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# Water Balance and Potency of the Duriangkang-Muka Kuning Reservoirs for Supporting the Raw Water Supply in Batam City, Indonesia

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**Abstract:** The Duriangkang and Muka Kuning reservoirs play an important role in supplying clean water to Batam City. The Duriangkang reservoir was built from 1992 until 1995 as the first estuary dam in Indonesia and the largest reservoir in Batam city. These two reservoirs are the cascade reservoirs. The dam with an effective storage capacity of 107 million m3 works to fulfill the water needs with a capacity of 2,500 l/s. However, the Muka Kuning reservoir was finished in 1990, but it was newly turned in 1992. At the beginning, the Muka Kuning WTP had a water production capacity of 310 l/s, but the capacity was increased to 600 l/s in 2015 along with the increasing water need in Batam. This research intends to analyze the water balance in the Duriangkang-Muka Kuning cascade reservoirs and to investigate the potency of the Duriangkang reservoir that can support the water availability in the Muka Kuning. The methodology uses water balance simulation in the Duriangkang-Muka Kuning reservoir to analyze the potency of the Duriangkang reservoir that can be used to support the water availability in the Muka Kuning reservoir. The catchment area of the Duriangkang reservoir now consists of residences, society plantations, forestry areas, empty land, and industry, which can decrease the amount of water availability to be stored every year. The results of the water balance analysis indicate that the water availability of the Duriangkang reservoir is in surplus conditions throughout the year in the wet, normal, and dry year conditions. Therefore, the Duriangkang reservoir has the potency to support the water availability in the Muka Kuning reservoir.

**Keywords:** water balance, water potency, Duriangkang, Muka Kuning.

# 杜良康-木卡坤宁水库的水平衡和效力，用于支持印度尼西亚巴淡市的原水供应

**摘要：**杜良康 和 穆卡库宁水库在为巴淡市提供清洁水方面发挥着重要作用。杜良康水库于 1992 年至 1995 年建成，是印度尼西亚第一座河口大坝，也是巴淡岛市最大的水库。这两个水库是梯级水库。有效蓄水量为 1.07 亿立方米的大坝以 2,500 升/秒的容量满足用水需求。然而，木卡库宁水库于 1990 年建成，但在 1992 年重新翻修。木卡库宁水厂最初的产水能力为 310 升/秒，但 2015 年产能增加到 600 升/秒随着巴淡岛用水需求的增加。本研究旨在分析杜良康-木卡昆宁梯级水库的水平衡，并调查杜良康水库支持木卡昆宁水供应的效力。该方法使用杜良康-木卡昆宁水库中的水平衡模拟来分析杜良康水库的效力，该水库可用于支持木卡昆宁水库的可用水量。杜良康水库集水区现在由住宅、社会种植园、林区、空地和工业组成，每年都会减少可供储存的水量。水量平衡分析结果表明，杜梁康水库全年可水量在丰水、常年和旱年均处于富余状态。因此，杜良康水库有能力支持木卡库宁水库的可用水量。

**关键词：**水平衡、水效、杜良康、木卡昆宁.

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# 1. Introduction

Human activity has many impacts on an ecosystem. This has been a long time understood and it naturally strengthens the proof that supports an indicator that humans have entered an anthrophony period (the period that begins human has effect) [1]. Many human activities have been recorded as one of the certain stimulation strengths that are simultaneous and integrated in making changes in the nature environment including the land use change [2]. Besides it, the changes are also affected by the spatial pattern of landscape and the existence of service that is carried out and the goods in an ecosystem that is supposedly giving the impact in disaster like flood [3]-[4]. Meanwhile, the flood and inundation problems are related to the climate change in general and mainly the rainfall intensity change [2].

Batam island as part of Riau islands province has the water resource potency with the less adequate hydro-climatology conditions because there is no groundwater basin, so the whole river area depends on the water source that comes from surface water or rainfall. Besides it, the thin humus layer in Batam island is necessary to obtain the special attention in the regional spatial design and regional management or conservation plans [5]. A reservoir is an artificial water storage that is functioned to store water in the rainy season and uses it during the dry season. The reservoir operation pattern determines how large the reservoir benefit that can be obtained, which is as one system unit. The sub-system of the reservoir operation pattern consists of water availability, water need in the reservoir downstream, electrical energy generation, reservoir physical condition, institutional and aspiration of the stakeholders. Each of the sub-system is interplaying [6].

In fulfilling the problem of uneven water availability and the increasing water needs, an overall and integrated model of water resource management is needed. Water resource management in a watershed must involve some stakeholders [7]-[8]; therefore, long and depth research is needed in the process. Some problems in the water resources management like flood control, irrigation water supply, the fulfilling of raw water need, and water supply for electrical energy generation [6]. In setting the operation pattern of multi-reservoir, the water transfer from overflow reservoir (donor) must consider the available capacity of the acceptance reservoir. A set rule of new release on every storage must be analytically made by considering the optimum condition of water balance and the storage capacity of each reservoir [9]. Therefore, the management of multi-reservoir needs a comprehensive consideration because there is a relationship between the reservoir storage and storage itself [6], [10].

The catchment area of Duriangkang reservoir now consists of a residence, society plantation, forestry area, empty land, and industry where there is potential to decrease the water availability that can be stored every year. The conservation study document of Duriangkang Dam explains that topographically, the upstream part of effluents is as hilly areas with the average slope of more than 10% and the valley area until the reservoir edge is as relatively plain area with the average of slope is under 10%. However, the land use in the catchment area of Muka Kuning in the dam mentions that the dominant forest is about 85% and the rest is the inundation area of the Muka Kuning reservoir.

In the cascade system of Duriangkang-Muka Kuning reservoirs, water is transferred from the downstream reservoir to fulfill the upstream storage by using a pump. The historical data of water-level depth that is recorded indicates that the Duriangkang reservoir has the big enough run-off by the end of 2017 until the beginning of 2018. Additionally, the run-off in the Muka Kuning reservoir becomes an additional inflow of the Duriangkang reservoir. This research aimed to evaluate the water availability in the cascade reservoir of Duriangkang-Muka Kuning. This evaluation is carried out to investigate the water potency of Duriangkang reservoir that can support the Muka Kuning reservoir in operating the reservoir.

# 2. Materials and Methods

### 2.1. Study Location

The study was conducted in the Duriangkang and Muka Kuning reservoirs that are located in the Batam city. Both reservoirs are as the cascade system where the Muka Kuning reservoir is in the upstream and Duriangkang reservoir is in the downstream and estuaries into the sea, as presented in Figures 1 and 2. Figure 3 presents the scheme of Duriangkang-Muka Kuning Reservoir.

The catchment area of the Duriangkang reservoir is about 75.18 km$^2$ with a volume capacity of reservoir is about 106.1 million m$^3$. However, the water catchment of the Muka Kuning Reservoir is about 9.64 km2 with a volume capacity of 6.32 million m$^3$.

Fig. 1 Catchment area map of the Duriangkang reservoir

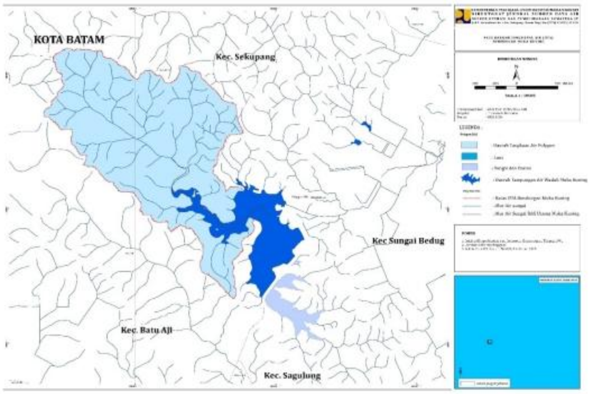


Fig. 2 Catchment area map of the Muka Kuning reservoir

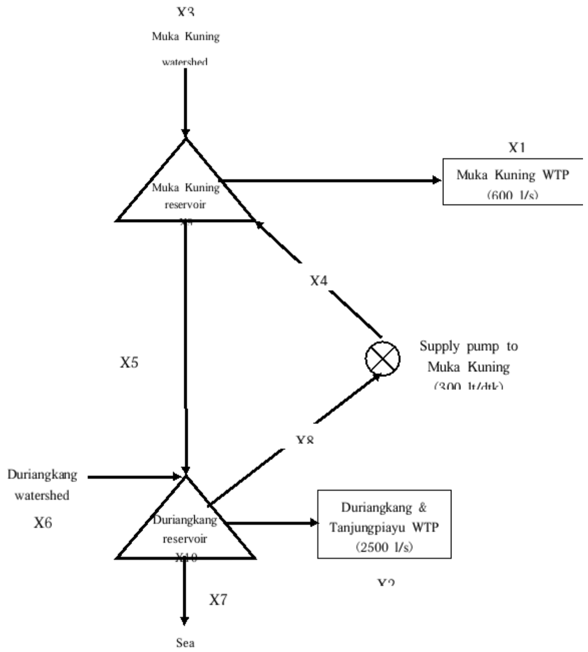


Fig. 3 Scheme of the Duriangkang-Muka Kuning reservoir

### 2.2. Water Balance

Water balance analysis is used to know the inflow and outflow in a system. Water balance analysis is generally performed for the following:

a. Analyzing the water availability in the soil surface and sub-surface;

b. Estimating the available water use pattern;

c. Balancing the surplus and deficit water;

d. Acting as the basis for optimization analysis in the water resource management.

A reservoir is a system of input and output. The reservoir has a water balance model as follows [11]:

$$I = O + \Delta S \quad (1)$$

where:

I – inflow;

O - outflow;

$\Delta S$ - change in storage.

## 3. Results and Discussion

### 3.1. Water Balance of Reservoir

The water balance of Duriangkang and Muka Kuning reservoir is based on the water availability and water need for every condition, as presented in Figures 4 and 5.

The analysis results of water balance, as presented in Figures 4 and 5, show that the water in the Duriangkang reservoir is surplus along year in the wet, normal, as well as dry year condition. Figure 5 shows that the water in the Muka Kuning reservoir is surplus along year only in the wet year condition. However, there is several times water deficit in Muka Kuning reservoir in the normal year conditions that are in February, March, and August. The bad water deficit in the Muka Kuning reservoir happens in the dry year conditions and the water surplus occurs only in July, November, and December.

The big enough water surplus in Duriangkang reservoir and the water deficit in the Muka Kuning reservoir show that there is the water potency that can be used for supplying the Muka Kuning reservoir. The water supply from the Duriangkang reservoir to the Muka Kuning reservoir is intended happened in the Muka Kuning reservoir, and to increase the usage of water storage in Duriangkang reservoir so there be no overflow. However, remembering that the topography of Muka Kuning reservoir is located in the downstream of Duriangkang reservoir, so the water supply to the Muka Kuning reservoir can only be carried out by using a pump. Therefore, it is needed the research on operation pattern optimization of the two reservoirs so the fulfilling of water need can be optimized.

### 3.2. The Potency of Water Supply in Duriangkang Reservoir

The potency of water usage in the Duriangkang reservoir for supplying the Muka Kuning reservoir is shown by the results of water balance analysis in each reservoir. The surplus condition as seen in the water balance of Duriangkang reservoir can be used for supplying the Muka Kuning reservoir when it is needed. Analysis of water supply potency from the Duriangkang reservoir is carried out using reservoir routing simulation in the Duriangkang-Muka Kuning reservoirs.

The simulation between the two reservoirs was carried out without considering the supply pump; therefore, the water overflow from the Muka Kuning reservoir to the Duriangkang reservoir is the only possible option, and there is no water transfer in the back direction. The water supply potency is the water volume that cannot be used from the Duriangkang reservoir as shown by the water volume that is overflowed from the spillway of Duriangkang reservoir.

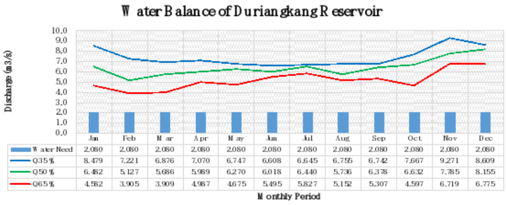

Fig. 4 Water balance curve of the Duriangkang reservoir

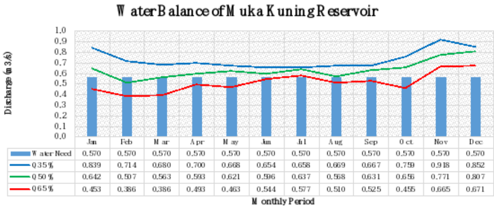

Fig. 5 Water balance curve of the Muka Kuning reservoir

The value of water supply potency from the Duriangkang reservoir varies and depends on the inflow conditions and water-level elevation of initial storage that can be seen in Figure 6. The greatest potency of water supply happens in wet year conditions with the supply discharge that can be used is in the range of 1.73-3.53 $m^3$/s. In the normal year condition, the water supply is still big enough with the discharge that can be supplied is in the range of 0.80-2.54 $m^3$/s. However, in dry year condition, the supply potency can occur if the elevation of initial water level is greater than +5.25 m that will give a supply discharge of 0.02 m3/s. The maximal supply discharge that can be given in the dry year condition is 1.30 $m^3$/s.

If it is reviewed the raw water need in the Muka Kuning reservoir is 0.57 $m^3$/s and water deficit in the Muka Kuning reservoir as presented in Figure 5, so the value of supply potency can be reliable for solving the deficit of water balance that happened. The value of water supply potency from the Duriangkang reservoir is large enough if it is compared with the water needed in the Muka Kuning, even in the wet and normal year conditions of inflow, the value of supply potency is larger enough than the value of water needed in Muka Kuning. In the dry year condition of inflow, the water supply reliability is relatively low that is in the range of 0-1.30 $m^3$/s, it is worried not to be able to fulfill the water need deficit in the Muka Kuning reservoir. Therefore, it is needed to regulate the reservoir operation that is inter-integrated between Duriangkang and Muka Kuning reservoirs to the water need can be fulfilled.

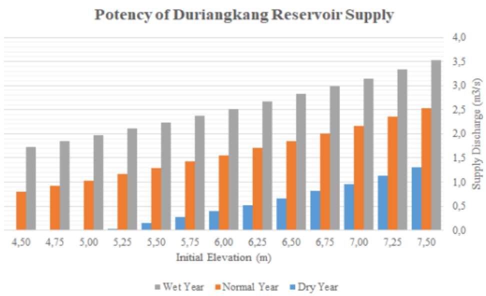

Fig. 6 Potency of the Duriangkang reservoir supply

## 4. Conclusion

If these are reviewed, if the raw water needed in the Muka Kuning reservoir is about 0.57 $m^3$/s and the water deficit condition in the Muka Kuning reservoir as seen in Figure 5, so the value of supply potency can be reliable for fulfilling the deficit of water balance that happened. The value of water supply potency from Duriangkang reservoir is large enough if it is compared with the water needed in Muka Kuning, even in the wet and normal year conditions of inflow, the value pf supply potency is more than water need in Muka Kuning. In the dry year condition of inflow, the reliability of water supply is relatively low that is in the range of 0-1.30 $m^3$/s, it is worried to be unable to fulfill the deficit water need in the Muka Kuning reservoir. Therefore, it is needed to regulate the reservoir operation that is inter-integrated between Duriangkang and Muka Kuning reservoirs to the water need can be fulfilled.

The results of the water balance analysis indicate that the water availability of Duriangkang reservoir is in surplus conditions throughout the year in the wet, normal, as well as dry year conditions. Therefore, the Duriangkang reservoir has the potency to support the water availability in the Muka Kuning reservoir.

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