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HYDROPOWER RESERVOIR FOR FLOOD CONTROL: A CASE STUDY ON RINGLET RESERVOIR, CAMERON HIGHLANDS, MALAYSIA

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ABSTRACT: Hydropower reservoir typically requires water level to be kept at minimum design level to store as much energy as possible for daily hydropower generation as well as to prevent any spillage at dam. However, as the reservoir storage volume is lost due to sedimentation, energy output from plant is affected, reservoir gradually losses capability to contain large flood inflows and control release of flood discharge through the spillway is inevitable (Abrishamchi et al., 2011; Shafiee et al., 2012) [1,16]. Results from the study show that the reservoir is only capable to storing 2.3 mil m^3 of water as compared against 6.7 mil m^3 at a pool elevation of 1071 m, which is a reduction of almost 65.7%. Meanwhile energy generation at Jor Power Station was found to be operating below the 200 GWh or at 62.5% efficiency at an average 2.5 mil m^3 live storage well below the original design capacity of 320 GWh. With the reduction in storage volume, the requirement for control release during floods is expected. Results from numerical simulation indicates that with a control release of 4-5 m^3/sec during flushing, the depth of water would be 0.8 –1 m and the total top width of flow is 7-8 m. Field test is also conducted to verify the findings of the simulation. Initial analysis from the topographic survey shows that the downstream river is incapable to contain the flood release from the reservoir due to encroachment of population into the river reserves. The study concludes by recommending both structural and non-structural measures to safety mitigate the risk of downstream flooding during the control release from the reservoir.

Keywords: Hydropower, flood simulation, control release, flood risk mitigation.

1. INTRODUCTION

All dams are designed to store flood-waters, primarily for the benefit of human beings. The damming of streams and rivers has been an integral part of human civilization from its early history. Reservoirs and dams are constructed by human to deal with the need of water and power. Dams and reservoirs are constructed primarily to function as multipurpose functions including as flood control, drinking water, agricultural water supply, hydro power generation, recreation and others [Braga et al., 1998; Verghese, 2001; Vyas, 2001) [5, 18,19].

Hydropower reservoir typically requires water level to be kept at minimum design level to store as much energy as possible for daily hydropower generation as well as to prevent any spillage at dam. The stored energy in the reservoir gradually increases cumulatively with the rise in water level. Primarily the development of operational policy involves a complex process of optimizing the total energy stored in reservoir combined with other cascading reservoir requirements if any. In Ringlet reservoir, since the volume of water stored is often utilized fully and effectively for hydropower generation, the secondary function of reservoir and dam as flood control is generally under utilized. However, as the annual sediment inflow is recorded to exceed the design value and as the sediment deposition occurs within the reservoir live storage, the reservoir continues to loose its storage capacity to sustain major floods.

This paper analyses the storage loss of the reservoir using actual bathymetric survey data. The longitudinal profile of the reservoir bed is plotted against historical data to show the increase in reservoir sedimentation. The present storage capacities is determined and compared against the original storage capacities through the storage-elevation curve. This study emphasizes the effects of reduction in reservoir storage capacity towards the hydropower generation and flood control.

This paper also presents the results of numerical analysis of various maximum discharges released from the gated spillway of the dam and its subsequent flooding risk parameters downstream such the flood width, water height, flow velocity and discharges. Based on the numerical simulation, the flood inundation map is produced to identify the high risk area and is verified during actual the field test of the hollow jet valve release. The study also recommends several flood mitigation strategies to mitigate the flood risk downstream of the dam.

2. OBJECTIVE

The primary objective of this paper is to analyze the sustainability of the reservoir to operate as storage for hydropower generation and for flood control structure (Abrishamchi et al., 2011) [1]. The focus will be to:

- Develop the revised storage-elevation curve based on the reservoir sedimentation data;
- Show the relationship between energy produced at power plant against the available live storage capacity of reservoir;
- Investigate various the flood release scenario at spillway through simple numerical analysis and to produce a inundation map for lower discharge;
- Propose implementation of strategic structural and non-structural measures to mitigate the flood risk.

3. STUDYAREA

Cameron Highland catchment area is mountainous terrain having various mountain peaks ranging from 1524m to 2032m. Under the Cameron Highlands Hydroelectric Scheme - Stage I Construction, the scheme was designed as a high head scheme which involves the combined flow from two major rivers, called Sungei Telom and Sungei Bertam being conveyed by pressure tunnel to an underground power station. The gross head estimated between S. Bertam and S. Batang Padang was 568 m. The total catchment area of Cameron Highlands Scheme is 180 km^2 comprising of 110 km^2 of Telom Catchment and 70 km^2 of Bertam Catchment as shown in Figure 1.

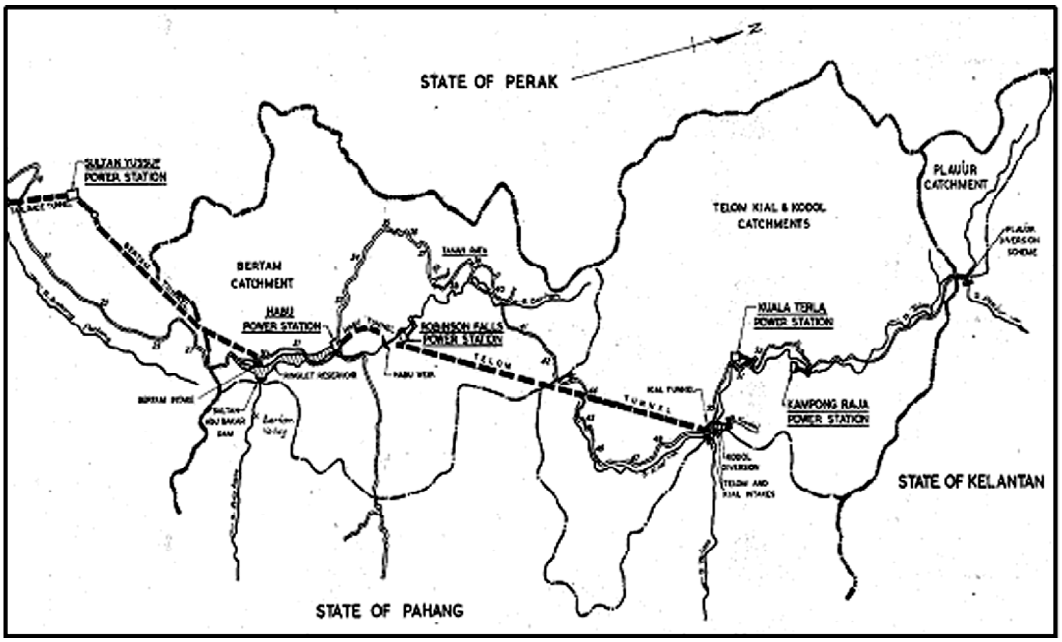

Figure 1: Map of Cameron Highland Catchment

The main feature of the scheme was the Ringlet Falls/Sultan Abu Bakar Dam (SAB Dam) which stands at 40 m comprising of concrete buttress fitted with four (4) gated spillways (Preece, Cardew and Rider, 1963)[15]. The reservoir elevation at full supply level is 1070.7 m and has a surface area of 60 hectares. The reservoir receives waters from the rivers namely Sg. Habu, Sg. Bertam, Sg. Ringlet and other minor tributaries. Ringlet Reservoir was designed for a gross storage of 6.3 million m^3, of which 4.7 million m^3 is the active/live storage and 1.6 million m^3 is the inactive/dead storage. The dead storage was designed for a useful lifespan of approximately 80 years which translates to 20,000 m^3/year of sediment inflow.

4. CAMERON HIGHLANDS HYDROELECTRIC SCHEME

The lower catchment covers the Sungai Bertam watershed down to Ringlet reservoir which was formed by the construction of the Sultan Abu Bakar dam. The catchment also receivers the diverted water from Sungai Telom. The Telom tunnel exits into Habu weir which is a concrete structure that was built immediately downstream of Robinson Falls Power Station. The Habu weir forms a small pond which receives the discharge turbined by the Robinson Falls generating station, the excess water from Sungai Bertam and the water received from

Telom tunnel. Habu weir serves as a pond for the Habu intake which conveys the water to the Habu generating station through a 1.75 km long tunnel. Three power stations were built on the lower catchment include:

- Robinson Falls (0.9 MW, 5.20 GWh/annum), which utilizes the water from Sungai Bertam's upper catchment of;
- Habu (5.5 MW, 25.5 GWh/annum), which combines the flows of both Sungai Bertam and the diverted Sungai Telom; and
- Sultan Yussof or JOR (100 MW, 320 GWh/annum), which turbines the waters regulated by Ringlet reservoir. A 7.42 km long tunnel conveys the water from Ringlet reservoir (Bertam intake) to the underground generating station. An 836 m tailrace tunnel links the power station to Jor reservoir.

5. METHODOLOGY

The methodology adopted for this study includes analyzing the sediment deposition in reservoir through the use of bathymetric survey and to produce a revised storage-elevation curve. The energy generated annual from Jor Station is analyzed to study the relationship between power generation and storage capacities. The event of near spilling cases at SAB dam and the spillway and outlet structure operation is also reviewed.

A simple numerical simulation model is developed to evaluate the impacts towards the downstream Sg. Bertam River during controlled flood release from the dam. Verification of the results is done during actual field test conducted at study area. The one dimensional flood inundation map is produced to show the depth of water at strategic critical area.

A schematic of the methodology is indicated in Figure 2.

6. OPERATIONAL REGULATION OF RESERVOIR

The original live storage of the reservoir between the normal minimum reservoir draw down level at 3474 ft. (1058.98 m) and the normal top water of 3515 ft. (1071.37 m) is 3820 acre-feet (4.71 km^2). At 3513 ft. (1070.76 m) the total capacity of the reservoir is 5420 acre feet (6.7 million m^3), the area of the water surface is 138.5 acres (56.05 hectares) and the maximum depth of the reservoir is about 113 ft (34.4 m).

Overflow from the reservoir is controlled by one tilting and three radial gates, which together will pass a total of about 34,000 cusecs (963 m^3/sec). The tilting gate is bottom hinged at 3504.0 ft (1068.02 m) above datum and is arranged to commence opening when the reservoir level is at 3513 ft (1070.76 m). It is fully open when the reservoir has risen to 3514 ft (1071.07 m) at which level it will pass approx 2,300 cusecs (65.13 m^3/sec). The radial gates commence opening at a water level of 3514.08 ft (1071.09 m) and are fully open when the reservoir has risen to 3515 ft (1071.37 m) at which level each will pass about 10,600 cusecs (300.16 m^3/sec). All four gates are float operated. Each tilting gate is 20ft (5.1 m) wide and the radial gates are each 40ft (13.2 m) wide. When in shut position, the highest parts of the radial gates are at a level of 3515.8 ft (1071.62 m). All four gates are capable of being manually opened by the operation of valves, provided that the reservoir level is at or above the level of the gate control intake i.e. above level 3510.75 ft (1070.08 m) for the tilting gate or 3508 ft (1069.24 m) for the radial gates.

The dam is also equipped with 70.9 in (1.8 m) internal diameter concrete lined bottom outlet pipe with its upstream centre line at level 3404.5 ft (1037.59 m) and controlled by means of a hollow jet regulator valve at its downstream end (normally kept shut) and the butterfly type guard valve near its upstream end (normally kept open). The discharge capacity of the bottom outlet with the regulator valve fully open is approximately 1100 cusecs (31.15 m^3/sec) when the reservoir is at 3484 ft (1061.92 m) (Waagner-Graz, 1962) [20].

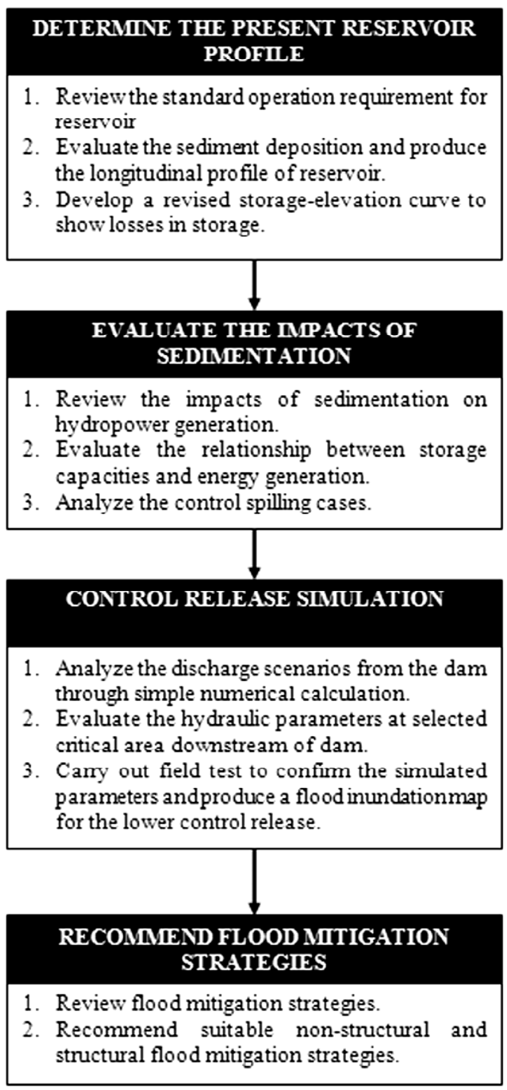

Figure 2: Methodology Flow Chart Adopted for Study

7. DEVELOPMENT OF STORAGE-ELEVATION CURVE

Based on the reviewed information, the survey computation the present storage-elevation curves in comparison to the original values were developed. The following process was adopted:

- Review of reservoir data (water and stream bed elevation at the dam, dam height, original storage-capacity curves.
- Evaluation of sediment volume deposition and generation of revised storage-elevation curve by area computation. Computation of the sediment area and volume, taking into consideration that the sediment area below 3470 ft (1057.66 m) equals the minimum draw down level. The sediment volume below 3470 ft (1057.66 m) are considered as dead storage capacity and included in the total capacity of the reservoir, but the volume above the 3470ft (1057.66 m) will be calculated as the average area between two successive elevations multiplied by the depth increment.
- Develop the revised depth-area and capacity curves of the reservoir, modified due to the effect of reservoir sedimentation.

8. RESERVOIR SEDIMENTATION

Analysis of reservoir sedimentation data shows that in just 35 years of operation since construction, 34% of its storage was already taken up by sediments which left the reservoir with a balance lifespan of 10 years. This represents a storage loss of 34.3% in 1999 and increased to 40% in 2005 and 45% in 2010. The long term annual capacity loss or sedimentation rate of Ringlet Reservoir in 1965 was estimated at 25,000 m^3/yr (Choy and Mohamad, 1990; Long, 1992) [7, 13], which has increased to an average of almost 6 fold to 139,712 m^3/yr (Jansen et al., 2011) [10] in 2008. Based on the bathymetric survey carried out in 2008, the longitudinal profile of the reservoir is plotted to show the elevation of the bed in time interval. The updated bed profile of the reservoir is plotted as shown in Figure 3.

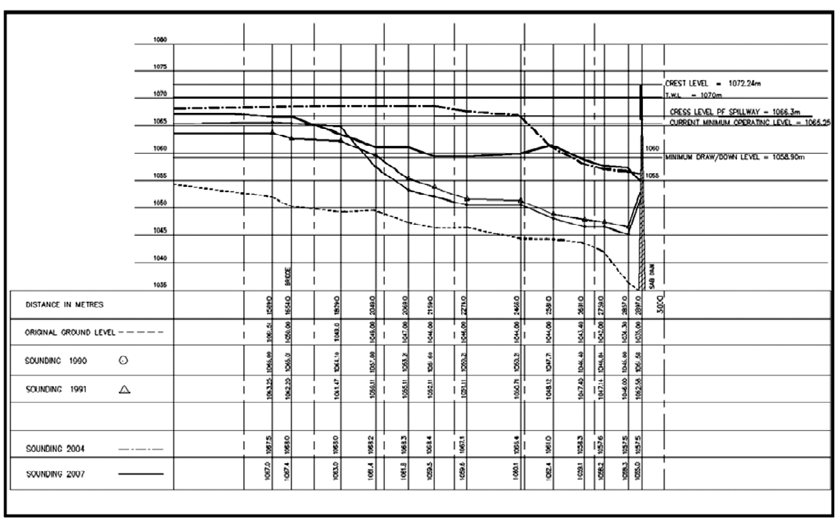

Figure 3: Longitudinal Profile of Reservoir Bed at Ringlet Reservoir as Compared to the Original Bed

9. RESULTS

The comparison between the original elevation-capacity curves and the revised curves are developed and shown in Figure 4. From the results, the reservoir is only capable to storing 2.3 mil m^3 of water as compared against 6.7 mil m^3 at a pool elevation of 1071 m, which is a reduction of almost 65.7%. The minimum storage elevation was also noticed to increase from the original 1045.5 m to 1057.7 m as a result of reservoir sedimentation.

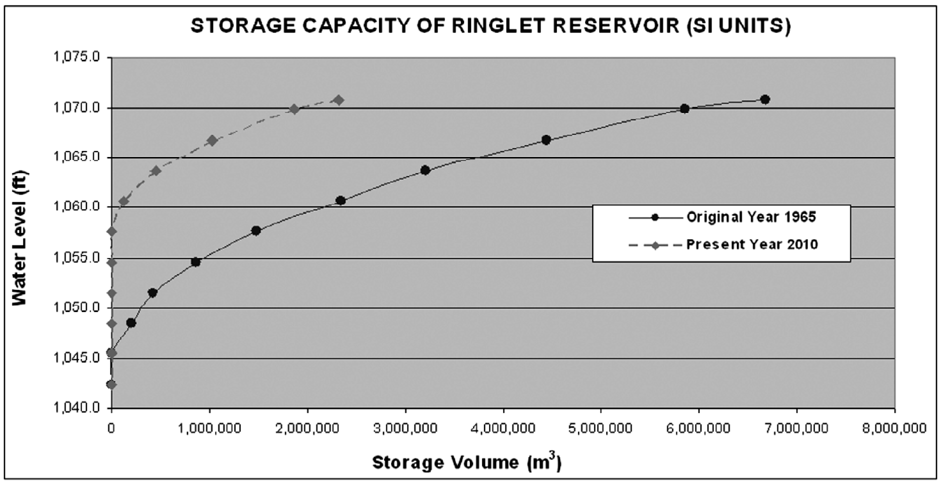

Figure 4: Original and Revised Capacity-Elevation Curves for Ringlet Reservoir

10. IMPACTS TO POWER GENERATION

Power generation is affected directly to the loss of storage in the reservoir. Rapid decrease in generation and frequent intake shutdown was experienced since 1988 due to the sharp drop in the live storage. In order to compensate the loss of storage in the reservoir, the operational periods of the power plants machines are further extended retain the reservoir level capacity at a minimum storage (Naidu, 2009) [14]. General reported problems associated with reservoir sedimentation include:

(*i*) Frequent choking of strainers
(*ii*) Choking and puncturing of cooler tubes
(*iii*) Damage to cooling water pumps, valves, etc.
(*iv*) Frequent damage of turbine shaft seal
(*v*) Damage to drainage and dewatering system besides siltation of sumps
(*vi*) Higher leakage through runner labyrinths resulting in high top cover pressure
(*vii*) Damage to guide vane bushes and their cap seals
(*viii*) Damage to seals of intake valve and main inlet valve
(*ix*) Seating/sealing problems in hydro-mechanical gates, intake as well as draft tubes
(*x*) Frequent operation of control release from spillway as reservoir losses capacity to contain large floods.

10.1. Hydropower Generation

Figure 5 shows the performance of Jor Power Station which was operating below 200 GWh given the live storage at an average 2.5 mil m^3 well below the original design capacity for the plant of 320 GWh. The result of the analysis shows that with the reduction in live storage, the peaking operating capability of the plant is greatly affected whereby the originally designed storage reservoir has converted itself automatically to a run-off river scheme. Such conversion is expected to have further risk on the scheme such as increased operation and maintenance problems and cost.

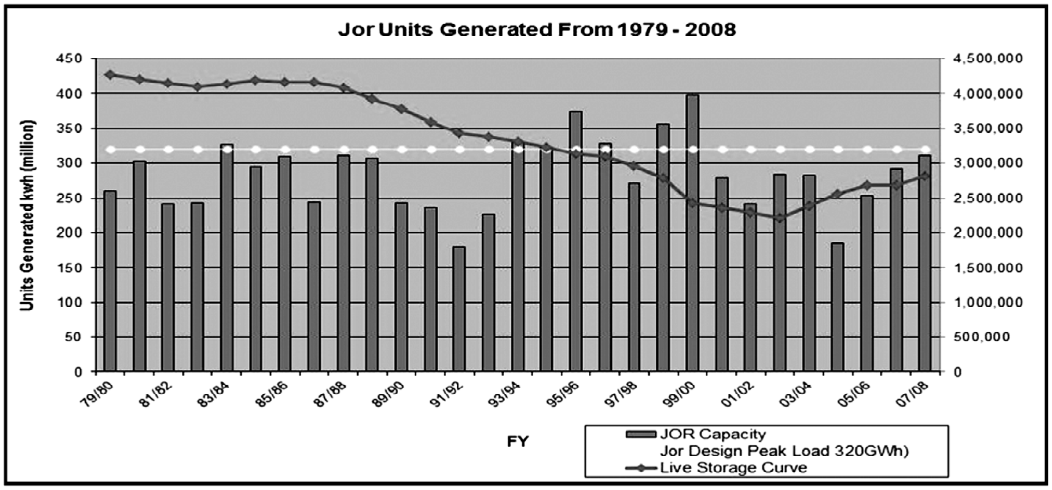

Figure 5: Average Live Storage Capacity Against the Average Units GWh Generated at Jor Power Station

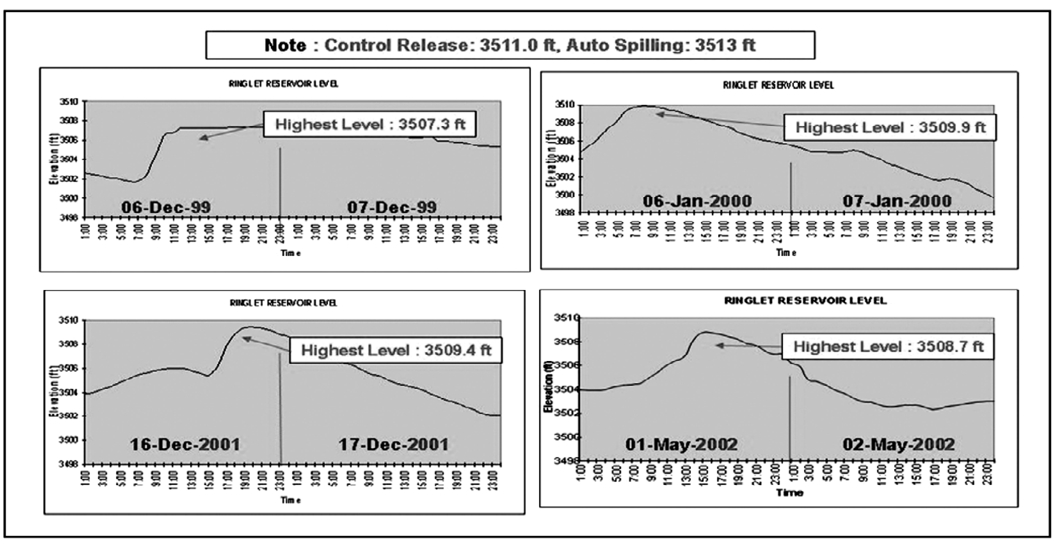

Figure 6: Monitored Water Level at Reservoir for Control Release

10.2. Control Release Cases

The reduction in storage capacity forces the requirement for control spilling (Abrishamchi et al., 2011; Shafiee et al., 2012; Afshar and Salehi, 2011; Teng et al., 2004) [1,16,2,17] as shown in Figure 6. It is observed that as the reservoir level increases gradually, control spilling is initiated at an elevation of 3511 ft (1070.15 m). This is done through the gradual opening of the radial gates by pumping water into the float chamber to lift the gate. This operation is important to prevent a sudden surge of flood water flowing downstream in which the titling gate operates automatically when the level reaches 3513 ft (1070.76 m).

11. FLOOD DISCHARGE SIMULATION MODEL

It is estimated that the existing live storage has been reduced to 2.3 million m^3 or 50%. With the reduced storage capacity in the reservoir it is expected that more frequent operation of the gates for control spilling will occur where the downstream population is at higher risk as shown in Figure 7. To study this condition, simple hydraulic analysis was used (Liu et al., 2006) [12]. The control discharge scenarios were selected as follows:

(*i*) Discharge of 4-5 m^3/sec during periodic flushing exercise

(*ii*) Discharge of 31.2 m^3/sec for full opening of hollow jet valve

(*iii*) Discharge of 65 m^3/sec for full opening of tilting gate located in spillway

(*iv*) Discharge of 300 m^3/sec for single radial gate opening located in spillway

(*v*) Discharge of 965 m^3/sec for full spillway opening including 3 radial gate and titling gate

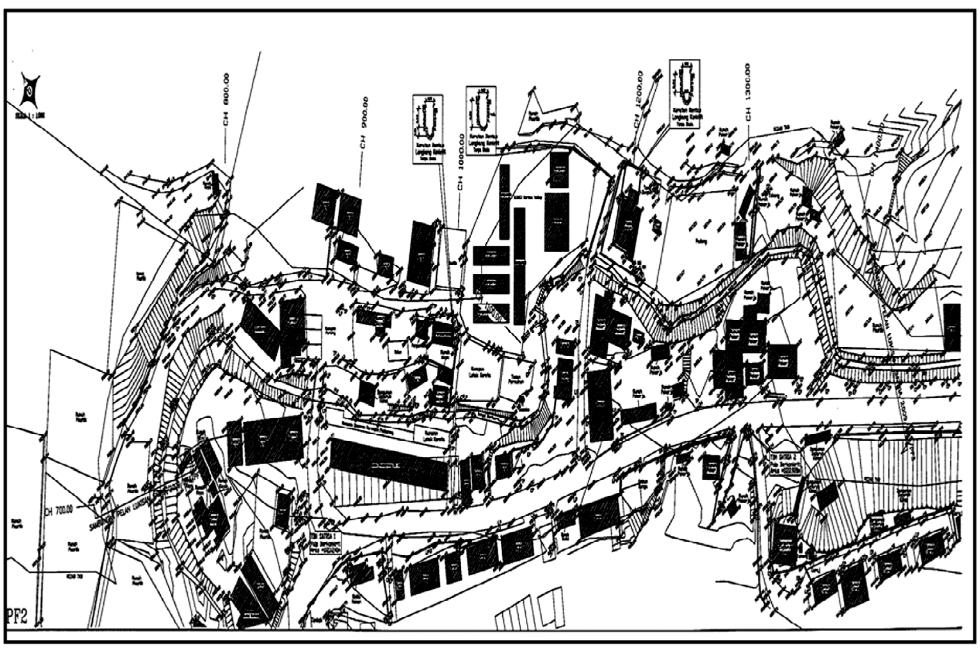

Figure 7: Topographic Map Showing Dense Population Occupying the River Reserves Downstream of Dam

The steady flow simulation model was used in which it assumes one-dimensional uniform flow (Berzi et al., 2003) [3], with Manning's roughness coefficient n of 0.029 which is earth canal excavated in alluvial silt soil, with deposits of sand on bottom and growth of grass (Chow, 1959) [6]. Mean value slope of is assumed at 0.002 and the mean side slope of 1 vertical to 3 horizontal.

12. RESULTS

The summary of the results is shown in Table 1. The water depths and top flow width was then incorporated in the flood inundation map at selected critical to see if a breach within the rivers banks had occurred.

Table 1
Summary Results of Flow Simulation Output for Various Flood Discharge Along Sg. Bertam

Original Bed Width				*2*	*m*			
Side Slope				*1*	*V*	*3*	*H*	
Manning, n				*0.029*				
Longitudinal Slope, S				*0.002*				
No.	*Depth of Water, y (m)*	*Bottom Width, b (m)*	*Horizontal Gradient, z*	*Wetted PerimeterP(m)*	*Top Width, T(m)*	*Area, A (m^2)*	*VelocityV* (m/s)*	*Discharge Q* (cumecs)*
1	0.50	2	3	5.2	5.0	1.8	0.8	1.4
2	1	2	3	8.3	8.0	5.0	1.1	5.5
3	2	2	3	14.6	14.0	16.0	1.6	26.2
4	3	2	3	21.0	20.0	33.0	2.1	68.9
5	4	2	3	27.3	26.0	56.0	2.5	139.4
6	5	2	3	33.6	32.0	85.0	2.9	243.3
7	6	2	3	39.9	38.0	120.0	3.2	385.2
8	7	2	3	46.3	44.0	161.0	3.5	570.0
9	8	2	3	52.6	50.0	208.0	3.9	802.0
10	9	2	3	58.9	56.0	261.0	4.2	1,086.0
11	10	2	3	65.2	62.0	320.0	4.5	1,425.0

*http://www.calctool.org/CALC/eng/civil/manning

From the results, at control release at 4-5 m^3/sec during flushing the depth of water would be 0.8 –1m and the total top width of flow is 7-8 m. At control release at 31 m^3/sec at full hollow jet valve opening, the depth of water would be 2-2.3 m and the total top width of flow is 15-16 m and at control release at 65 m3/sec of automatic tilting gates operation, the depth of water would be 2.5-3.0 m and the total top width of flow is 18-20 m. For a control release through one radial gate of 300 m^3/sec, the simulated depth of water would be 5.5-6.0 m. and the total top width of flow is 35-38 m. Finally at catastrophic flood discharge of 965 m^3/sec, where all gate is operated, the depth of water would be 8.5-9 m and the total top width of flow I downstream flood plain is simulated at 54-56 m. The discharge versus water level and discharge versus opt water width is shown in Figures 8 and 9, respectively.

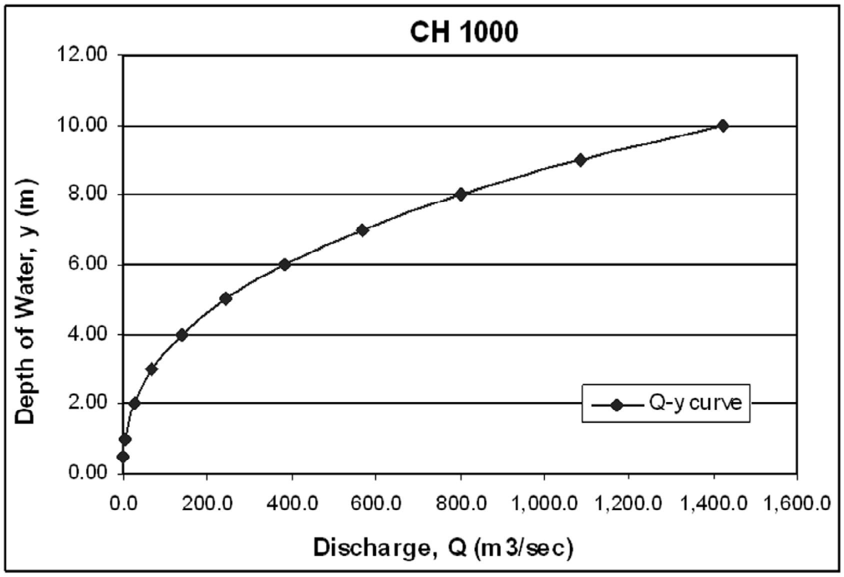

Figure 8: Discharge Against Depth of Eater Curve as Per Maximum Expected Control Release from Dam

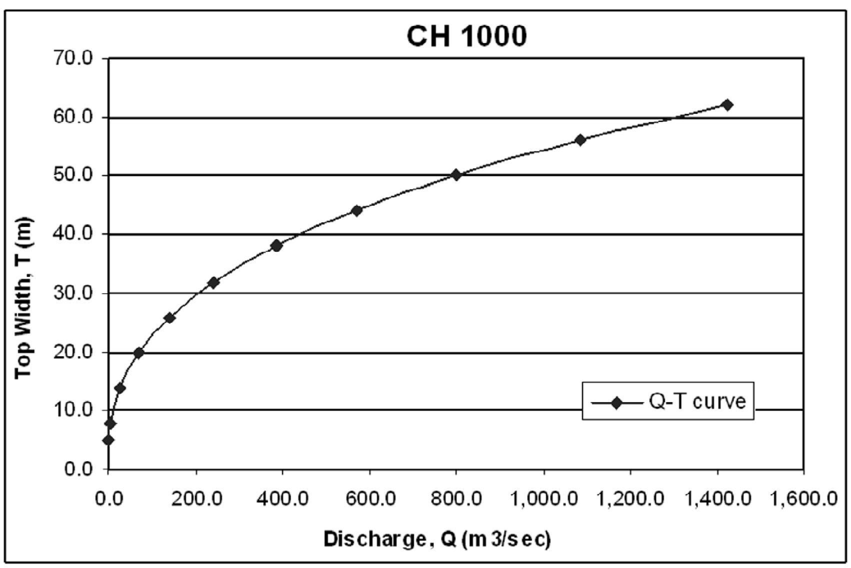

Figure 9: Discharge Against Top Width of Water Flow as Per Maximum Expected Control Release from Dam

From the steady flow simulation model output it was observed that area located within the flood plain close to the river bank will immediately flood even with a discharge of 4 m^3/sec. From the flow simulation, the flood inundation map was produced as shown in Figure 10 for discharge of 4 m^3/sec.

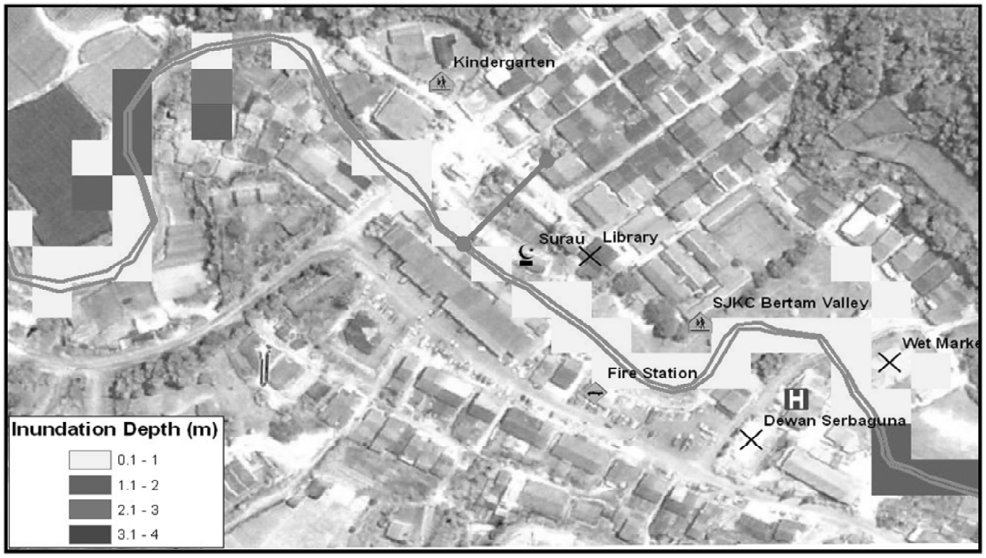

Figure 10: Model Inundations Map at Discharge of 4 m^3/sec Downstream of Dam

13. FIELD TEST

The field test was on 22 September 2011 to verify the simulated discharge flow at selected critical area downstream of the dam. Reservoir water was gradually released through the hollow jet valve located at the dam face as shown in Figure 11. The opening was gradually increased from 1 in (25.4 mm) to a maximum of 5 in (127 mm). Maximum discharge was monitored at 4 m^3/sec to prevent any flooding downstream. Figure 12 shows the almost breach of river bank flood at selected critical area near "surau" at CH 1000. Strict discharge limitation was however observed throughout the test to prevent any flooding at the predetermined critical area.

The field test confirms that even with small discharge of 4 m3/sec the downstream population and the structures located downstream are within the high risk zones of flooding. Therefore, a discharge of full opening of the gates at 965 m^3/sec would have catastrophic damage to the safety of the people located downstream (Francato et al., 2011) [8]. Another important question that is needed to be evaluated is, since the commissioning of the dam in the 1968 the dam has been classified as a large dam having a high downstream hazard. The once designated flood plain is now occupied by human population and activities. The original river reserve downstream at Sg. Bertam was gazetted in 1996 at 60 m from each bank providing at least a total river width for flood flows at 130 – 150 m. Present field inspection reveals that at certain location of only having 2-3 m of river width as shown in Figure 13 with structures such as temporary shed; "surau" and school build nearby the riverbanks.

Figure 11: Thick Concentrated Sludge Gushing out from Hollow Jet Valve at 2 in (5.1 cm) Opening.

Figure 12: Water Level Seen Almost Breaching the Base Level of Building Nearby. Depth of Water Recorded at 0.8 m at Discharge of 4 m^3/sec.

Figure 13: Water Level Gradually Increases Due to Restriction of Flow by Adjacent Structures and Bridge at CH 900

14. IMPLEMENTATION OF FLOOD RISK MITIGATION STRATEGIES

Field inspection revealed that downstream encroachment into the river reserve by horticulturalists has increased and the gazetted river reserve is no longer applicable and river beds looks merely as drains at several locations. This leads to a higher of risk flooding in the event of any release of water from the dam over that envisaged during the design of the dam.

Since the risk of flooding was identified, various flood mitigation strategies (Leon et al., 2012; Birkland et al., 2003, James and Korom, 2001) [11,4,9] were developed to reduce the impacts during flood events. Among the risk mitigation strategies includes:

(I) Non-Structural Measures/ Operational Measures

- Reservoir operation level control from 1070.76m – 1071.07m by overriding the radial gate automatic control for gradual release of flood waters.
- Increased present reservoir elevation flood buffer volume from 1068.02m – 1070.15m by continuous dredging and reservoir deepening.
- Initiating control spilling by operating radial gate at level above 1070.15m depending on reservoir level rise.
- Initiating controlled flood water release using hollow jet valve with maximum capacity of 36.5 m^3/sec.

- Longer operation of hydro plant in the event of large inflow and reduced live storage.
- Continuous meetings with the relevant local authorities and stakeholders to highlight the risk of downstream flooding and to put together a comprehensive land use and flood management plan.

(II) Structural Measures

- Proposed construction of widened downstream channel or U-drain for a length of 2 km downstream of dam to transfer flood waters safely from populated area by Drainage and Irrigation Department.
- Continuous dredging at reservoir, check dam and intake to increase storage capacity.

CONCLUSIONS

This study has shown that the loss of storage in reservoir due to sedimentation has direct impacts towards the sustainability of the reservoir and dam to operate for hydropower generation and to effectively contain the flood inflows. The revised storage-elevation curve developed shows that the peaking capability of the plant is greatly reduced due to the loss in storage volume and as a result control flood release is expected during high flood inflows.

Control flood release simulation model indicates that the existing river width is insufficient to contain the flood discharge. In such a case, flooding to the downstream population is anticipated at several critical areas. Survey results and the flood inundation map produced show that the downstream population has encroached into the river reserves and presently occupies up to a distance of 2 to 3km from the dam.

As a conclusion from the study, the control release of flood waters from the reservoir is a very real situation. Results from the scenarios tested indicate that the population downstream is at risk if such release occurs. Immediate implementation of both structural and non-structural flood mitigation strategies is therefore recommended to reduce the risk.

Acknowledgments

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