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Source: Journal of Coastal Research, 75(sp1) : 1347-1351

Published By: Coastal Education and Research Foundation

URL: <https://doi.org/10.2112/SI75-270.1>

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# The Impacts of Debris Torrents in Caribbean Coast of Honduras, Central America

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## ABSTRACT

Kim, S.; Lee, H., and Jun, K.W., 2016. The impacts of debris torrents in Caribbean coast of Honduras, Central America. In: Vila-Concejo, A.; Bruce, E.; Kennedy, D.M., and McCarroll, R.J. (eds.), *Proceedings of the 14th International Coastal Symposium* (Sydney, Australia). *Journal of Coastal Research*, Special Issue, No. 75, pp. 1347 - 1351. Coconut Creek (Florida), ISSN 0749-0208.

One of the main contributing factors in creating debris torrents is heavy rainfall. Global climate changes have led to an increase in localized downpours, causing an increase in torrent occurrences as well. The purpose of this experiment is to utilize numerical simulation for the analysis of debris torrents in their behaviour and mechanism. The numerical simulation is comprised of equations calculating mass continuity and momentum in order to consider erosion, deposition, and the combination of them both. The Finite Difference Method is applied to analyze the debris torrents. The numerical model of present study was applied to four rivers in Omoa and Puerto Cortes, Honduras (Central America). Out of the four rivers, the Cuyamel River exhibited the greatest value of water discharge and water depth, and the Tulian River showed the biggest runoff real volume value for the debris torrents. It is deduced that high levels of sediment concentration affect the environment surrounding the ocean in areas consisting of both mountain areas and the ocean.

**ADDITIONAL INDEX WORDS:** Debris torrents, climate change, sediment concentration, Honduras.

## INTRODUCTION

In October of 1998, a Category 5 hurricane called Mitch struck Central America. Mitch is considered one of the most devastating hurricanes to strike the Western hemisphere within the past two centuries. Among the five countries within Central America, Honduras experienced the most impact from hurricane Mitch, and the Eastern Caribbean region of Honduras suffered the most damage. The storm caused as many as 11,000 casualties, left over 1.5 million homeless, which is 20% of the population, and wrecked over one third of the nation (Hellin and Haigh, 1999; Hellin *et al.*, 1999). In combination with the hurricane's heavy rainfalls, the fundamental cause behind the damage is due to the impacts of the saturated soil and the debris torrents of the bare hillsides. As a result, the residents of the hillside regions suffered the greatest damage.

Climate changes are observed to affect debris torrents. Globally, debris torrents are occurring at a higher rate, thus increasing the number of casualties and damaged territories on a larger scale. The damage is caused by the water supplied from the upstream region of the debris torrent flowing downstream with high mobility, mixing with fractured rocks and sediments caused by erosion and deposition. On a spatial-temporal scale, disasters caused by debris torrents are nonhomogeneous and occur irregularly, making it difficult to predict for. Therefore, it is important to combine forces and take preventive measures in understanding the mechanisms and characteristics of catastrophe.

DOI: 10.2112/SI75-270.1 received 15 October, 2015; accepted in revision 15 January, 2015

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In this study, the district of Honduras' Caribbean coast connected to Guatemala's earthquake zone and the four main rivers is chosen for further analysis of the attributes of debris torrents including their water discharge and water depth. The results of the study show that the districts of Omoa and Puerto Cortes of the Honduras Caribbean Coast exhibit a variety of inclined slopes that help provide useful information in predicting debris torrent occurrences and establishing preventive measures.

## METHODS

The governing equations used to interpret the solid-liquefied mixture of the debris torrents are the continuity equation of water flow, which satisfies mass conservation, and the continuity equation of sediment particle, as shown in (1) and (2) respectively.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = \beta B \quad (1)$$

$$\frac{\partial (Ch)}{\partial t} + \frac{\partial (CM)}{\partial x} = C_* \beta \quad (2)$$

Where,  $A$  is area of flow section,  $Q$  is flow discharge,  $\beta$  is erosion velocity or deposition velocity,  $B$  is width of channel,  $C$  is sediment concentration in debris torrents,  $M$  is flow discharge per unit width,  $h$  is water depth, and  $C_*$  is maximum sediment concentration in the bed.

To calculate erosion or deposition velocity  $\beta$  the following equation is used (Takahashi *et al.*, 1992).

For deposition,

$$\beta = \alpha' \cdot \frac{C_\infty - C}{C_*} \cdot \frac{M}{d_m} \quad (3)$$

For the erosion,

$$\beta = \alpha \cdot \frac{C_{T\infty}}{C_* - C_{T\infty}} \cdot \frac{M}{d_m} \times \left\{ 1 - \frac{C}{C_\infty} \frac{\rho_m \tan \phi - (C_T / C_{T\infty})(C_\infty / C)\rho / \rho_m \tan \theta}{\tan \phi - \tan \theta} \right\} \quad (4)$$

where  $\alpha$  is erosion coefficient,  $\alpha=0.007$ ,  $\alpha'$  is deposition coefficient,  $\alpha'=0.01$ ,  $C_\infty$  is the equilibrium sediment concentration,  $C_T$  is the volume concentration of the total solid fraction,  $C_{T\infty}$  is the equilibrium of the total solids,  $\rho_m$  is the mixture density of water and sediment ( $\rho_m = (\sigma - \rho)C + \rho$ ),  $\sigma$  is the density of sediment particle,  $\theta$  is the angle formed by the bed slope and water surface elevation,  $\phi$  is the internal friction angle of the sediment.

To understand the movability of the solid-liquefied mixture flow, the momentum equation is applied; (5) shows the momentum conservation equation of the solid-liquefied mixture flow.

$$\frac{\partial M}{\partial t} + \frac{\partial \left( \frac{Q^2}{AB} + gA \cos \theta \right)}{\partial x} = gh \sin \theta - \frac{\tau_b}{\rho_m} \quad (5)$$

Where,  $g$  is gravity acceleration and  $\tau_b$  is the bottom shear stress. The changes in the thickness of soil strata due to erosion and deposition of the bed surface can be calculated with the following equation (6):

$$\beta = -\frac{\partial \xi}{\partial t} \quad (6)$$

Where,  $\xi$  is the deposition thickness of the bed measured from the original bed surface elevation.

The solid-liquefied mixture must satisfy the mass and the balance of the mass-momentum equation in order to observe the following equation (7) with (1), (2), and (5) in its conservative form (Chow, 1959).

$$\frac{\partial \mathbf{V}}{\partial t} + \frac{\partial \mathbf{\Omega}}{\partial x} = \mathbf{E} \quad (7)$$

Where,  $\mathbf{V} = \begin{bmatrix} A \\ M \end{bmatrix}$ ,  $\mathbf{\Omega} = \begin{bmatrix} Q \\ \frac{Q^2}{AB} + gA \cos \theta \end{bmatrix}$ ,  $\mathbf{E} = \begin{bmatrix} \beta B \\ gh \sin \theta - \frac{\tau_b}{\rho_m} \end{bmatrix}$

The equilibrium sediment concentration based on the particles' movement of the debris flow can be observed with the following equation (8).

$$C_\infty = \frac{\rho_m \tan \theta}{(\sigma - \rho_m)(\tan \phi - \tan \theta)} \quad (8)$$

Equation (8) shows that depending on  $\tan \theta$ , the following information can be classified: stony debris torrents, immature debris torrents, and turbulent debris torrents (Takahash, 1997).

Debris torrents are greatly affected by heavy rainfalls and the rainfalls' intensity brought upon by climate changes. Therefore, knowledge of discharge of debris torrents between intervals of elapsed time is important in the prediction and thereby the prevention of the disaster.

Therefore, the numerical model used by Kim and Lee (2015) is implemented for this study and the Finite Difference Method (FDM) is applied to effectively analyse debris torrents of various elapsed time intervals.

Honduras widely covers the Central American isthmus, covering an area of about 112,000km<sup>2</sup>. The climate of the Honduras Caribbean coast experiences seasonal easterly trade winds, causing the rainy season to last up to eight months each year. Annually, the annual rainfall exceeds 2000 mm and the average air temperatures range between 25°C and 29°C. In addition, this region is located within the hurricane belt and is connected to the earthquake zone of Guatemala (Bommer and Rodriguez, 2002). Therefore, such factors cause Honduras to always suffer from debris-torrents related disasters.

The following study analysed the characteristics and the discharge of debris torrents for four main rivers situated in two districts of the Honduras Caribbean coast, Puerto Cortes and Omoa. The four main rivers are the Tulian river, Masca river, Coto river, and the Cuyamel river.



Figure 1. Location of the selected study area at Caribbean coast in Honduras (Image source: Google map©).



Figure 2. Topographic maps of four rivers at Caribbean coast in Honduras (Image source: Google map©).

The data of rainfall intensity from 1998 of Hurricane Mitch are used as input data for the experiment, where the maximum rainfall intensities ranged from 138mm/hr (2-minute period) to 58.4 mm/ hr (60-minute period). Figure 1 shows the target site of the experiment.

**RESULTS**

Figure 2 is the topographic map of three of Omoa’s watershed areas and one of Puerto Corete’s watershed areas.

The following information is the drainage area (in square kilometres) and the main channel length (in kilometres) of the four rivers listed respectively: Tulian river 7.8km<sup>2</sup> and 7.6 km, Coto river 6.2km<sup>2</sup> and 2.8 km, Masca river 5.2km<sup>2</sup> and 1.2 km, and Cuyamel river 10km<sup>2</sup> and 2.2 km.

The conditions for calculating the numeral simulation are given. The supply water discharge is calculated using the rational formula using the values of rainfall intensity and rainfall runoff. The predicted value of rainfall intensity for all the four rivers were uniformly set with the average maximum range of 98.2mm/hr given by Hurricane Mitch of 1998, and for each river the supply water discharge was set using the watershed area of the upper stream.

The supply water discharge values are 212.77m<sup>3</sup>/sec for Tulian river, 169.12 m<sup>3</sup>/sec for Coto river, 141.84 m<sup>3</sup>/sec for Masca river, and 272.78 m<sup>3</sup>/sec for Cuyamel river.

In the designated area, the depth of suspended sediments is set to  $D_p=10m$  for the stabilization of the saturated sediment layer.

The mean diameter of sediment is  $d_m=30cm$ , the volume concentration of sediment in the static bed is  $C^*=52%$ , the density of sand particle is  $\sigma=2.65g/cm^3$ , and the internal friction angle of a sand is  $\tan \phi=0.7$ . The time lapse of the simulation was 360 seconds.

Figure 3 is a graph that exhibits the flow discharge and flow water depth of the designated watershed points at the Tulian river after the debris torrents reached the downstream over a 360 seconds time period. In Figure 3, the y-axis labels the flow discharge and the flow water depth, whereas the x-axis shows time elapses; from 288 meters to 2,448 meters are the points chosen from upstream towards downstream. Figure 3 shows that the peak flow discharge in the fastest time lapse occurred at the downstream 2,448 m point. On the other hand, the flow discharge line at the upstream 288 m point showed a more gradual slope.

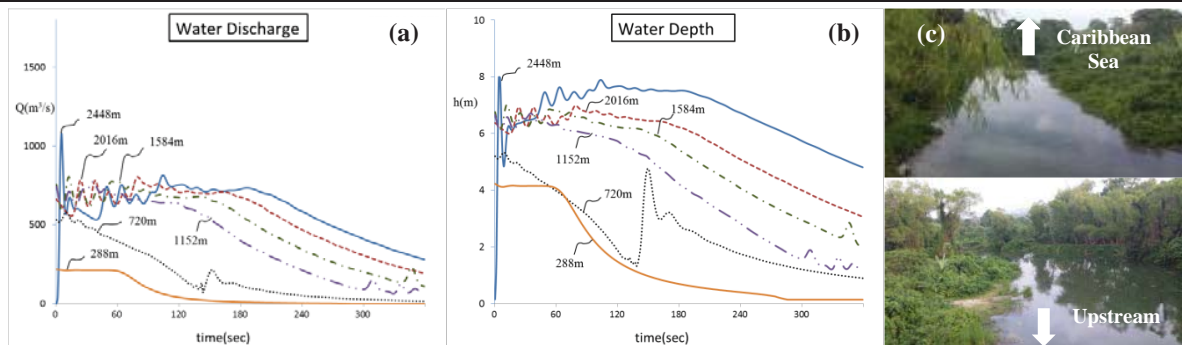


Figure 3. Predicted debris torrents characteristics in Tulian River (a), flow discharge (b), and flow depth (c).



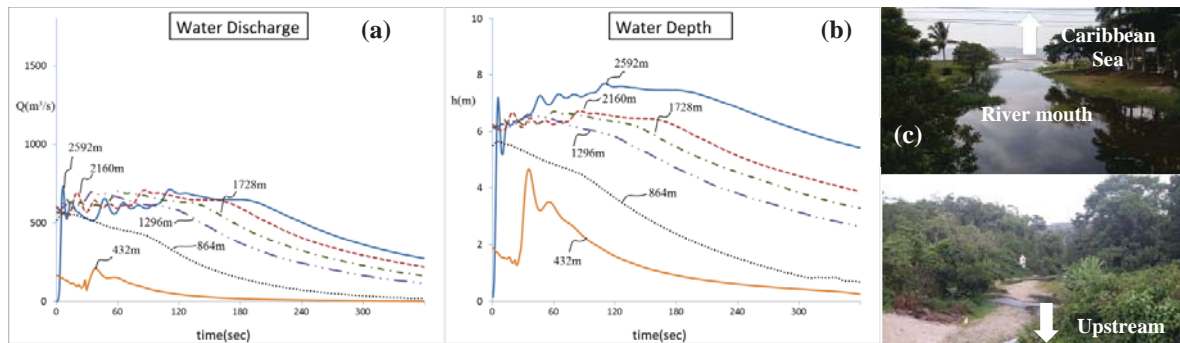


Figure 4. Predicted debris torrents characteristics in Coto River (a), flow discharge (b), and flow depth (c).

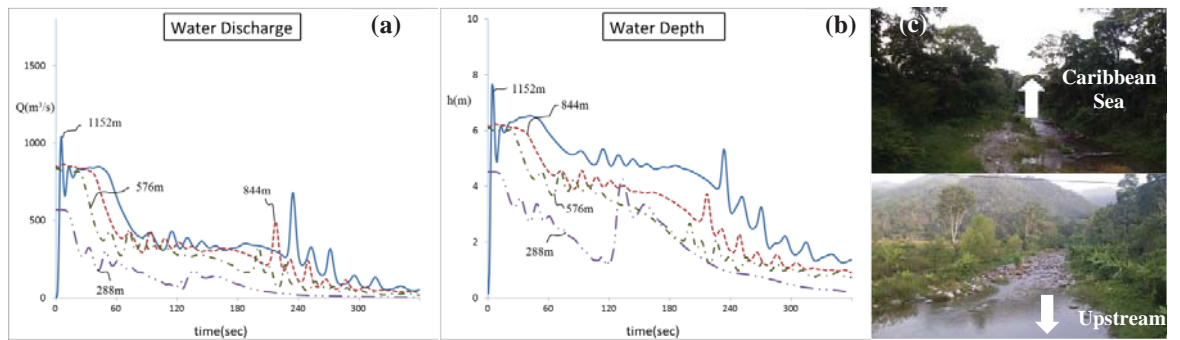


Figure 5. Predicted debris torrents characteristics in Masca River (a), flow discharge (b), and flow depth (c).

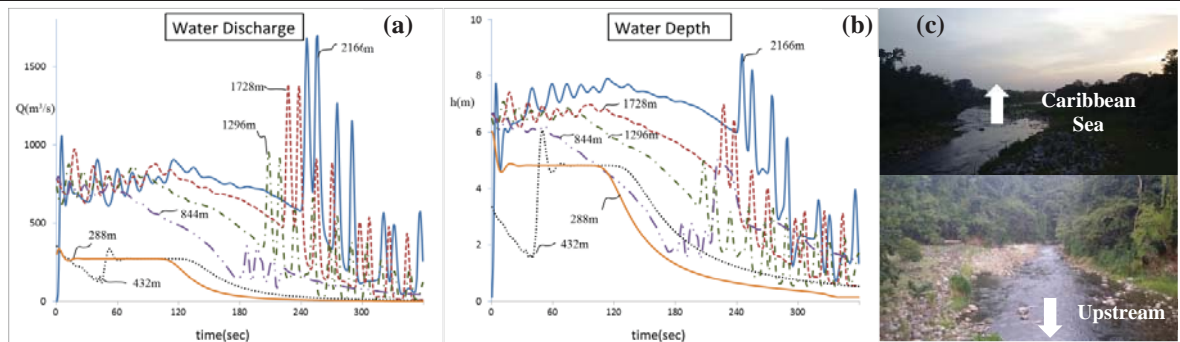


Figure 6. Predicted debris torrents characteristics in Cuyamel River (a), flow discharge (b), and flow depth (c).

The half point for all the main rivers showed fluctuation in the debris torrents, thus revealing distributions of high water discharge. As strong rainfall intensities develop from debris torrents of upstream mountainous areas, erosion and deposition repeatedly persist, thus causing much damage particularly around the mountainous area.

The depth of flow water shows similar conditions of water discharge. However, near the upstream 720 m point at around 150 seconds, a big height difference in water depth is observed.

The simulation result states the real volume of runoff debris torrents is about 136,080 m<sup>3</sup>.

In Figure 4, the peak water discharge value of the Coto river is small. The water depth value was high at the upstream 432 m point. In the case for Coto river, the flow rate exhibits an increase in water depth value from upstream continually towards downstream. The simulation result states the real volume of runoff debris torrents is about 120,962 m<sup>3</sup>.

Figure 5 shows that compared to the previous two rivers, the water discharge values of Masca river continually increase up to

the 60 secs point, and the downstream 1,152 m and 844 m points exhibit fluctuations at the 240 secs point. Among the four main rivers, Masca river has the shortest length, which may explain why the debris torrents show a faster arrival at the designated end point. The simulation result states the real volume of runoff debris torrents is about 67,630 m<sup>3</sup>.

Figure 6 shows that in the case of Cuyamel river, a high water discharge is seen spread along the downstream and then the water discharge fluctuates greatly between the 240 secs and the 300 secs time interval. It is deduced the high water discharge is due to the increase in supply water discharge caused by the wide watershed area and the long downstream length. The simulation result states the real volume of runoff debris torrents is about 124,417 m<sup>3</sup>.

### DISCUSSION

The erosion and deposition model established the numerical model where the governing equations consist of calculating for mass conservation and momentum conservation; the Finite Difference Method was applied and the results for each main river were inputted into a graph.

The supply water discharge values in four rivers are to be set up for simulating the program.

The flow discharge and flow water depth of the designated watershed points at the Tulian river after the debris flows reached the downstream over a 360 seconds time period in Figure 3. In Figure 3, the peak flow discharge in the fastest time lapse occurred at the downstream 2,448 m point. On the other hand, the flow discharge line at the upstream 288 m point showed a more gradual slope.

The peak water discharge value is small and the flow rate exhibits an increase in water depth value from upstream continually towards downstream in Figure 4. The water discharge values continually increase up to the 60 secs point and fluctuations at the 240 secs point in Figure 5. A high water discharge is seen spread along the downstream and then the water discharge fluctuates greatly between the 240 secs and the 300 secs time interval in Figure 6.

### CONCLUSIONS

In 1998, Honduras suffered much destruction from Hurricane Mitch. The destruction was mainly caused by the debris torrents provoked by the heavy rainfalls on the mountainous sloped areas. This study analysed the water discharge and water depth of the debris torrents located in the four main rivers situated in the Honduras Caribbean coast.

As the supply water discharge increases, the peak flow discharges shows a steeper slope and after a certain time period passes, the high water discharge undergoes a fluctuation.

At the mountainous upstream locations, strong rainfall intensities provoke a repeated circle of erosion and deposition which results in debris torrents causing much damage along the mountainous terrains.

Out of the four main rivers, the greatest values for water discharge and water depth are seen in the Cuyamel river, whereas the greatest value for runoff debris torrents of 136,080m<sup>3</sup> is seen for the Tulian river.

The analysis of the various slopes within the districts of Omoa and Puerto Cortes of the Honduras Caribbean Coast help

provide information to predict future debris torrent events and establish preventive precautions.

### ACKNOWLEDGMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (2013R1A1A4A01010397).

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