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Modeling residual flood risk behind levees, Upper Mississippi River, USA

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ABSTRACT

Flood protection from levees is a mixed blessing, excluding water from the floodplain but creating higher flood levels ("surcharges") and promoting "residual risk" of flood damages. This study completed 2D hydrodynamic modeling and flood-damage analyses for the 459 km^2 Sny Island levee system on the Upper Mississippi River. These levees provide large economic benefits, at least $51.1 million per year in prevented damages, the large majority provided to the agricultural sector and a small subset of low-elevation properties. However these benefits simultaneously translate into a large residual risk of flood damage should levees fail or be overtopped; this risk is not recognized either locally in the study area nor in national policy. In addition, the studied levees caused surcharges averaging 1.2–1.5 m and locally as high as 2.4 m, consistent with other sites and studies. The combined hydraulic and economic modeling here documented that levee-related surcharge + the residual risk of levee overtopping or failure can lead to negative benefits, meaning added long-term flood risk. Up to 31% of residential structures in the study area, 8% of agricultural structures, and 22% of commercial structures received negative benefits, totaling $562,500 per year. Although counterintuitive, structures at the margin of a leveed floodplain can incur negative benefits due to greater flood levels resulting from levees purportedly built to protect them. National levee policies and plans for local projects are unbalanced, crediting levee benefits but rarely fully planning for adverse impacts or considering alternatives.

1. Introduction

Recent floods in Europe have displaced half a million people and caused >€25 billion in insured economic losses (European Commission, 2014), and in the US flood damages have doubled (ASFPM, 2013). Such spiraling flood impacts are driven in part by increasing hydroclimatic extremes, but also by widespread reliance on structural flood-control measures, including urban floodwalls and levees (known regionally as "dikes", etc.). This research used (1) hydraulic modeling to precisely quantify and map surcharge and (2) economic flood-loss modeling using structure-by-structure assessor data to quantify levee benefits, costs, and residual risk. Analysis focused on the patterns and causes of economic 'negative benefits'—accrued by properties ostensibly protected by levees, but with higher long-term average flood risk than when modeled with no levees present. The purpose of this research was to map the hydraulic and economic impacts of levees in order to inform floodplain science, management, and policy.

US floodplains are lined by up to 161,000 km of levees (National Committee on Levee Safety, 2009), much of this in questionable states of repair. According to current US inspection data (National Levee Database as of 21 Dec., 2015), just 1.9% of levees by distance (by number, 103 of 2207 rated levees) were rated "Acceptable", with 53.7% of the nation's levees rated 'Minimally Acceptable' and 44.5% rated "Unacceptable". In the US, the benchmark for most levees is that they should protect for at least the 100-year recurrence interval flood, meaning the event that has a 1% chance of occurring or being exceeded in any given year. Under the US National Flood Insurance Program, floodplain land behind levees certified as providing ≥100-year protection (which should include 0.9 m [3 ft] of "freeboard", or safety margin) is removed from Special Flood Hazard Area on hazard maps (Federal Emergency Management Agency [FEMA] Flood Insurance Rate Maps). Other

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countries apply more stringent criteria for their levees, including The Netherlands, which requires at least 1250-year protection for river levees (Merz et al., 2010). Benchmarks such as the 100-year or even the 1250-year level are based on stationary flood statistics that may underestimate actual risk on rivers worldwide where both climate change and anthropogenic activities are increasing hydroclimatic extremes (e.g., Pinter et al., 2001; IPCC, 2014).

Levees function by confining flood discharges within the river channel and excluding overbank flows from some or all of the floodplain. This confinement causes higher water-surface elevations in the remaining portion of the channel (known as levee "surcharge"). These surcharges are caused by the loss of storage volume on the floodplain and loss of conveyance capacity (Yen, 1995; Bhowmik and Demissie, 1982; Heine and Pinter, 2011). A US Government Accountability Office study concluded "*[t]hat levees increase flood levels is subject to little disagreement*" (GAO, 1995), but the magnitudes of such surcharges are frequently disputed. Heine and Pinter (2011) surveyed long-term US Geological Survey river gages located close to levee construction projects. Surcharges were present at all sites, ranging from 42 cm up to 2.3 m. On the Mississippi and Missouri Rivers, a suite of large multivariate statistical models suggested up to 2.2 ± 0.2 cm of surcharge per 1% increase in floodplain area put behind levees (Pinter et al., 2008, 2010) —equivalent, for example, to an increase of 2.1 ± 0.2 m for a floodplain that went from 0% to 95% leveed.

Any levee is constructed to function up to a given maximum flood magnitude, above which flow will overtop the levee and flow into the levee-enclosed portion of the floodplain. In addition, some levee breaches occur before water reaches the levee crest for geotechnical reasons such as erosion, under-seepage, or through-seepage (Rogers et al., 2008; Flor et al., 2010; IFMRC, 1994). During widespread flooding in 1993 on the Mississippi River and its

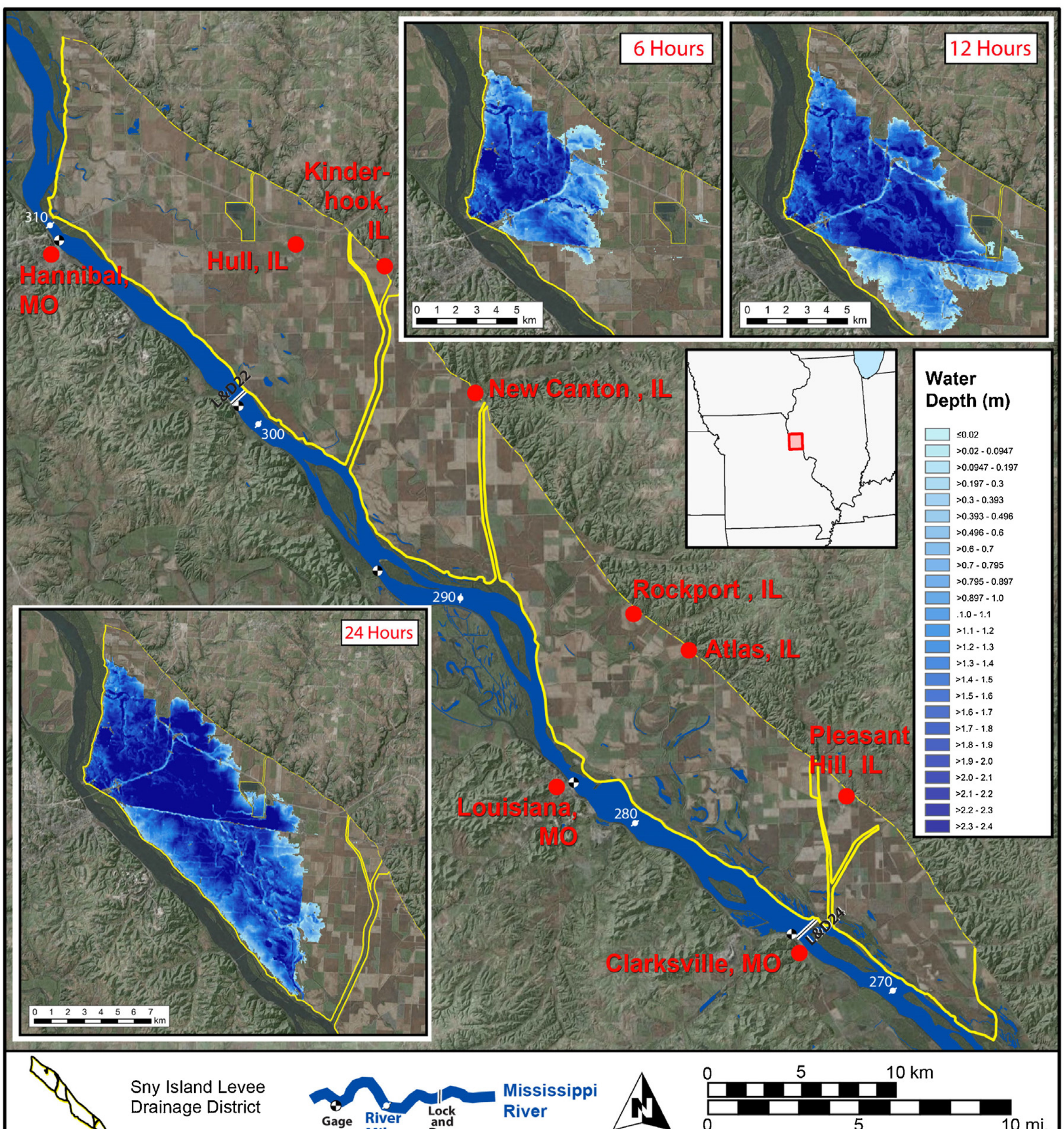

Fig. 1. The study area includes the natural floodplain circumscribed by the Sny Island levee system (yellow lines on map), along the east bank of the upper Mississippi River in Illinois, USA. Insets show water depths 6, 12, and 24 hours after a simulated breach in the upstream Sny levee cell.