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Technical article

Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: Application of the new HEC-RAS version 5

V. Moya Quiroga[a,b,*], S. Kure[a], K. Udo[a], A. Mano[a]

[a] International Research Institute of Disaster Science, Tohoku University, Sendai, Japan
[b] Instituto de Hidráulica e Hidrología, UMSA, La Paz, Bolivia

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ABSTRACT

Llanos de Moxos are vast plains in the Bolivian Amazonia that are continually flooded by the Mamore river. The flood lasts for several days affecting important cities like Trinidad, drowning people, drowning cattle and swamping arable land. Because of the cloudy skies, remote sensing observations are limited to some areas and few days. Thus, there is huge uncertainty about characteristics of flood events and possible consequences. Two-dimensional (2D) numerical simulation proved to be an important tool for understanding flood events. The HEC-RAS model is one of the most popular hydraulic models. In 2014 a new version of HEC-RAS (HEC-RAS-v5) was released including 2D capabilities. The present study applied the new HEC-RAS-v5 to simulate the February 2014 flood event in the Bolivian Amazonia. The flood simulated shows good performance when compared with satellite image of the flood event. In addition, the simulation provides information like water depth, flow velocity and a temporal variation of the flood. Specific locations where water begins to overflow were identified. Over most of the flooded area the water velocity is lower than 0.25 m s^{-1}. During first ten days of the flood the flood extent increases rapidly. The flood depth allows identifying areas exposed to different hazard levels. The west plain of the Mamore river is the most exposed to the flood; it shows bigger flood extent, longer flood duration and deeper water depth. The flood that threatens the city of Trinidad originates in two locations; one located 32 km at the north and other located 10 km at the south west. The flood from the north gets close to Trinidad twelve days after it begins to overflow, while the flood from the south gets close to Trinidad seven days after it begins to overflow. Although the flood from the north is deeper than the flood from the south, the flood from the south begins flooded before the north. Thus, water borne and vector borne diseases may originate at the south earlier than the north. The city of San Javier gets covered by flood five days after the water begins to overflow. The study shows the applicability and the value of the 2D capabilities of the new HEC-RAS for flood studies.

Aplicación de simulación numérica 2D para analizar la inundación de febrero de 2014 en la Amazonia Boliviana: aplicación del nuevo HEC-RAS versión 5

Palabras clave:
Simulación bidimensional
Simulación de inundación
HEC-RAS
Amenaza de inundación
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RESUMEN

Llanos de Moxos son planicies de inundación en la Amazonia Boliviana que constantemente son inundadas por el río Mamore. Las inundaciones se prolongan durante varios días afectando importantes ciudades como Trinidad, ahogando gente, ahogando ganado e inundando cultivos. La visibilidad de imágenes satelitales se ve limitada debido a la nubosidad. Por tal motivo se tiene un gran desconocimiento sobre las características de la inundación y sus posibles consecuencias. Simulación numérica bidimensional (2D) es una importante herramienta para simular y analizar inundaciones. El modelo HEC-RAS es

* Corresponding author.
E-mail addresses: vladyman@hotmail.co.uk, moyav@potential1.civil.tohoku.ac.jp (V. Moya Quiroga).

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uno de los más populares modelos hidráulicos. En octubre de 2014 la última versión de HEC-RAS versión 5 fue publicada con capacidades 2D. El presente estudio aplicó el nuevo HEC-RAS versión 5 para simular la inundación de febrero de 2014 en la Amazonia Boliviana. La inundación simulada muestra buen desempeño comparado con imagen satelital del evento. Además, la simulación provee información adicional como puede ser profundidad de agua, velocidad del flujo y la variación de la inundación en el tiempo. Se identificaron lugares específicos donde el agua comienza a inundar la planicie. En la mayor parte del área inundada la velocidad del flujo es inferior a 0,25 m s^{-1}. Durante los primeros diez días de inundación la extensión de la inundación se incrementa rápidamente. La profundidad de la inundación permite identificar zonas expuestas a distintos niveles de amenaza. La planicie al oeste del río Mamore es la más expuesta a la inundación; esta tiene mayor área inundada, duración más prolongada y mayor profundidad de inundación. La inundación que amenaza a Trinidad se origina en dos lugares; uno ubicado unos 32 km al norte de Trinidad y el otro ubicado unos 10 km al sudoeste. La inundación del norte se acerca a Trinidad en unos doce días después de iniciarse la inundación, mientras que la inundación del sudoeste se acerca a Trinidad unos siete días después de iniciarse la inundación. Pese a que la inundación del norte muestra mayor profundidad de inundación, la inundación del sur llega a Trinidad antes. Por tal motivo, es posible que brotes de enfermedades se originen en el sur. La ciudad de San Javier queda inundada unos cinco días después de iniciarse la inundación. El presente estudio muestra la aplicabilidad y los posibles beneficios de las nuevas capacidad 2D del nuevo HEC-RAS para estudio de inundaciones.

1. Introduction

Floods can be considered as the most important natural disaster with an occurrence higher than any other natural hazard and affecting more people than all the other natural hazards together [1]. Besides, climate change will increase flood probabilities and the magnitude of floods [2]. Floods are related to social–civil conflicts [3], environmental problems [4] and economic losses [5]. The Llanos de Moxos located in the Bolivian Amazonia are an example of floodplains that continually suffer severe flood events causing environmental, economic and social damages. Several hectares of arable land get swamped, several thousands of cattle heads are drowned, crops are flooded and some important cities are either flooded or threatened by flood waters. Besides, due to the flat topographic characteristics of the area the floods last for several days; hence, people are also exposed to water borne and vector borne diseases. Flood risk management measures are required for the Llanos de Moxos.

Flood risk assessment and management are fundamental steps for identifying current hazards, prone risk areas and reducing them in future flood events [6]. In order to propose flood management measures it is important to understand the flood and to analyze the effect of the proposed measures. A simple approach is to analyze floods based on in situ flood observations [7]. However, in situ flood observations are not always available. Other studies use remote sensing data for flood studies [8,9]. However, usually flood events occur during cloudy skies that limit the use of remote sensing data. Besides, flood studies based on observation are only valid for specific flood events. Hence, future flood events or the effect of flood structural measures cannot be analyzed by such observation based maps. The use of numerical models allows simulating flood events considering different scenarios. Hence, numerical models are important tools for understanding flood events, flood hazard assessment and flood management planning. Previous studies showed the applicability of numerical models for producing hazard maps considering different flood management strategies [10,11] or reconstructing past flood events [12].

Numerical models may use either one-dimensional (1D) or two-dimensional (2D) models. Although the 1D modelling approach could be useful in some contexts, mainly for artificial channels, it presents several limitations for overflow analysis [13]. When water begins to overflow it becomes a 2D phenomenon and the use of a 2D model is more suitable. Thus, 2D numerical models were successfully applied for flood modelling [14–16]; the discharge is used as upstream boundary condition of the main river channel and then a 2D simulation is performed. Nowadays there is a wide availability of numerical models with different capabilities and from different developers; some models are free while others require the purchase of a licence. One of the most popular hydraulic models is the American model HEC-RAS developed by the U.S. Army Corps of Engineers (USACE). HEC-RAS is a free software with a friendly graphical user interface that was successfully used for flood studies [17–19]. Moreover, it is under constant improvement and development by the USACE. However, one of its greatest limitations was that it was limited to 1D flows. Thus, studies usually combined HEC-RAS with other models 2D; flow discharges at certain cross section are used as boundary condition for the 2D model [16]. Last year (2014) HEC-RAS announced and released its new HEC-RAS version 5.0 Beta (HEC-RAS-v5) with 2D capabilities [20]. The model is still distributed as beta version and not fully available. Due to the popularity of HEC-RAS, this new 2D capabilities are a great innovation for future flood studies.

The present study aims to analyze the 2014 flood event in Llanos de Moxos using the 2D capabilities of the new HEC-RAS-v5. A 2D numerical simulation of the 2014 Llanos de Moxos flood event was performed with the new HEC-RAS-v5 and daily discharges of the Mamore river. The model provided daily simulation of the flood extent, flood depth and flow velocities. The simulated flood extent shows good performance when comparing to the flood extent observed by satellite image.

2. Study area and data

2.1. Study area

Llanos de Moxos are vast floodplains between latitudes 12.0° S and 17.0° S and longitudes 62.5° W and 67.0° W in the Bolivian Amazonia. They have a mean elevation below 150 m above sea level and a gentle slope lower than 10 cm km^{-1}. The central part of Llanos de Moxos is a floodplain subject to severe inundations that may inundate up to 150 000 km^2 affecting thousands of people and lead to human-economic losses equivalent to millions of U.S. dollars [21]. The low gradient and the impermeable clayey soils favour the inundation [22]. The main river is the Mamore river which is also the longest and most important Bolivian river. During the wet season the Mamore river overflows and floods the area. The most important economic activity within the study area is cattle with a production that accounts for about 42% of the Bolivian cattle. Besides cattle, crops like yucca, rice, banana and corn are also