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Original Research Article

Environmental flow assessment in Andean rivers of Ecuador, case study: Chanlud and El Labrado dams in the Machángara River

Q1 Ilia Alomía Herrera [a,*], Patricia Carrera Burneo [b]

[a] Escuela Politécnica Nacional, Facultad de Ingeniería Civil y Ambiental, Ladrón de Guevara E11 253, PO Box 17-01-2759, Quito, Ecuador
[b] Pontificia Universidad Católica del Ecuador, Av. 12 de Octubre 1076 y Roca, PO Box 17-01-21 84, Quito, Ecuador

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ABSTRACT

The environmental flow is a management tool to mitigate the impact of a dam on ecosystems. The Ecuadorian law requires that the environmental flow remains 10% of mean annual flow in old hydroelectric stations, however advances on this area suggest this is not adequate. The objective of this research was to assess the impacts of a 10% release and establish environmental flow recommendations in the Machángara and Chulco rivers which have been dammed by the Chanlud and El Labrado hydroelectric plants, in the watershed of the Machángara River (southern Ecuador). During twelve months physical, chemical parameters and aquatic macro-invertebrates were recorded. The analysis found significant differences in some parameters, indicating a decline in ecosystem condition and relations were found between the flow, the diversity of macro-invertebrates and the concentration of dissolved O_2 (DO). However, determining whether these impacts are unacceptable is difficult because Ecuador does not have established criteria for required ecological condition. This deterioration in ecological conditions can be minimized by applying more modern methods of environmental flow assessment such as the Base Flow Methodology (BFM) that allows the variability of the river flow. In the Machángara River (3000–4000 mamsl) an environmental flow of 27–51% of the mean annual flow for the rainy season and 29–42% in the dry season were determined by using BFM. Whereas for the Chulco River (3000–4000 mamsl) the environmental flow was 15–45% of the mean annual flow for the rainy season and 15–36% for the dry season.

1. Introduction

The paramo (high environments in the Andes highlands) is an ecosystem that regulates the hydrological regime of the high Andean-rivers. Large cities depend on the amount and quality of water provided by the paramo and therefore the conservation of this ecosystem. The high Andean-rivers also provide most of the water for irrigation (Buytaert et al., 2006), and through hydroelectric plants generate electricity for the country (Agencia de Regulación y Control de Electricidad, 2016).

Despite their importance, dams generate negative effects on the ecosystem, such as changing the natural flow regime of rivers, altering the population and diversity of native species, and the intrusion of alien species (Bunn and Arthington, 2002). The larger the alteration, the

* Corresponding author. Current address: Universidad Central del Ecuador, Facultad de Ingeniería en Geología, Minas, Petróleos y Ambiental, Ciudadela Universitaria, Ecuador. Fax: +593 991890899.
E-mail addresses: iliaalomia@hotmail.com (I. Alomía Herrera), pcarrera@puce.edu.ec (P. Carrera Burneo).

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greater the ecological changes (Baron et al., 2002; Poff and Zimmerman, 2010).

The theory of natural flow regime establishes the flow as the most important variable influencing the river ecosystem because of its impact on biotic and abiotic factors (Poff et al., 1997). For example, communities of aquatic insects respond to changes in habitat availability caused by hydrologic alteration. The declining of seasonal flows that maintain habitat alters the trophic composition and abundance, and lowers population densities and insect taxa (Walters and Post, 2011). The sudden increase in flows causes catastrophic effects downstream by sweeping along macro-invertebrates (14% monthly in Tennessee) (Layzer et al., 1989). The impact of the discharge is usually selective as it can result in the disappearance of flatworms, stoneflies, caddisflies, mayflies and beetles (De Jalon et al., 1994) and promotes the proliferation of poor quality taxa (Chironomids, Odonata) (Munn and Brusven, 1991).

A management tool to mitigate the impact of a dam on lotic ecosystems is the environmental flow, which is the quantity and quality of water required to maintain the functions, processes and resilience of aquatic ecosystems (Poff et al., 1997). This ensures the movement of water (with organic matter and nutrients), development of heterogeneous habitats and connectivity of the river and its tributaries (Arthington, 2012).

Ecuadorian environmental legislation decreed that hydroelectric plants built before 2003 should leave at least 10% of the multi-annual mean flow as an environmental flow, but this value can be modified if deterioration in the ecosystem is observed. For dams built after 2003, environmental and impact studies are required to evaluate the effects of dams on species, seasonal and inter-annual variability and floods, although no methodology is defined (Ministerio del Ambiente, 2007).

This provision was based on studies conducted by Tennant (1976) in rivers of the USA, whose results explain that aquatic populations are severely degraded with a minimum flow of 10% of the multi-annual mean flow, but the climatic and specific ecological characteristics of Ecuador were not considered for the adoption of the provision. Moreover, the same Tennant (1976) states that for species to have good survival conditions dams must leave 30% of the annual mean flow, 60% to preserve excellent survival conditions, and as flood flow an equivalent to 200% of the annual mean flow. The minimum flow used in Ecuador is the minimum indicated by Tennant (1976), for which is indicated that it could have been misinterpreted. Maybe the 10% of the mean annual flow keeps the aquatic life in the short term, but its applicability is unsustainable in the long term. Recommendations by Tennant (1976) were developed to be applied in rivers of temperate desert areas like those in the west central USA which have four seasons and a slope lower than 1% (Wood and Fosness, 2013), but not in humid tropical ecosystems of high mountain like those in the Andes, which have a bimodal climate regime.

El Labrado and Chanlud dams were built in 1970 and 1997, respectively. Because of the time of construction, the legislation required the dams to leave a free flow rate of 10% of mean annual flow. The objective of this research was to assess the impacts of a 10% release and establish environmental flow recommendations for two dammed rivers, Machángara and Chulco, located in the Andean highlands of southern Ecuador, and identify the inter-relationships between variation of flow, physical and chemical factors, with the diversity of aquatic macro-invertebrates.

2. Materials and methods

2.1. Study area

The dams Chanlud and El Labrado are located in the watershed of Machángara River (basin of Paute, Azuay and Cañar provinces), which is shaped like a pseudo triangle and is located between the coordinates: *X*: 727900 E, *Y*: 9681530 S (east); *X*: 716630 E, *Y*: 9712530 S (north); and *X*: 706530 E, *Y*: 9698600 S (south). It covers an area of 325 km^2 and has a length of 40.7 km (Instituto Geográfico Militar, 2010). The Machángara River originates at 4400 mamsl in the Machángaracocha Lake; it flows into the Tomebamba River at 2400 mamsl. There is a network of streams and small rivers at the top (3000–4400 mamsl) like the Chulco and Chacayacu, with slopes of 6–11%. In the middle part (2700–3000 mamsl) are the Saymirín and Paluncay rivers, with slopes of 5–17%. In the lower part (2700–2400 mamsl) are the Patamarca and Sinincay rivers, with slopes of 4–13% (Fig. 1).

The Machángara River Hydroelectric Complex is made up of two dams: Chanlud and El Labrado, at 3440 and 3420 mamsl, respectively. These dams became operational in 1972 and 1992, respectively. In 1985 the national environmental authorities declared the upper area of the watershed as a protected forest, so that agricultural activity was restricted, but the middle and lower zones continue to deteriorate (Ministerio del Ambiente, 2012). However, this type of conservation category does not receive economic support from the state to protect the ecosystem. Therefore, the main users, the hydroelectric company and the drinking water company of Cuenca (ETAPA), carry out activities for watershed protection, including native tree planting and training communities on environmental care.

In relation to the water quality downstream of the Chanlud dam, there is an active mudslide, in the area known as stream El Soroche. This mudslide is an important source of suspended solids (ETAPA, 2009). After Chanlud dam and before the mudslide the mean amount of suspended solids was 84 mg L^{-1}; after the mudslide it rose to 258 mg L^{-1}, then down to 197 mg L^{-1} downstream, at the junction of Chanlud with Chulco (ETAPA, 2009). This is the only mudslide in the area.

According to the classification of Snelder and Biggs (2002), the predominant climate in the area is the tropical high Andean; with high mountain-rivers originating in ponds, volcanic lithology, and with paramo vegetation, shrubs, and pasture/cultivated area. Sampling points were located in rivers of order 3–4, and slope > 4% (Snelder and Biggs, 2002). In the investigated area two periods of rainfall were recorded: the first from February to May and the second from October to December (annual mean of

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