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Disappeared Streams and Flood Risk in Atlanta, Georgia, Baltimore, Maryland, Phoenix, Arizona, and Portland, Oregon

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Disappeared Streams and Flood Risk in Atlanta, Georgia, Baltimore, Maryland, Phoenix, Arizona, and Portland, Oregon

by

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Abstract

Many urban streams have been moved, culverted, buried, or "disappeared" as urban infrastructure was constructed. This loss of natural streams provided land for urban development, but as climate change increases the frequency and severity of extreme weather events, these disappeared stream areas could threaten homes and other infrastructure with increased flood risk. This study developed spatial data layers to identify many of these lost streams for Atlanta, Georgia, Baltimore, Maryland, and Phoenix Arizona, using historical maps to find streams previously visible that disappeared by the present day. This process used the oldest available georeferenced maps from the United States Geological Survey and georeferenced scanned maps to better identify disappeared streams in downtown areas. A previously developed dataset of disappeared streams for Portland, Oregon, was also used as part of this study. To understand if these disappeared stream areas have a higher flood risk, data from the First Street Foundation that predicts flood risk at the parcel level was compared to disappeared stream locations. The comparison found higher flood risk in the 100m buffer compared to areas farther away than 100m for all of the study areas. Current land cover (2019) was evaluated around these disappeared streams, which found high levels of impervious area around these areas. It is also important to understand if disappeared stream locations are related to the value of housing, thus a hedonic analysis of house sale price in Portland, OR that included spatial variables representing disappeared stream locations was conducted. This analysis found that including a disappeared stream variable reduces the effect of proximity to existing streams on house sale price. This is the

first study to explore if the proximity to disappeared streams affects house sale price.

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Chapter 1. Introduction

Disappeared streams are streams that have been moved, removed, buried, or culverted during urban infrastructure construction. This removal or alteration of streams in urban environments is also known as buried or lost streams. These urban streams have often been removed to build businesses and homes and limit flooding, with many urban areas showing fewer streams than undeveloped areas (Steele et al., 2014). Urban streams provide critical ecosystem services and can limit water born nutrient pollution (Beaulieu et al., 2015), increase biodiversity in and around the streams (Meyer et al., 2007), and provide aesthetic values to people that live around or visit urban streams (Kenney et al., 2012).

Mapping these altered or removed streams over time can be used to understand both the levels of stream removal and the potential for future remediation (Napieralski et al., 2016). Post et al. (2022) mapped urban streams in Portland, Oregon, between 1852 and 2017 and found that stream disappearance was associated with residential development and agricultural land conversion. Itsukushima et al. (2021) traced and evaluated the buried streams in six river basins within the Tokyo Metropolitan area using 40 historical maps from 1909 to 2020 and found high levels of stream burial in central Tokyo that occurred before

1945, and that stream burial can be attributed to historical events (e.g., earthquakes, war reconstruction, flood control projects) in addition to urbanization.

Burying streams can potentially increase pluvial flood risk during large rain events because stormwater is likely to accumulate in low-lying areas (Rosenzweig et al., 2018). Streams were sometimes piped and buried to reduce flood risk by transferring the water away from homes, but these buried streams and stormwater systems may not be able to convey larger storm events expected under climate change scenarios (Zhou et al., 2019). Stormwater infrastructure often serve as components of a drainage basin in the place of streams in urban environments (Kaushal and Belt, 2012). There is an unanswered question if these disappeared stream locations have a higher current flood risk. Burying streams greatly alter the hydrologic characteristics of streams (Hintz et al., 2022). Forgrave et al. (2022) studied the hydrological characteristics by evaluating precipitation and storm discharge data from the Nine Mile Run Watershed in Eastern Pittsburgh, where a high proportion of streams are buried. They found that having a higher number of buried streams reduces the water retention ability of the network and leads to quicker, more flashy storm flows. Furthermore, there was a faster hydrologic response compared to urban areas with similar levels of imperviousness because of the high proportion (98%) of piped streams that could lead to flooding as storm intensity is predicted to increase with climate change (Forgrave et al., 2022).

Multiple studies have explored the impact of flooding on house sale prices (Chongwilaikasaem et al., 2022; Wu et al., 2021; Zhang 2016). The hedonic price method is one method used to assess the value of different environmental amenities (Taylor 2003). A recent study by Bui et al. (2022) found that a large flooding event caused a 9% reduction in house sale price in Ho Chi Minh City, Vietnam. A study in the United Kingdom that used a hedonic model, found that areas with flooding could impact house sale price by as much as 50% (Thompson et al., 2022). While multiple hedonic studies have explored proximity to existing water bodies like rivers and the ocean (e.g., Wen et al., 2017; van Dijk et al., 2016), as well as proximity to restored streams (e.g., Jarrad et al., 2018), there has not been a hedonic study exploring that has included a proximity to disappeared stream variable. My hypothesis is that not including a disappeared stream variable the effect of the proximity to existing streams on house sale price is overestimated because of omitted variable bias when not including the potential for heightened flood risk near disappeared streams.

A recent study was able to differentiate between the positive impacts of the benefits of living near a river and the negative impacts of flood loss from the river (Wu et al., 2021). In the case of disappeared streams, the proximity to disappeared streams does not have the same benefits because people cannot see the disappeared streams in most cases and do not have access to them compared to existing streams. Some culverted streams that have “disappeared” can remain visible but are not expected to serve as an amenity.

This study will address the following research questions:

1) Where are the disappeared streams located in Portland, OR, Baltimore, MD, Atlanta, GA, and Phoenix, AZ?

2) What are the near present-day land cover characteristics in the area around the disappeared streams in these cities?

3) Do the areas around disappeared streams have higher flood risk than those distant away from disappeared streams?

4) How does including a proximity to disappeared stream variable impact the effect of proximity to existing streams on house sale price in a hedonic model in Portland, Oregon?

Chapter 2. Study Areas

The study area consists of the areas within the city boundaries of Atlanta, Georgia, Baltimore, Maryland, Phoenix, and Portland, Oregon (Fig. 1). These cities represent a range of hydrologic and geographic characteristics, population densities, and urban development histories (Chang et al., 2021; Table 1). Portland, Oregon, is located in the Pacific Northwest region of the United States (U.S.) and receives a high amount of rainfall during winter and spring (915 mm mean annual precipitation). Winter precipitation intensity in Portland is expected to increase due to climate change (Cooley and Chang, 2021). To address increased flood risk and to better manage storm water and combined sewer overflows, Portland has installed green infrastructure since 1951, with widescale implementation of vegetation swales and infiltration areas in the 2000's (McPhillips, L.E. and Matsler, A.M., 2018). Phoenix, Arizona, is located in the Southwest U.S. and has a subtropical desert climate with a much lower precipitation level (211 mm mean annual precipitation). However, extreme precipitation events in this area are projected to increase by 2090 to 2099 (Georgescu et al., 2021), and there have been a number of recent extreme precipitation and pluvial flooding events in 2014 and 2016 (Rosenzweig et al., 2018). Atlanta, Georgia, is located in the Southeast region of the U.S. and has a hot and humid climate and has a 1263 mm mean annual precipitation. Flooding is expected to increase in Atlanta (Wobus et al., 2019), and the city has been implementing green infrastructure to combat climate change (Pallathadka et al., 2022). Baltimore, Maryland, is located in the Northeast region of the U.S is the oldest of all the cities in the study and has 1034 mm of mean annual precipitation. According to the 2008 Comprehensive Assessment of Climate Change Impacts in Maryland, Precipitation during the Winter months is projected to increase by 5, 6.6 to 6.8, and 10.4 to 12.6 percent by 2025, 2050, and 2090 respectively (Boesch, 2008).

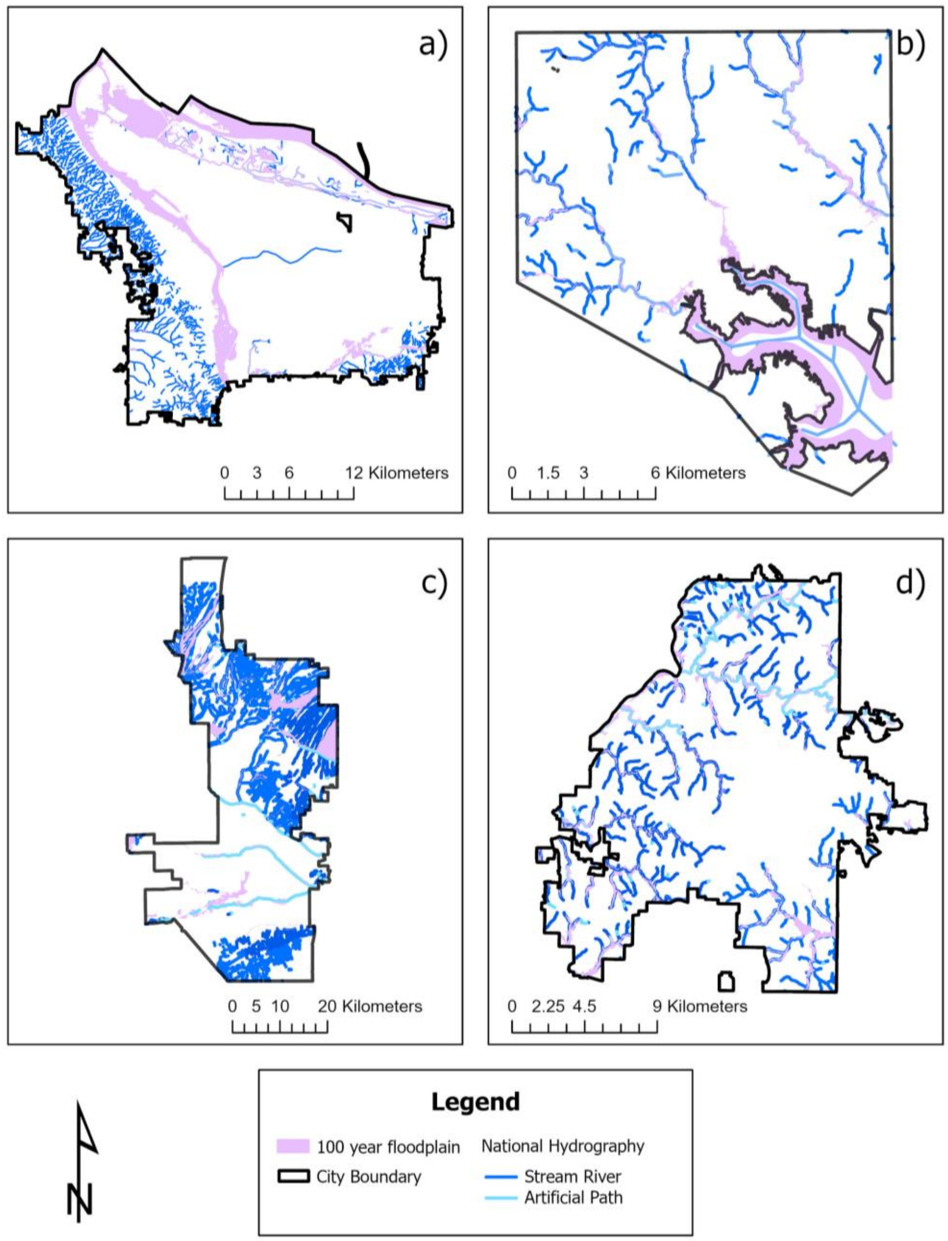

Figure 1: Study Area Map of the United States featuring the four cities comprising the study area showing existing streams, artificial paths from the National Hydrography Dataset (U.S. Geological Survey, 2017), and the 100 year flood plain: a) Portland Oregon, b) Baltimore Maryland, c) Phoenix, Arizona, and d) Atlanta Georgia.

Table 1: Selected Climate Characteristics, Population, and Area

Characteristic	Portland, OR	Phoenix, AZ	Baltimore, MD	Atlanta, GA
Mean Annual Temperature (°C) 1991 – 2020	12.83	24.22	13.44	17.56
Average Annual Precipitation (mm) 1991 – 2020	937.51	183.39	1143.00	1280.92
Population (2021)	647,176	1,591,119	592,211	492,204
Area (km^2)	375	1339	239	353

Chapter 3. Data

3.1 Flood Risk Estimates

First Street Foundation (FSF) publishes property-level flood risk estimates for the continental United States (Cooper et al., 2022). These include high-resolution flood risk estimates for historical, current, and future risks, where the future risk includes the projected impact of global climate change by 2050 (Cooper et al., 2022; First Street Foundation, 2020). Flooding estimates are created using the Fathom flood modeling framework (First Street Foundation, 2020; Wing et al., 2019), which includes a model builder and a hydrodynamic model (LISFLOOD-FP), to estimate flooding risk (Bates et al., 2010; Neal et al., 2012). The overall modeling approach uses regional flood frequency analysis (First Street Foundation, 2020; Sampson et al., 2015; Smith et al., 2015) that estimates river discharge by grouping catchments that have similar climate, area, and rainfall (Wing et al., 2017) so that gauged catchments can be used to estimate extreme river flow events in ungauged catchments (First Street Foundation, 2020; Sampson et al., 2015). The FSF has created a risk factor score that ranges from one to ten, which conveys the combination of the probability and level of flooding, where a score of 1 has minimal risk and depth of potential flooding, and a score of 10 has an extreme risk of high flooding depth over a 30 year time horizon (First Street Foundation, 2020).

3.2 Disappeared Streams in Portland, Phoenix, Atlanta, and Baltimore

Disappeared streams were previously digitized for Portland, Oregon using multiple United States Geological Survey maps and one historic scanned map that ranged in age from 1852 to 2017 (Post et al., 2022). The majority of the disappeared streams that were mapped (65%) did not appear on maps from 1953 when they were present in maps from 1896 and had likely been removed. There was a continued loss of streams between 1953 and 1989 (12%), and even in recent times, with 8% being removed between 1990 and 2017 (Post et al., 2022). For the purposes of this study, the spatial layers representing stream loss over time were merged into a single disappeared stream dataset.

There has been no formal research effort to identify and map disappeared streams that were covered up by urban development in the Atlanta, GA, downtown area.. An art project in Atlanta by Rachel Parish, "Emergence," identified the locations of the springs using monuments that identify the source of Proctor, Tanyard, Clear, and Intrenchment creeks, that start as buried streams and flow from the downtown area (Palmer, 2023). Proctor Creek, which starts under downtown Atlanta and flows to the Chattahoochee River, has been targeted for green infrastructure development using an Environmental Impact Bond (City of Atlanta Department of Watershed Management, 2023). Much of the headwater of the Flint River is buried in Atlanta, GA, which has resulted in reduced flows and drought conditions for the River (Muller, 2021). There is an ongoing project, "Finding the Flint" by the Conservation Fund, American Rivers, and the Atlanta Regional Commission to identify and restore headwater areas of the Flint River (Chambers, 2018).

In Baltimore City, a study combining DEM-based flow paths and remote sensing analysis found that approximately 66% of streams had been buried in catchment areas ranging from .1 to 100 km^2 (Elmore and Kaushal, 2008). A separate study concluded that 70% of streams associated with less than a 2.6 km^2 drainage area were buried in Baltimore City (O'Connor, 1999). Data from these previous studies are not available and were not used as part of this study.

Rivers in Phoenix have long been altered by humankind. The Hohokam started building canals in the area in the first century A.D., with the majority of the construction occurring between the 6th to the 15th century A.D. (Purdue, 2014). These canals transformed the landscape around Phoenix to support irrigated agriculture, allowing the Hohokam to survive in this challenging environment (Purdue, 2014). Interestingly, the Hohokam “collapse” and depopulation may be linked to extreme flood events that rendered portions of the canals unusable (Huckleberry et al., 2018). With the arrival of European settlers, a number of canals were added (some in the original Hohokam canal areas), and many of the natural streams now only flow seasonally or during flood events because of all the water diversion to canal systems (Marsh and Minckley, 1982).

3.3 High-Resolution Land Cover

One-meter land cover datasets was acquired for all of the study area cities. High resolution, 1m, US EPA EnviroAtlas land cover data was acquired for Portland, Oregon, Phoenix, Arizona, and Baltimore, Maryland (Pilant et al., 2020). For Atlanta, Georgia, 1m land cover data was downloaded from the UrbanWatch dataset (Zhang et al., 2022). Although the resolution of all datasets was 1m, both the acquisition date and categories varied between the EPA and Urban Watch land cover data sources. Landcover was acquired at the following times: Portland, Oregon, was completed in 2012, Phoenix, Arizona 2010, Baltimore, Maryland, 2018, and Atlanta, Georgia, 2014-2017 (classified from images between those time periods). Because the land cover categories varied between the two data sources, a new harmonized land cover category set was developed, as noted in Table 2, where the first column is the new land cover categories, the second column has one or more of the EPA EnviroAtlas categories, and the third column details one or more land cover categories from the Urban Watch land cover dataset. The high-resolution land cover provides a way to evaluate the environment in and around the disappeared stream locations. While the one m^2 resolution land cover used in this study was from various dates, ranging from 2010 to 2018, it is assumed that there was relatively little land cover change in historically urbanized areas where these streams were removed. Land cover areas were converted to percent areas to evaluate the land cover within 100m of a disappeared stream and describe the overall proportions of each city.

Table 2: High-Resolution Land Cover

Code	Harmonized Land Cover Categories used in this analysis	EPA 1m Land Cover Aligned Categories (Portland, Phoenix, Baltimore)	Urban Watch Land Cover Aligned Categories (Atlanta)
0	Unclassified	Unclassified	NA
10	Water	Water	Water
20	Impervious Surface	Impervious Surface	Building, Road, Parking Lot, Others
30	Soil and Barren	Soil and Barren	Barren
40	Trees and Forest	Trees and Forest, Woody Wetlands	Tree Canopy
70	Grass and Shrub	Shrubs, Grass & Herbaceous, Emergent	Grass/Shrub

		Wetlands	
80	Agriculture	Agriculture	Agriculture

3.4 House Price Data

Housing price data for Portland, OR, was obtained from the real estate brokerage company Redfin for house sales between 2018 and April, 2023 (Refin, 2023). Redfin compiles this data from local multiple listing services and also from their real estate agents, which are located throughout the United States (Redfin, 2023). Housing price data for Portland included addresses used to determine the location and the housing characteristics (from the multiple listing service data) used as part of this study.

Chapter 4. Methods

4.1 Georeferencing Scanned Maps

Scanned historical maps were obtained as raster images from internet sources (Table 3). In all cases, the scanned maps were not available with location information. Various scanned maps were considered for each location, and selection criteria focused on maps that showed both identifiable features and river networks at a relatively large scale. Although no scale information was present on the maps or in associated metadata, the scale of the maps appears to have ranged from approximately 1:18,000 to 1:27,000. Scanned images were georeferenced using the georeferencing tools in ArcGIS Pro version 3.1 (ESRI, 2022) by finding features visible in the scanned maps that were unchanged in modern features. In the case of Baltimore (from 1848) and Atlanta (1921), where the maps were primarily focused on downtown areas with visible road networks, the georeferencing process involved identifying road intersections, where the names and positions of the roads had not changed when compared to a modern vector road layer obtained from the U.S. Census, Tiger Lines geospatial data (US Census Bureau, 2021). Control point locations were manually placed in an evenly distributed manner, with a minimum of 75 control points being used for each map, each located at a road intersection. For both Atlanta and Baltimore, a single historical map was used to represent the downtown area, where it was challenging to identify streams in the historical USGS topographic maps.

A series of Maricopa County, Arizona Land Ownership Maps were georeferenced to represent the nearly pre-development condition of Phoenix, Arizona. This task was accomplished in a similar manner to the Atlanta and Baltimore maps, except, instead of roads, intersections of lines that are shown on these maps for location and boundary reference on the maps from the Public Land Survey System (PLSS) were used to locate control points and then georeference a series of land ownership maps. In each case, after control points were added, the estimated accuracy of each control point was evaluated using the ArcGIS georeferencing tools, control points with large errors were removed, and additional control points were added as necessary. Finally, affine and second-order polynomial transformations were evaluated by examining each transformation's estimated control point error. In most cases, the control point error was less than 50m and was in the range of 10-20 m. The map transformation with the best and most accurate result was finally visually examined to verify that the roads (or PLSS grids) lined up, and the georeferenced maps were exported in Tagged Image File Format (TIF).

The disappeared dataset for Portland, Oregon, was primarily created using a series of previously georeferenced USGS topographic maps, although the earliest map from 1852 was hand georeferenced in a manner similar to that used for Atlanta, Georgia, and Baltimore, Maryland. This map may have larger spatial errors because the scale was not consistent across the map (Post et al., 2022).

Table 3: Source of Georeferenced Maps

City	Year	Scale	Description	Link
Baltimore, Maryland	1848	1:24,000 (estimate)	Street map published by W. Williams (New York, NY)	https://jscholarship.library.jhu.edu/handle/1774.2/33257
Atlanta, Georgia	1921	1:18,000	Map of the City of Atlanta and Suburbs, published by Brownell Photo-Lithograph Company (Philadelphia, Pa.)	https://digitalcollections.library.gsu.edu/digital/collection/afpl/id/17/rec/35
Phoenix, Arizona	1903-1911	1:27,000	Maricopa County Land Ownership Maps	https://azmemory.azlibrary.gov/nodes/view/301

4.2 Digitizing Disappeared Streams

The disappeared stream digitization process was designed to use a series of available spatial datasets to visually confirm that a stream shown on a historical map (either scanned and georeferenced as part of this study, or from an available historic USGS map, Table 4) is not present today. This method closely follows the techniques described in our previous study (Post et al., 2022) and is outlined in Figure 2. The georeferenced historic scanned maps were projected into a coordinate system (typically UTM, NAD 83) that matched the other spatial data used for evaluation. The only exception to this was when high-resolution aerial photography was only available as a map service. In this case, a visual comparison of the aerial imagery with other spatial data, mainly the data from the National Hydrography Dataset (NHD; USGS, 2017), was used to confirm there was no obvious spatial distortion. Streams visible on the historical maps were compared with the NHD layer, Digital Line Graph stream layers (when available), and high-resolution aerial photography to confirm that the stream is no longer visible. Present-day high-resolution aerial photography provides a visual confirmation that, when combined with the NHD stream layers, it is possible to identify a disappeared stream with a high degree of certainty. After identification, the stream was carefully traced from the historic maps using the line creation tools in ArcGIS Pro version 3.1 (ESRI, 2022). This process was completed for each of the cities in the study area, except, as mentioned, for Portland, Oregon, where the dataset was previously created (Post et al., 2022).

Table 4: Georeferenced USGS Topographic Maps Used in this Study

City	Year(s)	Scale	Notes
Baltimore, Maryland	1894	1:62,500	1890 survey, 1897 edition
Atlanta, Georgia	1888	1:125,000	1888 survey, 1955 edition
Phoenix, Arizona	1914 1954 1906 1915	1: 62,500 1:250,000 1:62,500 1:62,500	Phoenix - 1912 survey, 1946 edition Phoenix - 1953 photo, 1976 edition Camelback - 1904 survey, 1948 edition Mesa - 1913 survey, 1938 edition
Portland, Oregon See: (Post et al., 2022)	1905 1914 1954 1954 1954 1954	1:62,500 1:62,500 1:24,000 1:24,000 1:24,000 1:24,000	Portland- 1896 survey, 1948 edition Oregon City - 1912 survey, 1945 edition Portland - 1951 photo, 1956 edition Lake Oswego - 1952 photo, 1957 edition Mount Tabor - 1952 photo, 1956 edition Gladstone - 1952 photo, 1956 edition

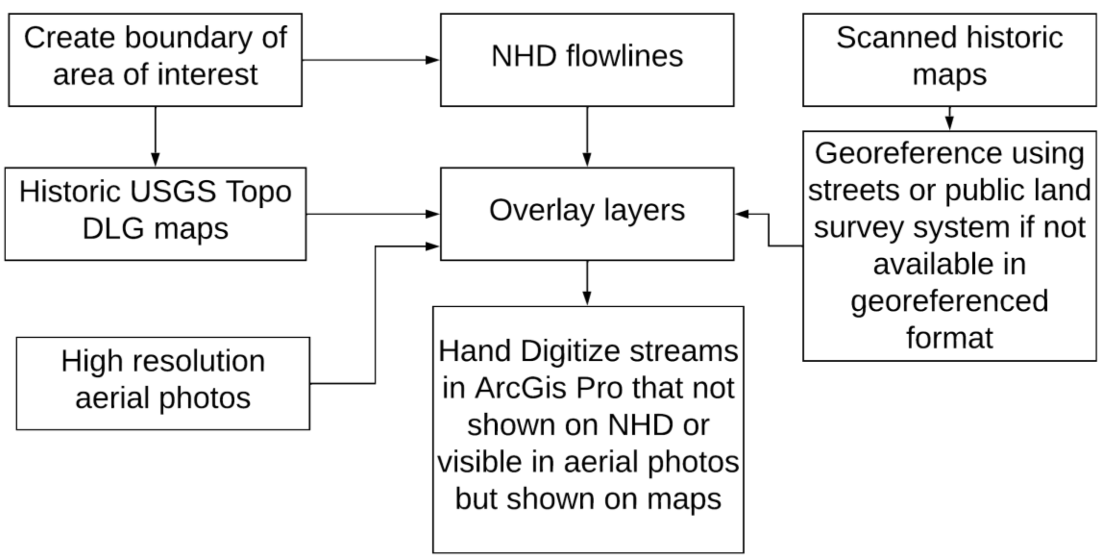

Figure 2: Process of identifying and digitizing disappeared streams

4.3 Disappeared Streams and Flood Risk

Flood risk, represented by the dwelling level First Street Foundation Flood factor score, was first assessed in a spatial buffer near disappeared streams (0m-100m) and compared to a buffer directly farther away (100m-200m) as well as with the proportion of flood risk in the rest of the city. We hypothesize that there is a statistically significant difference between the closest buffer compared to the two farther away buffers. A Kruskal-Wallis test was also conducted to identify if there is an increase in flood risk in these regions near (0-100m) disappeared streams. The null hypothesis is that the median flood risk within all three buffers is identical. We hypothesize that there is a higher median of flood risk scores within the closest buffer of disappeared streams.

Table 5: Kruskal Wallis test between 0-100m, 100-200m, and rest of properties in all four cities.

City	Kruskal-Wallis chi-squared	Degrees Freedom	p-value
Portland	2404.8	2	2.20E-16
Baltimore	12973	2	2.20E-16
Phoenix	286.21	2	2.20E-16
Atlanta	849.81	2	2.20E-16

4.4 Disappeared Streams and Hedonic Modeling

The hedonic price method (Rosen, 1974) is an estimation technique used to quantify consumers' preferences for a specific good's characteristics. For non-market evaluation, a buyer's value for a characteristic of differential good can be inferred by the purchase of that good, given all other characteristics are held constant. Many hedonic studies have explored the potential cost of different environmental variables, for example, tree cover (Netusil et al., 2010), dam removal and river restoration (Lewis et al., 2008), and improvement in water quality (Netusil et al., 2014; Kuwayama et al., 2022), because people's willingness to pay for an environmental attribute can be determined.

The Structure of the model is:

$$P = f(H, L, E),$$

Where P is the log of house sale price, H represents housing characteristics, L represents the distance to the central building district, and E represents environmental characteristics. The log of house sale price is used to evaluate the percent effect the independent variables have on house sale price.

A potential impact of having a higher flood risk around disappeared streams is impacting house sale price in these areas. To explore this, a hedonic model is formed to test if the distance to disappeared streams has an impact on house sale price. There are multiple variables that are useful for estimating house sale prices, such as the number of bathrooms in a house, building square feet, and lot size. All of these variables are useful for the hedonic model to fit with the new variables, distance to disappeared streams, distance to existing streams, flood factor score, and proportion of green cover. Daniel et al. (2009) found that not including flood risk and amenity variables in a hedonic analysis of proximity to water bodies causes bias when exploring the effect of flood risk on house sale price. Flood factor variables are included in this study to represent this flood risk.

In a hedonic model, willingness to pay is estimated by finding the set of characteristics that consumers are willing to buy a good and the minimum price a producer is willing to sell a good with those certain characteristics. The environmental variables used in this model are 1) a dummy variable if a house is within a 100 year floodplain, 2) flood factor score, 3) whether a building is within a 100-year floodplain, and 4) green cover percentage. Distance to the town hall was used as a proxy to distance to the central business district in both cities. Distance to the town hall was calculated using the near tool in ArcGIS Pro (ESRI, 2022) to find this distance on a per-parcel basis. The distance to disappeared streams and existing streams variables were also created using used near tool in

ArcGis Pro (ESRI, 2022) to calculate the distance in meters using the digitized disappeared streams and NHD PLUS hydrography dataset (U.S. Geological Survey, 2017) to represent known streams within the city boundaries. Many of these variables are spatial, which means spatial autocorrelation is possible. Two models that are often used to address spatial autocorrelation within data are the spatial lag model and the spatial error model. The spatial error model has an error term of $\epsilon_i = \lambda w_i \epsilon_i + u_i$. Lambda is the coefficient of a spatial error where if it equals 0, there is no spatial autocorrelation and i is location.

This dataset was then exported into R statistical analysis software version 4.2.3 (R Core Team, 2021) for harmonization and cleaning. All houses were filtered to Single Family Residential in Portland, OR, and Single Family. Any house that had null values was removed from the dataset. A total of 4235 houses were removed because of missing data. The final dataset, containing 30,172 prices of house sales was then exported to GeoDa software version 1.20.0.36 (Anselin et al., 2006) for spatial econometric analysis. Inverse distance weight was used because the greater the distance between houses the less spatial dependence. The inverse weight was created in Geoda using a specified bandwidth of approximately 703.87 meters for Portland, OR. Multiple spatial diagnosis tests were used to evaluate if the data is spatially autocorrelated, which included spatial lag and error models (Saputro, et al., 2019), and Moran's I test (Moran, 1950).

Chapter 5. Results and Discussion

5.1 Mapped Disappeared Streams

In Portland, disappeared streams are largely absent from much of the eastern portion of the city because of the flat relief, while the west hills with more varied topography have a higher density of disappeared streams (Figure 3). For Baltimore, Maryland, a scanned map from 1848 (Table 2; Figure 3) was used to identify streams in the downtown area, because the lost streams were not visible in the USGS topographic maps from 1894. Numerous disappeared streams were identified outside the downtown area. For Atlanta, Georgia, the best-scanned map that showed streams in the downtown area was from 1921 (Table 3; Figure 3). Interestingly, the USGS topographic map used to identify streams around the downtown area was from a much earlier time period (1888) but did not clearly show the streams in the downtown area. For Phoenix, Arizona, the land ownership maps from 1903-1911 (Table 2), clearly showed historic canals that were both buried and still exist in the present day, while a range of USGS topographic maps were used to find disappeared streams north and south of the main downtown area (Figure 6).

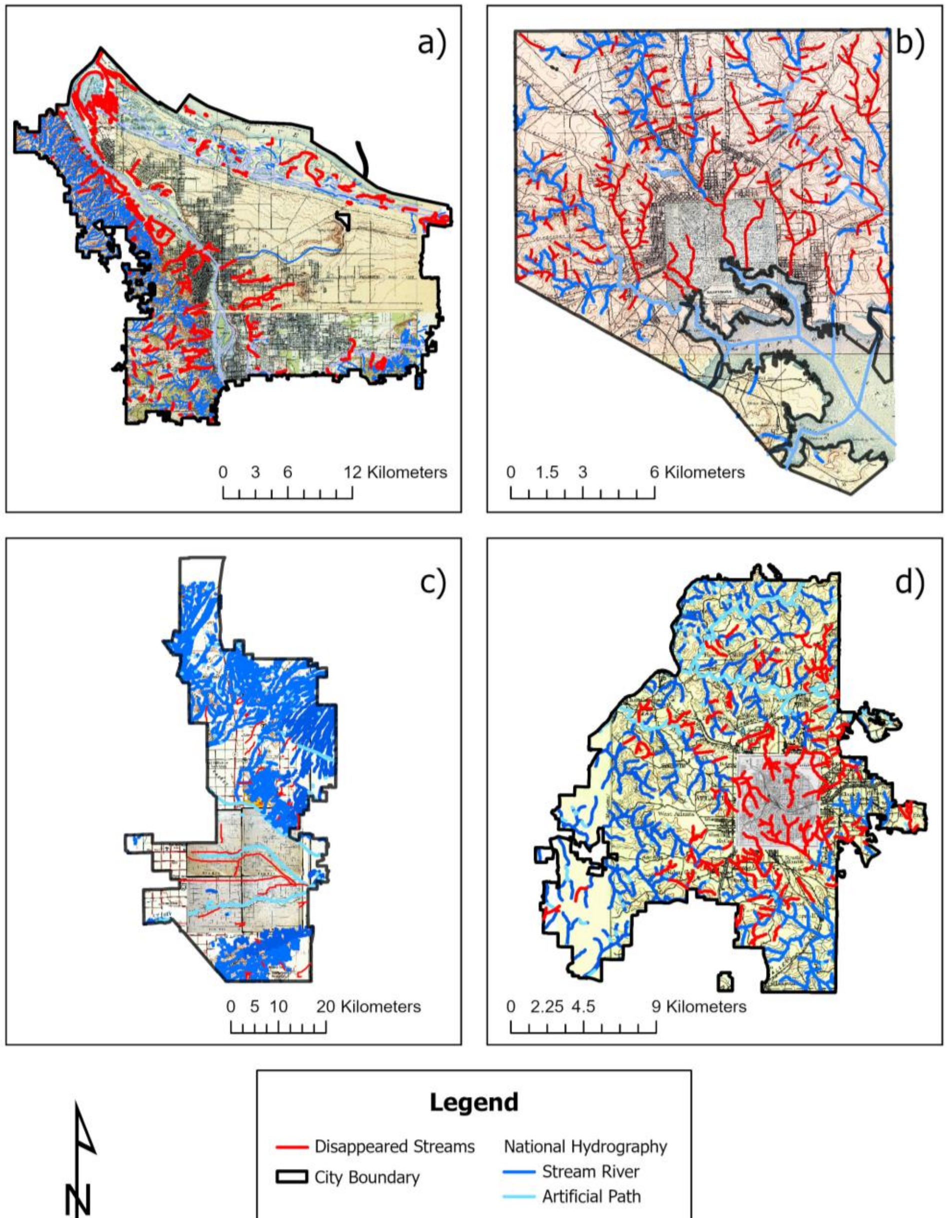

Figure 3: Identified disappeared streams in Portland, Oregon (a), Baltimore, Maryland (b), Phoenix, Arizona (c), and Atlanta, Georgia (d) showing historic map overlays for Baltimore, Phoenix, and Atlanta.

5.2 High-Resolution Land Cover of Areas Around Disappeared Streams

Analysis of high-resolution land cover maps helps understand the near present-day land cover in relation to disappeared streams in the context of the overall land cover in each metropolitan area (Table 6). In most cases, the proportion of impervious area around a disappeared stream was higher than the overall amount of impervious area within the study cities, except in Portland, OR, where there was a slightly higher impervious area in the city compared to the disappeared stream buffer area. This may be because there is large, topographically flat areas with no disappeared streams throughout the built city area in Portland (Figure 3). Also, in Baltimore, MD, the level of the impervious area was comparable between buffer and city areas (Figure 4). The overall level of impervious area was high, ranging from approximately 28% to as much as 53% impervious surfaces when looking across cities and buffer areas (Table 6). A higher level of impervious area around disappeared streams is expected given that, such as roads, sidewalks, and buildings, while more suburban areas can contain lower-density housing, reducing the relative quantity of impervious surface in an urban area. In the Potomac River Basin, areas with impervious area over 30% had higher levels of stream burial (Weitzell Jr et al., 2016). Similarly, in the Chesapeake Bay watershed, a study found that greater quantities of headwater, and smaller streams were buried with a rising proportion of impervious area (Elmore and Kaushal, 2008). Buffers around the disappeared streams in Baltimore, MD, and Phoenix, AZ, (Figure 4) had the highest level of impervious surface at a similar level, just above 50%. The amount of tree and forest cover was generally comparable between the disappeared stream buffer and the city area, but interestingly, in all cities, except Atlanta, GA (Figure 4) there was more tree cover in areas around disappeared streams compared with the overall city percentages. The highest level of tree cover was found in the Atlanta buffers and metropolitan area, with approximately 48% and 57%, respectively. For all cities, except for Phoenix, AZ, there was a low percentage of the area classified as soil and barren both around the disappeared streams and throughout each city. In Phoenix, there is a large proportion of the city area (54%), and the area around disappeared streams (33%) were classified as soil and barren, which is associated with the desert environment. Land cover change associated with urbanization can remove overall tree cover as forests are converted to urban areas (and other land uses, such as agriculture) (Julian et al., 2015). Interestingly, urbanization does not always reduce tree cover in riparian areas, as a study near Sacramento, CA, found (Solins et al., 2018).

Table 6: High-resolution Land Cover in a 100m Buffer Around Disappeared Streams Within Each Metropolitan Area

City	Portland	Portland	Atlanta	Atlanta	Phoenix	Phoenix	Baltimore	Baltimore
Land Cover Category	Stream Buffer Land Cover (%)	Land Cover (%)	Stream Buffer Land Cover (%)	Land Cover (%)	Stream Buffer Land Cover (%)	Land Cover (%)	Stream Buffer Land Cover (%)	Land Cover (%)
Water	2.17	10.07	0.23	0.47	0.23	0.59	0.73	11.83
Impervious Surface	37.77	40.99	36.73	28.74	53.47	28.31	51.08	46.97
Soil and Barren	0.34	0.26	0.37	0.33	33.48	52.37	0.34	0.69
Trees and Forest	29.72	26.70	48.03	56.72	5.17	4.61	31.14	24.95
Grass and Shrub	29.06	21.86	14.63	13.73	7.22	11.28	16.71	15.56
Agriculture	0.94	0.10	0.00	0.01	0.44	2.85	0.00	0

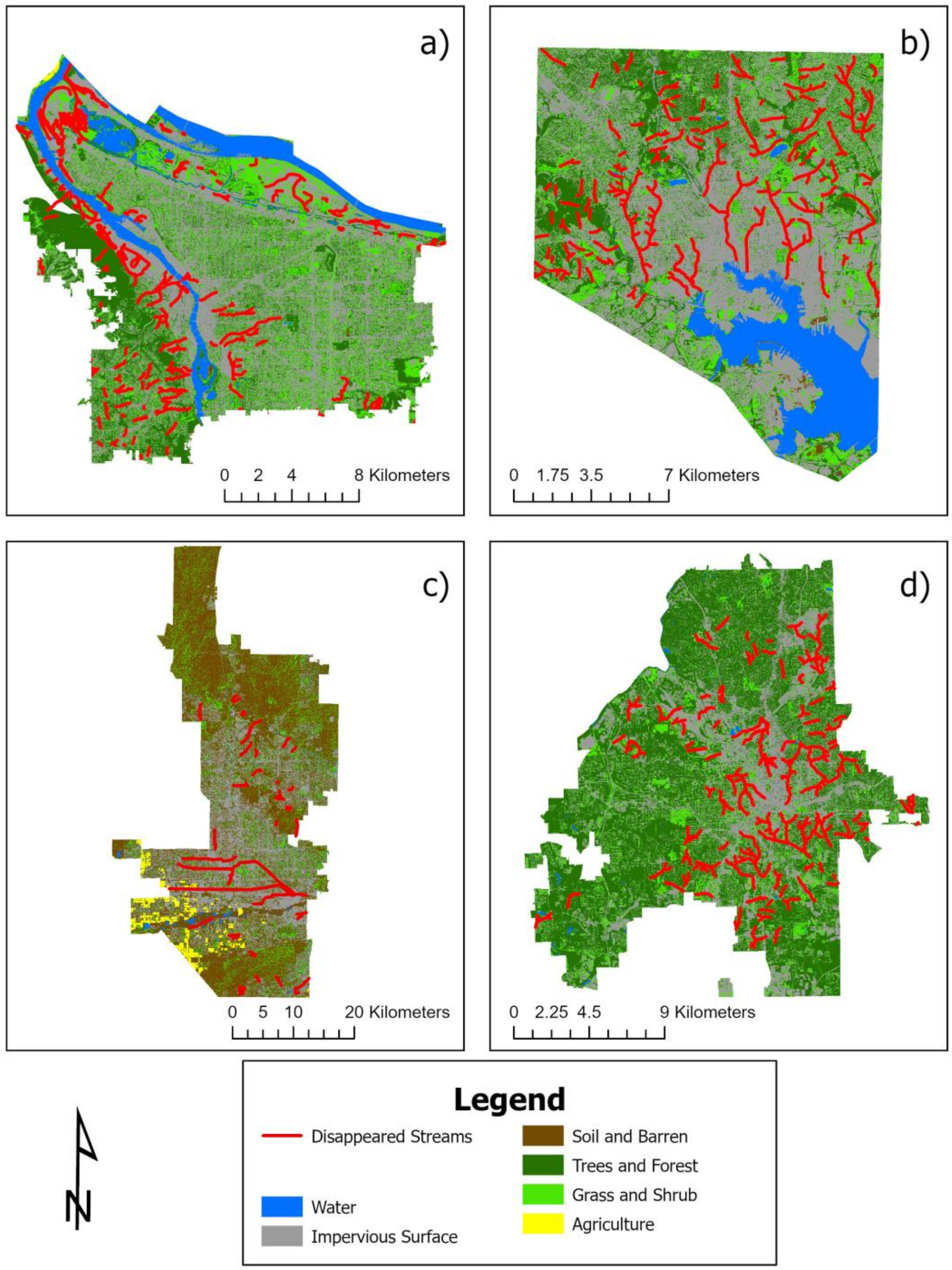

Figure 4: High resolution land cover with mapped disappeared streams for a) Portland, OR, b) Baltimore, MD, c) Phoenix, AZ, and d) Atlanta, GA

5.3 Flood Risk and Disappeared Streams

In all four cities, we could not reject the null hypothesis that the proportion of flood factor scores in the buffers around disappeared streams was different, indicating a higher flood risk in areas near disappeared streams. If flood factor scores per house were randomly distributed, we would expect there to be no difference in the proportion of flood factor scores. The Kurskall Wallace test showed that there is a higher median of flood risk scores within the 100-meter buffer around disappeared streams compared to the buffers that are farther away ($p < 0.01$?). One possible explanation of this is that disappeared streams are usually in close proximity to existing streams and the flood factor values are more tied to fluvial flooding. Another possible explanation is that there is higher impervious surface area around the disappeared streams causing higher surface runoff (Feng et al., 2021), however, in Portland, OR, there was actually a slightly lower proportion of impervious area around disappeared streams which may be attributable to the urban forest and green spaces that are evident throughout Portland.

Figure 8 shows the distribution of flood factor scores within a certain buffer within the four cities. In Portland, Baltimore, and Atlanta, there is a higher quantity of major to extreme flood risk scores within 100 meters of the disappeared streams compared to the two farther buffers. In Phoenix, there is a higher quantity of low flood risk scores farther away from the disappeared streams, but there are more major flood risk scores (6-7) within 100 meters of the disappeared streams. A possible explanation for such a difference in the proportion of scores in Phoenix compared to the three other cities is that all of Phoenix's streams are ephemeral, and many were already converted into culverts or canals before streams/canals visible on the oldest maps used in this study for digitization.

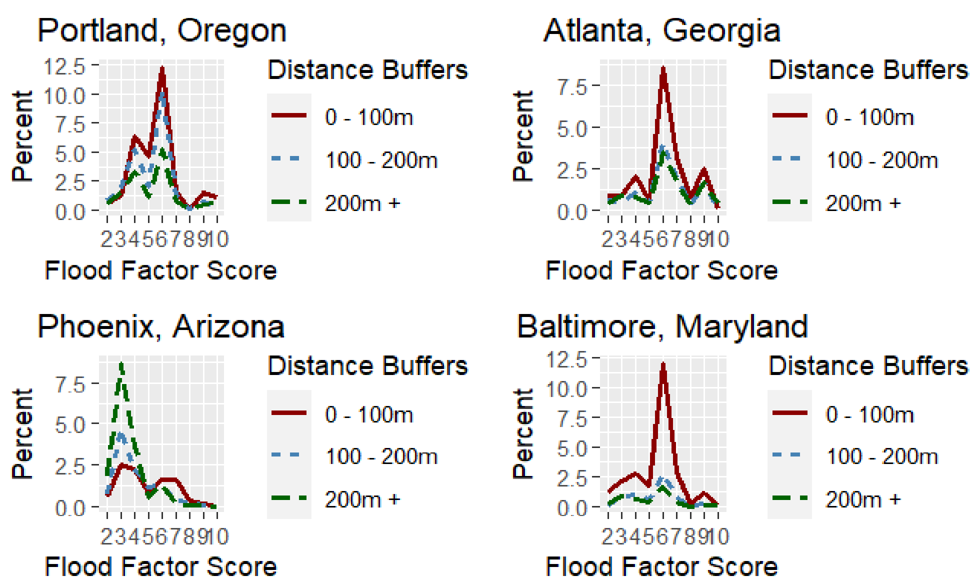

Figure 5: Flood risk within 100m and 200m, and more than 200m away from disappeared streams

5.3 House Sale Price and Disappeared Streams in Portland, OR

Table 7 shows the summary statistics for the variables used for the Portland hedonic model.

Table 7: Hedonic Model Summary Statistics for Portland, OR (n = 30172)

Variable	**Mean**	**Std. Dev.**	**Min**	**Pctl. 25**	**Pctl. 75**	**Max**
Log of house sale price	13	0.37	11	13	13	15
Building age year	71	32	0	51	97	175
Building square feet	2069	918	1	1400	2560	21305
Lot size (square feet)	6674	5260	435	4791	7405	462171
Number of baths	2	0.84	0.5	1	2.5	26
Distance to town hall (m)	7607	3001	897	5466	9336	15740
Flood Factor score	1.5	1.5	1	1	1	10
100 year floodplain	0.0049	0.07	0	0	0	1
Green cover percentage	0.65	0.17	0	0.55	0.77	1
Log distance to existing stream (m)	6.7	1.1	-1.6	6.2	7.5	8.2
Log distance to disappeared stream (m)	6.8	1.1	-2.2	6.3	7.7	8.4

Estimated coefficients for three hedonic price models for Portland, OR and shown in Table 8. Model one, the base model, includes characteristics known to determine house sale prices with flood factor scores, green cover proportion, and distance to existing streams in meters. The second model is a spatial error model that considers dependencies of the error values for a particular location as well as error values in locations associated with that area (Saputro, et al., 2019).

Table 8: Hedonic models output with only streams within Portland, OR

Variable	Model 1	Model 2
	Ordinary Least Squares	Spatial Error
Building Age	-0.000727162***	-0.000942255***
Square Feet	0.000192372***	0.000152652***
Lot Size	2.39E-06***	3.81E-06***
Bathrooms	0.0867423***	0.0826766***
Distance to Town Hall	-4.84E-05***	-5.28E-05***
Flood Factor	-0.00425774***	-0.000651703
Green Cover Proportion	0.0498277***	0.0340854***
Distance to Streams	0.00158752	0.027594***
Lambda		0.93536***
Constant	12.967***	12.9106***
Observations	30172	30172
r2	0.70047	0.748632
Akaike info criterion	-10440.1	-15420.4

Significance Codes: 0.01 ‘***’ 0.05 ‘**’ 0.1 ‘*’

Table 9: Hedonic model output with both streams and disappeared streams within Portland, OR

Variable	Model 1	Model 2
	Ordinary Least Squares	Spatial Error
Building Age	-0.000729694***	-0.000941718***
Square Feet	0.000192034***	0.000152648***
Lot Size	2.42E-06***	3.81E-06***
Bathrooms	0.0869103***	0.0826518***
Distance to Town Hall	-4.92E-05***	-5.31E-05***
Flood Factor	-0.00409156***	-0.0006191
Green Cover Proportion	0.0485587***	0.033957***
Distance to Streams	-0.00104654	0.0271176***
Distance to Disappeared Streams	0.00620707***	0.00428072
Lambda		0.935647***
Constant	12.9494***	12.8875***
Observations	30172	30172
r2	0.700609	0.748661
Akaike info criterion	-10461.1	-15421.4

Significance Codes: 0.01 '***' 0.05 '**' 0.1 '*'

Model one is the base model that includes the age of the house, the number of bathrooms, building square feet, and lot area. Model two has the same variables with a new distance to disappeared stream variable added in meters. The floodplain variable (SFHA) is a critical variable because this represents areas that FEMA designated as Special Hazard Areas, which translates to a 1% risk of flooding each year, with any federally backed mortgage being required by the National Flood Insurance Program to carry flood insurance (FEMA, 2021). According to the OLS regression, if a house was located in the SFHA boundary, the house would sell for approximately 6.6% less. This is consistent with other hedonic studies (Bin et al., 2008; Posey and Rodgers., 2010; Samarasinghe and Sharp., 2010). Netusil et al. (2019) found that houses sold within the 100-year floodplain in Portland, OR sold for approximately 8.6% less than those not within the 100-year floodplain. This relationship can also be represented as decreasing house value in relation to proximity to streams. Qiu et al. (2006) found a statistically significant negative relationship between the log of distance and house sale price in a hedonic study focusing on the Dardenne Creek watershed in the St. Louis, Missouri metropolitan area where for every meter farther away from the river, property sale decreased approximately $12 (The log distance to stream had a -.016 effect on house sale price). It is important to note that the negative impact on house sale price of the flood factor scores may not convey the real cost of flood risk because consumers respond less to indications of risk compared to the actual burden of flood damage (Rajapaksa et al., 2016).

Other researchers have noted the benefits of being near urban streams. Kousky et al. (2014) found that the increased effect of being closer to open spaces outweighed the negative effects of a house located within a 100-year floodplain, making a case for the value of floodplain conservation. Additionally, removing existing streams leads to the loss of biodiversity and potential recreational value, which is not addressed in this analysis. In Guangzhou, China, a study found that the closer a house was to an urban stream, the higher the value of the house due to the environmental amenities of the stream (Li et al., 2021). Wu et al. (2021), used a spatial quantile hedonic model to access the effect of the proximity of different apartment buildings to the Tamsui River in Taipei, Taiwan and found that there was an effect of .01% increase in the apartment's sale price per meter closer to the Tamsui River.

Moran's I index, which measures spatial autocorrelation, had a value of 0.154, which signifies that the model's residuals are positively spatially autocorrelated, and it is therefore possible to reject the null hypothesis that there is no spatial autocorrelation. The robust Lagrange Multiplier test results that error and lag are significant, representing spatial dependence within the model. The Akaike information criterion (AIC), which measures model fit for a dataset (Table 10), found that the spatial error model had the best fit with the lowest AIC value.

Table 10: Hedonic model spatial diagnosis tests for Portland, OR models

Test	MI/DF	Value	Probability
Moran's I (error)	0.1496	257.7352	0.00000
Lagrange Multiplier (lag)	1	8969.1013	0.00000
Robust LM (lag)	1	2048.7101	0.00000
Lagrange Multiplier (error)	1	27505.4167	0.00000
Robust LM (error)	1	20585.0254	0.00000
Lagrange Multiplier (SARMA)	2	29554.1267	0.00000

The green cover proportion for the Portland, OR model, shows a significant positive relationship between green cover and house price in both models which may be because people prefer to purchase homes with more tree cover. The Flood Factor score, representing the flood risk associated with a house, has a negative relationship with the house sale price, indicating a lower house sale price with a higher flood factor score and corresponding higher flood risk. Flood factor score and the 100 year floodplain variable were not both included in the final model because of multicollinearity concerns. There was no statistically significant relationship between house sale price and distance to existing streams in the standard OLS regression. However, there was a positive relationship between distance to streams and house sale price (Approximately 0.0276), which means the closer to a stream, the lower the house sale price within the spatial error model. Table 9 includes a distance to disappeared stream variable to see how it impacts the effect of the distance to existing stream variable. A Pearson's correlation coefficient was calculated between house distance to existing stream to house distance to disappeared stream and the null hypothesis could be rejected that there is no correlation between the variables with a correlation of 0.5446921. Even though the distance to stream and disappeared streams variables are correlated, they are not rejected by VIF so they can still be included in the model. When the disappeared stream variable is included in the model, the coefficient for the distance to existing stream variable has a decreased effect on house sale price (approximately 0.0271). Disappeared streams do not have a statistically significant effect on house sale price in the spatial error model but has a positive relationship in the standard ols model. Not including disappeared streams in hedonic models exploring the relationship between streams and house sale price may lead to omitted variable bias where the effect of proximity to existing streams is greater on house sale price. A possible explanation is that houses may experience more flood risk around disappeared streams which is not being picked up when just exploring flood risk and existing streams.

Conclusions

Disappeared streams represent areas where streams that were previously an integral part of the landscape have been mostly removed from now urban environments. This study found that there were formally large networks of natural streams in the downtown areas of Portland, OR, Atlanta, GA, and Baltimore, MD. In Phoenix, AZ, many of the canals built by Native People to control water flow and enable agriculture have also disappeared. This disappearance of streams caused a loss of ecological function, with one key function of natural streams and rivers to serve to convey water out of an area during extreme precipitation events. This study identified and mapped the location of many of these former streams and canals for the study areas. A comparison of the area around disappeared streams to city averages using high-resolution land cover found that all cities, except for Portland, had higher levels of impervious area. These disappeared stream locations were compared against house-level flood estimates from the First Street Foundation, and it was found that Atlanta and Baltimore have a higher flood risk in the 100m area around disappeared streams, while, in Portland, that increased flood risk area goes out to 200m. In Phoenix, there were both major flood risk scores (6-7) and moderate flood risk scores (3-4) within 100 meters of the disappeared streams, with a higher quantity of low flood risk scores farther away. A series of hedonic regressions were performed to examine the relationship between house proximity to disappeared streams and house sale price in Portland. Spatial hedonic regression methods performed better than a non-spatial ordinary least squares regression based on the r^2 and Akaike info Criterion for Models, with the spatial error model being the most accurate. According to the spatial error hedonic model, on average, if the effect of proximity to disappeared streams on house sale price decreases when a disappeared stream variable is included. This study's finding that there may be a reduction in house value near disappeared streams can be useful information for future econometric studies focusing on the impact of proximity to existing streams on house sale price. If datasets are available for digitized disappeared streams, researchers may want to include those variables in their study to avoid potential omitted variable bias., Practitioners and policy makers can potential target areas with disappeared streams for future research and potential future opportunities to restore disappeared streams to open streams which can become a potential amenity by restoration of urban stream biodiversity.

Future Work

This research has developed disappeared stream datasets that could be used as part of a number of future studies. The spatial hedonic regression could be improved by using a Quantile Regression that could help better represent spatial differences in the model (Liao and Wang, 2012). Different ways can be used to analyze distance to existing and disappeared streams (for example different distance buffers) and spatial fixed effects could be added to better involve the location of a property in estimating the effect on house sale price. In addition, it may be interesting to research the demographic characteristics of people living near disappeared streams. This is important because areas around disappeared streams may be subject to higher flood risk, while future stream daylighting and restoration could displace vulnerable communities. The intersection of this work, using the high-resolution land cover, flood risk analysis, and hedonic analysis could be used as the basis to determine stream prioritization methods for stream daylighting. With increased urban flood risk because of climate change induced extreme precipitation events, stream daylighting in areas with high flood risk could improve the resilience of urban landscapes. Although the cost of stream daylighting and restoration is high, climate change will require extensive changes in our urban landscape to adapt to the new realities.

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