CAN A MEANDER CUTOFF-INDUCED CHANNEL DEGRADATION BE ALTERNATIVE FOR THE CHANNEL DREDGING? CASE STUDY FOR THE HUALLAGA RIVER, PERU

KENSUKE NAITO
Centro de Investigacion y Tecnologia del Agua, Universidad De Ingenieria Y Tecnologia, Lima, Peru, knaito@utec.edu.pe

TOSHIKI IWASAKI
Faculty of Engineering, Hokkaido University, Sapporo, Japan, tiwasaki@eng.hokudai.ac.jp

LEO GUERRERO
Centro de Investigacion y Tecnologia del Agua, Universidad De Ingenieria Y Tecnologia, Lima, Peru, lguerrero@utec.edu.pe

HENRY VALVERDE
Centro de Investigacion y Tecnologia del Agua, Universidad De Ingenieria Y Tecnologia, Lima, Peru, hvalverde@utec.edu.pe

YULISSA ESTRADA
Centro de Investigacion y Tecnologia del Agua, Universidad De Ingenieria Y Tecnologia, Lima, Peru, yestrada@utec.edu.pe

JORGE D. ABAD
Centro de Investigacion y Tecnologia del Agua, Universidad De Ingenieria Y Tecnologia, Lima, Peru, jabadc@utec.edu.pe

ABSTRACT

In this study, an anticipated meander cutoff in the Huallaga River, a meandering river in Peruvian Amazon, is investigated. Approximately 80 km of the study reach includes several sites where channel dredging is planned to improve navigability. All these sites are located upstream of the anticipated meander cutoff point, which is approximately 75 km downstream from Yurimaguas. Due to the increasing concern about negative environmental impacts, alternative measure is sought. Natural channel degradation due to the meander cutoff is hence expected to replace the artificial river modification. In this study we study progradation of the upstream bed degradation and the downstream bed aggradation triggered by the cutoff. A simple two-dimensional numerical model is developed to achieve the objective. Prior to the model development, field measurements are conducted in order to obtain model input parameters such as channel geometry, water discharge, suspended load, bed load, bed material size and hydraulic resistance. Based on the model results, discussions are made in terms of the possibility to replace the artificial channel modification (i.e. dredging) with natural channel modification due to the meander cutoff to improve the channel navigability.

Keywords: meander cutoff, channel degradation, dredging, numerical modeling

1. INTRODUCTION

Rivers provide primary means of transportation in the Amazon basin (Dominguez, 2004). Maintaining navigability, therefore, is a crucial task for both federal and local governments. In recent years, the Amazon Waterway Project has been initiated in Peru. The project aims to improve the efficiency and safety of vessels, and “bad paths (or malos pasos in Spanish)” have been identified to be dredged along the major Peruvian Amazonian rivers: Maranon River; Ucayali River; and Huallaga River. Figure 1 shows a map of the Huallaga River between Yurimaguas, the largest port city in the region, and near the confluence with the Maranon River. The location of six potential dredging zone (as of December 2019) is also indicated.

While dredging the river courses can contribute the regional and federal economic growth, environmental impacts need to be studied carefully. Complex two-/three-dimensional behavior of the flow and sediment as well as complex planform dynamics of a meandering river, however, limit such assessment, hence the prediction of the effectiveness of the dredging and temporal interval of the dredging needed to maintain desired navigability is limited.

Here, we study bed degradation induced by a meander neck-cutoff in the Huallaga River, then assess as to whether the natural bed degradation can replace some of the planned dredging. Meander cutoffs result in shortening of the channel path, creating locally steep bed slope (Hooke 1995, Monegaglia et al. 2019). The steep bed profile diffuses both upstream and downstream, causing bed degradation in the upstream and aggradation in the downstream. Using two-dimensional numerical model, we study the progradation of the channel bed deformation. Out study site is the Huallaga River, where a meander cutoff is anticipated at approximately 75 km downstream of a major port city Yurimaguas (Fig. 1). All the planned dredging points are located upstream of the cutoff point.

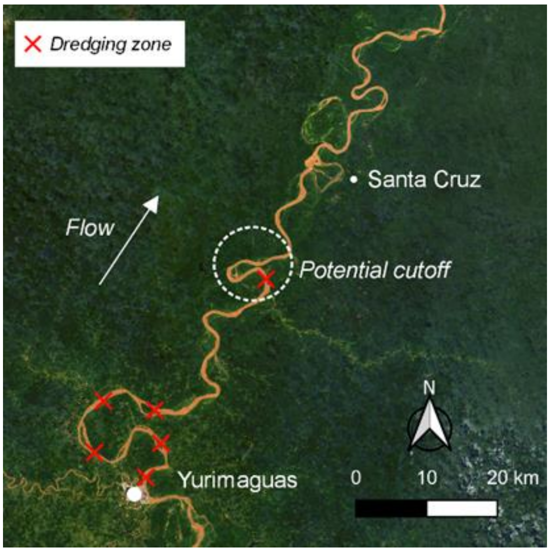

Figure 1. Map of the Huallaga River. Red-crosses indicate planned dredging points.

2. METHODOLOGY

The numerical simulation is performed using iRIC platform, and Nays2DH solver is selected for this study. Detailed description of the model can be found in Nays2DH user manual (https://i-ric.org/en/). Here, we modified the sediment transport relation to obtain the measured sediment transport rate of our river reach as explained in later section.

2.1 Computational setup

Computational domain is set to 80 km long and 450 m wide. The channel width is treated as invariable in space. Moreover, lateral bank erosion or deposition are omitted. First, the model is run with "before-cutoff" condition for two years. The initial channel slope is specified based on SRTM-DEM, and the initial cross-sectional shape of entire river reach is flat since sufficient bathymetric data is not available. That is, this "before-cutoff" calculation is intended to obtain the reasonable river bed feature of this reach. The artificial cutoff is then made by connecting the two channels at the meander neck. Figure 2a shows the resulted elevation map and the cutoff channel that was manually made. We then run the model for another two years to observe the progradation of the bed deformation.

2.2 Input parameters

Model input parameters are prepared based on a series of field measurement. Water discharge, suspended load, bedload and surface materials are collected. The measurements have been conducted along the course of the Huallaga River in March 2018, May 2019 and September 2019 in order to capture variation within a hydrologic year. We note here that the hydrograph reaches the highest in February-March and the lowest in August-September in the study area. In this study, the hydrograph, which is shown in Figure 2b, is used as a model input for water discharge rather than a single discharge in order to take seasonal flow variation into account.

We analyze the measured data to obtain a sediment transport relation. Egelund-Hansen type total load relation (Engelund and Hansen, 1967) is used in this study. The relation reads

$$\boldsymbol{q_t^*} = \boldsymbol{\alpha(Cz)^2(\tau^*)^\beta} \quad (1)$$

where q_t^* is dimensionless total load per unit width Cz is dimensionless Chezy resistance coefficient, τ^* is dimensionless bed shear stress (Shields number), and α and β are coefficient and exponent, respectively. Table 1 summarizes model input parameters. B is channel width, D_{50} is median bed material size and S_I is the initial channel slope, respectively.

Table 1. Summary of model input parameters.

Parameters	B (m)	D_{50} (mm)	Cz (1)	S_I (1)	L (km)	α (1)	β (1)
Values	450	0.3	12	0.0001	80	0.1	1.5

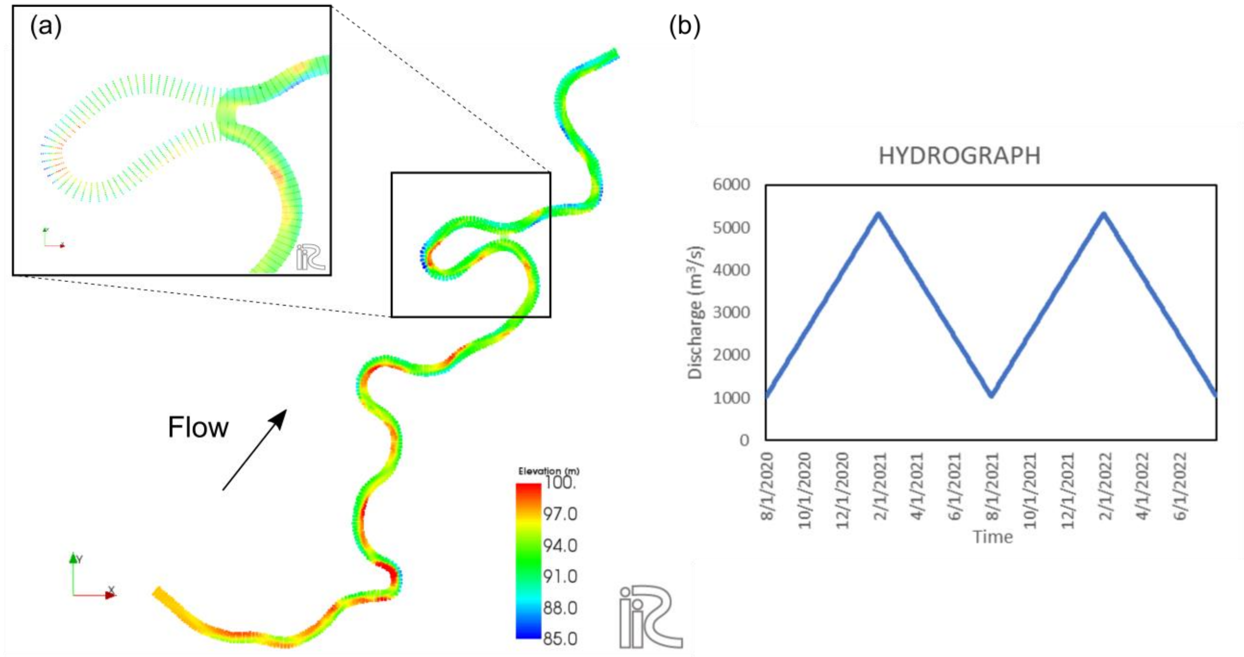

Figure 2. (a) Elevation map after two years of model run with "before-cutoff" condition and artificial meander cutoff. (b) Model-input hydrograph that is constructed based on measurement in February 2018, May 2019 and September 2019.

3. RESULTS

Figure 3 shows the model results of the two years-model run after the cutoff, between 20 km and 55 km of the domain. It shows initial channel bed (black line), after 0.5 years (blue), 1.0 year (light blue), 1.5 years (green) and 2.0 years (yellow). It should be noted that the hydrograph peaks at 0.5 years and 1.5 years (Fig. 2b). The result is somewhat noisy due in part to the use of hydrograph, which results in a dynamic and continuous evolution of the river channel (i.e., migrating sand bars), and makes it difficult to examine the degree of the effect of the cutoff.

The result does, however, show a trend of channel degradation. Plots of the cross-section average bed elevation (Fig. 3a) and minimum bed elevation (Fig. 3b) both indicate a trend of bed degradation at an upstream adjacent of the meander cutoff. While it is arguable that the effect propagates further upstream of the cutoff location in terms of the minimum bed elevation, the mean bed elevation profile indicates that the effect is limited to about 30 km from the upstream end.

It is indicated that downstream of the cutoff also experiences the bed degradation, and the degree of the degradation seems to be more severe than the upstream. The effect is, like the upstream part, spatially limited.

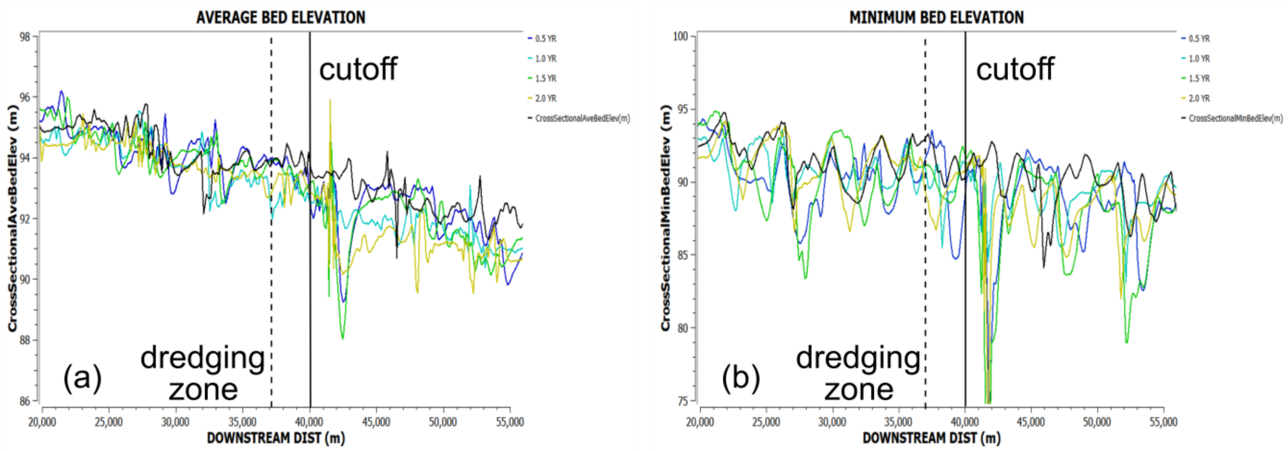

Figure 3. Downstream variation of (a) average cross-section elevation and (b) deepest elevation. The black line indicates the initial condition (after the model run with "before-cutoff" condition), blue line indicates model result after 0.5 years, light blue line indicates after 1.0 year, green line indicates after 1.5 years and yellow line indicates after 2.0 years, respectively. Computational domain between 20 km and 55 km from the upstream end is shown.

4. DISCUSSION

The model results show that degree of the channel incision due to the meander cutoff is limited, both in magnitude and space. Thus, it is unlikely that the cutoff affects the channel elevation sufficiently within desired timescale to replace the dredging, except one just upstream of the meander cutoff (Figs 1, 3).

In our simple two-dimensional modeling framework, lateral channel shift and lateral channel erosion are omitted. In the case of freely-meandering natural rivers, however, there are cases where channel-cross section modification dominates, rather than changing the longitudinal profile, after the cutoff (Hooke et al 1995, Zinger et al. 2013). This is due in part to timescale required for cross-section adjustment being much smaller (Monegaglia et al. 2019, Naito and Parker 2019). These effects can mitigate the longitudinal profile modification.

Furthermore, previous studies have reported the “triggering effect”, in which a meander cutoff accelerates the meandering process and consequential cutoffs at adjacent meander loops (Hooke 2002, Camporearle 2008, Schwenk and Foufoula-Georgiou 2015). This indicates, in the case of the Huallaga River, a possibility that the anticipated cutoff enhances the meander loop development and cutoff at the most adjacent meander (Fig. 1), which can in turn trigger the creation of the knickpoint and further upstream channel incision. A higher-order model that allows lateral channel shift and channel width adjustment are needed for such analysis.

5. CONCLUSIONS

Using two-dimensional numerical model, the effect of an anticipated meander cutoff of the Huallaga River, Peru is studied. The effect is assessed in terms of possible replacement for the engineering dredging that are planned (as of December 2019) to improve navigability of commercial vessels. The dredging is, however, opposed by local communities due to potential negative environmental impact. The model results show the channel degradation after the meander cutoff, both upstream and downstream of the cutoff point. The effect of the cutoff is, however, limited both in space and magnitude. Our model lacks several important physical processes of meandering rivers, such as lateral channel shift and self-width adjustment. Consideration of these processes can improve the model performance and reliability. Nevertheless, we note that consideration of meander cutoff into the river management planning could potentially reduce the number of dredging, mitigating negative environmental impact on the river system.

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