Environmental flow assessment of Kayan River: managing sustainability indicator of hydropower project

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Abstract. Nowadays, constructing a new hydropower plant is one of the most attractive solutions to overcome energy requirements. The Kayan Hydroelectric, built in the Kayan River, is projected to generate electricity of nine hundred megawatts. However, the dams have to be managed appropriately since alteration of river discharge will have a significant impact on the environment. This paper proposes an environmental flow assessment as an appropriate indicator to manage sustainability. Three environmental flow assessment methods were used: Flow Duration Curve Analysis (FDCA), Tennant method, and Building Block method. The environmental flow pattern was used as a benchmark to evaluate whether the operation rule of the dams fulfilled the sustainable requirement, particularly on the hydrological pattern of the river. Regarding the Tennant and FDCA method, the minimum discharge that has to be maintained for the minimum environmental flow of the river is about twenty-five cms (corresponds to ten percent of AFF) and thirty-five cms, respectively. Meanwhile, the Building block method informs a range of discharge from a hundred cms to twenty thousand cms during the flood. The environmental flow should be managed to guarantee that the river's ecosystem and carrying capacity can be preserved.

keywords: building block method, energy requirements, flow duration curve analysis, tennant method

1. Introduction

Environmental flow has been widely studied and commonly agreed as a necessity for a better river management practice. There is a wide spectrum of environmental flow definitions. However, a minimum environmental flow is a significant threshold to maintain the river environment [1,2]. The flow is a minimum water flow that must be preserved to maintain environmental value and the environmental capacity to support ecological systems along the river [3,4]. On the other hand, uncertainty is the main issue on how and what an environmental flow should be provided [5]. Regarding the regulation, the Indonesian Government decided that ninety-five percent of dependable river discharge has to be maintained as a minimum environmental flow [6]. Unfortunately, to implement the regulation, the availability of hydrological data in a most river in Indonesia is the main obstacle in applying the desktop type of environmental assessment methods.
Reviews [1,4,7–9] identify four types of environmental flow methods commonly used to identify the minimum environmental flow: hydrological, hydraulic rating, habitat simulation, and holistic methods.

This paper focused on the mesoscale perspective of environmental flow studied on the middle reach of the Kayan River. The river is important in the country located in North Kalimantan Province, with a total catchment area of 33.005 km² and 576 km. It is the main resource to provide water for more than 5,000-acre irrigation areas and other water demands within the province.[10,11]

The mesoscale approach is commonly used in climatology to represent the intermediate area which is part of the macroscale. Newson [12] stated that the mesoscale approach on the river could be represented varying at the main channel width and at river reach, which has similar channel width. Mesoscale became substantial since the river management has to be faced mostly with regional problems instead of site-specific (microscale) problems to have a more integrated approach. On the other hand, Frissell [13] stated that the macroscale approach of river management (in this case: basin-scale) mostly refers to a more general perspective in identifying common problems within the wider region such as river catchment.

Hydropower is one of the renewable energy sources that potentially applied in Indonesia, including in the North Kalimantan. However, this does not mean that hydropower has no impact on the environment at all [14–16]. One thing that needs to be considered is the impact of hydropower on discharge regulation, changing on discharge pattern at downstream of the concerned hydropower. As part of the heard of Borneo initiative, the Kayan river basin must be preserved and maintain its carrying capacity to support its biodiversity and conservation life.

This paper discusses how the environmental flow could be the strategic indicator to maintain sustainability of the concerned environment, particularly in ensuring the sustainability of the hydropower plant at the Kayan river basin.

2. Materials and Methods

Time series of rainfall data was collected from the rainfall station of Long Buluah, the district of Bulungan, from 2000 to the year 2004. The data has then been analyzed using HEC-HMS in order to provide discharge data of the corresponding period. The discharge result was then analyzed using several methods, namely: Tennant method [17], Flow Duration Curve Analysis (FDCA), and the building block method [18].

Richter [19] highlighted the Tennant (Montana) method as the second most widely used environmental flow method in North America regarding the methods. Since then, it has become the most commonly applied hydrological methodology worldwide. It comprises a table linking different percentages of average or mean annual flow (AAF/MAF) to different categories of river condition, on a seasonal basis, as the recommended minimum flows. The categories of the flow-related condition range from ‘poor or minimum’ (10% AAF) to ‘optimum range’ (60–100%AAF) [17]. At least twenty-five countries have either applied the method as originally expounded by Tennant in 1976, in a modified form based on various hydrological, geo-morphological, ecological or catchment-based criteria [11] or have simply utilized various (often arbitrarily designated) percentages or ranges of AAF.

In this research, the FDCA was also used to study the probability distribution of recorded data. Using the FDCA, discharge data were ranked and calculated its corresponding probability by using the following equation:

\[ P = (m/n+1)100\% \]  

where:

- \( P \) = probability (%)
- \( m \) = rank of corresponding data
- \( n \) = number of data

Building Block Method (BBM) is essentially a systematic approach designed to provide flow regimes to maintain rivers under certain conditions called an environmental flow [18]. In this research, BBM was conducted by a series of round-table discussions inviting related stakeholders. The discussions were
facilitated by WWF Indonesia using both online and offline meetings. The meeting has compromised and provided a series of discharge blocks representing natural’s flow regime of the Kayan river.

3. Result and Discussion

Some of the assumptions were used in this hydrological analysis, including the use of the Clark unit hydrograph method as a model for analyzing the rainfall-runoff transformation. In addition, the specified hyetograph is also used in the precipitation analysis. Initial and constant assumptions were chosen as the water loss method. Meanwhile, in order to obtain the amount of baseflow, this research utilizes the recession method.

Figure 1. The catchment area of the Kayan river at the site of corresponding hydropower.

Figure 2. Rainfall pattern of the Long Buluah, Bulungan
Precipitation data were collected from the water resources authority (BBWS Kalimantan III) at the rainfall station of Long Buluah, the district of Bulungan, on the period from 2000 to the year 2004 that can be viewed in Figure 2. The data has then been analyzed using HEC-HMS in order to provide discharge data of the corresponding period.

Based on the recommendation stated by Tennant (1976) [17,20], an environmental flow (EF), that mainly driven by time series data, was provided. Annual Average Discharge was calculated from 31,501 data collection, and a discharge of 443.82 cms is defined as Annual Average Flow (AAF). Furthermore, the environmental flow provided varies from 10% of AAF to 60%-100% of AAF as an optimum category of the Tennant method. Regarding the method, which uses the annual average flow (AAF) of the Kayan river as the basis of the analysis, the minimum discharge that has to be maintained for the environmental flow of the river site is 44.38 cms (corresponds to 10% of AAF). Meanwhile, the good category of an environment that has to be maintained is as an interval between 88.76 cms to 117.53 cms (20%-40% AAF). The other environmental value as categorized by Tennant (1976) is presented in Table 1.

| Description               | Recommended base flow regime (%) | Discharge (cms)      |
|---------------------------|----------------------------------|----------------------|
|                           | Oct.-Mar                         | Apr.-Sept.          |
| Average Annual Flow       | 100% of average flow              | 443.82              |
| Flushing or maximum       | 200 % of average flow             | 887.64              |
| Optimum range             | 60% - 100 % of average flow       | 266.30 – 443.82     |
| Outstanding               | 40%                              | 117.53              |
|                           | 60%                              | 266.30              |
| Excellent                 | 30%                              | 133.15              |
|                           | 50%                              | 221.91              |
| Good                      | 20%                              | 88.76               |
|                           | 40%                              | 117.53              |
| Fair or degrading         | 10%                              | 44.38               |
|                           | 30%                              | 133.15              |
| Poor or minimum           | 10%                              | 44.38               |
|                           | 10%                              | 44.38               |
| Severe degradation        | 10% of average flow to zero flow  | 44.38 - 0           |

Moreover, the FDCA method (Figure 3) indicates that the probability of 80% of the river flow, the minimum discharge that must be concerned, is 45.00 cms. The circle on the graph indicates the value. Compared to the Tennant method, the discharge of 90% FDCA is even smaller than the minimum environmental discharge set by Tennant (10% AAF).

![Figure 3. Flow Duration Curve of discharge data at research site](image-url)
The Building Block approach was performed by using a series of indebted discussions involving potential and concerned stakeholders. The discussions were facilitated by WWF Indonesia using both online and offline meetings. The meeting has compromised and provided a series of discharge’s patterns that represent the natural’s flow regime of the Kayan river. The discharge of 45.00 cms, corresponding to the probability discharge of 80%, was chosen as the minimum environmental flow of the river reach. On the other hand, discharge of 2000.00 cms, corresponding to the probability discharge of 10%, was compromised as the representation of peak discharge.

![Graph showing annual discharge pattern using Building Block method at a research site.](image)

**Figure 4.** Annual discharge pattern using Building Block method at a research site

The discharge pattern will be valuable if all involved parties implement and apply it on their decision concerning the discharge regulation on the corresponding reach of the Kayan river. Indeed, adjustments are still required to be made in accordance with developments in water resources and changing conditions that lead to alteration of river discharge, including climate changes.

4. Conclusion
The minimum environmental flow regarding Tennant method (Tennant, 1976) is 44.38 cms (10%AAF). The flow duration curve method provides 90% of a dependable flow of 19.4 cms. Using the building block method, it is provided that discharge of 45 to 2000 cms are identified as the model of annual environmental flow pattern. Discharge of 45 cms equivalent with a probability of 80% is decided to be the Kayan river's baseflow or minimum environmental flow setting. Meanwhile, extreme discharge of 2000 cms is provided in order to preserve flood conditions. Providing an annual discharge pattern consisting of low flow and extreme flow in the reservoir operating rules will be an indicator of guaranteeing ecosystem sustainability in the downstream reach of the Kayan hydropower plant. Further research on developing an environmental flow method for un-gauge Indonesian river has to be performed to support better river management. Various impacts due to climate change are also essential to be considered to support climate change adaptation strategic plan at any level of management.

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