Measuring Resilience to Climate Change: The Benefits of Forest Conservation in the Floodplain

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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). In addition, climate models predict increases in the intensity of precipitation events in many locations (Wuebbles and Hayhoe 2004; IPCC 2012). How such precipitation changes will alter flood risks is not well understood, but could lead to greater flood damages in the future. Given these findings, various stakeholder groups have suggested it is time to think more seriously about relocating people out of harm's way or preventing development of the riskiest areas. This has been suggested for certain coastal areas in the wake of Hurricane Sandy, but inland floodplains are also a focus of conservation efforts. Conservation lands in floodplains and other hazardous areas not only can reduce exposure and thus bring down disaster costs but may provide an array of other ecosystem services.

Despite this growing interest, very little economic analysis has been conducted on 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 (1) provide protection under a range of outcomes, (2) offer other ancillary benefits, and (3) come at a reasonable cost (Kousky and others 2012). 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, a collection of roughly 28,000 acres (11,330 ha) of conservation lands along the Meramec River in southern Missouri. Approximately 9,000 of those acres lie in St. Louis County, which is the focus of our study. 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 spaces. In a recent study, we estimated the benefits of the Greenway in terms of avoided flood damages and non-market benefits such as aesthetics and recreational access that are capitalized in 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, however. In this paper, we assess how increased flooding as a result of climate change would alter our estimates of 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? Does consideration of future changes suggest changes to the on-going land acquisition strategies in the region?

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, but instead are used to generate order-of-magnitude estimates of the climate resilience benefits of floodplain conservation. We look 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. Our methodology calculates the benefits from reduced exposure to flooding, i.e., 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. In our particular setting, such benefits are likely to be small: surrounding land uses do not include a lot of development at the present time and the residential lots that do exist are quite large. Furthermore, the Mississippi, into which the Meramec flows, 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.

We find that the Greenway lands provide substantial benefits in the form of reduced flood damages even without climate change. Slightly more than $13 million per year of flood damages are avoided, on average, by keeping the protected lands in the 500-year floodplain of the Greenway undeveloped. This is about a 38 percent reduction from average damages in a hypothetical scenario without the Greenway. On a per-acre basis, this amounts to about $6,000 per acre of floodplain protected lands. In Kousky and Walls (2013), we estimate that in combination with the recreational and aesthetic benefits of the lands, the Greenway passes a simple benefit-cost test, yielding benefits for the region in excess of the opportunity costs of keeping the land out of development.

Increases in flood risk make the Greenway lands even more valuable. For scenarios in which we increase peak discharges either 30 or 50 percent, the annual avoided flood damages of the Greenway increase by $3.8 million and $6.6 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 approximately 10 percent and 15 percent, respectively, in the two scenarios. This may justify additional expansions in conservation acreage. Increases in the frequency of flood events also raises 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 the largest flood events are the ones 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. We make no attempt in our analysis to discount future losses to the present or address other important dynamic concerns. We do include a discussion of these important issues, however, in the penultimate section of the paper. We also discuss other dynamic issues such as the irreversibility of development and certain kinds of "gray" infrastructure investments.

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 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 will be felt nationwide, affecting coastal and inland communities, and rural and urban areas (National Research Council 2010). While the 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 have also generally concluded that an increase in the frequency and intensity of heavy precipitation events is expected in the region 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 and others (2004) have identified an increase in heavy precipitation events. Kunkel and others (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; five-year floods have increased by 4 percent per decade nationally in the United States (Note: 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.) An increase in extreme precipitation is expected by many flood experts to exacerbate flood risk. 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 and others 2009). A global analysis found initial evidence that large floods (those exceeding 100-year levels) have increased in large river basins over the twentieth century (Milly and others

2002). A recent national level analysis, undertaken for FEMA, estimates how the discharge associated with the 100-year flood may change through 2100 based on climate and population scenarios (Kollat and others 2012). This study finds that the 100-year discharge could increase substantially, particularly in the Pacific Northwest, the Northeast, and in very urban areas. The authors estimate that these areas could see increases in the 100-year discharge of 30-40 percent by midcentury, and by more at century's end. The study did not examine sea level rise or storm surge but focused on riverine flooding.

There is, however, some disagreement between those researchers who run climate models and those who look at the historical record of flood stages. Despite the modeling predictions, there is only mixed observational evidence of 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 and others (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). And finally, all researchers agree that climate impacts have yet to materialize in full, creating a disconnect between the historical record and future projections.

BACKGROUND ON THE MERAMEC GREENWAY

The Meramec River joins the Mississippi River at the southern edge of St. Louis County. Much of the Missouri and Mississippi Rivers in the county are lined with levees, but the Meramec River is largely devoid of any structural protection. The river has long been used for recreation and when dams have been suggested for the river, public sentiment has generally been opposed. As a result, the river has remained 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 river with the Mississippi back 108 miles into the Ozark Uplands. It was initially created in 1975 and 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 (11,330 ha) 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 stated 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.

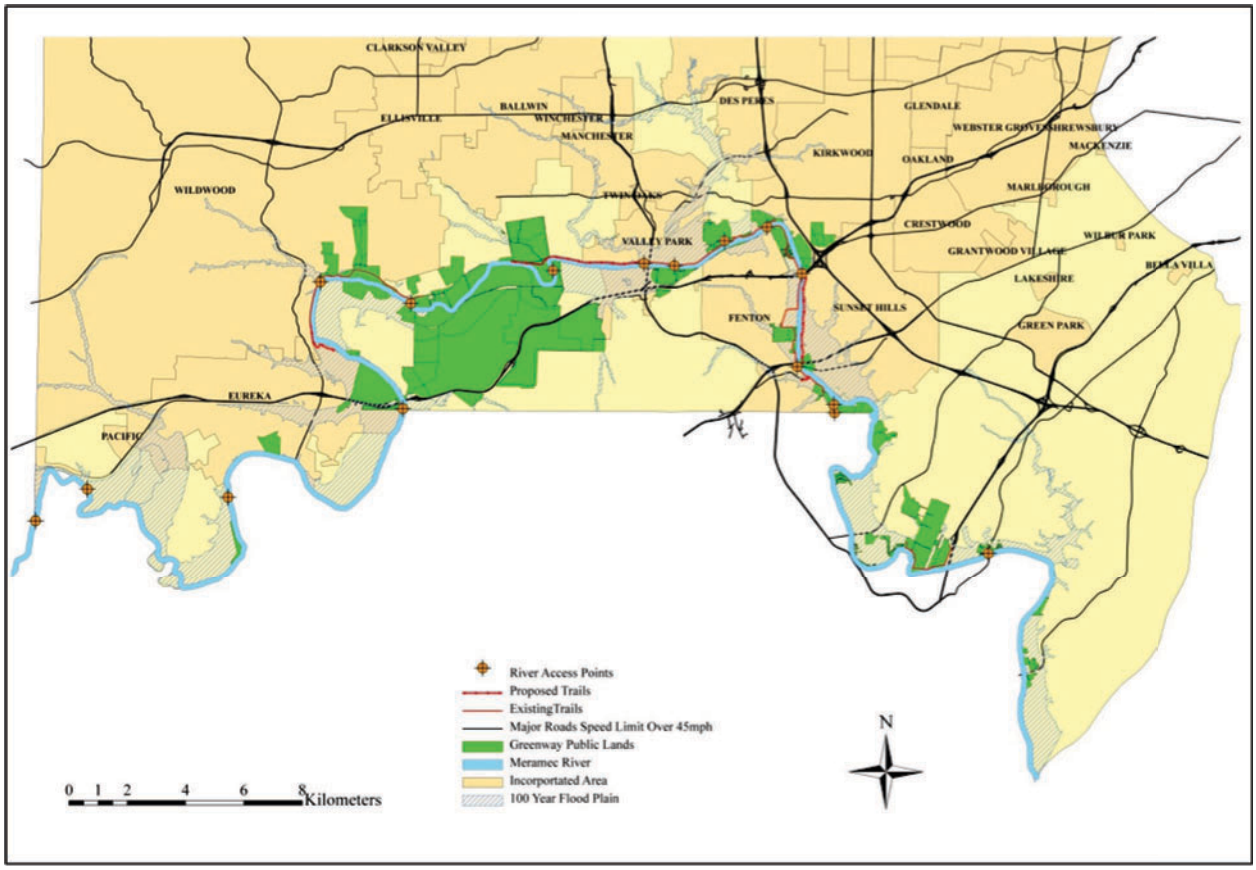

Figure 1. Meramec Greenway in St. Louis County, Missouri

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 USGS, we identified 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 is the next largest land cover class, making up slightly less than 11 percent of protected lands. These are open areas such as ball fields, other parkland, and subdivision open space that are covered mainly in recreational grasses. The lands in the Greenway that are unprotected 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. Another 23 percent of these lands are deciduous forest. Almost 20 percent of Greenway lands not currently in a protected status are developed.

Figure 2 shows a map of land cover for the entire Greenway. 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 are 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 unprotected areas of Greenway, as shown on the map.

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

	Protected Lands	Unprotected Lands
Deciduous Forest	73.3	23.0
Evergreen Forest	0.3	0.0
Mixed Forest	0.1	0.0
Developed Open Space	10.9	15.2
Emergent Herbaceous Wetlands	0.1	0.1
Woody Wetlands	4.1	5.1
Farmland[a]	4.5	26.8
Developed Uses[b]	2.1	19.5
Barren Land	0.7	4.6
Open Water	3.8	5.7

[a] Farmland includes pasture/hay, herbaceous vegetation and grasslands, and cropland.
[b] Development consists mainly of low intensity residential and commercial development.
Source: USGS 2006 National Land Cover Dataset and St. Louis County GIS Service Center, http://www.stlouisco.com/OnlineServices/MappingandData.

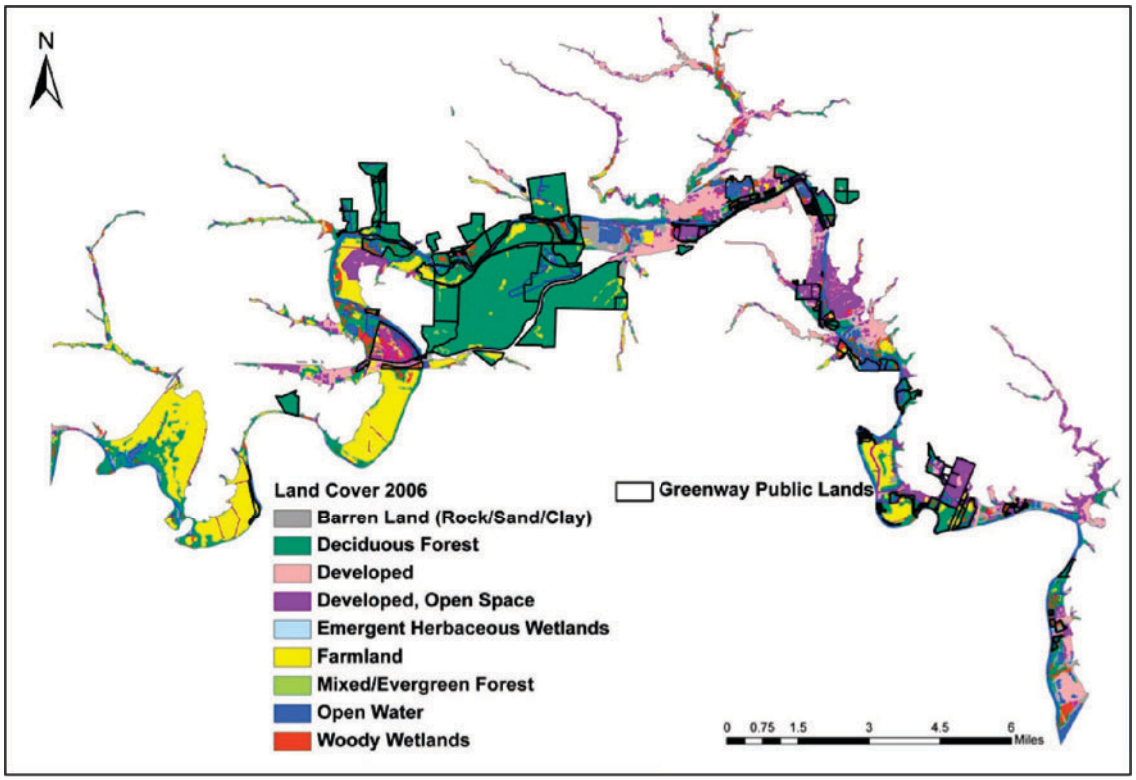

Figure 2. Land Cover for Meramec Greenway Lands

METHODS

To evaluate the avoided flood damage benefits of the Greenway, we need to make an assumption about what would have occurred on these lands had they not been protected from development. We then compare the estimated damages under various flood events in this hypothetical 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. We do not consider any changes in population or economic growth over time, but rather simply compare and contrast alternative flood scenarios. In addition, we do not account for additional adaptation measures that households and businesses might adopt in the event of climate change.

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 (DEM) to delineate the stream network for a region. We upgrade our analysis to a finer resolution DEM (1/3 arc-second) from the National Elevation Dataset maintained by the U.S. Geological Survey (USGS). We estimate our stream network with a resolution of 0.5 square miles. Once the stream network is created, Hazus invokes a hydrology 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. For more detail on the flood hazard module, see Scawthorn, Blais and others (2006).

The default settings for Hazus-MH estimate economic damages at a Census block level. 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 Hazus-MH. 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. Much of the developed land in unprotected areas of the 500-year floodplain of the Meramec and its tributaries is single-family residential development. Therefore, in our hypothetical counter-factual scenario, we assume that the Greenway-protected lands in the 500-year floodplain would have been developed as single-family residential properties in the absence of protection. [1] Lot sizes and property types and values are based on surrounding developed properties. 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 one home would have been on the parcel in our hypothetical case. We assume larger parcels would have had more homes—that is, they would have 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).

[1] Our flood damage modeling includes return periods up to the 500-year flood. Since 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.

Hazus will estimate flood depths and damages for various return intervals. We estimate building and content 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 year unknown). To estimate the AAL, we assume damages are constant in the intervals between return periods and equal to the average of damages at each end point. For example, for the return interval 5-10 years, we add the damages for the 10-year flood to those for the 5-year flood and divide by 2. Since 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 a x-year flood and a y-year flood (for 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). 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.

For the climate change scenarios, we estimate flood damages assuming (1) peak discharges are 30 percent greater than under current conditions, (2) peak discharges are 50 percent greater than under current conditions, (3) the probabilities of the 100-year, 250-year, and 500-year flood events are doubled, and (4) the probabilities of all flood events are doubled. In scenarios (1) and (2), flood events occur with the same frequency as under current conditions but peak discharge increases change the level of damages. In scenarios (3) and (4), 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 expected losses from flooding in a given year are higher. As stated above, we assume nothing about adaptation activities. We also do not assume there is any permanent change in location of households as a result of climate change.

Our changes in peak discharge are based on findings, some referenced in the previous section, that climate change could increase discharge values, although estimates are highly uncertain given the uncertainties in changes to temperature and precipitation, among other variables (e.g., Jha and others 2006). The Kollat and others study (2012), which the authors stress should not be used for very local estimates, suggests a median 40 percent increase in the 100-year discharge in the region of our study area for the combined effects of population and climate by the end of the 21st century, and somewhere around 30 percent for just the influence of climate. A roughly similar increase in discharge, but using different methods, was found for a river basin in Maryland (Gilroy and McCuen 2012). There is not much in the literature on how discharges for other return periods may change going forward. We thus estimate two scenarios, one below and one above the order-of-magnitude Kollat and others (2012) estimate. Our second scenario of a 50 percent increase should be taken as an upper bound and is used to see how sensitive results are to various discharge magnitudes. The justification of 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 are more common.

RESULTS BASELINE, CURRENT CONDITIONS

Figure 3 shows the flood depths 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, while the box in the Figure shows the entire river. As seen in the figure, there can be quite deep flooding immediately adjacent to the river, while farther back and along the tributaries, flooding is shallower. The figure also shows that flood depths can vary greatly depending on whether the property is along the main stem or a tributary, how far from the water the property is located, 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; not all parcels yield the same benefit, thus it makes sense to consider this when evaluating investments in public lands.[2] 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, therefore, roughly 30 percent of total property values. In our hypothetical 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 our hypothetical scenario rise to $264 million, a 60 percent increase over the losses under current conditions.

[2] In a study in the Lower Fox River Watershed in Wisconsin, we addressed this issue of spatial targeting in floodplains more carefully (Kousky and others 2012). Other economics studies that have focused on targeting conservation investments include Ando and others (1998) and Ferraro (2003).

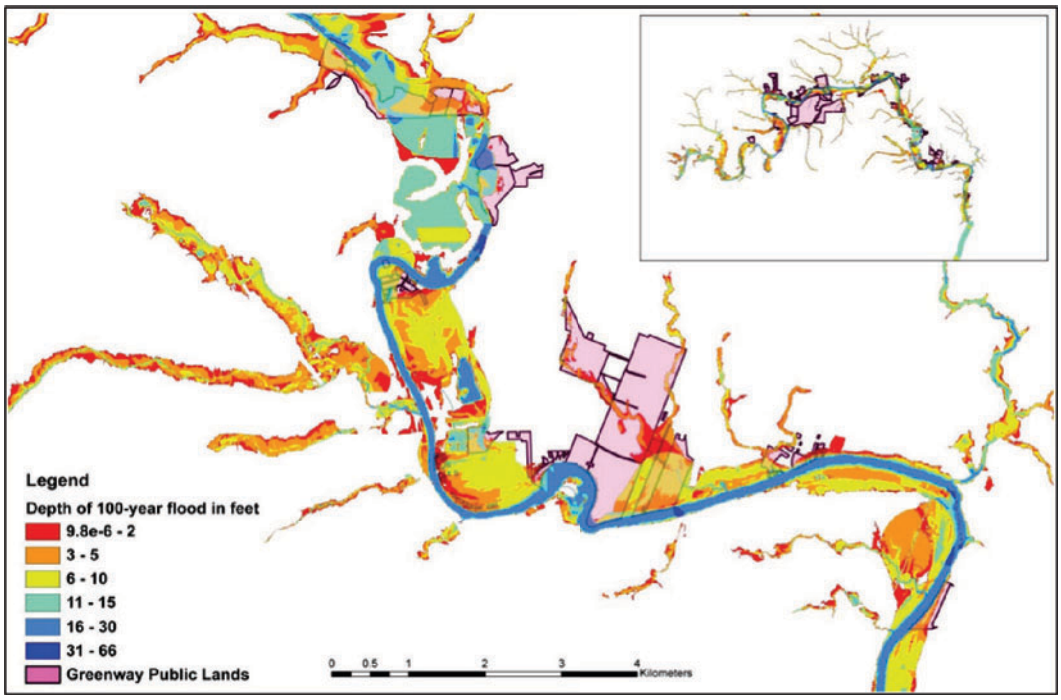

Figure 3. Flood Depths in the Meramec Greenway, for the 100-year Flood
Note: Large map is a section of the Greenway, enlarged to show the flood depths more clearly; insert box shows the entire Greenway.

Combining these losses from the 100-year flood 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 hypothetical scenario. The AAL for current conditions is $21.7 million; for the hypothetical it is $34.8 million. Thus, average losses for any type of flooding in a given year are approximately 38 percent lower than they otherwise would be if the Greenway protected lands were developed. This means that the protected lands are yielding 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. In Kousky and Walls (2013), we find that in combination with the co-benefits from aesthetics and recreation, the benefits of the Greenway outweigh the opportunity costs of keeping the land out of development.

Climate Change Scenarios: Increasing Peak Discharge

As we described 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 presented earlier, 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 floodplain in St. Louis County for the 100-year flood is 31.4 square miles under current conditions; this increases 9.8 percent with the 30 percent increase in peak discharges (to 34.5 square miles), and 15.3 percent with the 50 percent increase in discharges (to 36.2 square miles). Flood depths increase as well. Figure 4 shows the change in the floodplain

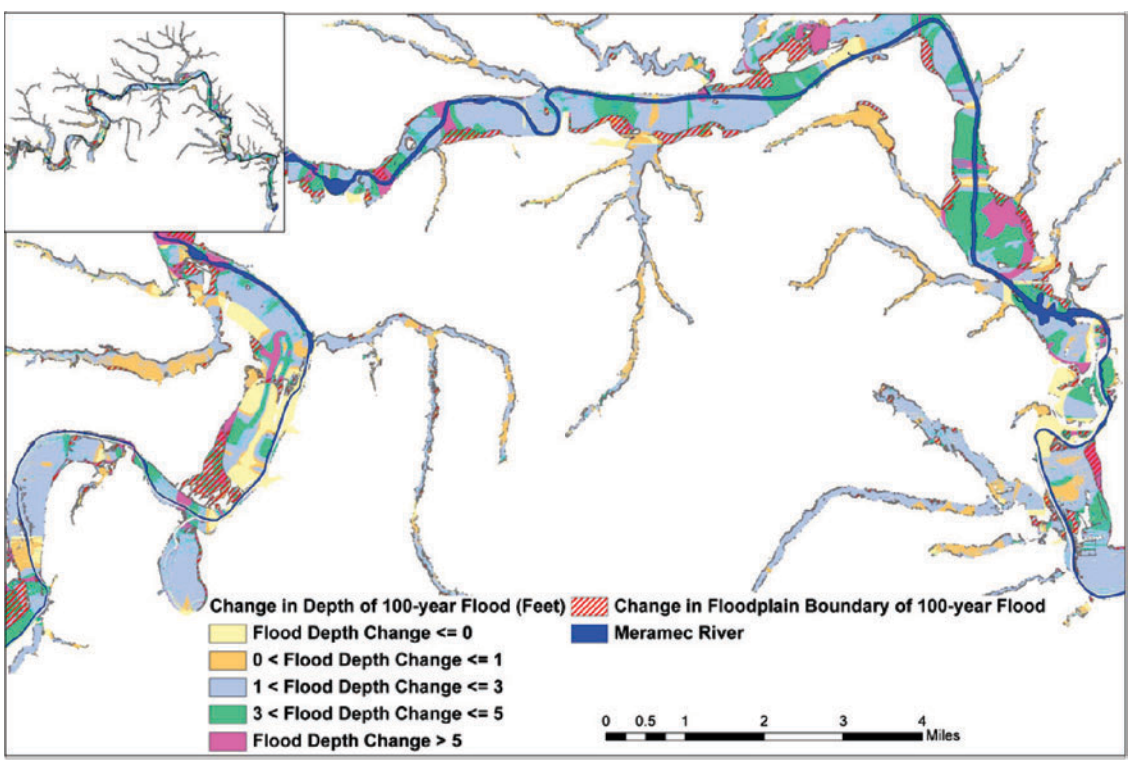

Figure 4. Changes in Flood Depths in the 100-Year Flood with a 50 Percent Increase in Peak Discharges
Note: Large map is a section of the Greenway, enlarged to show the flood depth changes more clearly; insert box shows the entire Greenway.

Table 2. Average Annualized Losses (AALs) and Avoided Flood Damages from the Meramec Greenway, Baseline Case and Climate Scenarios with Increased Peak Discharges (in millions).

	Baseline	30% increase in peak discharge	50% increase in peak discharge
Current AAL	$21.7	$27.5	$32.4
Hypothetical AAL	$34.8	$44.3	$52.1
Annual Avoided Damages	$13.1	$16.9	$19.7

and flood depths for the 100-year flood with a 50 percent peak discharge increase. The cross-hatched areas show the additional areas that are part of the 100-year floodplain when discharges are higher. The colors denote the increase in flood depths. In the 50 percent discharge increase scenario, approximately 25 percent of the floodplain sees an increase of 1 foot or less in the 100-year flood (the yellow and orange areas in the figure); 51 percent sees depth increases between 1 and 3 feet (the pale blue areas); 17 percent between 3 and 5 feet (green areas); and just over 6 percent has more than a 5-foot depth increase (pink areas). Most of the areas with flood depth increases of less than 5 feet are along the tributaries, with larger increases along the river itself.

Table 2 shows the AALs for the current conditions and under the hypothetical development case, for the two climate change scenarios, and for the baseline. The annual avoided flood losses from having the protected lands in the Greenway are shown in the last row. The benefits of the Greenway lands are greater in a world with climate change: the annual avoided flood damages rise by $3.8 million with a 30 percent discharge increase and by $6.6 million with a 50 percent increase; these losses are 29 and 50.4 percent greater, respectively, than those in the baseline case with no climate change.

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 the probabilities that the events will occur increase. 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 probability of the three worst events—the 100-year flood, the 250-year flood, and the 500-year flood—doubles but the probability of all other events stays the same.[3] Table 3 shows the results.

Clearly, the doubling of all events will double the AALs and this is shown in the numbers 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 and 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 are not that much different than in the baseline case. This is an important result to keep in mind. More

[3] 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. Average Annualized Losses (AALs) and Avoided Flood Damages from the Meramec Greenway, Baseline Case and Climate Scenarios with Increased Flood Probabilities (in millions)

	Baseline	Doubling of all flood events	Doubling of 100-year, 250-year, and 500-year events
Current AAL	$21.7	$43.4	$23.5
Hypothetical AAL	$34.8	$69.6	$37.8
Annual Avoided Damages	$13.1	$26.3	$14.3

critical may be keeping additional future development out of harm's way so as not to exacerbate the losses.

DISCUSSION

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 average annual losses 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, but the size of the extra benefit is not large relative to the benefits the lands already provide. With or without climate change, an open question is whether these avoided damages are true "benefits" as in theory, private property owners should take flood risks into account. The empirical literature suggests that properties in the floodplain are discounted relative to non-floodplain lands but the risk is likely not fully capitalized and the discount has been shown to vary over time depending on whether a recent disaster has made the risks salient (Bin and Polasky 2004; Bin, Kruse, and Landry 2008; Kousky 2010). In addition, private property owners are in most cases not bearing the full cost of flood risk due to disaster aid, discounted insurance, and/or other government funding. And finally, communities invest heavily in flood mitigation measures of all kinds—dams and levees as well as land conservation—thus knowing the payoff from any of these investments is important.

Moreover, the value of the ecosystem services from the lands is likely to swamp these climate-related flood protection benefits. In Kousky and Walls (2013), we estimate 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 are capturing aesthetic and recreational benefits to households that live near the Greenway but are likely an underestimate of the full recreational benefits, as they do not account for those who travel from farther away to recreate in the Greenway, and also do not fully capture water quality benefits that the lands provide, particularly as 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, benefits 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 explained in Section 3, much of the lands identified as part of the Greenway remain

unprotected. Local governments and conservation agencies in the region looking to purchase more acreage in the future will need to know which investments will yield the greatest return. Even within the floodplain, flood depths and damages vary greatly, as Figure 1 showed, thus not all investments will yield the same payoff. Consideration of areas that may see disproportionally higher changes in flood depths under multiple climate scenarios might be given greater weight in setting acquisition priorities. Our analysis excludes dynamic issues, which are pervasive in the area of climate change, and are important in this context, as well. If the additional benefits of the Greenway lands are reaped decades in the future when climate change manifests itself, then it is not clear exactly how to evaluate them vis-à-vis investments made today. Here, we estimated the climate benefits provided by lands that are already protected. But for additional conservation investments, the discounting of future benefits will be important. This brings up a contentious issue in climate policy, the appropriate discount rate to use when discounting future benefits and costs (Williams and Goulder 2012; Cropper 2013). Our benefit estimate of $6.6 million with 50 percent higher peak discharges is reduced to only $1.5 million if those benefits are reaped 50 years in the future and discounted at a (mere) 3 percent annual rate. While changes in risk levels will begin to be seen in advance of 50 years and will continue past 50 years, the difficulty comes in identifying such changes, given the infrequent nature of flooding. It takes a long record of weather events over time for changes in risk to be observed. These issues are complex and lead to difficult climate adaptation and mitigation policy decisions.

While 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 may be a more robust approach than traditional hard infrastructure approaches to flood risk. This is a topic worthy of further study. We also have not analyzed the possibility of a combination of "gray" and "green" approaches. In the context of the Meramec River, which is currently undammed and is used recreationally in its natural state, our view is that the combined approach may come at a significant cost. However, in many locations, this is an issue worthy of study.

Other dynamic concerns relate to the irreversibility of some investments. 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 of development to lock-in a suboptimal future would need to be explored in future work.

CONCLUSION

Climate change forecasts are fraught with uncertainty and forecasts of flood risks are no exception. This makes 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 asked two important questions: (1) what are

the flood mitigation benefits this investment is already providing and (2) how might those benefits change in the future with more extreme weather events?

Our findings suggest that the Greenway is yielding sizeable benefits in the form of reduced average annual flood damages. This return would be higher in a world with climate change, but 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 is providing value to the region. To focus on the added benefits in the form of climate resilience may be the "tail wagging the dog." In this paper, we have not discussed the opportunity costs of the Greenway as our focus is on the climate resilience issue, but in an earlier study, we found that the benefits outweighed these costs, without consideration of climate change (Kousky and Walls 2013). In that study, we estimate the opportunity costs as the value of the land in residential development, as that is the dominant land use in the study area.

In targeting future additions to the Greenway protected lands, however, local officials may want to consider climate change. While the climate resilience benefits are unlikely to justify, on their own, additional land acquisition, they should be included in the suite of benefits that such lands provide—the recreational benefits, water quality and other ecosystem services, and protection against today's flood risks.

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