DETERMINATION OF BUKIT MERAH RESERVOIR CAPACITY USING SEQUENTIAL PEAK ANALYSIS

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By

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ABSTRAK

Tasik Bukit Merah atau Takungan Bukit Merah adalah tasik buatan manusia pertama di Malaysia yang terletak di utara Perak dan dibina pada tahun 1906. Memandangkan struktur empangan sudah lama, ia akan menjejaskan fungsinya keberkesanannya dan terdapat masalah yang berkaitan dengan kapasiti penyimpanannya. Bagi kajian kes ini, penentuan kapasiti simpanan Takungan Bukit Merah adalah langkah penting untuk memelihara simpanan airnya yang mempengaruhi semua perkara asas penting seperti pengairan, domestik dan tebatan banjir. *Sequent Peak Algorithm* ialah teknik yang direka untuk menganggarkan saiz kapasiti aktif dengan menjejak aliran masuk dan aliran keluar dalam selang waktu. Ia adalah kapasiti penyimpanan minimum yang diperlukan untuk takungan adalah sama dengan maksimum defisit yang berlaku dalam tempoh yang ketat dan masa tertentu. Malah, *Sequent Peak Analysis* dipilih sebagai mudah untuk diprogramkan, sesuai dengan data yang besar dan mempertimbangkan kehilangan sejatan berbanding kaedah lain iaitu *Mass Curve Method*. Takungan diandaikan penuh semasa permulaan musim kering. Di samping itu, isu pencerobohan haram dan aktiviti penerokaan menyebabkan pengurangan kapasiti penyimpanan kerana pemendapan terkumpul akibat air larian yang berlebihan. Kadar sejatan yang tinggi turut menyumbang kepada masalah ini terutamanya fenomena El-Nino yang berlaku pada tahun 2016. Kajian ini menyimpulkan bahawa Takungan Bukit Merah tidak mencukupi untuk menampung pengairan dan bekalan domestik serta tebatan banjir. Permintaan air semasa adalah pelepasan yang tinggi berbanding kapasitinya (92.8 MCM). Penentuan kapasiti takungan adalah bahagian penting dalam projek pembangunan sumber air dan mengekalkan keperluan dalam tempoh jangka panjang.

ABSTRACT

Bukit Merah Lake or Bukit Merah Reservoir is the first man-made lake in Malaysia located in the north of Perak which was built in 1906. Since the structure of the dam is aging, it would affect its effective function and some of the problems introduced regarding storage capacity. For this case study, determination of Bukit Merah Reservoir storage capacity is the crucial step for preserving its water storage which influenced all the essential basic things such as irrigation, domestic and flood mitigation. A sequent peak algorithm is a technique designed primarily to estimate the size of active storage by tracking the inflows and outflows over an interval. It is the minimum storage capacity which is required for a reservoir to have been equal to the maximum of the deficit that occurs in a strict during a given period. The Sequent Peak Analysis is chosen because it is easy to program, suits with large data and considers evaporation losses compared to other methods which is Mass Curve Method. The reservoir is assumed to be full during the beginning of dry period. In addition, the issue of illegal encroachment and exploration activities led to reducing of storage capacity as sedimentation accumulated due to excess runoff. High rate of evaporation also contribute to this problem as there was El-Nino phenomenon occur in year 2016. It was concluded that Bukit Merah Reservoir is insufficient to accommodate irrigation and domestic supply as well as flood mitigation. The current water demand is high release compared to its capacity (92.8 MCM). Determining reservoir capacity is an important part of water resources development projects and sustains the needs in such a long-term period.

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LIST OF ABBREVIATIONS

DID	Department of Drainage and Irrigation
CP	Critical Period
MCM	Million Cubic Meter
Cusec	Cubic feet per second
Cumec	Cubic meter per second
FRL	Full Reservoir Level
MWL	Maximum Water Level
SPA	Sequential Peak Analysis
Col.	Column

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Definition of Dam and Reservoir

J. Thornton et al., 1992, 1996 stated that the term “dam” is meant by a physical structure where it is constructed on a river to retain water for one or more purposes whereas the term “reservoir” is the water body generated by a dam. Practically, these two terms are used interchangeably. In fact, the reservoir can be seen as a water body consisting of an embankment or a dam, and operate to provide specific community demands.

A reservoir's storage capacity is divided into a number of zones based on the practical functions it is required to serve. The various storage zones of a reservoir are depicted in Figure 1.1. The bottommost zone of a reservoir is known as the dead storage zone. The conservation zone takes up a significant amount of storage space. The flood control storage is situated above the conservation zone overlaid by the surcharge storage if the reservoir is used to regulate floods. The following process for determining the size of various storage zones is described in the following section.

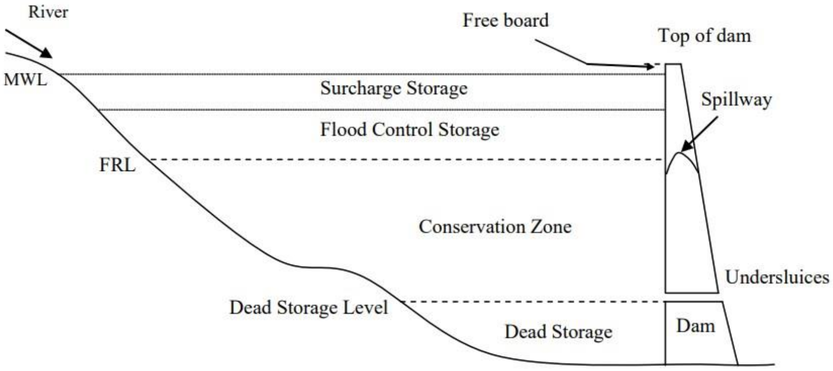

Figure 1.1: Storage Zones of Reservoir

1.1.2 Control Level of Reservoir

FRL: full reservoir level

It is the highest water level whereas the water surface will surge during regular operating conditions.

MWL: Maximum water level

It is the maximum level whereas the water surface will increase when the design flood exceeds the spillway

Minimum pool level

It is the lowest level up whereas the water is withdrawn from the reservoir under normal conditions.

Dead Storage

Dead storage refers to the volume of water stored below the pool's minimum level. It is designed to handle sediment deposition caused by impounding sediment in the water. It is usually equal to the volume of sediment projected to be deposited in the reservoir over the reservoir's design life.

1.1.3 Critical Period Techniques

Human have traditionally attempted throughout history to meet their freshwater needs from rivers and also the situations where the rivers were unable to meet demand with natural flow volumes. Therefore, they devoted to the method of creating storage. The timing of a scheduled stream, such as energy generation, storage, and transit, might be erratic. This may differ from the amount of time required for the amount of water needed for such reasons.

Storage reservoirs on rivers are being created to improve this imbalance. In addition, based on the flow rate which changes over time, it is required to establish the optimum volume of storage reservoirs to fulfil the needs. The wettest time is known as the river's natural flow exceeds demand while the dry season is occurred when the demand exceeds the natural flow (Alrayess, et al., 2017). On rivers, reservoirs are built to meet water demand during seasons when inflow is less than demand.

Reservoir hydrology is concerned with determining the storage capacity needed to sustain a yield with a particular chance of failure. The early methodologies of storage-yield analysis were those based on critical period (CP) principles. This CP defined as scarcity based on demand, is also crucial in determining the reservoir volume. (Aksoy, 2001; Oğuz & Bayazıt, 1991). The critical period (CP) is the time it takes for an initially full reservoir to empty after passing through several conditions (without spilling). The Mass Curve Approach, for example, was the first rational method for calculating a reservoir's required storage capacity. The Sequent Peak Method is another prominent method in this group.

1.1.4 Overview on Mass Curve Method and Sequent Peak Algorithms

The mass curve approach is the most common and well-known method for estimating reservoir size. It was created in 1883 by W. Rippl. The plot of cumulative inflow versus time is called a mass inflow curve, while the plot of cumulative demand versus time is called an outflow curve. This technique will be effectively works if the rate of outflow is constant. As a result, the mass curve approach entails calculating the biggest positive difference between the sequences of outflow and inflow, as well as the maximum deficit volume connected with inflow and outflow, to determine the reservoir's needed capacity. When dealing with data over a short period of time, the mass curve approach is appropriate. Seasonality, autocorrelation, and other flow factors are used in the analysis steps since they are contained in the historical flows. In fact, this method relatively basic and commonly known.

When analysing huge data sets with the aid of a computer, the sequent-peak algorithm is preferred. It compensates for some of the imperfections in the mass curve method. The cumulative values of inflow minus withdrawals are calculated using this method. Evaporation and seepage losses from the reservoir should be included in the withdrawals, despite the fact that they are known to be dependent on the reservoir's storage level. The highest difference between a peak and the lowest trough that follows that peak is the required storage for the observation period. It was offered as a way to avoid having in choosing the correct starting storage, which is required in the mass curve approach. The calculations are straightforward.

The Rippl diagram and the sequent-peak algorithm both provide single estimates of the reservoir capacity needed to meet demand during a particular drought. This case study involved only sequential peak analysis to estimate minimum storage capacity to meet a specified pattern, facilitate graphical plotting and analysis of large data with help of a computer.

1.2 Problem Statement

For thousands of years, dams have been utilised to conserve water for use in domestic, industrial, and agricultural applications. Additionally, hydroelectric dams serve as an alternative to non-renewable energy sources, which account for the vast majority of the world's energy. For rice farmers in the Kerian District, Bukit Merah was iconic due to its high harvest and later double-cropping.

However, as the reservoir ages, its condition could deteriorate or encounter issues. Due to its age and low water capacity, Bukit Merah Reservoirs, one of Malaysia's older reservoirs, are currently having serious issues supplying and controlling water to the Kerian district. This problem was influenced by reservoir sedimentation and siltation.

One of the biggest hazards to river ecosystems around the world is silt sedimentation. The reservoir's ability to store water will automatically decrease as sediment is deposited, and if the process of deposition continues for an extended period of time, a point may be reached when the entire reservoir may become silted up and unproductive (Garg, 2009). In order to give a pool enough volume to complete a stipulated design life, many were designed by estimating sedimentation rates. This design life, however, is often far shorter than what is actually feasible. As a result, reservoir management is crucial to achieving a complete sediment balance in order to extend their lifespan.

Furthermore, encroachment and illegal farming practises in the Bukit Merah Lake Reserve could lower the lake's water level, which would impair the irrigation of 24,000 hectares of rice paddies in the Kerian District and South Seberang Prai, Penang. This illegal activity exposes the land surface to excess surface runoff during heavy rainfall which resulting sedimentation.

Besides that, the impact of climate changes may disturb hydrological and biological process. It is a global argument that has an impact on the dams' role and safety in Malaysia. Extreme weather circumstances, such as heavy rain, will have an impact on the dams' potential to handle the increased water level. The release of water from dams is a common cause of flash floods in Malaysia. In addition, the dam overflowed due to heavy rains. Simultaneously, urban development is causing river and drainage system flow to be disrupted which led to floods event as a result of climate change. Climate change had an impact on the dam even when the weather was dry. According to the Department of Irrigation and Drainage (DID), water retention will be occurred due to hot and dry weather, which causes practically all major dams across the country to shrink.

If climate change creates higher water temperatures in lakes and estuaries, eutrophication concerns will worsen. Eutrophication lowers zooplankton's capacity to manage algae by allowing blue-green algae to take over, which is more difficult to feed on and digest. As a result, climate change and eutrophication will impair zooplankton's ability to manage algae, increasing the risk of dangerous blooms. Even low amounts of nutrient enrichment can cause such plant loss at higher temperatures. And yet again, the combination of nutrient enrichment and climate change exacerbates eutrophication issues.

In addition, surface evaporation may reduce amount of water reservoir. The evaporation is the transformation of a liquid into a gas. Water molecules are constantly moving, and some of them have enough energy to break through the water's surface and escape as vapour into the air. Evaporation is a useful process in controlling global water balance through the hydrological cycle, but it is also a factor in large losses from water bodies.

The loss of key water supplies due to evaporation from reservoirs is significant. The annual loss of water from storages due to evaporation could be as high as 40% of the total amount held. Water scarcity reduces agricultural production, putting some farmers under financial strain, especially during droughts. Water restrictions are often placed on metropolitan areas due to low water levels.

1.3 Objective

The main objectives of this study are:

1. To determine reservoir capacity using sequent peak algorithms using critical period technique.
2. To evaluate sufficiency in capacity of Bukit Merah reservoir needed for flood mitigation, irrigation, drought, domestic and other requirements.

1.4 Scope of Research

- Sequential Peak Algorithm method was used to determine the reservoir capacity
- The data required to perform this analysis is the data of water inflow and outflow of the Bukit Merah dam in addition to references from the schedule of irrigation and water supply required by the Lembaga Air Perak.
- The 5 years data from 2016 to 2020 was obtained from the Drainage and Irrigation Department Kerian.

1.5 Dissertation Outline

This dissertation has five chapters and the brief outlines of this dissertation are as follows:

Chapter 1 is an introduction on the dam and reservoir, control level of reservoir, critical period techniques, overview on Mass Curve Method and Sequent Peak Algorithm. This chapter also discussed about the problem statement, objective and scope of research.

Chapter 2 basically presents the literature review and related previous study of Sequential Peak Analysis, Inflow and Outflow, rainfall variability in Kerian District

Chapter 3 describes the methodology of the study. The technique applied to determine the Bukit Merah Reservoir capacity and data collection of this research are also discussed in this chapter.

Chapter 4 discussed on the results obtained from the data analysis by using Excel Programme and graphical plotting.

Chapter 5 presents conclusion on the study and provide some appropriate recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed on the previous research that have been done related to analysis of reservoir storage capacity using chosen method, Sequent Peak Algorithms. The previous studies will also be the references and additional knowledges for this research.

2.2 The Term of Reservoir

The word "reservoir" comes from the French word "reservoir," which meaning storage facility or known as storehouse. A reservoir is built with the goal of storing water that can be used for a variety of reasons. A reservoir can be found naturally or created artificially by stocking water in a dam or bar. At times, demand for water may be less than total inflow (at times of surplus flow), and at other times, demand may be higher than inflow (at periods of low flow), resulting in a demand-supply imbalance. Reservoirs are built with the goal of balancing excess and deficit inflow periods. Reservoirs retain or preserved water during periods of high-water flow to prevent flooding, and when natural water flow is insufficient to meet water demands, water is released. As a result, we may state that "a reservoir is a water storage facility that can meet a specific level of demand during periods of surplus water flow (Kohli, Garg and Dhawan, n.d.).

2.3 Critical Period Technique

The critical period (CP) is defined as the time it takes for a reservoir to go from full to empty without spilling in between (Mcmahon & Mein, 1986). If the deficit between the low inflow and the water demand placed on the reservoir system is to be satisfied, the CP denotes a period of severe low flows in the data record for which storage is required in the reservoir (Montaseri & Adeloye, 1999).

2.3.1 Mass Curve Method

The flow-mass curve is a plot of cumulative discharge volume vs time shown in chronological order. Where t_o is the time at the beginning of the curve and Q is the discharge rate, the ordinate of the mass curve is V at any time t. It is easy to observe that the mass curve is an integral curve (summation curve) of the hydrograph because it is a plot Q versus t. After Rippl (1982), who firstly proposed it used, this method is known as Rippl's mass curve (Subramanya, 2008)

$$V = \int_{t_o}^{t} Q \, dt \tag{2.1}$$

For reservoir design, water resources engineers typically employ the Rippl mass curve approach or the sequent-peak algorithm. The cumulative charting of net inflow to the reservoir is depicted in the Rippl diagram (Figure 2.1). The inflow is measured by the slope of the mass curve at any given time. A straight line reflects demand in the situation of a uniform rate of demand. The maximum deviation between the demand line and the mass curve gives the reservoir capacity required to supply the demand when the reservoir is assumed to be full anytime a demand line intersects the mass curve (Aksoy, 2001)

As a result, the mass curve approach entails estimating the biggest positive difference between the sequence of outflow and input, as well as the maximum deficit volume connected with inflow and outflow, to determine the reservoir's needed capacity (Kohli, Garg and Dhawan, n.d.).

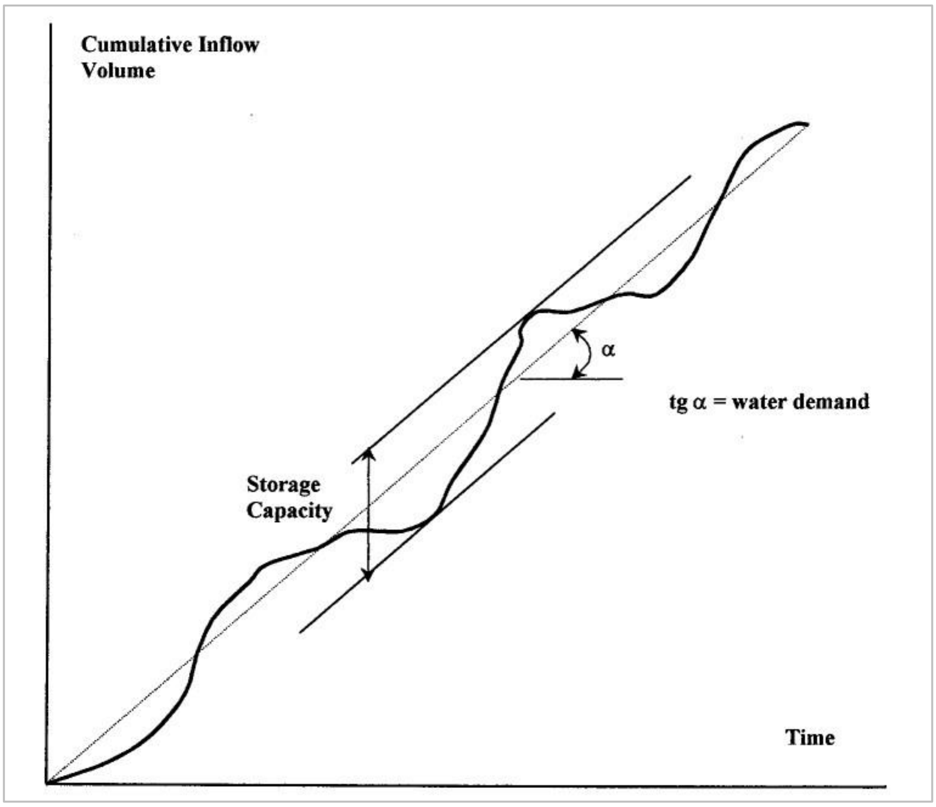

Figure 2.1: Example of Mass Curve Method (Aksoy, 2001)

2.3.2 Sequent Peak Algorithms

Sequent peak analysis is a modified type of mass curve analysis that works well with inflow data over a long period of time. The rule is the same in the sequent peak algorithm as well. The maximum deficit is estimated after capturing the critical period (period when the maximum deficit occurs).

The cumulative values of inflow minus withdrawals are calculated using this method. Evaporation and seepage losses from the reservoir should be included in the withdrawals, despite the fact that they are known to be dependent on the reservoir's storage level. The biggest difference between a peak and the lowest trough that follows that peak is the required storage for the observation period as shown in Figure 2.2 (Aksoy, 2001).

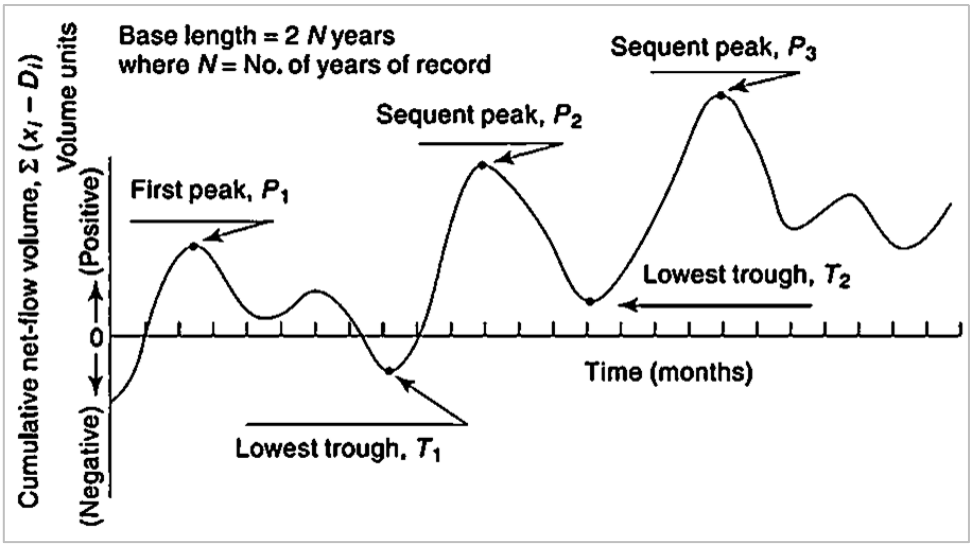

Figure 2.2: Example of Sequent Peak Analysis (Subramanya, 2008)

2.4 Utility and Limitations of Mass Curve Method

The plot of cumulative inflow versus time is known as a mass inflow curve, and the plot of cumulative demand versus time is known as an outflow curve. When the rate of outflow is consistent, this approach performs effectively. Therefore, the maximum deficit volume associated with inflow and outflow is the required reservoir capacity, and the mass curve approach comprises the assessment of the biggest positive difference between the sequence of outflow and input and the maximum deficit volume (Katyal, n.d). There are some restrictions attached to this approach.

Reservoir release or outflow must be constant and this is not accurate for monthly interval as demands are often seasonal. The storage capacity predicted via mass curve processes increases as the length of the record rises. As a result, relating storage size to economic life is more challenging. Besides that, this method is not possible to calculate a storage size for a given probability of failure. Evaporation and other losses that depend on level in reservoir cannot be factored into analysis. In addition, this technique assumes that future hydrology is like the past and another approach uses deficit analysis and addresses some of these issues (Katyal, n.d).

The mass curve has the additional flaw of not allowing for economic analysis. The size of the storage cannot be correlated with the project's economic lifespan, and estimates of the storage typically increase as record lengths are used. Furthermore, the storage size cannot be calculated for a specific reliability level (Jain, n.d.)

The mass curve approach has several advantages. The method's simplicity and ease of use are its key strength. These may be the factors contributing to its widespread use and popularity when small time period data is taken into account.

2.5 Utility and Limitations of Sequent Peak Analysis

The critical period (the period during the largest deficit occurs) is recorded and the maximum deficit is estimated in the subsequent peak analysis. In order to determine the largest of these collective deficits, the approach first calculates the maximum collective deficit over a succession of subsequent critical times. Large data sets may contain critical periods towards their conclusion, in which case it would be necessary to take into consideration the assumption that the inflow sequence will return in the future.

The sequential peak algorithm approach has a number of drawbacks because it was designed to work with copies of created data rather than a single historical record. In contrast to the mass curve approach, it may handle variable draughts as long as they can be stated without consideration of the reservoir content. However, it is also limited to the calculation of capacities that satisfy the rank 1 low flow sequence. A likelihood of failure can be indirectly obtained by using created flows. Some drawbacks of the subsequent peak algorithm technique include the exclusion of evaporation losses and the algorithm's incapacity to adjust to multi-reservoir systems (Katyal, n.d)

Therefore, Sequential Peak Analysis (SPA) would be the preferable way to determine Bukit Merah Reservoir storage capacity as it adapt with a lot of large data set and easy to program.

2.6 Factor influence on reduction in storage capacity

Problem related that dealing with nature will always face over the entire time and there are several issues that affect water storage in reservoir;

2.6.1 Sedimentation and Siltation in Reservoir

Sedimentation is the process of soil particles being eroded and transported by running water or other transportation media, then deposited as layers of solid particles in water bodies like reservoirs and rivers (Tundu et al., 2019). It could be the result of rainwater runoff eroding soil particles through the sheet, rill, and gully erosion processes. This mechanism is a complicated process that varies depending on the amount of sediment in the watershed, the rate of movement, and the form of deposition (Ezugwu, 2013).

Soil erosion processes in catchments can lead to sedimentation issues. Deforestation, grazing, incorrect tillage, and other imprudent agriculture and land use practices promote soil erosion, resulting in a significant increase in sediment influx into streams. Deposition of silt in channels or reservoirs causes a number of issues such as increment stream bed elevation, increased flood heights, clogging of navigation channels, and depletion of storage reservoir capacity. Reservoir sedimentation is widely acknowledged as a severe risk to available storage. Sedimentation is predicted to lose 0.5-1.0 percent of the world reservoir volume each year. In reality, the reservoir could be completely filled with sediment within a few years.

The major issue with the Bukit Merah reservoir is that its capacity has reduced. The rate of decay is unknown, however according to Department of Irrigation and Drainage (DID) Kerian's observations, the estimated reservoir capacity is only 60-65 percent. The main cause of reservoir storage depletion has been recognised as sedimentation and the existing plant known as Bakong or scientifically known as "Hanguana Malayana."

The rate of sedimentation in reservoirs is accelerated by uncontrolled development and land activities in catchment areas. Fertilizer use in agricultural operations significantly increased plant growth rates. Thus, resulting in the formation of enormous islands in reservoir area.

Despite the fact that catchment area is not urbanised, occurrence of soil erosion can be caused by oil palm, rubber, goat, and cow farms. The surface runoff to the river would be increased by destroying the natural forest or other vegetated region. The river's water quality will deteriorate, and a significant amount of sand or silt will be carried into the reservoir.

Sedimentation reduces reservoir storage capacity and life span, as well as river flows (Eroglu et al., 2010). As a result, it is required to address silting to ensure that capacity never falls short of requirements over the design period. The total volume of silt predicted to be deposited during the dam's designed life time is calculated, and a portion of that volume is left unused to allow for silting, which is referred to as dead storage. Effective storage, sometimes known as live storage, is the name given to the reminder. The amount of dead storage varies between 15 and 25% of the total capacity (Obiolor et al.,2019)

2.6.2 Climate Changes

Climate change had an impact on the dam even when the weather was dry. According to the Department of Irrigation and Drainage (DID), water retention will be occurred due to hot and dry weather, which causes practically all major dams across the country to shrink.

Climate change is a global issue that has an impact on the dams' function and safety in Malaysia. Extreme weather circumstances, such as heavy rain, will have an impact on the dams' ability to handle the increased water level. The release of water from dams is a common cause of flash floods in Malaysia.

The Klang Valley, for example, is prone to flash floods induced by dam overflow. La Nina, according to the Malaysian Meteorological Department, is to blame for three of East Malaysia's wettest years on record (1984, 1988, and 1999). A La Nina episode resulted in increased rainfall and flooding. The dam overflowed due to heavy rains. At the same time, urban development is causing river and drainage system flow to be disrupted. Finally, floods are a result of climate change. The drop in the dam water level has been influenced by the extremely hot and dry weather (Ismail, 2014)

2.6.3 Illegal Encroachment and Exploration of the Bukit Merah Lake reserve

Sahabat Alam Malaysia (SAM) found that part of the Bukit Merah Lake Reserve has been encroached and explored illegally with oil palm plantations for more than fifteen years and now the situation is becoming more worrying. These kinds of activity give the bad impacts towards environment and may lead to the deterioration of the water level of Bukit Merah Lake which in turn affects the irrigation of paddy fields in Kerian District, Perak and south Seberang Perai, Penang amounting to about 24,000 hectares.

The exploitation and destruction of the Bukit Merah Lake Reserve (conversion from forest land uses and natural land areas to other land uses) significantly exposes the land surface to excess surface runoff during heavy rainfall. This will result in sedimentation and accumulation of sediment as well as other transport at the bottom of Tasik Bukit Merah (Sahabat Alam Malaysia, 2016).

2.6.4 Rainfall Variability

Climate change has also been reported to have a significant impact on rainfall occurrences (Kumar et al., 2010). Due to rainfall unpredictability, there are many extreme occurrences have occurred in the last 10 - 12 years (Ghosh et al., 2012). Soil erosion and sedimentation are heavily influenced by these catastrophic events.

Rainfall variability is primarily concerned with kinetic energy changes and is proportional to rainfall intensity. Changes in rainfall intensity impact runoff, soil particle detachment, erosion, and transport, all of which affect a stream's sedimentation production. Changes in climatic conditions have a significant impact on numerous aspects of the hydrological system, such as a drop in the number of rainy days and an increase in extreme events, resulting in increased erosion and, as a result, increased sediment movement. Increases in rainfall intensity and decreases in wet days have been observed to increase the sedimentation rate of reservoirs.

2.6.5 Surface Evaporation

Annual loss of water from storages through evaporation can potentially exceed 40 per cent of water stored (Dawood et al., 2014). Evaporation is the transformation of a liquid into a gas. Water molecules are constantly moving, and some of them have enough energy to break through the water's surface and escape as vapour into the air. Evaporation is a useful process in controlling global water balance through the hydrological cycle, but it is also a factor in large losses from water bodies. (Based on Status Report on “Evaporation Control in Reservoirs” from Basin Planning and Management Organisation, New Delhi, 2006).

The evaporation of water from open water surfaces is influenced by a number of factors, the most important of which are;

2.6.5(a) Temperature

The rate of evaporation is affected by the temperature of the water and the air above it. Temperature affects the rate at which molecules are emitted from liquid water. The rate of evaporation increases as the temperature rises.

2.6.5(b) Wind Effect

The more the air movement above the water, the more water vapour is lost. Experiments on the relationship between wind speed and evaporation have shown that the two have a direct relationship up to a particular wind velocity, after which the relationship may break down. Surface roughness and the size of the water body have been reported to play a significant influence.

2.6.5(c) Water Surface Area

Evaporation is a surface process, hence the amount of water lost through evaporation from stored water is exactly proportional to the amount of its surface exposed to the atmosphere.

2.6.5(d) Atmospheric Pressure

Other factors affecting evaporation are inextricably linked to atmospheric pressure. As a result, evaluating its impact independently is challenging. With increasing pressure, the quantity of air molecules per unit volume increases. As a result, when the pressure is high enough, vapour molecules departing from the water surface are more likely to collide with an air molecule and rebound into the liquid. Hence, evaporation is anticipated to decrease as pressure rises.

2.6.5(e) Quality of Water

The rate of evaporation is affected by the amount of salt in the water. Experiments reveal that as the salt content of water increases, the rate of evaporation reduces. When all other conditions are equivalent, the evaporation rate of sea water is 2 to 3 percent lower than that of fresh water.

2.6.5(f) Vapour Pressure Difference

The rate at which molecules exit the surface is determined by the liquid's vapour pressure. Likewise, the rate at which molecules enter water is determined by the air's vapour pressure. The difference between the saturation vapour pressure at the water temperature and the dew point of the air determines the rate of evaporation. The greater the difference, the more evaporation occurs.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents on the details of the methodology process. Methodology is an important part in achieving the goal and objectives as discussed in Chapter 1. Thus, the approaches and method are applied to obtain the results and will be explained in this chapter.

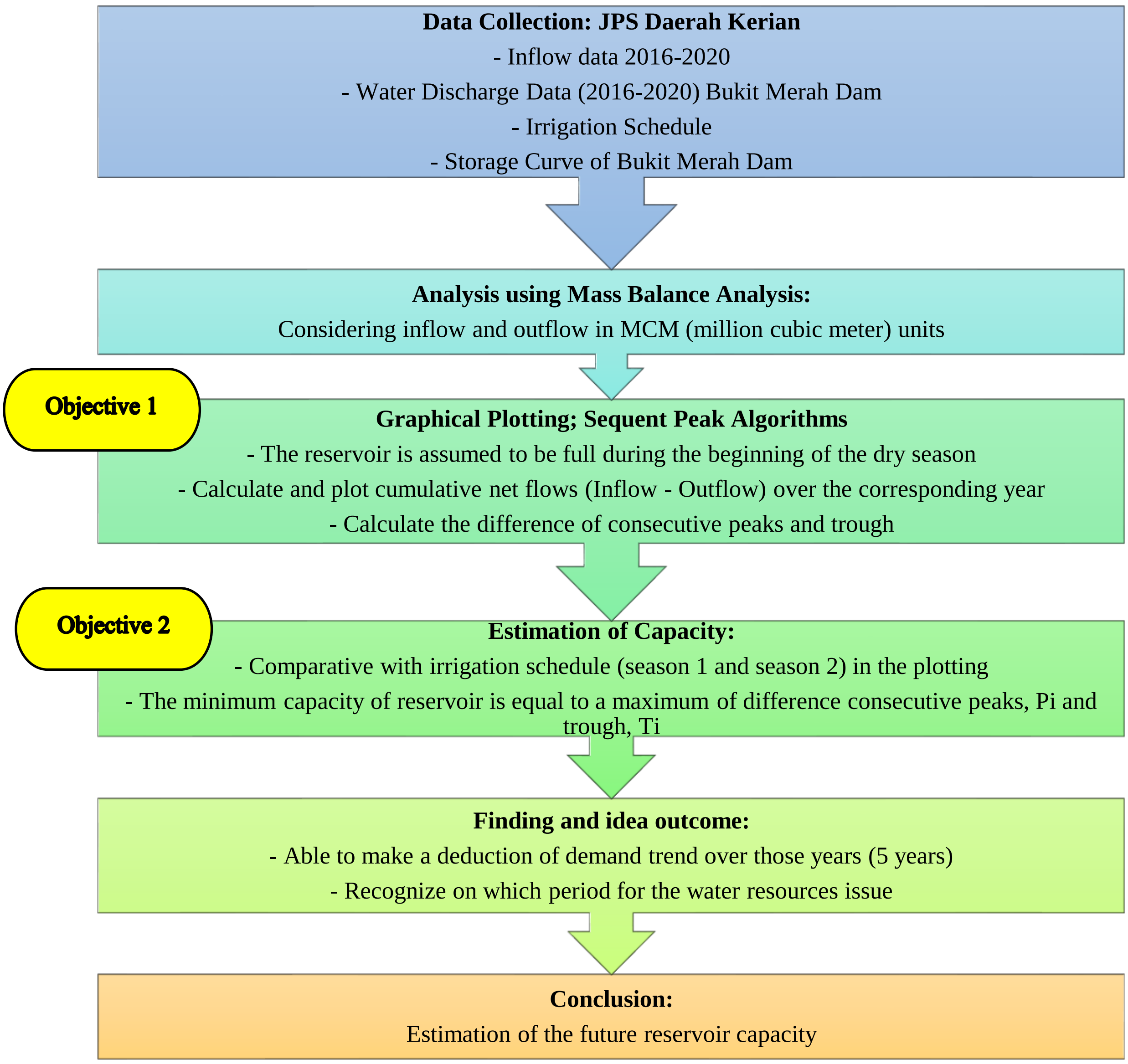

Figure 3.1: Methodology Flowchart

3.2 Description of the Study Area

- **Bukit Merah, Semanggol, Perak**

Bukit Merah Dam is a modified homogeneous earthfill embankment in the state of Perak, located upstream of the confluence of the Sungai Kurau and Sungai Merah rivers. The dam was built in 1906, and during the Second Malaysia Plan (1961–1955), the embankment was raised from RL 8.08m to RL 10.67m, and then again in 1984 to its current height of RL11.28m. It has a crest length of around 579 metres and a depth of about 9.1 metres. It has a storage capacity of **92.8MCM** at RL 9.10m and is drained by an area of around 480sq.km.

The major function of the dam is to distribute irrigation water to the Kerian District Sungai Manik Project's 24,000 ha of paddy area for double cropping. It also delivers 5.6 cumecs of water (m^3/s) to suit the domestic and industrial demands of the Kerian District in addition to agriculture. Local fisherman relies on the water in the reservoir for their livelihood.

Bukit Merah dam consist of several dam structure such as a main dam, two saddle dams, a gated service spillway, a gated auxilliary spillway and an irrigation intake headwork. The service spillway and auxilliary spillways are at the main dam sited on the left and right abutment respectively. There are two units of gates at the service spillway and seven units at the auxilliary spillway. The irrigation intake headwork is at the right abutment of Saddle dam II which is about 1km from the main dam. Releases from the headwork as in are controlled by six units of slide gates to two main irrigation canals namely, Terusan Selinsing and Terusan Besar.

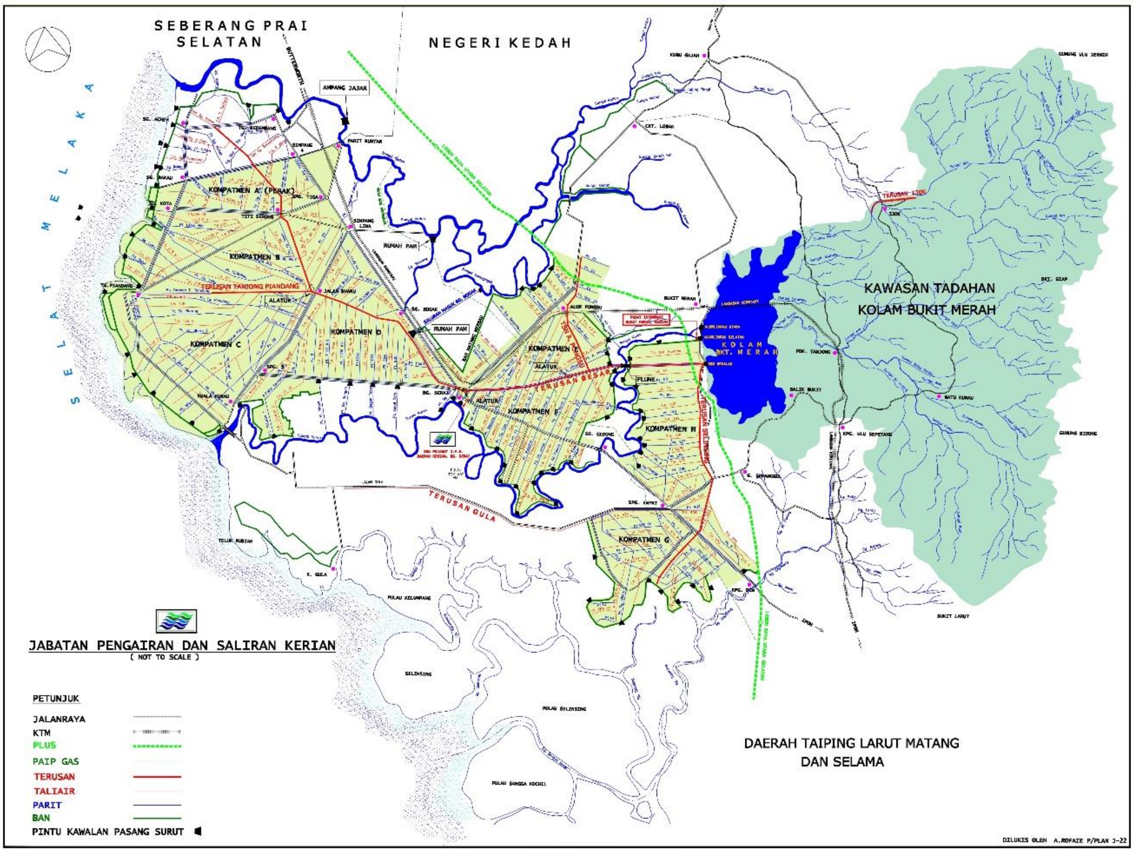

Figure 3.2: Irrigation Map of Kerian District

3.3 Data Collection

All the data obtained from the Department of Drainage and Irrigation (DID) in Kerian District and provided by Assistant District Engineer. Those data are entrusted to carry out the case study on determination Bukit Merah reservoir capacity using sequential peak analysis. However, such data are confidential to publicly display.

3.3.1 Inflow Data 2016-2020

DID provided the inflow of Bukit Merah Reservoir for a 5-year period from 2016 to 2020 in cumecs unit. The inflow is the amount of water that enters a body of water and is a part of the hydrologic cycle that helps keep water levels stable. It can also refer to the volume of entering water measured per unit of time. There are several inflows to all bodies of water, yet one inflow may prevail and be the greatest source of water. In many circumstances, however, no single input would prevail, and many primary inflows will exist. The inflow to a reservoir could be a river that flows into the reservoir. In addition, precipitation, such as rain, can be an inflow.

3.3.2 Outflow Data in Bukit Merah Dam (2016-2020)

It comprises with many aspects such as reservoir level, Sungai Merah level, Main Canal and Selinsing Canal (level in ft), Outflow of Main Canal and Selinsing Canal (Discharge in Cusec unit), Rainfall and Evaporation data (in mm unit)

3.3.3 Irrigation Schedule

Water supply period occurs 90 days for every schedule. The schedule of water supply to paddy field for main season every year.

3.3.4 Stage-Storage Curve of Bukit Merah Dam

A Polynomial Regression Bukit Merah Dam Stage-Storage Curve is used to evaluate the storage in million cubic metres (MCM) unit by referring to reservoir water level (m). The reservoir storage curve is an important metric for multipurpose reservoir operation, and its accuracy is important for water balancing and strategic risk management. A stage-storage curve allows to convert water depth to storage volume directly. Specialist software is used to calculate storage curves. Each storage curve is specific to the on-farm storage system (HEALTHY FLOODPLAINS PROJECT Floodplain Harvesting Measurement -Storage curves Guideline, 2020). The volume of water in the storage is proportional to the depth of water in the storage. For this case study, the storage can be evaluated using Equation 3.1 by referring to its corresponding reservoir level.