Ecological Economics 104 (2014) 119–128

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Floodplain conservation as a flood mitigation strategy: Examining costs and benefits

Carolyn Kousky *, Margaret Walls [1]

Resources for the Future, 1616 P Street NW, Washington DC 20036, United States

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 19 March 2014
Accepted 5 May 2014
Available online 22 May 2014

JEL classification:
Q51
Q54

Keywords:
Floodplain conservation
Benefit-cost analysis
Hedonic model
Hazus-MH
Floods

ABSTRACT

There is growing interest in floodplain conservation as a flood damage reduction strategy, particularly given the co-benefits that protected lands provide. We evaluate one such investment—a greenway along the Meramec River in St. Louis County, Missouri. We estimate the opportunity costs, the avoided flood damages, and the capitalization of proximity to protected lands into nearby home prices. To estimate avoided flood damages, we undertake a parcel-level analysis using the Hazus-MH flood model, a GIS-based model developed for FEMA that couples a hydrology and hydraulics model with a damage model relating flood depths to property damage. We examine the distribution of damages across parcels, demonstrating that careful spatial targeting can increase the net benefits of floodplain conservation. In addition, we estimate a hedonic model and find that the increased property values for homes near protected lands are more than three times larger than the avoided flood damages, stressing the continued importance of more traditional conservation values. The proximity benefits alone exceed the opportunity costs; the avoided flood damages further strengthen the economic case for floodplain conservation.

1. Introduction

Several severe flooding events over the last few years have brought increased attention to the damages caused by natural disasters. Worldwide, flooding is not only the most costly natural disaster, but has also affected the most people (Miller et al., 2008; Stromberg, 2007). In the United States over the twentieth century, out of all natural disasters, flood events were responsible for the highest number of fatalities and the most property damage (Perry, 2000). And the economic costs of flooding have been increasing over the last several decades, largely due to more people and property locating in hazardous areas (Pielke and Downton, 2000). In addition, many climate models predict an increase in heavy precipitation as the climate warms, which may increase the risk of flooding in certain locations (e.g. Kollat et al., 2012; Wuebbles et al., 2009).

Communities have shown increasing interest in removing structures from flood-prone areas as a flood damage reduction strategy. Two decades ago, after the devastating 1993 flood on the Missouri and Mississippi Rivers, the state of Missouri and local governments invested in floodplain land acquisition using Federal Emergency Management Agency (FEMA) grant funds and Community Development Block Grants. The state acquired over 4000 properties (Missouri State Emergency Management Agency, 2000). Some communities are preempting development in the first place using local funds. Milwaukee is one example; its Greenseams program acquires undeveloped streamside properties and retains them as open space. Similar programs have been adopted internationally, as well, such as the Room for the River program in the Netherlands.[2] Such investments may be driven in part by the high costs of structural flood control, as well as a growing awareness of green approaches. Perhaps more importantly, however, conserved riparian areas generate a range of ecosystem services, in addition to the hazard mitigation benefits they provide. Protected forests, grasslands, and wetlands along rivers and streams can improve water quality, provide habitat to many species, and offer a wide range of recreational opportunities.

There remains, however, large uncertainty concerning the benefits and costs of floodplain conservation, hindering greater investment. There is an opportunity cost associated with keeping lands out of development, which may be large, since many of these areas are desirable places to live. The precise benefits in terms of total avoided flood damages, not to mention the many other nonmarket benefits, are difficult to measure. Whether, on net, the investment pays off for a community depends on local conditions—the hydrology and hydraulics of streams and rivers, topography, land values and uses, residents' preferences, and a host of other factors.

* Corresponding author. Tel.: +1 202 328 5188.
E-mail addresses: kousky@rff.org (C. Kousky), walls@rff.org (M. Walls).
[1] Tel.: +1 202 328 5092.

[2] See the program website for more information: http://www.ruimtevoorderivier.nl/meta-navigatie/english/room-for-the-river-programme/.

http://dx.doi.org/10.1016/j.ecolecon.2014.05.001
0921-8009/

In this study, we look retrospectively at a floodplain conservation effort and evaluate the avoided flood damages, opportunity costs, and some of the nonmarket benefits. Our case study is southern St. Louis County, Missouri. The county lies in a triangle formed by three rivers—the Missouri, Mississippi, and Meramec—and has been dealing with flooding throughout its history. In contrast to the Missouri and Mississippi Rivers, which are lined with levees, the Meramec remains in a relatively natural state. We focus our analysis on the Meramec Greenway, a collection of lands along 108 miles of the Meramec River from its confluence with the Mississippi River back into the Ozark Uplands. In St. Louis County, as of 2013, roughly 9000 acres have been preserved to date as state and local parks, as well as some nonprofit conservation lands. This is roughly 15% of the 500-year floodplain of the Meramec and its tributaries in the County. Assessing the impacts of this investment is important for the region as conservation activities continue, not just in the Meramec Greenway, but also for the more extensive River Ring, a planned network of more than 45 greenways, and over 600 miles of trails along all of the rivers in the area, including the Meramec (Great Rivers Greenway, 2011; Meramec River Recreation Association, 2004).

In order to assess the flood damage reduction benefits of the Greenway, we compare flood damages under current conditions with a counterfactual, "developed floodplain" scenario in which the Greenway protected lands are developed instead. The difference between the flood damages in the two scenarios is a measure of the avoided flood damages from the conservation that has occurred to date. We estimate these avoided flood damages using the Hazus-MH model, a GIS-based model developed by FEMA to estimate the damages from several different natural hazards, including riverine flooding.[3] We undertake a parcel-level analysis, improving estimation over the default Hazus approach of aggregating data to census blocks.

We estimate the average annual avoided flood damages of the Greenway at $7.7 million. We estimate the annual opportunity cost of these protected lands at roughly $17.2 million. Avoided flood damages and opportunity costs are never distributed uniformly across a landscape. Our results show that while the bulk of parcels have modest average annual flood damages, a few parcels incur quite substantial damages. Thus the costs of this flood mitigation strategy could have been lowered with a more careful targeting of the parcels for protection.

Flood mitigation, however, was not the sole purpose of the protection of lands along the Meramec River. Another important benefit has been the recreational and aesthetic value provided by the conserved lands. Using property sales data between 2008 and 2012 for the neighborhoods surrounding the Greenway, we estimate a hedonic property value model to obtain locally specific estimates of the capitalization of the Greenway into housing values. We find that for every 1000 ft that a property is closer to a park or protected area, the sales price increases by almost 1%—$2156 for a median-priced home in our sample. Based on these econometric results, we calculate an order-of-magnitude estimate of these annual benefits of the Greenway in St. Louis County of roughly $24 million. These benefits are over three times the estimated avoided flood damages and exceed the opportunity costs.

With growing interest in floodplain conservation, it is important to evaluate the potential returns from such investments. Local governments are in need of economic analysis at a fine spatial scale to help justify expenditures, and our analysis can be a guide for how to estimate both costs and benefits. Two important findings come out of this research. First, land conservation comes at a cost in terms of the forgone opportunities on the land, and those costs may be only partially offset by the avoided flood damages. Moreover, careful spatial targeting is important for improving cost-effectiveness, as has been found in many other settings (Ando et al., 1998; Ferraro, 2003; Kousky et al., 2013). Second, the more traditional benefits provided by conserved land, such as recreational opportunities and aesthetics, can be substantial and should not be neglected. This latter finding highlights the importance of the multiple benefits obtained from protecting natural lands and stresses the need for a full consideration of these when developing protection strategies.

The paper proceeds as follows. The next section of the paper provides background on our study area. Section 3 discusses both the data and methods used for the Hazus modeling. Section 4 presents the results of the Hazus-MH analysis and our estimation of opportunity costs. Section 5 presents the methods and findings of the hedonic property model, comparing them with our other estimates. Section 6 concludes.

2. Background on Study Area

Being framed by three rivers, St. Louis County has repeatedly suffered flood events. Presidential disaster declarations were issued in the county in 2011, 2008, 2007, 2003, 1998, and 1993. Whereas the 1993 and 2011 floods were on the major rivers, substantial flash flooding along creeks in 2008 caused more than $2.2 million in damages to public infrastructure and created sewer backup problems on 1200 to 1400 properties, even though it was estimated to be only a 15-year storm event (Wilson, 2008). Flooding on the Meramec led to road closures as recently as June 2013.

The Meramec River joins the Mississippi at the southern edge of St. Louis County. Much of the Missouri and Mississippi Rivers in the county are lined with levees. The Meramec River, on the other hand, is largely devoid of any structural protection.[4] Flooding along the Meramec can occur when large floods on the Mississippi back up or when heavy spring and summer precipitation leads to seasonal flooding; in areas along the river with steep slopes and thin soil cover, flash flooding is common. 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 its confluence 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 from 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 lands remain in private hands. As of 2013, however, more than 28,000 acres were protected, with just over 9000 of those protected acres located in St. Louis County. The protected lands include state and local parks, private conservation lands, as well as buyouts of frequently flooded properties funded by FEMA in 1982 and 1993.[5] Fig. 1 is a map of the area created with the data described in the next section. It shows in green the currently protected lands in the St. Louis County portion of the Greenway.

Local park agencies and nonprofits in the region continue to plan for future acquisitions in the Greenway. The county adopted a Concept Plan for the Greenway in 2003 with multiple stated goals, including flood damage reduction, water quality improvements, and expanded recreational opportunities (St. Louis County Department of Planning, 2003). The Meramec Greenway is also one component of the larger River Ring project envisioned for the region. The River Ring will include a near circle of natural lands along the Cuivre River to the north, the Mississippi River to the East and the Meramec River to the south, as well as a greenway along the Missouri River and several smaller rivers and streams in St. Louis and surrounding counties (Great Rivers Greenway, 2011; Meramec River Recreation Association, 2004).

[3] Documentation and software available at: http://www.fema.gov/hazus.

[4] In our study area, there is one small levee, the Valley Park Levee, which would likely provide protection up to the 50-year event for a small subset of properties in our sample. There are only three protected parks in the protected area and they are each one acre or smaller; adjusting for these properties has a negligible influence on results.

[5] FEMA has several grant programs for state and local governments that can be used to acquire flood-prone properties and convert them to open space. Some grants are tied to the National Flood Insurance Program. The Hazard Mitigation Grant Program, funded after a presidentially declared disaster, will also give funds for this purpose.

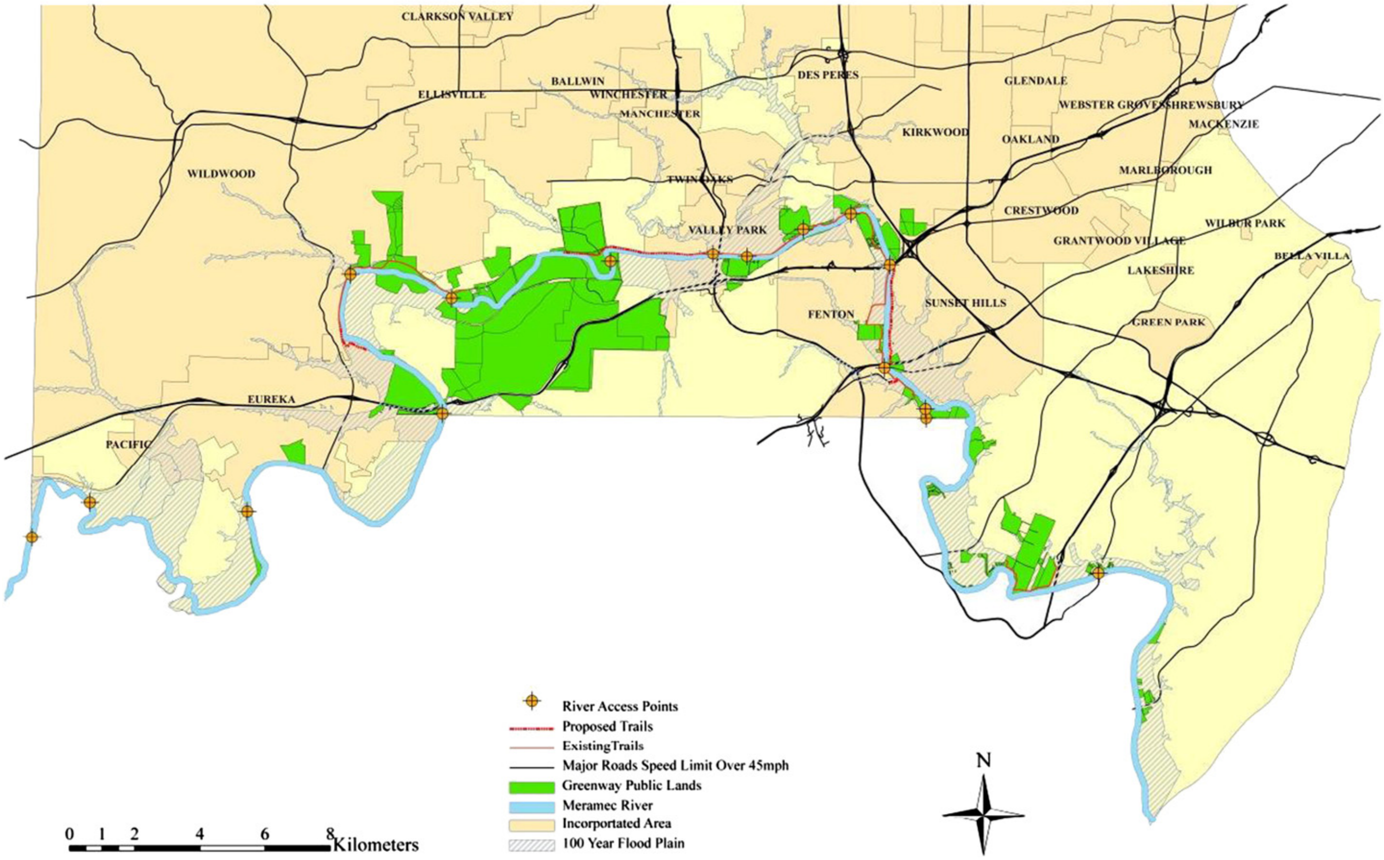

Fig. 1. Meramec Greenway in St. Louis County, Missouri.

3. Data and Hazus Modeling Methods

To estimate the avoided flood damages from the Greenway, we must construct a counterfactual scenario of what would have happened in the absence of the land conservation. While we have no way of knowing this precisely, there is a substantial amount of suburban development in the area, including in the 100-year and 500-year floodplain, and thus we assume that development would have occurred on these conserved lands had they not been protected. We then compare flood damages under current development with the flood damages under our "developed floodplain" counterfactual. In this section, we describe the data used for this analysis, how we construct our counterfactual, and our use of the Hazus-MH flood model for calculating avoided flood damages.

3.1. Data

For our analysis, we make use of several geographical information systems (GIS) datasets. The first is a parcel-level file from the St. Louis County Department of Planning, which indicates the land use of each parcel and gives appraised values of the land and structures separately. We use this GIS file to determine protected open space areas and the types of development on developed parcels. To confirm that we have identified all protected open space areas in the Meramec Greenway, we also obtained parcel-level data from Great Rivers Greenway on its land acquisitions and data from the St. Louis County Parks Department on FEMA buyouts. Finally, we acquired GIS files from the Department of Planning delineating the FEMA-mapped 100- and 500-year floodplains,[6] as well as major roads.

As we describe below, our estimation of avoided flood damages requires information on the structural characteristics of properties. For this, we obtained a database from the St. Louis County Revenue Department of all property sales in the county, which includes structural characteristics of buildings, such as number of stories and type of basement. We also use this sales data between 2008 and 2012, as we discuss in Section 5, to estimate a hedonic property model with proximity to protected lands as a key explanatory variable. For that analysis, we restrict attention to residential sales and exclude foreclosures and other sales that are coded as not being open market transactions.

3.2. Counterfactual Development Scenario

To create our counterfactual development scenario, we first examine the distribution of developed land uses in the unprotected areas of the 500-year floodplain of the Meramec River and its tributaries in St. Louis County. We find that 77% of the development in this area is single-family residential, and as such, we assume that the development on the protected lands that would have occurred in the absence of protection would have been single-family dwellings. Lands in the Greenway that are identified as vacant private properties are kept as vacant lands in the developed floodplain scenario.

We identify all the protected lands in the Greenway in the 500-year floodplain.[7] For each protected parcel that is below the 90th percentile of lot size for existing single-family residential parcels in the floodplains

[6] The floodplain data is from 1996 FEMA Q3 data. Updated flood hazard maps have not yet been provided for St. Louis County.

[7] 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.

—1.05 acres—we assume one home would have been on the parcel in our counterfactual case.[8] 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. In total, our counterfactual development scenario assumes 2075 additional single-family homes on roughly 2178 currently protected acres within the 500-year floodplain.

As flood damages will depend on the value of the structures, we assign each hypothetical home a value based on the appraised improved value (that is, the value of structures, not the land) of properties in nearby areas, using the data from the Department of Planning. This value should approximate the replacement cost value as used in the Hazus-MH default database. Specifically, we calculate the mean value of a single-family home in each school district along the Meramec Greenway (seven in total), as property values, and types of housing, vary across school districts. We also calculate separate mean improved values for properties in the 100-year and 500-year floodplains within each district. We then apply the appropriate estimate to the counterfactual development parcels.[9]

3.3. Hazus-MH Modeling

We estimate the flood damages that would have occurred on these hypothetically developed parcels using Hazus-MH (version MH-2.1, run using ArcMap 10), a national GIS-based model developed for FEMA by the National Institute of Building Sciences. Hazus-MH can estimate damages for multiple hazard types; here we use the riverine flood model. The state of Missouri used Hazus-MH for estimating flood risk in its state Hazard Mitigation Plan (Missouri State Emergency Management Agency, 2008) and the flood model has been used in academic studies of flooding, as well (e.g., Dierauer et al., 2012). In brief, Hazus-MH couples a flood hazard analysis, which estimates the depth of flooding, with an analysis of economic losses. Hazus-MH can be run at many levels, depending on the expertise of the user. A default run can be accomplished fairly simply, but the results are at a high level of aggregation. We improve the estimate of flood damages in Hazus-MH for the hazard estimation and the loss estimation as discussed specifically in the next two sections.

3.3.1. Calculating Flood Depths

To implement the flood hazard module, Hazus-MH relies on a digital elevation model (DEM) to delineate the stream network for a region. The default DEM for Hazus-MH is from the National Elevation Dataset maintained by the US Geological Survey (USGS) and has a resolution of 1 arc-second (about 30 m). We upgrade our analysis to a DEM with a resolution of 1/3 arc-second (roughly 10 m), also from USGS. The higher-resolution DEM improves the delineation of the stream network and improves estimation of the floodplain boundary (ASFPM, 2009). The resolution of the stream network can be varied from 0.25 to 10 mile^2. Finer resolution allows for evaluation of a more detailed drainage network but requires a trade-off in processing time. We estimate our stream network with a resolution of 0.5 mile^2. Once the stream network is created, Hazus-MH invokes a hydrology and hydraulics model to generate a flood surface elevation layer for the study region.[10] Hazus uses default Hydraulic Unit Codes and applies USGS regression equations and guage records to determine discharge frequencies. The output, for a given return period or discharge volume, is the depth of the flood across the study area, defined as the difference between the height of flood waters and the ground surface elevation. For more details on the flood hazard module, see Scawthorn et al. (2006) and the Technical Manual for the Hazus-MH flood model (DHS, 2012). While the Hazus estimates will, of course, contain model uncertainty, an evaluation of Hazus performance compared to detailed FEMA studies suggests that it should perform adequately in smaller watersheds with moderate relief; this characterizes our study area (ASFPM, 2009).

We use Hazus-MH to estimate flood depths for the 10-year, 25-year, 50-year, 100-year, 250-year, and 500-year flood events. As an example of the output from the flood module, we show the flood depths for the 100-year flood, along with the public lands in the Greenway, in Fig. 2. 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, quite deep flooding can occur 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. We return to this issue of spatial variability below.

3.3.2. Calculating Property Damages

The default loss analysis in Hazus-MH uses an inventory of structures drawn from multiple national databases and aggregated at a census block level. For an analysis such as ours that is at a small geographic scale, this averaging across census blocks can introduce large errors. We thus use the User Defined Facility tool in Hazus-MH to undertake a parcel-specific analysis, using the detailed parcel-level data that we have for our study area. It requires creating a parcel-level database for input into Hazus-MH, which we did by combining information from the sources described above. We created a point estimate of the location of each structure, which Hazus needs, by using the centroid of each parcel.[11] Depending on the type of structure, Hazus-MH then uses depth-damage curves to relate depth of flooding to building and content damages for each property.

Depth-damage curves are frequently used in flood loss analysis to relate the depth of flooding to the percentage of a building's replacement value or contents that are damaged. They are generally a stair-step function of water depth in feet. Hazus-MH has many such curves in its library and selects a default curve, which varies by property type (e.g., two-story single-family residential, mobile home, light industrial). We are assuming our counter-factual development is single-family residential, and for these property types, the depth-damage curve also varies by certain structural characteristics of the house, in particular the year built, the number of stories, and the type of basement.[12] Hazus also uses similar curves to estimate the damage to contents as a percentage of the property's value; again, these vary by structure type. We draw on the data from the Revenue Department to make the base assumptions for our counterfactual scenario; 80% of residential properties in our study area have a basement and the vast majority have one or two stories, so we assume these characteristics for our developed floodplain scenario. Finally, we use the mean year built of all structures built

[8] This was the case for 145 out of 246 total protected parcels.

[9] Communities participating in the National Flood Insurance Program must require all new development to be built at or above the level of the 100-year flood. As this is a simple counterfactual scenario, we cannot make assumptions about when the development would have occurred in relation to the timing of communities joining the NFIP and new maps being issued. In footnote 16, however, we present estimates of avoided damages under the assumption that all structures were built with their first floor at or above the level of the 100-year flood. This paper does not evaluate whether building codes or structural protection measures would have higher net benefits than conservation; we are simply evaluating the costs and benefits of a conservation strategy.

[10] Note, that we do not take account of backwater effects or flooding from the Mississippi River pushing back into the Meramec. In this sense, our numbers are an underestimate of avoided flood damages and thus our calculations of net benefits are conservative.

[11] For very large parcels, using a centroid could be inaccurate, if the building is located elsewhere in the parcel that experiences different flood depths than the centroid. Since we are hypothetically developing parcels, we assume they would have been in the centroid, absent any justification to locate them elsewhere in the parcel.

[12] The variations across depth-damage curves for the same building type can be substantial, but without a relationship empirically grounded in our study area, we rely on the Hazus-MH default curves, which are documented in the Hazus-MH Technical Manual (FEMA, 2012).

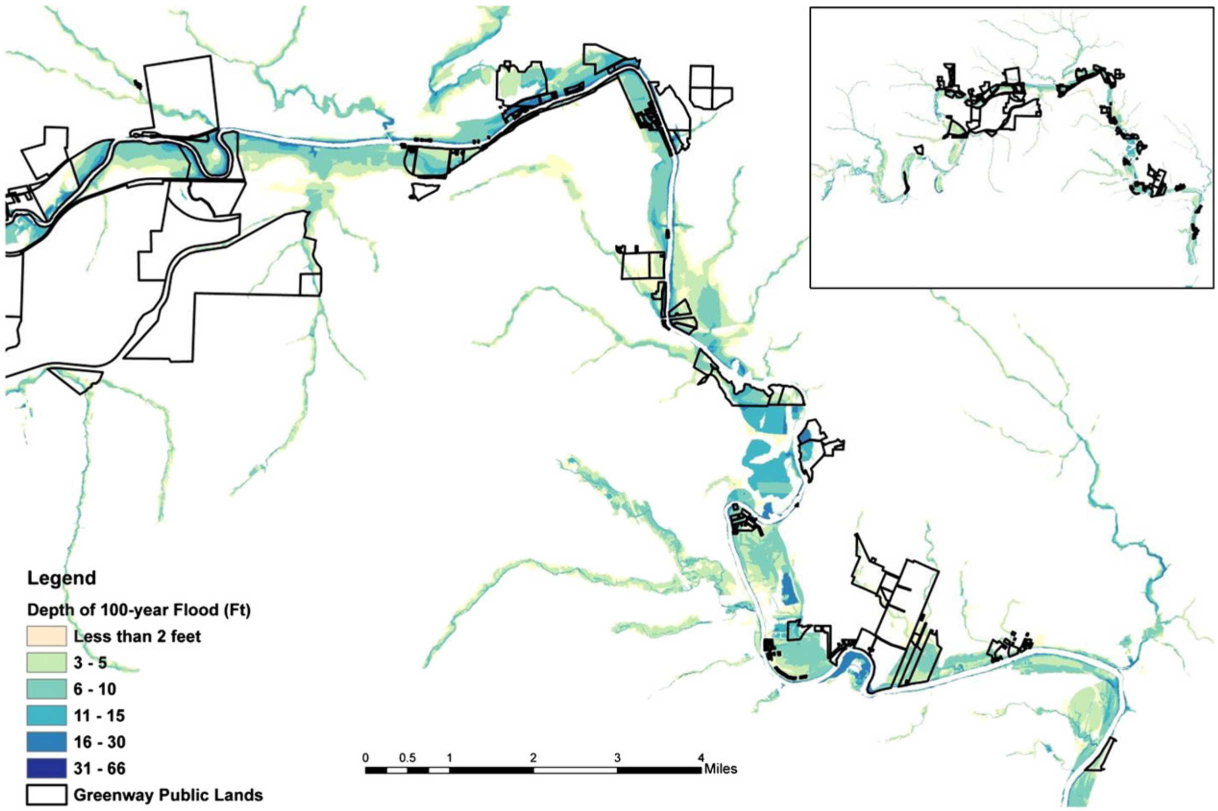

Fig. 2. Flood depths for the 100-year flood.

in the 500-year floodplain of the Meramec River. Below, we provide a sensitivity analysis by varying these assumptions.[13]

We use the estimates for each return period to calculate an average annualized loss (AAL) for each property. The AAL is the sum of the probabilities that floods of each magnitude will occur, multiplied by the damages if they do (FEMA, (Federal Emergency Management Agency) (n.d.)). To estimate the AAL from our return period estimates, we assume that (i) damages are constant in the intervals between return periods and equal to the average of damages at each end point, and (ii) the probability of a flood within the interval is equal to the difference between the probabilities at each end point.[14] For each property, then, we use this "binning" approach to get a property-level AAL and then sum the AAL for all properties in our developed 500-year floodplain scenario to get a total AAL estimate.[15]

A flood today that inundates protected areas, however, will still generate some damage to recreational infrastructure. We have an estimate of this value from the current GIS data with the appraised improved values of the protected parcels. We thus use these values to run Hazus-MH a second time, using the actual characteristics of the structures on the protected lands. This second run gives us an estimate of current annual average flood damages for comparison with our counterfactual development scenario. The difference between these two AAL numbers is an estimate of the avoided flood damages associated with the investment in floodplain conservation that has taken place along the Meramec River.

We caution the reader that the estimates of avoided flood damage used in this paper should not be taken as predictions. Like all modeling efforts, many simplifying assumptions are made in the Hazus-MH model, from the hydrology model to the assumed depth-damage curves. Our results should be seen as indicative of magnitude but not precise estimates of flood damages.

4. Hazus Results

4.1. Avoided Flood Damages from Greenway

As stated previously, we ran Hazus-MH for six different return periods. The total estimated flood damages to buildings and contents for our hypothetically developed parcels by each return period are shown in Fig. 3. As would be predicted, damages increase with the severity of the flood event. They increase at a decreasing rate, however; first rising rapidly as the return period increases to 100 years, then at a slower rate.[16] The total damages to buildings and property for these properties in the 100-year flood are estimated as $103.6 million.

Using the method described in the previous section, we estimate the average annual avoided damages of the greenway—i.e., the AAL under the developed floodplain scenario minus the AAL under current conditions. We find the total property-related (buildings and contents) avoided damages to be $7.70 million per year. Of this, we estimate that $5.39 million is from damage to buildings, and the remainder is damage to the contents of those buildings.

To put this estimate of avoided flood damages in context, the AAL for all parcels located in the 500-year floodplain for current development

[13] We choose not to use commercial or industrial properties in our hypothetical scenario, even in the sensitivity analysis, since the vast majority of this area is residential and damage modeling for these properties is notoriously uncertain and could easily skew our estimates by the selective choice of a depth damage function.

[14] For example, for the return interval 10–25 years, we add the damages for the 25-year flood to those for the 10-year flood and divide by 2 to get average damages; to obtain an expected value, we then multiply this average by the difference in probabilities of the two events, 0.06 (or 0.1–0.04).

[15] Of course, avoided damages are not equivalent to willingness to pay for risk-averse individuals. Other measures beyond the AAL could be used in policy analysis, as explored by Farrow and Scott (2013).

[16] The shape of a curve of this type will vary by location depending on the elevation of lands surrounding the river and tributaries and based on development patterns in the floodplain.

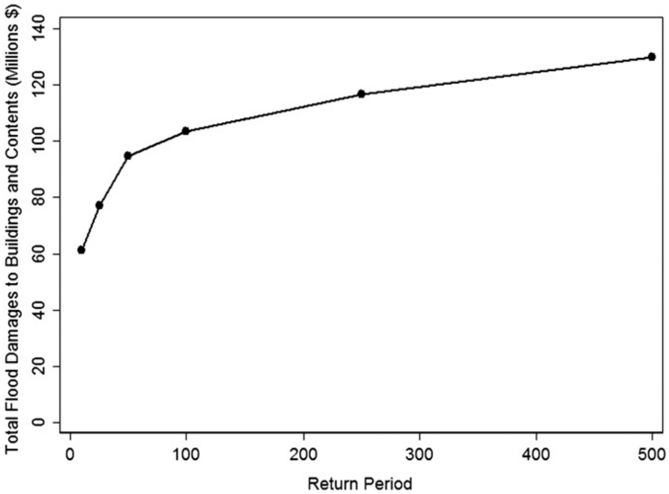

Fig. 3. Flood damages by return period for counterfactual development in the Meramec River Floodplain.

patterns (that is, without our additional hypothetical development) is \$12.95 million. Thus, without the protected lands of the Greenway, average annual flood damages to property in the St. Louis County floodplains of the Meramec River and its tributaries would be approximately 59% higher than under current conditions, according to our estimates. For reference, the appraised value (often referred to as the total flood exposure) of all the structures in the floodplain was roughly \$541 million in 2012.

As we are interested in the damages from a counterfactual scenario in which we had to make assumptions on the type of development that would have occurred in the absence of protection of those lands, we undertake a sensitivity analysis outside of Hazus on our assumptions. We vary whether or not homes have a basement, whether they are 1, 2, or 3 stories, and we examine building values that are up to 25% smaller and 25% larger than assumed in the base case just reported. For each different type of building assumption (e.g, basement or not and number of stories), we pull the relevant depth-damage default curve from Hazus and recalculate the AAL. Some of these runs produce larger estimates of avoided flood damages and some produce smaller estimates. The range across all the sensitivities on our estimate of the AAL of building damage is \$4.35 billion to \$9.87 billion. We use our estimate from the base case in the sections below, as we believe it to be the most plausible assumptions and at the conservative end of our sensitivity analyses.[17]

4.2. Opportunity Cost of Greenway Protected Lands

The opportunity cost of the Greenway protected lands is the total value of the lands in their next best use. As stated, since 77% of land use in the 500-year floodplain is single-family residential properties, we assume this same land use for the Greenway properties in our counterfactual development scenario. To calculate opportunity costs, we thus use the mean appraised per-acre land value of all single-family homes in municipalities that contain part of the Meramec Greenway, but are located *outside* the 500-year floodplain. If we were to use land values from inside the floodplain, to the extent that flood damages were already capitalized into those values, we would be double counting flood damages. The gross opportunity cost is the risk-free land value; the net opportunity cost is the risk-free land value less the avoided flood damages. Estimation of the capitalization of flood risk into property values suggests that floodplain land is indeed discounted relative to land that is not at risk of flooding (e.g., Bin and Polansky, 2004; Bin et al., 2008; Carbone et al., 2006; Daniel et al., 2009; Kousky, 2010). It is unclear, however, how accurate perceptions are of the flood hazard or how fully they are capitalized into property values, so we forgo using capitalized values in favor of our approach of estimated AALs. This allows us to separate the estimated flood risks and the risk-free land value. We calculate the average assessed land value from the tax assessment records for 2012 for single-family properties. This estimated average per-acre risk-free land value is \$157,780, which yields a total land cost of \$344 million for the 2180 acres of Greenway lands that would be developed in our counterfactual scenario.

We assume the Greenways lands will be protected in perpetuity, as this is the intention. We annualize the present value of \$344 million, using a 5% annual discount rate, to obtain an annual opportunity cost of \$17.2 million of the Greenway protected lands in St. Louis County. Of course, using a lower or higher discount rate would alter the opportunity cost: at 3%, the annual opportunity cost is \$10.32 million and at 7%, \$24.08 million. Table 1 summarizes the opportunity cost and avoided flood damage estimates using a 5% discount rate as a central case.

4.3. Conservation Targeting

Several economists have stressed the importance of targeting conservation investments to get the greatest "bang for the buck." Ando et al. (1998) show that achieving greater cost-effectiveness and economic efficiency requires examination of both costs and benefits, that is, ranking parcels by net costs and then investing until a budget is exhausted or a goal achieved. Work by Ferraro (2003) has found that examining both costs and benefits is particularly important when budgets are limited, benefits and costs are strongly positively correlated, and the relative variability in costs is greater than that of benefits. Kousky et al. (2013) show the importance of targeting in a study of the costs and benefits of land conservation for flood protection in a Wisconsin watershed.

In our study, the opportunity costs, based on our assumptions, do not vary dramatically across protected parcels. The avoided flood damages, however, do vary, as reflected in the map in Fig. 2. A small number of parcels are responsible for a large share of the overall damages. This can be seen in Fig. 4, which shows a quantile plot of average annual flood damages normalized by acreage of the protected area parcels that we develop in the counterfactual. The 45-degree line is shown for comparison, as it would represent a uniform distribution. This figure shows that the bulk of observations has relatively small losses and accounts for a very small share of total flood damages, while a few parcels account for a large share of the damages. For example, 50% of parcels have an AAL per acre less than \$6407. The top 10% of parcels, however, have an AAL per acre of over \$52,583. If parcels with the greatest potential for loss were targeted for conservation, more flood damage reduction could be achieved at a lower cost.

Table 1
Estimated annual net cost of the Meramec Greenway in St. Louis County: Opportunity costs less avoided flood damages (in millions of 2012 US\$).

Annual opportunity cost[a]	\$17.2
Annual average avoided losses from flooding	
Buildings	\$5.39
Contents	\$2.31
Total	\$7.70
Net annual opportunity cost	\$9.5

Assumptions for counterfactual development scenario: 2170 single-family homes on 2180 acres of (currently protected) floodplain lands in Greenway.

[a] Total present value of opportunity cost = \$344 million; annualized using 5% discount rate in perpetuity.

[17] When a community joins the National Flood Insurance Program, they are required to adopt regulations mandating that all development in the 100-year floodplain be constructed such that the first floor is at least as high as base flood levels (the estimated height of the water in a 100-year flood). If we make the assumption that all development would have been built to this standard in the counterfactual scenario, then our estimates of avoided flood damages to buildings range between \$730,000 and a bit over \$1 million, assuming our base assumptions for the value of structures.

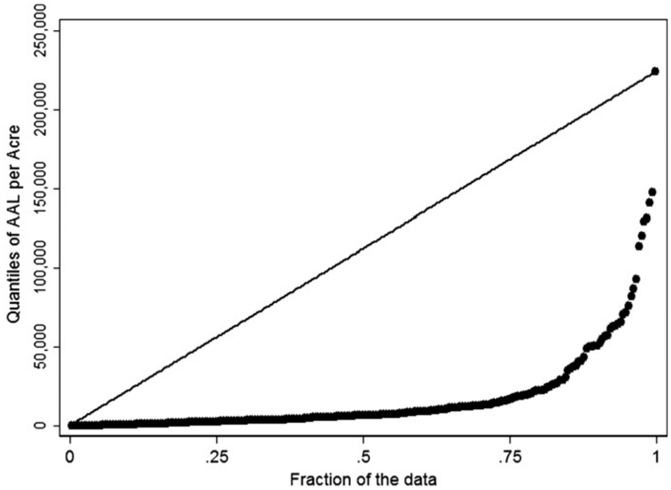

Fig. 4. Quantile plot of counterfactual development AAL normalized by acreage.

While such targeting would clearly improve the cost-effectiveness of floodplain conservation policies, implementing fine-scaled targeting is often not feasible. In the absence of eminent domain powers, communities are limited to acquiring parcels from willing sellers, and these may not be those at greatest risk of flooding (although there could be a positive correlation if individuals at greater risk are more inclined to move). Parcel size also varies and crosses floodplain boundaries, such that targeting and limiting acquisition to the areas of highest potential avoided losses may be impossible.

Perhaps more importantly, communities often pursue a "green" approach to flood mitigation instead of the gray infrastructure of dams and levees because of the aesthetic and recreational benefits that public lands provide. In this case, the many acres of land that provide a relatively small benefit in terms of avoided flood damages may provide relatively large additional co-benefits. Indeed, many of the public protected lands of the Meramec Greenway extend far outside the floodplain boundary, particularly the large parks. If the full costs of those acquisitions were included in our analysis (we looked at floodplain lands only), the investment would appear much more costly. But those acquisitions were not undertaken with a flood goal in mind; rather, provision of recreational opportunities was a key objective. In the next section, we investigate co-benefits in more detail.

5. Co-benefits of the Greenway

We estimate a hedonic model (Freeman, 2003; Rosen, 1974) to identify how proximity to protected lands in the Greenway is capitalized into housing values. There is a large body of literature on this topic, which has generally found that, indeed, proximity to protected lands is valued by residents, but the value is found to vary by setting and by type of protected lands (for a review of this literature, see McConnell and Walls, 2005). To obtain an estimate specific to our study area, we use sales data for residential properties sold between 2008 and 2012 and located within 5 miles of the Meramec Greenway. In our model, the natural log of a property's sale price is regressed on characteristics of the property, including proximity to parks.[18] We use the GIS files from the Planning Department to calculate the Euclidian distance between residential properties and the boundary of the nearest protected area. The coefficient on the distance variable can be interpreted as the marginal implicit price of proximity to protected lands.

To address concerns about omitted variable bias, we include numerous property-level controls, and also spatial fixed effects, at the census tract level, interacted with sale year fixed effects. This will purge the estimates of many neighborhood omitted variables, even those that vary differentially over time (Kuminoff et al., 2010; Linn, 2013). We also cluster our errors by census tract. We thus estimate the following equation:

$$\ln P_{it} = \beta_0 + \beta_1 dist_{it} + Z'_{it}\gamma + T_t * \theta_c + \varepsilon_{it}. \quad (1)$$

The selling price of property i in year t is given by P_{it}. The variable $dist$ is the distance from the property to the nearest protected area, as just described. A vector of property characteristics—including whether the structure is a floodplain, whether it is a multi-family home, the number of plumbing fixtures, the square feet of living area, the lot size, the distance to a major road, and fixed effects for its style and a grade given by the assessor for its condition—is given by $\boldsymbol{Z}_{it}$. We then include the year and census tract interaction terms.

Summary statistics of the variables are shown in Table 2. The mean selling price is roughly $318,600 dollars. The distance to the nearest park ranges from zero (for a property adjacent to a park) to close to 13,000 ft (just under 2.5 miles) with a mean of 2830 ft (roughly half a mile). The vast majority of the sample are single-family residential, with a mean living area of over 2000 square feet and a lot size of just under an acre.

Table 3 shows the results of our estimation. The coefficient on distance to parks indicates that for every 1000 ft closer a property is located to a park, holding all else constant, sales price increases by almost 1%. For a median-priced home in our sample, this is $2156. Other variables are as expected. Prices are lower for multifamily units and increase with increases in the number of plumbing fixtures (e.g., sinks, showers), the square feet of living area, and the acres of the property. Interestingly, while the coefficient on the floodplain dummy is negative, it is not significantly different from zero. Fixed effects for the style of the home and the assessor's grade of the state of the property are also significant, as are the census tract by year fixed effects (although the coefficients on the fixed effects are suppressed in Table 3).

To get a rough approximation of what these results mean in terms of total benefits,[19] we identify homes in our sample for which the closest protected land is part of the Meramec Greenway. There are slightly more than 36,000 such residential parcels. For these properties, we calculate the difference in distance between the Greenway protected lands and the closest non-Greenway protected lands. We then multiply this distance (in thousands of feet) by our estimated coefficient and the total assessed value of the property. This exercise yields a total benefit estimate of $352.56 million. Since many homes are financed with a 30-year mortgage, we annualized this amount over 30 years with a 5% discount rate; this amounts to an annual benefit of $22.93 million—$13.43 million more than our net cost estimate of $9.5 million. At 3%, the benefits are $17.99 million and at 7%, they are 28.41 million. These calculations suggest that the benefits of the Greenway exceed the costs by a sizable margin (see Table 4). It is also worth noting that the annual benefits of the Greenway as capitalized into housing values are over three times greater than the avoided flood damages. These more "traditional" values of green space continue to be critical components of the value of conserved floodplain lands, even as there is growing recognition of the additional value from flood exposure reduction.

The estimate of the co-benefits from the hedonic model should be considered a lower bound on the full suite of co-benefits provided by the protected lands. With our hedonic model, we are only capturing the benefits that are capitalized into house prices in a 5-mile surrounding area. It does not incorporate the value to individuals who live farther

[18] We exclude properties that are recorded as selling for less than $5000 and those selling for more than $10,000,000, as they could be recording errors, and if not, we do not want these outliers driving our results.

[19] Note that we are not estimating true willingness-to-pay (WTP) for proximity, which would require estimation of the second stage of the hedonic model, but instead getting a rough, order-of-magnitude indication of benefits. Further, the amount of the capitalization (as opposed to WTP) is likely to be of specific interest to local officials concerned on how conservation lands may increase tax revenue through higher values for surrounding properties.

Table 2
Summary statistics for hedonic regression.

Variable	Minimum	Maximum	Mean	Standard deviation
Price ($)	5145	9,581,100	318,620	532,580
Distance to park (1000s of feet)	0	12.831	2.8300	1.8817
100-year floodplain dummy	0	1	0.01341	0.11500
Multifamily dummy	0	1	0.01814	0.13345
Total plumbing fixtures	2	60	10.275	4.7145
Size of living area (square ft.)	139	14,732	2056.2	1134.6
Lot size (acres)	0	14,464	0.92090	86.945
Distance to nearest major road (1000s of feet)	0.055876	12.331	2.0249	1.5106
Style code	1	12	6.4021	3.8527
Assessor's grade code	1	6	2.7852	0.82532

Notes: The style code is given by the assessor's office and indicates architectural styles, such as ranch, colonial, and contemporary. The grade code indicates the quality of the home, from excellent to poor.

away, such that there is no impact on their housing values, but who still use the Greenway lands for recreation. It also does not fully capture the water quality improvement benefits that the Greenway lands might provide, such as the benefits to recreational river users from farther away and those accruing to municipal water utilities that may be able to reduce treatment costs.[20] Natural lands near waterways typically provide significant water quality benefits, which are often a motivation for conservation investments (e.g., Jaffee et al., 2010). Indeed, there are myriad other ecosystem services protected riparian lands could provide that we have not included here, such as carbon storage and species habitat. A large and growing literature has identified and begun to value these services in different contexts (e.g., Daily, 1997; Loomis et al., 2000; Martín-López et al., 2012; Nelson et al., 2009).

Our estimate also does not include benefits that could be obtained in terms of floodwater storage. If the conservation lands increase infiltration or store floodwaters, there could be benefits for surrounding parcels from lower flood depths. In principle, floodplain storage can reduce flood heights downstream, as well, and these benefits should be included in an analysis. In our study area, however, these impacts are likely to be small. The Meramec River empties into the Mississippi at the end of our study region and the Mississippi is lined with levees and heavily managed such that small changes to flood stages on the Meramec are unlikely to impact flood damages downstream.

6. Discussion and Conclusion

In this paper, we have undertaken a retrospective analysis of the costs and benefits of an investment in floodplain conservation, the Meramec Greenway in St. Louis County, Missouri. By developing a unique parcel-level database and a counterfactual scenario of forgone development, we were able to estimate the avoided flood damages of the Meramec Greenway and the full opportunity costs of the land preservation that has occurred to date. The floodplain conservation, like many such projects, was not undertaken solely for flood protection, however, but also for the range of other benefits these protected lands provide. We thus estimated a hedonic property model for the study area to identify the extent to which proximity to the Greenway was positively capitalized in housing values. Of note, these benefits are almost three times greater than the avoided flood damages and, on their own, exceed the opportunity costs of the conservation investment.

In this analysis, we have taken the perspective of the economy as a whole, estimating benefits and costs to whomever they may accrue. Of course, these benefits and costs will fall disproportionately on different groups and we have neither addressed such concerns here, nor the political economy implications. Notably, for a local government interested in undertaking conservation for the benefits it provides, what may be more important is an analysis of the fiscal impact to their budget.

There is a great deal of uncertainty in our estimates of costs, flood damages avoided, and co-benefits. The avoided flood damages depend on the specification of the counterfactual development scenario and the results of the Hazus-MH modeling, which incorporates a large degree of uncertainty in both the hydrology and hydraulics model of flooding and the estimation of property damages. Estimating nonmarket benefits such as the aesthetics of open space, as well as the recreational and other benefits that accrue to local residents, is a longstanding difficult exercise in environmental economics (Freeman, 2003). Our hedonic model provides a ballpark estimate of at least a portion of those benefits—the portion capitalized in surrounding home values—but is likely to underestimate the full benefits, as we discussed in the preceding section.

Despite these limitations, our exercise is useful for illustrating how to undertake a benefit-cost analysis of a floodplain conservation effort and highlights some important findings for managers. For example, our results demonstrate the importance of accounting for all benefits to fully evaluate the return on floodplain conservation. The more standard values of conservation appear—at least in this setting—to be much larger than avoided flood damages, although the risk management benefits do provide additional justification for floodplain conservation. Careful targeting of land acquisition could maximize the net benefits obtained strictly in terms of avoided flood damages, but targeting based on multiple benefits, which would seem a sensible approach for local governments, is much more difficult. The diverse

Table 3
Hedonic property model results, 2008–2012.

Dependent variable: ln(price)	
Distance to closest park (1000s of feet)	0.0098**
	(0.0047)
Located inside 100-year floodplain	−0.0068
	(0.0570)
Multi-family dummy	−0.1346***
	(0.0509)
Ln(total fixtures)	0.2937***
	(0.0177)
Ln(square feet of living area)	0.5335***
	(0.0254)
Acres	0.00001**
	(0.00001)
Distance to closest major road (1000s of feet)	0.0086
	(0.0055)
Style and grade FE	Y
Year*tract FE	Y
Observations	27,748
R-squared	0.7287

Notes: Clustered standard errors in parentheses.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

[20] It may capture a portion of the water quality benefits, if those are capitalized into house values. For examples of studies that use hedonic techniques to value water quality, see Leggett and Bockstael (2000), Bin et al. (2009), and Bin and Czajkowski (2013).

Table 4
Estimated annual costs and benefits of the Greenway (in millions of $).

Average annual opportunity cost	$17.2
Average annual avoided flood damages	$7.7
Average annual benefits capitalized in home prices	$22.93

benefits may not be perfectly correlated, such that the best parcels for achieving one benefit may not be the best for achieving another.[21] Targeting for cost-effectiveness in supplying multiple benefits first requires that the heterogeneity in all benefits across parcels be well understood, and then benefits need to be converted to a common currency or weighted in some fashion to evaluate the trade-offs or synergies for different land acquisitions.[22] In our case, there may well be high correlation between the benefits of avoided flood damages, recreation, and aesthetic value, since people enjoy viewing and recreating in protected riparian corridors. In practice, such multicriteria optimization may be prohibitive in many locations, where opportunities to acquire parcels from willing sellers take priority over economic optimization algorithms.

Another challenge for conservation investments designed to provide a range of benefits may be the siloed sources of funding for land acquisition. For instance, in the U.S., FEMA offers grants for buyout of properties when the flood related benefits are greater than the costs; a wastewater treatment facility may invest in land acquisition, but only of those lands that will have a large and immediate impact on water quality; and a parks group may be willing to fund acquisition of land needed to link two trails together to expand recreational opportunity. Combining these strategies may be difficult but could potentially yield total benefits that are greater than the sum of the parts.

Acknowledgments

This research was funded by a grant from the NOAA (NA12OAR4310094) Climate Program Office's Climate and Societal Interactions Program, Sectoral Applications Research Program (SARP). We appreciate the excellent research assistance of Ziyan Chu. We are also grateful to Lonny Boring, Carey Bundy, and Susan Trautman of Great Rivers Greenway for helping us in understanding 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 the helpful discussions about the Greenway and Alan Lulloff, Jonathan Remo, Leonard Shabman, Jeff Stone, and two anonymous referees for the important feedback on earlier drafts of this work. Finally, we thank Susan Poling and Tom Ott from the St. Louis County Parks Department for providing data on buyouts.

References

Ando, A., Camm, J., Polasky, S., Solow, A., 1998. Species distributions, land values, and efficient conservation. Science 279, 2126–2128.
Association of State Floodplain Managers [ASFPM], 2009. HAZUS-MH Flood Model Validation Final Report. Prepared for the National Institute of Building Sciences (July).
Bin, O., Czajkowski, J., 2013. The impact of technical and non-technical measures of water quality on coastal waterfront property values in South Florida. Mar. Resour. Econ. 28 (1), 43–63.
Bin, O., Kruse, J.B., Landry, C.E., 2008. Flood Hazards, Insurance Rates, and Amenities: Evidence from the Coastal Housing Market. J. Risk Insur. 75 (1), 63–82.
Bin, O., Landry, C.E., Meyer, G., 2009. riparian buffers and hedonic prices: a quasi-experimental analysis of residential property values in the Neuse River Basin. Am. J. Agric. Econ. 91 (4), 1067–1079.
Bin, O., Polansky, S., 2004. Effects of flood hazards on property values: evidence before and after Hurricane Floyd. Land Econ. 80 (4), 490–500.
Boyd, J., Epanchin-Niell, R., Siikamaki, J., 2012. Conservation Return on Investment Analysis: A Review of Results, Methods, and New Directions. Discussion paper, Resources for the Future, Washington, DC.

[21] Researchers have begun analyzing these relationships; see, for example, Raudsepp-Hearne et al., 2010.
[22] See Boyd et al. (2012) for a summary of the literature on multicriteria evaluation of conservation investments.

Carbone, J.C., Hallstrom, D.G., Smith, V.K., 2006. Can natural experiments measure behavioral responses to environmental risks? Environ. Resour. Econ. 33, 273–297.
Daily, G.C. (Ed.), 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D.C.
Daniel, V.E., Florax, R.J.G.M., Rietveld, P., 2009. Flooding risk and housing values: an economic assessment of environmental hazard. Ecol. Econ. 69 (2), 355–365.
Department of Homeland Security [DHS], 2012. Hazus-MH Flood Model Technical Manual, Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, Washington DC (Available online at: https://www.fema.gov/media-library/assets/documents/24609?id=5120).
Dierauer, J., Pinter, N., Remo, J.W.F., 2012. Evaluation of levee setbacks for flood-loss reduction, Middle Mississippi River, USA. J. Hydrol. 450–451, 1–8.
Farrow, S., Scott, M., 2013. Comparing multi-state expected damages, option price and cumulative prospect measures for valuing flood protection. Water Resour. Res. http://dx.doi.org/10.1002/wrcr.20217.
FEMA (Federal Emergency Management Agency), 2012. Hazus-MH Flood Technical Manual. Department of Homeland Security, FEMA, Mitigation Division, Washington, DC.
FEMA (Federal Emergency Management Agency). No date. *Flood Model: Hazus-MH MR5 Technical Manual*. Washington, DC: Department of Homeland Security, FEMA, Mitigation Division.
Ferraro, P.J., 2003. Assigning priority to environmental policy interventions in a heterogeneous world. J. Policy Anal. Manag. 22 (1), 27–43.
Freeman III, A.M., 2003. The Measurement of Environmental and Resource Values: Theory and Methods, 2nd ed. Resources for the Future, Washington, DC.
Great Rivers Greenway, 2011. Making St. Louis a Better Place to Live: An Update to the Regional Greenway Plan to Build, Promote and Sustain the River Ring. Great Rivers Greenway, St. Louis (Aug. 9).
Jaffee, M., Zellner, M., Minor, E., Gonzalez-Meler, M., Cotner, L., Massey, D., Ahmed, H., Elberts, M., Sprague, H., Wise, S., Miler, B., 2010. Using Green Infrastructure to Manage Urban Stormwater Quality: A Review of Selected Practices and State Programs. Illinois Environmental Protection Agency, Springfield, IL.
Kollat, J., Kasprzyk, J., Thomas, W., Miller, A., Divoky, D., 2012. Estimating the impacts of climate change and population growth on flood discharges in the United States. J. Water Resour. Plan. Manag. 138 (5), 442–452.
Kousky, C., 2010. Learning from extreme events: risk perceptions after the flood. Land Econ. 86 (3), 395–422.
Kousky, C., Olmstead, S., Walls, M., Macauley, M., 2013. Strategically placing green infrastructure: cost-effective land conservation in the floodplain. Environ. Sci. Technol. 47 (8), 3563–3570.
Kuminoff, N.V., Parmeter, C.F., Pope, J.C., 2010. Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? J. Environ. Econ. Manag. 60 (3), 145–160.
Leggett, C., Bockstael, N.E., 2000. Evidence of the effects of water quality on residential land prices. J. Environ. Econ. Manag. 39 (2), 121–144.
Linn, J., 2013. The effect of voluntary brownfields programs on nearby property values: evidence from Illinois. J. Urban Econ.
Loomis, J., Kent, P., Strange, L., Fausch, K., Covich, A., 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecol. Econ. 33 (1), 103–117.
Martín-López, B., Iniesta-Arandia, I., García-Llorente, M., Palomo, I., Casado-Arzuaga, I., et al., 2012. Uncovering ecosystem service bundles through social preferences. PLoS ONE 7 (6), e38970. http://dx.doi.org/10.1371/journal.pone.0038970.
McConnell, V., Walls, M., 2005. The Value of Open Space: Evidence from Studies of Non-market Benefits. Resources for the Future, Washington, DC.
Meramec River Recreation Association, 2004. Featuring Great Rivers Greenway District. Meramec Greenway Newsletter, 29 (Summer).
Miller, S., Muir-Wood, R., Boissonnade, A., 2008. An exploration of trends in normalized weather-related catastrophe losses. In: Diaz, H.F., Murnane, R.J. (Eds.), Climate Extremes and Society. Cambridge University Press, Cambridge, UK, pp. 225–247.
Missouri State Emergency Management Agency, 2000. Stemming the Tide of Flood Losses: Stories of Success from the History of Missouri's Flood Mitigation Program. State Emergency Management Agency, Jefferson City, MO.
Missouri State Emergency Management Agency, 2008. Missouri State Hazard Mitigation Plan. State Emergency Management Agency, Jefferson City, MO.
Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front. Ecol. Environ. 7 (1), 4–11.
Perry, C.A., 2000. Significant Floods in the United States During the 20th Century-USGS Measures a Century of Floods: USGS Fact Sheet 024–00. U.S. Geological Society, Lawrence, Kansas.
Pielke Jr., R.A., Downton, M.W., 2000. Precipitation and damaging floods: trends in the United States 1932–97. J. Clim. 3625–3637 (15 October).
Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proc. Natl. Acad. Sci. 107 (11), 5242–5247.
Rosen, S., 1974. Hedonic prices and implicit markets: product differentiation in pure competition. J. Polit. Econ. 82, 34–55 (January–February).
Scawthorn, C., Blais, N., Seligson, H., Tate, E., Mifflin, E., Thomas, W., Murphy, J., Jones, C., 2006. HAZUS-MH flood loss estimation methodology I: overview and flood hazard characterization. Nat. Hazards Rev. 7 (2), 60–71.
St. Louis County Department of Planning, 2003. St. Louis County Meramec River Greenway Concept Plan. St. Louis County Department of Parks and Recreation, St. Louis County Department of Planning, St. Louis, MO.
Stromberg, D., 2007. Natural disasters, economic development, and humanitarian aid. J. Econ. Perspect. 21 (5), 199–222.

Wilson, D.A., 2008. Hurricane Ike and impact of localized flooding in St. Louis County. In: Criss, R.E., Kusky, T. (Eds.), Finding the Balance between Floods, Flood Protection, and River Navigation. Saint Louis University, Center for Environmental Sciences, St. Louis, MO.
Winston, W.E., Criss, R.E., 2003. Flash flooding in the Meramec Basin, May 2000. In: Criss, R.E., Wilson, D.A. (Eds.), At the Confluence: Rivers, Floods, and Water Quality in the St. Louis Region. Missouri Botanical Garden Press, St. Louis, MO.
Wuebbles, D.J., Hayhoe, K., Cherkauer, K., 2009. Climate change and the Upper Mississippi River Basin. In: Criss, R.E., Kusky, T. (Eds.), Finding the Balance Between Floods, Flood Protection, and River Navigation. Proceedings of a Conference Held November 11, 2008. Saint Louis University, Center for Environmental Sciences, St. Louis, MO, pp. 47–54.