Valuation of the Flood Attenuation Ecosystem Service in Difficult Run, VA, USA

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Research article

Valuation of the flood attenuation ecosystem service in Difficult Run, VA, USA

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ABSTRACT

Floodplains and riparian wetlands provide several ecosystem services that directly benefit people. We present a methodology for valuing the flood attenuation ecosystem service in Difficult Run, a suburban watershed with extensive natural floodplains in northern Virginia. High-resolution lidar-derived data were combined with GIS modeling techniques to produce estimates of flood inundation. We combined the modeled estimates with parcel-level property and primary economic data using a baseline and a counterfactual scenario to estimate the magnitude of flood attenuation and the associated value of the ecosystem service. Our framework brings new models and data to look at floodplains and an alternative land surface scenario in a way that has not previously been done. Annualized avoided property losses totaled $42,184 in the baseline scenario and $115,596 in the counterfactual scenario for the combined 200-, 100-, 50-, 20-, 10-, and 5-year flood events. We estimate the total annualized value of the flood attenuation ecosystem service in Difficult Run is $73,412, which is $77 per hectare of floodplain area and is consistent with similar valuation studies of floodplains. The framework presented here is not specific to the study area and could be deployed at larger spatial areas in other locations. Our methods may better inform land use decision making on the impacts of development in and surrounding floodplain areas.

1. Introduction

Floodplain ecosystem functions provide many benefits to humans often referred to as ecosystem services (Costanza et al., 1997; Daily et al., 1997). Floodplains and riparian wetlands benefit people by recharging groundwater aquifers (Acharya, 2000), retaining sediment and nutrients thereby purifying water by reducing stream and river loads (Loomis et al., 2000), provisioning fauna and open space for wildlife and people, and regulating extreme flow events (U.S. Environmental Protection Agency, 2015). A major floodplain ecosystem service is flood attenuation, sometimes referred to as flood mitigation.

Floodplains have long been recognized for their impact on flooding by retaining water and reducing flow velocity, thus lowering flood peaks downstream (Rak et al., 2016; Thomas and Nisbet, 2007). As early as 1972, the US Army Corps of Engineers (USACE) identified and preserved 8422 acres of wetlands along the Charles River in Massachusetts to reduce flood damages to urban areas in the lower portions of the watershed (U.S. Army Corps of Engineers New England Division, 1993). Designated the Charles River Natural Storage Areas, these riparian wetland areas remain intact and undeveloped, providing natural flood damage protection. Physically, the floodplains store and retain runoff during flooding events, which results in a delay and reduction in magnitude of downstream flood peaks during heavy precipitation events. Vegetation and tree cover also increases hydrologic roughness, further reducing flood peaks (Anderson et al., 2006). Properties that might otherwise be exposed to flood risks without functioning floodplains can have reduced, or even completely avoided, damages.

Previous studies have considered the flood mitigation ecosystem service of floodplains (Kadykalo and Findlay, 2016). One approach to value this service is contingent valuation (e.g. Brouwer et al., 1999; Ragkos et al., 2006; Ryffel et al., 2014), which uses stated preferences from a sample of people to derive the economic value of a floodplain. While these studies can give reasonable estimates of stakeholder preferences and priority, there is no explicit analysis of physical processes. Nin et al. (2016) used a combination of expert elicitation and spatial multicriteria modeling to identify areas that provide flood attenuation and other ecosystem services. Another approach is the replacement cost method (Pithart et al., 2010), which uses the cost of human-built infrastructure substitutes to provide ecosystem function as a proxy for value, but does not include simulated or realized monetary costs. Most

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Motivations

- Sustaining Environmental Capital Initiative (SECI)
  - Floodplain ecosystem services
  - Water and habitat quality
  - Freshwater mussels

- Improve natural resource management

Floodplains Provide a Multitude of Ecosystem Services

- Recharge groundwater aquifers
- Retain sediments and nutrients (purifying water)
- Provisioning of open space
- Regulate extreme flow events

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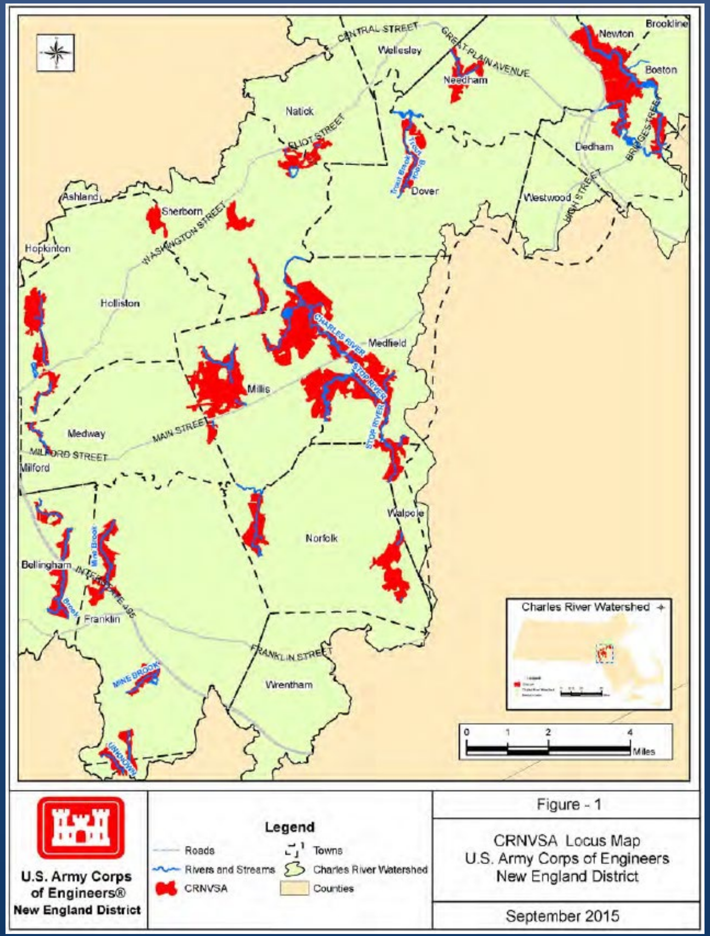
Linking Flood Attenuation Service to Values

Link water storage
to flood attenuation

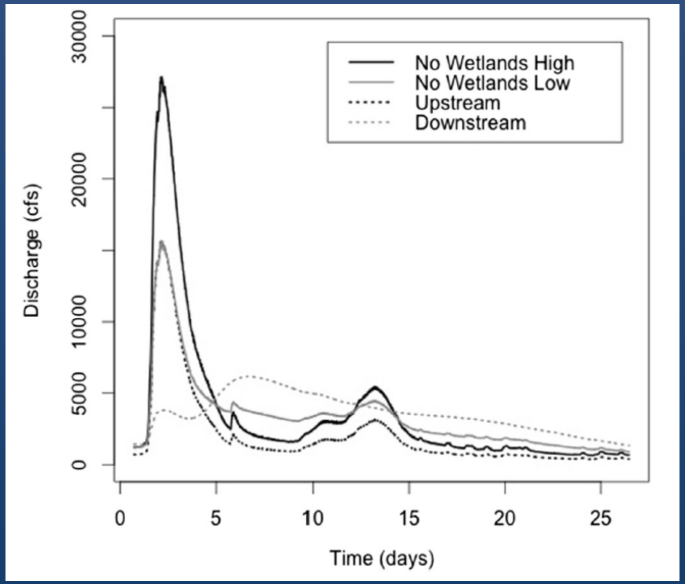
Link flood attenuation
to avoided damages

Photos courtesy of Chesapeake Bay Program

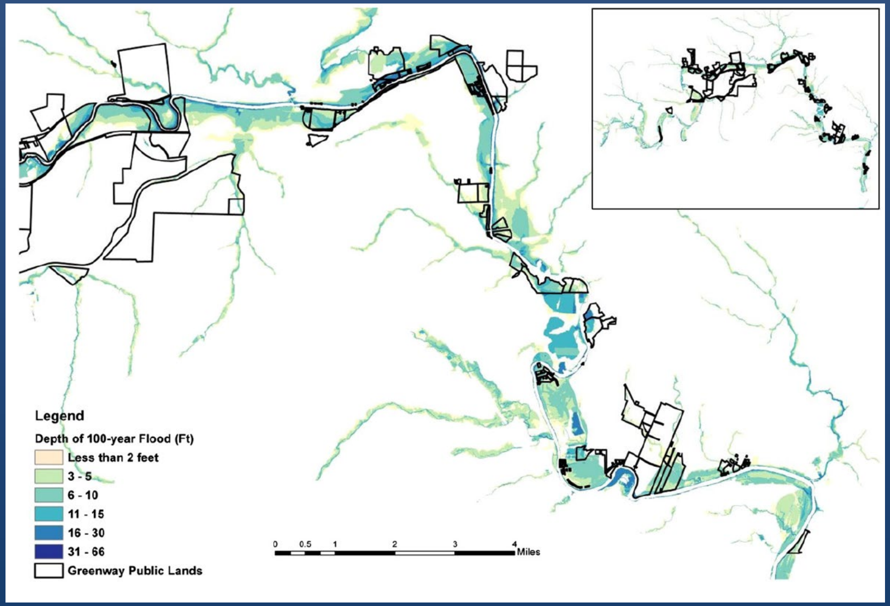
Flood Attenuation in Practice



USACE, 2015



Watson et al., 2016



Kousky and Walls, 2016

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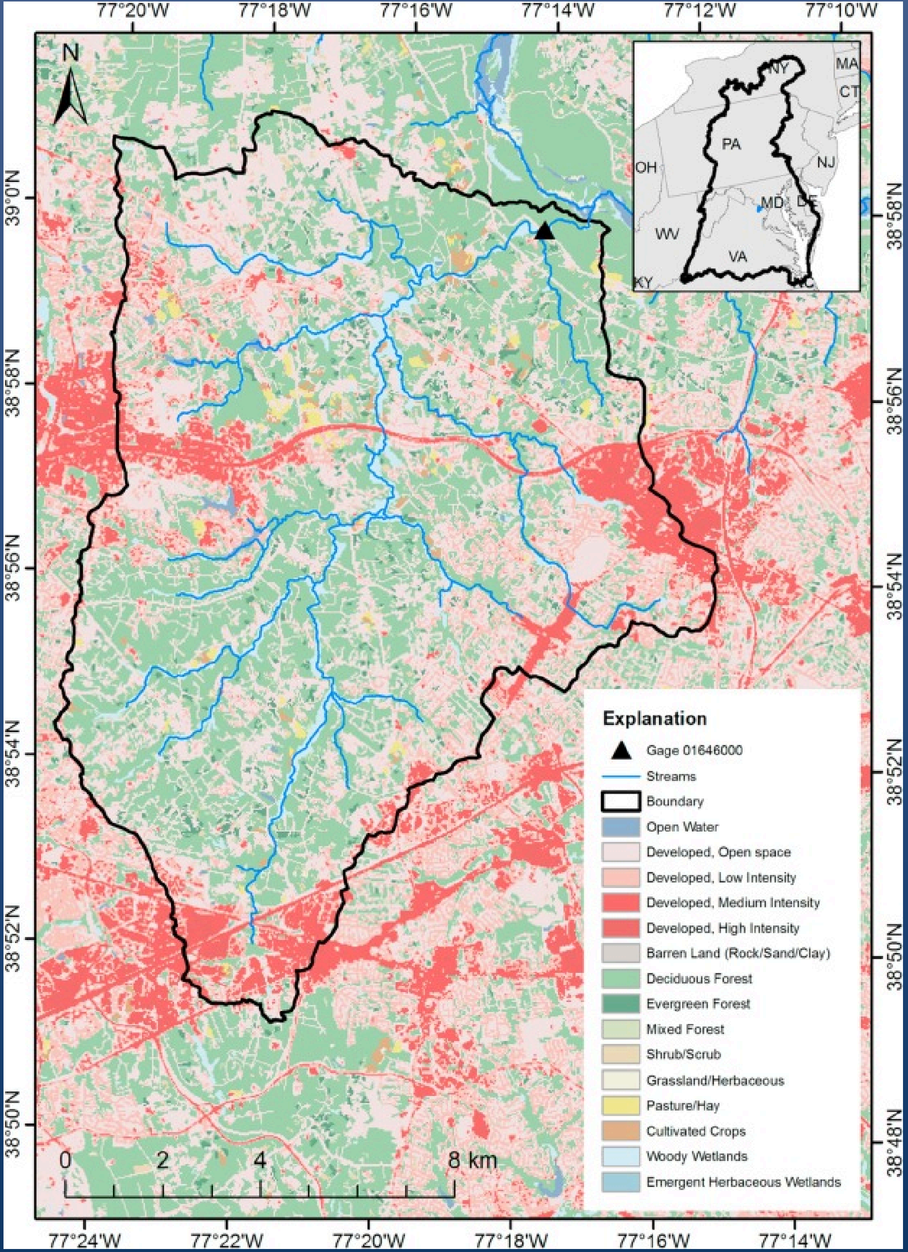
Difficult Run Watershed

- Chesapeake Bay Watershed
- Fairfax County, VA
  - Population: 1.13 million (2016)
  - High property values
- Suburbs, Deciduous Forest, Woody Wetlands
- Extensive floodplains (>6% total land area)
- Previous biophysical and ES studies (e.g. Noe and Hupp, 2009; Gellis et al., 2017; Hopkins et al., 2018)



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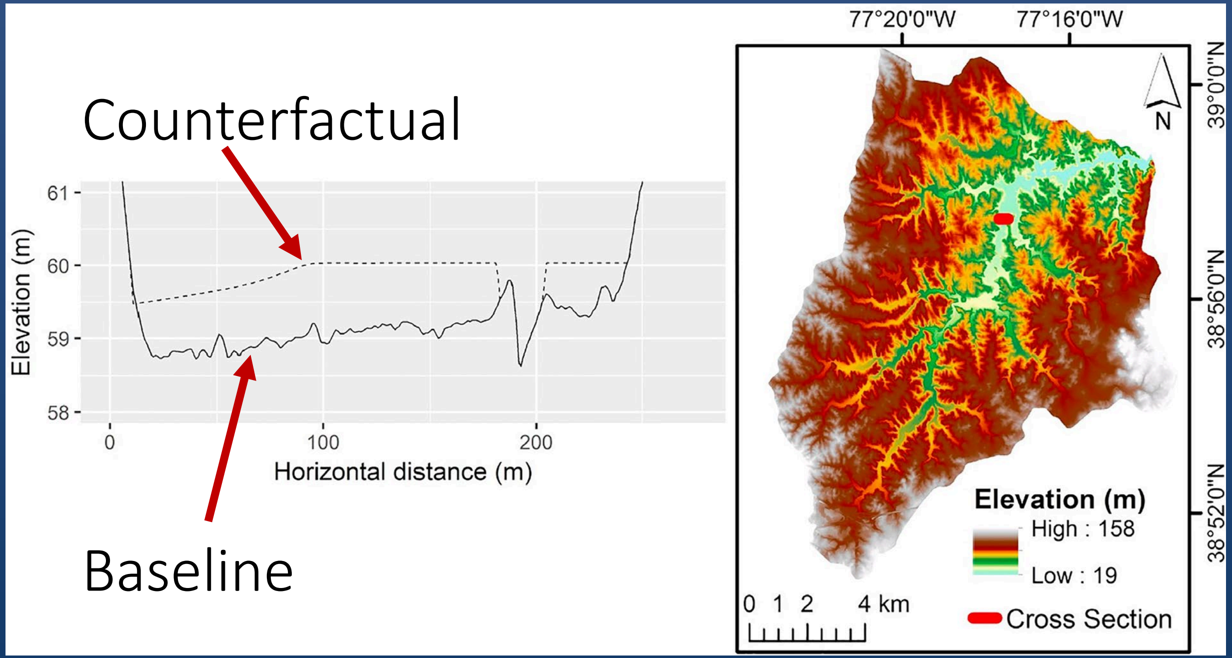
Counterfactual Scenario of No Floodplains

- Simulates reduced storage during flood events and higher peak discharge
- Raised elevation of Digital Elevation Model (DEM) within floodplain
- Leave channel, non-floodplain land surface the same
- Estimate floods with baseline and counterfactual DEMs



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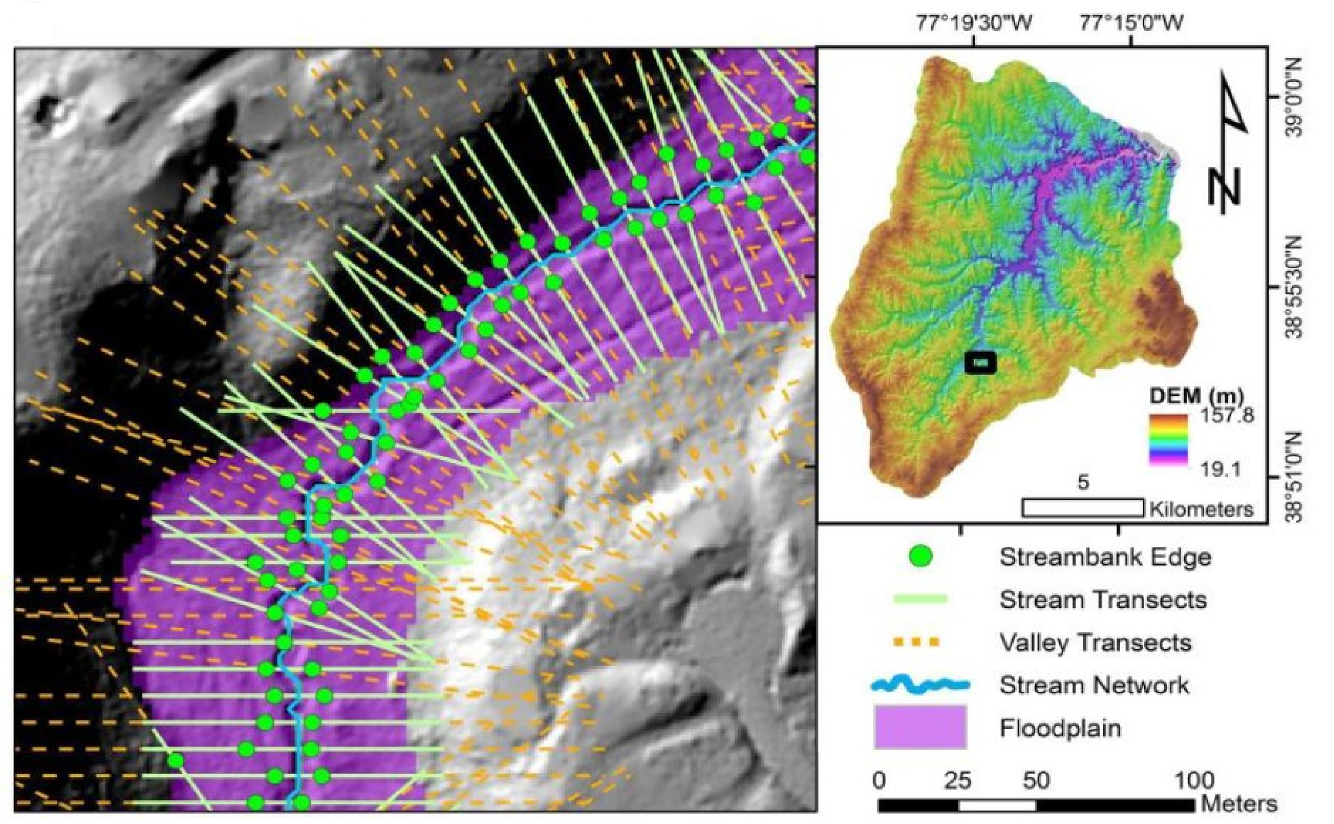
Stream Channel and Floodplain Metric Toolbox

- USGS toolbox developed by Hopkins et al., 2018
- Uses cross sections to analyze DEM
- Determines streambank edge, floodplain boundary
- Derives floodplain:
  - Width
  - Max/Min elevation
  - Elevation mean and standard deviation
- 3 m resolution DEM for model output



Hopkins et al., 2016

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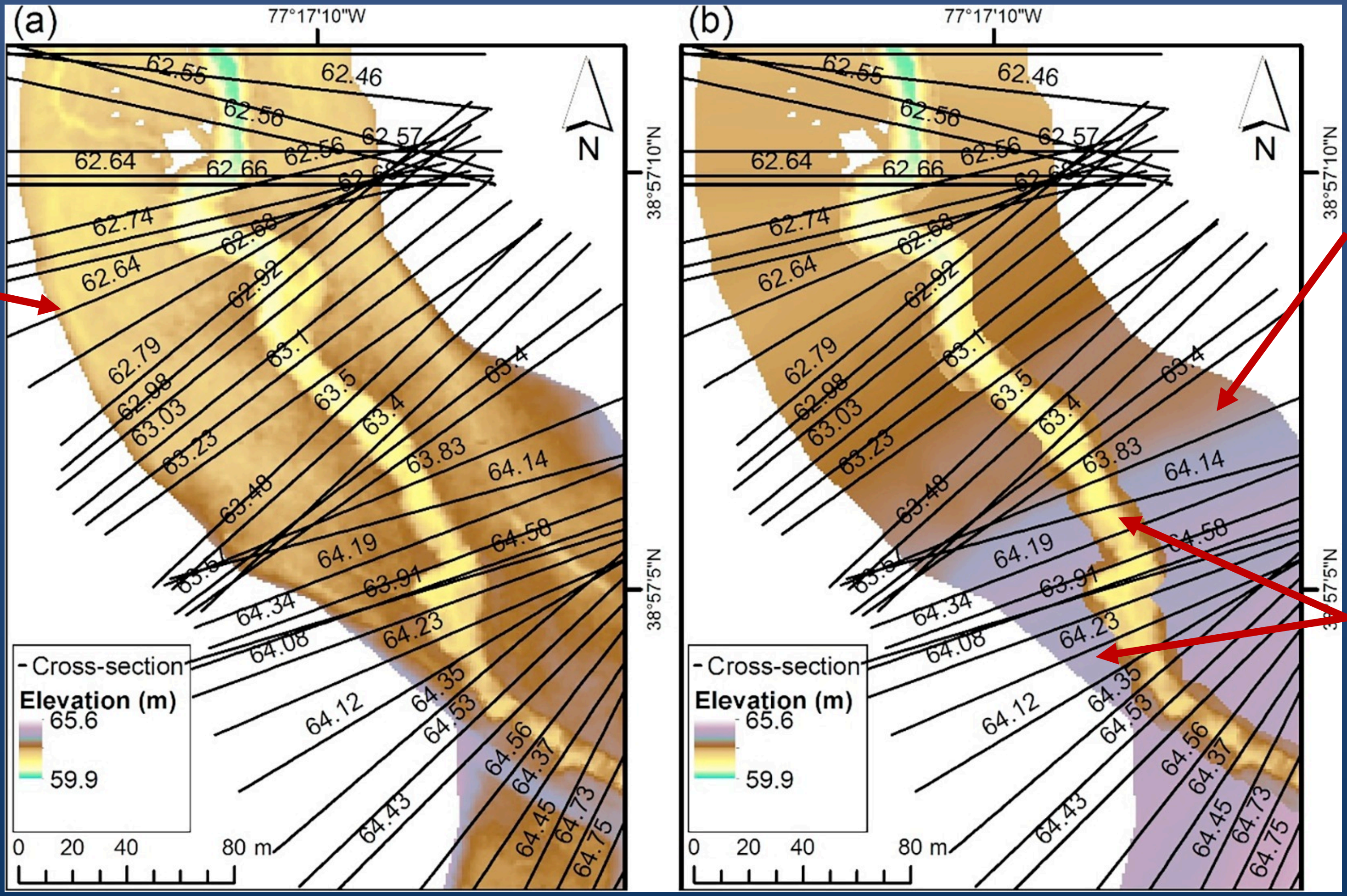
Developing a Counterfactual DEM

Baseline DEM

Counterfactual DEM

1. Assigned maximum floodplain elevation as cross section value



2. Interpolated surface using cross sections as elevation cross sections

3. Created mosaic from counterfactual in floodplain and baseline DEM in stream and outside floodplain

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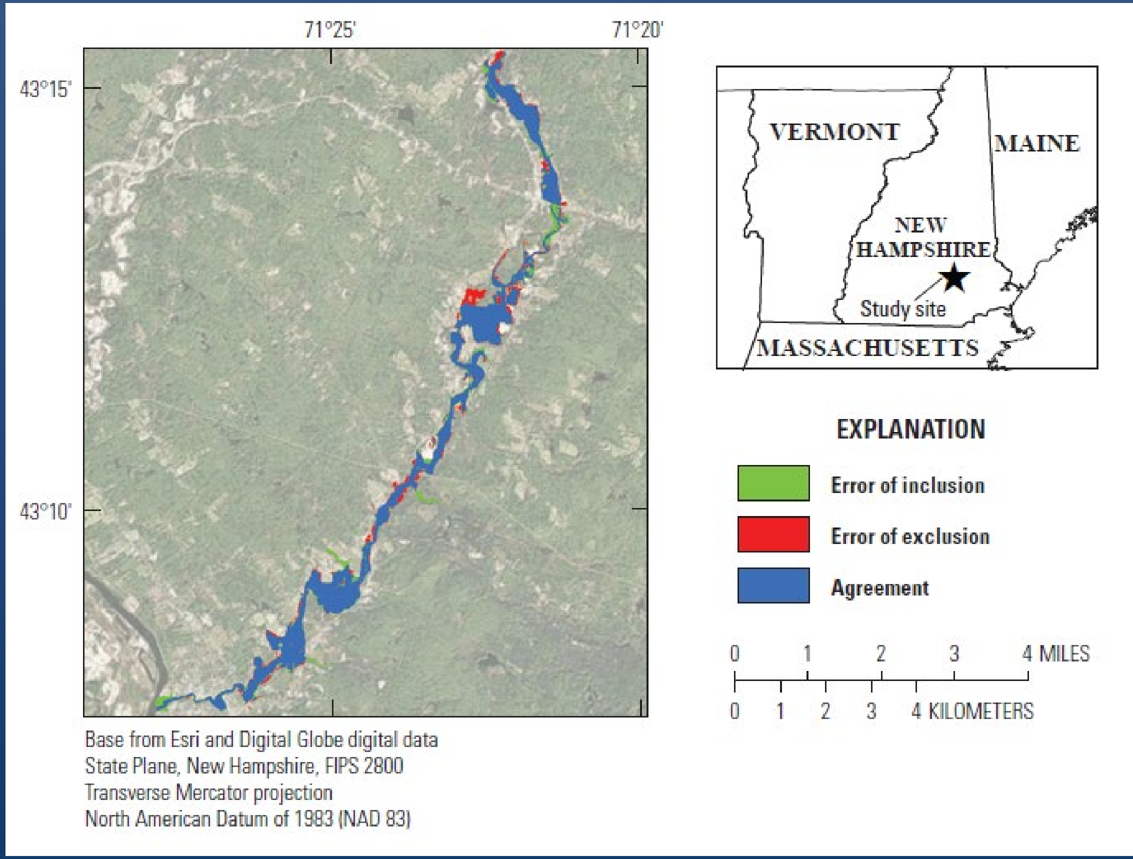
Modeling Flood Inundation with the GIS Flood Tool (Verdin et al., 2016)

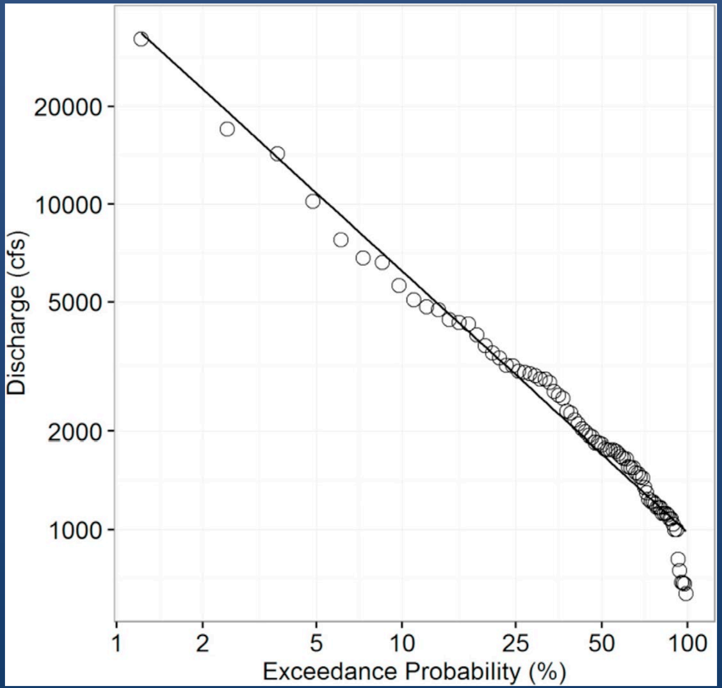
- Based on Manning's equation
- Requires DEM, known flood stages
- Fast estimation of flood inundation with and without detailed data
- Good agreement with 1-D hydraulic modeling in test cases
- Run with 1-meter DEM in this study



Verdin et al., 2016

Streamgage Record for Difficult Run

- USGS streamgage station 01646000, Difficult Run near Great Falls, VA
  - Annual Peak streamflows from 1935 – 2015
  - Rating curve data to relate annual peak flows and flood stage
- Return intervals calculated from linear model fit of exceedance probability curve



Return Interval (years)	Stream Discharge (m^3 s^{-1})	Flood Stage (m)
200	1896	7.45
100	1115	6.14
50	640	5.01
20	307	3.81
10	176	3.10
5	101	2.51
2	48	1.70

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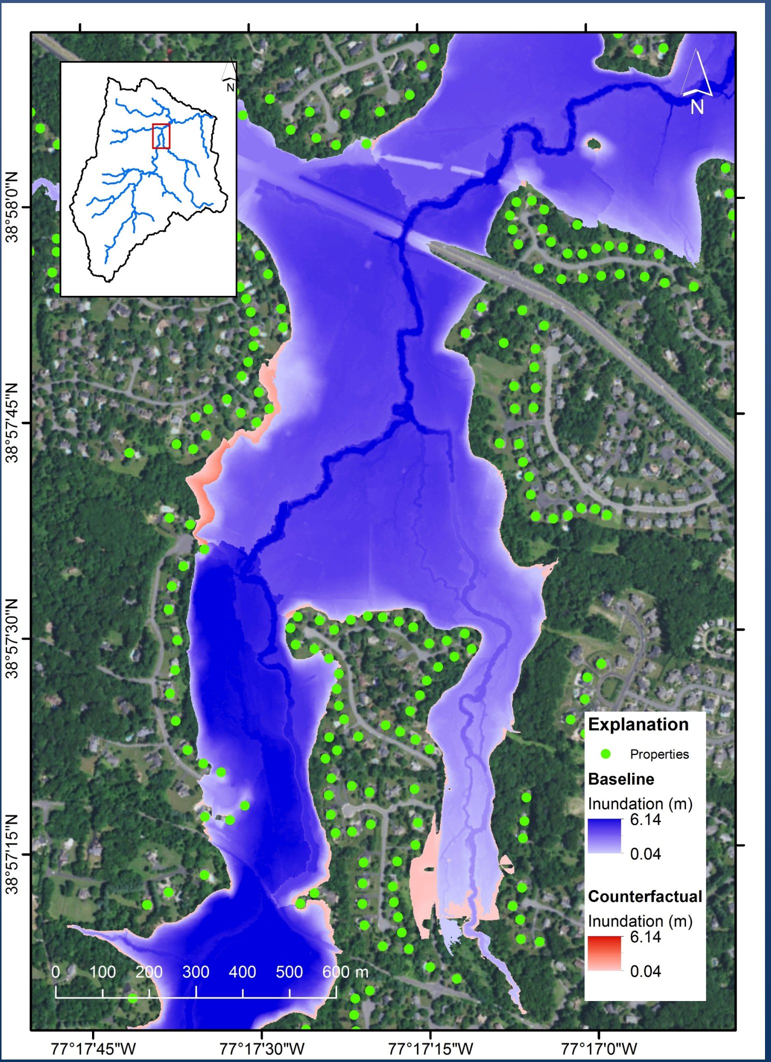
Results: Flood Inundation Modeling

- Flood extent ranged from bankfull (2-year event) to fully inundated floodplain (100- and 200-year events)
- Higher magnitude floods mostly resulted in higher flood heights, not flooded area
- Most structures outside of floodplain and inundated area
- Counterfactual scenario resulted in more inundated properties for all recurrence intervals



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Valuation of Flood Attenuation Ecosystem Service

- Damage costs avoided method (de Groot et al., 2002)

$$AAL = \sum_{r=2,5,10,20,50,100,200} (Damage_r \cdot Probability_r)$$

$$ES_{value} = AAL_{counterfactual} - AAL_{baseline}$$

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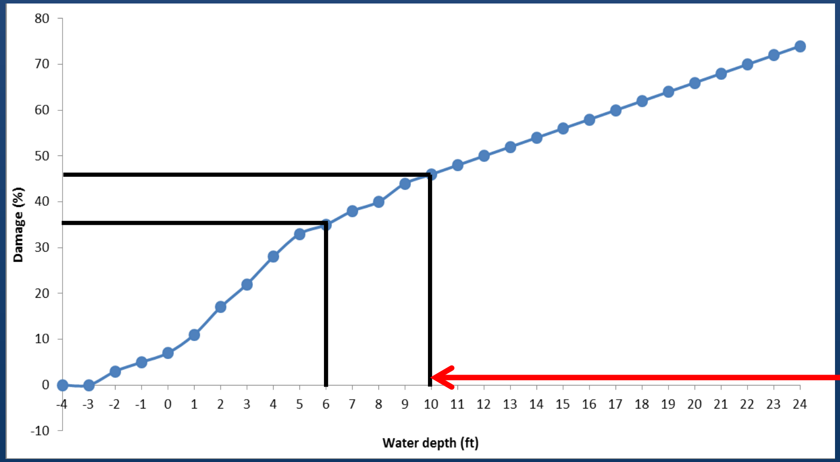
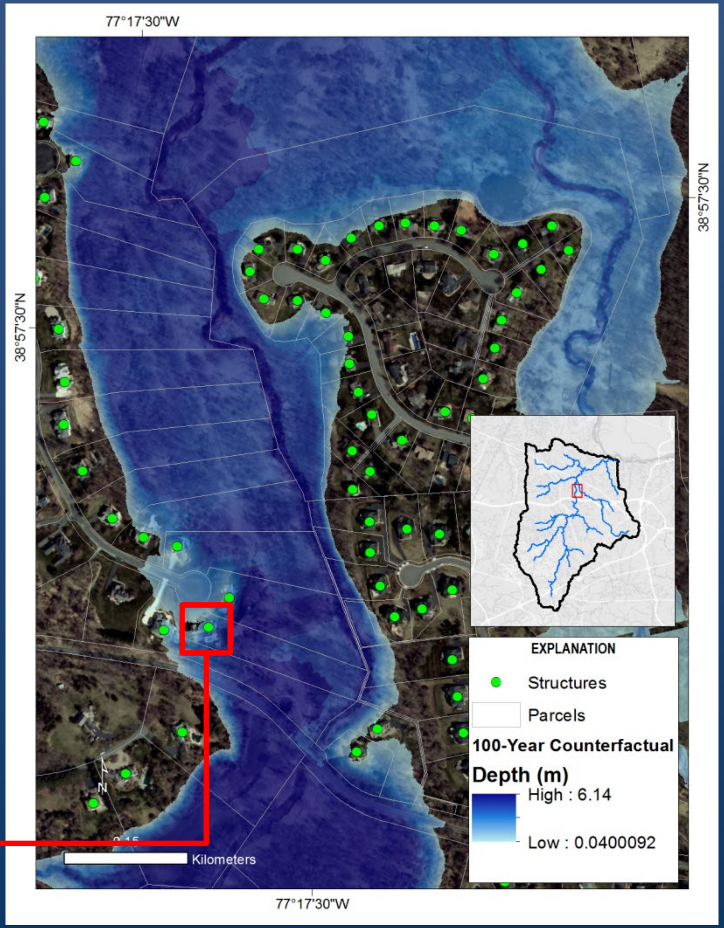
Estimating Damages

- Parcel-level property data
  - Improvement on census-block level analysis in HAZUS
  - More granular results
- FEMA depth-damage curves for 2-story houses without basements

$$Damage_{baseline} = 0.35 \times \$924{,}070 = \$323{,}424$$

$$Damage_{cf} = 0.46 \times \$924{,}070 = \$425{,}072$$





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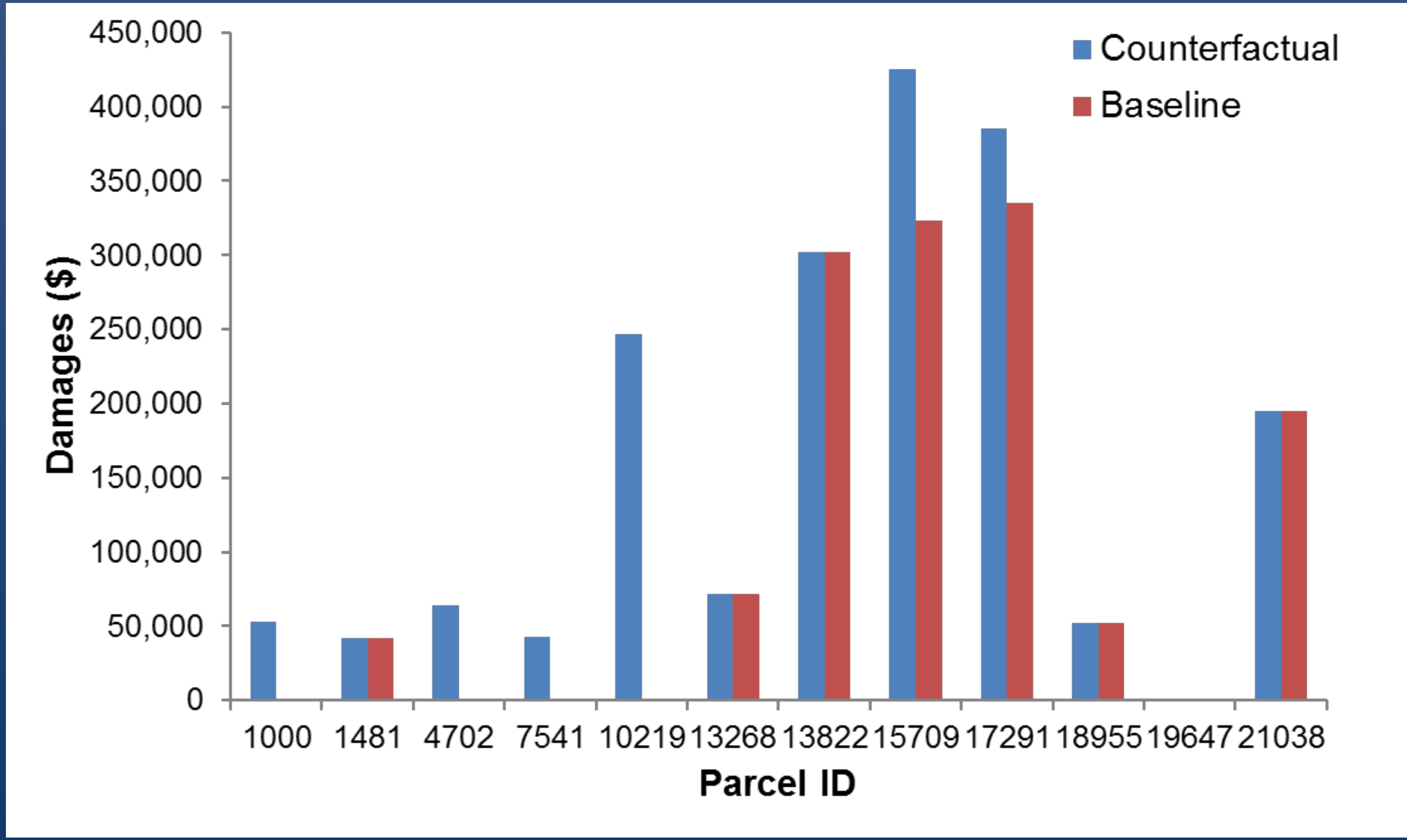
Results: Damages for 100-year Event



Results: Valuation

- At least one property inundated in counterfactual scenario for 5-, 10-, 20-, 50-, 100-, and 200-year flood events
- At least one property inundated in baseline scenario for 20-, 50-, 100-, and 200-year flood events
- Total annualized damages:

Counterfactual damages	$115,596
Baseline damages	$42,184
Ecosystem service value	**$73,412**

- $77 per hectare per year for 958 hectares of floodplains in Difficult Run

Conclusions

- Flood attenuation is a valuable ecosystem service in Difficult Run, but is location dependent.
- Open source models and available data can provide a high-quality framework for ecosystem service valuation.
- Developing scenarios requires some creativity (and subjectivity).
- Floodplain ES valuation can demonstrate the value of floodplains (especially of high value) and support tradeoff analyses.