Flood Damage Assessment for Pergau Hydroelectric Power Project using HEC-FIA

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Abstract: Dams play a vital role in our modern life but it may fail in any undesirable situation and have a disastrous effect on society, economy and environment. As most of the dams in Malaysia undergo aging factors, the integrity of dams should be examined. This research assesses the flood impact analysis on direct damages and loss of life (LOL) for the Pergau Hydroelectric Dam breach under the probable maximum flood (PMF) scenario using Hydrologic Engineering Center's Flood Impact Analysis (HEC-FIA) software. The results are also compared with the United States Bureau of Reclamation method. The model was populated with inundation and flood arrival time grid, LOL parameters and structure inventories as input and the simulation results showed that 17 affected villages would subject to direct damage of RM 79,433,437 and 380 LOL. The percentage difference between the two methods is 2.75% for direct damage and 4.12% for LOL.

1. Introduction

Dams are built upstream of the river like a huge barrier and play several significant roles as they hold and utilize the stored water for power generation, water supply, irrigation purposes and even for a recreational area and flood preventer [1-2]. They are supposedly designed with a no-failure mode in any undesirable situation [3].

As the impact of climate change is increasing day by day, the earth's temperature is increased as well as the increase of evaporation rate, rainfall intensity and seawater level. This polemic has begun to transform the rainfall pattern in Malaysia. It was proven when a devastating flood occurred in December 2014 struck the Northern and Eastern states of Kelantan, Terengganu, Pahang, Perak and Johor in Peninsular Malaysia. Hashim et al. showed that the annual rainfall in the Kinta River basin increased on monthly and seasonal rainfall also during Northeast monsoon and Southwest monsoon from the year 1960-2006 based on the Mann Kendall (M.K.) test [4]. The maximum annual rainfall for the Sungai Pahang river basin is increased over 45 years [5]. A greater disaster such as extreme flood events, drought intensity, and prolonged drought will occur due to these changes.

Malaysia has 104 dams in total, with average age exceeded 40 years and experienced several dam incidences that involved life and economic losses. For example, Sultan Abu Bakar (SAB) dam released a tremendous amount of water, and so a flood occurred in the downstream area on October 23, 2013. Almost 100 houses were destroyed or underwater, more than 100 vehicles were severely damaged and three people were killed [6]. Besides, according to MyDAMS, cofferdam at Paya Peda Dam collapsed in 2012 due to overtopping by flood during construction [7].

Due to the enormous amount of water retain behind dam structure during monsoon season and these existing dams undergo aging factors, this issue has threatened the safety features. A catastrophic
flood accident may likely occur and cause devastating damage to society, economy and environment. An accurate assessment of the calculation of losses caused by a flood is possible with Flood Impact Analysis (FIA).

This research aims to estimate the direct consequences of flood damage and LOL for the Pergau Hydroelectric Power Project using HEC-FIA under the PMF scenario and comparative analysis between simulated results and the USBR method.

The collaboration of Hydrologic Engineering Centre's (HEC), Risk Management Centre (RMC) and the Engineering Research and Design Centre (ERDC) have developed a tool to analyze the flood damage. The impacts of a single flood event can be identified accurately on economic and agricultural losses and life losses on a structure-by-structure basis by HEC-FIA.

Life loss has commonly been estimated for dam safety risk assessments using a method developed by the USBR. The simulation approach's development is due to the limitation of semi-empirical and another system, which is widely known [8]. In the assessment of LOL, HEC-FIA uses the more straightforward method of the LIFESim process. It is well suited for the valuation of shelter and life loss [9]. While, HEC-FIA measures the direct losses for structure, in line with the U.S. Army Corps of Engineers (USACE) framework which consists of damages on structural and the content and vehicle, as described in Planning Guidance Notebook (E.R. 1105-2-100) published by USACE in the year 2000 using relationships described in Economic Guidance Memorandum (EGM 01-03) published in 2003 [10-11].

2. Methodology

The study area of this research is the Pergau Hydroelectric Project, which is located in the north-western part of Kelantan Darul Naim, about 75-km south-west of Kota Bharu, the state capital, as shown in Figure 1. The project consists of an underground power station with a 600 MW installed capacity, which draws water from a dam located on the Sg. Pergau just downstream of its confluence with Sg. Yong. The pumped water transfer enhances the scheme's flow capture from the adjacent southern catchment through an approximately 24 km long aqueduct tunnel. The detailed information of the study area is described in Table 1. A re-regulating pond located near Kg. Lawar controls the outflow from the power plant into Sg. Pergau.

| Table 1. Details of Pergau Hydroelectric Project Dam |
|-------------------------------------------|--------------------------|
| **Type of Dam**                          | **Zoned Earthfill**      |
| Year Completed                          | 2000                     |
| Dam Purpose                            | Hydropower               |
| Dam Height (m)                         | 75                       |
| Dam Crest Level (m MSL)                | 642                      |
| Dam Crest Length (m)                   | 750                      |
| Type of Spillway                       | Concrete weir with chute and flip bucket |
| Spillway Discharge Capacity (m$^3$/s) | 2470                     |
| Surface Area (sq.km)                   | 4.3                      |
| Storage Capacity (million liters)      | 62 500                   |
| Normal Top Water Level                 | EL 636 m                 |
A watershed configuration describes a modeled physical state of the watershed. The base elements of a watershed configuration consist of a terrain grid, a stream alignment, a set of cross-sections and storage areas, and common computation points. A minimum requirement HEC-FIA to compute hydraulic information at a location is a terrain grid when all gridded data is provided, as shown in Figure 2 [12]. Importing stream alignment is optional but considered in the study, which represents the stream. The arrangement indicates where confluentes and bifurcations occur and provide a sense of distance and scale.

The minimum requirement to compute structure damages from flood event consequences is the maximum depth grid or inundation grid, while for LOL computation, HEC-FIA needs inundation and flood arrival time grid. A combination of these data created an event and used for the simulation in this study. The non-evacuation depth threshold and 1.5 meters are defined in this study. Based on the survey by KTA Tenaga Sdn. Bhd. in October 2013, residential areas were only well prepared for floods of up to a depth of 1.5m. Once the flood level has breached that level, the residents would be in a helpless situation [13].

The point shapefile is generated for structure inventory and all attributes are assigned to each point. Through dam-break modeling results using MIKE software, 17 villages were impacted in the PMF scenario for the Pergau Hydroelectric dam with a range of 10-60 kilometers distance from the reservoir, as shown in Table 2. Structure characteristic and number of populations for all contributed
villages is done by survey. According to Table 3, 138 residential structures and 37 non-residential structures with 7985 people are analyzed in the study.

| I.D | Villages       | Distance from reservoir (km) | Population |
|-----|----------------|------------------------------|------------|
| 01  | Kg. Pendok     | 8.84                         | 405        |
| 02  | Kg. Gunung     | 15.2                         | 785        |
| 03  | Kg. S. Long    | 22.73                        | 525        |
| 04  | Kg. SeberangJeli | 26.6                       | 700        |
| 05  | Kg. Berdang   | 30.9                         | 195        |
| 06  | Kg. Pasir Dusun | 36.6                        | 385        |
| 07  | Kg. Reka       | 42.78                        | 70         |
| 08  | Kg. Renyok     | 45.36                        | 405        |
| 09  | Kg. Lubok Bongor | 47.3                      | 720        |
| 10  | Kg. Jabir      | 49.68                        | 120        |
| 11  | Kg. KaborDatu  | 53.13                        | 710        |
| 12  | Kg. Bukit Selar | 55.33                       | 175        |
| 13  | Kg. Relak      | 55.99                        | 165        |
| 14  | Kg. Batu Jering | 58.7                       | 1085       |
| 15  | Kg. Batu Tok Ali | 61.4                       | 500        |
| 16  | Kg. Tunku Abdul Rahman | 64.2                   | 350        |
| 17  | Kg. Kuala Balah | 66.58                       | 690        |

The Damage categories and structure occupancies defined in the study are shown in Table 4. Damage categories are the first aggregation level for flood damages. It represents a high-level grouping for structure while structuring occupancy types is the next level of aggregation for installations in HEC-FIA and imperative for any consequence calculation [14]. The occupancy type describes the depth-damage relationship and general information of the arrangements.
Table 4. Damage categories and structure occupancies defined in the study

| Damage Category | Occupancy Type | Description       |
|-----------------|---------------|-------------------|
| Residential     | RES1          | Masonry structures|
|                 | RES2          | Semi Bricks structures |
|                 | RES3          | Wood structures   |
| Commercial      | COM1          | All commercial structures |
| Institutional   | INS1          | All institutional structures |

The value of properties and their content value is depicted in Table 5. These values were based on the market value and all residential structures were assumed with similar essential household items such as washing machines, refrigerators and television. Each unit also consists of 2 types of vehicles, which are one motorcar and one motorcycle.

Table 5. Structures and content defined values in the study

| Structure Type | Value (R.M.) | Content Value (R.M.) | Vehicle Value (R.M.) |
|---------------|--------------|----------------------|----------------------|
| Residential   |              |                      |                      |
| 1 Storey Masonry | 140,000   | 3,700                | 33,000               |
| 2 Storey Masonry | 220,000   |                      |                      |
| 1 Storey Semi Bricks | 60,000  |                      |                      |
| 2 Storey Semi Bricks | 90,000   |                      |                      |
| 1 Storey Wood   | 35,000      |                      |                      |
| 2 Storey Wood   | 60,000      |                      |                      |
| Commercial     |              |                      |                      |
| Shop Lot       | 20,000-      |                      |                      |
| Petrol Station | 150,000     |                      |                      |
| Mosque         | 300,000     |                      |                      |
|                | 500,000-     |                      |                      |
|                | 1,000,000    |                      |                      |
| Institutional  |              |                      |                      |
| School         | 2,000,000-   |                      |                      |
|                | 4,000,000    |                      |                      |

The depth-damage percentage shown in Table 6 is according to the application of the loss estimation model in Japan, which covered all structure types and their content. Dutta et al. derived a stage-damage function for the different objects from the averaged and normalized data published by the Japanese Ministry of Construction [15]. For the vehicle function, a survey done by USACE is referred for this study to determine the direct flood damage. It serves as the independent variable in explaining vehicles' variations in the percentage of damage [11].

Table 6. Depth-damage functions defined in the study

| Depth (m) | Residential Masonry (%) | Semi Bricks (%) | Wood (%) | Commercial Institutional (%) | Structure Content (%) |
|-----------|-------------------------|-----------------|----------|----------------------------|-----------------------|
| 1         | 24.37                   | 25.41           | 26.44    | 34.8                       | 25.56                 |
| 2         | 39.67                   | 39.84           | 40.00    | 52.94                      | 47.33                 |
| 3         | 50.92                   | 51.07           | 51.22    | 61.00                      | 60.00                 |
| 4         | 56.78                   | 57.79           | 58.80    | 63.63                      | 72.33                 |
| 5         | 59.11                   | 60.25           | 61.86    | 63.63                      | 73.78                 |
| 6         | 60.00                   | 60.49           | 64.26    | 63.63                      | 75.22                 |

There are three life loss parameters considered in this study. The first one is the warning system, which is the relationship between the time from warning issuance and the percentage of the population.
at risk that received warning results in warning diffusion curves that help define the warning information in HEC-FIA [12]. Siren system was selected as Pergau Hydroelectric Dam uses it and the default curve was defined.

The second parameter is the Mobilization time between the receipt of the alert and the warning person leaving their structure. The default type is used in this study, while there are two more types of curves below and above the average mobilization rate. The final parameter is the Lethality Zone and Fatality Rates. The lethality zone set in HEC-FIA consists of three zones, which are chance zones with an average speed of 91 percent, compromised zones with an average rate of almost 12 percent, and safe zones with the fatality rate are practically zero or 0.0002 2003 [16].

3. Results and Discussion
All structures were flooded from the simulation, and the report showed RM 79,433,437 in total damage and 380 LOL for Pergau Hydroelectric Dam, respectively, as shown in Table 7. HEC-FIA computed the damage percentage according to its flood depth for all villages, as shown in Figure 3. Thus, the direct cost to a structure and its contents were calculated according to the depth-damage relationship. While for the communities that have exceeded the maximum depth defined in the depth-damage relation, the percent damage of each structure computed by HEC-FIA is the maximum percentage in each structure occupancy type. Moreover, there is no car damaged in the simulation for this Pergau Hydroelectric dam breach. This is because HEC-FIA uses a vehicle or on foot action in the evacuation process to reach a safe place within the shortest route [17-18]. Therefore, people exposed to risk are successfully evacuated with all cars that available in each village.

Based on Table 7, it is being shown that the number of people that received the warning is 7195, which is 86% of the total population and 7168 people have mobilized after received the warning message. Those who evacuated from the danger zone location are called "Total Cleared," with 6763 people or 81% of the total population. 5.4% of the community or 432 people are not mobilized and are caught in the buildings, but they are all warned of the flood. Still, 52 of them have survived and 380 people or 4.8% of the total population, were in the chance zone and lost their lives in this flood.

Table 7. Direct Damages and Life Loss reported by HEC-FIA under PMF scenario

| ID | Villages       | Flood Depth (m) | Structure Damage (RM) | Content Damage (RM) | Car Damage (RM) | LOL (Day) | LOL (Night) |
|----|----------------|-----------------|-----------------------|---------------------|----------------|-----------|-------------|
| 01 | Kg. Pendok     | 2.38            | 4,680,355             | 156,059             | 0              | 0         | 0           |
| 02 | Kg. Gunung     | 7.76            | 7,149,069             | 436,953             | 0              | 47        | 47          |
| 03 | Kg. S. Long    | 5.36            | 5,698,058             | 288,571             | 0              | 0         | 0           |
| 04 | Kg. SeberangJeli | 6.54          | 4,457,283             | 322,844             | 0              | 39        | 39          |
| 05 | Kg. Berdang   | 6.79            | 2,055,318             | 108,542             | 0              | 12        | 12          |
| 06 | Kg. Pasir Dusun | 4.36           | 3,580,543             | 207,575             | 0              | 0         | 0           |
| 07 | Kg. Reka       | 12.18           | 664,266               | 38,964              | 0              | 4         | 4           |
| 08 | Kg. Renyok     | 6.80            | 3,505,509             | 225,434             | 0              | 21        | 21          |
| 09 | Kg. Lubok Bongor | 12.06          | 9,326,418             | 400,772             | 0              | 36        | 36          |
| 10 | Kg. Jabir      | 8.79            | 1,165,698             | 66,795              | 0              | 7         | 7           |
| 11 | Kg. KuborDatu  | 11.8            | 9,562,443             | 395,206             | 0              | 38        | 38          |
| 12 | Kg. Bukit Selar | 22.17           | 1,282,164             | 97,410              | 0              | 9         | 9           |
| 13 | Kg. Relak      | 22.82           | 1,217,808             | 91,844              | 0              | 10        | 10          |
| 14 | Kg. Batu Jering | 12.15           | 9,316,317             | 603,941             | 0              | 65        | 65          |
| 15 | Kg. Batu Tok Ali | 23.08         | 3,731,361             | 278,314             | 0              | 30        | 30          |
| 16 | Kg. T. A. Rahman | 16.64          | 2,606,979             | 194,820             | 0              | 21        | 21          |
| 17 | Kg. Kuala Rahman | 17.77          | 5,135,730             | 384,073             | 0              | 41        | 41          |
| Total |       | 75,135,319  | 4,298,118             | 0                   | 380            | 380       |             |
From the results between HEC-FIA and USBR method, the absolute differences of structural damage for both ways are 4.43% and 4.12% for a residential and commercial structure. However, many differences between institutional and contents injuries were recorded, 21.22% and 27.29%. Thus, the total variation of direct damages between both approaches is 2.75%. These differences are subjected to different procedures of calculation by each method. USBR method defined the flood severity and converted to fatality rates ranging from 0.5 to 0.9 or 50% to 90% damages from the exposed value while HEC-FIA computes according to the depth-damage curve defined by the user.

The total margin of life-loss between both approaches is 4.12%. The computational of LOL in HEC-FIA is more sensitive to the mobilization curves. It incorporates several simplifying assumptions, such as the population is homogeneous in response to warnings, and the evacuation route is a straight line from the structure to the nearest safe location. Besides, the community also will stop evacuation once the non-evacuation depth is exceeded, while the USBR method used flood severity to measure the flood intensity and destructiveness [19]. From these categories, it adjusted the fatality rates and converted the population at risk to LOL, as shown in Table 8.

### Table 8. Direct Damage and LOL Percentage Differences between both methods

| Type of Damages | Damaged Value (R.M.) | Difference (%) |
|-----------------|---------------------|----------------|
| Residential     | USBR Method 61,970,000 | HEC-FIA 64,776,947 | 4.43 |
|                 | Commercial 2,650,000  | 2,761,542 | 4.12 |
|                 | Institutional 9,400,000 | 7,596,830 | 21.22 |
|                 | Contents 3,259,330  | 4,298,118 | 27.49 |
|                 | Total 77,279,330  | 79,433,437 | 2.75 |
|                 | LOL Total 396 | 380 | 4.12 |

Both the USBR and the HEC FIA applied in the software approaches have some similarities and use in the dam failure event, but there are several differences in the estimation of the direct damage and the LOL. HEC-FIA software can calculate direct damages and LOL in a single catastrophic event. HEC-FIA methods used stepwise mortality function, where different zones can be divided according to their flood characteristics and apply one mortality to each zone to determine LOL. While the original USBR method is almost similar to HEC-FIA, but the mortality rate depends on the flood characteristic within that zone. Besides, the evacuation model uses by HEC-FIA is a manual capacity model that takes preventive and vertical evacuation into account but not in the USBR method [20].
4. Conclusion

Flood related impact in society included property damages as well as LOL. In this research, two renowned methods, such as the HES-FIA and the USBR methods, are used to determine property damage and LOL. The simulation results showed that 17 affected villages would subject to direct damage of RM 79,433,437 and 380 LOL. The percentage difference between the two methods is 2.75% for direct damage and 4.12% for LOL. According to flood history in Malaysia, the development of damage-depth relationships could be developed and would significantly improve the model. With enhanced data and additional inputs such as flood velocity, the results are expected to strengthen and more realistic damage estimation could be made. Further study on agricultural and indirect damages could be done in the future for this particular dam. Moreover, this flood damage analysis using HEC-FIA also be implemented for all dams in Malaysia as it is free software and user friendly. The limitations of this study are the lack of detailed information on each structure location. The buildings in each village are supposed to scatter according to their actual location. However, this study's residential, commercial and institutional structures are grouped and assigned for one point only within the villages' respective boundaries. Therefore, the direct damages computational are only producing one value of flood depth level on the particular grid.

5. References

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