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A TALE OF TWO DAMS UNDER EXTREME WEATHERS IN UPPER LANGAT RIVER BASIN

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ABSTRACT

This paper provides an updated review of the performance of morning glory spillways during extreme weather conditions under hydrological dam safety assessment exercises. The revised performance evaluation was undertaken on two existing water supply reservoirs in the upper Langat river basin, one of the major river systems in the state of Selangor. For uniformity, both dams were assessed and compared deterministically in this study of their respective spillway discharge capacities using a new set of much higher Probable Maximum Precipitation (PMP) by NAHRIM (2008). This set of PMPs were derived some 20 years post dam commission. The PMPs adopted in the design of the dam were based on an earlier derivation reported in SMHB (1992, 1994). The findings of this study causes a grave concern on the safety aspects of the dam in light of this recent set of PMPs, therefore, a general consensus by various stakeholders is required to evaluate deterministically the probability and likelihood of the extreme floods of PMP magnitude overtopping the dam crests. A positive co-relationship was also presented for selected existing water supply dams by relating the draining catchment area to the product of equivalent spillway length and headroom.

1.0 INTRODUCTION

Malaysia is endowed with abundance water resources potential vis-à-vis world statistics (NAHRIM, 2008, NWRS, 2011), of about 2400 and 3100 mm/year of rainfall in Peninsular and Borneo respectively. Unfortunately, water resources are also limited by both unequal demand-supply horizons, and spatiality-temporality in distribution. Both factors in one way or another affect the water resource planning endeavors. In fact, this is especially true in reference to raw water security which is lagging behind the pace of increasing urbanization with high density population concentrations in Klang Valley (both in Selangor and the Federal Territory of Kuala Lumpur). Therefore, dams or reservoirs play important roles in both effective and efficient management of water resources considering the extreme spatial and temporal differences in river flows in Malaysia.

The purpose of a dam or reservoir is to even out the fluctuating inflows that vary sharply across the time and space domain. The dam provides a continuous and secured supply of raw water to the treatment plant directly from its prior storage during wet seasons. In addition, it also supplies and augments low flow regimes at the downstream intakes (by releasing waters ahead of time) in regulating reservoir operation.

With only some minor exceptions, almost all dams constructed are gigantic monolithic barriers rising above the river bed to the top of the valley. Waters are then impounded behind these dam structures for beneficial purposes such as water supply, flood mitigation, hydropower generation, navigation, and some opportune benefits of recreation, water sport, and tourism. However, in a very rare case of military strategy, the dam is also designed to provide threat in international warfare. This is the case of the Peace dam on Han river in South Korea. However, the primary and perhaps sole purpose would be to intercept torrential outflows from another cascade dam upstream and as such the dam is kept empty most of the time.

The dam structures are both theoretically and practically to designed to reduce any chance of failure as described by selecting a priori with a low probability of failure. This is important as any major incident such as dam breaching by overtopping would impart catastrophe to the downstream inhabitants. This will result in immeasurable loss of human lives, property and economy consequences. Specifically, failure of embankment such as in earth fill and rock fill type of dams can be fatal as the erosions of the downstream face of the dam are caused by uncontrolled overspill of water (Heng et al, 2014). The high velocity torrent in turn toggles negative pressures on the surface of the embankment, which literally is capable of eroding the embankment materials due to the head cutting process.
As such, failures caused by overtopping highlight the need for accurate scrutiny of their safety features such as emergency action plans that can be devised and implemented ahead in anticipation of fateful, probable catastrophic events (Singh, 1996, Coleman, et al., 2002; FEMA, 2004; Khoo et al., 2009; Tingsanchali and Tawanee, 2012, Heng and Hii, 2013a, Heng and Hii 2013b, Heng et al, 2013, Heng et al, 2014, Heng et al, 2016). One of these measures is the hydrological inspection and evaluation that plays a crucial role in estimating the overtopping probability of the dam or reservoir in light of a probable maximum precipitation (PMP) scenario. Based on the results of probable risk of overtopping, subsequent and prompt remedial measures can then be undertaken. By doing so, a series of proactive measures may help to avoid such disastrous accidents during extreme meteorological events.

1.1 DAM OVERTOPPING EVENT IN THE CURRENT STUDY

Amongst the dam structural appurtenances, spillway capacity is one of the most significant factor attributed to the ability of a dam to sustain a maximum flood. Inadequate spillway capacity that leads to failure accounts for about one-third of dam failure modes (Singh, 1996). In a similar study (Heng et al, 2013a), the maximum flood magnitude is estimated based on the probable occurrence of an extreme storm, i.e. Probable Maximum Flood, PMF (as derived from Probable Maximum Precipitation, PMP). In other words, the dam body itself is designed such that the risk of overtopping will be somewhat minimum by adopting the highest design storm and flow, which is also known as Spillway Design Flood (SDF).

If the dam overflows by the uncontrolled overspill, a high velocity flow field both at the crest and downstream face of the dam body will be anticipated. This high velocity will induce surface cavitation at the location of the negative pressure zone, thus, causing erosion of the downstream face of the dam structure. Conversely, the concrete gravity and rolled compacted concrete dams are much less susceptible as they are constructed of materials with a higher strength compared to the compacted earth and rock structures (Heng et al, 2013a).

1.2 SPILLWAY CAPACITY CRITERIA IN THE CURRENT STUDY

As mentioned in the past study (Heng et al. 2013a), there are two (2) types of spillways which are normally used in the conveyance of flood waters through the reservoir water body. A free flow or non-regulated spillway is commonly used in most of the water supply purpose of dams or reservoirs whereas the gated or regulated spillways are a common feature and mostly associated with the flood mitigation of hydropower dams or reservoirs.

It is important to stress that the gated spillway offers the advantage of increase in both the reservoir storage volume and available hydraulic head. In addition, any spillover from the dam is also controlled by the gates and/or other types of hydraulically controlled equipment. However, one of the disadvantages of the gated spillway is the higher maintenance cost for the mechanic-electrical components of the gate structures. It was discovered from experience that most of the regular and frequent operation and maintenance of the gated structures were routinely overlooked. In light of an extreme meteorological event, the gates either fail or are slow to respond and operate primarily due to equipment malfunction (Heng et al, 2013a).

2.0 OBJECTIVES OF THIS STUDY

The primary objective of this study is to assess and compare the risk of overtopping and the performance of the spillway of the existing Langat (Catchment Area, CA= 41km^2) and Semenyih (CA= 57 km^2) dams in the Langat river basin under a recent new set of PMPs stipulated by the National Institute of Hydraulic Research (NAHRIM) in 2008.

2.1 PROBLEM STATEMENT IN THE CURRENT STUDY

The spillway performance in terms of its spillway adequacy is evaluated routinely to find out if there is (1) a physical land-use alteration upstream of the dam catchment and (2) a revision of PMPs. Due to strict enforcement of dam catchment protection measure by the authorities, there is no significant land use change within the catchment boundary of both Langat (CA= 41km^2) and Semenyih (Catchment Area, CA= 57 km^2) dams. This, therefore, does not present any major issues on the threat of altered storm runoff and potential reservoir sedimentation. However, the prime concern arises due to derivation of a new set of PMPs in light of availability of continued acquisition of rainfall record and database. Of late, exceptionally higher PMPs have been derived by NAHRIM (2008). This new set of PMPs was at least two-fold higher than the values adopted earlier in both dam designs (SMHB, 1992, 1994). Therefore, this raises an alarm on the adequacy of the spillway capacity in light of a higher PMP scenario.

This undertaking was subsequently conceived out of concerns on the risk of dam overtopping if the spillway could not provide a safe passage for flood torrents out of the reservoir catchment.

In addition, due to close proximity of these two dams (both are located in similar hydro-meteorological as well as geographical region) located within the same Langat river basin, they offer an opportunity for comparison of their respective spillway hydraulic behaviors.

2.2 DESCRIPTION OF PROJECT AREAS: LANGAT AND SEMENYIH DAMS

Both the Langat dam (Catchment Area, CA= 41 km^2) and Semenyih dam (Catchment Area, CA= 57 km^2) were built in the mid 1970's and in the late 1980's respectively. Both schemes contribute more than 1000 Mld of combined treated waters to the Kuala Lumpur metropolitan center. Both dams are located southwest of Kuala Lumpur on the Langat river tributaries in the upper Ulu Langat Reserved forest catchment area. Opportunity was available to carry out an analysis by comparing their respective spillway adequacies between these two (2) similar sized existing reservoir schemes that lie within the homogeneous hydro-meteorological and geographical region.

The Langat dam (Catchment Area, CA= 41 km^2) is a 61-m high earthfill embankment dam with a crest length of 366 m. The impounded reservoir stores up to 38.4 MCM at its full supply level (FSL), i.e. +221.0 m msl. The embankment crest level (ECL) is at +223.8 m msl. This effectively gives some 2.8 m of headroom for flood attenuation during extreme flooding events. The lake surface area is 2.5 km^2 at FSL level as the general catchment slope is fairly steep especially in the headwater region of the Langat river basin.

The Semenyih dam (Catchment Area, CA= 57 km^2) is a 50-m high earthfill embankment dam with a crest length of 800 m at +115.0 m msl. The impoundment with a reservoir surface of 3.6 km^2, stores up to 61.4 MCM of water at its full supply level (FSL), +111.0 m msl. This effectively gives some 4.0 m of headroom for flood attenuation during extreme flooding events.

Both dams are equipped with similar features and appurtenances, such as variable level intake towers and morning glory or drop shaft type of spillways at FSL. The conventional practice is for the water to be stored up at the FSL level for a single purpose water supply reservoir so that full utilization of its storage volume can be possibly made. Though with smaller catchments, the Langat dam (Catchment Area, CA= 41 km^2) has a morning glory spillway of 27.5 m in diameter, which gives an equivalent weir length of about 86 m. On the other hand, for the Semenyih dam (Catchment Area, CA= 57 km^2), although drains a slightly larger catchment area at the dam site but is only equipped with a smaller diameter spillway of about 14 m, at half the size of the former. The hydraulic feature and difference between these two reservoirs are mainly distinguished by their relative headroom, where for the Langat dam (Catchment Area, CA= 41 km^2), a larger diameter spillway is required to compensate for a lower headroom of 2.8 m.

The head elevations over spillway radius ratios (H/r_o) for both dams are in compliance to both Vischer and Hager (1998) and USBR (1987). A ratio of about 0.40 demarcates the transition of free surface weir overflow to orifice and/or pressure shaft flow regime. Higher ratios would drastically change the hydraulic regime into either an orifice or conduit or pressure flow, which is undesirable due to the sharp rise in hydraulic head over only a small range of discharges and a possibility of inducing vibration in the long slender spillway shaft. As such the spillway of a circular type is normally designed based on weir flow regime, as much as desirable. Figure 1 shows the location map of the Langat and Semenyih dams in the Langat river basin and a side elevation sketch of the dam body

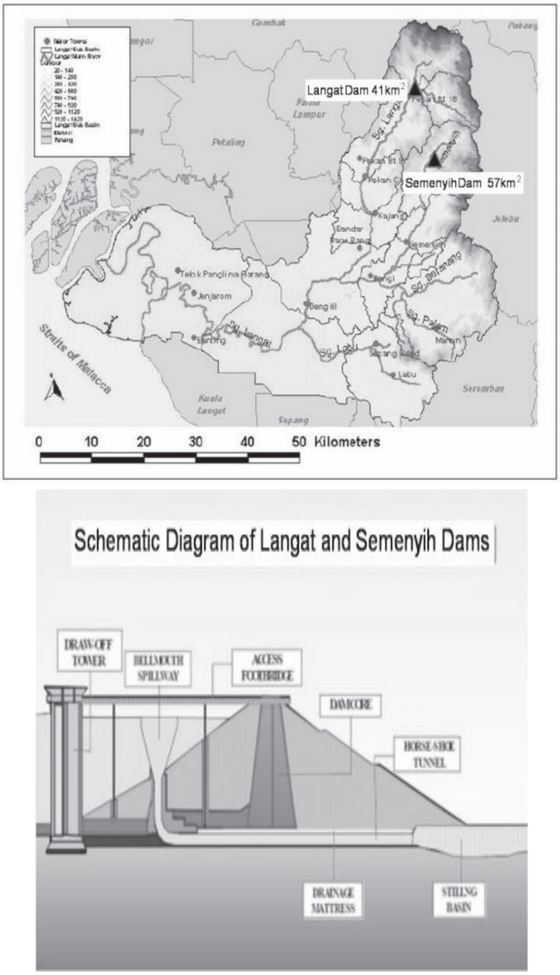


Figure 1. Location of Langat and Semenyih Dams in the Langat River Basin (source: www.luas.gov.my)

3.0 TECHNIQUE OF ASSESSMENT/METHODOLOGY

The methodology of a dam safety review involves the following steps: (1) reviewing and derivation of PMPs at the project/study site, (2) translating PMPs to PMFs/SDFs using a catchment rainfall runoff model, and (3) routing the PMFs through the reservoir using a reservoir routing technique. The results of this undertaking envisage the estimation of the reservoir outflows and their corresponding flood rises. The spillway capacity is deemed inadequate if the flood rises over and abbove its crest (Embankment crest level, ECL)

3.1 PMP DERIVATION AND REVIEW TECHNIQUE

Probable Maximum Precipitation (PMP) is defined as the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year; in practice, this is derived over flat terrain by storm transposition and moisture adjustment to observed storm patterns (WMO, 1986, 2009). In essence it represents the upper limit of the precipitation/rainfall level under probable and favorable contributing factors, such as availability of moisture and other favorable meteorological conditions, an absence/presence of moisture barrier such as higher mountainous range in the path of storm movement, availability of cumulus or particles that water vapors can be adhered to and others.

Probable Maximum Precipitations (PMPs) are derived based on observed maximum rainfall records with the provision of storm maximization and transposition techniques in tandem (WMO, 1986, 2009). Based mostly on practical experiences in Malaysia, they are derived utilizing the historical maximum rainfall records mostly in the east coastal regions of the Peninsular Malaysia. This region is prone to severe storm events during the northeastern monsoon season that lasts from November to January annually.

In this study, risks of overtopping for both the Langat and Semenyih dams were assessed based on the previous derivation of PMPs presented by water resource studies in both regions (SMHB, 1992, 1994). These two series of PMPs, coastal and inland PMP series were used in most of the dam design projects in Malaysia, including for the two dams examined in this study. The coastal series was derived in the late 1970's based on observed maximum storm records in the eastern coastal region of Peninsular Malaysia. These observed records of Mersing and Air Tawar which spanned about five days, were the highest recorded rainfall during the Northeastern monsoonal season. The highest records were duly maximized with meteorological parameters following the procedures and the design philosophy of WMO (1986, 2009).

Over the years with more database accrued from extensive rain gauge network, these maximum records in the 1970's were thoroughly checked with available updated rainstorm database collected throughout Malaysia. They were not in any way surpassed by the observed rainfall database compiled in both NAHRIM (2008) and Atikah (2009). On the other hand, the inland series, which was a reduced version of the coastal PMP ~~while~~ taking into consideration the occurrence of a PMP event in the inland region/site of the western coast of Peninsular Malaysia. This is normally accomplished by a reducing or transposing factor from the epicenter of the storm, normally at the eastern coastal region to the dam sites of interest in the interior region.

The inland series (SMHB, 1992; 1994) was adopted for both the Langat (Catchment Area, CA= 41 km^2) and Semenyih (Catchment Area, CA= 57 km^2) dams design, out of consideration of the meteorological characteristic of the interior region of the river basin in the west coast of Peninsular Malaysia. In general, the inland PMP, though represents the most severe storms on the western coastal seafront, is also shielded by the mountainous barrier of Sumatra Island in Indonesia. The southwest monsoonal wind surge from intervening wet months from April to May generally brings in an abundance of moisture. Both the Langat (Catchment Area, CA= 41 km^2) and Semenyih (Catchment Area, CA= 57 km^2) dams can be deemed to be on the lee side of the torrential surge.

The observed records, that were collected, consisted of both recording and non-recording maximum rainfalls alike. These records provide the basis for PMP derivation. Over the years, many national and regional studies were carried out in the Kelantan Flood Mitigation Project (SSP and SMHB, 1997), National Water Resources Study (SMHB et al, 2000), Interstate Raw Water Transfer from Pahang to Selangor (Nippon Koei and SMHB, 2000), and Batu Pahat River Study (SMHB, 2012). A review of past PMP studies can also be found in Desa et al, (2001), Al-Maimum and Hashin (2004), Desa and Rakhecha (2007), NAHRIM (2008), and Heng & Hii (2011). Desa et al. (2001) presented the results of a 1-day statistical PMP estimation for the state of Selangor, where both the Langat and Semenyih dams are located. The PMP estimation was carried out mainly based on the Hershfield (WMO, 1986) approach. In general, for the interior region of the state of Selangor, the point PMPs were generally much lower than the PMP adopted in the design of both dams (SMHB, 1992, 1994). This was not uncommon, as recently NAHRIM (2008) concurred lower PMPs by statistical Hershfield methodology vis-à-vis the estimation carried out using a data-intensive hydro-meteorological approach.

NAHRIM (2008) summarized more than 150 rainfall stations with point PMP of various durations after duly undergoing a maximization process by taking into consideration of the perceptible waters based on actual storm event and maximum dew point temperature. Generalized isohyetal maps were then prepared according to the climatic zones. By screening through the database, the most geographically closest rainfall station, the Kajang rainfall station was chosen to represent the PMPs at both dam sites. It is situated downstream in the peripheral of the town of Kajang. Compared to others, NAHRIM (2008) PMPs generally double the inland PMPs for most of the short duration storms. This gives rise to uncertainties on the adequacy of existing spillways of both the Langat and Semenyih dams in light of an extreme weather event of PMP/PMF magnitude. Table 1 summarizes the PMPs of short and long durations for both coastal and inland regions (SMHB, 1992, 1994), and NAHRIM (2008).

Table 1. Coastal, Inland and NAHRIM PMP (of Both Short- and Long-Duration)

Duration (hour)	**Coastal PMP (mm)***	**Inland PMP (mm)***	**NAHRIM Kajang Station PMP (mm)****
Short Duration			
1-	211	188	571
3-	338	300	754
6-	440	391	775
12-	584	518	797
24-	777	692	1411
Long Duration			
48-	1356	908	1642
72-	1593	1067	1813
120-	2030	1360	1879

*Adapted from *SMHB (1992, 1994; **NAHRIM (2008)*

3.2 PMP/PMF ROUTING TECHNIQUE

To estimate the impending floods into a reservoir water body, an appropriate deterministic technique is needed to translate the PMPs into probable maximum flood (PMF). In turn it is adopted for the spillway design of a dam.

The procedure to translate PMP to PMF is accomplished by a conventional rainfall runoff routing by convoluting the generated runoff based on rainstorm temporal distribution. Translating and routing by convolution of temporally distributed PMPs into PMFs of various rainstorm durations, i.e. from 1 to 120 hours is one of the important tasks in a standard PMP/PMF study.

Out of many hydrological rainfall runoff techniques available at disposal, two (2) approaches or models are the most commonly used in the local context, (1) the hydrological procedure HP No: 11 on flood estimation (Taylor and Toh, 1980), and (2) the rainfall runoff modeling approach using proprietary as well as non-proprietary mathematical models or software package. For uniformity and ease of comparison, only the former was adopted in this study.

3.3 RESERVOIR ROUTING TECHNIQUE

The purpose of outlet structures such as sluice gates and spillways of a dam shall be for evacuation during extreme flood of PMP/PMF magnitude in order to protect the main dam structures since overtopping due to inadequacy of outlets and/or spillway capacity is accountable for most of the dam failures worldwide (Singh, 1996). Similarly for gated spillway, such as a top sealed radial gate, it is advisable to fully open the gate on the onset of an impending PMP/PMF event.

A water balance description is quantitatively represented in the form of flow continuity equation over a reservoir. The rate of change of storage in the reservoir water body is the summation and quantification of all inflows from various sources by appropriately deducting the amount of outflow via outlet structures, such as spillways or bottom outlet of a reservoir/dam. A level pool reservoir routing has been adopted for this study (Chow et al., 1988). For simplicity in the water balance calculation, it is assumed that the bottom outlet flow and other losses such as seepage through the dam body are negligible. In addition, the reservoirs are also assumed to be at their full supply levels during the beginning of a PMP/PMF event (Heng et al 2013a).

4.0 RESULTS AND DISCUSSIONS

The discussion of the results of this study is presented henceforth. The PMPs adopted in this study was based both on inland (SMHB, 1992, 1994) and NAHRIM (2008) as shown in Table 1. Point PMP derived based on long-term observed record of the Kajang rainfall station was adopted for uniformity.

4.1 ANALYSIS ON PMP/PMF CATCHMENT ROUTING TECHNIQUE

The catchment routing procedure was a simple rainfall runoff modeling procedure based on the Snyder type of Synthetic Unit Hydrograph (SUH) approach. Firstly, the estimated 10 mm unit hydrographs for various durations were derived. Major topographic and geographic characteristics such as the length, area, and slope of the catchment were used to derive the unit hydrograph. Convolution of the time varied generated runoffs were then performed subsequently by integrating through the entire temporal distribution of PMPs.

The direct rainstorm falling onto reservoir areas at FSL for both dams were included in the PMP/PMF generation. Since the reservoir areas are only 2.5 and 3.6 km^2 for the Langat (CA= 41 km^2) and Semenyih (Catchment Area, CA= 57 km^2) dams respectively, the generated hydrographs showed some sharp rises in the inflow hydrographs notably only for shorter durations to be reckoned with. The surcharging volumes above the FSL of the dam could attenuate these sharp peak inflows into the reservoir. The critical storms for both dams were mostly of short duration.

It was also assumed that due to smaller catchment sizes, PMPs were effective for the entire catchment without prior adjustment by the areal reduction factors (ARFs). The inland PMP/PMF hydrographs for both dams for 1 to 120-hour durations are shown in Figure 2. It is important to note that the highest peak value indicated in the Figure 2 represents the Probable Maximum Precipitation and Flood value. For good practice, the estimated PMF was compared to the PMFs in the past studies in the form of a Creager type of curve that relates the catchment area at the dam sites to the estimated PMFs. Figure 3 shows the relationship between the catchment area and the estimated PMFs of past studies.

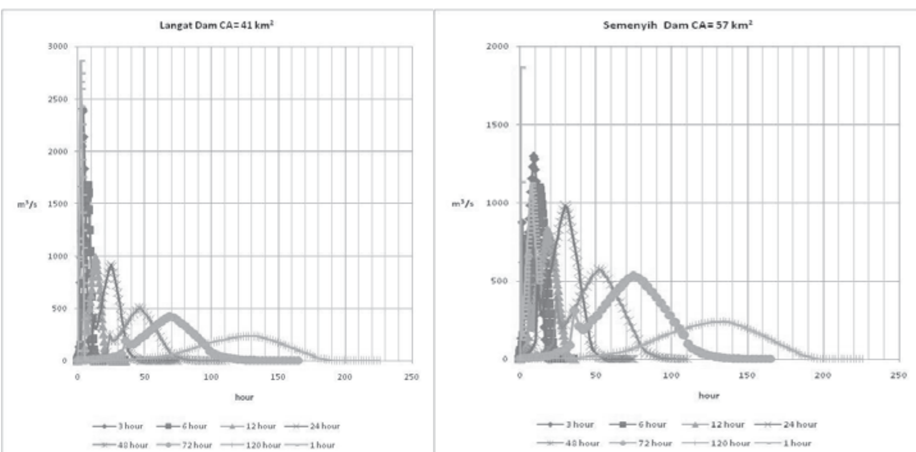


Figure 2. PMP/PMF Catchment Routing: 1- to 120-hour

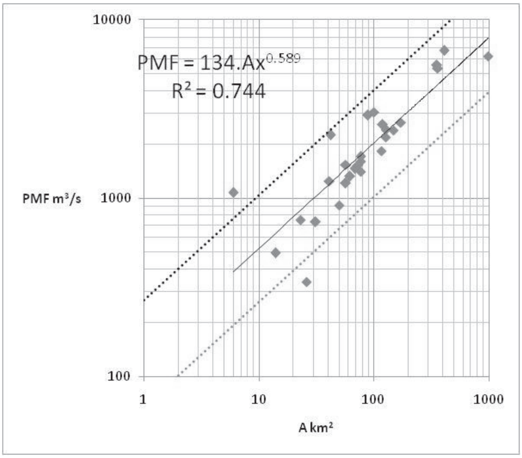


Figure 3. Catchment Area and Probable Maximum Flood (PMF) Relationship (Nippon Koei and SMHB, 2000)

4.2 INTERPRETATION ON RESERVOIR ROUTING TECHNIQUE

The primary purpose of this segment is to estimate both outflows and their corresponding flood rises of the PMPs/PMFs as they passed through the reservoir (Heng et al, 2013a). From a safety point of view, it is utmost critical that the maximum flood rise for various durations is less than the embankment crest level (ECL) of the dam, failing which, it would then run into the risk of being overtopped. Spillways of both the Langat (CA= 41 km^2) and Semenyih (CA= 57 km^2) dams shall have sufficient diameters to remain as the weir flow regime on top of their respectively spillway sills. This was quantitatively assessed by head elevations over spillway radius ratios (H/r_o) of less than 0.50 ideally.

For the case of the design of PMPs/PMF, the reservoir routing of both the Langat (CA= 41km2) and Semenyih dams (Catchment Area, CA= 57 km2), showed that the surcharging storage above the FSL were able to attenuate higher influxes for both short and long durations. Under this design conditions, the maximum flood rises were basically confined well below the ECL of the dam due to adequate headrooms of 2.8 and 4.0 m for the Langat (Catchment Area, CA= 41km^2) and Semenyih (Catchment Area, CA= 57 km^2) dams respectively. Both dams were designed based on inland PMPs (SMHB, 1992, 1994) in the early 1970's and 1980's. Table 2 shows the results of both the Langat (CA= 41km^2) and Semenyih (Catchment Area, CA= 57 km^2) dams in a past study carried out for ten (10) small dams with similar morning glory spillway (Heng et al, 2016).

Table 2. PMP/PMF, Outflow, and Flood Rises, Head rise over Radius Ratio (Heng et al, 2016)

Dam	Catchment area (km^2)	PMF m^3/s	Outflow m^3/s	Flood rise +m msl	FSL +m msl	ECL +m msl	H/r_o ratio
Mengkuang	4	307	35	+44.06	+43.30	+46.34	0.17
Air Itam	5	193	174	+235.90	+234.70	+236.00	0.11
Tinggi	40	719	205	+61.96	+59.50	+63.50	0.50
Langat	41	1080	820	+223.74	+221.00	+223.70	0.20
Semenyih	57	746	602	+114.50	+111.00	+115.00	0.50
Terip	26	559	366	+105.01	+103.00	+107.00	0.21
Durian Tunggal	41	683	381	+30.31	+28.40	+31.00	0.17
Jus	23	524	107	+74.60	+73.00	+75.50	0.40
Juasseh	29	729	413	+85.01	+82.50	+86.50	0.34
Gerugu	14	262	177	+31.93	+30.00	+33.00	0.30

However, if higher PMPs (NAHRIM, 2008) were adopted, the results showed overtopping of both dams of their crests were imminent especially even for mostly shorter duration PMPs. This was definitely expected if the short duration of PMPs were double the design of PMPs. Table 3 shows the results of PMP/PMF catchment and reservoir routing for both dams (see Figures 4 and 5).

4.3 COMPARISON OF CATCHMENT AREA, SPILLWAY WIDTH AND HEADROOM

The dam catchment area and the ungated spillway width or equivalent length (in the case of circular shape spillway, the spillway length taken as the circumference of the bell mouth spillway), are two of the most prominent physical parameters that can be obtained readily. However, a meaningful correlation could not be obtained directly from these two physical parameters without one more important parameter.

It was proposed that a third parameter be included to improve the co-relationship which is the headroom, defined in this context as the difference in elevation between the FSL and ECL. This third parameter could explain the co-relationship better. This extra parameter was then multiplied to the spillway width, known as the product of the headroom and spillway width, LL in this study. A power type of regression equation indicated improved co-relationship between catchment area and LL of selected dams. An adopted yardstick of a factor of two, in the form of upper 100% and lower 50% bounds was then used to decide on the goodness of fit of these relationships. Figure 6 (see Table 4) shows the relationship of the catchment area and LL for the selected dams in Malaysia.

Amongst the nine (9) existing dams in the northern region of Peninsula Malaysia, the Air Itam dam has the lowest headroom but was equipped with a relatively large morning glory spillway. As such, this had provided an effective tradeoff for the safe passage of flood evacuation with its smaller headroom. If compared to the smaller dams of the same catchment sizes, Malut (Catchment Area, CA=3.5 km^2), Mengkuang (Catchment Area, CA=4 km^2), and Air Itam (Catchment Area, CA=5 km^2) dams, the product of both spillway length and headroom of these dams, suggested a positive co-relationship between the catchment area draining at the dame site and the product of the spillway width and the headroom.

On the other hand, both the Kinta dam (Catchment Area, CA=148 km^2) and the Bengoh dam (Catchment Area, CA=127 km^2) showed the highest product of the headroom and the stepped spillway length. Both dams of the Rolled Compacted Concrete (RCC) type and stepped spillways were designed by the same designer perhaps based on the same approach and design philosophy for an exceptionally long spillway width as a safety factor against high uncertainty in PMP/PMF events. In this regard, the dams gave the highest product amongst the dams considered in this study. If compared to other dams of similar sizes in the vicinity, such as the Pedu (Catchment Area, CA=171 km^2), Ahning (Catchment Area, CA=122 km^2) and Beris dams (Catchment Area, CA=112 km^2), both RCC dams were unique and were deemed the most conservative in terms of the spillway design.

Table 3. Results of PMP/PMF Reservoir Routing: 1- to 120-hour Duration

Duration Hour	**Unit hydrograph Q**	**Time to peak tp**	**Base Flow Time tb**	**PMP**	**PM F**	**Q**	**Flood rise**
	m^3/s /cm	hour	Hour	mm	m^3/s	m^3/s	m msl
Langat Dam under NAHRIM (2008) PMP							
1	53	2	5	571	2865	2027	failed
3	36	3	7	754	2409	1984	failed
6	25	5	9	775	1667	1440	failed
12	15	8	15	797	986	897	failed
24	8	14	26	1411	916	879	failed
48	4	25	49	1642	503	492	222.95
72	3	37	72	1813	420	414	222.74
120	2	60	117	1879	235	234	222.19

Table 3 (Contd). Results of PMP/PMF Reservoir Routing: 1- to 120-hour Duration

Duration Hour	**Unit hydrograph Q**	**Time to peak tp**	**Base Flow Time tb**	**PMP**	**PM F**	**Q**	**Flood rise**
	m3/s /cm	hour	Hour	mm	m3/s	m3/s	m msl
Semenyih Dam under NAHRIM (2008) PMP							
1	20	7	15	571	1863	908	failed
3	18	8	16	754	1297	1117	failed
6	15	10	19	775	1095	973	failed
12	12	13	25	797	829	758	failed
24	8	19	36	1411	981	941	failed
48	4	30	59	1642	574	559	114.32
72	4	42	82	1813	532	524	114.18
120	2	64	125	1879	239	238	112.88

Note:

Langat dam

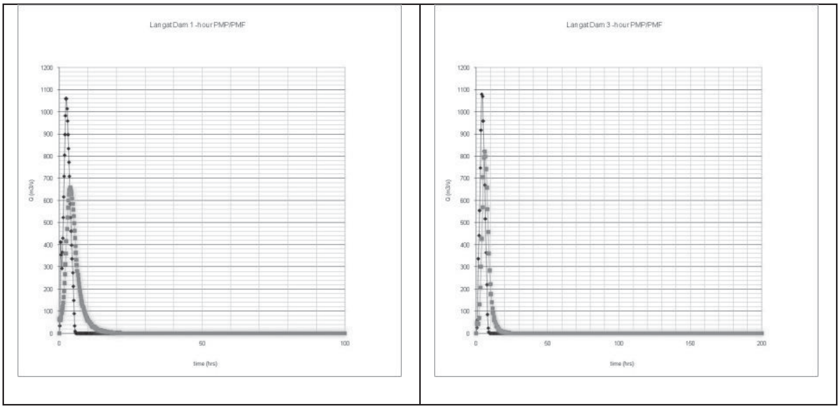
FSL +221.0 m msl

ECL +223.8 m msl

Semenyih dam

FSL + 111.0 m msl

ECL +115.0 m msl



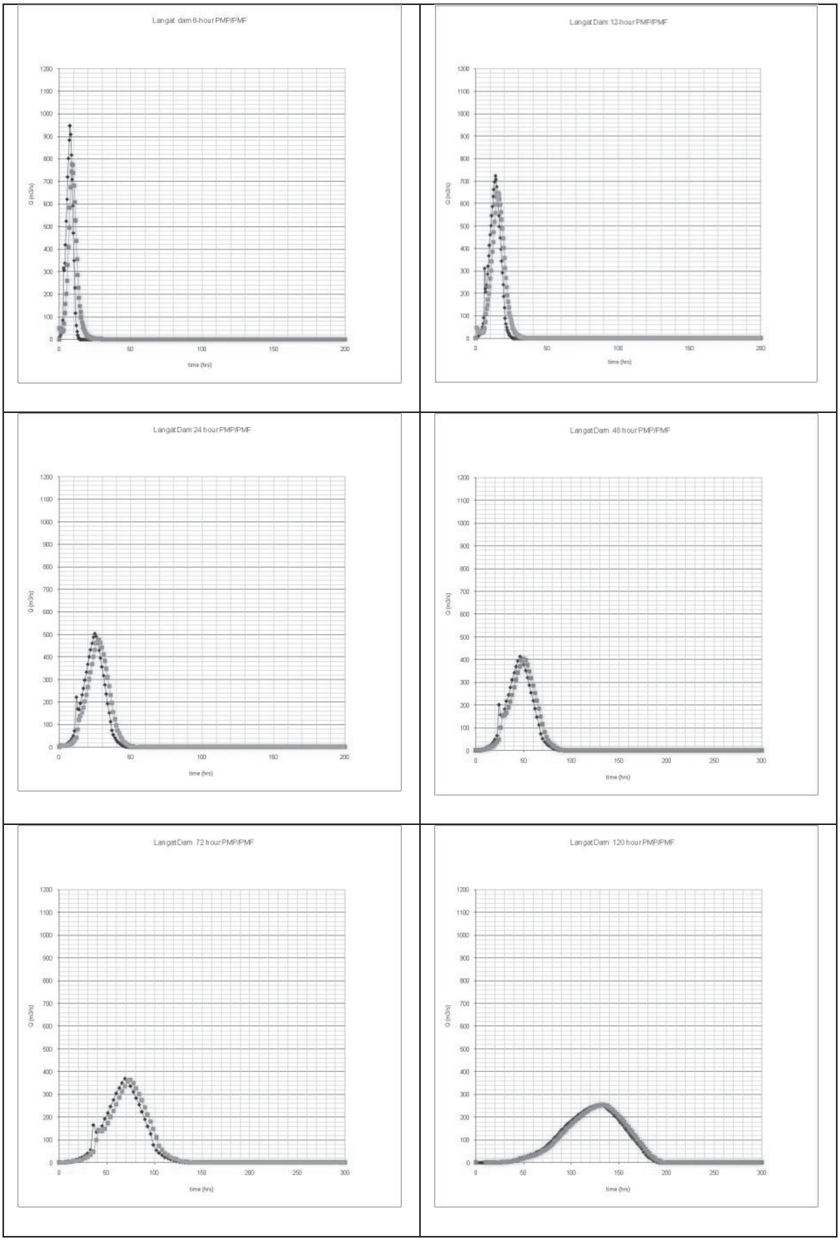
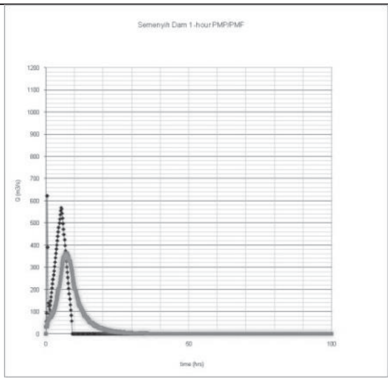
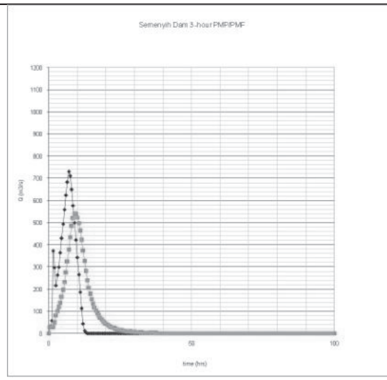
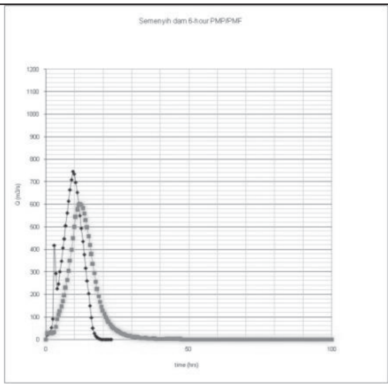
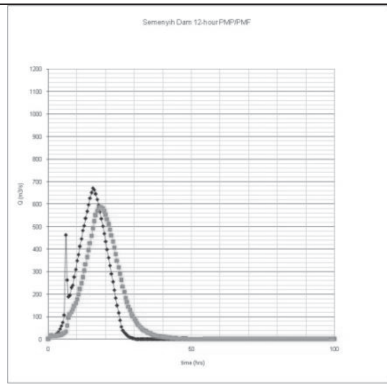


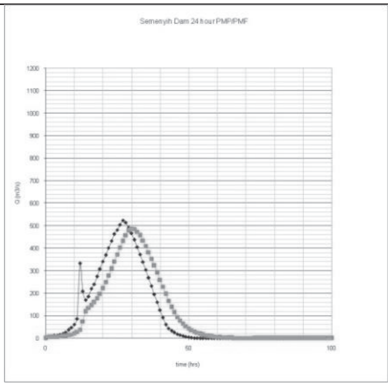
Figure 4. Reservoir Routing Procedure: Langat Dam

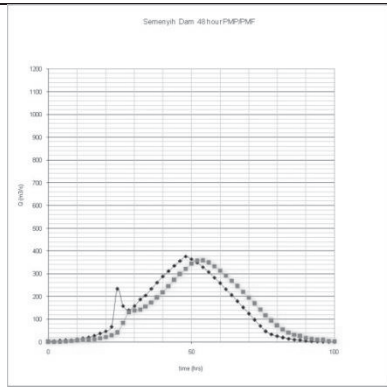

Semenyih Dam 1-hour PMP/PMF
Q (m3/s)
time (hrs)


Semenyih Dam 3-hour PMP/PMF
Q (m3/s)
time (hrs)


Semenyih dam 6-hour PMP/PMF
Q (m3/s)
time (hrs)


Semenyih Dam 12-hour PMP/PMF
Q (m3/s)
time (hrs)


Semenyih Dam 24 hour PMP/PMF
Q (m3/s)
time (hrs)


Semenyih Dam 48 hour PMP/PMF
Q (m3/s)
time (hrs)

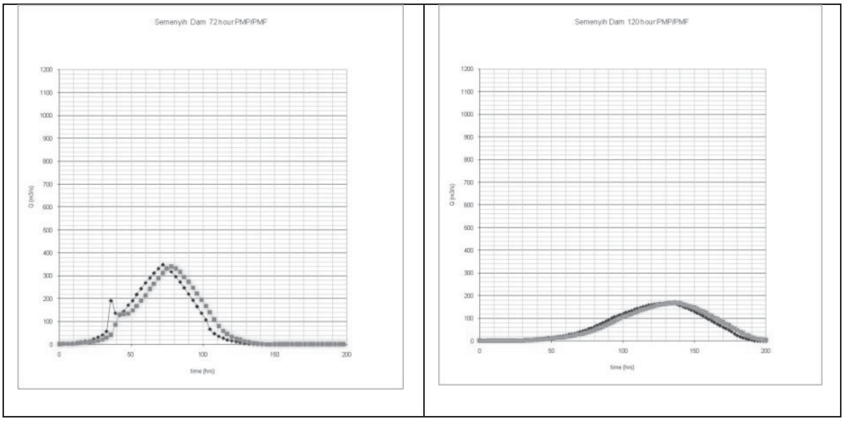


Figure 5. Reservoir Routing Procedure: Semenyih Dam

A similar characteristic was also observed in the central region of Peninsular Malaysia. A lower headroom was adequately compensated by a wider spillway length in the Langat dam (Catchment Area, CA=41 km^2) vis-à-vis the neighbouring Semenyih (Catchment Area, CA=57 km^2) and Terip (CA=26 km^2) dams of smaller spillway width but with a much bigger headroom. In the far most northern edge of this central region, properties of both Tinggi (Catchment Area, CA=40 km^2) and Selangor (Catchment Area, CA=197 km^2) dams in the northern Selangor river basin were also compared consistently with their neighbouring counterparts in the Langat river catchment area by exhibiting a positive co-relationship between the catchment area and the combined product of the spillway length and headroom. The only exception that deviated from this norm was the smaller Meru dam (Catchment Area, CA=10 km2) which was designed in the earlier 1950's prior to the advent of the PMP protocol of WMO (1986, 2009).

In summary, the Meru dam (Catchment Area, CA=10.3 km^2), Kinta dam (Catchment Area, CA= 148 km^2) and Bengoh dam (Catchment Area, CA=127 km^2) were mostly outliers of both the lower and upper bound curves. In addition to this, the Jus dam (Catchment Area, CA= 23 km^2) with its smaller diameter spillway of 8.0 m and the Beris dam (Catchment Area, CA= 112 km^2) of narrower 30.0 m wide spillway width are plotted marginally outside of the lower bound curve (also see Figure 6). It was concluded that the product of both headroom and spillway width, LL could be used as a preliminary guide in dam or reservoir planning.

Table 4. Comparison of Catchment Area, Ungated Spillway Width, and Headroom of Selected Dams

Dam	**Catchment area (km^2)**	**Spillway width (m)**	**Headroom ECL-FSL (m)**	**Type of spillway**
Peninsula				
Malut	3.5	30	3	chute spillway
Muda	984	93	5.62	chute spillway
Pedu	171	44.2	4.3	chute spillway

Ahning	122	52	5	Ogee crest
Beris	116	30	4	Ogee side channel
Kinta	148	100	6	Ogee crest stepped
Mengkuang	4	28	4	Bell mouth
Air Itam	5	69	1.3	Bell mouth
Teluk Bahang	10	28	5	Ogee weir
Tinggi	40	31	4	Bell mouth
Selangor	197	47	7	Horseshoe
Batu	50	23	4.65	Ogee side channel
Meru	10.3	13.5	1.3	Ogee type
Langat	41	86	2.8	Bell mouth
Gelami Lami	22	23	5	side channel chute
Semenyih	57	44	4	Bell mouth
Terip	26	61	4	Bell mouth
Kelinchi	37	45	6	chute type
Durian Tunggal	41	69	2.4	square mouth
Jus	23	25	2.5	Bell mouth
Juasseh	29	47	4	Bell mouth
Linggiu	216	50	5.5	Ogee
Upper Layang	30.5	60	2.4	Fusegate on principal spillway
Lebam	18	49	2	Ogee
Kahang	62	30	4	Chute spillway
Sarawak and Sabah				
Gerugu	14	41	3	Bell mouth
Bengoh	127	77.5	6.2	Stepped
Babagon	30	70	3.5	Bell mouth

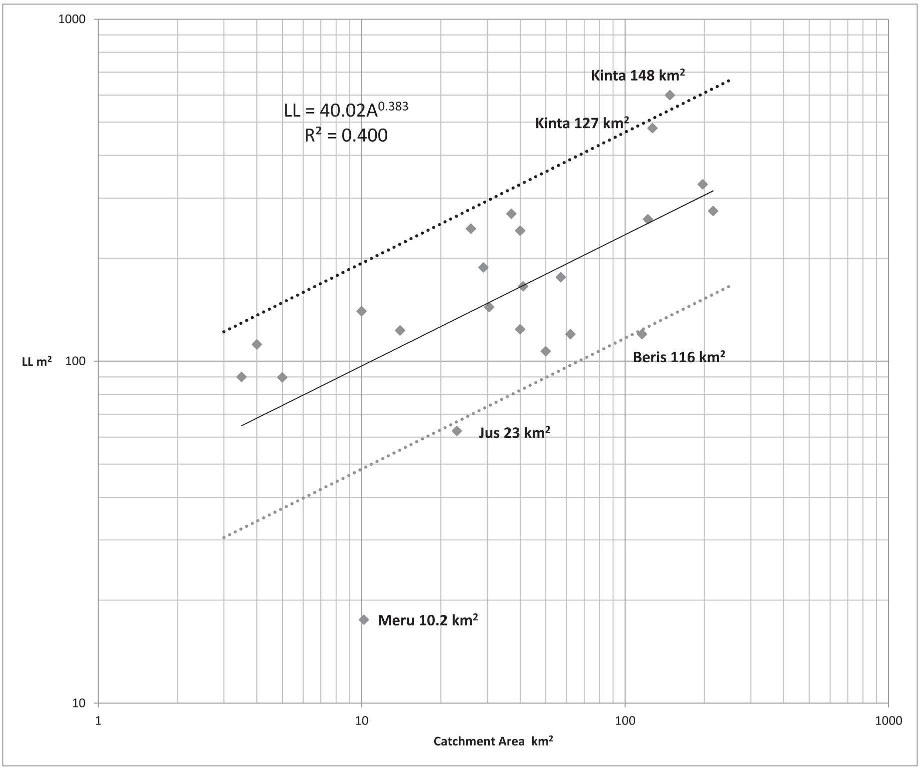


Figure 6. Catchment Area, Spillway Width and Headroom

NOTE:

Lower and upper bound broken line by factor of two curves.

The solid line is a perfect fit line.

Meru dam (Catchment Area, CA=10.2 km^2), Kinta dam (Catchment Area, CA= 148 km^2) and Bengoh dam (Catchment Area, CA=127 km^2) are outside of both lower and upper bound curves.

Jus dam (Catchment Area, CA=23 km^2), and Beris (Catchment Area, CA=117 km^2), dams are marginally at a lower bound curve.

5.0 CONCLUSIONS

A hydrological dam safety assessment was carried out with the objective for assessing the hydraulic behavioral performance of the Langat (Catchment Area, CA= 41 km^2) and Semenyih (Catchment Area, CA= 57 km^2) dam spillways in light of an extreme meteorological event of the PMP/PMF magnitude. Both the Langat and Semenyih dams are major water supply reservoirs in the Kuala Lumpur water supply scheme and are located in the upper Ulu Langat forest reserve catchment of the Langat river basin.

For uniformity and ease of comparison, this study adopted both Inland PMPs (SMHB, 1992, 1994) and the recent PMPs of 1- to 120-hour durations of the Kajang rainfall station (NAHRIM, 2008) due to their close proximity in the same river basin. A catchment routing procedure using HP 11 (Taylor and Toh, 1976) was then used to translate the PMPs to PMFs for a duration of 1 to 120 hours. A conventional reservoir routing procedure was then carried out to estimate the outflows and corresponding flood rises.

Both the Langat (Catchment Area, CA= 41 km^2) and Semenyih (CA= 57 km^2) dams fell short of shorter duration PMPs/PMFs derived by the recent NAHRIM (2008) study. This was to be expected as the new set of PMPs have been doubled from the original design of PMPs (SMHB, 1992, 1994). For the long duration PMP, both dams performed well below the ECL as the difference between two PMP series were much smaller.

Recommendations were made for the structural measurements to increase the spillway capacity by adding another spillway. In the preliminary desk assessment performed at both dam sites, there appears to be limited space in order to increase the spillway length of the existing drop shaft type spillways, mainly due to both site and technical constraints. As such, options to look for alternative auxiliary spillways in the remote saddled valley away from the main dam body are imperative and perhaps a viable option to be considered.

On a non-structural approach, the reservoir levels could be lowered prior to the onset of an extreme event of a PMP/PMF magnitude. The reservoir storage can be evacuated safely by constant releases via the outlet structure. This constant release shall not in any way cause localized flooding downstream and it is also subject to hydraulic carrying capacity of the river network. This approach appears viable and cost effective as an interim measure, and could be readily incorporated into the 5-yearly review of Operation and Maintenance (O&M) and Standard Operation Procedure (SOP).

A third parameter, the headroom was used to explain the changes in the spillway width of some selected dams by correlating to their respective catchment areas. Inverse relationships were observed in terms of the headroom and equivalent spillway length for both dams. A smaller headroom is adequately compensated by a longer equivalent spillway length for the case of the Langat dam (Catchment Area, CA= 41 km^2) vis-à-vis Semenyih (CA= 57 km^2) dam with a 4-m high headroom but with a smaller diameter spillway. By adding a third parameter, a positive relationship can be explained by a power curve regression of the catchment area to the product of the equivalent spillway length and headroom. The product of these latter two dam properties can be used as a design guide for preliminary dam layout and planning.

6.0 REFERENCES

- A.L. Maimum and A. Hashim, Generalized Long *Duration Probable Maximum Precipitation Isohyetal Map for Peninsular Malaysia. J. Spatial Hydrology*, **4(1)**, pp. 212-234 (2004)
- S. Atikah, Extreme Flood Event: A Case Study on Floods of 2006 and 2007 in Johor, Malaysia. *Technical Report. Colorado State University*, Fort Collins, CO, USA (2009)
- Australia Bureau of Meteorology, *The Estimation of Probable Maximum Precipitation in Australia: Generalized Short-Duration Method*, Bureau of Meteorology, Melbourne, Australia (2003)
- V.T. Chow, D.R. Maidment and L. Mays, *Applied Hydrology*. McGraw Hill, New York, New York (1988)
- S.E. Coleman, D. P. Andews, and M.G. Webby, *Overtopping of Noncohensive Homogeneous Embankment*. Journal of Hydraulic Engineering, **128(9)**, pp. 829-830 (2002)
- M.N. Desa, A.B., Noriah and P.R. Rakhecha, *Probable maximum precipitation for 24 h duration over southeast Asian monsoon region – Selangor, Malaysia.* Atmospheric Research, **58 (1)**, pp. 41-54 (June 2001)
- M.N. Desa and P.R. Rakhecha, *Probable maximum precipitation for 24-h duration over an equatorial region: Part 2-Johor, Malaysia*. Atmospheric Research, **84(1)**, pp. 84-90 (2007)
- FEMA, *Federal Guideline for Dam Safety: Selecting and Accommodating Inflow Floods for Dams*. US Department of Homeland Security, Federal Emergency Management Agency, Washington, DC. USA (2004)
- H.H. Heng and C.P. Hii, *A Review on PMP Estimation in Malaysia.* Int. Jour. Hydrology Science and Technology. **1(1/2),** pp 63-87 (2011)
- H.H. Heng and C.P. Hii, *Risk Assessment Scenario of Machap Dam Overtopping Using New Malaysian PMP Series*. Jordan Journal of Civil Engineering, **7 (1),** pp 101-110 (2013a)
- H.H. Heng and C.P. Hii, *A case study on dam overtopping under different PMP scenario*, UNIMAS e-Journal of Civil Engineering (2013b)
- H.H. Heng, C.P. Hii and K.T. Kho, *An Assessment of Bengoh Dam Overtopping Scenarios.* Geomatics. Natural Hazards, and Risk, DOI:10.1080/19475705.2013.781547 (2013c)
- H.H, Heng, C.P. Hii and W.F. Pan, *Comparison of Water Supply Dams Spillway Performance in Malaysia*, Int. Jour. Hydrology Science and Technology. **4(1)**, pp 39-57 (2014)
- H.H. Heng, C.P. Hii and W.F. Pan, Overtopping of Morning Glory Spillway: 10 Dam Review. Submitted to Int. Jour. Hydrology Science and Technology (2016)
- F.W.L. Khoo, P.L. Law, S.H. Lai, Y.W. Onn, and H.S. Ting, *Quantitative Dam Break Analysis on a Reserv Earth Dam.* Int. J. Envron. Sci. Tech., **6(2)**, pp 203-210 (2009)
- NAHRIM, *Derivation of Probable Maximum Precipitation for Design Floods in Malaysia*. Technical research publication (TRP) No. 1, Ministry of Natural Resources and Environment, Kuala Lumpur, Malaysia (2008)

- Nippon Koei and SMHB, *Nippon Koei in association with SMHB, 2000. Pahang-Selangor Raw Water Transfer Project Engineering Services and Detailed Engineering Design*: Hydrograph, Final Report. Malaysia, JBA, JKR (2000)
- V.P. Singh, *Dam Breach Modelling Technology*. Kluwer Academic Publishers Boston, MA (1996)
- SMHB, *Study on Comprehensive Water Resources Planning and Development in the State of Pahang*. Final report. Economic Planning Unit. Government of Malaysia (1992)
- SMHB, *Study on Comprehensive Water Resources Planning and Development in the State of Johor*. Final report. Economic Planning Unit. Government of Malaysia (1994)
- SMHB, Ranhill Bersekutu, and Jurutera Perunding Zaaba, *National Water Resources Study 2000-2050*. Economic Planning Unit, Government of Malaysia (2000)
- SMHB, *Water Resources Study for Sg. Batu Pahan Basin*. EPU, Malaysia (2012)
- SSP and SMHB, *Kelantan River Flood Mitigation Project: Feasibility Study*. Jabatan Pengairan dan Saliran, Kuala Lumpur, Malaysia (1997)
- M.A.W. Taylor, and Y.K. Toh, *Design Flood Hydrograph Estimation for Rural Catchments in Peninsular Malaysia. Kuala Lumpur, Hydrological Procedure No*: 11. (HP 11) Jabatan Pengaliran dan Saliran, Ministry of Agriculture ,Malaysia (1980)
- T. Tingsanchali, and S. Tanmanee, *Assessment of Hydrological Safety of Maei Sruai Dam, Thailand*. Procedia Engineering, **32**, pp 1198-1204 (2012)
- United State Bureau of Reclamation, *Design of Small Dams*. 3rd Edition, Water Resources Technical Publication, Denver, CO (1987)
- D.L.Vischer and W. H. Hager, *Dam Hydraulics*, Wiley, New York, New York (1998)
- WMO, *Manual on Estimation of Probable Maximum Precipitation. Operational Hydrology Report No. 332, World Meteorological Organization*, Geneva (1986)
- WMO, *Manual on Estimation of Probable Maximum Precipitation. Operational Hydrology Report No. 1045, World Meteorological Organization*, Geneva (2009)
- www.luas.gov.my