Reservoir surface area at FSL	[km^2]	369
Main Dam		
Type		earth core rockfill dam
Max. height	[m]	155.00
Crest length / crest width	[m]	800 / 10
Elevation of dam crest (design)	[m]	155.00
Elevation of top of core	[m]	154.00
Max. camber provided	[m]	1.00
Upstream / downstream slope		1(v):1.8(h) / 1(v):1.75(h)
Design Flood		1/1000 years
PMF (original)	[m^3/s]	15,500
PMF (revised - Kenyir II FS)	[m^3/s]	21,200
Spillway		
Type	ungated free overflow with the chute	
Crest length	[m]	140
Crest elevation	[m]	145.00
Max. discharge capacity at PMF	[m^3/s]	6,500
Diversion tunnels		
Length	[m]	875 & 767
Height x width (horseshoe-shape)	[m]	15 x 12
Headrace tunnels		
No. x length	[m]	4 x 300
Lined diameter	[m]	4.25
Power station		
Type	surface, at dam toe on the right abutment	
No. and type of generating units		4 Francis
Installed capacity of generating units	[MW]	4 x 100
Maximum discharge	[m^3/s]	140

The location of study area is shown in Figure 1. The Kenyir reservoir was created by impounding the Sg. Terengganu; 15 km west of Kuala Berang and 55 km upstream of Kuala Terengganu. The area of the Kenyir catchment is 2,600 km^2

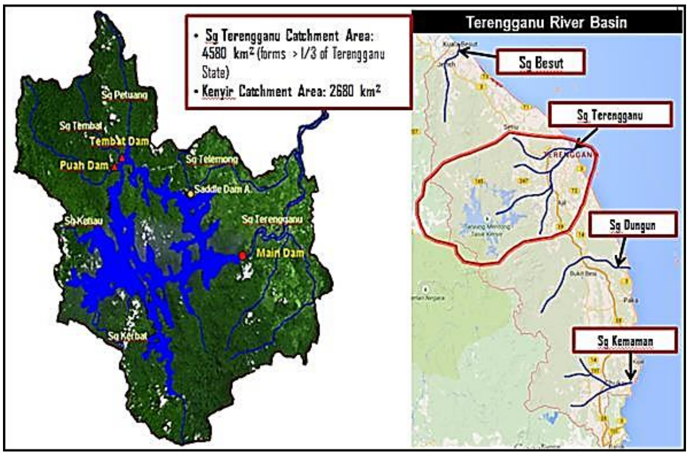

Fig. 1. Location of Kenyir Dam

The total rainfall stations that are available in the study area are 35 stations. Out of 35 stations, there are 18 DID rainfall stations located in the Kenyir Hydroelectric Scheme while the remaining 17 rainfall stations are owned by TNB. Figure 2 shows the location of rainfall stations for the scheme.

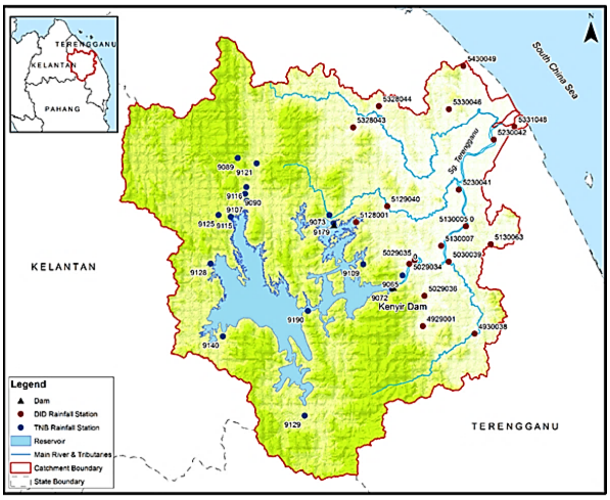

Fig. 2. Location of Rainfall Stations for Kenyir Hydroelectric Scheme

3 Hydrological Analysis

The highest rainfall observed in a particular period during a year is called the annual maximum rainfall for that duration. For example, the maximum rainfall observed in a period of 1-day or in a period of 2 consecutive days during the year is called the annual maximum rainfall for 1-day or 2-day duration respectively. The annual maximum rainfall recorded at a station over a long period of time form a series of rainfall values that can be used for estimating design rainfall by statistical methods and in particular by frequency analysis techniques. It is important to know the values of the highest rainfall for 1-day, 3-day and 5-day duration that nature has produced at different stations in Kenyir catchment. The highest recorded rainfall values of 1, 3 and 5 days duration for each of the 24 stations during the period of their records are given in Table 2.

Design rainfalls are needed to estimate flood runoff for the design of hydraulic structure when rainfall-runoff models such as the unit hydrograph method, rational method and others are used. The annual maximum rainfall series of 1-hr, 3-hr, 6-hr, 12-hr, 1-day, 3-day and 5-day durations at the 24 rainfall stations in Kenyir have therefore been subjected to statistical analysis to determine the values of design rainfall for the return periods of 5, 10, 50 and 100-year [17]. The most common form of design rainfall data required for use in peak discharge estimation is from the relationship represented by the IDF curves.

Table 2. Highest Recorded Rainfall (mm) for 1, 3 and 5-day Duration

No.	Station No.	Station Name	1-day (mm)	3-day (mm)	5-day (mm)
1.	9072	Kajiklim Kenyir	254.4	439.3	554.6
2.	9107	Empangan Pelana F (Kenyir)	230.6	389.4	504.0
3.	9115	Sg. Tembat	224.5	370.0	447.1
4.	9116	Sg. Petuang	232.4	379.9	465.5
5.	9125	Sg. Ketiar	171.1	299.2	367.2
6.	9128	Sg. Terenggan	146.5	231.0	278.0
7.	9129	Ulu Sg. Kerbat	222.1	388.9	475.4
8.	9140	Kuala Sg. Kerbat	240.5	441.3	532.5
9.	4929001	Kg.Embong Sekayu di Ulu Terengganu	537.1	857.5	1111.9
10.	4930038	Kg. Menerong	856.7	1,361.5	1,675.2
11.	5029034	Kg. Dura	575.1	1,020.8	1,398.2
12.	5029035	Sek. Keb. Kg. Dusun di K. Brang	595.0	765.0	890.0
13.	5029036	Rumah Pam Paya Kemat	438.4	686.0	987.5
14.	5030039	Hospital K. Brang / (Dipindahkan ke JPS.Hulu Trg.)	379.0	873.0	1,278.0
15.	5128001	Sg. Gawi	541.2	930.0	1,197.7
16.	5129040	Rumah Pam Paya Rapat	404.6	700.0	1,046.0
17.	5130063	Stn. Pertanian Ajil	414.4	757.4	1,038.1
18.	5230041	Sek. Keb. Kuala Telemong	468.5	581.1	767.1
19.	5230042	Rumah Pam Pulau Musang	505.0	1,037.0	1,528.0
20.	5328043	Kg. Bkt. Berangan di Setiu	438.6	760.0	958.9
21.	5328044	Kg. Sg. Tong	411.2	879.3	1,328.0
22.	5330046	Sek. Keb. Kg. Gemuroh	437.3	755.5	1,081.0
23.	5331048	Setor JPS Kuala Terengganu	575.5	1,065.5	1,499.0
24.	5430049	Kg. Padang Maras	437.3	817.0	1,352.0

The method adopted for the PMP value of various durations is in accordance with the industrial standard for dam design worldwide and local standard [14]. The technique used for PMP derivation is by using statistical method namely Hershfield statistical analysis approach. This PMP is then used to derive the corresponding PMF at Kenyir dam site using rainfall-runoff routing model namely HEC-HMS for determining the PMF.

4 Results and Discussion

The PMP values for this study have been summarized in Table 3 below. The PMP values obtained were also compared with previous study results undertaken by SMEC and SMHB in 1986 and 2007 respectively [18-19]. The different values were probably caused by the method used to generate the PMP. For the study by SMEC, a conventional transposition and dew-point maximization were used for this extreme precipitation development [18]. While for SMHB, the PMP derivation is based on a hydrometeorological approach that involved D-A-D (Depth- Area- Duration) analyses of major storms and development, storm moisture maximization and transposition. The procedure is described in the WMO Manual No. 32 [14]. Whereas, this research used the Statistical Hershfield method, which is a common practice for developing PMP in Malaysia. Based on Table 3, the PMP value for 3-day (72-hour) duration produced by this research is quite high compared to PMP values developed by SMEC and SMHB for same duration [18-19]. This is because the rainfall data used up to 2017 compared to previous studies by SMEC and SMHB which are relatively old, (up to the year 1976 and 2007 only).

Table 3. Probable Maximum Precipitation (PMP) Values for the Study

Duration (hours)	Estimated Extreme Catchment Rainfall (mm)	PMP based on Hydrometeorological Method (mm)	PMP based on Hershfield Method (mm)
	SMEC [18]	SMHB [19]	This Research
1	-	-	293.0
3	-	-	462.1
6	-	-	647.8
12	290	-	912.6
24	470	-	1,145.7
48	900	-	1,794.4
72	1,280	1,474 *(generalized)* 1,195 *(after applying transposition factor 0.81)*	2,091.2
96	1,450	-	-
120	1,520	-	2,920.1

The PMF and design flood for 5, 10, 50 and 100-year average return period (ARI) results achieved from the HEC-HMS model are based on the available data that were obtained from previous studies conducted by TNB Research, TNB and from hydrological assumptions. In this study, the calibrated HEC-HMS model was used to simulate the catchment response to the PMP for Kenyir Dam catchment.

According to the previous studies including the final design report by SMEC, since the catchment area of Kenyir dam is large, it is appropriate to apply and use the most severe flood, which will produce a high volume and peak discharge [18]. Major storms considered are those with long durations and cover large areas. Hence, for this study, the PMF generated for 3-day storm duration has been used, as this duration has generated a high volume and peak discharge. The PMF inflow and outflow reservoir level produced by this study and previous studies are compared in Table 4 and the hydrograph the PMF inflow and outflow for this research is shown in Figure 3.

Table 4. The PMF Simulation Results for Kenyir Dam

Study Reference	PMF Inflow (m^3/s)	Outflow (m^3/s)
This Research	23,923.1	5,563.2
SMEC (1986a)	15,500	6,500
SMEC (1997)	21,200	-
SMHB (2007)	18,619 (Type1)* 20,532 (Type2)**	5,776(Type1)* 5,602 (Type2)**

*(Note: *Type 1-Based on actual Mersing Storm in the year 1970*
***Type 2- Based on actual Mersing Storm in the year 1970 by using Nested Bell Shape)*

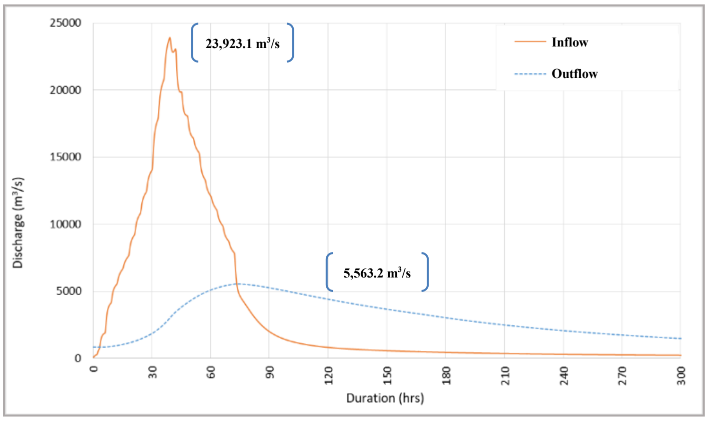

Fig. 3. The PMF Hydrograph for Kenyir Dam

According to Figure 3, it is being shown that the time of concentration (t_c) is about 40hr where the peak flow is 23,923.1 m^3/s. The summary of the design flood hydrograph inflow, outflow and maximum reservoir level of 5, 10, 50, and 100-year return periods for 3-day storm duration are tabulated in Table 5.

Table 5. Summary of the Design Flood Hydrograph for Kenyir Dam

Flood Return Period (year)	Inflow (m^3/s)	Outflow (m^3/s)	Maximum Reservoir Level (m)
5	4,507.2	1,144.7	147.5
10	6,095.6	1,425.5	147.9
50	9,660.0	2,159.5	148.8
100	11,201.9	2,512.5	149.2

The PMF estimated for Kenyir Dam is significantly different from the results presented by previous studies as tabulated in Table 6. The table shows the comparison of the results of all studies that have been done before including the current result that has been produced.

Table 6. Result Comparison for Kenyir Dam

Details	SMEC (1986 a)	SMEC (1997)	SMHB (2007)	This research
Kenyir Dam (Dam Crest Level - 155.0 m / Dam Clay Core - 154.0 m, Area 2,600 km^2)				
PMF Inflow (m^3/s)	15,500	21,200	18,619 (Type 1*) 20,532 (Type 2**)	23,923.1
Spillway Outflow (m^3/s)	6,500	-	-	5,563.2
PMF Volume (Mm^3)	-	-	3,188 (Type 1*) 3,145 (Type 2**)	3,761.5
Maximum reservoir Level (m)	152.92	154.16	152.3 (Type 1*) 152.1 (Type 2**)	152.1

*(Note: *Type 1-Based on actual Mersing Storm in the year 1970*
***Type 2- Based on actual Mersing Storm in the year 1970 by using Nested Bell Shape)*

According to the table, it is being shown that the revised PMF value by this research is higher than that of the PMF value from Final Design Report produced by SMEC [18]. However, when the PMF value was revised in the year 1997 by SMEC, the revised PMF estimation was increased by about 37% from 15,500 m^3/s assumed for the original design, as 21,200 m3/s. The revised PMF value by this research is slightly higher than the revised PMF value by SMEC in the year 2007 (11% difference). On the other hand, the PMF value produced by SMHB is 20,532 m^3/s, which is 16% lower than the PMF value generated by this research i.e. 23,923.1 m^3/s. This is because the PMP obtained from this study is more than the previous study. The difference is due to the incremental of rainfall depth values that have been used for the study and due to the incremental of land use percentage that depends on the development of the study area. The dam clay core level for Kenyir Dam is 154.0 m, whilst the maximum reservoir level obtained from the revised study is 152.1 m; hence, Kenyir Dam is expected to be safe from overtopping under PMF condition.

The summary of PMF simulation results for this study using the updated and available flow data is presented in Table 7.

Table 7. Summary of Probable Maximum Flood (PMF) and Design Flood Values for the Study

Flood Return Period (year)	Inflow (m^3/s)	Outflow (m^3/s)	Maximum Reservoir Level (m)
5	4,507.2	1,144.7	147.5
10	6,095.6	1,425.5	147.9
50	9,660.0	2,159.5	148.8
100	11,201.9	2,512.5	149.2
PMF	23,923.1	5,563.2	152.1

Since the catchment area of the Kenyir dam is large, it is appropriate to apply and use the most severe flood, which will produce a high volume and peak discharge. Major storms considered are those with long durations and cover large areas. Hence, for this study, the PMF generated for 3-day storm duration has been used, as this duration has generated a high volume and peak discharge.

The PMF inflow results for Kenyir Dam catchment is 23,923.1 m^3/s. The PMF values obtained from the current study for the dam are significantly higher compared to the previous study by SMEC and SMHB [18-19]. The values were reasonable and expected as the revised design flood is based on the current international standards as required by International Commission on Large Dams (ICOLD). The derived PMP and PMF values of this research were reviewed and endorsed by an International hydrological expert Professor Jung Kwansue Jung, Ph.D. who is the appointed reviewer from Department of Civil Engineering, Chungnam National University and the Director of International Water Resources Research Institute and the Vice President of Korea National Committee on Large Dams (KNCOLD).

5 Conclusion

In this research, the calibrated HEC-HMS model was used to simulate the catchment response to the PMP for Kenyir Dams. The PMF simulation results for Kenyir Dam were obtained from the updated and available rainfall data. The PMF value obtained in this research is 23,923.1 m^3/s, will be used in the hydraulic models (MIKE 11 and MIKE 21). The clay core level for Kenyir Dam is 154.0 m, while the maximum reservoir level obtained from the revised study of this research is 152.1 m. Hence, the dam reservoir level is still below from the clay core level (154.0 m) by 1.9 m and Kenyir Dam is expected to be safe from overtopping under PMF condition. However, the Flood Hazard Map is not designed which can be obtained from the results of this research and can be used as a tool to update the existing Emergency Response Plan for the communities downstream in the future.

References

1. Sidek L, Basri H, Lee LK, Foo KY: The performance of gross pollutant trap for water quality preservation: a real practical application at the Klang Valley, Malaysia. Desalination and Water Treatment. 57(52):24733-24741. (2016).
2. Sammen, S.S., Mohamed, T.A., Ghazali, A.H., Sidek, L.M. and El-Shafie, A.: An evaluation of existent methods for estimation of embankment dam breach parameters. Natural Hazards, 87(1):545-566. (2017).
3. Che Ros, F., Tosaka, H., Sidek, L.M. and Basri, H.: Homogeneity and trends in long-term rainfall data, Kelantan River Basin, Malaysia. International journal of river basin management, 14(2):151-163. (2016).

4. Razali, J., Sidek, L.M., Rashid, M.A., Hussein, A. and Marufuzzaman, M.: Probable Maximum Precipitation comparison using Hershfield's statistical method and hydro-meteorological method for Sungai Perak Hydroelectric Scheme. International Journal of Engineering and Technology (UAE), 7(4):603-608. (2018).
5. Hossain, M.S., Sidek, L.M., Marufuzzaman, M. and Zawawi, M.H.: Passive congregation theory for particle swarm optimization (PSO): An application in reservoir system operation. International Journal of Engineering and Technology (UAE), 7(4):383-387. (2018).
6. Lee, K., Shahabudin, S., Mokhtar, M., Choy, Y., Goh, T., Simon, N.: Sustainable Water Resources Management and Potential Development of Multi-Purpose Dam: The Case of Malaysia. Applied Ecology and Environmental Research, 16(3):2323-2347. (2018).
7. Rouhani, H. and Leconte, R.: A methodological framework to assess PMP and PMF in snow-dominated watersheds under changing climate conditions–A case study of three watersheds in Québec (Canada). Journal of Hydrology. 561:796-809. (2018).
8. Al-Ani, I.A.R., Sidek, L.M. and Basri, N.E.A.: Expert system for mitigating erosion and sedimentation due to storm water during construction activities in Malaysia. European Journal of Scientific Research, 38(1):38-44. (2009).
9. Hafiz, I., Nor, N.D.M., Sidek, L.M., Basri, H., Hanapi, M.N. and Livia, L.: Application of Integrated Flood Analysis System (IFAS) for Dungun River Basin. In IOP Conference Series: Earth and Environmental Science 16(1):012128). (2013).
10. Hafiz, I., Sidek, L.M., Basri, H., Fukami, K., Hanapi, M.N., Livia, L. and Jaafar, A.S.: Integrated flood analysis system (IFAS) for Kelantan river basin. In 2014 IEEE 2nd International Symposium on Telecommunication Technologies (ISTT). pp. 159-162. (2014).
11. Zahari, N.M., Khairuddin, P.N., Mohiyaden, H.A., Sidek, L.M. and Mohamad, D.: August. Biological performance of integrated fixed film activated sludge (IFAS) process. In IOP Conference Series: Materials Science and Engineering. 551(1). pp. 012005). (2019).
12. Ayub, K.R., Sidek, L.M., Ainan, A., Zakaria, N.A., Ghani, A.A. and Abdullah, R.: Storm water treatment using bio-ecological drainage system. International Journal of River Basin Management, 3(3):215-221. (2005).
13. Rouhani, H. and Leconte, R.: A novel method to estimate the maximization ratio of the Probable Maximum Precipitation (PMP) using regional climate model output. Water Resources Research, 52(9), pp.7347-7365, (2016).
14. World Meteorological Organization. Manual on Estimation of Probable Maximum Precipitation (PMP), World Meteorological Organization, WMO-No. 1045, 259 pp. (2009)
15. Beauchamp, J., Leconte, R., Trudel, M. and Brissette, F.: Estimation of the summer-fall PMP and PMF of a northern watershed under a changed climate. Water Resources Research, 49(6):3852-3862.(2013).
16. Kaleris, V., Papanastasopoulos, D. and Lagas, G.: Case study on impact of atmospheric circulation changes on river basin hydrology: uncertainty aspects. Journal of Hydrology. 245(1-4):137-152.(2001).
17. E. J. Gumbel, Statistics of Extremes, Columbia University Press, New York. (1958).
18. Snowy Mountains Engineering Corporation (SMEC), Trengganu Hydroelectric Project-Kenyir Dam and Associated Works, Final Design Report. (1986).
19. SMHB Sdn. Bhd, Kenyir Dam Safety Review-June 2007. Final Report. (2007)