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Towards dynamic flow regime management for floodplain restoration in the Atchafalaya River Basin, Louisiana

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ABSTRACT

This study proposes a novel approach for establishing adaptive environmental-flow prescriptions for rivers, channels, and floodways with substantial flow augmentation and a limited decision space using the highly altered Atchafalaya River Basin (ARB) in Louisiana as an example. Development of the ARB into the primary floodway of the Mississippi River and Tributaries Project has contributed to hydrologic changes basin-wide that have altered the river-floodplain interface threatening important ecosystems, notably the expansive baldcypress-water tupelo swamp forests. Current restoration efforts only address the spatial distribution of water in local areas of the basin; however, the timing, frequency, magnitude, and duration of ecologically-important high and low flows are determined at the basin-wide scale by the daily implementation of a federal flow mandate that limits available water management options. We used current hydrologic conditions and established flow-ecology relationships from the literature to develop an environmental flow prescription for the ARB that provides basin-wide flow targets to complement ongoing restoration efforts. Hydrologic analysis of current flows and the flow-ecology requirements for these wetland forests revealed an overlap in the range of flow variability under the current water management model, suggesting environmental flows can be complementary with the desired hydraulic and geomorphic characteristics of the floodway. The result is a first step towards an adaptive flow regime that strives to balance important flow-ecology relationships within a decision space limited by a federal flow mandate. We found high potential for success in managing water for nature while accommodating other management needs for the river.

1. Introduction

Many river systems around the world have been engineered to produce a select set of ecosystem services which provide substantial economic and social benefits to society (Nilsson et al., 2005). These benefits come with substantial externalities such as altered hydrology, increased nutrient loads, reduced ecological and habitat diversity, and degraded water quality (Sparks, 1995; Bunn and Arthington, 2002). Efforts to reduce these externalities include implementing more natural flow regimes and improving floodplain connectivity (Rood et al., 2003; King et al., 2010); however, socioeconomic constraints, existing infrastructure, and a lack of scientific knowledge of watershed-scale process dynamics in large river systems challenges the ability of managers to meet environmental goals (Wohl et al., 2005). Increasing demand for water resources (Vörösmarty et al., 2000) and the uncertain effects of climate change on specific river systems (Palmer et al., 2008) will further challenge current river management approaches.

Restoring a natural flow regime (Poff et al., 1997) is a preferred approach to river restoration, but in many systems, socioeconomic demands and extent of physical alteration preclude the implementation of a natural flow regime. In these cases, environmental flows based on the natural flow regime are prescribed (see: Landres et al., 1999; Keane et al., 2009). Environmental flows attempt to restore particular characteristics of the natural flow regime when management options are limited (Acreman and Dunbar, 2004; Arthington, 2012). As such, many researchers have advocated for holistic approaches to river restoration where

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knowledge of the fluvial processes that historically structured target ecosystems is paired with established uses of the river, via the current flow regime, to develop an environmental flow prescription that operates within a socially relevant decision space (Arthington and Pusey, 2003; Poff et al., 2003; Richter et al., 2003; Tharme, 2003; Jacobson and Galat, 2008; Acreman et al., 2014).

Improving or reconnecting floodplain flows on regulated rivers is a primary target of river restoration (Opperman et al., 2009; Jacobson et al., 2011; Schindler et al., 2014; Guida et al., 2015). Functioning floodplains are considered among the most valuable, productive ecosystems on Earth (Tockner and Stanford, 2002; Costanza et al., 2014), but their benefits have been historically undervalued or unrecognized (Millennium Ecosystem Assessment, 2005; Acreman et al., 2014). Since regulated rivers provide services to society that one can assume will remain in demand, floodplain restoration efforts depend largely on recognizing fundamental changes that have occurred in a river system and identifying a management approach that addresses those changes while meeting existing socioeconomic demands (Holling, 2001; Williams et al., 2007; Arthington et al., 2010). Effectively, the decision space for efforts to restore or rehabilitate floodplain wetlands and associated ecosystem services in regulated river systems is delineated by current policies, established socioeconomic uses, and scientific understanding of current and historical hydrological and ecological processes. In many river systems, this scientific understanding will likely need to take place in the absence of a scientific panel or detailed scientific information, such as hydraulic models, due to a lack of resources.

In this paper we develop an adaptive environmental flow prescription for a flow diversion for flood mitigation. The restoration target is floodplain forests in the highly regulated and altered Atchafalaya River Basin (ARB), Louisiana (Fig. 1). To do this we work within existing management constraints and examine physical and hydrologic changes in the ARB to propose an environmental flow prescription based on a hydrologic analysis and a multi-disciplinary literature review that relates target ecosystem needs to a variety of flow components. The result is an environmental flow prescription that functions within current management constraints to restore, to the extent possible, the basin-wide flow conditions necessary to sustain important habitat and complement existing restoration goals. This is the first attempt we know of to develop adaptive environmental-flow prescriptions for a river or floodway with substantially augmented flows related to flood mitigation and this framework is potentially transferrable to other regulated river systems worldwide.

2. Study system

The ARB is the largest contiguous wetland in North America (Ford and Nyman, 2011) and the keystone of a flood mitigation effort that protects large areas of Louisiana from inundation including substantial port infrastructure on the Lower Mississippi River and the city of New Orleans. Its development into a federal floodway and the resulting water management model has altered the physical landscape threatening ecologically important and socially desirable habitat (Piazza, 2014).

In 1928, the ARB was designated a principal floodway of the Mississippi River and Tributaries Flood Control Project to be maintained and operated by the U.S. Army Corps of Engineers (USACE). To achieve the desired hydraulic characteristics for flood mitigation, the ARB was significantly modified: basin area was reduced to 26% of its historic size by flood protection levees (Lambou, 1990; Sabo et al., 1999); 22 natural distributaries were cut-off from the main channel; new channels for freshwater distribution were constructed; and the main channel of the Atchafalaya River was leveed for the first 85 km of its length to contain its flow (Reuss, 2004). Also, bank stabilization and river engineering caused a rapid disconnection of swamp habitats from the Atchafalaya River and its distributaries (Piazza, 2014).

The increased capacity of the main channel and a more efficient flow path to the Gulf of Mexico contributed to the Atchafalaya River capturing an increasing proportion of Mississippi River flow. To prevent total capture of the Mississippi River by the Atchafalaya River, the Old River Control Structure (ORCS) was completed in 1963 to regulate flow from the Mississippi River into the ARB. The authorizing legislation for ORCS requires that the total annual flow distribution between the Mississippi, Red, and Atchafalaya Rivers be in proportions that occurred in 1950, when 70% of total flow discharged down the Mississippi and 30% discharged through the ARB. Because the Red River flows directly into the ARB, the ORCS regulates flow only from the Mississippi River. Flow through ORCS, z, can be conceptualized with the equation:

$$z = 0.3\ (x + y) - x \tag{1}$$

where x is the flow in the Red River and y is the flow in the Mississippi River. The result is 60–93% of the flow in the Atchafalaya River comes from the Mississippi River (Mossa, 1996), maintaining a flow regime that mimics the Mississippi River and results in seasonal inundation of floodplain forests and riverine wetlands (Piazza et al., 2015). With the exception of flood events, USACE policy is to meet this 70/30 flow distribution on a daily basis allowing for a $\pm$7.5% operational margin (Water in the Basin Committee, 2002; Piazza, 2014).

The policy of daily adherence to the 70/30 flow distribution limits options for non-flood related water management efforts. The ARB maintains large expanses of floodplain inundation, supports large areas of remote wild lands, high levels of biodiversity, unique habitat (Reuss 2004; Ford and Nyman 2011; Piazza 2014), and provides market and non-market ecosystem services, including commercial fisheries, recreational hunting and fishing, ecotourism, and high levels of nutrient cycling, valued in the billions of dollars annually (Cardoch and Day, 2001; Atchafalaya Basin Program, 2014). Especially important are the baldcypress (*Taxodium distichum*) – water tupelo (*Nyssa aquatica*) swamp forests, which are ecologically critically important and also an integral part of the economy and culture of the region.

These swamp forests make up 43% (106,227 ha) of the Lower Atchafalaya Floodway (Fig. 1; Faulkner et al., 2009) and support rapid nutrient removal (Groffman et al., 1992; Chambers et al., 2005; Rivera-Monroy et al., 2010) and carbon storage (Watt and Golladay, 1999). They provide critical habitat for many species (Gooding et al., 2004; Crook, 2008; Ernst and Lovich, 2009), especially for juvenile crawfish, which represent a direct intermediate link in the food web between detritus material and recreationally and commercially important fish species (van Beek et al., 1979; Lambou, 1990; Bryan et al., 1998). When flooded, cypress-tupelo swamps are "hot-spots" for commercial crawfishing, the dominant commercial fishery in the ARB, producing crawfish yields more than 100 times greater than other swamp habitats (Huner and Barr, 1991; Chambers et al., 2005).

Cypress-tupelo swamp productivity and reproduction is determined by the timing, frequency, duration, and spatial distribution of floodplain inundation events, making water stage, rather than discharge, most relevant to forest health. Baldcypress depend on specific hydrological cycles for regeneration (Conner et al., 1986; Kozlowski, 1997; Keim et al., 2006) but can survive and grow in nearly permanent inundation, commonly living 400–600 years, with trees found to exceed 1600 years in age (Stahle et al., 1988; Wilhite and Toliver, 1990; Keeland and Young, 1997). Both species can regenerate in damp and frequently inundated soils but seeds