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A Nationwide Analysis of Community-Level Floodplain Development Outcomes and Key Influences

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Key Points:

- Substantial development took place in floodplains across the US from 2001 to 2019 but less than expected given the extent of flood hazards
- Floodplain development outcomes vary across a number of key factors, including geography, socioeconomics, and flood risk management
- Nationwide indexes capturing local outcomes enable evaluation of floodplain management policies and drivers of floodplain development

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract Development patterns and climate change are contributing to increasing flood risk across the United States. Limiting development in floodplains mitigates risk by reducing the assets and population exposed to flooding. Here, we develop two indexes measuring floodplain development for 18,548 communities across the continental United States. We combine land use, impervious surface, and housing data with regulatory flood maps to determine what proportion of new development has taken place in the floodplain. Nationwide from 2001 to 2019, 2.1 million acres of floodplain land were developed, and 844,000 residential properties were built in the floodplain. However, contrary to conventional perceptions of rampant floodplain development, just 26% of communities nationwide have developed in floodplains more than would be expected given the hazard they face. The indexes and the analyses they enable can help guide targeted interventions to improve flood risk management, to explore underlying drivers of flood exposure, and to inform how local-to-federal policy choices can be leveraged to limit hazardous development.

Plain Language Summary Development in areas prone to flooding increases flood risk by increasing the exposure of people and infrastructure. Reducing or limiting development in hazardous areas can be a critical way for communities to manage flood risk. In this study, we use national flood hazard, impervious surface, and housing data sets to create two indexes measuring the extent of floodplain development across the United States from 2001 to 2019. Surprisingly, we find that despite seemingly large aggregate numbers, most communities have actually limited hazardous development when we account for how much of their developable land is in the floodplain. We show that floodplain development outcomes vary across key influences, including geography, wealth, and flood risk management efforts. Our indexes enable comparisons across community contexts, potentially unlocking important lessons for effective floodplain management. Proactive, climate-smart land use planning will be key to ensuring resilient growth for communities moving forward.

1. Introduction

Flooding threatens the safety and productivity of communities across the United States. Millions of people, properties, critical infrastructure, and other assets are located in areas prone to flooding, and major flood events cause billions of dollars in losses every year (NOAA National Centers for Environmental Information, 2023; Wing et al., 2022). Flood risks are expected to increase considerably into the future due to development patterns and climate change (IPCC, 2022). Climate change is exacerbating the frequency and intensity of flood hazards (Bevacqua et al., 2019; Nicholls et al., 1999; O'Gorman & Schneider, 2009), and continued development in flood-prone areas increases both the likelihood that a flood will affect people and infrastructure and the severity of the harms and losses when it does (Blum et al., 2020; Bouwer, 2013; Brody, Zahran, Highfield, et al., 2007; Burby & Dalton, 1994; Burby et al., 1999; Burby & French, 1981; Strader & Ashley, 2015; Wing et al., 2018). Limiting floodplain development is therefore a key strategy in reducing flood damages. Land use planning and floodplain management policies can proactively steer development away from hazardous areas or even remove development that has already occurred (Burby et al., 1999, 2000; Burby & French, 1981; Butler et al., 2016; Holway & Burby, 1993; Mach et al., 2019; Olsen, 2006; Stevens et al., 2011).

Past research has identified factors that influence floodplain management, including regulations, policies, and government practices at the local level. Studies have suggested that the property tax revenue generated by development (Bagstad et al., 2007; Berke & French, 1994; Burby, 2000; Deyle et al., 2008; Loucks & Stedinger, 2007), especially in high-amenity coastal floodplains (Beltrán et al., 2018; Bin et al., 2008; Gourevitch et al., 2023), can influence floodplain management decision-making in some communities. State and local planning mandates (Berke, 1996; Berke & French, 1994; Burby & Dalton, 1994; Burby et al., 1999, 2000; Lyles et al., 2013), along with organizational and adaptive capacity (Brody et al., 2010; May & Deyle, 1998; Posey, 2009), have been shown to shape the adoption and quality of floodplain management policies, including zoning ordinances, setbacks, and construction standards. Local geographic, socioeconomic, and demographic factors can also affect the use and effectiveness of floodplain management actions, including the Community Rating System (Brody et al., 2009; Highfield & Brody, 2017; Li & Landry, 2018) and voluntary property buyouts (Mach et al., 2019; Miao & Davlasheridze, 2022; Zavar & Fischer, 2021).

However, the lack of comprehensive data measuring floodplain development to date has substantially limited our understanding of how the factors that influence floodplain management, and floodplain management actions themselves, influence development outcomes—the actual construction of new buildings and structures in the regulatory floodplain. Studies that have connected management contexts and actions with actual floodplain development outcomes have been historically confined to small geographic scales (Burby & French, 1981; Deyle et al., 2008; Montz & Gruntfest, 1986), and none has explored this connection for communities nationwide. This disconnect has resulted in a fundamental gap in understanding of the management and governance contexts, approaches, and policies most effective in steering development away from floodplains. Identifying where communities have been both successful and unsuccessful in restricting floodplain development, and why, is critical to uncovering actionable insights into effective floodplain management.

Here, to enable systematic investigation of the relationships between the drivers and patterns of floodplain management actions and development outcomes, we develop two national indexes measuring floodplain development for 18,548 communities across the continental United States. We combine geospatial analysis of remotely sensed land use, impervious surface, and housing data with national flood hazard data to determine what proportion of new development in each community has taken place in regulatory 100-year floodplains over a nearly two-decade period. We create a Floodplain Development Index (FDI) and Floodplain Housing Index (FHI). The FDI for each community is calculated as the share of new development (increase in imperviousness) in the regulatory floodplain from 2001 to 2019, divided by the share of developable land (land physically fit for development and not under federal jurisdiction) in the floodplain. Similarly, the FHI for each community is calculated as the share of new housing built in the floodplain from 2001 to 2019, divided by the share of developable land in the floodplain. While the FDI considers all forms of floodplain development (e.g., residential, commercial, industrial) by area, the FHI considers only new residential parcels.

By constructing the indexes as a proportion of development and as relative to floodplain size, we account for differences in the extent of flood hazard and growth rates across communities (Figure 1). Intuitively, communities with disproportionately large floodplains should be expected to have more floodplain development and vice-versa. If new development were distributed randomly across all developable land, development in the floodplain would occur in proportion to developable land in the floodplain (FDI or FHI = 1). We refer to communities with an FDI or FHI >1 as having concentrated floodplain development (i.e., there is a higher share of new development than developable land in the floodplain), while a community with an FDI or FHI <1 has limited floodplain development (i.e., there is a lower share of new development than developable land in the floodplain) (Figure 1).

After calculating the floodplain development indexes nationwide, we use them to determine (a) overall trends in the distribution of floodplain development, and (b) what factors (e.g., geography, socioeconomics, and floodplain management efforts) explain differences in floodplain development outcomes across communities. These analyses link the factors related to floodplain management to actual development outcomes, confirming some but challenging other hypotheses about the connections between context, governance, and floodplain development. By establishing standardized measures, our approach allows for cross-community comparisons. It creates a foundation for systematically understanding the ways in which development drivers, policy innovations, and local practices shape floodplain development. To that end, these indexes will enable critical research assessing whether

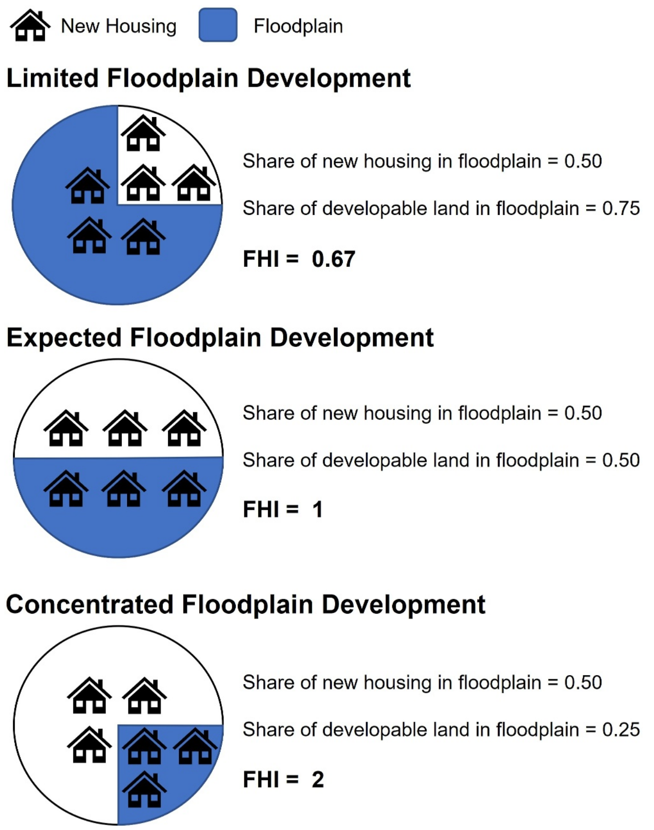

Figure 1. *Floodplain development outcomes differ when accounting for the extent of flood hazards in communities*. The schematic diagrams illustrate three different floodplain development outcomes. In each case, the circle represents the total developable land in the community, the area shaded blue is the 100-year floodplain, and the houses are new development. Each community has the same share of new development in the floodplain, but a different share of developable land in the floodplain and, therefore, a different floodplain development outcome.

and how states and municipalities have effectively used legal and regulatory tools to limit floodplain development.

2. Methods

The goals of this study were: (a) To quantitatively measure and characterize floodplain development outcomes nationwide and (b) to analyze patterns in floodplain development outcomes across community-level characteristics. To this end, we (a) created standardized indexes of floodplain development and floodplain housing at the community level and (b) analyzed variation in floodplain development outcomes based on factors identified in existing scholarship as relevant to floodplain management (Figure 2).

2.1. Impervious Surface Change

Impervious surface change was determined based on the National Land Cover Database (NLCD) Urban Imperviousness data sets from 2019, the most recent edition, and 2001, the first edition (National Land Cover Database, 2019b). NLCD urban imperviousness data sets report percent impervious surface at a 30 × 30 m spatial resolution (i.e., the percentage of each 30 × 30 m pixel that is impervious surface) across the continental United States. Impervious surface is estimated in these products by training a regression tree model on Landsat imagery of select urban cores to predict impervious surface across the contiguous United States (Yang et al., 2018). Impervious surface values from existing products are cross-checked against predicted values from the model, and projections are corrected and updated. Impervious surface change was calculated for each 30 × 30 m pixel by subtracting the 2001 impervious surface value from the 2019 value. For example, if a pixel was 20% impervious surface in 2001 and 50% impervious surface in 2019, the impervious surface change would be 30%. Any pixel with ≥10% impervious surface change was classified as new development.

2.2. Floodplain Maps

Flood hazard data were collected from state-level Federal Emergency Management Agency (FEMA) Digital Flood Insurance Rate Maps (DFIRMs), downloaded through the FEMA Flood Map Service Center (MSC) for each state (Federal Emergency Management Agency, n.d.-c). The files were downloaded in the spring of 2018 and only reflect communities with digitized maps in effect at that time. We defined the floodplain as any flood zone designated as a Special Flood Hazard Area (SFHA), also known as the 100-year floodplain, in the DFIRM. Our development measures reflect change over a nearly two-decade period. While regulatory maps and flood zone boundaries do change over time, older maps are less likely to be digitized, making it extremely hard to track how the zones change over time. So, we use the maps that were in effect at the end of our study period. We used the DFIRM panel data to determine the effective map date for flood maps used in our analysis. For map panels with effective dates (i.e., those not missing data), both the mean and median effective year was 2010; so, these panels would have been effective on average for at least half of the study period (2001–2019).

2.3. Communities

The Federal Emergency Management Agency defines "community" in a regulatory sense as a "political entity having the authority to adopt and enforce floodplain ordinances for the area under its jurisdiction," including tribes, states, or political subdivisions thereof (Federal Emergency Management Agency, 2020). In this spirit, we used the term communities to refer to: (a) Incorporated municipalities, (b) unincorporated places participating in the National Flood insurance Program (NFIP), (c) the remaining unincorporated area of a county (to recognize the role of county governments as floodplain authorities), or (d) tribal reservations. Information on NFIP-

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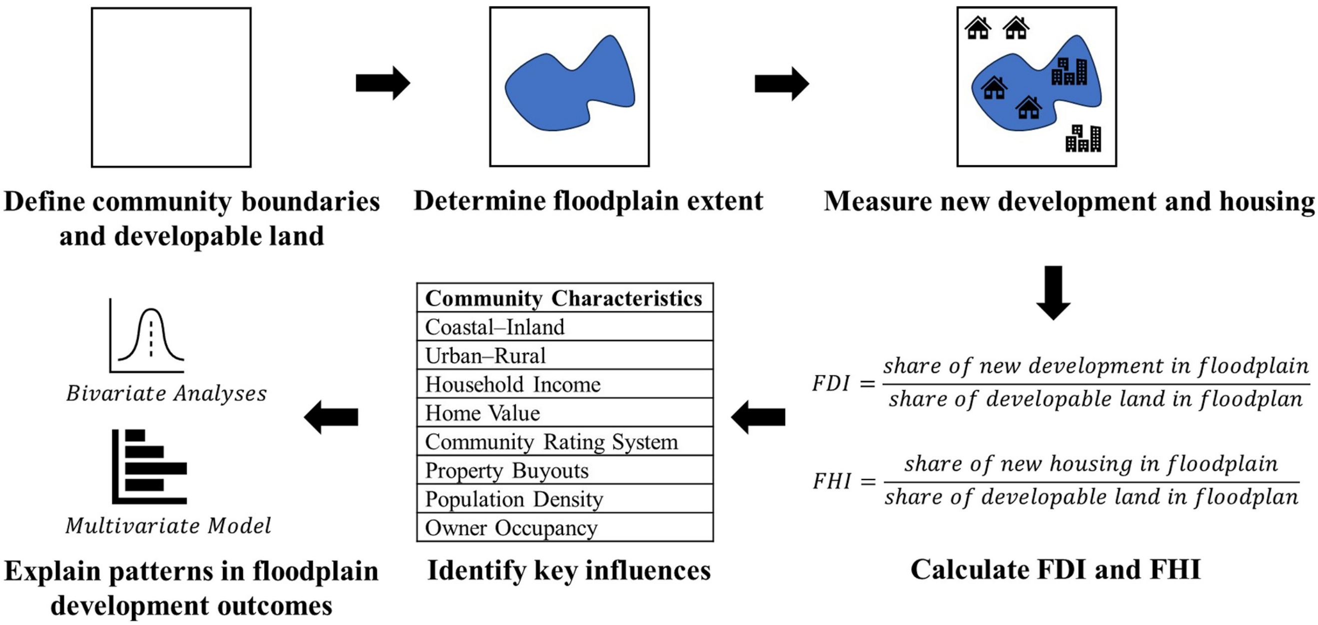

Figure 2. *Floodplain development is measured using two indexes, and outcomes are analyzed across communities*. The diagram provides an overview of the research methods. We combine land use, impervious surface, and housing data with regulatory flood maps to measure new floodplain development and housing. These steps culminate in calculating an Floodplain Development Index and Floodplain Housing Index for each community. Then, we identify key community characteristics that we expect to influence floodplain development. These characteristics are used in bivariate and multivariate analyses to explain patterns in floodplain development outcomes across communities.

participating communities was accessed through the FEMA Community Status Book data set for each state (Federal Emergency Management Agency, n.d.-b).

Overall, we produced 28,016 communities that, together, cover the continental United States. Of these communities, 21,237 have ≥95% of their land area mapped in their respective DFIRM. Of these flood-mapped communities, 18,548 had developable land in the floodplain and were used in our analyses. These threshold filters were applied to limit our analysis to only those communities for which we can confidently characterize the extent of flood hazard. Community-level geometries were downloaded through the tigris package in R, which accesses the 2019 Census TIGER/line shapefiles (U.S. Census Bureau, 2019). The geometry of an unincorporated community (category iii) was determined by performing a geometric set difference on the overall county and the other communities within it.

2.4. Developable Land

Developable land was defined as the total land area of a community excluding open water, non-local protected areas, and areas of steep slope. Open water was defined as any 30 × 30 m pixel that was designated as open water (classes 11 and 12) in the 2019 NLCD Land Cover data set (National Land Cover Database, 2019a). Protected areas shapefiles were downloaded through the USGS Protected Areas Database (PAD-US) for each state (U.S. Geological Survey, 2022). Protected areas with a management type designation of "non-local" were defined as non-locally managed protected areas. Slope data were downloaded through the LANDFIRE (LF 2016 Remap) slope data set (LANDFIRE, 2021). Areas of steep slope were defined as any 30 × 30 m pixel with a slope of greater than 14° (i.e., 25%). Open water was excluded due the significant physical difficulty of development; non-locally managed protected areas were excluded because relevant land use decisions fall outside the purview of our communities; areas of steep slope were excluded because steep land is physically more difficult to develop.

2.5. Floodplain Development Index and Floodplain Housing Index

Floodplain maps were overlaid on the impervious surface change raster to determine what share of developable land and new development, respectively, fell in the floodplain. The FDI was calculated as the ratio of the share of new development in the floodplain to the share of developable land in the floodplain for each community:

$$FDI = \frac{\frac{\text{new floodplain development}}{\text{all new development}}}{\frac{\text{developable land in the floodplain}}{\text{all developable land}}}$$

Communities in which >5% of the total land area is not included in a DFIRM were excluded from these calculations due to our inability to confidently characterize the extent of flood hazard in those communities. Community-level outcomes were aggregated to the state-level to calculate statewide results. A FHI was calculated as an analogue to FDI for only residential development. FHI replaces the numerator of FDI with the share of new housing built in the floodplain from 2001 to 2019:

$$FHI = \frac{\frac{\text{new floodplain housing}}{\text{all new housing}}}{\frac{\text{developable land in the floodplain}}{\text{all developable land}}}$$

New housing was defined based on property data from the Zillow Transaction and Assessment Data set (ZTRAX) (Zillow, 2020). New housing includes a range of residence types including single-family, townhouse, mobile homes, and rural residences. Income properties (e.g., apartment buildings) are not included. In rare instances, due to small gaps in the DFIRMs, there are properties that do not have an SFHA classification. These are included in the "all new housing" figure in the equation for FHI.

2.6. Community Characteristics and Bivariate Statistical Analyses

A number of characteristics were used to evaluate how floodplain development outcomes vary across communities, and statistical analyses were performed to determine the relationship between FDI and FHI and these characteristics.

Communities were geographically classified across two divides: coastal–inland and urban–rural (Figure 5 and Figure S3 in Supporting Information S1). Communities with wave exposure (i.e., communities that intersect flood zones designated as "VE" in a DFIRM) were classified as coastal ($n = 944$), and the complement was classified as inland ($n = 17{,}603$). Communities with >50% of their land area in a census-defined urban area were classified as urban ($n = 6{,}240$), and the complement was classified as rural (12,307). Urban area data were downloaded through the Census TIGER/line urban area shapefiles (U.S. Census Bureau, 2019). Welch's *t*-tests were used to determine if mean FDI and mean FHI significantly varied between the coastal and inland groups and between the urban and rural groups. Pearson's chi-square tests were used to determine if the frequency distribution of communities with FDI >1 and FHI >1 significantly varied between the coastal and inland groups and between the urban and rural groups.

We used the ZTRAX data to assign housing values at the parcel scale. ZTRAX data include records for total assessed, market, and appraisal values. Few states have complete coverage for all housing value types, and when multiple types of property values are reported for a single property, the values can differ significantly. The procedure to assign housing values is described in Supporting Information S1 *Appendix*.

An overall median home value was assigned to each community based on the aggregated housing value data for properties in that community. A relative median home value was then calculated for each community by comparing the median home value in that community to the statewide median. For example, if the median home value in a community was $100,000 and the median home value in the corresponding state was $80,000, the relative median home value for that community would be 1.25. The resulting relative median home values were then arranged in a national distribution and divided into deciles, with communities assigned to their respective decile. Only those communities with ZTRAX property value data were included in this analysis ($n = 17{,}634$). Mean FDI and mean FHI as well as the fraction of communities with both concentrated floodplain development (FDI >1) and housing (FHI >1) were calculated for each decile of relative median home value. These fractions were then compared across deciles (Figure 5 and Figure S3 in Supporting Information S1).

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Three metrics of community floodplain management practices were analyzed: participation in the FEMA Community Rating System (CRS), class rating in the CRS, and number of buyouts implemented (Figure 6). CRS data were gathered from the 2005 and 2019 evaluations of the CRS (Federal Emergency Management Agency, n.d.-a). Communities were first classified as "participating" (n = 1,450) or "not participating" (n = 17,097) based on whether they participated in at least one of the two CRS editions. Welch's t-tests were used to determine if mean FDI and mean FHI significantly varied between the participating and non-participating groups. Pearson's chi-square tests were used to determine if the frequency distribution of communities with FDI >1 and FHI >1 significantly varied between the participating and non-participating groups. Communities were also classified as "improving" (n = 474), "worsening" (n = 117), or "no change" (n = 383) based on whether their CRS class increased, decreased, or remained the same between the 2005 and 2019 editions (communities that only participated in 1 edition were not classified). Mean FDI and mean FHI as well as the frequency distribution of communities with FDI >1 and FHI >1 were compared across groups.

Buyout data were gathered from the FEMA Hazard Mitigation Assistance Mitigated Properties data set (Federal Emergency Management Agency, 2022). Mitigation actions categorized as "Acquisitions" were defined as buyouts, and buyouts were assigned to their respective communities. The number of buyouts for each community was calculated as the cumulative number of unique acquisitions in that community. Communities were first classified as "with buyouts" (n = 1,508) or "without buyouts" (n = 17,040) based on whether they had implemented at least 1 FEMA-funded buyout. Welch's t-tests were used to determine if mean FDI and mean FHI significantly varied between the with buyouts and without buyouts groups. Pearson's chi-square tests were used to determine if the frequency distribution of communities with FDI >1 and FHI >1 significantly varied between the with buyouts and without buyouts groups. Communities with buyouts were also classified based on the number of buyouts they had implemented. The number of buyouts implemented in all communities were arranged in a national distribution and divided into quartiles, with communities assigned to their respective decile. Mean FDI and mean FHI as well as the fraction of communities with both concentrated floodplain development (FDI >1) and housing (FHI >1) were calculated for each quartile of number of buyouts.

Additional bivariate analyses were performed based on community characteristics including median household income, population density, and owner occupancy. Median household income data was gathered for each community from the American Community Survey (ACS) 5-year estimates over 2016–2020 (U.S. Census Bureau, 2022). A relative median household income was then calculated for each community by comparing the median household income in that community to the statewide median. For example, if the median household income in a community was $125,000 and the median household income in the corresponding state was $100,000, the relative median household income for that community would be 1.25. The resulting relative median household incomes were then arranged in a national distribution and divided into deciles, with communities assigned to their respective decile. Only those communities which were included in the ACS estimates (n = 12,584) were included in this analysis. Importantly, therefore, this analysis excluded unincorporated counties. Mean FDI and mean FHI as well as the fraction of communities with both concentrated floodplain development (FDI >1) and housing (FHI >1) were calculated for each decile of relative median household income. These fractions were then compared across deciles (Figure S6 in Supporting Information S1).

The number of residential parcels per acre was used as a proxy for population density in each community. The number of residential parcels in each community was gathered from the ZTRAX data. The number of parcels was then compared to the acres of developable land in each community. The resulting ratio for each community was then arranged in a national distribution and divided into deciles, with communities assigned to their respective deciles. Only those communities with ZTRAX parcels data were included in this analysis (n = 18,479). The fraction of communities with both concentrated floodplain development (FDI >1) and housing (FHI >1) were calculated for each decile of number of residential parcels per acre. These fractions were then compared across deciles (Figure S4 in Supporting Information S1). Proxies, rather than direct measures, for population and population density were used because they allowed greater data coverage (i.e., for unincorporated and tribal communities).

Owner occupancy information was also gathered from the ZTRAX data, with each community assigned a percent owner occupied. These values were then arranged in a national distribution and divided into deciles, with communities assigned to their respective deciles. Only those communities with ZTRAX owner occupancy data were included in this analysis (n = 16,162). The fraction of communities with both concentrated floodplain

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development (FDI >1) and housing (FHI >1) were calculated for each decile of owner occupancy. These fractions were then compared across deciles (Figure S6 in Supporting Information S1).

2.7. Random Forest Model

A random forest model (from the scikit-learn library in Python) was used to build a binary classifier to predict whether a community will have limited or concentrated floodplain development based on its characteristics (i.e., features). Features included in the model for each community were: number of residential parcels per acre, number of residential parcels, share of land in the floodplain, Census division (based on the Census Bureau Regions and Divisions of the United States), percent owner occupied, relative median home value, state, urban (binary), percent urban (fraction of community in an urban area), whether the community was unincorporated, coastal (binary), percent urban (fraction of community with wave exposure), the use of buyouts (binary), the number of buyouts implemented, data of first entry to the CRS, change in CRS class, and participation in CRS (binary). Only those communities with complete data across all these features were included in the model ($n = 16{,}163$).

The synthetic minority oversampling technique (SMOTE) was applied to address class imbalance. Class imbalance emerges as a problem in classification tasks when the majority class far outnumbers the minority class in the data set, thus biasing the classifier toward the majority class. In our data set, there was approximately a 3:1 ratio of majority class (FDI >1) to minority class (FDI <1) data points. SMOTE addresses the problem of class imbalance by adding new points to the minority class. Rather than simply adding copies of data points in the minority class (as is done in traditional oversampling), however, SMOTE generates new synthetic points along the line joining a randomly selected minority class point in the feature space and its nearest neighbor (Chawla et al., 2002). The data were split using a 80–20 training-testing ratio, and cross-validation was used for hyperparameter tuning, with the random state controlled for reproducibility.

2.8. Sensitivity Analyses

Sensitivity analyses were conducted to ensure that our results were robust to the exclusion of protected areas and steep slope from our definition of developable land. The floodplain development analyses were first repeated including protected areas (holding all other factors constant). FDI values differed by an average magnitude of 0.016 when results excluding protected areas were compared to results including protected areas. The analyses were then repeated, this time including areas of steep slope (holding all other factors constant). FDI values differed by an average magnitude of 0.074 when results excluding areas of steep slope were compared to results including areas of steep slope.

A sensitivity analysis was also performed to ensure that there was no major "built-out" effect in our data. Because we define new development as at least a 10% increase in impervious surface between 2001 and 2019, any area with more than 90% impervious surface in 2001, by definition, cannot be developed. There is therefore a potential built-out effect, where communities might record little to no new floodplain development because they already built out their floodplain before 2001. To test sensitivity to this definition, we repeated our analyses excluding any area with more than 90% impervious surface in 2001 from the developable land area of the community. The share of developable floodplain land changed by a magnitude greater than 0.01 in 4% of communities. FDI values differed by an average magnitude of 0.056 when results excluding built out areas were compared to results including built out areas.

Finally, the analyses presented here are sensitive to differences in underlying geospatial libraries (GEOS/GDAL/PROJ). Specifically, differences in spatial projection across coordinate reference systems (CRS) can cause slight (pixel scale) variation in some estimations, to which overall results were robust.

3. Results

3.1. Measurement of Floodplain Development

Several definitions are relevant to our measurement of floodplain development. Although the term "community" evades a universal definition, FEMA defines it in a regulatory sense as a "political entity having the authority to adopt and enforce floodplain ordinances for the area under its jurisdiction," including tribes, states, or political subdivisions thereof. In this spirit, we use the term communities to refer to: (a) incorporated municipalities, (b) unincorporated places participating in the NFIP, (c) the remaining unincorporated area of a county (to recognize the role of county governments as floodplain authorities), and (d) tribal reservations.

We define the floodplain as the SFHA, also known as the 100-year floodplain, in a FEMA DFIRM. Recent studies have documented the systematic underestimation of flood risk in FEMA floodplain maps (Bates et al., 2021; Sanders et al., 2022). Nevertheless, we use the FEMA maps because they carry regulatory influence (through the NFIP) and are the most common basis on which communities manage their floodplains. We define developable land as the total land area of a community excluding open water, areas of steep slope, and non-locally protected areas (e.g., military bases or state parks) (*Materials and Methods*). The intent is to include only land that might be commonly developed in the absence of local regulations (although we recognize that even open water and steep slopes are developed in some cases) and over which a local government might reasonably exert control to prevent development. New development is defined as any ≥10% change in impervious surface in the NLCD from 2001 to 2019, measured at a 30 × 30 m spatial resolution. Alaska and Hawaii are excluded due to lack of impervious surface data. New housing includes residential properties with a year built from 2001 to 2019, as recorded in the Zillow Transaction and Assessment Data set (ZTRAX).

3.2. Distribution of Floodplain Development

Extensive floodplain development has occurred over the past two decades, shaping flood risk across the United States (Figure 2). Across all communities with a regulatory flood hazard map (n = 18,548), 2.1 million acres of floodplain land were developed (7.6% of new development), and 844,000 new residential properties were built in the floodplain (5.4% of new housing) from 2001 to 2019. When we consider that 11.0% of all developable land is in the floodplain, however, the United States has an FDI of 0.69 and an FHI of 0.49. At a national scale (i.e., if the US as a whole had developed in proportion to its share of floodplain land), development at random would have resulted in 3.1 million acres of new floodplain development and 1.7 million properties built in the floodplain. At a community scale (i.e., if each community had developed in proportion to its share of floodplain land), development at random would have resulted in 3.6 million acres of new floodplain development and 2.1 million properties built in the floodplain.

Absolute and relative measures of floodplain development provide contrasting, yet complementary insights into patterns of flood hazard and exposure (Figure 3). In Louisiana, 447,00 acres of floodplain land were developed from 2001 to 2019, the highest total for any state. In absolute terms, this accounts for 21% of all new floodplain development across the United States. In relative terms, however, Louisiana has an FDI of 0.55 because, although 25% of its new development occurred in the floodplain, 45% of its developable land is in the floodplain. In Florida, 398,000 new residential properties were built in the floodplain from 2001 to 2019, the highest total for any state. In absolute terms, this accounts for over 47% of all new floodplain housing across the United States. In relative terms, however, Florida has an FHI of 0.52 because, although 21% of its new housing was built in the floodplain, 40% of its developable land is in the floodplain. This general geographic pattern is evident in the southern United States, especially around the Mississippi River and Florida where despite substantial new floodplain development (Figures 3a and 3b), high levels of flood hazard in those regions (Figure 3c) result in lower measurements of FDI and FHI. The reverse of this geographic pattern is observed in much of the western United States where despite little floodplain development in absolute terms, relatively low hazard levels result in higher index measurements.

Unsurprisingly, states with higher shares of floodplain land tend to have higher shares of floodplain development and housing (and vice-versa), but exceptions exist (Figure S1 in Supporting Information S1). Four of the five states with the most developable land in the floodplain also have the highest shares of new development in the floodplain: Louisiana (24% of new development in floodplain), Florida (21%), Mississippi (15%), and Arkansas (11%). Although North Carolina has the fifth most developable land in the floodplain (16%), it has only 4.6% of its new development in the floodplain (FDI = 0.29). Conversely, West Virginia has only 6.7% of its developable land in the floodplain but 9.9% of its new development in the floodplain (FDI = 1.49). Similarly, three of the five states with the most developable land in the floodplain also have the highest shares of new housing built in the floodplain: Florida (21% of new housing built in floodplain), Louisiana (20%), and Mississippi (10%). Yet North Carolina has only 3.7% of its new housing built in the floodplain (FHI = 0.24). Conversely, New Jersey has only 15% of its developable land in the floodplain, but 17% of its new housing was built in the floodplain (FHI = 1.16).

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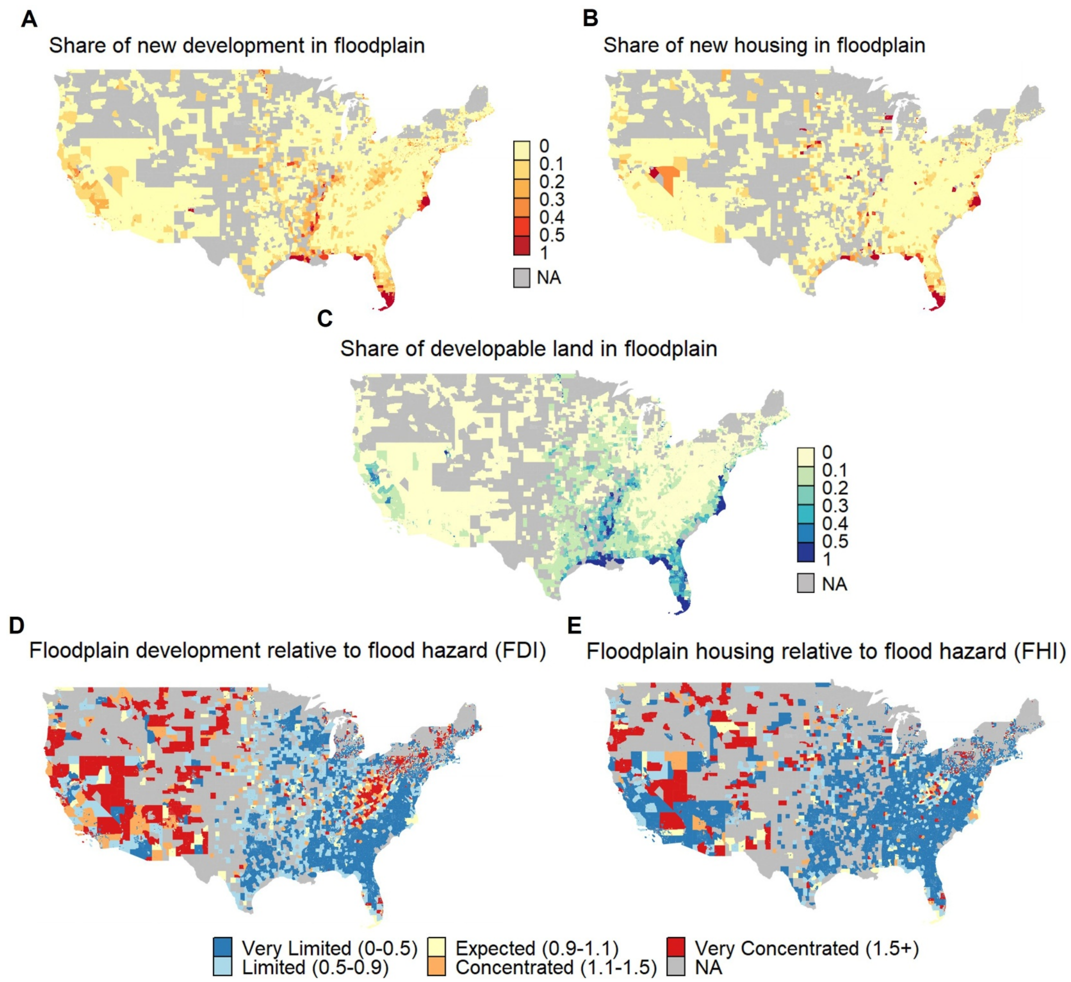

Figure 3. *Geographic patterns of floodplain development differ between absolute and relative measures.* (a) The fraction of new development from 2001 to 2019 that went into the floodplain for each community. (b) The fraction of new housing from 2001 to 2019 built in the floodplain for each community. (c) The fraction of total developable land in the floodplain for each community. (d) The Floodplain Development Index for each community. (e) The Floodplain Housing Index for each community.

So, while the extent of flood hazards in a state tends to be positively correlated with floodplain development, there are examples of states with relatively little or relatively high levels of floodplain development given the hazard they face.

Most communities in the continental United States have limited floodplain development and housing relative to their hazard (Figure S2 in Supporting Information S1). Overall, of the communities that recorded any new development from 2001 to 2019 (n = 18,497), 74% have relatively limited new development in the floodplain (FDI <1), and just 26% have concentrated new development in the floodplain (FDI >1). The mean community-level FDI is 0.92 (median, 0.50; IQR, 0.84). Housing construction data indicate even more limited floodplain development than the impervious surface measures. Overall, of the communities with at least one property built from 2001 to 2019 (n = 15,411), 87% have limited new housing in the floodplain (FHI <1), and just 13% have concentrated new housing in the floodplain (FHI >1). The mean community-level FHI is 0.51 (median, 0.13; IQR, 0.52). Echoing state-level results, these finding show that many communities with large shares of floodplain land have actually limited new floodplain development.

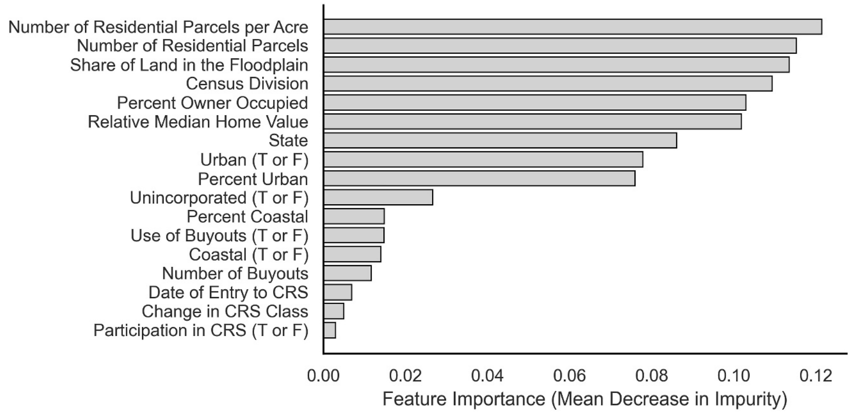

Figure 4. *Factors influencing floodplain management also shape patterns of variation in floodplain development outcomes.* Feature importance as mean decrease in impurity corresponds to the relative importance of each feature in the model's classification decision.

3.3. Patterns and Key Influences of Floodplain Development Outcomes

We explore patterns in floodplain development relative to key social, economic, and geographic factors that might explain variation across communities. We do this first with a broad set of community characteristics using a random forest classification model, then we test for differences across specific factors.

A random forest binary classification model predicts whether communities will have limited (FDI <1) or concentrated (FDI >1) floodplain development based on a number of factors (Pedregosa et al., 2011) (Figure 4). Only a subset of communities without missing data across all features is included in the model (n = 16,031). We apply the SMOTE to address class imbalance (Chawla et al., 2002; Lemaitre et al., 2016). The three most important features for predicting floodplain development outcomes, as measured by mean decrease in impurity, are number of residential properties per acre (used as a proxy for population density), number of residential properties (used as a proxy for population), and share of land in the floodplain (Figure 4). The model has an overall classification accuracy of 76% and a weighted accuracy of 64%.

We next focus on three factors in the model that have been previously identified as relevant to floodplain management and development: geography, wealth, and flood risk management (Bagstad et al., 2007; Beltrán et al., 2018; Berke & French, 1994; Bin et al., 2008; Brody et al., 2009, 2010; Brody, Zahran, Highfield, et al., 2007; Brody, Zahran, Maghelal, et al., 2007; Burby, 1998; Burby & French, 1981; Butler et al., 2016; Cigler et al., 1987; Cordes & Yezer, 1998; Gourevitch et al., 2023; Highfield & Brody, 2017; Li & Landry, 2018; Loucks & Stedinger, 2007; Mach et al., 2019; Posey, 2009; Zahran et al., 2009, 2010). To test hypotheses relating to these three factors, described in each subsection below (3.3.1–3.3.3), we compare FDI and FHI across groups using two metrics: mean and fraction of communities above 1. Throughout, we use Welch's t-tests to determine if there is a significant difference in means between groups and Pearson's chi-square tests (with Yates' correction for continuity) to determine if there is a significant difference in the frequency distribution of concentrated floodplain development between groups.

3.3.1. Development Concentrated in Coastal and Urban Floodplains, Housing in Rural Floodplains

First, we hypothesize that coastal and urban communities are more likely to concentrate development and housing in the floodplain due to the higher appeal of floodplain occupancy than in inland and rural communities, respectively (Bagstad et al., 2007; Brody, Zahran, Highfield, et al., 2007; Brody, Zahran, Maghelal, et al., 2007; Butler et al., 2016; Cordes & Yezer, 1998; Montz & Gruntfest, 1986). Communities with coastal wave exposure (i.e., communities with land in flood zones designated "VE" in a DFIRM) are classified as coastal, and the rest are classified as inland. Communities with a majority of their land area in a census-defined urban area are classified as urban, and the rest are classified as rural (although we recognize future work may want to refine this simplified binary system). The results of our analysis partially support this first hypothesis.

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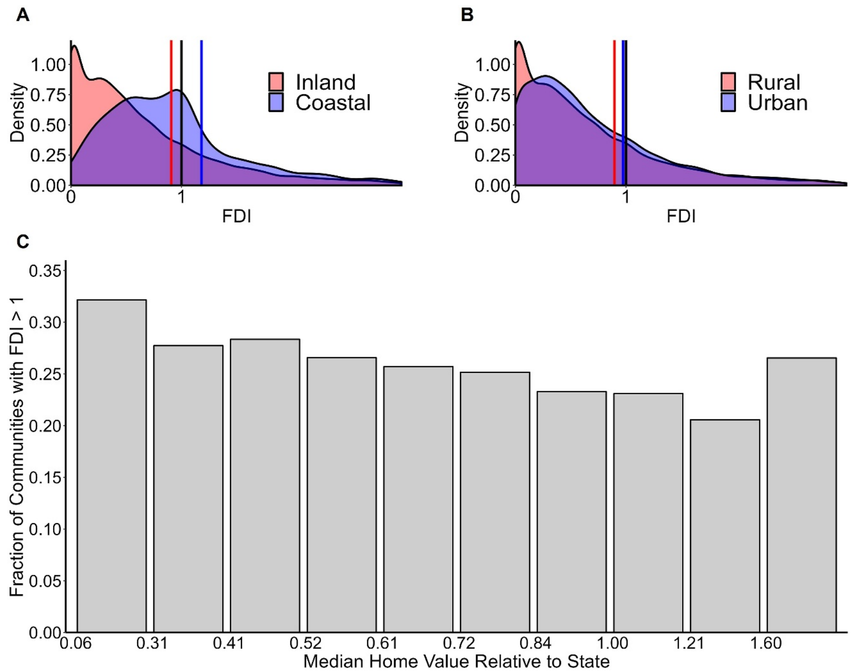

Figure 5. *Coastal and urban communities, as well as those with the lowest relative home values, more often concentrate floodplain development*. (a) Densities and means (vertical solid lines) of Floodplain Development Index (FDI) for inland (n = 17,603) and coastal (n = 944) communities. $P < 0.05$. Vertical black line represents a reference point for FDI = 1. (b) Densities and means of FDI for rural (n = 12,307) and urban (n = 6,240) communities. $P < 0.05$ (c). Fraction of communities with concentrated floodplain development for each decile of relative median home value (n = 18,494).

Coastal communities (n = 944) are more likely to concentrate both floodplain development and housing than inland communities (n = 17,603) (Figure 5a and Figure S3A in Supporting Information S1). Coastal communities have a mean FDI of 1.18, compared to 0.91 for inland communities ($P < 0.05$), and 40.8% of coastal communities have concentrated floodplain development, compared to 25.2% of inland communities ($P < 0.05$). Similarly, coastal communities have a mean FHI of 0.69, compared to 0.50 for inland communities ($P < 0.05$), and 24.5% of coastal communities have concentrated floodplain housing compared to 12.1% of inland communities ($P < 0.05$).

Urban communities (n = 6,240) are more likely to concentrate floodplain development, whereas rural communities (n = 12,307) are more likely to concentrate floodplain housing (Figure 5b and Figure S3B in Supporting Information S1). Urban communities have a mean FDI of 0.97, compared to 0.90 for rural communities ($P < 0.05$), and 28.0% of urban communities have concentrated floodplain development, compared to 25.0% of rural communities ($P < 0.05$). Conversely, urban communities have a mean FHI of 0.37, compared to 0.60 for rural communities ($P < 0.05$), and 10.1% of urban communities have concentrated floodplain housing, compared to 14.3% of rural communities ($P < 0.05$).

We also find that the most densely populated communities are most likely to concentrate floodplain development, whereas less densely populated communities are more likely to concentrate floodplain housing (Figure S4 in Supporting Information S1). This is consistent with both (denser) urban communities being more likely to concentrate floodplain development as well as (less dense) rural communities being more likely to concentrate floodplain housing.

3.3.2. Wealth Non-Linearly Associated With Floodplain Development

Second, we consider two competing hypotheses about the relationship between wealth and floodplain development. On the one hand, we expect that less wealthy communities are less likely to limit development in the floodplain due to both increased need for property tax revenue generated by development and decreased likelihood of sufficient government capacity for stringent land-use planning (Bagstad et al., 2007; Berke & French, 1994; Brody et al., 2010; Burby & French, 1981; Li & Landry, 2018). On the other hand, in wealthier communities, an amenity effect (i.e., higher property values on waterfronts) coupled with potential for high property tax revenues could also incentivize floodplain development (Beltrán et al., 2018; Bin et al., 2008; Gourevitch et al., 2023). The results of our analysis suggest a generally negative, but non-linear, relationship between wealth and floodplain development.

Two indicators of wealth are considered: median home value and median household income. Median home value is calculated for each community using ZTRAX property value data (Materials and Methods). Relative median home value is calculated by taking the ratio of a community's median home value and the corresponding state's median home value. A relative median home value of one indicates parity with the state's median home value. These values are then divided into deciles based on the resulting national distribution. Only those communities with ZTRAX property value data are included in this analysis (n = 17,634).

The likelihood of concentrating floodplain development and housing generally decreases as a community's median home value relative to the state increases (Figure 5c and Figure S3C in Supporting Information S1). Communities with the lowest relative median home values are the most likely to concentrate both floodplain development and housing (32.2% FDI >1, mean = 1.14; 15.8% FHI >1, mean = 0.53). As relative median home value increases, the fraction of communities with concentrated floodplain development and housing decreases until a point. Communities with relative median home values above one (in the 1.21–1.6 range) are the least likely to concentrate both floodplain development and housing (20.6% FDI >1, mean = 0.78; 10.6% FHI >1, mean = 0.44). For communities with the highest relative median home values, however, the fraction of communities with concentrated floodplain development and housing increases (26.5% FDI >1, mean = 0.86; 12.8% FHI >1, mean = 0.42). A similar generally decreasing relationship holds between relative median household income and floodplain development outcomes (Figure S5 in Supporting Information S1).

3.3.3. Floodplain Management Practices Showing Mixed Relationships With Outcomes

Third, floodplain management practices could be reflected in floodplain development outcomes. On the one hand, one might expect communities that engage in floodplain management practices to have lower levels of floodplain development. For example, the Community Rating System (CRS) rewards communities that adopt certain practices (e.g., land use ordinances to limit floodplain development) with discounted flood insurance rates (Brody et al., 2009; Highfield & Brody, 2017; Li & Landry, 2018; Zahran et al., 2010). On the other hand, the “land use management paradox” theorizes that communities are more likely to implement flood risk management when they have already developed in the floodplain and, therefore, perceive heightened risk (Burby, 1998; Burby & French, 1981). In this case, communities might join the CRS specifically because they have failed to limit floodplain development in the past. Even more directly, communities might engage in buyouts—a type of government property acquisition to remove structures on flood prone properties—to redress historical floodplain development (Mach et al., 2019; Miao & Davlasheridze, 2022; Shi et al., 2022; Zavar & Fischer, 2021; Zavar & Hagelman III, 2016). We therefore explore how FDI and FHI relate both to the CRS and buyouts (Figure 6).

We first compare communities that do and do not participate in the CRS. Communities participating in the CRS (n = 1,450)—measured by the presence of scores in either the 2005 or 2019 evaluations—are more likely to concentrate both development and housing in the floodplain than non-participating communities (n = 17,097) (Figures 6a and 6b). 31.9% of participating communities have concentrated development in the floodplain, compared to 25.5% of non-participating communities ($P < 0.05$), but mean FDI is equal between the groups. Similarly, 17.8% of participating communities have concentrated housing in the floodplain, compared to 12.3% of non-participating communities ($P < 0.05$), and participating communities have a mean FHI of 0.60, compared to 0.50 for non-participating communities ($P < 0.05$).

Second, we compare development outcomes to CRS scores, focusing only on participating communities. Communities that improved in CRS class from 2005 to 2019 (n = 474) are somewhat less likely to concentrate both floodplain development and housing than communities that worsened in CRS class (n = 117) (Figures 6a and 6b). Communities in which CRS class worsened between 2005 and 2019 had a mean FDI of 1.10, compared to 0.92 for communities in which CRS class improved, and 35.0% of worsening communities have concentrated development in the floodplain, compared to 30.2% of improving communities. Similarly, communities in which CRS class worsened between 2005 and 2019 had a mean FHI of 0.87, compared to 0.60 for communities in which CRS class improved, but 15.4% of worsening communities have concentrated housing in the floodplain, compared to 20.7% of improving communities.

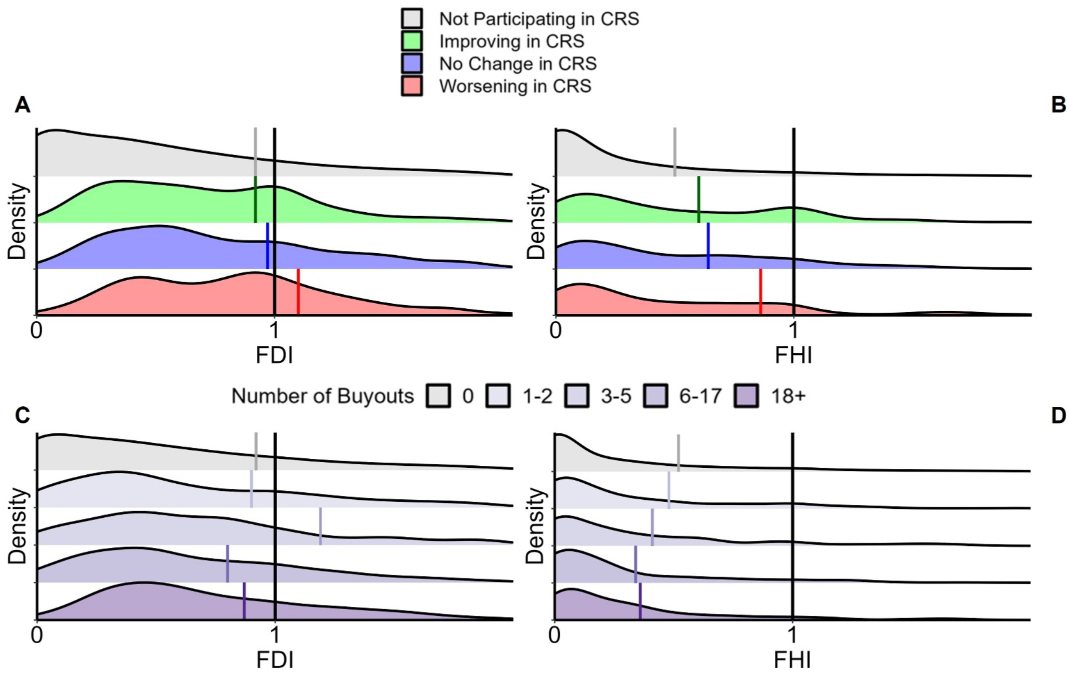

Figure 6. *Improvement in CRS corresponds to more limited floodplain development and housing, while implementation of buyouts corresponds only to more limited floodplain housing*. (a) Densities and means (vertical solid lines) of Floodplain Development Index (FDI) for communities not participating in CRS (n = 17,097) and communities in which CRS class worsened (n = 117), improved (n = 474), or did not change (n = 383) from the 2005 to the 2019 edition of the CRS. Vertical black line represents a reference point for FDI = 1. (b) Densities and means of Floodplain Housing Index (FHI) for communities not participating in CRS and communities in which CRS class worsened, improved, or did not change from the 2005 to the 2019 edition of the CRS. (c) Densities and means of FDI for communities without (n = 17,040) and with (n = 1,508) buyouts (divided into quartiles based on number of buyouts implemented). (d) Densities and means of FHI for communities without and with buyouts.

Evidence is mixed regarding the relationship between buyouts and floodplain development outcomes (Figures 6c and 6d). 11.4% of communities with buyouts (n = 1,508) have concentrated housing in the floodplain, compared to 12.9% of communities without buyouts (n = 17,040) ($P > 0.05$), and communities with buyouts have a mean FHI of 0.41 compared to 0.52 for communities without buyouts ($P < 0.05$). Conversely, 28.5% of communities with buyouts have concentrated development in the floodplain, compared to 25.8% of communities without buyout ($P < 0.05$), and mean FDI is equal between the groups.

Furthermore, among communities that have implemented at least one buyout, an increasing number of buyouts corresponds to improved floodplain housing outcomes, whereas no clear trend emerges for development outcomes (Figures 6c and 6d). 13.8% of communities with only 1–2 buyouts have concentrated floodplain housing (mean FHI = 0.48), compared to 9.1% of communities with 18+ buyouts (mean FHI = 0.36). 29.8% of communities with only 1–2 buyouts have concentrated floodplain development (mean FDI = 0.90), compared to 28.3% of communities with 18+ buyouts (mean FDI = 0.87).

4. Discussion

Development patterns contribute to increasing flood risk across the United States by intensifying flood hazards and increasing exposure. To date, the lack of comprehensive, community-scale data measuring floodplain development has limited our understanding of where and how communities have concentrated or limited development in the floodplain. In this study, we seek to address this gap by developing a Floodplain Development Index (FDI) and a Floodplain Housing Index (FHI) at the community level for the continental United States. We further use these indexes to determine the relationship between floodplain development outcomes and factors previously identified in literature as relevant to management of floodplain development. Here, we discuss potential mechanisms underlying each of our main findings based on existing literature, and we identify future research and policy implications that stem from our results. We also discuss study constraints and limitations before closing with a high-level summary of our findings.

Our findings show that while extensive floodplain development has taken place nationwide from 2001 to 2019, it has done so at a rate lower than would be expected by chance alone (Figure 3). Studies of past and future flood risk often stress the importance of steering new development away from hazardous areas and attribute the brunt of flood damages to the failure to do so (Blum et al., 2020; Bouwer, 2013; Burby, 2000; Burby et al., 1999; Holway & Burby, 1993; Larson & Plasencia, 2001; May & Deyle, 1998; Strader & Ashley, 2015; Wing et al., 2018, 2022). In fact, however, most communities across the United States are already limiting floodplain development to some extent (Figure S2 in Supporting Information S1), although whether this is the direct result of proactive floodplain management or simply a consequence of other development tendencies remains to be explored. If studies of flood risk focus only on damages in places that have disproportionately increased exposure through floodplain development, we could be prone to drawing conclusions from a sample that represents a minority of American communities. Future work should focus on assessing the policy suites, including legal and regulatory tools, that state and local governments have used to restrict development in hazardous areas. With our indexes, direct connections can be made between the use of land use management tools aiming to limit floodplain development (e.g., special purpose zoning ordinances, growth management ordinances, stormwater management plans) and actual outcomes. Understanding the contexts in which these tools have been implemented to effectively limit exposure is a critical next step for research.

Geographic contexts contribute to differing landscapes of flood risk (Figure 5 and Figure S3 in Supporting Information S1). Coastal communities have higher levels of both concentrated floodplain development and housing than their inland counterparts. This finding confirms the expectation that development in coastal communities is disproportionately sited in high-risk areas (Bagstad et al., 2007; Bin et al., 2008; Brody, Zahran, Maghelal, et al., 2007; Butler et al., 2016; Cordes & Yezer, 1998) (e.g., due to coastal waterfronts being perceived as a more desirable amenity than riverine waterfronts in inland communities). Interestingly, however, FDI and FHI diverge across the urban–rural divide, where urban communities are more likely to concentrate impervious surface in the floodplain but not new housing (and vice-versa for rural communities). Higher levels of floodplain development in urban communities may be indicative of larger development projects and structures in urbanized floodplains that lead to substantial increases in impervious surface (Brody, Zahran, Highfield, et al., 2007; Brody, Zahran, Maghelal, et al., 2007; Butler et al., 2016; Cordes & Yezer, 1998; Montz & Gruntfest, 1986). Conversely, higher levels of floodplain housing in rural communities may be due to a higher likelihood of constructing residential properties in rural floodplains as opposed to larger development projects that would be registered by changes in impervious surface.

The relationship between wealth and floodplain development outcomes is generally negative but non-linear (Figure 5 and Figure S3 in Supporting Information S1). The least wealthy communities (as measured by both home value and household income) are the most likely to concentrate both floodplain development and housing, and increases in wealth are generally associated with a decreased likelihood of concentrating floodplain development. This trend is consistent with multiple interpretations. The first possibility is limited government capacity (Li & Landry, 2018; Posey, 2009) in poorer communities to engage in floodplain management (e.g., to hire multiple full-time planners or floodplain managers). Second, it is consistent with the high opportunity cost to communities of foregoing the property tax revenue generated by development (Berke & French, 1994; Burby, 2000; Burby & French, 1981; Deyle et al., 2008; Loucks & Stedinger, 2007), although in this case we might expect to see communities with higher property values pursue more floodplain development because the property tax revenue in absolute terms would be higher and the development pressures are expected to be greater. The issue might therefore be more about potential tax revenue as a fraction of potential local revenue sources, rather than as absolute gain—this dynamic remains to be explored.

Notably, however, communities with the very highest home values and incomes see a relatively higher fraction of concentrated floodplain development and housing. This finding is consistent with the expectation that, in the wealthiest communities, floodplains can have commercial and residential amenity value and are more likely to be developed (Beltrán et al., 2018; Bin et al., 2008; Gourevitch et al., 2023). Although any level of development in the floodplain may be detrimental to flood risk management goals, development in hazardous areas may have substantial other benefits, such as providing access to natural resources, proximity to educational and economic opportunity, or other site-specific needs. While both poor and wealthy communities are developing in hazardous areas at relatively high rates, they are likely doing so for very different reasons. Wealthy, coastal, urban communities could be opting-in to risk by developing in high-value, amenity floodplains that offer desirable locations for residents and businesses. On the other hand, poor, inland, rural communities could be developing floodplains that offer cheap and lucrative (but risky) land. This finding supports the idea that risk is both constitutive of and produced by geography and wealth (Zavar & Fischer, 2021), and effective floodplain management must be attuned to these disparities.

Our findings also demonstrate a nuanced relationship between floodplain management actions and development outcomes (Figure 6). Merely participating in the CRS does not correspond to decreased floodplain development outcomes; instead, performance in the program is critical. Communities participating in CRS are actually more likely to concentrate both floodplain development and housing than non-participating communities (Figures 6a and 6b). This result supports the land use management paradox, which suggests that those communities that have already developed in the floodplain are more likely to pursue flood risk management, due to a heightened perception of flood risk (Burby & French, 1981). It is also consistent with the hypothesis that the CRS may perversely incentivize floodplain development by offering participating communities discounted flood insurance rates, thus making it cheaper to occupy floodplains (Brody, Zahran, Maghelal, et al., 2007). Improved performance in the CRS over time, however, is associated with more limited floodplain development outcomes (Figures 6a and 6b). Improved outcomes for communities that improve in the CRS supports studies that show that the program can in fact be an effective tool in reducing flood risk and damages (Brody, Zahran, Highfield, et al., 2007; Highfield & Brody, 2017). Given that improved performance is associated with more limited floodplain development, further work exploring the factors that enable participating communities to improve in the CRS (Brody et al., 2009; Sadiq & Noonan, 2015) is warranted.

The use of buyouts is associated with limited floodplain housing but not development (Figures 6c and 6d). Communities that have implemented buyouts have a lower average FHI than those that have not, whereas there is no significant difference in FDI. Furthermore, average FHI tends to decrease as the number of buyouts implemented in a community increases, whereas there is no clear trend for FDI. That the use of buyouts would be reflected in floodplain housing outcomes is intuitive as buyouts focus on the removal of flood-prone residential properties (Mach et al., 2019; Miao & Davlasheridze, 2022), which is captured by the FHI. This finding is indicative of a more aggressive strategy to limit new floodplain housing, and thereby manage flood risk, among those communities that have bought out flood prone properties in the past, especially those that have used buyouts more than once (Mach et al., 2019; Zavar & Hagelman III, 2016). Buyouts, however, are not mutually exclusive with floodplain development. For example, in North Carolina where the FHI is just 0.24, 10 homes have been built in the floodplain for every one home that was bought out (Hino et al., 2023). Increasing support for buyout programs (Shi et al., 2022) can serve a key role in both redressing past floodplain development and attuning communities to the benefits of limiting floodplain housing moving forward.

Our work is limited by both data constraints and study design. First, we define floodplain based only on effective regulatory floodplain maps that have been digitized. So, we cannot characterize the extent of flood hazards in communities without digitized floodplain maps, and these communities are excluded from our analysis even though many of them may have floodplain land. Furthermore, given the potential underestimation of flood risk in FEMA flood hazard maps, it does not necessarily follow that development outside these designated areas is risk-free. Nevertheless, these maps carry regulatory influence and therefore reflect the primary basis on which most municipalities will manage their floodplain land. It will be necessary to attune future work to shifts in flood hazard, as the extent of both geomorphological and regulatory floodplains change over time. Second, we do not account for the possibility of "un-development." That is, we only allow for positive changes in impervious surface and do not register floodplain development that may have been removed (e.g., through a property buyout). Third, we only consider new development in the period between 2001 and 2019 (the earliest and latest years of the NLCD impervious surface data set). Our index therefore does not capture, for example, whether a community had already largely built out its floodplain prior to 2001. A sensitivity analysis, however, shows that this does not systematically affect our results (*Material and Methods*). Nor do we capture tear-down and rebuild patterns where the new build is less than 10% bigger than the old building. Finally, our indexes indicate that floodplain development has occurred but does not distinguish how it occurred. Not all floodplain development is equally vulnerable if certain adaptive measures are taken (e.g., elevation, flood-proofing), so our indexes are not full metrics of risk.

5. Conclusion

Contrary to conventional perceptions of rampant floodplain development, our findings show that approximately 1 out of 4 communities nationwide has concentrated development in the floodplain, and 1 out of 8 has concentrated housing in the floodplain. Local factors including geography, wealth, and floodplain management efforts help explain important patterns in floodplain development across communities. This analysis offers a high-level view of floodplain development outcomes and patterns, and the indices developed create a foundation for valuable lessons from in-depth, cross-community comparisons and case studies. Future work could consider examples of comparable communities that have both limited and concentrated floodplain development, to examine the community-specific contexts and floodplain management practices, including legal and regulatory tools, that may lead to those differential outcomes. Land use planning and management occupies a central place in risk management and hazard mitigation, supporting the adaptive, climate-smart growth of communities.

Conflict of Interest

Authors declare that they have no competing interests.

Data Availability Statement

All supporting data and code are available through DesignSafe Data Depot (Agopian et al., 2024). Housing data were provided by Zillow through the Zillow Transaction and Assessment Data set (ZTRAX). More information on accessing the data can be found at http://www.zillow.com/ztrax. The results and opinions are those of the authors and do not reflect the position of Zillow Group.

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