Environmental flows by proxy – a case study from Sarawak, Malaysia

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Key Points

- A method has been developed to determine a viable base flow for the diversion reach of a mini-hydro scheme.
- The method is based on identification of a proxy catchment, which has similar physical conditions but a reduced catchment area and associated base flow
- Comparison of the aquatic species mix identified in the two catchments assists with determining the suitability of a reduced base flow in the hydro scheme diversion reach

Abstract

The mountainous terrain of Sarawak is a remote, sparsely populated region of Malaysia. The development of a run-of-river mini-hydro scheme on a high energy boulder bed stream, Sg Kota, in the northern hinterland has been proposed. Whilst there is no population in the project catchment, the project will have significant benefits for downstream communities.

In the absence of an environmental flow provision, the 4.5 km diversion reach could become ephemeral, which is unlikely to support the current ecosystem. With very limited hydrological and ecological data, and limited site accessibility, determining an appropriate base flow was a challenging task. Common practice is to assume a flow exceedance value in the range of 2.5% to 10%. As an alternative, we pursued the use of a proxy catchment to assist with defining base flows. This approach has not yet been widely practiced, and has the advantage of being based on aquatic species requirements and geomorphic considerations rather than default values.

The nearby Sg Raya has a similar boulder bed and pool habitat, and being a smaller catchment, was considered to be a good proxy for a reduced flow regime scenario in Sg Kota. Based on analysis of flow regime and aquatic species present in the two catchments, a suitable base flow in the diversion reach of Sg Kota has been proposed.

Keywords

Environmental flow, hydro, diversion, boulder stream, Sarawak, base flows, flow regime, aquatic species

Introduction

Sg Kota is a steep boulder bed tributary to the Lawas River, in a relatively intact mountainous catchment in Malaysia (Figure 1). The catchment hillslopes are prone to landslides which supply much of the in-stream sediment material. A mini-hydro power station has been proposed for this site. The 'run-of-river' project requires a 5 metre high diversion weir to divert up to 6 m^3/s through a pipe to a downstream power station, where the flow is returned to the River. Approximately 4.5 km of river is bypassed by the diverted flow in this

process, the 'diversion reach' (Figure.1). The purpose of this study was to determine a recommended base flow to be maintained in the bypassed reach.

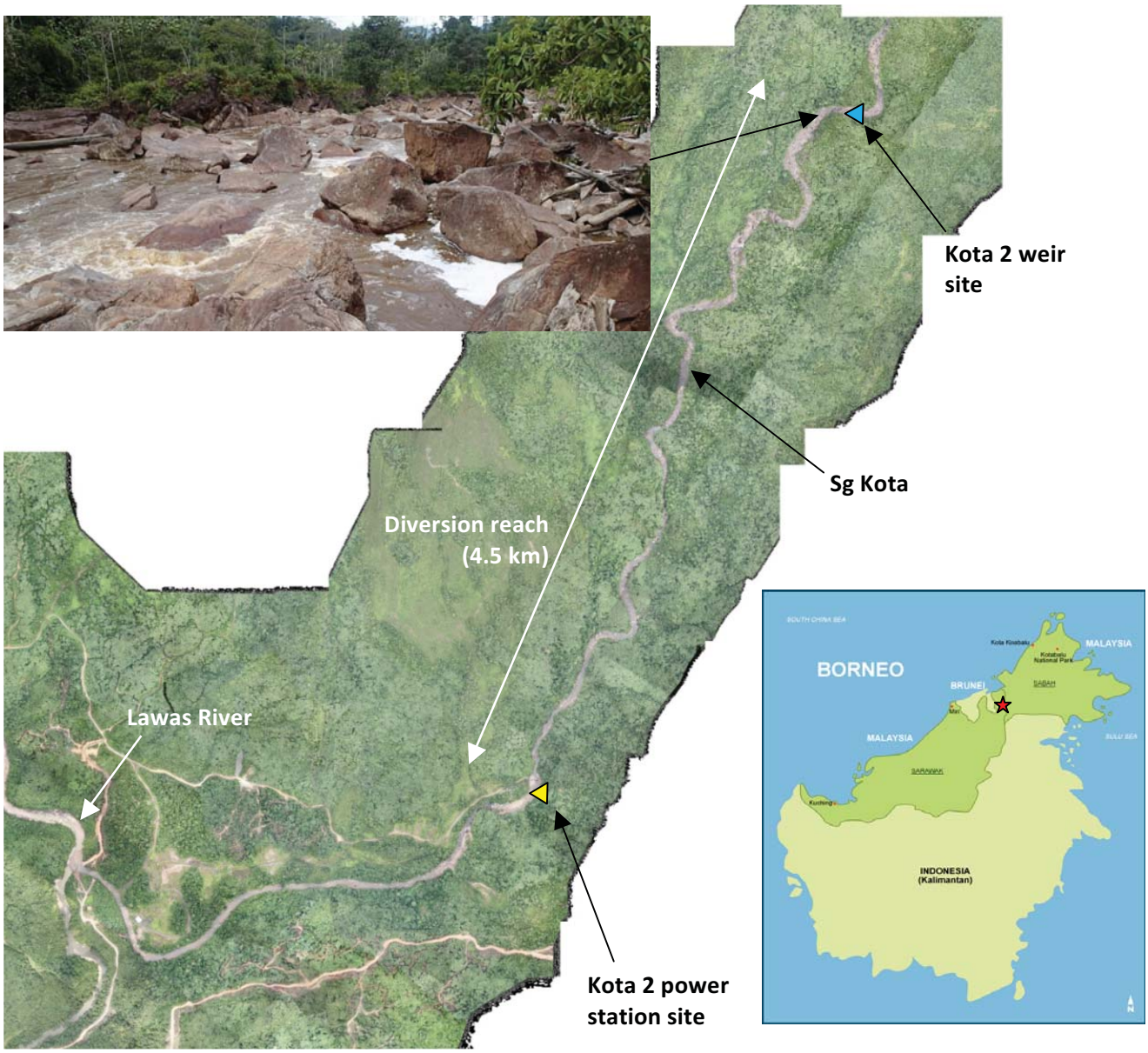

Figure 1. Sg Kota, showing the diversion reach with the photo near the diversion weir site

Environmental conditions and values

The physical habitat in the Sg Kota catchment waterways and diversion reach is characterised by the following:

- Fast flowing water along the main stem of the river
- Ponding in pools created by the rocks and boulders
- Low suspended solid and nutrient levels within the water column
- Relatively low water temperatures (for a tropical river stream) of between 22°C - 25°C

Aquatic biota are uniquely adapted to this environment. Among the main features:

i. The low temperature and nutrient levels translate to low productivity levels. This includes plankton, but particularly macrobenthic fauna, which cannot establish well on hard sediment (Jowett and Richardson, 1990). Macrobenthic organisms consist of insects, whose larvae are demersal and less dependent on the sediment to survive. This in turn, means the prevailing biomass macrofauna is low compared to the main Lawas River.

ii. Most amphibians and fish tend to survive in pools, where the absence of strong currents and nutrient accumulation make living conditions less stressful. Fish tend be small, insectivorous species that are supplanted by larger, piscivorous species further downstream (Rahel and Hubert, 1991). The depths of the pools vary according to the size of the river and the extent of fragmentation by the rock bed. In the case of the Sg Kota, based on data collected during this current study, pools varied in size from 0.78 m^2 to 3.14 m^2, while the depths varied from 0.2 to 1.2 m.

iii. Crustaceans are similarly confined to areas with cover or at the stream edge. Jowett and Richardson (2006), in evaluating the presence of crayfish (*Pranephrops planfrons*) in upper streams, found that they tended to gravitate to water that was 0.2 - 0.3 m in depth.

Macrofauna, including fish species and freshwater crustaceans, rely on the right combination of water depth and flow velocity to move upstream. Sudden jumps in water level (rapids, small waterfalls, cascades) can also present barriers to migration. If fish are unable to move upstream this will represent a considerable reduction in available habitat, with a likely consequence on fish populations.

Preserving the pooling nature of the stream and, most importantly, the pool depths and connectivity, is a key objective for maintaining environmental values in the system.

Social values

There are no communities or settlements in the Sg Kota catchment, and no-one living along the diversion reach. Human activities in the catchment include some commercial logging in the upper catchment, and hunting by local tribes. There were no social needs identified that would be affected by the reduced flows in the diversion reach.

Since flows downstream of the power station are not significantly affected, communities using the Lawas River will not be impacted. There will be no discernible change in streamflow in the Lawas River as a result of the project.

Altered streamflow conditions

The diversion of flow to the power station will result in reduced flows in the 4.5 km diversion reach, including potential cease-to-flow conditions for over 40% of the time (Figure 2).

Sg Kota has high degree of natural water level fluctuation (Figure 3). The proposed diversion flow is 6 m^3/s, which will have negligible impact on high flow events. As such the objective for this study has been to focus on determining a suitable base flow for the diversion reach.

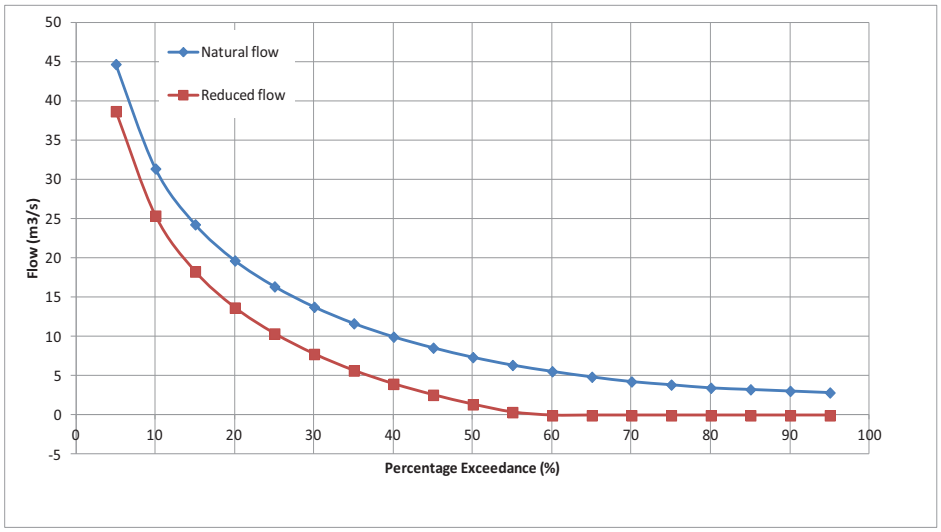

Figure 2. Flow exceedance curve downstream of diversion weir based on model simulation (Entura, 2014)

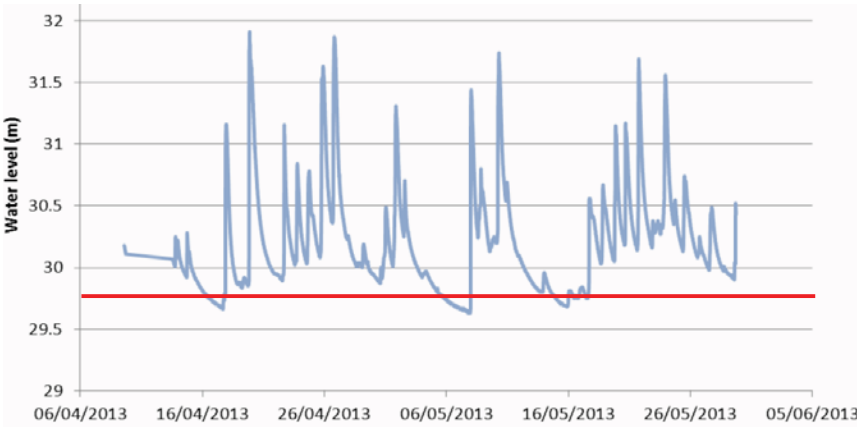

Figure 3. Water level fluctuations at Sg Kota gauge site (Entura, 2013). The red line indicates the water level corresponding to 6 m^3/s, which is the proposed diversion flow

Study objectives

The overall environmental objective for the Sg Kota diversion reach is to ensure aquatic biota are not detrimentally impacted by the altered flow regime.

The proposed reduction in base flow along the diversion reach may have a significant impact on instream biota, particularly macrofauna including fish species and freshwater crustaceans. A reduction in flow can result in:

- Lower water depths
- Lower velocities in the general stream. There may also be higher velocities if the reduced flow is confined to a narrower 'low flow' channel or channels
- Low flows spilling over and between rocks may prevent some fish species from moving upstream

In the event that flows cease, or become very low, the reach may be reduced to a series of poorly connected or ephemeral pools. This will suit some species better than others.

The estimation of specific ecological flow requirements for aquatic biota in Sg Kota is difficult due to limited understanding of species requirements, including habitat preferences and species movements (e.g. seasonal spawning patterns). Therefore, the traditional approach to environmental flow assessments – an assessment of habitat and flow requirements for all species has not been possible at this time. Rather, the focus is on known fish species in Sg Kota, and defining adequate base flow conditions using a proxy catchment approach.

The specific objective for this study has been to:

1. Determine if fish species identified in Sg Kota are likely to tolerate a reduced base flow similar to that in the diversion reach, and
2. Define a minimum base flow for the diversion reach.

Proxy catchment

Catchment and waterway comparison

Like Sg Kota, Sg Raya, is a boulder bed stream (Figure 4) , but with a smaller catchment area and associated streamflow. Sg Raya is the next significant downstream tributary on the right bank of Lawas River, as shown in Figure 4. The Sg Raya catchment area is approximately 11.7 km^2, in comparison with the Sg Kota catchment area at the diversion weir of 151 km^2. Both catchments have similar land use, although the upper reaches of Sg Kota are subject to some logging activities, while Sg Raya is not.

Figure 4. Sg Kota near proposed weir site (top) and Sg Raya, a smaller tributary of Lawas River (bottom), and catchments (right)

Flow comparison

There is no gauge on Sg Raya to establish flows. Estimated flows for the two catchments were completed using the rational method, and applying tropical area factors. The analysis was also calibrated to the previously modelled Sg Kota flows. The rainfall regimes can be expected to be similar in the two catchments, and the comparison of event flows, and their ratio, is shown in Table 1. These ratios were extrapolated to estimate flows associated with more regular events (Table 2).

Table 1. Estimated flows in Sg Kota and Sg Raya

Annual Exceedence Period (years)	Sg Kota (m^3/s)	Sg Raya (m^3/s)	Flow factor (resulting from relative catchment areas)
0.25 (3 months)	20.7	2.4	8.6
0.5 (6 months)	85.7	12.9	7.1
1	149.9	23.3	6.4
2	217.0	33.9	6.4
5	301.6	47.6	6.3

Table 2. Comparison of Sg Kota and Sg Raya – regular events

	Sg Kota	Sg Raya	Ratio
Catchment area (km^2)	151	11	13.7
20% exceedence flow (m^3/s)	19	2.2	8.6
30% exceedence flow (m^3/s)	14	1.6	9*
50% exceedence flow (m^3/s)	7	0.7	10*

* assumed ratio

Aquatic species

Fish sampling surveys were undertaken in both Sg Kota and Sg Raya. The objective was to establish if Sg Raya was able to sustain a similar suite of fish species to that in Sg Kota. The results are shown in Table 3. All the species that were found during the survey of Sg Kota were also found in Sg Raya.

Table 3. Comparison of fish species sampled in Sg Kota and Sg Raya

	KOTA	RAYA	
Seluang	✓	✓	
Batu	✓	✓	
Keli	✓	✓	
Sebarau		✓	
Tilan	✓	✓	
Lumut		✓	

Selecting the base flow value

The flow events shown in Table 2 have been selected arbitrarily but are illustrative of regular / frequent flows in Sg Raya that support the aquatic communities there, and as such could be adopted as base flows in Sg Kota to support the same communities.

In the absence of suitable ecological data, the base flow is usually expressed as the 90% or 95% exceedance flow (Pryce, 2004), or defined based on minimum depth requirements for fish passage. The percentage flow exceedance approach relies on being able to develop a flow duration curve for the waterway. In the case of Sg Kota, which has a rapidly fluctuating flow regime, the lower end of the base flow scale would be satisfactory. Based on the flow duration values developed for this study, the 95% exceedance flow would be 2.5 m^3/s.

However, with the ecological data obtained (Table 3), we have a basis for refining the assessment of flow requirements for the aquatic species in Sg Kota. From Table 2, a flow of 2.2 m^3/s in Sg Raya represents the 20% exceedance flow. If this flow is adopted as a minimum environmental flow for Sg Kota it is likely that the aquatic communities identified in the sampling events would experience a suitable flow environment, all other factors being equal.

The same arguments could be used to support a lower base flow. However, we consider that compared to Sg Kota, Sg Raya has a much reduced width, and therefore flow depths and velocities will likely be greater than for the same flows in Sg Kota. For this reason, we consider that base flows in Sg Kota should be maintained in the upper range of those experienced in Sg Raya. The change in the flow exceedance curve based on 2.2 m^3/s base flow is shown in Figure 5.

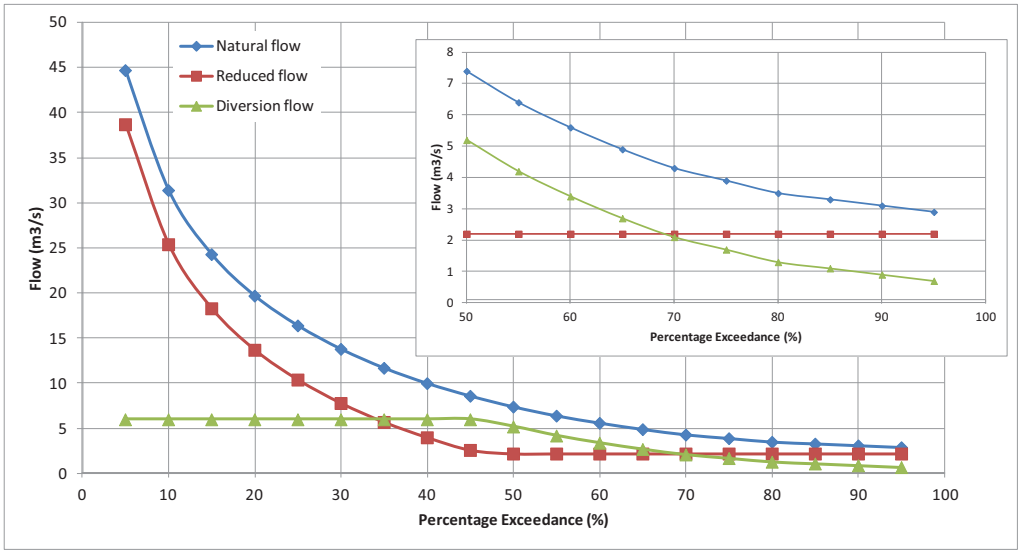

Figure 5. Flow curves for min environmental flow = 2.2 m3/s (reduced flow = natural flow – diversion flow). The reduced flow in Sg Kota has a minimum value of 2.2 m3/s

A flow equivalent to, or less than, a minimum environmental flow of 2.2 m^3/s in the diversion reach of Sg Kota, would naturally occur around 3% of the time (97% exceedance). However, this level of flow can be found in Sg Raya approximately 80% of the time (20% exceedance).

Conclusions

Flow conditions in Sg Raya have been used to assist in defining a suitable base flow for the Sg Kota diversion reach, on the basis that Sg Raya is a suitable proxy catchment for Sg Kota, and that both catchments support a similar suite of fish species. The outcome of this assessment has been a recommendation for a minimum environmental base flow of 2.2 m^3/s for the diversion reach of Sg Kota.

This study provides an initial assessment of base flow for the proposed hydro scheme diversion reach of Sg Kota. The approach has been tailored to available (limited) data, and ongoing monitoring of flows, aquatic life, water quality, and river condition may lead to adjustments to the recommended minimum environmental flow during the Operation and Maintenance Stage.

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