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Flooding hydrology and peak discharge attenuation along the middle Araguaia River in central Brazil

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ABSTRACT

The Araguaia River in central Brazil is the largest river draining the Brazilian savanna. Located in a tropical wet-dry climate, the middle Araguaia River has an extensive and complex alluvial floodplain composed of a mosaic of geomorphologic units, dense alluvial forest, and many floodplain lakes. The Araguaia River is not currently dammed, and thus it provides an opportunity to analyze flooding hydrology in a relatively un-altered tropical system. Using average daily discharge measurements from 1975 to 2011, we analyze patterns of peak discharge attenuation (defined as the reduction in absolute peak discharge in $m^3 s^{-1}$). We link peak discharge attenuation to bankfull discharge, explore whether peak discharge attenuation results in increased base level flows in the dry season following peak discharge, and use a simplified short-term water budget to determine whether peak discharge attenuation results in the loss of discharge from the channel over the flooding season (November to May). In addition, we explore other potential factors causing peak discharge attenuation, including surface water connectivity between the channel and floodplain lakes and floodplain lake area change between the dry season and the wet season. Although fluvial connectivity between the main channel and the floodplains starts before bankfull stage, we find that large peak discharge attenuation (up to 30% reduction in peak discharge) in the middle Araguaia usually occurs when the river rises above bankfull discharge. The river flow that is lost to the floodplain and floodplain lakes when peak discharge attenuation occurs usually returns to the channel by the end of the flooding season. However, the odds of increased baseflows in the dry season after flooding seasons with peak discharge attenuation are higher compared to flooding seasons without peak discharge attenuation for one of the studied reaches. Some types of floodplain lakes greatly increase in area from the dry season to the wet season, and many floodplain lakes become connected via surface water in the wet season. We have not found similar examples of peak attenuation in this type of tropical wet-dry floodplain system, indicating that the middle Araguaia River may be a unique system or that further research is needed.

1. Introduction

Flooding drives the exchange of water, nutrients, and sediments between rivers and floodplains, provides transitional areas for aquatic species, and creates mixing zones of waters from local and upstream sources. Through the creation of physical complexity and connectivity within the river-floodplain ecosystem, flooding sustains a diverse set of habitats for aquatic and terrestrial species (Amoros and Bornette, 2002; Fryirs and Brierley, 2013; Junk et al., 1989; Ward et al., 2002). However, the role of floods in ecological connectivity in large rivers does not depend only on the hydrologic regime and flood pulses, but also on channel and floodplain geomorphology and complex floodplain flow paths (Marchetti et al., 2013; Mertes et al., 1995; Montero and Latrubesse, 2013; Paira and Drago, 2006; Stevaux et al., 2013). In general, flooding has been studied from an ecological or hydrological approach (e.g., Junk et al., 1989), resulting in a lack of analysis of the mechanisms of flood transmissions from a hydrogeomorphic approach (Fryirs and Brierley, 2013). Large rivers, which are dominantly anabranching systems, contain the most complex floodplains (Dunne and Aalto, 2013; Latrubesse, 2015), and the use of hydrology without considering geomorphic mapping and the relationships between hydrogeomorphology and vegetation limits understanding of floodplain dynamics.

The tropics contain the largest rivers in the world in terms of water discharge (Latrubesse, 2008; Latrubesse et al., 2005). Large, relatively un-altered South American Rivers, such as the Araguaia River in central Brazil, provide an opportunity to investigate flooding patterns through a geomorphic lens. The Araguaia River is not currently dammed along the large main stem of the river and has an unmodified flow regime with pronounced wet and dry seasons. However, the Brazilian government has looked into constructing dams on the main stem of the Araguaia, and there are planned and operational dams in the upper portions of the watershed (Castello et al., 2013; Latrubesse et al., 2005). In addition,

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land clearing for agriculture has impacted mostly the upper part of the watershed, with downstream geomorphic effects (Ferreira et al., 2008; Latrubesse et al., 2009; Sano et al., 2010). There are also plans to develop portions of the Araguaia River for the Tocantins-Araguaia waterway in order to transport commodities, and these developments could modify the geomorphology of the river via channelization and/or straightening (Agência Nacional de Transportes Aquaviários, 2013; Castello et al., 2013; Latrubesse and Stevaux, 2002).

The middle Araguaia River displays peak discharge attenuation (Aquino et al., 2008), which we define as the absolute reduction in peak discharge as a peak moves downstream (in $m^3\ s^{-1}$). The main factors that influence peak attenuation include storage areas, roughness, geometry, and hydrology (Fig. 1) (Sholtes and Doyle, 2011; Turner-Gillespie et al., 2003; Woltemade and Potter, 1994). The potential geomorphic mechanisms that cause this peak attenuation along the Araguaia, such as floodplain lakes (storage) and floodplain lake connectivity (geometry), have been previously explored (Aquino et al., 2008; de Morais et al., 2005), but detailed patterns of peak attenuation in relation to bankfull discharge and the influence of peak attenuation on baseflows have not been investigated. Floodplain storage, floodplain inundation, and flood wave attenuation have been demonstrated in tropical rivers such as the Amazon River, the Negro River, the Mekong River, and the Congo River (Alsdorf et al., 2010; Frappart et al., 2005; Lee et al., 2011; Richey et al., 1989), but peak attenuation has not been documented in other large tropical river systems similar to the Araguaia River. In that context, the un-altered Araguaia River provides an opportunity to characterize the patterns and mechanism of flood transmission and channel-floodplain connectivity in a large tropical river.

This paper describes flooding characteristics and peak discharge attenuation in the Araguaia River, linking flood transmission with the geomorphic characteristics of the floodplain. We aim to improve the existing characterization of peak discharge attenuation along the middle Araguaia River, relate these patterns to bankfull discharges, and determine whether peak attenuation results in higher-than-average baseflows in the dry season. Peak attenuation should be related to flows above bankfull discharge, because the floodplain plays an important role in causing attenuation by providing storage areas and slowing the flood wave (Fig. 1) (Sholtes and Doyle, 2011; Woltemade and Potter, 1994). Because one of the factors causing peak attenuation is the storage of water outside of the channel, for example, in the floodplain or in floodplain lakes (Frazier and Page, 2009), large peak attenuation could result in higher baseflows in the dry season due to gradual draining of storage areas after the wet season has ended. We also use a simplified water budget to determine whether peak discharge attenuation results in an overall loss of discharge from the channel to the floodplain during the flooding season. Finally, we examine the geomorphic mechanisms causing peak discharge attenuation by determining changes in floodplain lake areas (storage) and floodplain lake connectivity (geometry) between the dry and wet season.

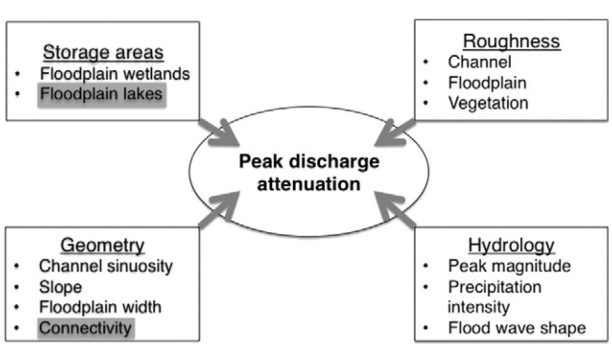

Fig. 1. The four main factors that influence peak discharge attenuation. The gray boxes indicate the factors focused on in this paper, which are floodplain lakes acting as storage areas and connectivity between the main channel and floodplain lakes. Connectivity can also include lateral subsurface connectivity as well as vertical exchanges of water.

2. Study area: the Araguaia River

The Araguaia River watershed is approximately 377,000 km^2 in area, with a mean annual discharge of 6420 $m^3\ s^{-1}$ (Latrubesse and Stevaux, 2002) (Fig. 2). The region has a tropical wet-dry climate, which influences the patterns of flooding on the Araguaia River. The dry season occurs from May to September and the rainy season from October to April, corresponding with an annual flooding season. Annual precipitation in the region ranges from 1300 to 2000 mm across the basin, with 95% of the annual rainfall between October and April on average (Agencia Nacional de Aguas, 2012). Flooding lags slightly behind the onset of the rainy season, usually occurring from November to May (Latrubesse and Stevaux, 2002). Most of the vegetation in the Araguaia River watershed is classified as *Cerrado*, the Brazilian savanna, although a small portion of the lower watershed is characterized as Amazonian rainforest. The *Cerrado* has been identified as a biodiversity hotspot (Myers et al., 2000) and includes forestlands, shrublands, grasslands, and wetland vegetation (Sano et al., 2010). However the Araguaia basin was highly impacted by land use changes during the last decades, particularly in the upper portion of the watershed (Ferreira et al., 2008; Sano et al., 2010).

Situated in Brazil's central highlands, the geology of the Araguaia River watershed includes Quaternary fluvial deposits, Precambrian rocks, and Paleozoic and Mesozoic rocks (Latrubesse and Stevaux, 2002). Latrubesse and Stevaux (2002) divide the river into three sections: upper, middle, and lower (Fig. 2). The 450 km upper section of the river, from the headwaters to Registro do Araguaia, is more confined than the middle Araguaia River, flowing over Precambrian and Paleozoic rock units. The 1160 km middle Araguaia River, from Registro do Araguaia to Conceição do Araguaia, has created an alluvial floodplain, with the floodplain width ranging between 2 and 10 km. The 500 km lower section of the river extends from Conceição do Araguaia until the river flows into the Tocantins, and lacks an extensive floodplain, flowing over Precambrian rocks. The Araguaia River is an axial tributary system, meaning that it flows through a well-defined and fringing linear valley-floodplain (Latrubesse, 2015).

The middle Araguaia River is an anabranching river with a tendency to braid (Latrubesse, 2008; Latrubesse et al., 2009). It consists of three main geomorphologic units, classified by Latrubesse and Stevaux (2002) using elevation data, satellite imagery, and fieldwork (Fig. 3). Unit I, the oldest unit, is a lower elevation backwater area containing oxbow and paleochannel lakes, termed the "impeded" floodplain. Unit II consists of paleomeanders and oxbow lakes. Unit III is a complex of accreted bars and islands that exists close to the active river channel (Latrubesse and Stevaux, 2002). Unit I, usually the farthest from the

Fig. 2. The Araguaia River watershed in central Brazil, with the two study reaches in the right panel.