Bukit Merah Reservoir Sedimentation Assessment

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Abstract - Reservoir sedimentation is a serious problem because it leads to the loss of reservoir storage capacity. A sedimentation estimation study was carried out at Bukit Merah reservoir, sedimentation is expected to have occurred. The aim of this study are to estimated the sedimentation rate and determine the sedimentation pattern in Bukit Merah Reservoir. The 1965 and 1998 plans used in this study were converted to Digital Elevation Model (DEM) in the form of raster grid and Triangulated Irregular Network (TIN) format and were compared to identify changes of bed elevations and the sedimentation deposition in the reservoir. The largest changes from year 1965 to year 1998 occurred at the wider entrance of the reservoir, which is Kurau River. It was estimated that more than 10.3 million m$^3$ of sediment deposited in the reservoir between year 1965 to 1998. From the calculation, sedimentation rate between these two years was estimated around 0.3 million m$^3$ per year. It was only about 859m$^3$ per day. From the longitudinal distribution of sediment deposition along the reservoir, delta was evidently formed.

Keyword: Sedimentation, Bukit Merah Reservoir, Digital Elevation Model.

I. INTRODUCTION

The reservoir becomes a natural means for retention of transported sediment [1]. As a result of runoff from rainfall, soil particles on the surface of a watershed can be eroded and transported through the processes of sheet, rill, and gully erosion [2]. Once eroded, sediment particles are transported through a river system and are eventually deposited in a reservoir, river or sea.

Sedimentation problems often arise due to soil erosion processes in the catchments. Uncontrolled deforestation, grazing, improper method of tillage, an unwise agricultural and land use practices accelerate soil erosion resulting in a large increase of sediment inflow into streams. The deposition of sediment in channels or reservoirs creates a variety of problems, such as raising of stream beds, increasing flood heights, choking of navigation channels and, of course, depletion of capacity in storage reservoirs. It is accepted that reservoir sedimentation poses a serious threat to available storage [3]. It is estimated that 0.5-1.0% of the world reservoir volume is lost from sedimentation annually [4]. Some reservoirs have a much higher storage loss for example the Sanmenxia Reservoir in China losses about 1.7 yearly [3]. In actual fact, reservoir may complete fill with sediment even within just a few years [5].

Bukit Merah Dam was constructed in year 1906 and it is predictable that sedimentation happened since it is more than 100 years old. Unfortunately, no detailed studies and lack of data from relevant authorities makes it difficult to determine the impact of the mentioned activities. Nonetheless, the year 1965 and year 1998 bathymetry surveys make it feasible to determine sedimentation rate and pattern between these two years.

Main problem faced by Bukit Merah reservoir is its capacity had subsided. Decay rate of this reservoir is unascertained but from observation by Department of Irrigation and Drainage (DID) Kerian the estimated reservoir capacity only remained about 60-65%. Sedimentation and plant which are known as Bakong or scientifically called “Hanguana Malayana” has been identified as the main cause of the reservoir storage depletion. Uncontrolled development and land activities in catchments area accelerate sedimentation rate in reservoir. Use of fertilizers in agricultural activity also caused the plant growth rate increase and form large islands in reservoir area.

II. STUDY AREA

Bukit Merah Reservoir is the oldest manmade lake in Malaysia, located in the district of Kerian in Northern Perak State as shown in Figure 1. Bukit Merah Reservoir is situated at a longitude of 5°2’00” and latitude 100°40’00”. It has a length of about 13.8km and 4.5km width. The reservoir area is 33.3 km$^2$ with the maximum operation
depth of about 5.3m. Bukit Merah dam is an earth filled embankment constructed at the upstream of Kurau River and Merah River confluence in 1906. The main purpose of the reservoir is to provide irrigation water for double cropping planting intensity to Krian Irrigation Scheme. About 10,000 farmers with some 24,000Ha of paddy land are depending on this rice cultivation industry. In addition to the irrigation supply, it also provides some fresh water to meet the domestic and industrial demands to Kerian District as well as Larut Matang District.

III. RESERVOIRS SEDIMENTATION

Reservoir is an efficient sediment trap. When stream flow enters a reservoir, its velocity decreases and sediment can easily deposit. Normally, the location and amount of deposition depends on the detention storage time, the size and shape of reservoir, operating procedures, and other factors [6].

Comparatively, storage volume of Bukit Merah Reservoir is small and both the location of deposits and the loss of storage capacity are the concern. Reservoir sedimentation is an ongoing natural depositional process that can remain invisible for a significant portion of the life of the reservoir [7].

IV. SEDIMENTATION ANALYSIS

In this study, the bathymetry survey plans were provided by the Department of Irrigation and Drainage (DID) Kerian for the year 1965 and 1998. The 1965 plan was in hard copy (image) and 1998 was in the digital format (AutoCAD). Processing of 1965 plan involved scanning the image and using ArcGIS to rotate, rescaling, and georeferencing the image to match the actual size and position. Contour polylines were then traced from the processed image. The year 1998 plan only involved georeferencing process. These data were then converted to Digital Elevation Model (DEM) in the form of raster grid and Triangulated Irregular Network (TIN) format. Figure 2(a) and Figure 2(b) show the transformation of survey plan to georeferenced DEM.

The bathymetry survey of years 1965 and 1998 covering the same geographic area were compared to identify changes of bed elevations and the sedimentation deposition in the reservoir. This analysis was presented by color coded to determine the amount of changes. Areas shaded with orange color indicate the significance of sediment deposition. Areas with no overlapping data remained green, as shown in figure 3. The larger changes from year 1965 to year 1998 occurred at the wider entrance of the reservoir, which is Kurau River. The accuracy of these maps may affected by the density of the data coverage. Due to inaccurate bathymetric survey, certain points especially around Merah River catchment area can be neglected.

As compared to Merah River catchment, Kurau River catchment area is 83.31km² while Merah River catchment area is only 4.25km² as shown in figure 4. Kurau River sub-catchment also has more activities based on 2007 satellite image. There were widespread land use activities. Although the catchment area is not urbanized but the oil palm, rubber plantation also goat and cow farm can induce soil erosion. By clearing away the natural forest or any vegetated area it would increase the surface runoff to the river. This will decline the water quality of the river and bring along substantial amount of sand or silt to the reservoir. It can be conclude that Kurau River system supply higher sediment rate than Merah River system.

V. SEDIMENTATION PATTERN

Method of sediment deposition analysis in the Bukit Merah Reservoir was based on the comparison of bathymetry survey in year 1965 and 1998 to estimate the sediment volume. Reservoir capacity was simply calculated using Arcview GIS 3.3 application in TIN format under area and volume statistic. The base height will be calculated as 8.5m based on the normal operation level of Bukit Merah Reservoir. From a comparison of year 1998 reservoir volume with the year 1965, it was estimated that more than 10.3 millions m³ of sediment deposited in the reservoir.

Based on the volume of accumulated sediment between year 1965 to 1998 rate of sedimentation per year can be compute as below.

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\text{Rate of sedimentation per year} = \frac{\text{Sediment Volume}}{\text{Years}}
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From the calculation, sedimentation rate between these two years was estimated around 0.3 million m³ per year. It was only about 859m² per day. This is the rate after more than 60 years of operation. The rate was considered low because there is a decrease in sedimentation rate with time. This phenomenon can be explained by the fact that as time passes a decrease in the reservoir storage capacity occurs, flow velocities for the same discharges are increased, the sediment carrying capacity of the flow being the limiting factor of sediment is in turn increased [8].

There are several depositional pattern identified by Morris [9]. The patterns depend on the inflowing sediment characteristics and reservoir operation.

The four basic types of deposition pattern are listed below:

1. Delta deposits contain the coarsest fraction of the sediment load which is rapidly deposited at the zone of inflow. It may consist entirely of coarse sediment (d>0.062) or may also contain a large fraction of finer sediment such as silt.

2. Wedge-shaped deposits are thickest at the dam and become thinner moving upstream. This pattern is typically caused by the transport of fine sediment to the dam by turbidity currents. Wedge-shaped deposits are also found in small reservoirs with a large inflow of fine sediment, and in large reservoir operated at low water level during flood events, which causes most sediment to be carried into the vicinity of the dam.

3. Tapering deposits occur when deposit become progressively deposition of fines from the water moving towards the dam.
4. Uniform deposits are unusual but do occur. Narrow reservoir with frequent water level fluctuation and a small load of fine sediment can produce nearly uniform deposition depths.

Based on the TIN generated from the 1965 and 1998 bathymetry surveys, a longitudinal profile (cross the long axis, line A-A) was plotted for both TIN layers as shown in figure 2a and 2b. The lines created at the reliable occurrence of sedimentation based on the elevation range from year 1965 to 1998. After creating the lines, by using PE 6.0 3D Analyst extension, data will be analyzed and transform into graph using Microsoft Office Excel.

From figure 5, longitudinal profile for 1965 and 1998 survey indicated a generally smooth, low relief floor sloping gently from the headwater to the reservoir. The sediment was deepest in the middle part and delta was evidently formed after cross section of 1500. This pattern looks similar to the delta depositional pattern illustrated by Morris and Fan [9] in figure 6 below.

VI. CONCLUSION AND RECOMMENDATION

The loss of reservoir storage due to reservoir sedimentation can be considered as a serious threat to reservoir performance. Result visualized in Arcview indicated that Kurau River contributed most of the sediment in Bukit Merah Reservoir. From the sedimentation pattern, Kurau River contributed more sedimentation than Merah River. High deposited volumes along Sungai Kurau channel believe to be caused by uncontrolled land use activities from upstream.

Sedimentation issues have to be taken into account when implementing the landuse and development plan surrounding the reservoir area in order to control sedimentation in Bukit Merah Reservoir. It is also advisable to construct bank protection structures at the outlet to decrease the erosion problem which will lead to deposited sediment. Flow conditions in the reservoir also need to be created and stabilized to control the deposition of sediment. In this case, it can help to extend the reservoir life.

Reservoir sediment accumulation can be approximately theoretical. However, an accurate reservoir sedimentation survey is the best way to monitor the current reservoir sedimentation, future sediment inflow and also the deposition analysis. Result from the survey is beneficial for planning future reservoir.

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Figure 1: Bukit Merah location

Figure 2: a) Transformation of 1965 plan from hard copy to georeferenced DEM, b) Transformation of 1998 plan from digital format (AutoCAD) to georeferenced DEM

Figure 3: Sediment deposition area

Figure 4: Kurau River and Merah River catchment area
Figure 5: Delta pattern resulting from cross section analysis

Figure 6: Delta depositional pattern [8]