Flooding and Resilience

Valuing Conservation Investments in a World with Climate Change

Carolyn Kousky, Margaret Walls, and Ziyan Chu
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Abstract

Communities in the United States are showing increasing interest in the use of forests, wetlands, and other natural areas to provide protection against extreme events. As the climate changes and such events become more frequent and/or more severe, investments in the conservation of natural areas should become more valuable. But how much more valuable is an open question. In this study, we evaluate the climate resilience benefits of a green infrastructure investment in Missouri: the Meramec Greenway. A buffer of forested lands and other open space, the Meramec Greenway runs along the Meramec River from its confluence with the Mississippi River south of St. Louis into the Ozark uplands. The study builds off of a recent benefit–cost analysis of the Greenway conducted by the authors but evaluates the additional benefits of floodplain conservation that might be provided if floods in the region (a) become more frequent and/or (b) worsen in severity. Results suggest that the benefits of the Greenway in terms of avoided flood damages are greater in both types of climate change scenarios. However, the size of the benefits under current conditions is the more important finding; climate change reinforces the value of the conservation investment but is not the main story.

Key Words: land conservation, extreme weather events, peak discharges, Hazus, avoided flood damages

JEL Classification Numbers: Q54, Q57, Q51, Q25, Q24
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Carolyn Kousky, Margaret Walls, and Ziyan Chu*

1. Introduction

The economic costs of flooding have increased in the United States over the last several decades, largely as a result of more people and property—and more valuable property—located in harm’s way (Pielke and Downton 2000). If flooding becomes more frequent or more severe with climate change, these costs will further rise. Climate models predict increases in the intensity of precipitation events in many locations in the future (Wuebbles and Hayhoe 2004; Intergovernmental Panel on Climate Change [IPCC] 2012). The precise effect that these precipitation changes will have on flood risks is uncertain, but various stakeholder groups are suggesting that it is time to think more seriously about relocating people out of harm’s way or preventing development of the most flood-prone areas. This has been suggested for certain coastal areas in the wake of Hurricane Sandy; inland floodplains are also a focus of conservation efforts. Restoring or maintaining natural lands in floodplains and other hazardous areas may not only reduce exposure, and thus bring down disaster costs, but may also provide an array of other ecosystem services.

Despite this growing interest, very little economic analysis has examined the costs and benefits of conservation to lower future damages attributable to climate change. Can the benefits of reduced future damage from extreme events justify conservation investments today? When coupled with the other benefits that natural areas provide, would consideration of the reduced damages from future extreme events alter land acquisition strategies? If so, which investments provide the greatest “bang for the buck”? Communities are searching for “no regrets,” or “low regrets,” options that can (a) provide protection under a range of outcomes, (b) offer other ancillary benefits, and (c) come at a

* The authors are fellow, research director and senior fellow, and senior research assistant, Resources for the Future. Corresponding author: Walls (walls@rff.org). This work was funded by a grant from the National Oceanic and Atmospheric Administration Climate Program Office’s Climate and Societal Interactions, Sectoral Applications Research Program. An earlier version of this paper was presented at the Pinchot Institute for Conservation conference, Forest Conservation in the Anthropocene, Washington, DC, September 17–18, 2013. We appreciate the helpful comments and suggestion from conference participants. We are also grateful to Lonny Boring, Carey Bundy, and Susan Trautman of Great Rivers Greenway for helping with our understanding of the history of and facts about the Meramec Greenway and for providing some of the data used in the study. We thank Ben Knox for helpful discussions as well. Finally, we thank Susan Poling and Tom Ott from the St. Louis County Parks Department for providing data on property buyouts.
reasonable cost. Thus, sound quantitative analysis of the costs and benefits of the land conservation approach is critical.

We take a step toward such an analysis here by estimating the additional benefits that would be provided by floodplain conservation lands if flooding were to worsen in the future as a result of climate change. Our case study is the Meramec Greenway in southern St. Louis County, Missouri, a collection of roughly 9,000 acres of conservation lands along the Meramec River. The Greenway includes two state parks, many local parks, and a system of trails and river access points. The lands consist primarily of hardwood forests and a small amount of open recreational space. In a recent study, we estimated the benefits of the Greenway in terms of avoided flood damages and nonmarket benefits, such as aesthetics and recreational access, that are captured in hedonic property values; we also compared these benefits to an estimate of the opportunity costs of preserving the lands from development (Kousky and Walls 2013). We did not consider the impacts of climate change, yet climate resilience is one of the oft-touted benefits of investments in natural infrastructure (Arkema et al. 2013; Jones et al. 2012).

In this paper, we assess how increased flooding as a result of climate change would affect the avoided flood damages from the Greenway. In other words, how much more is the Greenway worth in a world with more extreme flooding events? As local governments and conservation agencies continue to conserve lands in the Greenway, does consideration of future climate change suggest changes to their land acquisition strategies?

Climate projections at a local level are notoriously uncertain. Given that uncertainty, we look at several plausible future scenarios of flood risk, based loosely on findings in the literature, to provide some bounds on how potential changes in flood risk could translate into economic damages. These scenarios are not meant to represent any particular future reality; instead, they are used to generate order-of-magnitude estimates of the climate resilience benefits of floodplain conservation. We look both at scenarios in which the discharge of a given flood event is increased and scenarios in which the probabilities of floods of various magnitudes increase.

Even under no changes in flood risk, we find that the Greenway lands provide substantial benefits in the form of reduced flood damages. Slightly more than $13 million per year of flood damages are avoided in St. Louis County, on average, by keeping the protected lands in the 500-year floodplain of the Greenway undeveloped. This is about a 38 percent reduction from what average damages would be without the Greenway. It
implies a flood reduction benefit of roughly $6,000 per acre of protected lands. Previously, we estimated that, in combination with the recreational and aesthetic benefits of the lands, the Greenway passes a simple benefit–cost test, yielding positive net benefits for the region (Kousky and Walls 2013).

Increases in flood risk due to climate change make the Greenway lands even more valuable. For scenarios with peak discharge increases of 30 and 50 percent, the annual avoided flood damages of the Greenway increase by $4.5 million and $7.9 million, respectively. Thus, climate change reinforces the rationale for keeping the Greenway lands protected. The size of the flooded area increases in these scenarios—the 100-year floodplain grows by 12.8 percent and 18.6 percent, respectively, in the two scenarios. This may help to justify additional expansions in conservation acreage.

Increases in the frequency of flood events also raise the benefits of the Greenway lands. Doubling the probabilities of each individual flood event, from the 5-year flood up to the 500-year flood, doubles the annual avoided damages (from $13 million to $26 million). Some experts have suggested that it is the largest flood events that will worsen with climate change. We find that doubling the frequency of only the worst events (the 100-year, 250-year, and 500-year floods), leaving the frequencies of the smaller floods the same, has a relatively minor effect on avoided damages: annual avoided losses total $14.3 million instead of $13 million.

Climate change will manifest itself gradually over the decades to come. Assuming a gradual rise in damages over time alters our calculations and slightly lowers our estimates of resilience benefits. How much it lowers them depends on the rate used to discount future flood damages. The appropriate discount rate to use in climate policy analysis is a perennially contentious issue (Arrow et al. 2013; Cropper 2013). Several other dynamic issues are important as well—the robustness of particular investment choices to a range of climate outcomes, for example, and the costs of irreversible investments. We discuss some of these issues but leave more in-depth analysis for another day.

Our methodology calculates the benefits from reduced exposure to flooding—that is, the benefits from keeping developed properties out of harm’s way. It does not calculate the additional hazard mitigation benefits that might be provided by forest cover in terms of altering the hydrology of the riverine environment. Forests can intercept rainfall before it reaches the ground, and the soils can store water and reduce the flow to nearby streams and rivers. Thus, surrounding properties may experience reduced flooding...
because of flood storage on the Greenway lands, and lower flows on the Meramec may lead to less flooding downstream on the Mississippi River (the Meramec flows into the Mississippi). In our particular setting, such benefits are likely to be small: surrounding land uses currently do not include a lot of development, and the residential lots that do exist are large, which should limit flood damages to structures on those lots. Furthermore, the Mississippi is a highly managed river with a system of levees and dams that control flooding; thus, changes in flows from the Meramec are likely to have little impact downstream. In other settings, these additional benefits of natural systems may be important to quantify. However, it is our view that the avoided damages from preventing development in risky areas may still be an order of magnitude larger than the benefits from altered hydrology in many locations. More quantitative analysis of this important issue is needed.

The next section of the paper grounds the scenarios we choose to explore in the literature on the impacts of climate change on flooding. The third section provides background on our study area. Section 4 discusses our methodology, and Section 5 presents our numerical results. Section 6 provides some discussion of the results and additional considerations beyond our calculations. Some brief concluding remarks are provided in Section 7.

2. Review of the Literature on Climate-Induced Changes in Flood Damages

Over the twentieth century, floods accounted for more lives lost and more property damage in the United States than any other natural disaster (Perry 2000). Most climate models predict that these problems will worsen in the future; in fact, in a comprehensive overview of the likely effects of a changing climate on the nation, flooding is almost unique as an impact that is expected to be felt nationwide, affecting coastal and inland communities and rural and urban areas (National Research Council 2010). Although the climate models vary widely in assumptions and results, they tend to find that warming will lead to greater moisture loads in the atmosphere, accelerating the hydrologic cycle and increasing the frequency, intensity, and/or duration of storm events.

Regional climate models specific to the Midwest, and thus more relevant for our study, have also generally concluded that an increase in the frequency and intensity of heavy precipitation events is expected under likely future climate scenarios (Easterling and Karl 2001; Wuebbles and Hayhoe 2004). These model predictions are supported by some studies of the historical record. Using historical data from the Midwest, Angel and
Huff (1997) and Groisman et al. (2004) have identified an increase in heavy precipitation events. Kunkel et al. (1999) found that the frequency of extreme precipitation events occurring on average once per year—that is, “one-year” flood events—has increased 3 percent per decade nationally in the United States since the early part of the century; the frequency of five-year floods has increased by 4 percent per decade nationally in the United States.¹

An increase in extreme precipitation is expected by many flood experts to exacerbate flood risk. A global analysis found initial evidence that the number of severe floods (those exceeding 100-year levels) in large river basins has increased over the twentieth century (Milly et al. 2002). A study for the Upper Mississippi Basin that coupled a hydrology model to downscaled and bias-corrected climate projections found that, by the end of the century, winter, spring, and summer peak flows will increase, as will the flashiness of the hydrograph, particularly in the spring (Wuebbles et al. 2009).² A recent national-level analysis, undertaken for the Federal Emergency Management Agency (FEMA), estimates how the discharge associated with the 100-year flood may change through 2100 based on climate and population scenarios (Kollat et al. 2012). This study, which focused on riverine flooding, finds that the 100-year discharge could increase substantially, particularly in the Pacific Northwest, the Northeast, and in very urban areas. The authors of the study estimate that these areas could see increases in the 100-year discharge of 30–40 percent by midcentury, and more by century’s end.

However, some disagreement exists between those researchers who run climate models and those who look at the historical record of flood stages. Despite the modeling predictions, only mixed observational evidence points to increasing flood stages. Part of the issue is that flood stages are related to precipitation in a complex way (this is even more true for flood damages). It is difficult to tease apart the competing forces of climate change, land use, dam operation, levee construction, and other structural flood control measures. Pinter et al. (2008) have looked at these issues on the Mississippi River, but such studies are rare. Further, flood events depend not just on precipitation but also on antecedent soil moisture and changes in frozen ground cover, both of which may also be influenced by climate change (Hirsch 2011). Finally, all researchers agree that climate

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¹ A 1-year flood in this context refers to an extreme precipitation event that has a recurrence interval of 1 year. This classification can be extended to a 5- or 100-year flood based on the severity and probability of its occurring.

² A flashy stream is one that exhibits significantly increased flows immediately after the onset of a precipitation event and a quick return to pre-rain conditions after the event. In a flashy stream’s watershed, the water moves quickly from the land into the stream rather than being absorbed into the soils; this is worse for flooding.
impacts have yet to materialize in full, creating a disconnect between the historical record and future projections.

3. Background on the Meramec Greenway

St. Louis County is bordered by rivers: the Missouri in the north, the Mississippi in the east, and the Meramec in the south. The Meramec River joins the Mississippi River at the southern edge of St. Louis County. Levees line much of the length of the Missouri and Mississippi Rivers in the county, but the Meramec is largely devoid of any structural protection. The river has long been used for recreation; when dams have been suggested for the river, public sentiment has generally been opposed. As a result, the river remains mostly in a natural state. Flooding along the Meramec in St. Louis County can occur when large floods on the Mississippi back up into the Meramec or when heavy spring and summer precipitation lead to seasonal flooding; in areas along the river with steep slopes and thin soil cover, flash flooding is common (Winston and Criss 2003). In 2000, for example, flash flooding along the Meramec River damaged structures, roads, and bridges and led to two deaths (Winston and Criss 2003).

The Meramec Greenway runs from the confluence of the Meramec River with the Mississippi back 108 miles into the Ozark uplands. Initially created in 1975, the Greenway encompasses the lands around the river in the floodplain, the surrounding bluffs within sight of the river, upland areas deserving special protection, and publicly owned lands connected to the river valley (St. Louis County Department of Planning 2003). Much of the land remains in private hands, but the Greenway currently includes over 28,000 acres of parks and conservation lands, 9,000 of those acres in St. Louis County. This is roughly 15 percent of the 500-year floodplain of the Meramec and its tributaries that lie within the county. FEMA funded buyouts of frequently flooded properties in 1982 and again in 1993. St. Louis County adopted a concept plan for the Greenway in 2003 with multiple goals, including flood damage reduction as well as water quality improvements and expanded recreational opportunities (St. Louis County Department of Planning 2003). A map of currently protected lands in the St. Louis County portion of the Greenway is shown in Figure 1.

Table 1 shows the percentage of the Greenway protected lands in various land cover classes as well as the percentage for the unprotected portion of the Greenway. Using 2006 land cover data from the U.S. Geological Survey (USGS), we found that deciduous forests make up 73.3 percent of the land cover of the Greenway protected
lands in St. Louis County; mixed and evergreen forests are not common in the area, comprising only 0.4 percent of the Greenway protected lands and none of the unprotected acreage. Developed open space—areas such as sports fields, other parkland, and subdivision open space that are covered mainly in recreational grasses—is the next largest land cover class, making up slightly less than 11 percent of protected lands. The unprotected lands within the Greenway have a quite different distribution of land covers. These are lands that remain mostly in private ownership but may be targets for future protection. The most common land cover, at roughly 27 percent, is agriculture. Deciduous forest covers another 23 percent of these lands. Almost 20 percent of Greenway lands not currently in a protected status are developed.

Figure 1. Meramec Greenway in St. Louis County, Missouri

Figure 2 is a map of land cover for the entire Greenway, showing the spatial distribution of the land cover classes with the protected lands outlined in black. Most of the farmland is in the western portion of the Greenway. The large area of deciduous forest in the center of the map, in green, covers two state parks and county parkland as well as a private reserve. Forest cover exists in smaller patches throughout the Greenway. The purple areas show the developed open space; in the case of protected lands, much of
this is in local parks. Development is concentrated in a few parts of the remaining unprotected areas of the Greenway, as shown on the map.

Table 1. Percentage of Meramec Greenway Lands in St. Louis County in Various Land Cover Classes

<table>
<thead>
<tr>
<th>Land Cover Class</th>
<th>Protected lands</th>
<th>Unprotected lands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous forest</td>
<td>73.3</td>
<td>23.0</td>
</tr>
<tr>
<td>Evergreen forest</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Mixed forest</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Developed open space</td>
<td>10.9</td>
<td>15.2</td>
</tr>
<tr>
<td>Emergent herbaceous wetlands</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Woody wetlands</td>
<td>4.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Farmland</td>
<td>4.5</td>
<td>26.8</td>
</tr>
<tr>
<td>Developed uses</td>
<td>2.1</td>
<td>19.5</td>
</tr>
<tr>
<td>Barren land</td>
<td>0.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Open water</td>
<td>3.8</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Footnotes:

a Farmland includes pasture/hay, herbaceous vegetation and grasslands, and cropland.

b Developed uses consist mainly of low-intensity residential and commercial development.


4. Methods

We estimate the avoided flood damage benefits of the Greenway—both under current conditions and with climate change. To do this, we need to make an assumption about the land uses that would have occurred on these lands in the absence of protection. To assess the benefits of protection, we then compare the estimated damages under various flood events in this counterfactual scenario with the damages under current conditions. The difference is a measure of the benefits from the Greenway. To assess the benefits in a world with climate change, we undertake the same exercise but make assumptions about heightened levels of discharges and/or changes in the frequency of flood events.

This setting of the “no-Greenway” counterfactual scenario is important. For researchers who work on issues related to the “return on investment” in conservation, this represents the baseline against which to compare the investment outcomes (Boyd et al. 2012). In the debate over carbon offsets in the context of greenhouse gas mitigation policy, researchers often refer to “additionality,” or the need to make sure that the benefits are “additional to” a business-as-usual scenario (IPCC 2000). This too is similar to the issue we face here. In general, to consider benefits and costs of particular public
investments, it is necessary to establish a no-policy counterfactual outcome for comparison. We assume that the Greenway lands would have been developed as single-family homes, which account for most of the surrounding development, and we use surrounding property values as a guide for setting the value of the properties in this counterfactual.

**Figure 2. Land Cover for Meramec Greenway Lands**

To estimate flood damages, we use the Hazus-MH model, a national, GIS-based model developed for FEMA by the National Institute of Building Sciences. Hazus-MH couples a flood hazard analysis, which estimates the depth of flooding, with an analysis of economic losses. To implement the flood hazard module, Hazus relies on a digital elevation model to delineate the stream network for a region. We upgrade our analysis to a digital elevation model with a finer resolution (1/3 arc-second) than the National Elevation Dataset maintained by USGS. We estimate our stream network with a resolution of 0.5 square miles. Once the stream network is created, Hazus invokes a hydrologic and hydraulics model to generate a flood surface elevation layer for the study.
region. For a given return period or discharge volume, this estimates the depth of the flood from a depth–frequency curve.\(^3\)

The default settings for Hazus-MH estimate economic damages at the level of a Census block. For a small-scale analysis, such as ours, this can introduce large errors. Hence, we undertake a parcel-level analysis using the User Defined Facility tool in Hazus-MH and drawing on parcel-level data we obtained from the St. Louis County Planning Department and the St. Louis County Revenue Department. To do this, we create a database of the structures in the Meramec floodplain for inputting into the model. Depending on the type of structure, Hazus-MH then uses depth–damage curves to relate depth of flooding to building and contents damages for each property. As much of the developed land in unprotected areas of the 500-year floodplain of the Meramec and its tributaries is single-family residential development, we assume this type of development for the Greenway protected lands in the 500-year floodplain in our counterfactual.\(^4\) Lot sizes and property types and values are based on surrounding developed properties.\(^5\)

Hazus will estimate flood depths and damages for various return intervals. We estimate building and contents damage to our properties for 5-year, 10-year, 50-year, 100-year, 250-year, and 500-year flood events. We then use these estimates to calculate an annual expected loss from flooding for each property. This expected value is referred to as the average annual loss, or AAL; it is the sum of the probabilities that floods of each magnitude will occur, multiplied by the damages if they do (FEMA n.d.). Using the AAL rather than just the losses from a single event, such as the 100-year flood, allows for a more comprehensive assessment of likely flood damages in a given year.\(^6\)

\(^3\) For more detail on the Hazus-MH flood hazard module, see Scawthorn et al. (2006).

\(^4\) Our flood damage modeling includes return periods up to the 500-year flood. Because we do not model greater flood events, there is no need to put hypothetical development on lands outside the 500-year floodplain—even though the Greenway does include protected areas outside the 500-year floodplain— as they would never flood in our analysis.

\(^5\) For each protected parcel that is below the 90th percentile of lot size for existing single-family residential parcels in the floodplains, which is 1.05 acres, we assume that one home would have been on the parcel in our counterfactual. We assume larger parcels would have had more homes—that is, they would have been developed as multiple lots. For these parcels, we use an average lot size of 1.05 acres and place as many houses as will fit on the parcel. For more detail, see Kousky and Walls (2013).

\(^6\) To estimate the average annual loss (AAL), we assume that damages are constant in the intervals between return periods and equal to the average of damages at each endpoint. For example, for the return interval of 5–10 years, we add the damages for the 10-year flood to those for the 5-year flood and divide by 2. Because the x-year flood gives the probability of that flood or greater occurring \((1–F[x]\), where \(F[x]\) is the cumulative probability distribution), the probability of a flood occurring in the interval between an x-year flood and a y-year flood \((y>x)\) is equivalent to \(1/x\) minus \(1/y\). We do this for each interval and then calculate the total average damage across all “bins.” We then sum the AAL for all properties for each scenario: current development and our hypothetical development absent the Greenway. It is important to keep in mind that this is an approximation to the true expected value as we are not estimating the entire distribution of damages, just the damages for particular discrete flood events (Farrow and Scott 2013).
For the climate change scenarios, we estimate flood damages assuming that (a) peak discharges are 30 percent greater than under current conditions; (b) peak discharges are 50 percent greater than under current conditions; (c) the probabilities of the 100-year, 250-year, and 500-year flood events are doubled; and (d) the probabilities of all flood events are doubled. In scenarios (a) and (b), flood events occur with the same frequency as under current conditions, but peak discharge increases change the level of damages. In scenarios (c) and (d), the discharges stay the same, but flood events occur more often; in these cases, the estimated losses from a particular flood event stay the same, but because the probabilities are higher, the total expected losses from flooding in a given year, the AALs, are higher. All of the scenarios essentially represent changes in the distribution of flood events, but this separation into increases in peak discharges and increases in frequency is useful for thinking about how exactly the shifts in the distribution might come about. In climate change discussions, one hears frequent mention of “the 100-year flood of today becoming the 50-year flood of tomorrow;” thus, we try to represent this kind of change through our increases in flood frequencies. Similarly, some scientists predict an increasing severity of storms; thus, we model that as well.

Our changes in peak discharge are based on findings in the literature, some referenced in the previous section. But estimates are highly uncertain given the uncertainties in changes to temperature and precipitation, among other variables (e.g., Jha et al. 2006). The Kollat et al. (2012) study, which the authors stress should not be used for localized estimates, suggests a median 40 percent increase in the 100-year discharge in the region of our study area by the end of the twenty-first century, considering the combined effects of population and climate, and somewhere around 30 percent considering the influence of climate alone. A roughly similar increase in discharge, but estimated using different methods, was found for a river basin in Maryland (Gilroy and McCuen 2012). The literature includes scant information on how discharges for other return periods may change going forward. We thus apply our discharge increases uniformly across all return periods but caution that this assumption is not based on existing literature. Our second scenario of a 50 percent increase should be taken as an upper bound intended to determine how sensitive results are to various discharge magnitudes. The justification for our third scenario is that a greater share of precipitation could come in the form of heavy downpours. A report on climate impacts in the Midwest estimates that heavy downpours are now twice as frequent as they were 100 years ago and are expected to increase by more than 40 percent over the next several decades.
(Union of Concerned Scientists 2009). Our fourth scenario simply takes this increased frequency a step further by assuming that all flood events become more common.

None of these scenarios is meant to represent a specific forecast of expected future flooding. Rather, the scenarios are used to give some sense of how more extreme weather, which most scientists agree is likely in the future, may alter flood damages through changes in the frequency and severity of flooding.

5. Results

5.1. Baseline, Current Conditions

Figure 3 shows the flood depths, under current conditions, for the 100-year flood from our Hazus-MH modeling results, along with the public lands in the Greenway. The figure is a close-up of a portion of the Meramec River, and the inset box within the figure shows the entire river. As seen in the figure, quite deep flooding can occur immediately adjacent to the river, whereas, farther back and along the tributaries, flooding is shallower. Flood depths can also vary greatly depending on whether the property is along the main stem or a tributary, the distance from the water to the property, and the elevation of the land between the river and the property. This spatial variability can be important for targeting conservation investments in a cost-effective way; because all parcels do not yield the same benefit, it makes sense to consider this variability when evaluating investments in public lands.7

The total property damages (building and contents) for the 100-year flood under current conditions is $165 million. To put this number into perspective, the total appraised value of all structures in the 500-year floodplain of the Meramec and its tributaries was approximately $541 million in 2012. The losses from a 100-year flood are thus approximately 30 percent of total property values. In our counterfactual development scenario, we have 2,170 additional single-family homes on roughly 2,180 currently protected acres. The estimated damages for the 100-year flood in this scenario are $264 million, a 60 percent increase over the losses under current conditions.

7 In a study in the Lower Fox River Watershed in Wisconsin, we addressed this issue of spatial targeting in floodplains more carefully (Kousky et al. 2013). Other economics studies that have focused on targeting conservation investments include Ando et al. (1998) and Ferraro (2003).
Combining the 100-year flood losses with losses for the 5-year, 10-year, 50-year, 250-year, and 500-year flood events, we solve for the AALs for both the current conditions and the counterfactual development scenario. The AAL for current conditions is $21.7 million; for the counterfactual, it is $34.8 million. Thus, average losses for any type of flooding in a given year are approximately 38 percent lower than they would be if the Greenway protected lands were developed. This means that the protected lands are currently yielding (without any of the effects from climate change) an average annual benefit in the form of avoided flood damages in St. Louis County of $13.1 million—just over $6,000 per acre of floodplain lands protected.

5.2. Climate Change Scenarios: Increasing Peak Discharges

As we describe above, most scientists believe that precipitation in the Midwest will increase with climate change. Some studies have further concluded that this increase will come in the form of an increase in peak discharges. In line with those results, we run
the Hazus-MH model for both a 30 percent increase and, as an upper bound, a 50 percent increase.

These increases in peak discharges increase the extent of the floodplain for all flood events. For example, the Meramec River 100-year floodplain in St. Louis County is 31.4 square miles under current conditions; this increases by 9.8 percent (to 34.5 square miles) and 15.3 percent (to 36.2 square miles) with the 30 percent and 50 percent discharge increases, respectively. Flood depths increase as well. Figure 4 shows the change in the floodplain and flood depths for the 100-year flood with a 50 percent peak discharge increase. The cross-hatched areas show the additional areas that become part of the 100-year floodplain when discharges increase. The colors denote the increase in flood depths. In the 50 percent discharge increase scenario, approximately one-quarter of the floodplain sees an increase in depth of one foot or less in the 100-year flood (the yellow and orange areas in the figure); just over one-half sees depth increases between one and three feet (the pale blue areas); 17 percent between three and five feet (green areas); and just over 6 percent has more than a five-foot depth increase (pink areas). Most of the areas with flood depth increases of less than five feet are along the tributaries, with larger increases along the river itself.

Table 2 shows the AALs for the current conditions and under the counterfactual development case, for the two climate change scenarios featuring increases in peak discharges, and for the baseline. The annual avoided flood damages from having the protected lands in the Greenway are shown in the last row. Most of the increase in the AALs in the climate change scenarios—and the benefits in the form of avoided damages—are due to increased flood depths on the parcels that we assume are developed in the counterfactual scenario. However, we also account for the growth of the floodplain, which results in flooding of more properties. Specifically, we approximate the additional damages avoided on the protected lands that are not in the 500-year floodplain currently but will be with increases in peak discharges. This is an additional 600 acres and 384 acres with the 50 percent and 30 percent discharge increase, respectively.8

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8 We do not run Hazus with these additional lands developed but merely approximate the (small) additional benefits using our estimate of the average avoided damages per acre multiplied by the additional acres and an adjustment factor based on flood depths in the 100-year flood. Because these lands are on the edge of the floodplain, the flood depths are well below average; thus, damages should be below average.
Figure 4. Changes in Flood Depths with a 50 Percent Increase in Peak Discharges, 100-Year Flood

Notes: Large map is a section of the Greenway, enlarged to show the flood depth changes more clearly; inset box shows the entire Greenway.

Table 2. AALs and Avoided Flood Damages from the Meramec Greenway—Baseline Case and Climate Scenarios with Increased Peak Discharges (in Millions)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>30% increase in peak discharge</th>
<th>50% increase in peak discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current AAL</td>
<td>$21.7</td>
<td>$27.5</td>
<td>$32.4</td>
</tr>
<tr>
<td>Hypothetical AAL</td>
<td>$34.8</td>
<td>$45.1</td>
<td>$53.4</td>
</tr>
<tr>
<td>Annual avoided damages</td>
<td>$13.1</td>
<td>$17.6</td>
<td>$21.0</td>
</tr>
</tbody>
</table>

The benefits of the Greenway lands are greater in a world with climate change: the annual avoided flood damages rise by $4.5 million with a 30 percent discharge increase (to $17.6 million) and by $7.9 million (to $21 million) with a 50 percent
increase. These avoided losses are approximately 34 and 60 percent greater, respectively, than those in the baseline case with no climate change.

5.3. Climate Change Scenarios: Increasing Flood Probabilities

It is possible that climate change will manifest itself as an increase in the frequency of flooding rather than an increase in discharges. In this case, the losses from the individual flood events stay the same as under current conditions, but the AALs increase because of increased probabilities that the events will occur. We look at two possibilities, one in which the probability of each flood event that we model in Hazus-MH doubles and a second in which only the probabilities of the three worst events—the 100-year flood, the 250-year flood, and the 500-year flood—double, but the probabilities of all other events stay the same. Table 3 shows the results.

Clearly, the doubling of all events will double the AALs, and this is shown in the table. As a result, the annual benefits from the Greenway also double—from $13.1 million to $26.3 million. If only the worst floods become more common, the benefits of the Greenway increase by a much smaller amount, $1.2 million (the AAL rises from $13.1 million to $14.3 million). This is only a 9.2 percent increase in benefits, yet the worst flood events occur twice as often in this scenario. These large flood events are relatively uncommon—even if they occur twice as often, they are still very infrequent. Therefore, the expected annual flood damages do not differ much from those in the baseline case. This is an important result to keep in mind. For one thing, it illustrates that the exact manner in which the distribution of extreme events shifts with climate change is important for how damages are affected. For another, the result highlights that the most critical thing may be to keep additional future development out of harm’s way so as not to exacerbate the losses.

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9 The choice of terminology for flooding becomes unfortunate here because the “100-year flood” is no longer the flood that occurs with probability 0.01 in any given year; it now occurs with probability 0.02, which is technically a “50-year flood.” However, for our purposes, this nomenclature is irrelevant; we have simply altered the flood distribution and recalculated the AAL.
Table 3. AALs and Avoided Flood Damages from the Meramec Greenway—Baseline Case and Climate Scenarios with Increased Flood Probabilities (in Millions)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Doubling of all flood events</th>
<th>Doubling of 100-, 250-, and 500-year events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current AAL</td>
<td>$21.7</td>
<td>$43.4</td>
<td>$23.5</td>
</tr>
<tr>
<td>Hypothetical AAL</td>
<td>$34.8</td>
<td>$69.6</td>
<td>$37.8</td>
</tr>
<tr>
<td>Annual avoided damages</td>
<td>$13.1</td>
<td>$26.3</td>
<td>$14.3</td>
</tr>
</tbody>
</table>

6. Discussion

6.1. Co-Benefits under Current Conditions

As a conservation investment, the Meramec Greenway is yielding sizeable benefits in the form of avoided flood damages. We estimate that if the Greenway protected lands in the floodplain were developed, the region’s AALs from flooding would be about 38 percent higher than they are today. Per acre of protected land, the annual avoided damages are about $6,000. These benefits increase if flooding becomes more frequent or more severe with climate change. However, our climate scenarios—especially the 50 percent peak discharge increase and the increase in frequency of all flood events—may be at the upper end of what can be expected with climate change in the foreseeable future. In light of that, in our view, the size of the extra flood mitigation benefit in a world with climate change is not especially large relative to the benefits the lands already provide.

Moreover, the recreational and aesthetic benefits and the value of the ecosystem services from the lands are likely to swamp these climate-related flood protection benefits. In Kousky and Walls (2013), we estimated that the benefits captured in hedonic property values total $25 million per year, well in excess of the avoided flood damages, with or without climate change. These hedonics capture the wide range of benefits that are capitalized in property values near the Greenway, but they probably underestimate the full recreational benefits because they do not account for benefits from people who travel from farther away to recreate in the Greenway, and they do not fully capture water quality benefits that the lands provide, particularly considering that the river is a source of drinking water. In our view, the real story of the Greenway is the wide range of
benefits these natural lands provide under current conditions and not the additional, and highly uncertain, flood mitigation benefits with climate change.

6.2. Conservation Targeting in a World with Climate Change

The climate scenarios could be useful for another purpose, however, and one that we did not investigate: how to target additional forest conservation investments along the Meramec River. As we explain in Section 3, much of the land identified as part of the Greenway remains unprotected. Local governments and conservation agencies in the region will be looking to purchase more acreage in the future and should consider which investments will yield the greatest return. Many factors come into play in calculating that return—flood damages avoided, recreational benefits, and other ecosystem services along with the opportunity costs associated with preserving the properties from development. With climate change, as Figure 4 shows, the flood damages avoided are altered because of variation among parcels in flood depth increases. When thinking about which currently unprotected parcels to target for future purchase, an assessment of these additional impacts might be worthwhile.

As an example, suppose that local governments and conservation agencies in the region adopt a strategy to purchase only properties that are expected to receive more than five feet of flooding in the 100-year flood event. (This strategy is an arbitrary one used simply to illustrate a point; conservation decisions are, we hope, made in a more sophisticated manner.) Under current conditions, 660 unprotected parcels meet the criterion. But with a 50 percent increase in peak discharges, 1,003 parcels would meet it. Local governments may want to give some consideration to the additional 343 parcels that climate change may hit relatively hard—parcels that, without climate change, their rule would tell them to ignore for now. Interestingly, under current conditions, the parcels that get more than five feet of flooding account for 42 percent of all parcels that experience any flooding at all in the 100-year flood. But in the climate change scenario, the parcels with more than five feet of flooding account for 63 percent of all flooded parcels. Local governments and conservation agencies may want to begin preparing for these additional conservation investments.

6.3. Dynamic Issues and Uncertainty

Our analysis excludes dynamic issues, which are pervasive in the area of climate change and are important in this context, as well. The resilience benefits of the Greenway lands will be reaped decades in the future when climate change manifests
itself, or gradually over time if flooding worsens gradually. Moreover, a great deal of uncertainty surrounds these benefits. Our calculations thus far have ignored these issues.

6.3.1. Gradual Change and Discounting

Considering the timing of climate change impacts can alter our calculations. As an illustration, we focus on the scenario with a 50 percent increase in peak discharges and make the simple assumption that the AAL increases linearly over the next 37 years. Thus, the AAL rises from $21.7 million in 2013 to $32.4 million by 2050 with the Greenway and from $34.8 million to $53.4 million without the Greenway (see Table 2). In this gradual change scenario, the average annual avoided damages from the Greenway total $17.5 million, compared with $21 million in our “all-at-once” scenario.

Including discounting alters the calculations even further. If we discount the avoided damages at a (mere) 3 percent annual rate, the average annual discounted benefits in this gradual change scenario drop to $10.2 million. For comparison, discounting the benefits under the no–climate change baseline, using the same 2013–2050 time period, yields an average annual benefit of $8.2 million. This means that the climate resilience benefits, beyond the benefits that the Greenway lands are already providing, amount to about $2 million per year ($10.2 million minus $8.2 million). By comparison, our all-at-once results above, with no discounting, show added resilience benefits of $7.9 million per year. If we use a 5 percent discount rate, the benefits in the climate change scenario and in the current conditions are almost indistinguishable—$7.6 million versus $6.3 million—implying that the added benefits from the Greenway in the form of resilience to climate change total only $1.3 million per year.

This exercise serves to highlight the difficult issues of when climate impacts can be expected to occur and how to evaluate impacts that occur in the future. The appropriate discount rate to use in climate policy analyses has become a contentious issue in general (Arrow et al. 2013; Williams and Goulder 2012; Cropper 2013). In our setting, the discount rate and the timing of impacts become particularly important in thinking about future conservation investments. How should local decisionmakers think about flooding impacts that might occur in the future when they are evaluating conservation investments today? These issues are complex and lead to difficult climate adaptation and mitigation policy responses.

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10 We are not suggesting that this is a likely, or realistic, outcome. We use the linear increase only as an example to illustrate some simple points about how the benefit calculations can change depending on the timing of climate change.
6.3.2. Robustness and Irreversibility

Although we have focused on the extra avoided damages due to increased flood risks, another important benefit of floodplain conservation in the context of climate change is the robustness of this approach to reducing flood damages. Changes to flood risk and the timing of the changes are inherently uncertain. Given this, some scholars have suggested that, instead of identifying optimal investments, it is more appropriate to search out robust investments—those that provide benefits under a range of future climate scenarios (RAND 2013). In some cases, strategic conservation of natural lands is likely to be a more robust approach than traditional hard infrastructure approaches to flood risk as conservation does not tend to lock a community into an irreversible and costly investment. This is a topic worthy of further study.

The investment irreversibility issue is important in other ways as well. Generally, once land is developed, it is very difficult to reverse those investments and return the land to open space. Combined with the uncertainty associated with climate change, this may increase the rationale for protecting the Greenway. This possibility that development would “lock in” a suboptimal future is another dynamic issue that should be explored in future work.

7. Concluding Remarks

Climate change forecasts are fraught with uncertainty, and forecasts of flood risks are no exception. This makes the evaluation of alternative approaches to adaptation difficult. Few studies have thus far attempted to combine expected biophysical outcomes from climate change with an economic assessment of costs and benefits. We have taken some first steps in this paper in an evaluation of a forest conservation investment in the floodplain. Using the Meramec Greenway in St. Louis County, Missouri, as a case study, we assessed the flood protection benefits this investment is already providing and how those benefits might change in the future with more extreme weather events.

Our findings suggest that the Greenway is yielding a significant return in the form of reduced average annual flood damages. This return would be higher in a world with climate change, but how and when that climate change occurs is important to the size of the added benefit. In our view, the current benefits are the real story. When combined with the recreational and ecosystem services benefits of the lands, the Meramec Greenway has great value. To focus on the added benefits in the form of climate resilience may be an example of the “tail wagging the dog.”
In targeting future additions to the Greenway protected lands, however, local officials may want to consider climate change. Although the climate resilience benefits are unlikely, on their own, to justify additional land acquisition, they should be included in the suite of benefits that such lands provide—the recreational benefits, water quality improvements, other ecosystem services, and protection against today’s flood risks.
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