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THE ENVIRONMENTAL FLOW METHOD FOR SUPPLEMENTING THE WATER NEEDED FOR THE MANAGEMENT OF SELANGOR RIVER, MALAYSIA

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ABSTRACT

The shortage of water resources is one of the main problems in the world today, and water pollution and under-utilization of water resources are two factors contributing to this shortage. Appropriate supplement environmental flow can have a positive impact on dilution of pollutants, and consequently on fish habitats and the characteristics of the river channels. The purpose of this study is to determine the environmental water demand of the lower Selangor River, known as Sungai Selangor, through the Tennant Method, and then compare the data with the findings in available documents in order to ascertain the most economical and favorable supplement environmental flow method. The results of this study show that the months of November and December between the years 2009 and 2018 were the peak periods of discharge, with it being important for the discharge of these two months to meet 200% of the average annual flow needed to maintain fish habitats and channels in downstream Sungai Selangor. To meet the requirements of supplement environmental flow and improvement of water quality, it is recommended that the spillway working gate of the Sungai Kerling hydropower plant be modified so that the flow can be discharged downstream to supplement the environmental flow. Providing environmental flows for downstream would generate economic benefits and allow upstream and downstream regions to share resources.

KEY WORDS: Sungai Kerling hydropower plant, Sungai Selangor, Supplement Environmental Flow, Tennant Method, Water Environmental Capacity

INTRODUCTION

Most rivers in Malaysia have become polluted in recent years (Najah *et al*., 2021).There are five sources of this pollution— manufacturing industries, agricultural-based industries, sewage treatment plants, piggeries and wet markets (Chai, 2020). Among these sources, the agricultural-based industries discharge the highest amount of pollutants into the river on average. This pollution can be further aggravated by a serious shortage of water as well as serious water pollution, causing the ecosystem to be destroyed. Therefore, to ensure the ecological balance of the system, a certain amount of water needs to be maintained in the river. The Tennant method is most commonly used to calculate environmental flow. This method employs the use of historical flow data records for the purpose of recommending an e-flow setting in order to maintain the desired health level of the river (Suwal *et al.*, 2020). Specifically, environmental water demand requires the maintenance of the self-purification capacity of the water body and the sediment balance of the river. Releasing a specific amount of water from upstream of the entered pollution point, referred to as dilution flow, is one of

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the possible operations to manage the balance (Darmian *et al*., 2018). Alternatively£¬flushing flows, also called substrate maintenance flows, may be used. Flushing flows can bring about some positive effects, including the removal of surface veneers of fine sediment, the scouring of algae, and opening-up of interstitial space in the river bed. If this interstitial space is not opened in the bed of the river, fine sediment will remain embedded in it (Bledsoe *et al*., 2013).

Both the above types of supplement environmental flow need to meet high water quality standards, specifically Class II of the National water quality standards for Malaysia. The water quality index has been classified by the Department of Environment (DOE) according to a number of classes, namely class I, II, III, IV and V. The higher the index value, the higher will be the quality of the water; the lower the index value, the lower the water quality (Mohiyaden *et al.*, 2019).

The Sungai Kerling hydropower plant can be modified to supplement the flushing flow downstream to solve the problem through dilution of pollutants. Therefore, change to the storage of the hydropower station is recommended; currently there is no storage. By saving water during the high-flow season— spring, rainy season—and releasing water during the low-flow season—winter, dry season—hydropower projects with a storage basin would have the ability to store water for later use. This method would be economical because the spillway gate will be used to transform the discharge; this means the working gate of the spillway will be transformed to supply the environmental flow.

STUDY AREA AND DATA

The Selangor basin is the main source of water for drinking purposes in Kuala Lumpur and the Klang Valley area. This Sungai Selangor basin emerges from the foothill of Fraser's Hill and traverses the north-east region of Selangor for 110 km right up to the coast. The main tributaries of the river basin are Sungai Sembah, Sungai Kanching, Sungai Kerling, Sungai Rawang and Sungai Tinggi.

This study was conducted downstream of Sungai Selangor and its tributary, Sungai Kerling. The main functions of Sungai Selangor involve water supply, ecosystem, tourism and leisure, sand mining, aquaculture, and inland waterway navigation. The total area of the lower catchment of this river is about 500 km^2, with its length being about 57 km below Rantau Panjang (Awang, 2015). The Sungai Kerlingtributary of Sungai Selangor is located at the upstream section of the main river. There is a small hydropower plant in the Sungai Kerling tributary, constructed in order to solve the power shortage problem for the residents of Hulu Selangor. Due to human activities in this tributary, the pollutants entering the lower Sungai Selangor have increased in amount.

In order to analyze the environmental flow of Sungai Selangor, the Rantau Panjang station was selected as the site for collected river flow data. The Rantau Panjang station is at the boundary between upstream and downstream of the river and the data collected by this station can be used to estimate the water environment capacity and environmental water demand downstream of Sungai Selangor. Environmental water demand was estimated by the Tennant Method to determine the flow required to maintain the ecological balance of the lower reaches of Sungai Selangor. This estimated data was compared with the findings in the documents available to determine the most economical and favorable environmental flow replenishment method. Water quality and flow data were obtained from the Rantau Panjang station. The discharge data from 2009 to 2018, which is relatively comprehensive and covers ten years, was used to estimate the environmental water demand.

METHODOLOGY

For the calculation of the environmental flow, the method that is most commonly used is the Tennant method, which was developed by Tennant in 1976. This method is also used to estimate the flushing flow when the river flow meets 200% of the mean annual flow(Kondolf and Wilcock, 1996). This method employs the use of historical flow data records for the purpose of recommending an e-flow setting in order to maintain the desired health level of the river (Suwal *et al*., 2020). Specifically, environmental water demand requires the maintenance of the self-purification capacity of the water body and the sediment balance of the river (Darmian *et al.*, 2018). Alternatively, flushing flows, also called substrate maintenance flows, may be used. Flushing flows can bring about some positive effects, including the removal of surface veneers of fine sediment, the scouring of algae, and opening-up of interstitial space in the river bed. If this interstitial

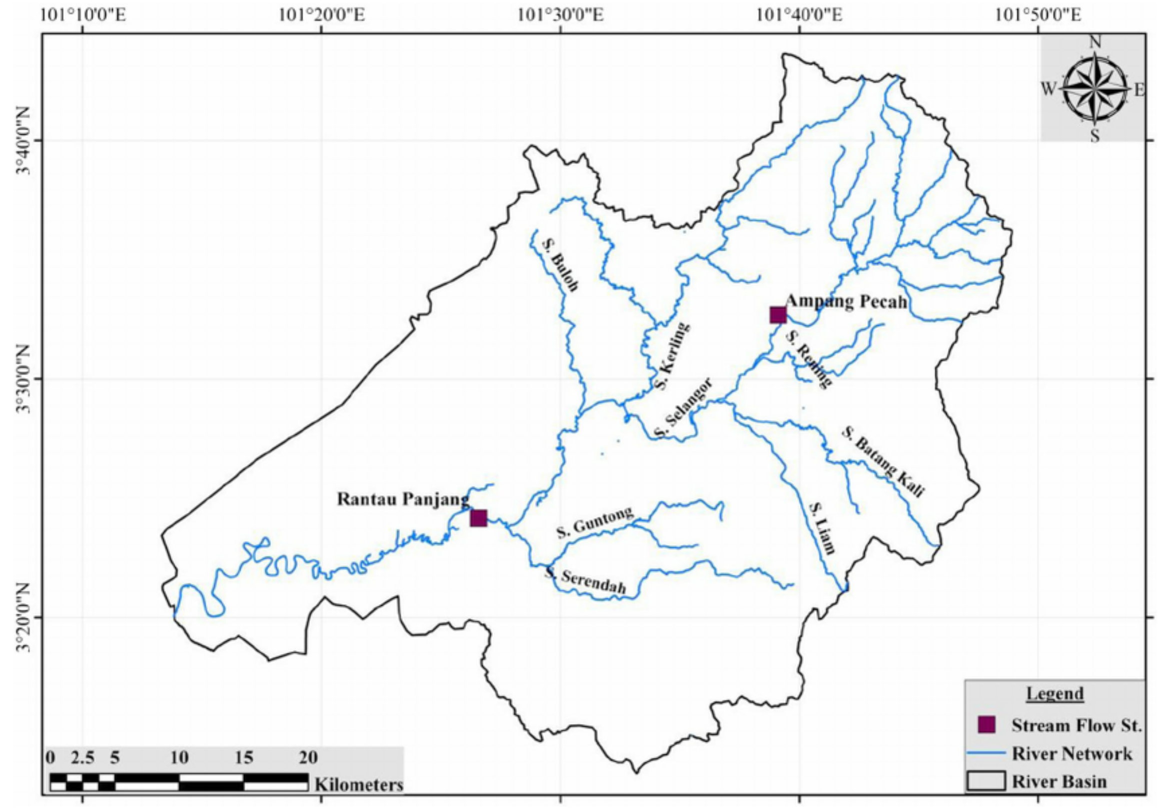

Fig. 1. The locations of the stream flow stations and the main tributaries in the Sungai Selangor basin

space is not opened in the bed of the river, fine sediment will remain embedded in it.

Environmental water demand is the amount of water required to improve the water environment so as to meet the water quality goals while maintaining the normal ecosystem of the river (Li *et al.,* 2018). The Tennant method is based on historical hydrological data and usually uses a certain percentage of the average flow for many years as the environmental flow so as to maintain the river in an acceptable ecology (Yin *et al.*, 2018). This method is used to measure the flow that meets the needs of fish and other aquatic organisms while also maintaining recreational and aesthetic qualities (Rahman *et al.*, 2019). When the Tennant classification is followed, there is a different percentage of the annual flow allocated during the seasons of high-flow and low-flow, with the former defining normal years and the latter defining dry years (Pastor *et al.*, 2014).

Table 1. Percentage of Mean Annual Flow based on the Tennant Method (Author, 2021)

Habitat Quality Description	% Mean annual flow	
	Low Flow Season	High Flow Season
Flushing or Maximum	200	200
Optimum	60-100	60-100
Outstanding	40	40
Excellent	20	20
Good	30	30
Fair	10	10
Poor	10	10
Severe degradation	<10	<10

This study has been conducted by qualitative research, with the secondary data being collected from recent articles, reports, and books. The relationship between the Sungai Kerling hydropower plant and the economic benefits upstream of Sungai Selangor have been analyzed. This data has been analyzed through literature reviews. Pollution is a major factor aggravating insufficient river flow and threatening aquatic life. Therefore, the main measure used to protect rivers is the controlling of the pollution sources. From 2011 to 2019, the water quality data were collected through the Rantau Panjang station. Due to the incomplete data of 2009 and 2010, the data of these two years was not selected for the water quality analysis in this paper. The 2011 to 2019 water quality analyses were therefore used and compared against the National

Water Quality Standards for Malaysia (WEPA, 2006).

RESULTS AND DISCUSSION

The Tennant method used for the environmental flow assessment

The mean annual flow was found to be 1658 m^3/s. July was the driest of the seven dry months from January to March and June to September, with the remaining five months regarded as wet months. The minimum environmental flow was 166 m^3/s, and the flushing flow was 3316 m^3/s. Hairan *et al.* (2021) also observed that according to the hydrological method, the minimum environmental flow requirement was 115.5 m^3/s, which was almost near the minimum environmental flow replenishment obtained by the Tennant method in this study. The mean monthly values that are shown in Table 2 and Table 3 illustrate the percentage of flow in different conditions based on the Tennant method.

It can be seen that from January to October, the flow rate was maintained at 60%-100% of the average annual flow rate, which was the optimum range. November and December were the peak periods of flow, ideal for being used as flushing flow to maintain the ecological balance of the downstream of Sungai Selangor. However, the flow of the two last months of the year was insufficient to meet the flushing flow demand of 200% of Mean Annual Flow.

Therefore, as indicated in the above Tables, the flow of downstream Sungai Selangor was not satisfactory during the wet months. It is important

Table 2. Mean monthly flow at Rantau Panjang station of Sungai Selangor (Author, 2021)

Months	Average Monthly Flow (m^3/s) (During 2009-2018)
January	1399
February	1189
March	1637
April	1945
May	2325
June	1269
July	1151
August	1160
September	1293
October	1648
November	2636
December	2240

Table 3. Percentage of Mean Annual Flow (MAF) (Author, 2021)

Percentage of MAF	Flow (m^3/sec)
200% (Flushing Flow)	3316
60%-100% (Optimum Range)	995-1658
60% (Outstanding)	995
50% (Excellent)	829
40% (Good)	663
30% (Fair or Degradation)	497
10% (Poor)	166

that about 200% of Mean Annual Flow (around 3316 m^3/s) be available during the months of November and December. Natural precipitation and runoff patterns produced clearly defined periods of low and high flow. Appropriate environmental flow replenishment could have a positive impact on dilution of pollutants, fish habitats and characteristics of the channel. The main functions of the downstream of Sungai Selangor include aquaculture and recreation. There are 102 fish species found in this river, most of which have undergone evolution to adapt to the normal hydrograph of the system, which includes conditions of run-off and base flow. Here, the most benefits may be provided by the flow releases scheduled during the normal periods of peak-flow (LUAS, 2015; Reiser *et al.*, 2018).

Sungai Selangor is famous for ecotourism because of the Kampung Kuantan fireflies and Remis Beachin the downstream area. These two places are where many local tourists conduct various activities such as inner tubing, water rafting and canoeing. In order to maintain the shape of the channel and provide leisure opportunities such as water rafting and canoeing, the downstream of Sungai Selangor needs sufficient flow to flush fine sediments and plant materials from the edge of the river in order to prevent the river bank from encroaching on the active channel and prevent changes in the size and shape of the channel. Here, the November and December peak periods of discharge could be helpful; Table 4 shows the corresponding e-flow. The e-flow requirement from June to August, the dry months, should be 995 /s but for November and December, the wet months, it should be much higher at 3316 m^3/s.

The environmental flow of Sungai Selangor is supplied through natural rainfall and the Selangor Reservoir Dam, but the dam prioritizes the allocation of water resources for water supply and irrigation purposes. If the Selangor Reservoir dam

Table 4. Environmental Flow demand based on Tennant Method (Author, 2021)

Months	E-Flow (m^3/sec)		Remarks
June	10% of	166	Dry months
July	Mean	166	
August	Annual Flow	166	
November	200% of	3316	Wet months
December	Mean	3316	(Flushing
	Annual Flow		Flows)

supplies the flushing flow of the river, the water demand for various uses and departments will encounter multiple problems and there will be difficulty in allocating the water. This may in turn cause problems in the allocation of water resources in different economic and social development sectors in the region. Consequently, it is not recommended that the Selangor Reservoir Dam be used to supply the flushing flow. Because the water used by the Sungai Kerling hydropower plant returns downstream, it is recommended that the spillway gate be used to transform this discharge, which means that the working gate of the spillway can be transformed to supply the environmental flow. Hairan *et al*. (2021) noted from their study that the high pulse duration is 2 or 3 days, and therefore the recommended flushing flow time is 2 or 3 days. November is the rainy season with the highest flow rate of 2636m^3/s to meet flushing flow of 3316 m^3/s. It is recommended that the flow rate be supplemented in November at approximately 680 m^3/s.

The impact of human activities on river flow

Figure 1 shows that the total solids pollutants progressively increased in Sungai Selangor over the eight-year period between 2011 and 2019. This was due to the rapid increase in sediment brought about by deforestation and sand mining activities in the upper part of Sungai Selangor. The large amount of sediment changed the size of the river channel and threatened fish survival. The sediment also altered the flow velocity of the river, causing the flow from upstream to downstream to become less fluid. Figures 2 and 3 indicate that nitrogen and phosphorus pollutants had not been well controlled. Nitrogen pollutants generally increased, while phosphorus levelled off, and the water quality was below the National Water Quality Standards for Malaysia. A survey conducted on citizens living in upper Sungai Selangor found that most of the discharges from pastures and residents were not connected to municipal pipelines. Therefore, these pollutant-laden wastewater flowed directly into the river, causing the river to become gradually eutrophic. Nitrogen and phosphorus pollutants in the agricultural wastewater were the main sources of pollution in upper Sungai Selangor. It is a major agricultural area, with the fertilizers used by farmers containing a lot of nitrogen and phosphorus pollutants. These pollutants were deposited in the river and threatened the health of its aquatic systems. Nitrogen and phosphorus pollutants were the main causes of eutrophication of the river, allowing a large number of algae to multiply rapidly and kill a lot of fish. It is suggested that the aquatic life of the river can be protected by diluting these pollutants through sufficient flushing flow. Figure 4 shows that the Biochemical oxygen demand (BOD) also increased over the eight years. The source of these pollutants was mainly domestic sewage, with most of the discharge from residential areas in upper Selangor not being connected to sewage treatment plants, but instead flowing directly into the river through open channels. Excessive discharge of such pollutants into the water body resulted in a lack of

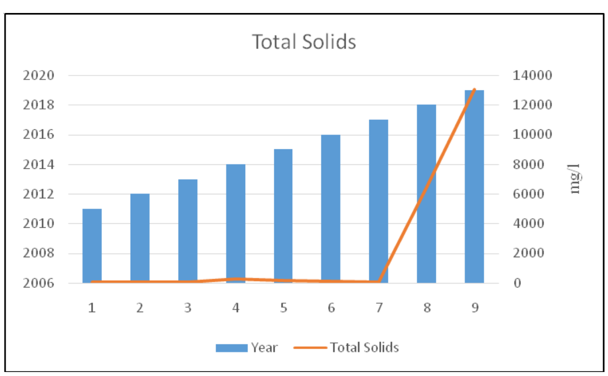

Fig. 2. Mean concentrations of Total Solidsin the Sungai Selangor.

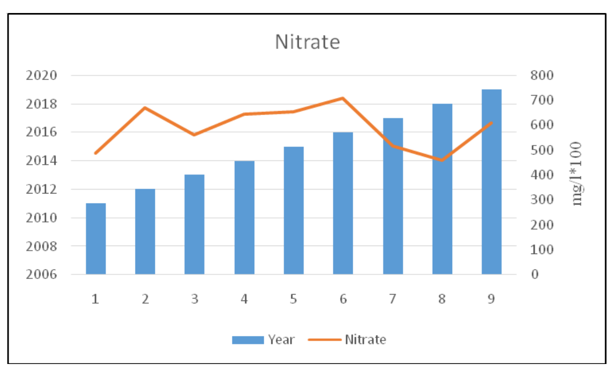

Fig. 3. Mean concentrations of Nitrate in the Sungai Selangor.

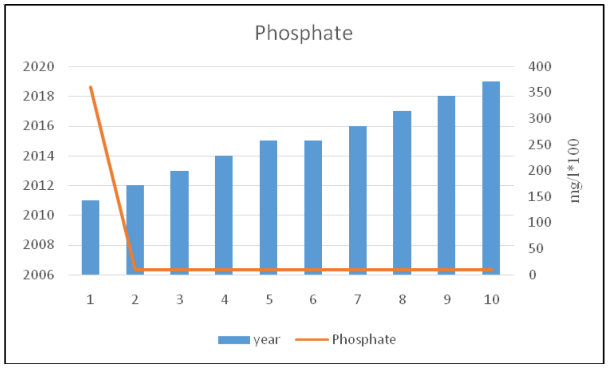

Fig. 4. Mean concentrations of Phosphate in the Sungai Selangor

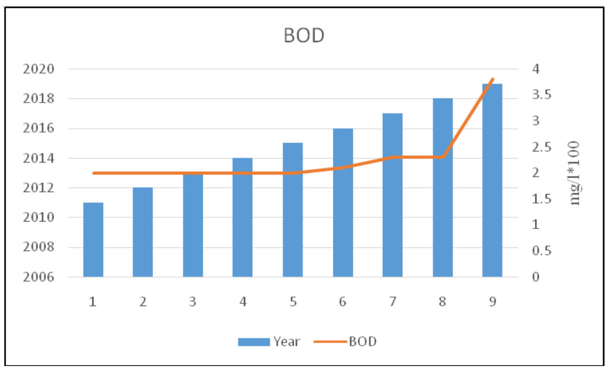

Fig. 5. Mean concentrations of Phosphate in the Sungai Selangor

dissolved oxygen in the water. Consequently, the population growth in the region led to an increase in the amount of domestic water, which exacerbated the continued growth of BOD pollutants. This pollution produced odorous gases such as methane, causing the water body to deteriorate and stink.

Because these sources of pollution intensified rapidly and the river flows were insufficient, the river ecosystems were destroyed. Therefore, it was necessary to meet the 200% annual environmental flow through upstream discharge to flush out these sediments, dilute the pollutants, and improve the downstream aquatic system.

CONCLUSION

In conclusion, the pollution dilution capacity downstream of Sungai Selangor has been observed to be reduced. The results show that in order to maintain the fish habitat for the survival of fish and provide sufficient water for recreational purposes downstream of Sungai Selangor, it is necessary to supplement environmental flow to meet the flush flow of 200% of Mean Annual Flow. Non-point source pollution was confirmed to be the cause of the pollution in the lower reaches of the river; this is because upstream agriculture and most residential discharges are directly discharged into the river. Therefore, it is suggested that the existing run-of-the-river hydroelectric power station on the upstream of one of the tributaries of Sungai Selangor be retrofitted to supplement the flushing flow downstream of the river. This may be the most economical and beneficial method. This research will help decision makers pay more attention to environmental flow, thereby providing a legal basis for the implementation of environmental flow so that environmental water rights can be traded in the trading market.

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Data Availability Statement

All relevant data are included in the paper or its Supplementary Information.

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