



## Research Paper

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# Buy them out before they are built: evaluating the proactive acquisition of vacant land in flood-prone areas

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**Summary**

Rising flood damages have prompted local communities to implement buyout and property acquisition programmes to eliminate repetitive losses for at-risk properties. However, buyouts are often costly to implement and are reactionary solutions to flooding. This study quantifies the benefits of acquiring vacant private properties in flood-prone areas rather than acquiring such properties after they are built up. Using a geodesign framework that integrates concepts and analytical approaches derived from geographical, spatial and statistical-based disciplines, we analyse vacant properties with high development potential that intersect current and future floodplain areas in Houston (TX, USA). We use geospatial proximity analysis to select candidate properties, land-use prediction modelling to estimate future development and sea-level rise and benefit–cost analysis to assess the economic viability of buyouts. The results indicate that cumulative avoided flood losses exceed the cost of vacant land acquisition by a factor of nearly two to one, and up to a factor of ten to one in selected areas. This study emphasizes the benefits of proactive property buyouts that focus on acquiring parcels before they are built up, while also avoiding the social and institutional problems associated with traditional buyout programmes.

**Introduction**

Following the catastrophic impact of large storms, purchasing chronically damaged properties and restoring them to open spaces continues to gain popularity as a flood mitigation strategy in the USA (Zavar 2015). This is usually referred to as a buyout, and it traditionally involves local governments' purchase of buildings in flood-prone areas that have been repeatedly flooded and restoring them to vacant open spaces. Over 40 000 such properties have been acquired across the USA since 1989, primarily through the Federal Emergency Management Agency (FEMA) programme funds (Mach et al. 2019). Floodplain-based property acquisition is expected to play an increasing role in local floodplain management (Winsemius et al. 2016, Wing et al. 2018).

Buyouts often result in economic and ecological benefits, such as the prevention of flood losses and protection of environmental assets (Conrad et al. 1998, Zavar 2015). However, most buyout programmes are initiated in a reactionary manner, which leads to several problems. For example, homeowners who relocate after a buyout may face socioeconomic and psychological distress (Binder et al. 2015, 2020). Many buyout programmes in the USA are also flawed by limited policy learning and a lack of transparency in the selection process, potentially contributing to social injustice and reduced participation for socially vulnerable households (Greer & Binder 2017, Siders 2019). Checker-boarding of buyouts may also limit opportunities for creating open space clusters, resulting in small, isolated patches of open spaces in residential neighbourhoods (Blanco et al. 2009, Maly & Ishikawa 2013, Freudenberg et al. 2016, Zavar & Hagelman III 2016). Additionally, many property owners are emotionally attached to their homes and reluctant to leave, even under dire circumstances; the perception of the government taking over private property often makes homeowners less willing to participate in voluntary buyout programmes (Maldonado et al. 2013, Marino 2018). These limitations make purchasing properties with existing development more problematic compared to buying out vacant land or promoting policies that prevent development in high-risk locations.

This study builds on the idea of proactive land acquisition and conservation by examining private vacant lands at multiple spatial scales. Rather than focusing on the existing open space restoration approach (demolishing buildings and restoring parcels to open space), this study analyses an open space conservation approach (buyout of vacant land before buildings are erected). 'Vacant land' is a ubiquitous urban land use (Pagano & Bowman 2000) and accounts for nearly 17% of land in each large US city (Newman et al. 2016). When vacant lands in flood-

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**Table 1.** Vacant parcel selection and analysis through the geodesign process (adapted from Steinitz 2012, Newman et al. 2019).

Model	Parameters	Task	Scale	Input	Output
Representation	Description of study area	Inventory	City	GIS mapping of vacant property selection	Map of vacant properties in study area
Risk and exposure	Analyse flood risk and exposure	Floodplain, development prediction, historic flood loss, wetlands	Watershed	GIS Spatial analysis	Rank of watershed based on vacancy and flood risk
Change	Analyse potential for future development	Intersection of flood risk and future development	Watershed	GIS Spatial analysis	Test site location for BCR analysis
Impact	Current impact if development occurs in vulnerable location	Flood hazard modelling	Site	Hazard exposure modelling HEC-RAS Python	BCR of test vacant sites
Decision	Evaluate development options	Estimate BCR	Site	Economic analysis BCR	Decision to keep vacant or develop based on economic analysis

BCR = benefit–cost ratio.

prone areas remain vacant, they automatically record no direct economic loss from flooding and can even reduce flood losses to surrounding development by storing floodwaters (Brody et al. 2014, 2017, Highfield et al. 2018). Vacant open spaces provide other opportunities such as protecting wetlands and floodplains (Conrad et al. 1998), restoring native vegetation (Harter 2007), increasing property value due to opportunities for recreation (Geoghegan 2002, Crompton 2005), biodiversity conservation (Hausmann et al. 2016) and so on.

Previous studies have assessed the economic benefits of conserving open spaces. For example, Johnson et al. (2020) estimated the cost and benefits of conserving open spaces across different flood zones in the conterminous USA while also accounting for future development projections. Although a nationwide study such as this provides a broad picture of proactive open space protection at a large scale, the study does not capture the nuanced local conditions at smaller scales, thereby providing a comparative component for local decision-makers to consider when making decisions about open space management. These decisions become even more critical due to changes in floodplain delineations resulting from sea-level rise (SLR). Kousky and Walls (2014), on the other hand, estimated the benefits of open space conservation at a smaller scale. While their study provides a local context to vacant open space acquisition, it does not account for future development projections, which may result in overestimating open space benefits. Additionally, the study does not address the potential impact of SLR, which may lead to underestimating the avoided losses from vacant land conservation.

To address these gaps, we quantified the avoided flood damages to vacant private properties given future development and SLR projections at a small spatial scale. We develop a methodological framework that identifies eligible vacant properties for buyouts through a multi-criterion spatial procedure. This study is aimed at meeting two objectives: (1) apply a geodesign framework (Steinitz 2012) in selecting vacant flood-prone properties that intersect future development and SLR conditions; and (2) assess the economic implications of buying out vacant flood-prone properties now as opposed to buying them out post-development given future built environment and SLR conditions. This approach highlights the importance of accounting for local demographic and development conditions in the configuration of open spaces in a manner that will save local communities the additional cost of constructing public infrastructure in vulnerable locations (BenDor et al. 2020). This also ensures that local

officials evaluate open space conservation options without overstating or underestimating their economic benefits, while also accounting for future environmental conditions.

### Methods and data analysis

The analytical basis for selecting and evaluating candidate vacant properties for buyouts is informed by the geodesign framework (Steinitz 2012). This model systematically integrates concepts and analytical approaches derived from geographical, spatial and statistical-based disciplines in site selection. We apply this framework by integrating methods related to flood resilience, urban growth prediction modelling and planned real estate development. Newman et al. (2019) applied a similar approach in selecting a site for landscape performance and flood analysis. We begin our analysis by selecting eligible vacant properties that intersect flood risk and future development in Houston, Texas. We further highlight a change watershed that is prone to flooding, new development and SLR. Next, we create an impact model, which tests a case of vacant test sites in the selected watershed. The final decision model focuses on conducting a site analysis to determine whether the benefit–cost ratio (BCR) of buying out vacant land now is higher than that of buying out a set of hypothetical built properties on the vacant land. Table 1 highlights the geodesign process, while Fig. 1 shows the selection and analytical process of the multi-scale analysis in this research.

### Study area

The Houston–Galveston region is one of the most flood-impacted area in the USA, experiencing on average one hurricane every 15 years (Parisi & Lund 2008). Recent hurricanes in the region such as Ike (2008) and Harvey (2017) caused damages exceeding US\$35 and US\$125 billion, respectively (NOAA 2017). FEMA has spent c. US\$555 million to acquire over 4300 flooded properties throughout the state, with c. US\$205 million of this total used to acquire properties in the Houston area alone, while Harris County (which is covered mainly by the city of Houston) has paid out over US\$342 million to acquire c. 2462 properties since 1985 (Atoba et al. 2020). Rising population coupled with expanding development in the region will continue to exacerbate flood problems (see HGAC 2018 for recent population statistics). Land cover data from the US Geological Survey (USGS) shows that urban area in

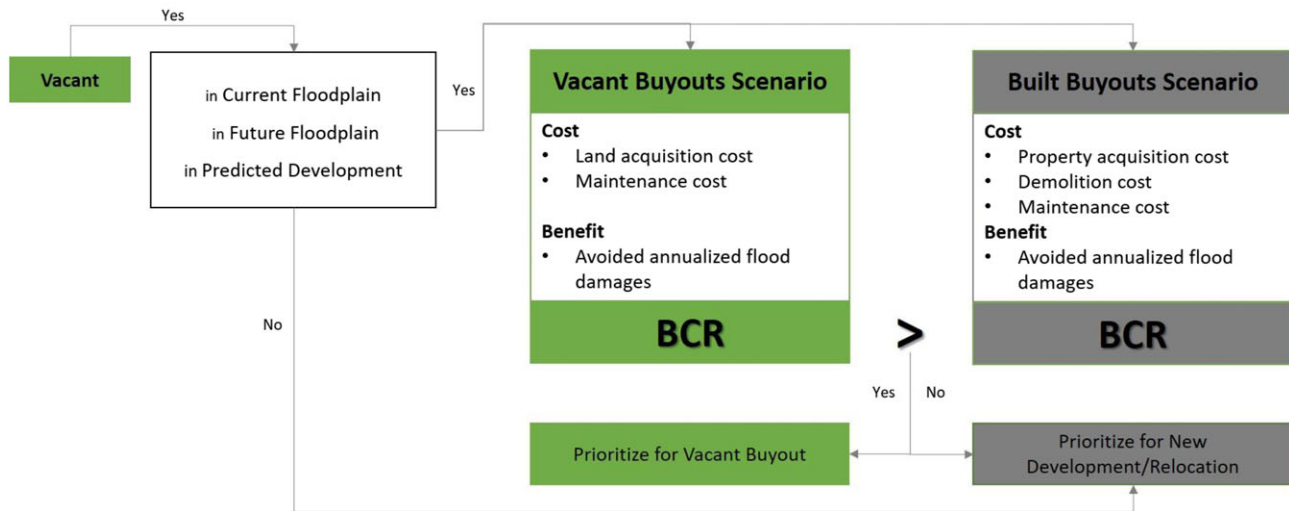


Fig. 1. Selection framework for vacant properties in flood-risk areas. BCR = benefit-cost ratio.

Harris County expanded from 1854.5 km<sup>2</sup> (716.0 mi<sup>2</sup>) in 2001 to 2203.5 km<sup>2</sup> (850.8 mi<sup>2</sup>) in 2011. Currently, within the city of Houston, there are over 800 000 residential properties and over 90 000 vacant parcels (c. 22 400 of which are in the 100-year floodplain). Figure 2 shows the locations of all of the vacant properties in the study area, indicating the vast amount of vacant land available for future development.

### Predicting future development and SLR floodplains

We predict future urban growth using the Land Transformation Model (LTM), a spatial prediction tool that uses an artificial neural network model to predict future land use (Pijanowski et al. 2002). This study employs 12 driving factors and 2 land cover maps from 2001 to 2011 and compares the predicted 2011 land use with the real land cover map in 2011 to justify model validation. The drivers include proximity-based measures (water, floodplain, highways, roads, bus routes, parks, businesses, existing urban, hospitals and schools) and socio-demographic measures (population density and race) frequently employed in urban land change literature (Pijanowski et al. 2014, Jafari et al. 2016, Ku 2016, Losiri et al. 2016, Kim & Newman 2020). By following the previous urban growth ratio of land area (99.45 km<sup>2</sup>, 9445 pixels in 100 × 100 m resolution) for the population increase (287 343 persons) between 2001 and 2011, the forecasted future urban area expands to 273.57 km<sup>2</sup> (27 357 pixels) for the projected population increase of 832 294 persons between 2012 and 2040, according to the State Plan Population Projection Data (TWDB 2012).

The prediction was validated with four calibration measures: percent correct metric (PCM),  $\kappa$  coefficient, overall agreement (OA) and area under curve (AUC). Each measure supports the accuracy of the predictions (PCM: 52%,  $\kappa$ : 41%, OA: 82% and AUC: 71%) at an acceptable level. We delineate future flood risk by combining 100-year floodplain zones with 3 and 6 ft (0.9 and 1.8 m) SLR conditions utilizing a bathtub approach (Marcy et al. 2011), representing extreme cases targeting years 2050 and 2100 (see Kim and Newman 2019 for the prediction model and SLR details). To identify eligible vacant properties in the most extreme SLR condition, we select properties that are within the 6 ft (1.8 m) SLR floodplains for further analysis.

### Selecting vacant properties at watershed and site levels

To select vacant properties, we use appraised parcel data from ATTOM, a private data company focused on collecting property datasets from appraisal districts and cleaning them to better present accurate estimates of property value. We select occupancy codes 'C1' and 'C3', which are defined as 'vacant lots/tracts' and 'vacant', and cleaned the dataset by removing parcels that appear to have been mislabelled as vacant properties, such as those that intersect road segments and those with buildings. This procedure resulted in removing 2015 vacant parcels from the dataset. As is shown in Fig. 1, the selection criteria prioritized candidate vacant properties for buyouts if they intersected or were within both the existing and future floodplain and areas of predicted future urban development by the LTM between 2012 and 2040. Out of all of the 90 506 vacant parcels in the study area, 9495 fell within the selection criteria, with a mean parcel area of c. 9000 m<sup>2</sup>.

To select a watershed for impact analysis, we developed a ranking system of vacant land and flood risk for all USGS Hydrological Unit Code 12 (HUC-12) watersheds using a composite scoring method. Factors considered for the ranking include the cost of acquiring vacant land, the amount of FEMA flood claim pay-outs and areas of vacant land, wetlands, floodplains and predicted development in each watershed. The ranking revealed that the Clear Creek watershed has the highest intersection of vacancy and flood risk in Houston. This watershed is one of the most flood-impacted watersheds in the region (Brody et al. 2012, Highfield et al. 2014). The landscape is characterized by typical gulf coast environmental attributes, such as low topographical relief, wide floodplain boundaries and low soil permeability, all of which contribute to frequent flooding. Additionally, the watershed contains several large vacant lots that are attractive to development interests as they are suitable for conversion to residential development types.

### Vacant sites impact analysis

The site-level impact analysis focuses on the south-western corner of the Clear Creek watershed (see Fig. 3(c)). This section was selected because it has over 93% of its vacant parcels within the SLR floodplain, it is located at the intersection of two major highways and it is adjacent to existing flood-prone residential development. It also falls within the Beltway region in the south-western part of the study

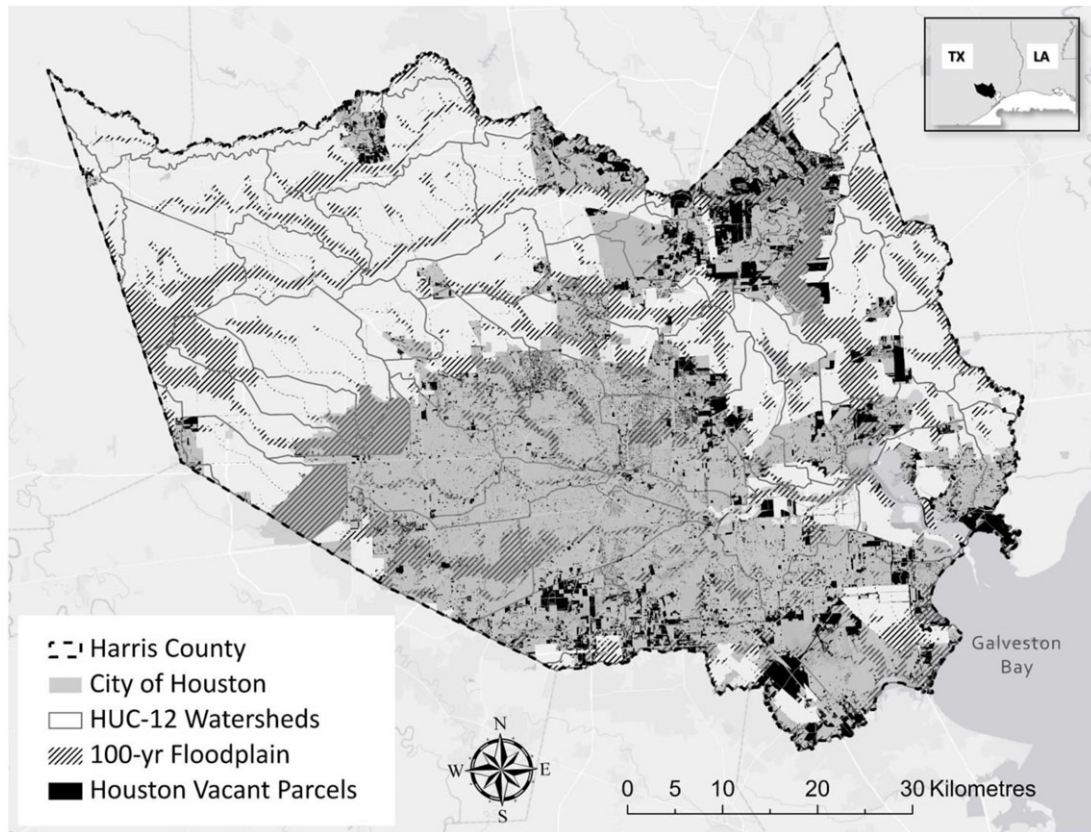


Fig. 2. Hydrological Unit Code 12 (HUC-12) watersheds and vacant properties in Houston, Texas.

area, which is projected to have the highest household population and number of jobs by the year 2045 (HGAC 2018). Because 92% of floodplain properties in the region are designated as single-family residential, we assumed that the development on these test sites would be single-family residential homes. We further assumed that development types that will occur on these vacant sites will be similar to those of surrounding neighbourhoods, so we duplicated the building characteristics of residential properties within 1.5 km of the vacant sites. This procedure resulted in creating 1103 residential homes on the test sites.

*Estimating flood depth and property damages*

We modelled inundation levels for different storm intensities from 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year flood levels using a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers (USACE), HEC-RAS. This system was designed primarily to simulate hydraulic responses such as flow conveyance and water surface elevation within open-channelled water bodies, and it has been applied in previous flood risk and hazard studies in the area (Gori et al. 2019, Juan et al. 2020). We used the two-dimensional version (HEC-RAS 2D), which allows for the simultaneous simulation of riverine and pluvial flooding. We used the 2018 terrain obtained from the Houston-Galveston Area Council and the 2016 Land Use Land Cover (LULC) data obtained from the Multi-Resolution Land Characteristics Consortium. These datasets were used to represent the physical characteristics of the study area. For the flood impact analysis, 24-hour duration storms ranging from 2-year to 500-year return periods were simulated, reflecting the most recent rainfall statistics for the region published by National Oceanic

and Atmospheric Administration (NOAA) Atlas 14 (NOAA 2018). We further used depressed areas in the test sites as locations for retention/detention ponds. These pond locations were determined by evaluating topographical conditions from the national hydrography dataset, inundation data from HEC-RAS 2D and aerial imagery. As is shown in Table 2, the first development option generated 1103 properties and assumed that the parcels would be maximized for development irrespective of ground elevation conditions. A second development type generated 918 properties and assumed that there would be no development in naturally depressed areas, which will serve as retention or detention ponds.

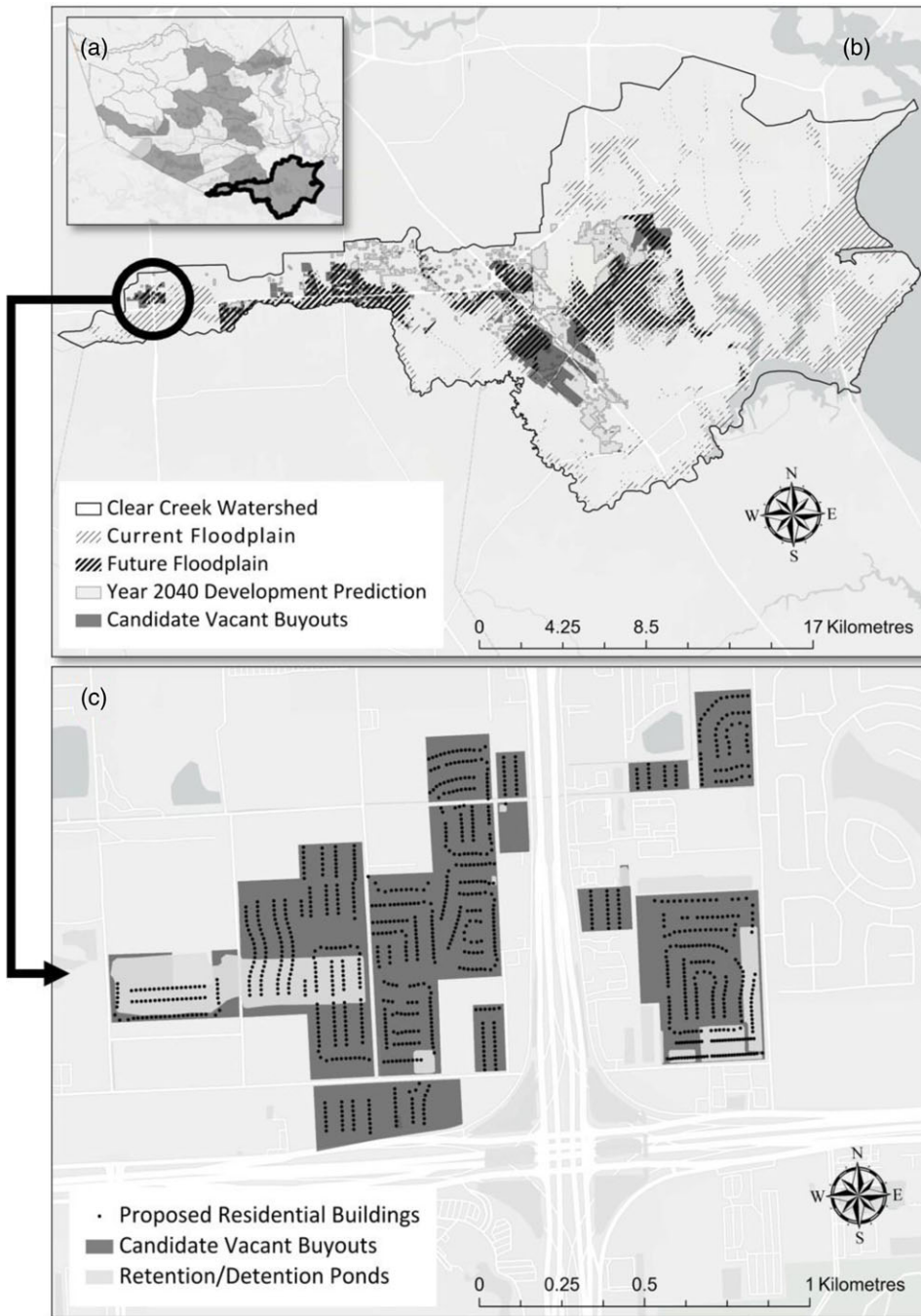
Next, we performed a flood impact analysis of the projected future development using the inundation values generated from the HEC-RAS 2D model and USACE depth-damage functions. We further estimated the average annual losses (AALs) for each of the proposed residential developments using the following formula:

$$AAL_j = \sum_i Flood Loss_{ij} \times prob(i)$$

$$i = 2.5, 10, 25, 50, 100 \text{ and } 500$$

where *i* is the flood return period and *j* is the inundated residential property.

A similar approach for calculating AALs has been used in previous flood and buyout studies in the USA (see Tate et al. 2016, Atoba et al. 2020). To determine the present dollar value of the future damages, we apply a 2.8% discount rate through a 30-year period, a method used for discounting nominal flows often encountered in lease-purchase analysis such as a federally backed



**Fig. 3.** (a) Top 10 Hydrological Unit Code 12 (HUC-12) watersheds (Clear Creek watershed highlighted); (b) Clear creek watershed showing candidate vacant properties; and (c) test site showing proposed residential properties on vacant land.

mortgage (OMB 2016). We calculate the BCR by dividing discounted AALs by the sum of the property acquisition cost, demolition cost and cost to maintain the lot for the next 30 years, similar to methods used in recent buyout studies (Tate et al. 2016, Johnson et al. 2020). We estimate demolition cost at US\$7 per building square foot (Mobley et al. 2020) and US\$565.76 per hectare as the yearly maintenance cost of vacant properties or patches of land after buyouts (BenDor et al. 2020).

The benefit–cost analysis (BCA) was based on the following assumptions: (1) the costs and benefits are borne by local governments; (2) vacant properties would be bought out now, retained as open space and maintained by local governments; and (3) built properties represent a hypothetical residential development that

would be bought out now all at once, retained as open space and maintained by local governments.

## Results

### *Vacant property conservation*

The selection process identified 9495 vacant parcels as candidate vacant buyouts in the city of Houston, totalling c. 85.4 km<sup>2</sup> (8540 ha) (Fig. 3(a)). The mean parcel size is c. 9000 m<sup>2</sup> (0.9 ha), while the average distances to parks and streams are c. 146 and 217 m, respectively. The Clear Creek watershed has 581 vacant candidate properties with a total area of over 17 km<sup>2</sup>,

**Table 2.** Summary statistics of development with and without retention ponds.

Measure	Minimum	Maximum	Sum	Mean	SD
<i>Development without retention/detention ponds (n = 1103)</i>					
Building area (m <sup>2</sup> )	142.97	381.08	239 652.59	217.27	43.53
Property value (US\$)	157 600.00	294 100.00	240 038 400.00	217 623.20	23 968.75
Number of storeys	1.00	2.00	1,768.00	1.60	0.49
100-year inundation (m)	0.00	7.72	835.15	0.96	1.74
500-year inundation (m)	0.00	10.63	1303.66	1.38	2.47
Average annual loss (US\$/year)	0.00	112 246.53	7 585 525.83	12 040.52	23 090.82
Individual residential building BCR	0.00	5.01	344.94	0.31	0.83
<i>Development with retention/detention ponds (n = 918)</i>					
Building area (m <sup>2</sup> )	142.97	381.08	202 045.43	220.09	44.63
Property value (US\$)	157 600.00	294 100.00	201 744 500.00	219 765.25	24 697.45
Number of stories	1.00	2.00	470.00	1.60	0.49
100-year inundation (m)	0.00	1.41	219.88	0.32	0.19
500-year inundation (m)	0.00	2.04	345.86	0.46	0.25
Average annual loss (US\$/year)	0.00	92 857.00	1 360 109.54	2810.00	7916.77
Individual residential building BCR	0.00	3.79	58.38	0.06	0.25

BCR = benefit–cost ratio.

**Table 3.** Summary of flood losses and benefit–cost ratios (BCRs) for vacant and built buyout scenarios.

Buy out vacant parcels		Buy out built parcels	
<i>Development without retention ponds (n = 1103)</i>			
Cost (US\$)		Cost (US\$)	
Land acquisition cost	11 319 731	Property acquisition cost	240 074 100
Demolition cost	0	Demolition cost	18 061 778
Discounted 30-year maintenance cost	4 122 972	Discounted 30-year maintenance cost	4 122 972
Total cost	15 442 703	Total cost	262 258 850
Benefit (US\$)		Benefit (US\$)	
Discounted 30-year loss	160 183 685	Discounted 30-year loss	160 183 685
Total benefit	160 183 685	Total benefit	160 183 685
Vacant BCR	10.372	Built BCR	0.61
<i>Development with retention ponds (n = 918)</i>			
Cost (US\$)		Cost (US\$)	
Land acquisition cost	11 319 731	Property acquisition cost	201 780 200
Demolition cost	0	Demolition cost	15 228 178
Discounted 30-year maintenance cost	4 122 972	Discounted 30-year maintenance cost	4 122 972
Total cost	15 442 703	Total cost	94 755 063
Benefit (US\$)		Benefit (US\$)	
Discounted 30-year loss	28 721 457	Discounted 30-year loss	28 721 457
Total benefit	28 721 457	Total benefit	28 721 457
Vacant BCR	1.86	Built BCR	0.13

with almost 42% of the watershed predicted for future development. This watershed also has the largest amount of federal flood insurance claim payments under the National Flood Insurance Program (NFIP) in the county, with over US\$780 million already spent by FEMA as pay-outs from previous flood events. These historically flooded neighbourhoods are in close proximity to flood-prone vacant properties, averaging a distance of *c.* 270 m for the watershed.

**Avoided flood losses from sample vacant sites**

Our analysis results in two buyout scenarios: (1) buyout of existing vacant properties; and (2) buyout of a hypothetical built residential development on the vacant site. The built buyout scenario generated large amounts of potential property losses from flooding if built on the vacant sites. The average property value of the proposed development is US\$218 000–220 000. The combined AALs from flooding is US\$1.3–7.5 million depending on the development type, with the mean AAL ranging from US\$2810 to US\$12 040. These results show that an annual loss of

US\$6.73–31.65 per square foot would occur for each residential building if the vacant sites are developed. Table 2 shows the results of the 100- and 500-year storms to provide some context to losses from the top two highest storm intensities. For the development without retention/detention ponds, inundation averages 0.96 and 1.38 m for the 100- and 500-year floods. Development with retention/detention ponds has lower inundation values; average inundation is *c.* 0.32 m for a 100-year flood and 0.46 m for a 500-year flood, while the maximum is 2.04 m for a 500-year flood.

**Benefit–cost analysis of proposed development**

The results of the BCA indicate that proactive buyouts of vacant properties are generally more favourable than buying out already built properties in flood-prone areas. For the development without retention/detention ponds, if the vacant properties are bought out now, there are savings of US\$10.37 for every US\$1 spent (Table 3). On the other hand, if the buyouts occur in the built parcel scenario, only US\$0.61 is saved for every US\$1 spent. For development with retention/detention ponds, the BCR is much less than US\$1, implying that it is not beneficial to buy out the properties when

they are already built. Conversely, there will be savings of *c.* US\$1.86 for every US\$1 spent if local governments prevent development on those parcels. In general, individual structures in development types where retention/detention ponds are used have lower mean BCR values than those without a retention/detention pond (Table 2). For both development types, only *c.* 10% of the properties in the proposed development are responsible for high flood losses, and they primarily influence the BCR values.

## Discussion and conclusion

Our results show that if new development continues to follow existing spatial and development patterns, the future cost of buy-outs would be significantly higher than preventing these developments from occurring in the first place. Based on our findings, there are two key benefits of vacant open space buyouts. First, methodologically, the geodesign process allows local officials to identify areas where flooding and future development are likely to have the highest impact. Our multi-spatial selection criteria at the watershed scale can help officials prioritize vacant land based on ecological and open space attributes to protect the most stressed watersheds in their community. Although our study focuses on only one major city and watershed in the USA, it highlights the importance of selecting properties at smaller scales that a nationwide study may not expose. This approach can complement a larger study, which makes it easier to draw conclusions and add a comparative component to the analyses. Our second major finding is that a proactive strategy of vacant buyouts significantly outweighs a reactionary, post-development approach. Notably, these benefits are *c.* 10 times greater than the cost of the buyouts and provide a large return on investment in a selected location. The benefits could even be higher if consideration is given to the cost of infrastructure to support residential neighbourhoods, as well as the monetary loss of abandoning or even demolishing such infrastructure post-buyouts.

Our results also suggest that, although there is a high BCR for vacant buyouts, a review of the individual BCRs shows that only *c.* 10% of these properties are responsible for the high BCRs. It is not surprising that only selected properties within a buyout area are cost-effective (see Kousky & Walls 2014, Tate et al. 2016). This also reflects the existing scattershot pattern of buyouts rather than the contiguous acquisition of entire neighbourhoods (Freudenberg et al. 2016). Buying out these properties when vacant highlights the potential of accruing additional benefits, such as the protection of ecological services, strategic clustering of open spaces, reduced maintenance cost and the avoided losses in constructing new infrastructure or maintaining/demolishing already-built infrastructure.

The results also suggest that avoided losses are lower when additional mitigation strategies such as retention and detention ponds are used in floodplain development. However, this result should be interpreted with caution. For example, our analysis shows that only *c.* 190 buildings are removed from the placement of retention/detention ponds, leaving the remaining 910 properties in vulnerable locations. Construction of compensatory storage in flood-prone areas may be insufficient for addressing flooding problems, as previous research shows that innovative mitigation measures in floodplains can still exacerbate flooding (Stevens et al. 2010).

Although the proactive acquisition of vacant properties proposed in this study restricts development in selected floodplains, it is up to local officials to harness additional site-level analysis in their decision-making. This includes flood vulnerability studies,

community visioning and neighbourhood-scaled design through citizen science to select the most optimal ways of conserving or developing vacant land (Hendricks et al. 2018, Newman et al. 2020). Additionally, local officials need to identify the best methodological approach for estimating future hydrology conditions. The bathtub approach in this study only estimates inundation areas under hydrostatic conditions, ignoring wave, erosion and other hydrologic impacts (Anderson et al. 2018). Other models, such as those that account for groundwater inundation (Habel et al. 2019), can be utilized in future research.

While this research highlights the economic benefits of preserving flood-prone vacant lands, it is important to emphasize that without the provision of incentives, landowners would sell the land to the highest bidder or succumb to market forces. Landowners are likely to hold onto their properties until they bow to the pressure of selling them to developers due to rising tax rates (Lee et al. 2018). It is also up to local governments to reconcile the loss of their tax base with the benefits accrued from avoided flood losses. However, previous research shows that vacant lots repurposed as open space can increase the property value of surrounding residential development (Crompton 2005, Kousky & Walls 2014), subsequently increasing the tax base for local communities. Local governments also have to determine how to reconcile the benefits of open space conservation with the opportunity cost of preventing developments in flood-prone areas, as well as the potential cost-sharing if they are to receive federal funding post-disaster. Moreover, there are several other options for open space conservation that can be employed by local governments without compromising tax benefits. These include policies such as the transfer of development rights, density bonuses, development clustering and so on (Brody et al. 2020), and these can be addressed in future research.

Our analysis also identifies vacant properties in low-flood-risk areas that can be prioritized for new development. These can serve as viable development alternatives and ease the negative fiscal impacts of developing in other municipalities (Fig. 1). Recent studies show that for existing and future buyout programmes, factors such as the distribution of buyouts, relocation within or outside the city and management practices of acquired properties will determine whether these programmes come at a profit or loss to local communities (Lamie et al. 2012, BenDor et al. 2020). A vacant property buyout policy can complement existing built buyout programmes. The approach will serve the dual purpose of preventing floodplain development (thereby avoiding the need for future buyouts) and complementing the open spaces currently recovered from existing built buyout programmes. This proactive vacant buyout model combined with other planning tools and incentives can encourage landowners to support the efforts of local governments in open space conservation.

This paper evaluated the potential for cost savings when vacant lands are preserved as open spaces compared to developing and buying them post-development. The geodesign framework helps local decision-makers to proactively identify flood-prone vacant properties at multiple scales in their communities while incorporating land transformation datasets, high-resolution flood simulations and future SLR floodplain delineation. The impact analysis enables local officials to create a decision model based on a BCA to determine whether development should occur, the property should remain vacant or development should be moved to other suitable locations. By evaluating the economic implications of proactive open space acquisition, we hope to promote an open space conservation culture to decision-makers so that future

development can be adjusted in scope and scale to best support the mitigation and adaptation of flood risk within these communities for better future benefits.

This study represents an important step in performing BCA for open space protection and flood risk reduction. Additional research and data analytics should be conducted to address some of the limitations in this study and further advance this area of enquiry. First, the costs and benefits of property acquisition are not only borne by local governments, but also by federal governments as well as individuals. A detailed statistical analysis can further reveal how these benefits are distributed across different governmental agencies where most buyout funding comes from. Second, because buyouts occur incrementally over time, future studies need to account for the dynamic nature of the built environment and property acquisition programmes. Third, although SLR floodplain delineations can identify properties with increased future flood risk, future studies should also assess how the inundation and damages of residential structures in these floodplains will be exacerbated by rising precipitation and flooding events due to climate change.

**Supplementary material.** To view supplementary material for this article, please visit <https://doi.org/10.1017/S0376892921000059>

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