Indicators to follow-up hydro impacts and mitigation

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Abstract

This article is centered on a hydro project to be located in The Rio Verde, 60 km from the Oaxaca coastline in South Pacific, Mexico. The river flow regime is identified as a master variable, therefore its natural variability has stated as the base condition to compare and scale impacts. At present a small derivation dam (5 m in high) and 11 km of levees built in 1992 are located approximately at 35 km downstream and have modified mainly ecosystems connectivity, sediment transport and riverbed geomorphology. From the proposed hydro project under study some changes are also expected on the hydrological regime, connectivity, sediment and nutrients transport. Under the present scenario, the main indicators are related to the derivation volumes during dry season and its impact on the low and extreme low flows downstream. During rainy season flows surpass the small dam and, as a consequence, loads of sediments and nutrients (nitrogen and phosphorous). These loads have been estimated annually and monthly to identify the potential retention of the new higher dam. Movement of fish and crayfish species is also observed during this season, but baseline studies are just started. Levees have modified the riverbed and lateral connectivity changing deposition patterns. In this regard, floods from different return periods of time (1.5 and 4 years) have been identified as the driven factor to allow lateral connectivity with mangroves and lagoons. For the scenario with the proposed hydro project a re-regulation dam has been considered to mitigate four hours daily peaking flows mainly during dry season. Reducing flows during this season every three or four years has been pointed out as a need to allow aquatic habitat development and biological cycles.

Introduction

The operation of several dams in the world is being modified to reduce the impacts imposed on aquatic ecosystems in the reservoir and downstream (Waite and Carpenter, 2000, Hickey and Warner, 2005). For new dams, environmental flows and re-regulated dams are being used as indicators for a sustainable approach of producing energy (TNC and ENEE, 2007; HSAP, 2010). These new schemes are protecting rivers' connectivity and the aquatic ecosystems, since flow regime variability is reproducing at some scale and alterations are considering between seasonal and temporal thresholds.

Associated to flow variables lateral connectivity with riparian and lagoon ecosystems as well as transport of sediment and nutrients are other indicators estimated and analyzed in this paper.

Study area

In The Rio Verde, Oaxaca, Mexico, the site for a planned hydro project has not been altered by any large dam upstream (Figure 1). The river maintains a regular inter-annual hydrograph according to the nearest hydrometric gauge (Table 1 and Figure 2).

A small derivation dam is located 35 km downstream of the new project site and it has a low impact in the natural flow regime variability due to its minimum deviated volume (20 hm^3/year, during dry months). However, it has altered mainly the riverbed and lateral connectivity due to 11 km of levees as it is shown in figure 3.

The planned project comprises a 195 m high Concrete Face Rockfill Dam (CFRD), with a storage capacity of 1126 hm^3 and a reservoir of 25.60 km^2. The total installed capacity will be 870 MW for an annual power generation of 1872 GWh.

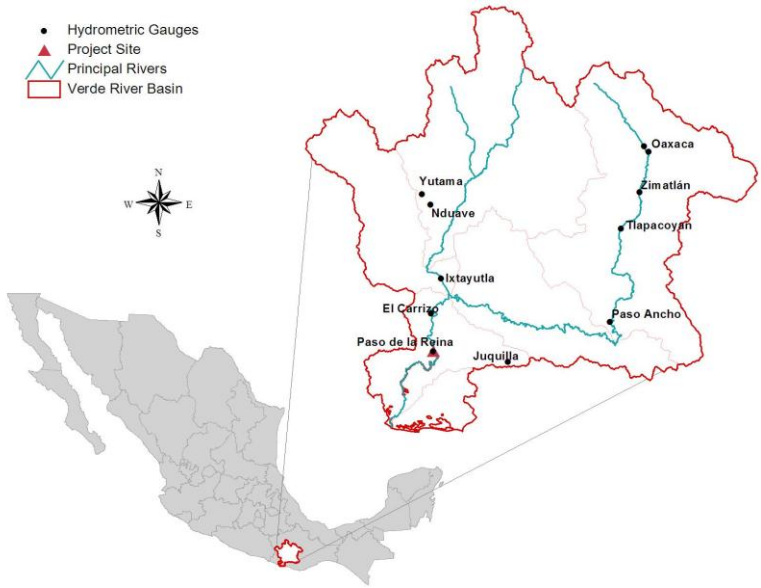

Figure 1. Rio Verde Basin and proposed hydro project site

Table 1. Daily hydrometric available data

Hydrometric Gauge	
Feature	Paso de la Reina
North Latitude	16º 16’ 30’’
West Longitude	97º 36’ 30’’
Period with data	1962-2005
Catchment area (km^2)	17 617,00
Annual runoff volume in the river (hm^3)	5 071,70
Annual daily medium flow (m^3/s)	161
km upstream Pacific Ocean	60

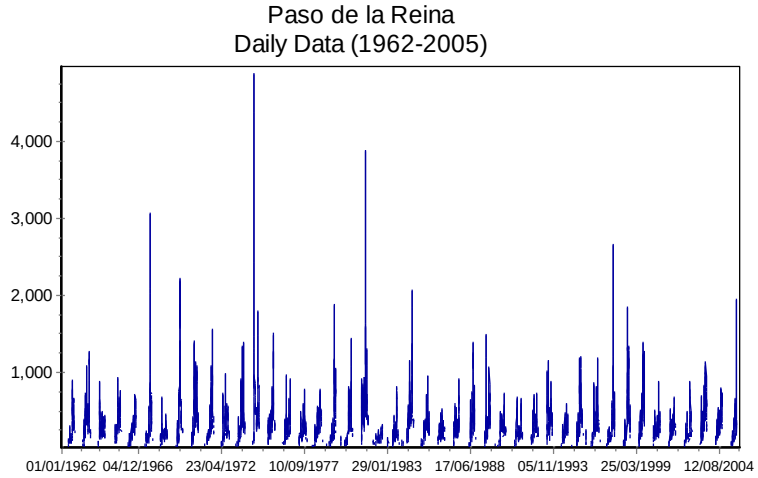

Figure 2. Regular inter-annual hydrograph at the proposed site

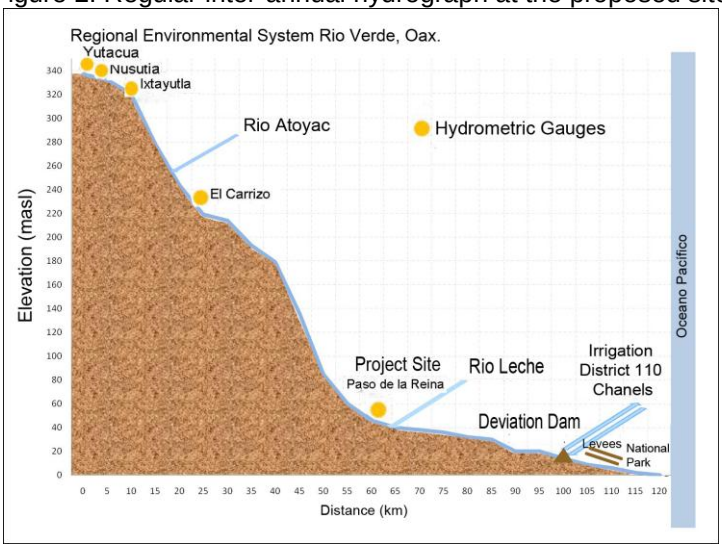

Figure 3. Profile showing project site and baseline conditions

Objective

Identify environmental indicators to follow-up impacts and mitigation of a proposed hydro project in a region with low level of eco-hydrological alteration.

Methodology

Classify the Regional Environmental System associated to a large proposed hydro project in terms of its eco-hydrological alteration (Garrido, *et al.,* 2010).

State a set of indicators to follow-up impacts and mitigation related to changes in river flow regime and alteration thresholds using the software IHA-RVA (TNC, 2009).

Evaluate ecosystem connectivity by analyzing return period flows needed to flood areas of interest and to transport sediment and nutrients loads, using a model for generalized loads at watershed level (AV-GWLF, Evans, *et al.,* 2008).

Results

The Rio Verde sub-basin associated to the proposed hydro project has been classified as of moderated alteration in terms of its eco-hydrological indicators. Using 75 criteria and eleven indicators, Garrido, *et al.*(2010), have pointed out three main impacts on national rivers: 1) on the fluvial network; 2) on the riparian zone and 3) on the hydrographical basin.

At the same time, the project area has been also classified as low water pressure zone since there is a low demand for this resource. It has also been classified as of moderated ecological importance due to the presence of the irrigation district, land use changes, fishing and tourism exploitation.

For these reasons, in a new Environmental Flow Standard (under review at present) the conservation objective has been set as B (indicator to allocate water for environmental flows and aquatic ecosystem preservation among certain limits of alteration). These limits are between 25 to 39% monthly for perennial rivers and they can be achieved by the project.

Nevertheless, from the analysis of historical daily average flows, during hydro operation the expected hydro picking flows would be in the level of 450 m^3/s during four hours. The resulting

volume is then storage at the small re-regulated dam downstream. This dam would release water at a rate of 75 m^3/s during 24 hours. Therefore, during part of dry season (January to May) flows will be upper than percentile 90 (Table 2) as if all years were rainy years. That is beyond the limits of natural variability for these months (Percentiles 25 – 75 -Richter *et al*., 1997).

Table 2. Monthly percentiles at Paso de la Reina Gauge for reference values of natural variability

Months	Period of Analysis: 1962-2005 (44 years) daily average flows m^3/s				
	10	25	50	75	90
January	34.67	44.66	50.13	58.27	63.98
February	25.94	34.05	37.44	42.61	49.31
March	21.13	23.93	27.46	31.85	35.77
April	15.68	19.42	23.07	28.14	33.67
May	19.24	23.17	33.91	51.3	54.28
June	52.87	82.52	128.9	198	327.2
July	122.5	160	194.9	238.6	390
August	133.2	171.4	259	359.1	464.1
September	207.3	298	351.8	514.6	727.9
October	157.5	192.2	246.6	350.8	483.2
November	74.23	96.12	114.2	135.2	163
December	48.33	62.26	68.77	77.53	93.78

Approximately 35 kilometers downstream of the proposed site, the small dam for irrigation and its levees have modified mainly lateral connectivity due to flood control. However, due to the river connection with the lagoon system and with a flooded forest, floods from two main return periods have been identified as needed to allow freshwater penetration: flows of 1.5 years return (1 100 m^3/s) and 4 years of return period of approximately 2 800 m^3/s.

In terms of nutrients loads, using a generalized watershed loads functions model AV-GWLF, results pointed out that 7 220 tons of nitrogen and 2 602 tons of phosphorous are annually discharged in the coastal area and the lagoons system by the Rio Verde basin. From these loads, The Regional Ecological System (RES, Figure 4) produces 56.2% of nitrogen (4 060.4 tons/year) and 21.3% phosphorous (554.2 tons/year).

Upstream the project site but in the RES, 55% of nitrogen (2 235.4 tons/year) and 77.7% of phosphorous (430.5 tons/year) is produced. Downstream the project site, 45% of nitrogen (account to 1 825 tons/year) and 22.3% of phosphorous are approximately 123.6 ton/year (figure 4).

These roughly figures indicate the loss of sediment and nutrients that the reservoir could retain and represent indicators to be considered in the follow up program.

Conclusions

At present, hydrological data and approaches to set environmental flows are more available than other indicators to monitoring and follow-up hydropower projects impacts.

Hydropower impacts are more related to water daily or even hourly increases rather than extractions, therefore environmental flow standard viewed as monthly percentage can be achieved, but additional indicators to identify minor flows needed for the aquatic ecosystem and communities need to be reviewed.

Based on hydrological results adaptive operation is needed to reduce the continuous higher daily discharge during dry season. A strategy is recommended to reduce flows every two or four years at limit of percentile 25 from March to May to allow the development of habitats (maybe as a part of the turbines' maintenance or using a small turbine). At the same time, it is important to reproduce floods that allow connectivity with coastal and wetlands, during rainy season. Apart from magnitude, duration and frequency are important considerations for both low flows and floods. Due to the hypothesis on connectivity and biological responses, this adaptive approach is highly recommended.

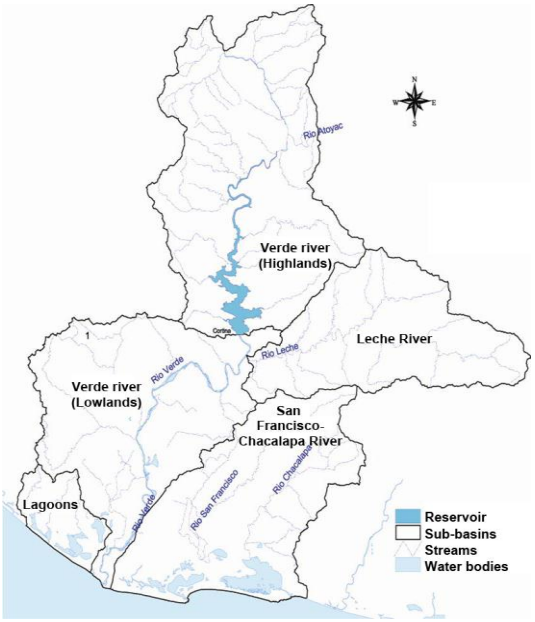

Figure 4. Main sub-basins in the Regional Ecological System

The indicators that classified the study area as of moderated importance for conservation need to be follow up, after dam construction and operation in terms of its biological richness and ecosystems preservation, since some changes are expected.

Finally it is important to study in more detail the sediments and nutrients contributions from the river and their importance to the inter-connected ecosystems.

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