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# HYDROLOGICAL RISK ASSESSMENT: A COMPARISON OF MORNING GLORY SPILLWAY CAPACITY

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**ABSTRACT**

An investigation on dam overtopping risk was carried out for ten single purpose water supply dams with a common outlet feature of drop shaft (or morning glory) spillways. These dams had been designed as early as the 1930's in the west coast region of Peninsular Malaysia. Tasks were carried out using uniformed and common methodology for each selected dam, firstly by selection of appropriate Probable Maximum Precipitations (PMPs) which served as influx into the reservoir. Subsequently an empirically derived synthetic unit hydrograph (SUH) approach was then used to translate the PMPs into Probable Maximum Floods (PMFs). Finally, the outflows and corresponding flood rises over the sills of spillways were estimated accordingly. The outcomes of this study have indicated that, in general, the flood rise level for most of the dams were lower than the ECL level by at least 0.50 m and this in essence, has provided some factors of safety in light of heavy and gutsy wind surges at the top of the reservoir water surface. Thus, this has provided some flexibilities during emergency operations at the onset of a probable PMP/PMF event. In conclusion, the dams had been safe from the risk of overtopping based on an extreme meteorological event of PMP/PMF magnitude.

## 1.0 INTRODUCTION

There are more than fifty (50) dams or reservoirs in Malaysia serving multiple purposes, such as for flood mitigation, provision of raw water sources for water supply (both domestic and irrigation), generation of electricity by hydro-energy conversion, and to a certain extent include side benefits such as, recreation and tourism. In addition to these existing dams, there are also potential dam schemes, about fifty (50) of them have been proposed for future water supply and demand planning in order to meet the nation's economic development needs (SMHB et al., 2000; JPS, 2011).

These existing dams are an integral part of the water resources system and infrastructure as they serve many useful purposes in the management and optimal distribution of scarce water resources in both time and spatial domains. Over the millennium, they have been commissioned to moderate the fluctuating inflows. Excess waters are stored in the reservoir water body and are released during the wet dry seasonal cycle.

These dams are required to regulate the uneven hydrological fluctuation and distribution at both extreme ends of the spatial and temporal spectrums prevailing in tropical Malaysia. The social and economy developmental disparity also warrants the implementation of dam-related water resource projects to meet both the pressing current and future water demand for multifaceted sectors, especially since many towns and cities are currently experiencing the rural-urban economical migration with run-a-way population boom.

On the other hand, dams are practically constructed based on a stringent standard of design at a very remote probability of future failure. Any sort of accident such as dam breaching or collapse would spell a major catastrophe to the downstream riparian users such as the inhabitants in towns and cities, fauna and flora alike.

Failure of dam structures by overtopping leads to the need for a fair and accurate assessment of their safety features such that emergency actions can be planned and implemented ahead of probable catastrophic events. Over the years, hydrological safety aspects has been addressed as part of the routine comprehensive dam safety inspection program (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 and Hii, 2013c; Heng et al, 2014). One of the tasks of the hydrological safety assignments is to estimate the overtopping risk of the dam or reservoir in light of an extreme meteorological event, i.e. during a probable maximum precipitation (PMP) occurrence (Heng et al, 2013c).

## 1.1 PROBLEM STATEMENT

The safety issue of the dam or reservoir structures is one of the post construction operation and maintenance (O&M) undertaking that is being carried out routinely with the primary purpose of ensuring continuous functioning of the reservoir structure.

In essence, the adequacy in the capacity of the hydraulic infrastructure to resist the onslaught of extreme natural phenomena is utmost critical and important. Natural catastrophes such as an earthquake, heavy precipitation events that lead to eventual high floods, evidences of animal burrowing of the dam or reservoir structure (in the case of both earth and/or rock-fill dam structures) etc. are part of the exercise to be carried out according to the O&M protocol.

An inspection seeks to identify the current status of the dam or reservoir structure in light of calamity that might impair the structural integrity and therefore the structure itself. An inspection checklist gives the full safety/health status to the dam or reservoir scheme for continuous operation for many years to come until the next due inspection, which in the Malaysia's dam inspection guideline requires a 5-year interval for any major dam structure.

One of the important aspects of the dam inspection programs involves the hydrological adequacy assessment and appraisal on the existing spillway capacity in light of a PMP/PMF event. The performance of a spillway on the onset of a calamity is crucial to the dam or reservoir structure itself. Overtopping over the dam crest occurs if the reservoirs cannot adequately and sufficiently attenuate the inflows during an extreme PMP/PMF event.

Failure of a dam or reservoir due to overtopping that is beyond the confinement of a spillway is one of the leading and most frequent occurrences worldwide. This occurs when the water level in a reservoir rises and exceeds its outlet capacity (i.e. also reaching and overtopping the dam crest) of the dam or reservoir. Causes are now being identified as inadequacy of the spillway capacity and/or settlement of the dam crest elevation, i.e. a type of foundation defect and another leading cause of dam or reservoir failure.

Dam overtopping occurs whenever the water level rises unexpectedly or rapidly and most of the time without prior and/or with a very short time of warning of impending storm in the upper catchment area. The examples are flashy type of floods, heavy storm/rainfall, a landslide occuring in the upper catchment area of the dam or reservoir that sends torrential water waves toward the dam embankment downstream. The results of the dam failure could be far reaching and jeopardizing for the structural integrity of the dam or reservoir.

The design parameter, PMPs used in the earlier design of dam or reservoir structures are subjected to review during each inspection interval. Unfortunately, during the earlier design of the dam or reservoir structure, the hydrological information at the dam or reservoir sites or in the vicinity might not be adequate, thus prevented a thorough and comprehensive assessment during the detailed design stage of the dam or reservoir. This is especially true for the dam or reservoir structures that were designed and built in the earlier 1950's when the hydrometric collection and sampling program was generally lacking and inadequate during the early years of independence. As such there is a pressing need for a comprehensive assessment of the hydrological safety criteria of the dam or reservoir structures in the light of climatological or meteorological extremities.

An illustrative example of the inadequacy of the hydrological assessment is the PMPs that are adopted to the dam or reservoir design. The PMPs are mostly inconsistent as they are subjected to the knowledge and experiences accumulated by the individual designers, i.e. consulting engineers/specialists' experiences. Even for the same dam, most if not all of the time, the PMPs are reported and derived differently by different engineering specialists.

In summary, the hydrological assessment of the dam or reservoir's safety is an essential part of the dam inspection program, in light of a new and updated set of PMP using concurrent and latest observed hydrological information. Therefore, it is of prime importance to carry out this special task of hydrological investigation and examination.

## 2.0 OBJECTIVES AND AIMS

The objectives of this study are to; (1) assess the risk of overtopping of existing water supply dams equipped with morning glory spillways in the upper catchment area of major river basins; (2) compare the relationship of catchment area-equivalent weir length and headrise relationships with the existing dam or reservoir schemes in the same meteorological/hydrological region; and (3) recommend, if any, the remedial measure(s)/option(s) to mitigate the deficiency in spillway capacity.

Once constructed, dams are always designed and equipped with an emergency mode for evacuating a large and voluminous water behind the dam within a reasonable time frame. Normally various outlets are incorporated as part of the dam appurtenances such as bottom outlets, spillways, gates etc. To a limited extent, the bottom outlets are normally used for releasing reservoir waters downstream for environmental flow and augmentation purposes. As previously mentioned, the sizing of the spillways shall be undertaken during the very early construction stage so that they are adequately designed to contain or allow safe passage of PMPs/PMFs downstream. The safety issue dictates clearly that the function of the spillway to contain the most extreme flood flow of a PMP/PMF magnitude.

Morning glory or drop shaft spillway is a common fixture appurtenance for both earth and rockfill embankment dams if suitable sites on the natural ground abutment could not be found readily. There are ten (10) existing dams that are equipped with this particular type of spillway. These dams primarily function as single purpose water supply mode of operation throughout Malaysia. One of their common features is their relatively smaller catchment area ranging from the Mengkuang dam of 4 $km^2$ to the largest Semenyih dam (CA= 57 $km^2$). A comparison of physical features demonstrates the relationship in terms of their catchment areas, head rises (difference between ECL and FSL) and effective spillway lengths. A summary of dams equipped with drop shaft spillway is presented in Table 1 and Figure 1.

These dams are designed based on varying criterion by different engineering experts over the years, before the advent of a standard practice in the PMP/PMF derivation. It is therefore critical to assess their safety aspects in terms of uniformity in methodology.

**Table 1. Catchment Area, Equivalent Ungated Spillway Width, Headroom and Storage of Selected Dams**

| Dam | Catchment area ($km^2$) | Equivalent Spillway width (m) | Headrise/room ECL-FSL (m) | Storage at FSL (MCM) |
|---|---|---|---|---|
| Mengkuang | 4 | 28 | 3.0 | 23.6 |
| Air Itam | 5 | 69 | 1.3 | 2.6 |
| Tinggi | 40 | 31 | 4.0 | 122.5 |
| Langat | 41 | 86 | 2.7 | 38.4 |
| Semenyih | 57 | 44 | 4.0 | 61.4 |
| Terip | 26 | 61 | 4.0 | 48.0 |
| Durian Tunggal | 41 | 69 | 2.4 | 30.0 |
| Jus | 23 | 25 | 2.5 | 48.0 |
| Juasseh | 29 | 47 | 4.0 | 32.6 |
| Gerugu | 14 | 41 | 3.0 | 14.0 |

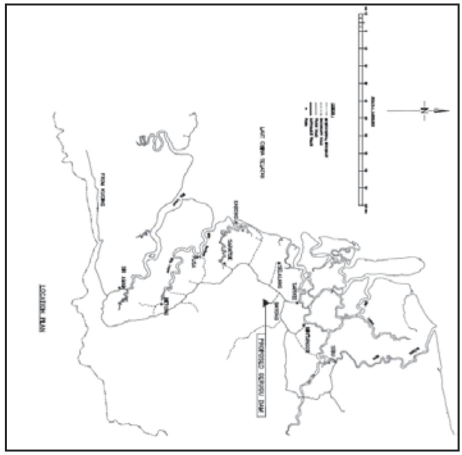


**Figure 1. Location Map of Existing Dams with Morning Glory Spillway**

## 3.0 ASSESSMENT AND METHODOLOGY

For a meaningful comparison and assessment, an uniformed procedure was therefore adopted for this study. This primarily envisages a review of the spillway capacity and dam overtopping probability and likelihood under a PMP/PMF scenario. The steps involved in tandem were (1) derivation of PMPs at these 10 dam sites; (2) translation of PMPs to PMFs/SDFs using a calibrated catchment rainfall runoff or response function model; and (3) a conventional reservoir routing or water balance accounting technique to estimate the flood rise over the dam's full supply level (FSL) (Heng et al, 2013c).

The task of derivation of PMPs is outside the scope of this study, instead recourse is made mostly by reviewing the available past studies and findings in Malaysia. The prevailing PMP convention is duly reviewed and adopted appropriately. Catchment response and convolution lumped parameter model is used to translate PMPs to PMFs for various durations. Finally, the derived PMFs are then appropriately routed through the lumped parameter reservoir. The final results of this exercise/undertaking was to ensure that the dam is not overtopped passing its embankment crest level (ECL) (Heng et al, 2013a, Heng et al, 2013c).

Similar to previous studies (Heng et al, 2013a), the water supply reservoirs chosen in this study are mainly equipped with a detached morning glory spillway near the dam site. They are evaluated based on the same methodologies of safety evaluation. This serves as a basis of uniformed comparison in their respective parameters and outcomes during a PMP/PMF event. The sizing of drop shaft type of spillway follows the convention to ensure an open channel flow regime while channeling waters into the drop shaft. The estimation of the spillway diameter is the most critical factor during the iterative design process. According to Vischer and Hager (1998), the ratio of head/water rise over the radius of the spillway (H/r) ranges from 0.30 to 0.45 to keep an open flow regime where the governing equation used in the design process is essentially based only on the head over weir nonlinearly. An usual exponential of 1.50 is normally adopted in this case. During the design stage, it is also equally important to carry out a physical model undertaking to verify and confirm the size of the spillway under both full and partial blockage condition.

All ten (10) dams or reservoirs selected for this study, in a way or so, follow the same conventional design procedures of rainfall catchment, runoff and reservoir routing procedures.

### 3.1 PMP REVIEW AND DERIVATION

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; ABM, 2007). It represents the upper limit of the precipitation/rainfall under probable and favorable contributing factors, such as availability of moisture and other favorable meteorological conditions, absence/presence of moisture barrier such as higher mountainous range in the path of storm movement, availability of cumulus or particle that water vapors can be adhered to and others.

Probable Maximum Precipitation (PMP) is derived based on the maximum observed rainfall records with the provision of storm maximization and transposition (WMO, 1986, 2009). Based mostly on practical experiences in Malaysia, PMPs are derived based on the historical maximum rainfall records mostly in the east coast regions of Peninsular Malaysia. This region is exposed to more severe storm events during the northeastern monsoon season.

The observed records have been collected over the years, both through the recording and non-recording mode of rainfalls alike. These maximum rainfall records of various durations provide the fundamental basis of PMP derivation. Primary derivation of PMP based on observed maximum rainfall records in the northeastern state of Johor in 1970 was adopted for most of the water supply dam designs in Malaysia.

The PMPs were derived by SMHB (1992, 1994) by reference to the earlier works carried out in the late 1970’s, specifically in the detailed of the Semenyih dam. These sets of PMPs are being adopted in most of the dam/reservoir studies and designs in Malaysia. Some years later, comprehensive reviews were then carried out in the Kelantan Flood Mitigation Project (SSP and SMHB, 1997), National Water Resources Study (SMHB et al, 2000) and Interstate Raw Water Transfer from Pahang to Selangor (Nippon Koei and SMHB, 2000). 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 and Hii (2011).

Almost all dams included, with the exception of the Air Itam dam (CA= 5 $km^2$) in Penang, were designed based on the derivation of PMPs presented in both regional water resources studies (SMHB, 1992, 1994). Two series of PMPs generally considered by the geographical location of the dam site, namely (1) coastal and (2) inland PMP series were used in most of the dam design projects in Malaysia (Heng et al, 2013a). The coastal series was derived earlier in the late 1970’s based on observed records of long-duration storm occurrences in the eastern coastal region of Peninsular Malaysia. The observed records of the Mersing and Air Tawar dams, which were the highest recorded at that time were used for the PMPs. The highest rainfall records in the 1970's do not in any way exceed the observed records reported by Atikah (2009) and NAHRIM (2008). On the other hand, the inland series is merely a reduced version of the coastal PMP with an appropriate transposition factor to the inland region of the western coast of Peninsular Malaysia (Heng et al, 2013a).

In general, inland PMP represents the most severe storms on the western coastal sea front, due mainly to the mountainous barrier of Sumatra Island in neighboring Indonesia. Most of the dams in the west coastal region of the Peninsular are effectively shielded from major southwestern monsoon during the intervening months of April to July. A reduction is needed when transposing the coastal PMP series from the southeastern region of the peninsular. Table 2 summarizes the PMPs for both coastal and inland regions of 1 to 120-hour durations.

**Table 2. Coastal and Inland PMPs (Short- and Long-Duration)** (SMHB, 1992, 1994)

| **Duration (hour)** | **Coastal PMP (mm)** | **Inland PMP (mm)** |
|---|---|---|
| 1- | 211 | 188 |
| 3- | 338 | 300 |
| 6- | 440 | 391 |
| 12- | 584 | 518 |
| 24- | 777 | 692 |
| 48- | 1356 | 908 |
| 72- | 1593 | 1067 |
| 120- | 2030 | 1360 |

**Table 3. PMP/PMF, Outflow and Flood Rises, Headrise over Rise Ratio**

| **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 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 |

### 3.2 PMP/PMF CATCHMENT ROUTING

As indicated by previous studies, (Heng et al, 2013a), in order to estimate the incoming floods into a reservoir, a similar conventional technique used in a rainfall runoff modeling process is needed to translate the PMPs into probable maximum flood (PMF) simulations. In turn, it is adopted for the spillway design of a dam. The mechanisms and procedures on the translation of the Probable Maximum Flood (PMF) using Probable Maximum Precipitation (PMP) is mostly carried out using a conventional rainfall runoff routing procedure by convoluting the generated runoff based on rainfall temporal distributions.

PMF is the probable flood magnitude that may be expected from the most severe combination of critical meteorological and hydrologic factors/conditions that are reasonably possible in a particular catchment basin/area (Chow et al, 1988). The Probable Maximum Flood (PMF) is therefore deemed as the design flood inflow or SDF into reservoirs where it is involved in spillway design.

From past studies (Heng et al, 2013c), the rainfall runoff modelling approach has been the conventional and industrial standard in assessing the quantitative flooding impacts of extreme storm events in a watershed or basin. The mathematical modelling tools are also frequently used to assess the magnitude of flood flows and stages for a given probability of rain storm occurrence in a river basin or channel. To elaborate further, they are also being routinely used to generate rainfall induced runoff hydrographs for special hydraulic structure designs such as dams and outlet structures, etc.

Two main approaches have been combined for the derivation of PMFs in this study due to their relative surface areas of the dams or reservoirs at their respective full supply level. The ratio of lake surface area to the total catchment is paramount to whether the earlier rise in flood peak can be observed. Reservoirs with small catchments generally show a sharp rise in the inflow hydrograph for short durations if the lake surface dimension is significant in comparison to the drainage area. This indicates a fast and swift response effect of this higher lake surface area to the catchment area and the PMPs that are falling directly are duly taken into consideration in the translation of PMPs to PMFs.

Translating by convolution of temporally distributed PMPs into PMFs of various rainstorm durations, i.e. from 1- to 120-hour is one of the important tasks in a standard PMP/PMF study (Heng et al, 2013a). Out of many hydrological rainfall runoff techniques available, two (2) approaches or models are the most commonly used in the local context; (1) hydrological procedure No: 11 on flood estimation (Taylor and Toh, 1976), and (2) modeling approach using proprietary as well as nonproprietary mathematical models/software. For uniformity as well as simplicity, the former is adopted in this study as well as other studies (Heng et al, 2013a, Heng et al, 2013c).

### 3.3 RESERVOIR ROUTING

The primary purpose of reservoir routing is to estimate the outflows of the PMPs as they pass through the reservoir. At the same time, the stage or flood rise is also estimated from the outflow-stage rating relationship. It is desirable that the maximum flood rise for various durations is less than the embankment crest level (ECL) of the dam, failing which, it runs the risk of being overtopped. It is important for the outlet structures, i.e. bottom sluice gates and spillways to be able to evacuate an extreme flood of PMP/PMF magnitude essentially for the protection of the main body of the dam or reservoir.

The common reservoir routing procedure is based on the modified Puls technique (Chow et al., 1988). Water balance description can be quantitatively written in the form of flow continuity equation over a fixed control volume domain, in this case, in a reservoir schematic. Similar to past studies (Heng et al, 2013a, Heng et al, 2013c), the rate of change of storage in the reservoir water body is the summation and quantification of all inflows from various sources, appropriately deducting the amount of outflow via outlet structures, such as spillways or bottom outlet of a reservoir or dam. For simplicity, it is assumed that other losses such as seepage through the dam body are negligible.

## 4.0 RESULT AND DISCUSSION

Based on a similar and uniform way of assessment using the PMP series (Inland and Coastal), the final results mainly showed consistency, in terms of flood rises that are generally lower than the embankment crest level (ECL) of the dams, with the exception of the Air Itam and Langat dams (Air Itam, CA= 4 km2 and Langat, CA= 41 km2), where the flood rise marginally exceeded the respective ECLs.

In general, the flood rises for most of the dams were generally lower than the ECL level by at least 0.5 m and this in essence, gives some leeway during heavy and gutsy wind surges at the reservoir water surface. This also gives some flexibility for emergency operations during the onset of a probable PMP/PMF event so that timely evacuation of the dam storage could be made. In addition, the hydraulic behavior of the spillway for each dam was also examined by checking the ratio of headrise over the radius of the morning glory spillway.

The ratio of PMP/PMF headrise over the radius of the drop shaft spillways (H/r) was generally less than 0.50 for all dams (Vischer and Hager, 1998). Free flow open channel hydraulic mode has prevailed over weir prevails in all the dams evaluated in this study. All spillway design was based on the premise of lower H/r ratio so that the flow remains as an open channel regime. Table 3 summarizes the results of PMFs, outflows and corresponding flood rises above the crest level. Figures 2 and 3 show both the PMP/PMF inflow and outflow routing hydrographs for various durations of the Tinggi dam (CA= 40 $km^2$).

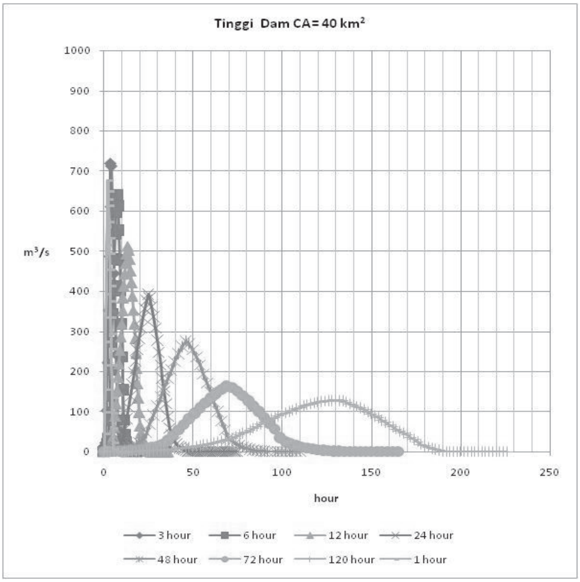
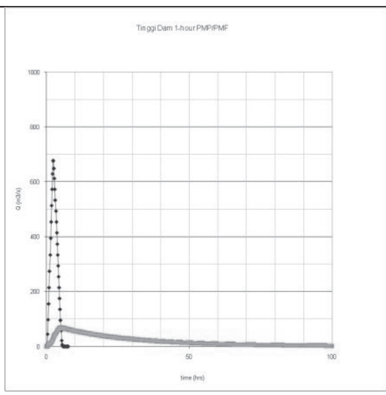
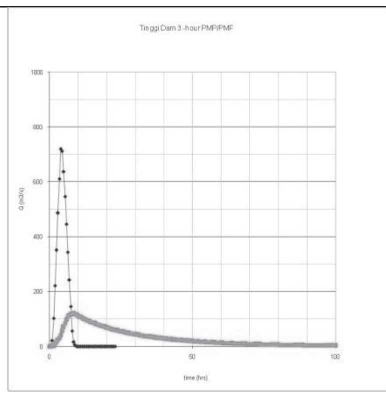



**Figure 1. PMP/PMF Catchment Routing: 1- to 120-hour**

<table>
<tr><td colspan="2">Tinggi Dam (40 km$^2$) Inland PMP</td></tr>
<tr><td>
</td><td>
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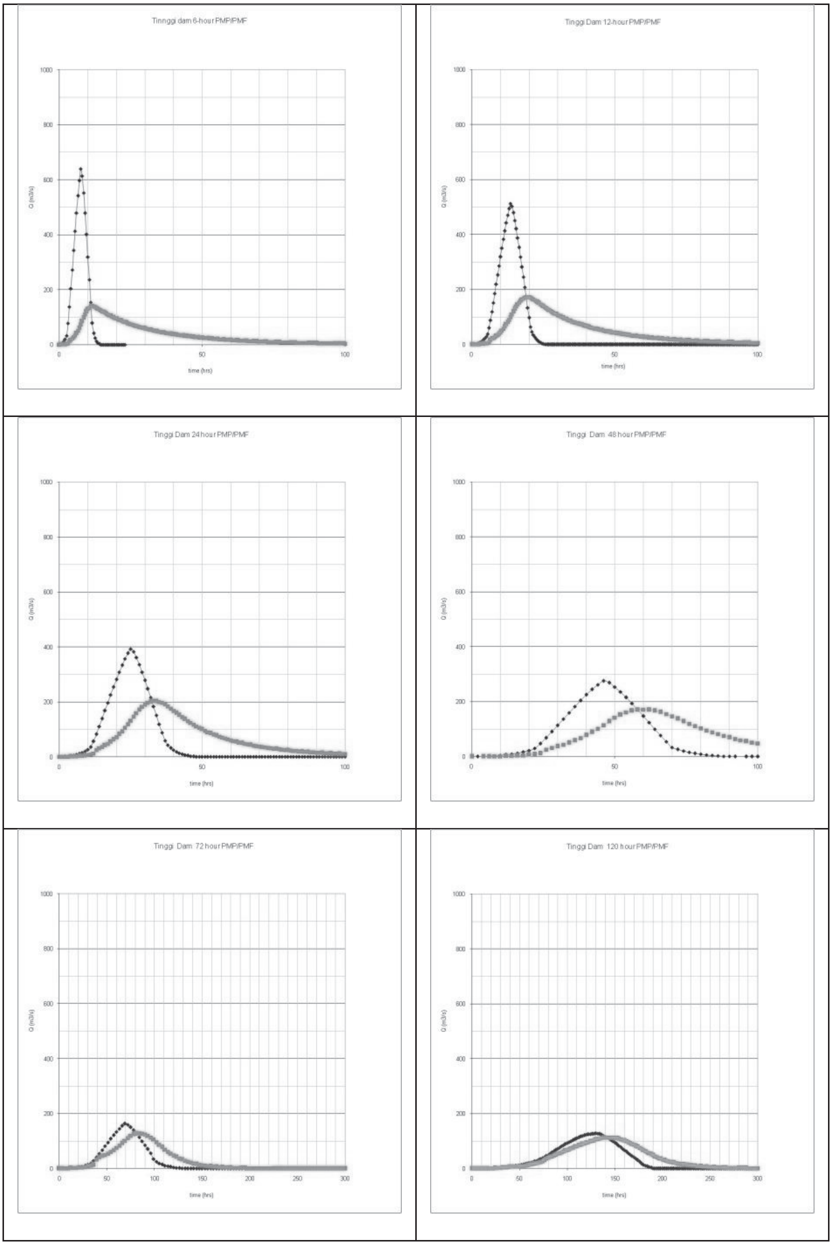


**Figure 2. Dam/Reservoir Routing: 1- to 120-hour Duration**

### 4.1 COMPARISON OF BELL MOUTH AND MORNING GLORY SPILLWAYS

Bellmouth spillway is an alternate spillway selection for dam sites where no suitable spillway sites could be found on both embankments. In the dam design convention, it is normal to opt for the spillway to operate under an open weir flow mode/regime. This is carried out by larger diameters at the entrance through the transition into the shaft underneath. A larger diameter, in turn, increases the linearized weir length. In this case, the flood rise will be relatively lower. It is most undesirable to keep the flow regime under orifice and/or pressure flow mode. If this occurs, the conduit leading to the outflow portal downstream of the dam will be subjected to unduly higher stresses induced by the water pressure. This study basically confirmed that all ten (10) water supply purpose dams with morning glory spillways are able to act as an open channel regime which was what they were designed for.

In the northern peninsular region, there are two (2) dams equipped with morning glory spillways. Both of them consist of small catchment reservoirs with less than 5 $km^2$ in drainage area. A clear compensating factor is vividly demonstrated by the following two dams, i.e. Mengkuang (CA=4 $km^2$) and Air Itam (CA= 5 $km^2$), both located in the same meteorological region in the northern peninsular. Though they are of relatively smaller catchment areas but they are equipped with larger bell mouth spillways. The headrises for both dams are markedly different even with about the same catchment areas. Air Itam dam with its larger bell mouth spillway allows a lower flood rise compared to the Mengkuang dam which is equipped with a smaller spillway but higher headroom. Therefore, it can be clearly seen that, a smaller bell mouth diameter such as the Mengkuang dam is being compensated by a higher allowable headrise for an effective surcharge storage during a PMP/PMF event.

There are only three dams out of ten in the central region of the peninsular, i.e. in the state of Selangor and the Federal Territory of Kuala Lumpur that are equipped with bell mouth or morning glory type of spillway structures (see Table 3, a summary of bell mouth spillways in Malaysia). A comparison amongst them is therefore carried out to demonstrate the relationships in terms of their catchment areas, head rises (difference between ECL and FSL) and effective spillway lengths.

This was also clearly shown in the neighboring Langat river basin of two water supply dams, i.e. Langat (CA= 41 $km^2$) and Semenyih (CA= 57 $km^2$) dams. Despite the relatively larger catchment area, the Semenyih dam (CA= 57 $km^2$) has a smaller spillway but with a bigger 4-m flood headroom to contain the surcharging PMP/PMF flood flows before being overtopped. On the other hand, the Langat dam with its relatively larger spillway diameter only allows a substantial reduction in the head rise, most probably due to the topographical constraints.

A clear fact on the compensation and tradeoff is vividly demonstrated by these two (2) dams, i.e. Mengkuang (CA=4 $km^2$) and Air Itam (CA= 5 $km^2$) dams. Though they have relatively smaller catchment areas but they are equipped with fairly larger bell mouth spillways which translates into longer weir lengths. The headrises for both dams are markedly different even with about the same catchment areas and located in the same hydro-climatic zone. Air Itam dam (CA= 5 $km^2$) with its larger bell mouth spillway can allow a lower flood rise compared to Mengkuang dam with a smaller spillway. Therefore, it can be clearly seen that, a smaller bell mouth diameter such as for the Mengkuang dam is being compensated by a higher allowable headrise for effective surcharge storage during a PMP/PMF event.

Both Mengkuang (CA=4 $km^2$) and Air Itam (CA= 5 $km^2$) are small catchment dams in the state of Penang. Both dams supply vital raw water sources to the state. Both of them are located in the same meteorological region in northern peninsular. Air Itam dam (CA= 5 km4) which was built in the 1930's, supplies raw water to the Air Itam Water Treatment Plant (WTP). It has a small scale direct supply mode of operation with only 18 Mld. Whereas Mengkuang (CA= 4 $km^2$) operates on a pump-storage mode with a relatively large volume of storage compared to its drainage area. The dam was expanded recently by raising of the ECL to accommodate the increasing demand for the state of Penang. A new piano key spillway was incorporated to counter the risk of the dam body being overtopped during a PMP/PMF event. A similar comparison is also made between the Tinggi, Semenyih and Langat dams as all of them are located in the same meteorological and topographical regions of Sg. Selangor and Sg. Langat basins. Whereas the Juasseh dam (CA=29 $km^2$) and the Terip dam (CA=26 $km^2$) have about the same catchment area but with a lower weir length compared to the three dams mentioned earlier.

With limited information on existing dams drop shaft spillways, it can be demonstrated that Air Itam (CA = 5 $km^2$), Langat (CA= 40 $km^2$) and Durian Tunggal dams (CA= 41 $km^2$) belong to the same design philosophy and category where the low headrise is compensated with much larger spillway diameters.

## 5.0 CONCLUSION

The assessment was carried out using common methodology, by first carrying out a review and selection of the PMPs and recent PMPs by SMHB (1992, 1994). Secondly, a rainfall runoff modeling technique was used to translate the PMPs into PMFs of various durations, i.e. the inflows into the reservoir at the onset of an extreme storm event of PMP magnitude. Finally, a conventional reservoir routing procedure of modified Puls technique was used to estimate the outflows and corresponding flood rises at the spillway of the reservoirs.

The results of this study indicated that, in general, the flood rises for most of the dams were lower than the ECL level by at least 0.50 m except for the Air Itam (CA= 5 $km^2$) and Langat (CA= 41 $km^2$) dams. This in essence, will offer some leeway in wave surging in light of heavy and gusty winds at the reservoir water surface.

The hydraulic behavior of the spillway for each dam was examined by checking the ratio of headrise over the radius of the morning glory spillway. The ratio of PMP/PMF headrise over the radius of the drop shaft spillways (H/r) was generally less than 0.50 for all dams (Vischer and Hager, 1998), suggesting mainly free flow hydraulic mode of flood water flow over weir prevailing in all the dams evaluated in this study.

In conclusion, these dams, except for Air Itam (CA= 5 $km^2$) and Langat (CA= 41 $km^2$) were safe from the risk of overtopping using the standard set of PMPs derived in SMHB (1992, 1994) despite some of the dam designs being based on individual experiences of the consultants prior to the advent of standardized PMPs by both major water resources studies. Both Air Itam (CA= 5 $km^2$) and Langat (CA= 41 $km^2$) dams shall be investigated further in terms of exploring the possibility of incorporating additional spillways or installation of parapet walls as an interim solution.

From the author's point of view, it is suggested that further evaluation of the spillway capacity shall also be made using recent PMPs of NAHRIM (2008) by both statistical Hershfield and data-intensive hydro-meteorologic approaches. It is anticipated that failure of the existing dam spillway is imminent if latter PMPs by hydro-meteorological approach were to be adopted. The PMPs derived using this approach generally give a much higher PMP for shorter durations up to 24 hours, almost by two-fold. As such, it is also anticipated that these existing dams of smaller drainage areas especially Air Itam (CA= 5 $km^2$) and Mengkuang (CA=4 $km^2$) dams are the most vulnerable and the existing design of spillways will not be able to provide a safe passage of PMP induced floods.

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