Merging Federal Flooding and Housing Data to Gain Insight into Flood Impacts on Federally Assisted Households: A Case Study in Kansas City, Missouri

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Abstract

Previous research on the differential impacts of floods has found that race, ethnicity, income, gender, age, and housing tenure and type influence people's ability to prepare for and respond to flood events. However, studying the impacts of flooding is often challenging due to data limitations, especially for storm- and snowmelt-related flooding in noncoastal areas. This article draws on Federal Emergency Management Agency (FEMA) flood risk maps, the U.S. Geological Survey (USGS) Flood Inundation Mapping (FIM) Program, and U.S. Department of Housing and Urban Development (HUD) administrative data to provide a methodological example of integrating federal flooding and housing data to gain local housing insights. The USGS FIM Program provides a unique opportunity to help communities visualize potential areas at risk for flooding near local streams and rivers. Unlike FEMA flood risk maps, USGS FIM maps allow researchers to investigate local flooding processes, such as the predicted extent and depth of housing-unit flood exposure. To demonstrate the utility of USGS data for housing research, this article presents a case study investigating the impact of flooding on housing units where households receiving federal rental assistance live in Kansas City, Missouri. The presented analysis contrasts local housing unit trends in flood exposure to census-tract-level trends of flood risk derived from FEMA riverine flood maps. This case study demonstrates how USGS and FEMA data can inform housing analyses at different scales for researchers and practitioners interested in flood impacts on local communities and vulnerable populations.

Introduction

Climate change has increased the frequency and severity of extreme weather events, including floods, hurricanes, and severe storms (IPCC, 2022). Extreme weather events pose a threat to the built environment and housing (Hallegatte and Przyluski, 2010) and further exacerbate social inequalities by disproportionately affecting low-socioeconomic-status communities (Howell and Elliott, 2019) and communities of color living in areas of infrastructural disinvestment (Hendricks and Van Zandt, 2021).

Municipalities are taking increasing steps to address disproportionate risks from natural disasters by building back more resilient infrastructure or investing in infrastructural resilience before a disaster (HUD, n.d.a.). However, planning in ways that preempt natural disasters depends on the availability of data used to identify areas and structures most at risk of environmental hazards. This article explores using U.S. Geological Survey (USGS) Flood Inundation Mapping (FIM) Program, Federal Emergency Management Agency (FEMA) flood risk, and U.S. Department of Housing and Urban Development (HUD) administrative data to provide a methodological example of integrating federal flooding and housing data to gain local housing insights.

Flooding is the most prevalent natural disaster in the United States and is expected to become more frequent and severe due to climate and land use change (Brody et al., 2007). Social vulnerability research on flood risk has drawn attention to the impacts of race, ethnicity, income, gender, and age (Cutter, Boruff, and Shirley, 2003; Rufat et al., 2015; Walker, 2012) and housing tenure and type (Lee and Van Zandt, 2018; Mehta, Brennan, and Steil, 2020) on flood exposure and capacities to prepare for and recover from flood events. Research investigating the impacts of Hurricane Harvey found that the areal extent of flooding was significantly greater in neighborhoods with higher percentages of non-Hispanic Black and low-socioeconomic-status residents (Chakraborty, Collins, and Grineski, 2019) and people with disabilities (Chakraborty, Grineski, and Collins, 2019). In addition, the areal extent of Hurricane Harvey flooding within 100 meters of residents' homes was significantly greater for racial/ethnic-minority and low-socioeconomic-status households (Collins et al., 2019). The social impacts of flood exposure cannot be disentangled from structural constraints on housing markets. Many low-income and racial/ethnic-minority households live in flood-prone areas because of the lower housing costs (Levine, Esnard, and Sapat, 2007). Those stark geographies are pronounced particularly in the U.S. South, where Carrera and Coleman Flowers (2018) documented how White landowners and cotton production aggregated in higher elevations with better drainage, whereas Black residents were limited to living in lowland areas that were more prone to flooding.

A growing number of hazard vulnerability studies aim to link social vulnerability and housing by focusing specifically on the location of federally subsidized households and their exposure to major flooding events (Chakraborty et al., 2021; Davlasheridze and Miao, 2021; Hamideh and Rongerude, 2018; Hernández et al. 2018). Chakraborty et al. (2021) investigated the impacts of Hurricane Harvey on tenants receiving federal rental assistance and found that they were more likely to live in areas with greater flood extent. Davlasheridze and Miao (2021) found that not only do floods reduce the number of available housing units for federally subsidized tenants, but they can also increase the average time on waitlists to determine eligibility for housing programs and the share of rent paid by tenants in those programs. Studying the impacts of Hurricane Sandy on federally subsidized households, Hernández et al. (2018) found that many residents in New York City Housing Authority units were unlikely to evacuate or relocate despite experiencing power outages, flooded streets, and damaged building infrastructure because they feared displacement if city inspectors condemned their apartment. The impact of flooding on federally assisted households is not isolated to extreme storm events; a 2017 report by the New York University (NYU) Furman Center found that approximately 9 percent of government-subsidized households live in a 1-percent annual exceedance probability area (commonly referred to as a 100-year floodplain), an area with a 1-percent probability of flooding each year (Rosoff and Yager, 2017). Together, the research points to a need to identify areas where federally assisted households live in housing at risk of flood exposure and to develop strategies to support economically disadvantaged communities likely to experience more frequent and severe storm events.

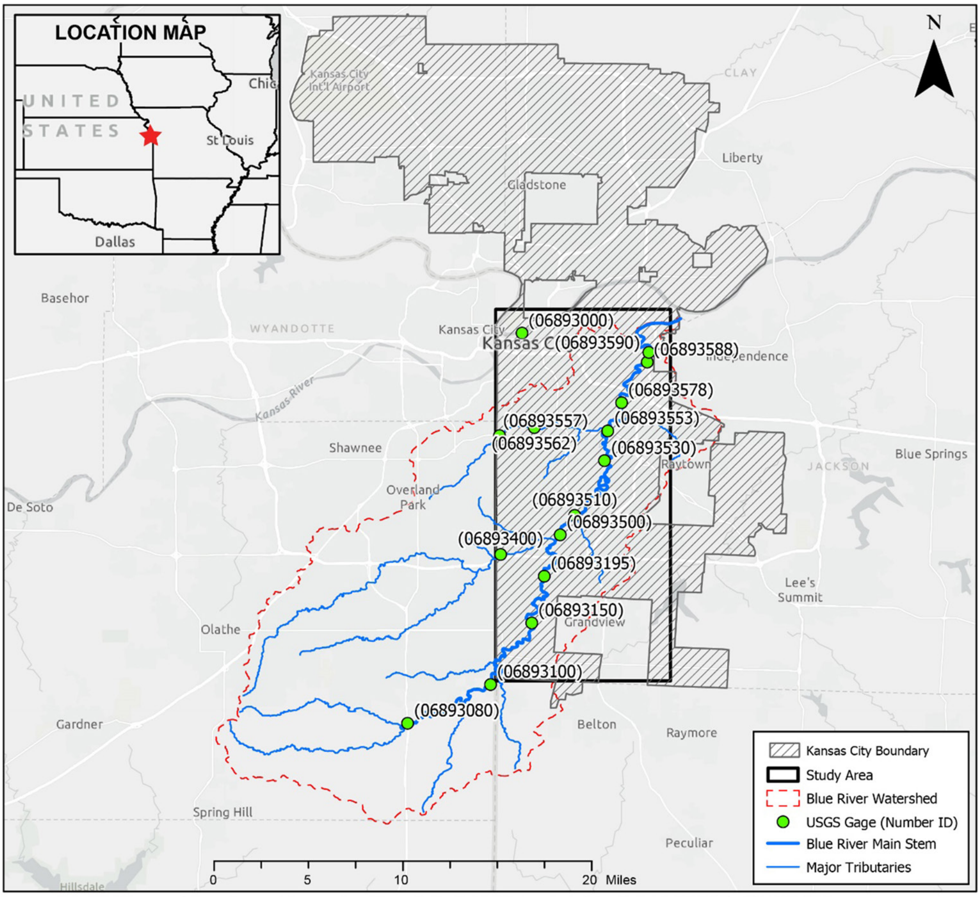
This article contributes to the research on flood exposure for federally subsidized households and housing units. Rather than investigating flooding following a natural disaster, the authors examine the possibility of using USGS Flood Inundation Mapper data (USGS, 2019) to identify flood exposure under set stream conditions for housing units where federally assisted households live. The authors also explore the use of FEMA flood risk maps (FEMA, n.d.) to ascertain relative flood risk for census tracts where federally assisted households are located. The study focuses specifically on riverine flooding, which can be more unpredictable than coastal flooding and can occur more frequently, with annual flash flooding due to climate change-driven increases in storm magnitude and frequency (Vanucchi, 2021) and increased runoff from impervious surfaces due to urbanization (Shuster et al., 2005). A focus on riverine flooding can also support U.S.-based studies that aim to investigate links between racial and economic segregation and vulnerability to climate hazards. Previous studies found that areas of concentrated social disadvantage in the United States were associated with greater inland flooding, whereas areas with more socially advantaged populations were associated with greater coastal flooding (Chakraborty et al., 2014; Qiang, 2019; Ueland and Warf, 2006). The sections that follow present a case study for Kansas City, Missouri (KCMO), integrating USGS riverine flood models and HUD administrative data, and compare USGS flood models with FEMA flood risk maps to provide a blueprint for data sources and analysis methods that can inform future research on flood risk across different scales of analysis.

Study Area: Blue River Kansas City, Missouri

The USGS FIM program works with local communities to produce flood models for stream sections identified by USGS and local stakeholders. Although the FIM map library contains flood inundation maps for 27 U.S. states, the maps are limited to local streams and rivers. In KCMO, the FIM maps encompass the Lower Blue River and its tributaries (exhibit 1). Thus, the study area in this analysis does not encompass all KCMO but is limited to a bounding box containing the USGS FIM mapped area.

Exhibit 1

Blue River Watershed with Locations of USGS Gages Used to Develop Flood Inundation Models



Basemap: Missouri Dept. of Conservation, Missouri DNR, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

USGS = U.S. Geological Survey.

Notes: The study area containing the Blue River within KCMO is outlined. Eight-digit numbers along the Blue River main stem and major tributaries represent the numeric IDs of USGS stream gage sites.

Sources: 2021 118th Congressional District TIGER/Line Place State-based Shapefile; National Hydrography Dataset (NHD); USGS StreamStats website (https://streamstats.usgs.gov)

Demographics

Kansas City, Missouri, is a city in the U.S. Midwest that covers approximately 313 square miles (810.7 square kilometers) and is home to more than half a million (508,090) residents (U.S. Census Bureau, 2023). The population of KCMO is racially and ethnically diverse; 11 percent of the population identifies as Hispanic or Latino, 26 percent of the population identifies as Black or African-American, and 56 percent of the population identifies as White.[1] The median household

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[1] Data accessed from American Community Survey table B03002: HISPANIC OR LATINO ORIGIN.

income in KCMO is $63,396, and approximately 13.4 percent of the population lives in poverty (U.S. Census Bureau, 2023).

Like many other U.S. metropolitan areas, KCMO has been taking steps to address gaps in affordable housing. In May 2021, KCMO created the Housing and Community Development Department. One aim of the department is to assist renters with finding and maintaining safe and affordable housing (City of Kansas City, Missouri, 2021). More than 27,000 people in KCMO live in HUD-assisted households, the majority of whom are extremely low-income (82 percent; HUD, n.d.b). More than 70 percent of households receiving federal rental assistance in KCMO are female-headed (72 percent), and most household heads are non-Hispanic Black (76 percent; HUD, n.d.b). Approximately 90 percent of all households receiving federal rental assistance in KCMO live in the study area containing the Lower Blue River.

Hydrology

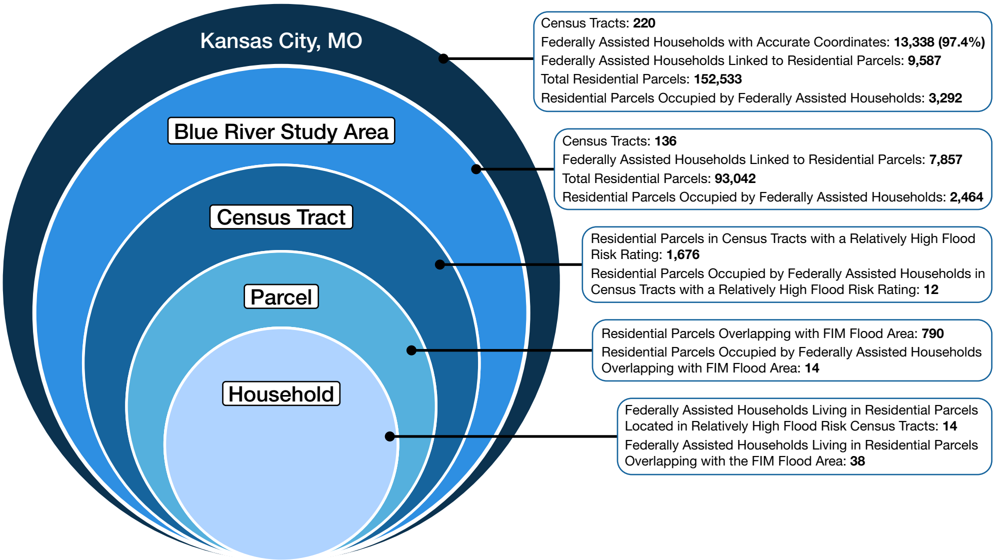
Flooding is generally the most common and costliest type of disaster Missouri experiences (Missouri Department of Public Safety, n.d.). Much of the historic flooding in KCMO has occurred along the Blue River and several tributaries, most notably in 1951, 1961, 1977, 1984, 1990, 1998, 2010, and 2017 (Heimann et al., 2014; USGS, 2023a). The Blue River is an approximately 39.8-mile (64.1-kilometer)-long tributary of the Missouri River, with a drainage area of approximately 270.5 square miles (700.5 square kilometers; USGS, 2023b). Along the lower reaches of the mainstem floodplain and along its major tributaries (Brush Creek, Indian Creek, and Tomahawk Creek), the river is moderately to highly developed, with a mix of residential and commercial properties. The Blue River flows northward through most of the southern half of the Kansas City metropolitan area within Johnson and Wyandotte Counties in Kansas and Jackson and Cass Counties in Missouri. The headwaters of the Blue River outside the city limits consist of grass- or forestland (exhibit 1; Wilkison et al., 2006); however, the watershed is still under development, with continued construction of residential properties in the headwaters (Heimann et al., 2014). The river is prone to annual flooding due to urbanization of the floodplain and surrounding watershed, leading to increased runoff and changes in the natural basin hydrology (Driever and Vaughn, 1988; Wilkison, Armstrong, and Blevins, 2002) that will be exacerbated further by projected increases in precipitation due to climate change (Byun, Chiu, and Hamlet, 2019). Levees have been built near the confluence of the Blue River and Missouri River and near the confluence of Indian Creek and Blue River to mitigate flooding (Heimann et al., 2014), and the channel has been straightened and armored to minimize inundation and maximize stormwater conveyance (Wilkison et al., 2006).

Data Sources

Many spatial studies of flooding investigate impacts at the census-tract or block-group level because data are commonly available at this spatial scale. Household- and housing-unit-level studies are less common because they often require that researchers collect household survey data rather than relying on publicly available data sources (Collins et al., 2019) or have flood models accurate enough to make inferences about flood depth and extent at the housing unit level. HUD administrative data are a unique dataset that allows researchers to study housing-unit-level environmental impacts across a subset of the population. When HUD administrative data are paired with USGS FIM models and local parcel data, researchers can investigate the depth and extent of flooding that will affect the housing units where federally assisted households live (exhibit 2).

Exhibit 2

Datasets Used in the Analysis Within the Lower Blue River Study Area



Census Tracts: **220**
Federally Assisted Households with Accurate Coordinates: **13,338 (97.4%)**
Federally Assisted Households Linked to Residential Parcels: **9,587**
Total Residential Parcels: **152,533**
Residential Parcels Occupied by Federally Assisted Households: **3,292**

Census Tracts: **136**
Federally Assisted Households Linked to Residential Parcels: **7,857**
Total Residential Parcels: **93,042**
Residential Parcels Occupied by Federally Assisted Households: **2,464**

Residential Parcels in Census Tracts with a Relatively High Flood Risk Rating: **1,676**
Residential Parcels Occupied by Federally Assisted Households in Census Tracts with a Relatively High Flood Risk Rating: **12**

Residential Parcels Overlapping with FIM Flood Area: **790**
Residential Parcels Occupied by Federally Assisted Households Overlapping with FIM Flood Area: **14**

Federally Assisted Households Living in Residential Parcels Located in Relatively High Flood Risk Census Tracts: **14**
Federally Assisted Households Living in Residential Parcels Overlapping with the FIM Flood Area: **38**

Notes: The text boxes summarize information about the variables from each contributing dataset. The nested diagram represents the relationship between spatial scales (e.g., a household is contained within a parcel) and is not meant to be a representation of physical scale.

Sources: Authors' analysis of census tract flood risk ratings from Federal Emergency Management Agency Riverine Flood Risk maps; U.S. Geological Survey Flood Inundation Mapping Program flood models for the Lower Blue River; Kansas City, MO, city parcel data; HUD administrative data

Housing: HUD Administrative Data and Kansas City Parcel Data

Household-level data for participants in federal housing rental assistance programs were extracted from HUD's internal database containing information collected via HUD form 50058.[2] This dataset contains entries describing demographic, economic, and program variables for all tenants receiving federal rental assistance in tenant- and project-based rental assistance programs. The Housing Choice Voucher (HCV) program is the primary tenant-based rental assistance program administered by HUD. In this program, tenants can use their housing subsidy to rent a housing unit on the private market that meets housing condition, health, and safety requirements. In project-based rental assistance programs, private property owners enter a contract with HUD to provide affordable rental units to tenants participating in HUD programs. Unlike tenant-based programs, tenants participating in project-based rental assistance programs cannot take subsidies with them when they move.

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[2] HUD makes this household-level data available to external researchers via data licenses (https://www.huduser.gov/portal/research/pdr_data-license.html). Extracts of these data are publicly available at the census-tract level (https://www.huduser.gov/portal/datasets/assthsg.html).

Data current as of December 2022 for all households in Kansas City, Missouri, participating in HUD rental assistance programs were extracted from HUD's internal database. To observe whether tenant- or project-based program participants live in areas of more or less flood exposure, the authors stratified households by program type. The downstream analysis relied on having accurate locations of households participating in HUD programs. Although all records in HUD's database contain addresses and are geocoded, the level of geocode quality varies; therefore, the authors removed records whose addresses could not be verified with latitude and longitude coordinates accurate to the dwelling rooftop level.

Households receiving federal rental assistance may reside in single and multifamily homes. To identify flood impacts on housing units where households receiving federal rental assistance live, household-level HUD administrative data were linked to KCMO parcel data (Bender, 2023; exhibit 2). The presented analysis considered only residential parcels identified by KCMO land use codes for single-family, mobile home, townhouse, duplex, condominium, and multifamily development (Bender, 2021). Identifying both the location and footprint of housing units affected by flooding allowed the authors to estimate the relative flood risk using FEMA flood maps and the predicted depth and extent of flooding for affected parcels using USGS FIM maps.

Flooding: FEMA Riverine Flood Risk and USGS Flood Inundation Mapper

FEMA's National Risk Index (NRI; Zuzak et al., 2023) was used to investigate census-tract-level riverine flood risk trends. Housing parcels occupied by federally assisted households located in census tracts likely to be affected by riverine flooding were identified using FEMA's NRI Riverine Flooding map (FEMA, n.d.). FEMA calculates risk ratings at the census-tract level on the basis of floodplain boundaries and historic storm and flood events, representing a relative risk where communities are grouped in percentiles based on national ratings (Zuzak et al., 2023). Rather than relying on a single source of flooding data, the presented analysis is informed by combining FEMA and USGS data sources. This approach can help guide decisionmaking under increasingly uncertain climate scenarios, for which flood maps can become quickly outdated (Smiley, 2020).

The purpose of the FIM Program is to provide information to communities regarding local flood risks and planning tools for cost-effective mitigation. Unlike the FEMA flood maps, USGS FIM maps do not indicate the risk of inundation but only a detailed model of the extent and depth of inundation for a given flood stage. The FIM Program has two main functions. The first is to partner with communities to create and validate a library of maps displaying potential areas of flooding over a range of water levels for local streams and rivers. USGS has standardized the procedures for creating flood inundation maps for flood-prone communities using scientifically sound methods, including hydraulic and topographic modeling based on real data (USGS, 2023a). The second goal of the FIM Program is to provide these inundation maps online along with additional data, including real-time streamflow data, flood forecasts, and potential loss estimates.

USGS began creating the flood inundation library for the Blue River and selected tributaries in cooperation with the city of Kansas City in 2012. The library consists of 345 estimated flood inundation maps along a 39.7-mile stretch of the Blue River, subdivided into 15 reaches based on USGS stream gage locations, to its confluence with the Missouri River in KCMO (exhibit 1).

The inundation maps depict the areal extent of modeled flooding at various flood stages and the depth of water at each flood stage. The library of flood inundation maps was developed using a variety of data sources, including streamgage data and existing hydraulic models from the U.S. Army Corps of Engineers (USACE) and the city of Kansas City. Additional model parameters, including topographic and bathymetric data, were collected along several cross sections along the study reach; geometry data of bridges and structures crossing the channel were collected to model backwater effects, and appropriate roughness coefficients were refined by model calibration. These data were then used to compute water-surface profiles using the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) Depth-Averaged Flow and Sediment Transport Model (FST2DH) software programs. These flood stages were created at 1-foot intervals referenced to the streamgage datum and ranging from the National Weather Service Action stage (the approximate top of bank flow—i.e., the amount of flow that a channel can carry without overflowing its bank, thus 0 feet of inundation) to that which exceeds the stage of the estimated 0.2-percent annual exceedance probability. The simulated water-surface profiles were then combined with a digital elevation model of the study area to delineate estimated flood inundation areas as shapefile polygons and depth grids for each water-surface profile in a geographic information system (GIS) software program.[3] The study area for this analysis is defined as the region in KCMO containing the Blue River and tributary flood inundation maps produced by USGS.

Methods

All analyses were performed using R Statistical Software (v4.2.2; The R Foundation, 2022). To facilitate the replication of this analysis, the R code is available in the appendix of this article.

Data Linkage

HUD administrative household data was linked to housing-unit parcels and census tracts. First HUD administrative data was subset to only households whose address coordinates were accurate to the dwelling rooftop level. Then, the spatial intersection function in R's *sf* package (Pebesma, 2018) was used to identify residential parcels occupied by federally assisted households on the basis of georeferenced coordinates for addresses. Parcels were considered to be residential if they were identified in the KCMO parcel file as single-family homes, mobile homes, townhouses, duplexes, multifamily homes, or condominiums. Census tracts containing residential parcels occupied by federally assisted households were similarly identified to quantify the number of housing units in census tracts with low, moderate, and high FEMA riverine flood risk ratings.

Flood Measures

Using both FEMA and USGS data facilitated the measurement of several indicators of flood risk and exposure. FEMA risk ratings are calculated at the census-tract level on the basis of floodplain boundaries and historic storm and flood events. These ratings represent a relative flood risk based on national ratings (Zuzak et al., 2023). FEMA flood risk ratings are grouped into census tracts

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[3] For more information regarding the methodology of the inundation map models, please refer to USGS Scientific Investigations Report 2014-5180 (Heimann et al., 2014) and the USGS Flood Inundation Mapping Science website (https://www.usgs.gov/mission-areas/water-resources/science/flood-inundation-mapping-science).

of Very High (80th to 100th percentile), Relatively High (60th to 80th percentile), Relatively Moderate (40th to 60th percentile), Relatively Low (20th to 40th percentile), and Very Low (0 to 20th percentile) risk (Zuzak et al., 2023). Census tracts with no infrastructural, population, or agricultural annual loss associated with riverine flooding expected are classified as No Rating (Zuzak et al., 2023).

Unlike FEMA maps, the USGS FIM maps do not indicate the risk of inundation but only a detailed model of the extent and depth of inundation for a given flood stage. To calculate the expected flood depth and extent for affected parcels, a GIS-based methodology comprising of several steps was used. First, the area covered by all pixels with a predicted flood depth greater than zero from the FIM model within each parcel was summed and the maximum flood depth in the parcel area was identified. FEMA's guide to retrofitting homes to mitigate flooding identifies flood depth as affecting structures when floodwaters exert increased pressure as flood depth increases. Two to 6 feet of flooding can push on exterior walls and up on floors; if a structure is not designed to resist that pressure, it can cause structural damage, possibly leading to the structure collapsing (FEMA, 2014). Thus, flood inundation depths were categorized into intervals of 0–2 feet, 2–6 feet, 6–15 feet, and 15 feet or greater. Finally, the expected flood extent was calculated by dividing the flooded area by the area of the parcel (in square feet) to derive the proportion of the parcel expected to experience flooding. The R package *stars* (Pebesma and Bivand, 2023) was used to analyze flood raster grids.

Results and Discussion

This analysis draws on two federal data sources predicting local impacts of flooding and HUD administrative data on households receiving federal rental assistance linked to city residential parcel data to investigate the impacts of flooding on structures in which federally assisted households live. The following sections present results summarizing anticipated flood impacts when using FEMA and USGS data and briefly discuss exposure to flood hazards across different federal rental assistance programs. The discussion concludes by contrasting FEMA and USGS flood data and describing the potential applications and limitations of those data sources.

FEMA Flood Risk Maps

More than one-half of residential parcels occupied by federally assisted households in the study area (51.1 percent) are in census tracts with no FEMA riverine flood risk rating, indicating no expected annual loss due to flooding. A relatively small percentage are in areas on the very low (5.3 percent) and relatively high extremes of riverine flood risk (0.5 percent). The majority are in census tracts with a relatively low (29.3 percent) or relatively moderate (13.9 percent) flood risk rating. Trends for housing units where federally assisted households live are relatively consistent with all residential housing units in the study area (exhibit 3).

Exhibit 3

Share of All Residential Parcels and Residential Parcels Occupied by Federally Assisted Households in the Lower Blue River Study Area Located in Census Tracts Classified by FEMA Riverine Flood Risk Ratings

FEMA Riverine Flood Risk Rating	Residential Parcels Occupied by Households Receiving Federal Rental Assistance (%)	All Residential Parcels (%)
No Rating	51.1	52.1
Very Low	5.3	6.9
Relatively Low	29.3	27.6
Relatively Moderate	13.9	11.5
Relatively High	0.5	1.8

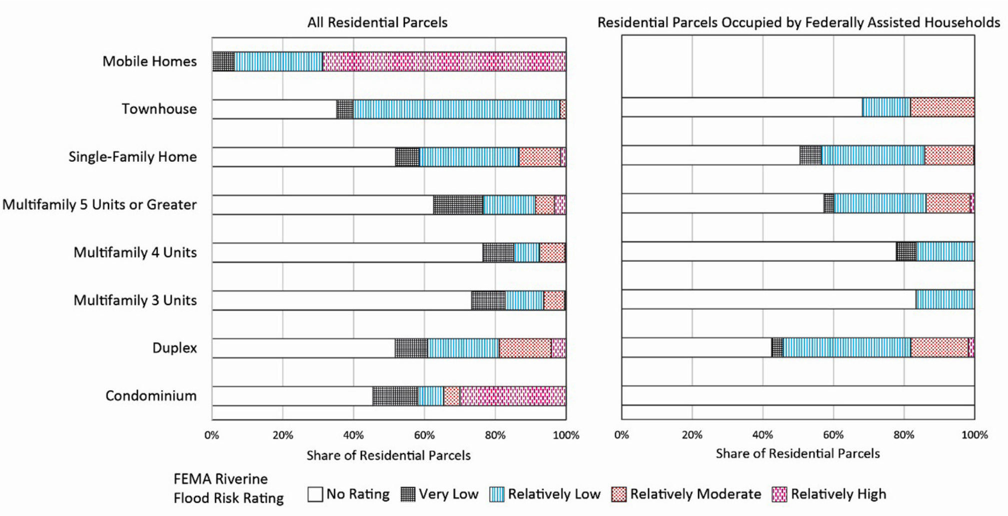
FEMA = Federal Emergency Management Agency.

Sources: Authors' analysis of FEMA Riverine Flood Risk maps; Kansas City, MO, city parcel data; HUD administrative data

A total of 1,676 residential parcels in the study area are located in census tracts with a relatively high riverine flood risk rating, including 12 occupied by federally assisted households. The 12 affected residential parcels are occupied by 14 households receiving federal rental assistance. For all residential parcels, housing in census tracts with a relatively high riverine flood risk rating includes single-family, multifamily, and mobile homes (exhibit 4). Notably, more than one-half of all mobile homes (68.8 percent) in the study area are in census tracts with a relatively high riverine flood risk rating.

Exhibit 4

All Housing Units and Housing Units Occupied by Households Receiving Federal Rental Assistance, by Census Tract Flood Risk Rating and Parcel Structure Type



FEMA = Federal Emergency Management Agency.

Sources: Authors' analysis of FEMA Riverine Flood Risk maps; Kansas City, MO, city parcel data; HUD administrative data

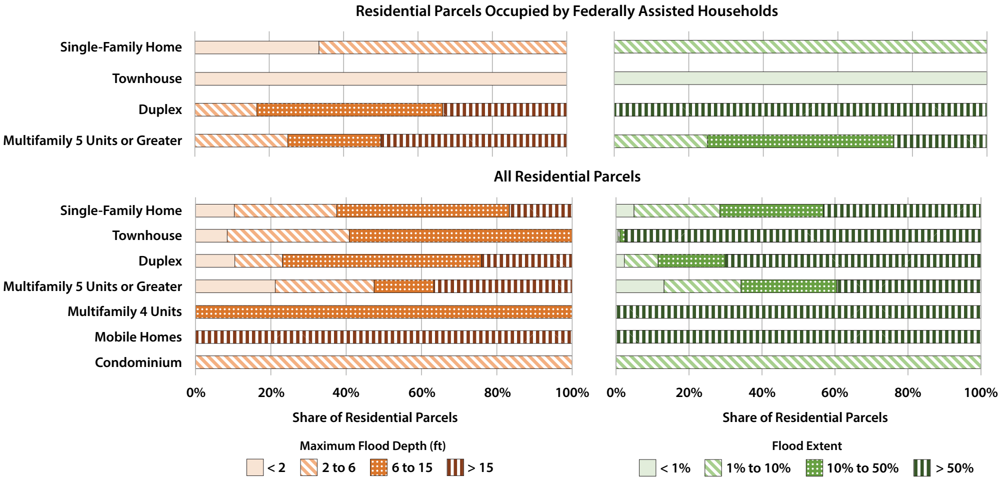
USGS FIM Maps

The study area contains 61 percent of the residential parcels in KCMO, and 8.4 percent of residential parcels in the study area are occupied by federally assisted households. Approximately 0.9 percent of the residential parcels in the study area have some overlap with USGS flood inundation maps for the Blue River. This share is lower for parcels occupied by federally assisted households (0.2 percent).

Federally assisted households in 14 residential parcels are predicted to be affected by flooding from the Lower Blue River. Those parcels are occupied by 38 households receiving federal rental assistance. As with the presented analysis of FEMA flood risk data, using FIM flood maps reveals flood impacts across single-family, multifamily, and mobile homes. In addition, FIM data facilitated an estimation of the expected flood depth and extent for affected parcels (exhibit 5). For all residential parcels, including those occupied by households receiving federal rental assistance, the predicted maximum flood depth is lower for single-family homes and townhomes than duplexes, multifamily homes, and mobile homes (exhibit 5). Single-family homes and townhomes occupied by federally assisted households within the predicted flood area of the Lower Blue River may be less affected by flooding than those not occupied by federally assisted households because the former are in regions with lower flood depths and have a smaller degree of overlap with expected flood areas (exhibit 5).

Exhibit 5

Expected Maximum Flood Depth and Flood Extent Affecting All Housing Units and Housing Units Occupied by Households Receiving Federal Rental Assistance that Overlap with U.S. Geological Survey Flood Inundation Mapping Maps, by Parcel Structure Type



Note: Lighter colors represent lower predicted flood depth and extent.

Sources: Authors' analysis of U.S. Geological Survey Flood Inundation Mapping flood models for the Lower Blue River; Kansas City, MO, city parcel data; HUD administrative data

Federal Rental Assistance Programs and Flood Exposure

Approximately 90 percent of the housing units in KCMO occupied by households receiving federal rental assistance are occupied by tenants participating in the tenant-based HCV program. Tenants participating in public housing (5.9 percent), project-based Section 8 (2.8 percent), project-based HCV (0.96 percent), and other multifamily programs (0.52 percent) occupy the remaining housing units linked to households receiving federal rental assistance.

Investigating flood risk relative to housing assistance program type revealed that only housing units occupied by tenants participating in the tenant-based HCV program were in census tracts with a relatively high flood risk rating (exhibit 6). However, housing units in census tracts with a relatively high flood risk rating represent a small share (0.5 percent) of overall housing units occupied by households participating in the tenant-based HCV program. Housing units occupied by households participating in the project-based HCV program had the largest share in census tracts with relatively moderate flood risk. Similar to the analysis of FEMA riverine flood risk ratings, only participants in the tenant-based HCV program were observed living in areas that are predicted to be affected by flooding from the Blue River (exhibit 7).

Exhibit 6

Share of Housing Units Occupied by Federally Assisted Households in the Lower Blue River Study Area, by Census Tract FEMA Riverine Flood Risk Rating and Federal Rental Assistance Program Type

FEMA Riverine Flood Risk Rating	Residential Parcels Occupied by Federally Assisted Households (%)	All Housing Choice Vouchers (%)	Tenant-Based Vouchers (%)	Project-Based Vouchers (%)	Project-Based Section 8 (%)	Public Housing (%)	Other Multifamily (%)
No Rating	51.1	51.8	51.9	37.5	61.4	34.7	53.8
Very Low	5.3	5.4	5.4	0.0	0.0	6.1	7.7
Relatively Low	29.3	28.5	28.4	37.5	15.7	49.0	23.1
Relatively Moderate	13.9	13.8	13.7	25.0	22.9	10.2	15.4
Relatively High	0.5	0.5	0.5	0.0	0.0	0.0	0.0

FEMA = Federal Emergency Management Agency.

Sources: Authors' analysis of FEMA Riverine Flood Risk maps; Kansas City, MO, city parcel data; HUD administrative data

Exhibit 7

Share of Housing Units Occupied by Federally Assisted Households in the Lower Blue River Study Area that Fall Within and Outside the Flood Area Predicted in U.S. Geological Survey Flood Inundation Mapping Maps, by Rental Assistance Program Type

USGS Flood Inundation Map Area	Residential Parcels Occupied by Federally Assisted Households (%)	All Housing Choice Vouchers (%)	Tenant-Based Vouchers (%)	Project-Based Vouchers (%)	Project-Based Section 8 (%)	Public Housing (%)	Other Multifamily (%)
In Flood Area	0.6	0.6	0.6	0.0	0.0	0.0	0.0
Outside Flood Area	99.4	99.4	99.4	100.0	100.0	100.0	100.0

USGS = U.S. Geological Survey.

Sources: Authors' analysis of USGS Flood Inundation Mapping flood models for the Lower Blue River; Kansas City, MO, city parcel data; HUD administrative data

Overall, the authors' analysis found a higher share of housing units occupied by tenants participating in the tenant-based HCV (85.8 percent) program located in census tracts with Relatively Low, Very Low, and No Rating classifications for flood risk than both project-based HCV (75.0 percent) and project-based Section 8 (77.1 percent) program participants. This finding suggests that in KCMO, the tenant-based voucher program may provide opportunities for many recipients to live in areas of lower environmental risk and that project-based programs may concentrate recipients in areas of greater risk. However, the small share of housing units occupied by tenant-based HCV program participants living in census tracts identified as having a relatively high flood risk and areas overlapping with the predicted flood zone of the Lower Blue River suggests that opportunities exist to provide housing counseling to tenant-based voucher recipients during their search for housing to prevent them from renting housing units in high-risk flood areas, where they may be displaced.

Comparison of FEMA and USGS Flood Data

Twelve residential parcels were identified as occupied by households receiving federal rental assistance located in census tracts with a relatively high flood risk rating and 14 were identified in areas predicted to be affected by flooding from the Lower Blue River in USGS FIM maps. The authors expected a high degree of overlap between residential parcels in census tracts with a relatively high FEMA flood risk and areas that are predicted to be affected by flooding in USGS FIM models; however, only one parcel occupied by a household receiving federal rental assistance was found in a census tract with relatively high flood risk that overlapped a USGS predicted flood area. Of the remaining residential parcels, seven were in census tracts with relatively moderate flood risk and six with relatively low flood risk.

The lack of overlap between flood data sources is likely due to the different methods used to produce FEMA and USGS flood maps. FEMA risk ratings are calculated at the census-tract level on the basis of floodplain boundaries and historic storm and flood events. FEMA ratings represent a relative flood risk based on national ratings (Zuzak et al., 2023). Unlike the FEMA flood maps, the USGS FIM maps do not indicate the relative risk of inundation but only a detailed model of the extent and depth of inundation for a given flood stage. USGS flood inundation maps are developed using a variety of local data sources, including streamgage data, one-dimensional HEC-RAS hydraulic models, and topographic and bathymetric data collected along cross sections in the study reach. Thus, FEMA maps represent a relative measure of flood risk while USGS maps provide a model of expected local flood depth and extent. A combined analysis of these data sources identified 25 residential parcels occupied by federally assisted households within the study area at high risk of flooding. Although predicted risk does not guarantee flood exposure, the expected flood impacts on those housing units can be further explored through outreach and ground truthing.

The study area in this analysis was limited to the region in KCMO with available USGS FIM data containing the Lower Blue River and its tributaries (exhibit 1). The study area contains the majority of all residential parcels (60 percent) and the majority of residential parcels occupied by federally assisted households (75 percent) in KCMO. However, residential parcels located outside the study area may also be at risk of flooding: 2,077 additional residential parcels and 16 additional residential parcels occupied by households receiving federal rental assistance are located in census tracts with a Relatively High FEMA Riverine Flood Risk Rating outside the study area.

Conclusions

The USGS FIM Program provides a unique opportunity to help communities visualize potential areas at risk for flooding near local streams and rivers. Unlike FEMA flood risk maps, USGS FIM maps allow researchers to investigate local flooding processes, such as the predicted extent and depth of housing-unit flood exposure. To demonstrate the utility of USGS data for housing research, this paper presented a case study using these data to investigate the impact of flooding on housing units in KCMO, where households receiving federal rental assistance live. Integrating HUD administrative data with FEMA and USGS maps facilitated the identification of 25 housing units occupied by federally assisted households at high risk of flood exposure. This case study demonstrates how USGS and FEMA data can inform housing analyses at different scales for researchers and practitioners interested in flood impacts on local communities and vulnerable populations.

Both USGS and FEMA flooding data sources have limitations. USGS FIM maps are confined to certain stream reaches with USGS streamgages, making a national analysis impossible using these data. However, at the local level, USGS FIM maps allow researchers to identify the expected flood extent and depth for affected households. USGS FIM map libraries are available for 155 sites in 27 states. The presented analysis for KCMO can serve as a blueprint for studies replicated at other sites with available USGS FIM data. Although FEMA riverine flood risk maps are national in scope, the census tract flood risk measures are relative to national indicators of flood risk. Using multiple flooding data sources in a local analysis can help overcome gaps in data and provide information for affected households at multiple scales. For instance, multiscale flood vulnerability studies have identified that finer spatial scales (e.g., the census block versus the census tract) allow researchers to identify vulnerable communities overlooked at larger spatial scales (Remo, Pinter, and Mahgoub, 2016; Tanir et al., 2021). The presented analysis demonstrates this assertion at the parcel level. Six housing units occupied by federally assisted households at high risk of flooding from the Blue

River were identified on the basis of USGS FIM maps but located in census tracts with a relatively low FEMA flood risk.

This case study demonstrates the potential of using flood maps and parcel-level analysis to identify structures where households receiving federal rental assistance live in regions of high flood inundation and risk. Unlike census-tract-level analysis based on FEMA flood risk maps, combining parcel data and USGS FIM flood maps can give a more detailed picture of where the greatest damage from flooding may occur. However, both approaches can underestimate the impact of flooding in urban areas, where impervious surfaces and the capacity of stormwater systems can lead to flooding beyond floodplains. Recent calls point to limitations of existing flood maps and advocate for new analyses and maps to incorporate urban components that influence flooding (National Academies of Science, Engineering, and Medicine, 2019). Future research could draw on data sources and flood models that incorporate infrastructural elements to better describe the movement of water in urban landscapes. Future studies can also draw on the demographic variables present in HUD administrative data to understand who will be affected by flooding in addition to the impacts of flooding on structures where federally assisted households live.

Appendix: R Code for Analysis

```
#2023 Analysis for KC HUD - USGS Case
#for data cleaning
library(tidyverse)
#for working with spatial data
library(sf)
library(mapview) #interactive map viewer
library(tigris) #Census Tiger line shape files
#packages for raster data analysis
library(raster)
library(stars)
library(nngeo)
sf_use_s2(FALSE) # setting to prevent invalid loop error for st_join

#Data Setup
#Data Files
#HUD household - level data - internal to HUD
MOHUD_2022_new <- read_csv(“Path to Household level lat lon data”)
KCHUD_2022_sf <- MOHUD_2022_new %>%
        filter(!is.na(UNIT_LAT_DEG_MSRE)) %>%
        filter(UNIT_CITY_NAME == “Kansas City”) %>%
        st_as_sf(., coords=c(“UNIT_LGT_DEG_MSRE”,”UNIT_LAT_DEG_MSRE”), crs=4326) %>%
        filter(UNIT_LVL_CD == “R”)

#FEMA National Risk Index for KC
NRI_KC <- st_read(“NRI_KC.shp”) #National census tract level file downloaded from
https://hazards.fema.gov/nri/data-resources#shpDownload
```

```
#Kansas Parcels
Parcels <- st_read(“geo_export_a877e9f6-455d-48c1-b296-db1ee89e1444.shp”) #Downloaded
from https://data.kcmo.org/dataset/Parcels/vuy6-s5is
LandCodes <- read.csv(“Land_Use_Codes.csv”) #Downloaded from https://data.kcmo.org/
Construction/Land-Use-Codes/83fx-3sa2

Parcels <- Parcels %>%
        left_join(., LandCodes, by =c(“landusecod” = “Code”))

#Clip NRI data to KC and write out data file
NRI <- st_read(“ShapeFiles/NRI_Shapefile_CensusTracts/NRI_Shapefile_CensusTracts.shp”)
KC <- st_read(“ShapeFiles/KC_Boundary/KC_Boundary.shp”)
NRI <- st_transform(NRI, st_crs(KC))
NRI_KC <- st_intersection(st_make_valid(NRI), KC)
st_write(NRI_KC, “ShapeFiles/NRI_KC.shp”)

#Reproject to USGS Flood Grid CRS
grids <- c(“BlueR_12thStreet(06893590)_depth_grids/27”, #1
    “BlueR_17thStreet(06893588)_depth_grids/26.flt”, #2
    “BlueR_63rdStreet(06893530)_depth_grids/63rd_19.flt”, #3
    “BlueR_BlueRidge(06893150)_depth_grids/26.flt”, #4
    “BlueR_COave(06893553)_depth_grids/25.flt”, #5
    “BlueR_Highway71(06893510)_depth_grids/hwy71mo_23.flt”, #6
    “BlueR_KansasCity(BannisterRd_06893500)_depth_grids/28.flt”, #7
    “BlueR_KennethRd(06893100)_depth_grids/moken_26.flt”, #8
    “BlueR_RedBridge(06893195)_depth_grids/29.flt”, #9
    “BlueR_StadiumDr(06893578)_depth_grids/mostad_28.flt”, #10
    “BlueR_Stanley(06893080)_depth_grids/mostan_21.flt”, #11
    “BrushCk_RockhillRd(06893562)_depth_grids/rockmo_22.flt”, #12
    “BrushCk_Wardpkwy(06893557)_depth_grids/14/”, #13
    “IndianCk_103rdStreet(06893400)_depth_grids/mo103rd_16.flt”, #14
    “MORiver_Backwater(06893000)_depth_grids/morvrback_22.flt”) #15

gridx <- read_stars(grids[15])
projection <- st_crs(gridx)
NRI_KC_Flood <- st_transform(NRI_KC, projection)

Parcels <- st_transform(Parcels, projection)
KCHUD_2022_sf <- st_transform(KCHUD_2022_sf, projection)

#Link HUD household data to Parcels (objectid) and NRI census track riverine flood risk index
(RFLD_RISKR)

#Point in Polygon for KCMO parcel data
HUD_Parcels <- st_join(st_make_valid(KCHUD_2022_sf), Parcels, join = st_intersects)
```

```
HUD_Parcels_count <- count(as_tibble(HUD_Parcels), objectid)
Parcels_HUD_sf <- left_join(Parcels, HUD_Parcels_count, by = “objectid”) %>%
        rename(HUD_HH = n)

Parcels_HUD_sf <- HUD_Parcels %>%
left_join(Parcels_HUD_sf, ., by = “objectid”)

#Point in Polygon for NRI flood data
Parcels_NRI <- st_join(st_centroid(Parcels_HUD_sf), NRI_KC_Flood, join = st_within)

#Filter residential land use codes
Parcels_NRI <- Parcels_NRI %>%
        st_drop_geometry() %>%
        filter(landusecod %in% c(1111, 1112, 1121, 1122, 1123, 1124, 1125, 1126))

#Define Study Area
studyArea <- data.frame(lon = c(-94.60825698480055, -94.4743909204287), lat =
c(38.84500509860179, 39.129928)) %>%
        st_as_sf(coords = c(“lon”, “lat”), crs = 4326) %>%
        st_bbox() %>%
        st_as_sfc()

studyArea <- st_transform(studyArea, projection)

#Clip Parcels to Study Area
myParcels <- Parcels[st_make_valid(studyArea), ] %>% dplyr::select(objectid, geometry)
Parcels_SA <- Parcels_NRI[st_make_valid(studyArea), ]

Parcels_SA_sf <- Parcels_SA %>%
        st_drop_geometry() %>%
        left_join(., myParcels, by = “objectid”) %>%
        st_as_sf()

# Link Parcel data to USGS flood grids
##Area is in feet2 in both the parcel and flood files
#Function to calculate Flood area and depth
FloodStats <- function(grid, shape) {
        gridx <- read_stars(grid) %>%
                st_as_sf()
        mycol <- names(gridx)[1]
        shape <- st_transform(shape, st_crs(gridx))
        Parcelsx <- shape %>%
                st_join(., gridx) %>%
                drop_na(objectid) %>%
                st_drop_geometry() %>%
                group_by(objectid) %>%
```

```
        summarise(MaxDeapth = max(!!as.name(mycol)), Count = n()) %>%
        mutate(Area = ifelse(!is.na(MaxDeapth), Count * st_area(gridx[1,]), NA))

}

#Read in raster grids and calculate flood area and depth for parcels
SummaryStats1 <- FloodStats(grids[1], Parcels_SA_sf)
SummaryStats2 <- FloodStats(grids[2], Parcels_SA_sf)
SummaryStats3 <- FloodStats(grids[3], Parcels_SA_sf)
SummaryStats4 <- FloodStats(grids[4], Parcels_SA_sf)
SummaryStats5 <- FloodStats(grids[5], Parcels_SA_sf)
SummaryStats6 <- FloodStats(grids[6], Parcels_SA_sf)
SummaryStats7 <- FloodStats(grids[7], Parcels_SA_sf)
SummaryStats8 <- FloodStats(grids[8], Parcels_SA_sf)
SummaryStats9 <- FloodStats(grids[9], Parcels_SA_sf)
SummaryStats10 <- FloodStats(grids[10], Parcels_SA_sf)
SummaryStats11 <- FloodStats(grids[11], Parcels_SA_sf)
SummaryStats12 <- FloodStats(grids[12], Parcels_SA_sf)
SummaryStats13 <- FloodStats(grids[13], Parcels_SA_sf)
SummaryStats14 <- FloodStats(grids[14], Parcels_SA_sf)
SummaryStats15 <- FloodStats(grids[15], Parcels_SA_sf)

#Join Flood Parcel data frames
KCParcelFloodStats <- rbind(SummaryStats1[!is.na(SummaryStats1$MaxDeapth),],
    SummaryStats2[!is.na(SummaryStats2$MaxDeapth),],
    SummaryStats3[!is.na(SummaryStats3$MaxDeapth),],
    SummaryStats4[!is.na(SummaryStats4$MaxDeapth),],
    SummaryStats5[!is.na(SummaryStats5$MaxDeapth),],
    SummaryStats6[!is.na(SummaryStats6$MaxDeapth),],
    SummaryStats7[!is.na(SummaryStats7$MaxDeapth),],
    SummaryStats8[!is.na(SummaryStats8$MaxDeapth),],
    SummaryStats9[!is.na(SummaryStats9$MaxDeapth),],
    SummaryStats10[!is.na(SummaryStats10$MaxDeapth),],
    SummaryStats11[!is.na(SummaryStats11$MaxDeapth),],
    SummaryStats12[!is.na(SummaryStats12$MaxDeapth),],
    SummaryStats13[!is.na(SummaryStats13$MaxDeapth),],
    SummaryStats14[!is.na(SummaryStats14$MaxDeapth),],
    SummaryStats15[!is.na(SummaryStats15$MaxDeapth),])

#Only keep max flood depth for each parcel
KCParcelFloodStats_noDUP <- KCParcelFloodStats %>%
    group_by(objectid) %>%
    slice(which.max(MaxDeapth))

#Join HUD parcels with flood data
```

```
HUD_Parcels_Flood <- Parcels_SA_sf %>%
        left_join(., st_drop_geometry(KCParcelFloodStats_noDUP), by = “objectid”) %>%
        filter(landusecod %in% c(1111, 1112, 1121, 1122, 1123, 1124, 1125, 1126))

#Assign Area and depth categories
#0-2 ft, 2-6 ft, 6-15 ft, 15+ ft
HUD_Parcels_Flood <- HUD_Parcels_Flood %>%
        mutate(DepthGroup = case_when(MaxDeapth < 2 ~ “< 2”,
                MaxDeapth >= 2 & MaxDeapth < 6 ~ “2 - 6”,
                        MaxDeapth >= 6 & MaxDeapth < 15 ~ “6 - 15”,
                        MaxDeapth >= 15 ~ “>15”),
                AreaGroup = case_when(100*area/ShapeArea < 1 ~ “< 1”,
                        100*area/ShapeArea >= 1 & 100*area/ShapeArea < 10 ~ “1 - 10”,
                        100*area/ShapeArea >= 10 & 100*area/ShapeArea < 50 ~ “10 - 50”,
                        100*area/ShapeArea >= 50 ~ “> 50”))
```

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