IS THE HEADWARD EROSION A DOWNSTREAM EFFECT OF DAMMING THE COCA RIVER?

Comment l'altération anthropique des flux hydrosédimentaires a perturbé les infrastructures stratégiques situées sur le fleuve Coca ?

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RÉSUMÉ

L'Équateur est un pays andin soumis à une activité géodynamique impressionnante. En 2016, le pays a inauguré la "Centrale Hydroélectrique Coca Codo Sinclair" CCSHP, située sur le versant oriental des Andes, dans le "bassin versant du Rio Coca" CRW, un affluent du Rio Napo et donc du Rio Amazone. Au début du mois de février 2020, l'effondrement de la Cascada de San Rafael, dans le CRW, a déclenché un violent processus d'"Erosion vers la tête" HE, qui a affecté les infrastructures stratégiques du Pays présentes dans le CRW.

L'objectif de notre travail était d'évaluer comment l'altération anthropique des flux hydrosédimentaires a influencé les régimes d'érosion et de sédimentation de la rivière, perturbant en même temps la géomorphologie fluviale et les infrastructures stratégiques situées dans la CRW.

Pour ce faire, ce travail a été abordé sous deux angles: Hydrosedimentologique et Géomorphologique. Les résultats préliminaires montrent que ce processus naturel de HE était présent dans l'histoire géologique du « Rio Coca » (CR). En fait, le CR a subi des barrages naturels périodiques en raison de l'activité géodynamique de la région. Le CR a répondu par des processus érosifs afin de libérer son énorme débit. La construction du CCSHP a modifié les régimes de debit solide et liquide de la rivière et donc sa géomorphologie et ses régimes d'érosion-sédimentation.

ABSTRACT

Ecuador is an Andean country subjected to awesome geodynamic activity. In 2016 the country inaugurated the "Coca Codo Sinclair Hydroelectric Plant" (CCSHP), which is located on the eastern slope of the Andes in the "Coca River Watershed" (CRW), a tributary of the Napo River and therefore of the Amazon River. At the beginning of February 2020, the collapse of the Cascada de San Rafael, in the CRW unleashed a violent process of "Headward Erosion" HE, which has affected strategic infrastructure of the Country present in the CRW.

The aim of our work was to evaluate how the anthropogenic alteration of the hydrosedimentary flows influenced the erosion and sedimentation regimes of the river, disturbing at the same time the fluvial geomorphology and the strategic infrastructures located in the CRW.

In order to do this, this work was approached from two perspectives: Hydrosedimentological and Geomorphological. Preliminary results show that this natural process of HE was present in the geological history the "Coca River" CR. In fact, the CR suffered periodic natural damming as a result of the geodynamic activity of the area. CR responded with erosive processes in order to release its enormous flow. The construction of the CCSHP altered the river's solid and liquid flow regimes and therefore its geomorphology and erosion-sedimentation regimens.

MOTS CLES

Coca River Watershed, geodynamic activity, Geomorphology, Headward Erosion, Hydrosedimentology.

1 INTRODUCTION

The CRW covers an area of 5284 km^2 and is located in northeastern Ecuador, in a transition zone between the Cordillera Real mountain range and the Amazon biome, known as the subAndean zone - Napo uplift, figure 1. This watershed is characterized by high rainfall, steep slopes and unusual geodynamic activity manifested by the presence of volcanoes and earthquakes.
The CRW has been characterized by two fundamentals facts:

1. Natural fact "*1987 earthquake*", this CRW suffered two earthquakes triggering of one of the most catastrophic landslides of the 20th century—worldwide (Schuster, 1996).
2. Antrophic fact "*CCSHP*", In the 1970s, the National Electrification Institute of Ecuador (INECEL) initiated pre-feasibility studies for the Coca Codo Sinclair Hydroelectric Project. After the 1987 earthquake and the associated major landslides, some studies questioned this project and the need for a substantial revision of the studies arose. However, the final project was presented in 2007 in the CRW and its construction began in 2010. This hydroelectric power plant is classified as "run-of-the-river", so its intake and engine room are located at distant locations. Finally, the CCSHP was inaugurated in 2016.

Only four years after the beginning of the CCSHP´s operation, the San Rafael waterfall collapsed and the CR began an aggressive process of headward erosion that threatens the CCSHP and other strategic infrastructure of the Country present in the CRW. Actually, the erosion front is nearly 8 km from the intake.

The aim of our work was to evaluate how the anthropogenic alteration of the hydrosedimentary flows influenced the erosion and sedimentation regimes of the river, disturbing at the same time the fluvial geomorphology and the strategic infrastructures located in the CRW.

2 METHODOLOGY

The research methodology involves two sets of variables: 1. those concerning hydrosedimentology; and 2. those concerning geomorphology and geology

2.1 Hydrosedimentology:

Several hydrosedimentological parameters were analyzed, such as the annual rainfall, solid and liquid discharge. These data come from the hydroelectric, INAMHI and EMAPS databases.

2.2 Geomorphology and Geology

The morphological evolution of the Coca River and its tributaries was carried out based on the analysis of the erosion rate and morphological changes in these 2 erosion years. These data come from the CELEC.

The Instituto de Investigación Geológico y Energético made the geological study of this area: lithology, stratigraphy and the geological model between San Rafael Waterfall and Malo River.

3 DISCUSSION AND CONCLUSION

3.1 Hydrosedimentology

The CHRC is the second place more humid in the Amazonian Watershed and it has a dynamic river system, whose Salado River sub-watershed is characterized by providing the greatest contribution per square kilometer in terms of both solid flow (1,078.15 t/km-2 yr-1) and liquid flow (114.06 l.s-1.km-2), figure 2.

3.2 Geology and Geomorphology

In this zone, the lithology of the riverbed is mainly made up of volcanic deposits from the Reventador volcano (avalanche deposits) and fluvial-lacustrine deposits resulting from the close relationship between the CR and the Reventador volcano throughout its geological history. The geological model shows a natural process of HE, that was present in the CR geological history. In fact, the CR suffered periodic natural damming as a result of the geodynamic activity of the area (earthquake and volcano) and the river responded with erosive processes in order to release its enormous flow, figure 3.

Nevertheless, the construction of the CCSHP altered the hydraulics river (solid and liquid flow regimes) wand therefore its geomorphology and the erosion-sedimentation patterns. The most striking geomorphological change results from the HE, which was triggered on February 2, 2020 after the collapse of the San Rafael waterfall. At the outset, it is necessary to go back to the origin of this waterfall approximately 12,000 years ago, when a lava flow from the Reventador volcano interrupted the original riverbed, creating a waterfall that acted as a natural barrier, or knickpoint, that dammed all the material along the riverbed upstream of it. With the CCSHP´s construction, the river lost a great quantity of bedload sediments and this situation could have been a factor that catalyzed the infiltrations already present in the cascade´s sill located behind the waterfall column, thus accelerating a process that could have taken hundreds or thousands of years to cause a total failure of the structure. Indeed, our erosion rate model showed that, after the construction of this project, there was a 42% increase in the erosion rate measured at the "Coca en San Rafael" station, figure4. These results show the impact of the project on the river's dynamics, changes that are evident in the morphology of the river and in its erosion and sedimentation patterns. However, it´s not concluding due to the lack of information about the destiny of earth removed during the CCSHP´s construction (aprox. 2,300,000 m^3 of earth)

Since the waterfall collapse, the erosion process has advanced at an alarming rate of approximately 11 km in less than 22 months. During this time, this phenomenon has caused a deep change in the landscape of the upper Coca, incising the riverbed and increasing the new floodplain´s width.

The erosion rate has not been permanent or sustained, as the peak discharge during the rainy season and the riverbed lithology have accelerated or slowed the advance of erosion, figure 5. The erosive front has been temporarily stopped twice during the dry season but has continued to erode the banks of the Coca river and influence the erosion of tributaries such as the Montana, Marker and Malo rivers. Since its beginnings, the regressive erosion has marked the evolution of the river profile in the form of a slide that loses slope as it moves away from the old waterfall, figure 6.

Sedimentation patterns have also been changed due to the large amount of solid material that is now flowing downstream the CR, causing disturbances to both the population and the hydroelectric plant. Without a doubt, the communities living along the CR and whose lifestyle is closely related to the river have been affected by the loss of land, the impossibility of fishing, flooding or even access to water, which is undoubtedly generating conflicts.

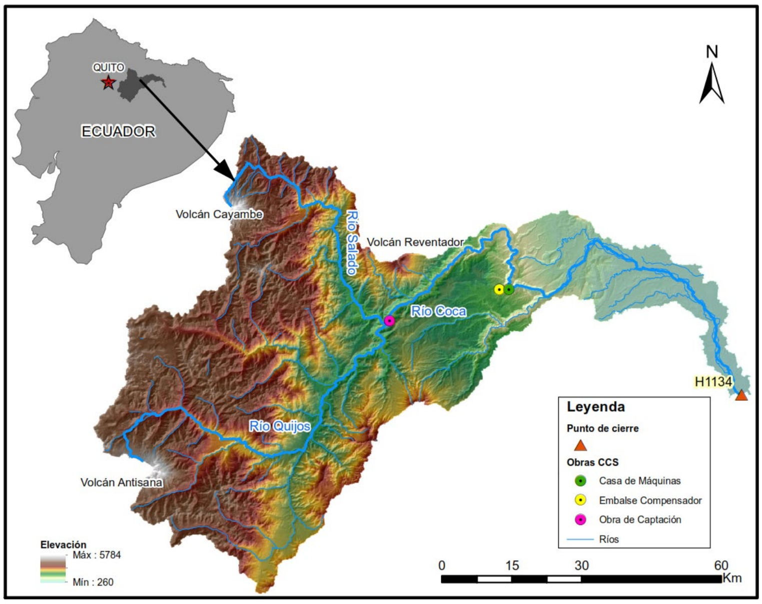

Figure 1.- Study Area

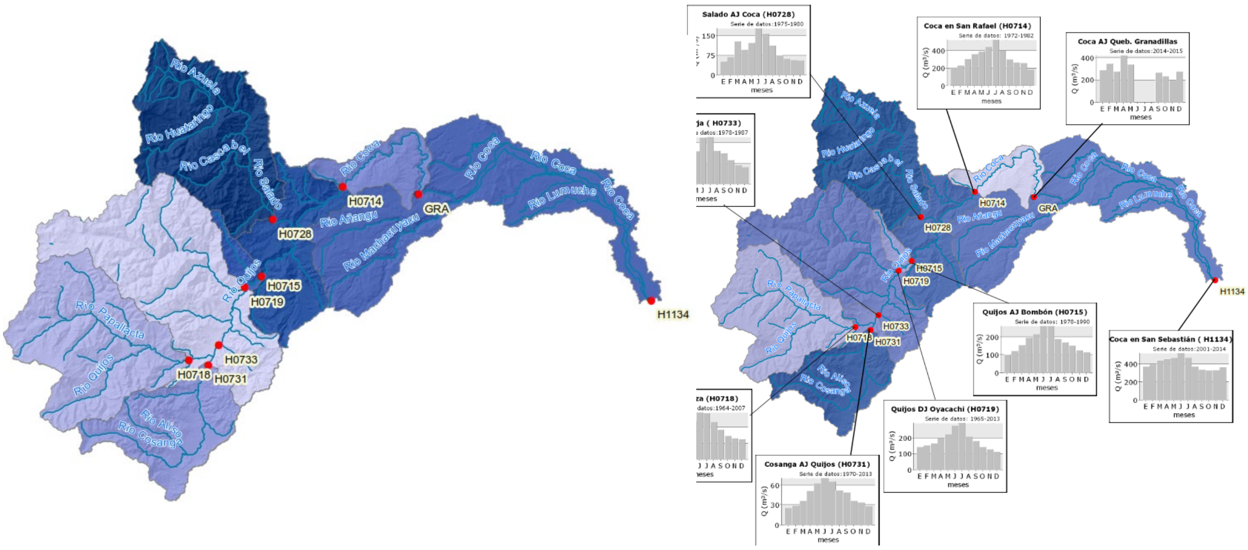

Figure 2.- Solid and Liquid Discharge in the Coca River Watershed

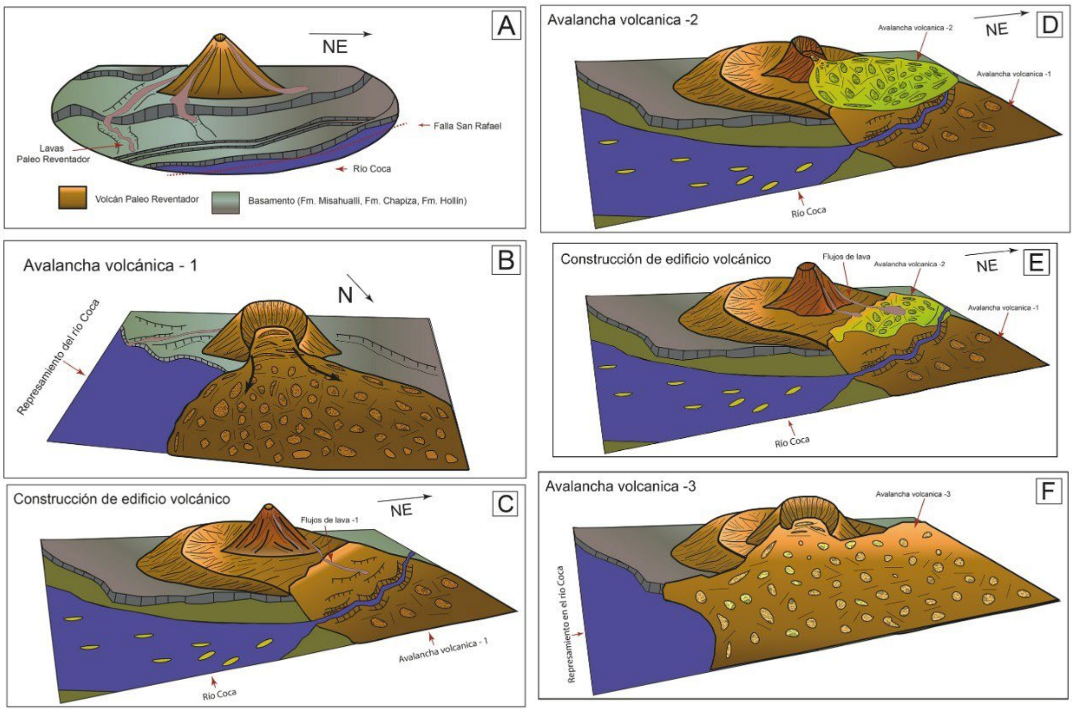

Figure 3.-Study Area Geological Model, IIGE 2020

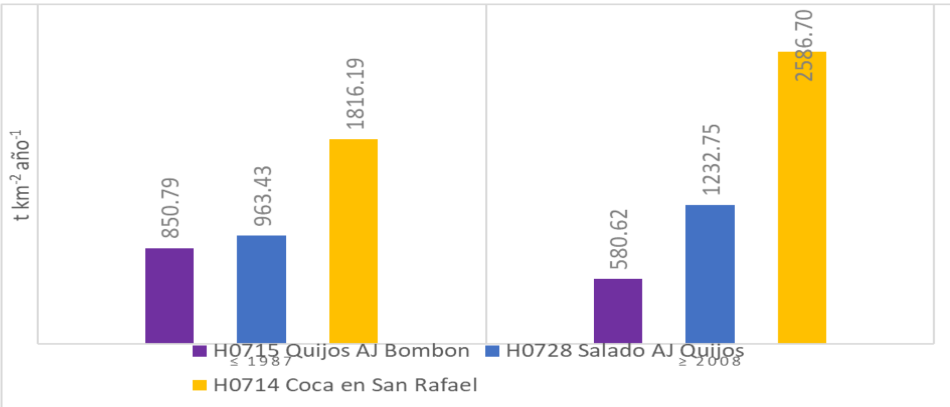

Figure4.- Estimated erosion rates - Period <1987 and >2008

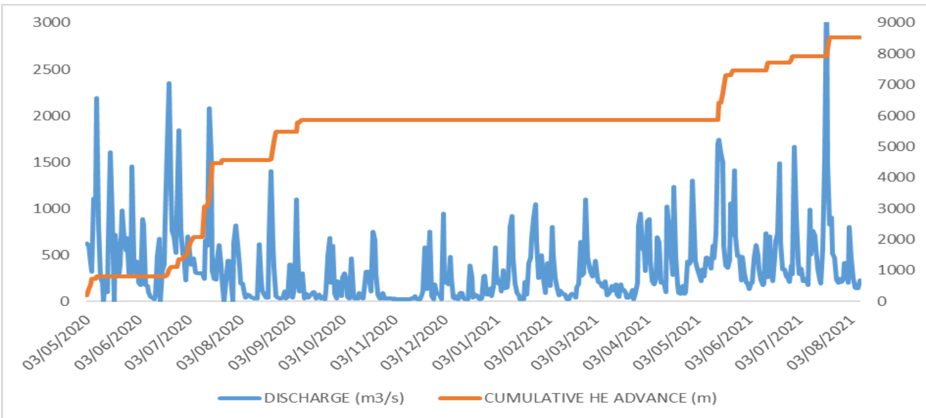

Figure 5.- Erosion Advance vs. Discharge

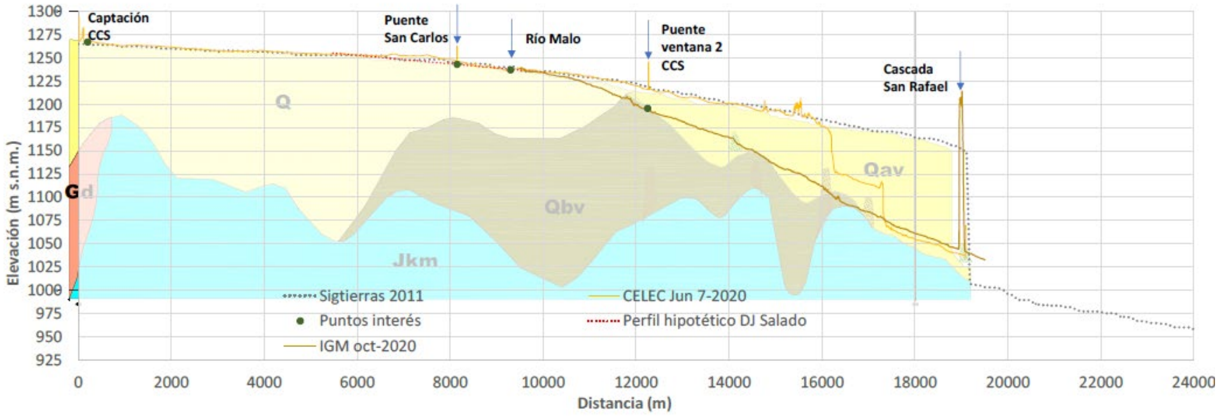

Figure 6.- Coca River´s Profile Evolution, Abril, 2021

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