Cities 165 (2025) 106126

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

The vertical premium: Relationship between relative height of properties from real flood elevation and housing prices

Youjung Kim [a], Bon Woo Koo [b,*], Sungmin Lee [c]

[a] School of Public Affairs, University of South Florida, FL, USA
[b] Department of Urban Planning and Engineering, Yonsei University, Seoul, Republic of Korea
[c] Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, TX, USA

A R T I C L E I N F O

Keywords:
Relative property height
Flood risk
Housing price
Hedonic estimation

A B S T R A C T

This study investigates the effect of relative height—defined as a property's elevation compared to the actual flood level—on housing prices in Calgary before and after the 2013 flood. Previous research has mainly focused on flood risk or proximity to floodplain, often neglecting relative height. Given that land elevation does not uniformly increase with distance in flood-prone areas, distance-based assessments may be inadequate. Using spatial hedonic modeling, we examined the impact of relative height on property values over six years, covering three years before and after the flood. Results indicate that relative height significantly affects housing prices in riverine areas with a stronger effect within 200 m from rivers, where a 10-m increase in height raised property values by 4.77 % before the flood and 6.94 % after. Beyond this distance, the trend remained stable for both periods, with most coefficients becoming smaller and less significant. These patterns suggest that buyers awareness of flood risk increased following the flood event, particularly within a limited distance from the rivers. Overall, the findings demonstrate that prospective buyers recognize flood risks in riverine areas and are willing to pay a premium for properties located higher above the flood level.

1. Introduction

Flooding is one of the most common natural hazards globally, and the consequent disasters impact vulnerable communities and areas, with Canada being no exception. Despite continuous efforts by Canadian and local administrators to mitigate flood hazards and regulate development within floodplains, the historic trend of catastrophic losses has increased. Notably, the fiscal toll of severe weather events in Canada reached $2.1 billion in Canadian dollars in 2021 (IBC, 2022; CATIQ, 2022). This increase in flood damage was caused by a combination of factors, including extreme precipitation and rising development alongside escalating asset prices within flood-prone areas (Berndtsson et al., 2019). The phenomenon of global warming changes climatic patterns, resulting in extreme precipitation events that directly exacerbate both urban and fluvial flood occurrences (ECCC, 2019). More urban development amplifies surface runoff, resulting in the geographical expanse of floodplain areas (Gori et al., 2019). Another contributing factor is the increasing urban development, population, and property values in flood-prone areas (Berndtsson et al., 2019; Kunreuther & Michel-Kerjan, 2007). It is estimated that approximately 9 % of Candan's population, equivalent to 3.31 million of people, resides within 100-year floodplains (Mohanty & Simonovic, 2021), and this flood-prone population rate is expected to increase due to the influx of population into flood-prone zones (Andreadis et al., 2022; Kunreuther & Michel-Kerjan, 2007).

Such flooding and hazard risks can significantly influence housing prices. Previous studies on flood risks and housing prices have predominantly examined the relationships between housing prices and flood risks, considering factors such as proximity to designated flood risk zones such as 100-year or 500-year floodplains, distance from flood-prone areas, and associated insurance premiums (Bin & Polasky, 2004; Kousky, 2010; Zhang & Leonard, 2019). However, while property elevation would be directly related to flood damage, a lack of empirical study exists that specifically examines the relationship between relative property height —defined as the difference from the base flood elevation and a property elevation — and its impact on housing prices. Although a few prior studies have considered property elevations as a variable inland settings proximal to rivers or water bodies (McKenzie & Levendis, 2010; Rajapaksa et al., 2016), these have typically used elevation in absolute terms. The intricate and multifaceted relationship between relative height and property value, particularly in river-frontage but

* Corresponding author at: Department of Urban Planning and Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, Republic of Korea.
E-mail addresses: youjungkim@usf.edu (Y. Kim), bonwookoo@yonsei.ac.kr (B.W. Koo), sungminlee@tamu.edu (S. Lee).

https://doi.org/10.1016/j.cities.2025.106126
Received 5 May 2024; Received in revised form 9 April 2025; Accepted 30 May 2025

flood-prone areas, remains underexplored. The proposed study aims to: (1) investigate how relative property height affects housing prices, assessing the variation in this impact before and after a flood event and (2) examine fluctuations in the influence of relative property height on housing prices across different distances from the rivers in Calgary, Canada.

2. Literature review: Elevation, flood risk, and housing prices

The determination of housing prices is intricately tied to both the risks associated with flood-prone areas and buyer willingness to invest in a property. Despite the critical factor, a notable gap exists in research regarding the influence of relative property height on housing prices. To address this gap, we conducted a comprehensive review of existing literature from a dual focus: 1) exploring the potential benefits of property elevation near rivers on housing prices and 2) examining the impact of flood risk on housing prices.

2.1. Empirical literature regarding the elevation effect on the housing prices

Despite the limited studies on the impacts of relative property height on housing values, a few studies have examined the discernible influence of river-frontage and elevated locations on real estate valuations. Nicholis and Crompton (2018) emphasize the substantial premium placed on properties with direct river views, which are typically located in elevated in-land properties. The high property premiums were attributed to aesthetic appeal, enhanced recreational opportunities, and limited availability. Furthermore, research by Botzen et al. (2013) highlights the influence of elevation, particularly in mitigating flood risks; thereby amplifying property values in higher-lying areas adjacent to rivers. Rajapaksa et al. (2017) further delineate a linear relationship between property price escalation and increased elevation. Their study highlights an interaction effect between distance and elevation, revealing a more pronounced price premium for properties at lower elevations, albeit diminishing with distance. Miller et al. (2019) used elevation as a proxy for flood risks related to sea-level rise and found inconsistent evidence of markets pricing flood risks associated with low elevations, with variations depending on location. Collectively, these findings underscore the multifaceted determinants—scenic attractiveness, recreational amenities, scarcity, and risk mitigation—that substantially augment property valuations in elevated in-land settings proximal to rivers or water bodies.

2.2. Flood risk and housing prices

Nevertheless, when considering flood risks near riverbanks, the situation becomes more intricate. Several studies underscore the intricate relationship between flood risk and housing prices, offering insights into the temporal and spatial dynamics of price fluctuations post-flood events. MacDonald et al. (1987) emphasizes the importance of flood risk in influencing individuals' willingness to invest in housing, a principle that aligns with the hedonic model. This model integrates variables such as flood risks and insurance factors into its analytical framework.

Previous studies have identified the impact of perceived flood risk on housing prices within flood zones as well as its temporal effects and distance from the risks. Bin and Polasky (2004) found that housing prices within the 100-year floodplain are lower than those outside the floodplain, and the price discount within the floodplain significantly increases after a flood event compared to before a flood. Similarly, Bin and Landry (2013) observed a temporary price discount after multiple storms within flood-prone areas, which vanished after 5 or 6 years after a flood event. Atreya et al. (2013) investigated housing price changes within the 100-year floodplain after a flood event and identified that flood risk discounts occurred significantly but disappeared between four to nine years after the event. Zhang (2016) highlighted the significant impact of flood events on property values within the 100-year floodplain, with a greater effect observed on lower-priced homes compared to higher-priced ones. Additionally, Bin et al. (2008) identified that the price discount is equivalent to the capitalized value of flood insurance premiums.

Kousky (2010) compared housing price changes within the 100-year and 500-year floodplains after a flood event and found that prices in the 100-year floodplain remained relatively stable while those in the 500-year floodplain declined significantly. Yi and Choi (2020) also confirmed that housing prices remained stable within the 100-year floodplain before and after a flood event. However, unexpected inundation led to price discounts following the event. Jung and Yoon (2018) identified that the flood discount affects properties within 300 m from the flood extent, and this discount disappears after 1 year following the disaster. Zhang and Leonard (2019) compared the estimated housing discount following a flood event inside the 100-year floodplain to those outside the floodplain at different distances and identified spatial and temporal variations in the flood discount. Additionally, a rebounding effect was identified for uninundated houses within the 100-year floodplain. In flood-prone areas, elevation (above mean sea level) has also been found to have a positive relationship with selling prices, with a premium of 1.4 % per foot in flood-prone areas pre-Katrina, increasing to 4.6 % post-Katrina (McKenzie & Levendis, 2010).

Focusing on flood risk perception, Rana and Routray (2016) compared actual and perceived flood risk through survey in three cities in Pakistan and found that perceived risk increases as actual risk grows. Adding to that, Rana et al. (2020) identified key determinants of flood risk perception such as past flood experience and hazard proximity. Pommeranz and Steininger (2020) examined both direct and indirect effects, particularly spatial spillovers from neighboring properties, on housing prices in flood zones. Their study highlighted that indirect effects, such as neighborhood-level perceptions of flood risk, significantly impacted property values, underscoring the importance of considering spatial dependencies when assessing flood-related price effects. Fuerst and Warren-Myers (2021) investigated how current flood risk is capitalized into property values, observing a discount for properties in known flooded areas. However, they found that perceived flood risks, such as sea level rise, have no effect on property prices, possibly due to a lack of information about future risks or relatively affordable insurance. Ali et al. (2022) found that people living farther from rivers had higher risk perceptions and better access to risk communication, highlighting the role of past flood experiences in shaping risk perception. They also suggested that improving risk communication can enhance preparedness and resilience in flood-prone areas. These studies collectively emphasize that flood risk perception is shaped by both personal experiences and spatial factors, with perceived risks often diverging from actual risks. Moreover, the influence of neighborhood-level perceptions and access to risk communication plays a critical role in how individuals and markets respond to flood hazards.

2.3. Research gap and research questions

Despite acknowledging the benefits of elevation and perceived flood risks on housing values, the intricate relationship between property elevation and property value, particularly in river-frontage but flood-prone areas, remains complex and multifaceted. The elevated areas near rivers are associated with both positive factors, such as visual amenities and avoidance of the hazard of flooding, and negative factors, such as being away from water sports facilities and open space as well as persistent perceived flood risks. These conflicting elements contribute to the complexity of understanding the overall impact of river-frontage and elevated locations on property values, especially flood-prone areas, highlighting the need for further research and a nuanced approach to assessing these factors.

Notably, no prior flood-related studies have delved into the relationship between relative property height from real flood elevation and housing price. While existing studies related to flood risk and housing price have used property elevation directly as a control variable in the hedonic model, their focus has primarily focused on land parcel elevation (Rajapaksa et al., 2017; Rambaldi et al., 2013) or elevation between a house and the height of near watercourse (Belanger & Bourdeau-Brien, 2018). McKenzie & Levendis, 2010 identified a vertical premium using elevation; however, direct elevation fails to fully capture flood risks, as floodplain boundaries may not correspond equally to elevation, even within the same neighborhood or in close proximity.

This study uniquely employs the real flood elevation (RFE) of the 2013 flood, allowing it to accurately depict flood risk in terms of height compared to the elevation from mean sea level or the base flood elevation (BFE) derived from the 100-year floodplain. This study will investigate the relationship between relative height and housing prices in riverine areas, including flood-prone zones, and assess whether these relationships remain consistent across various distance intervals from the rivers. Our research questions are as follows:

(1) To what extent does relative height influence housing prices?
(2) How is the effect of relative height different before and after a flood event?
(3) How do variations in distance impact the relationship between relative height and housing prices?

3. Research methods

3.1. Study area

Calgary is the third-largest city in Canada, with its population increasing by an average of 2.16 % annually from 1.1 million in 2010 to 1.4 million in, 2022. (Alberta, 2023). The city of Calgary is located in the southwestern part of the Alberta province, bordered by the Rocky Mountain Foothills to the west and the Canadian Prairies to the east. Our study area encompasses the riverine areas extending 1600 m from the major rivers, namely the Bow and Elbow rivers, which are directly associated with the flood event, as illustrated in Fig. 1. Due to its mountainous terrain, the city's elevation ranges between 1000 and 1200 m above sea level. The Bow and Elbow rivers enter the city from its western boundary, merge in the downtown area, and flow out in the southern part of the city. The city of Calgary and the southern part of Alberta experienced two major flood events in the 2000s: one in 2005 and another devastating flood in June 2013, both caused by riverbank overflow resulting from extreme rainfall (Alberta, 2015; Noad & Energy, 2014). The 2013 event led to monetary losses of 6 billion dollars for rebuilding costs, the damage of approximately 14,500 homes, and the displacement of 100,000 people.

3.2. Data

The unit of analysis for this study is single-family residential property sales transactions. Table 1 presents the summary statistics of structural, transportation accessibility, and neighborhood characteristics. The sales transaction data for the city spanning from June 21, 2010, to June 20, 2016, were sourced from Pillar 9™ (Alberta One Realty Listing Services Inc.). This dataset encompasses a total of six years of transactions, including the three years before and after the flood event on June 21, 2013. The time frames vary in previous studies: 1.5 to 1.8 years (McKenzie & Levendis, 2010), 3 to 4 years (Bin & Landry, 2013), and even longer (Atreya et al., 2013; Kousky, 2010). The authors consider this six-year timeframe adequate for market adjustments to incorporate the perspectives of market participants. Detailed information on individual transactions, such as sold price, structural features, property description, and geographical location, is included in the dataset. Our study focuses specifically on single-family properties located within 1600 m of the Bow and Elbow rivers. The 1600-m distance cutoff was determined based on research indicating it represents a maximum walking distance of approximately 20 min (Choi et al., 2023; El-Geneidy et al., 2014). Accordingly, our study sample includes 24,488 single-family houses: 12,306 pre-flood and 12,182 post-flood. To make a meaningful comparison, we have adjusted all sale prices to 2016 Canadian dollars, using a housing price index from Statistics Canada.

For relative height, we utilized the 2013 flood extent data from the City of Calgary's open data portal, geographic location from transaction records, and digital elevation model (DEM) data. This process involved determining both the house elevation and the nearest elevation point on the 2013 flood extent, followed by creating a subset within these values using ArcGIS Pro software. Relative height is calculated by subtracting the nearby flood elevation in 2013 from the ground elevation of each house (i.e., relative height = ground elevation – flood elevation). For example, as illustrated in Section A of Fig. 2, the property on the right side has a ground elevation of 1118.5 m, and the nearest flood elevation is 1066.0 m, resulting in a relative height of +52.5 m. Additionally, the upstream and downstream 2013 flood elevations vary, as shown in Fig. 2. Specifically, the flood elevation difference between Section A and Section B is 69.6 m: with Section A's flood elevation at 1066.0 m and Section B's downstream flood elevation at 996.4 m. In Calgary, ground elevation does not increase linearly as the distance from the river increases. When comparing Sections A and B, the distance from the river does not adequately represent flood risk, nor does property elevation alone. Furthermore, Sections A, B, C, and D represent different river

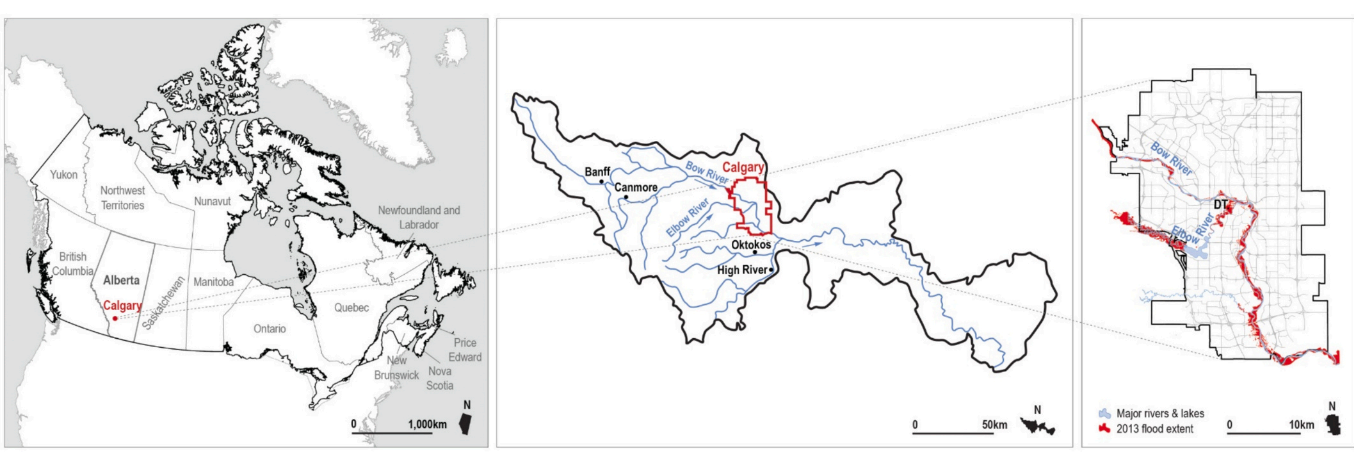

Fig. 1. Study area location, watershed, and the 2013 flood extent of Calgary.
Note. In section A, the relative height of the house on the right was calculated by subtracting the 2013 flood elevation from the ground elevation: 1118.5 m – 1066.0 m = Δ + 52.5 m.

Table 1
Variable description and descriptive statistics.

Variable	Description	Pre-Flood (3 years)				Post-Flood (3 years)			
		Mean	SD	Min.	Max	Mean	SD	Min.	Max
Dependent Variable									
Housing Sales Price	House sale price adjusted to 2016 in Canadian dollars	611,748.59	379,730.47	138,002.00	6,369,309.00	646,494.34	388,370.17	135,190.00	11,454,998.00
Independent Variable									
Relative Height	Vertical height in meters between a property and 2013 flood level	29.96	28.40	−28.88	173.30	30.13	27.62	−28.56	173.03
Structural Characteristics									
Bedroom No.	Number of bedrooms	3.54	0.90	1.00	6.00	3.58	0.88	1.00	9.00
Living Area	Total living area in square feet	1628.58	648.96	469.00	7751.00	1652.47	655.20	483.00	7751.00
Building Age	Age of building in year	34.62	26.95	1.00	113.00	34.74	26.91	1.00	122.00
Basement Finished	Dummy variable: 1 if property's basement is fully finished, 0 otherwise	0.65	0.48	0.00	1.00	0.68	0.47	0.00	1.00
Walkout	Dummy variable: 1 if property has a walkout feature, 0 otherwise	0.10	0.29	0.00	1.00	0.10	0.30	0.00	1.00
Cooling	Dummy variable: 1 if property has a cooling system, 0 otherwise	0.13	0.33	0.00	1.00	0.16	0.37	0.00	1.00
View	Dummy variable: 1 if property has a scenic view, 0 otherwise	0.08	0.26	0.00	1.00	0.17	0.38	0.00	1.00
Location									
Proximity to Sports Facility	Distance in meters to sport facility	277.92	165.64	8.01	1035.82	278.52	172.70	7.28	1524.99
Proximity to River	Distance in meters to river	877.34	420.90	12.69	1599.89	890.69	415.88	12.69	1599.74
Proximity to Park	Distance in meters to park	118.96	88.13	3.02	791.08	118.98	88.44	3.01	688.55
Proximity to Commercial	Distance in meters to commercial facility	427.49	322.43	0.00	2634.23	414.31	301.20	0.00	2540.20
Proximity to School	Distance in meters to school	525.89	433.70	41.31	3099.59	520.19	420.84	38.32	3131.81
Flood Elevation	Near flood elevation in 2013	1043.91	29.01	991.98	1108.45	1042.28	29.39	990.73	1108.45
Neighborhood Characteristics									
Population Density	Population density per square kilometer at dissemination area (2016 census)	2799.88	1465.81	36.15	17,622.49	2785.38	1447.34	36.15	12,723.49
Visible Minority	Visible minority population in percentage at dissemination area (2016 census)	17.89	9.70	0.00	58.79	18.38	9.91	0.00	58.79
Median Income	Median household income at dissemination area (2016 census)	93,210.63	57,990.38	29,057.00	556,177.00	90,413.82	56,633.40	29,057.00	556,177.00
Transportation Accessibility									
Proximity to Major Road	Distance in meters to major road	311.06	215.37	11.02	1251.39	303.46	209.76	0.20	1271.46
Proximity to LRT Station	Distance in meters to LRT station	3008.17	1933.81	46.83	7865.16	3114.41	2013.96	65.12	8125.26
Proximity to Bus Stop	Distance in meters to bus stop	169.86	109.62	4.41	1212.88	169.10	107.48	5.20	901.11
Observations		12,306				12,182			

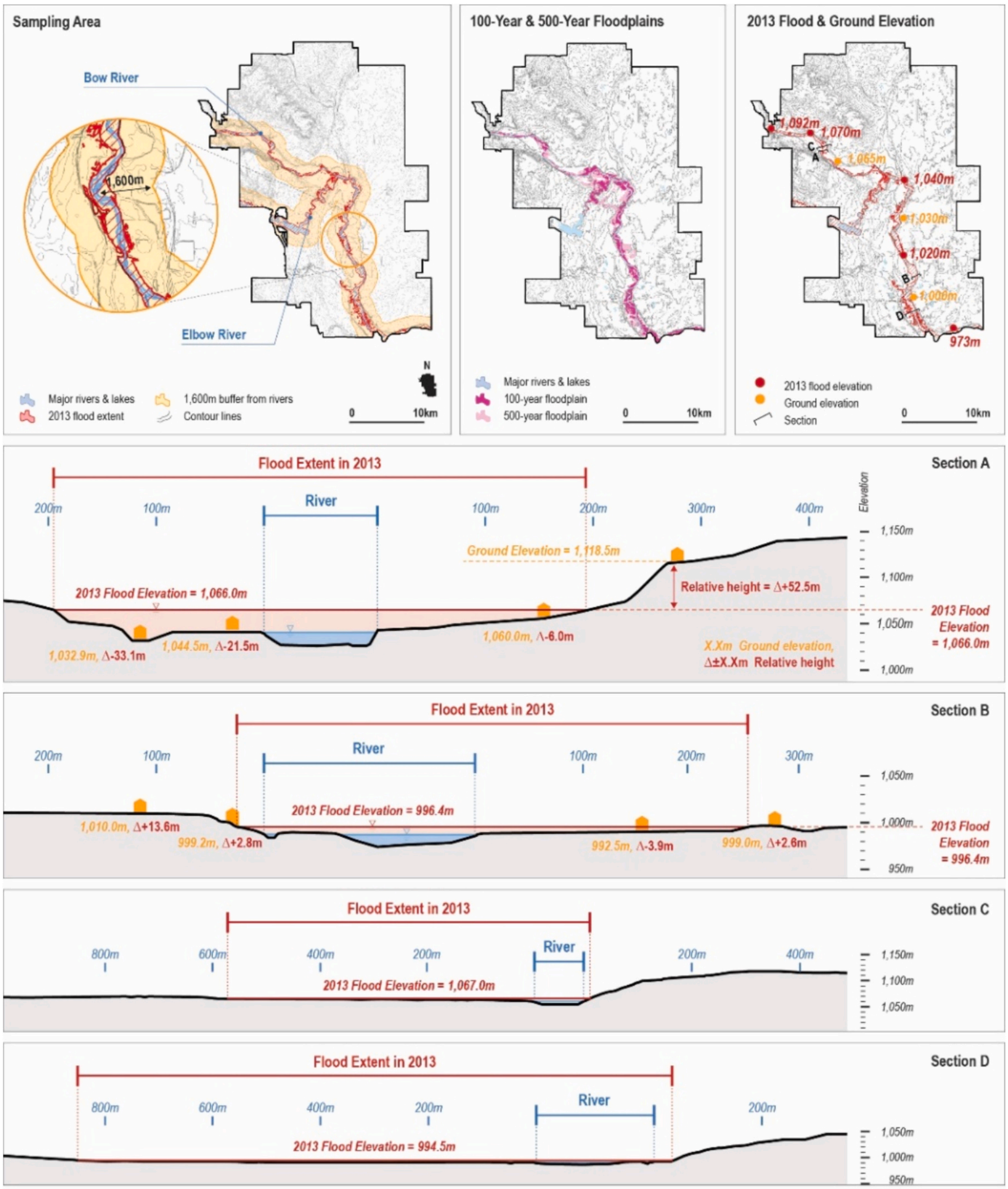

Fig. 2. Sampling area (properties 1600 m from rivers), floodplains, elevations, and conceptual sections illustrating relative property height and river distance. *Note.* a. Housing numbers within the 2013 flood extent in each interval are stated in parentheses. Significant coefficients are printed in bold; ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. The complete results of the interval models are presented in Table 1 in the appendix.

distances to the 2013 flood extent boundaries, with Section D being >800 m from the river.

The structural characteristics of individual properties encompass the number of bedrooms, bathrooms, total living area, building age, finished basement development, walk-out, cooling system, view, and new construction. The walkout basement feature, which arises from Calgary's hilly geography, provides direct outdoor entrance, more natural sunlight, and additional living space. The view factor, which indicates whether a house offers a scenic view to the outside, was originally included in the dataset provided by Pillar 9™. By including view as a controlled factor, we aim to account for an alternative explanation: properties with greater relative heights are associated with higher housing prices due to their views. In essence, we incorporate the view as a control variable to mitigate the likelihood that the regression coefficient for relative height is confounded by the effects of the view amenity. This approach allows the coefficient for relative height to better reflect the perception of flood risk, rather than the benefits of an attractive view.

Geographical features (i.e., amenity and transportation accessibility) for individual properties were derived using each property's location and dataset from the city's open data portal, including accessibility to the nearest sport facility, river, park, commercial, school, major road, light rail transit (LRT) station, and bus stop. As illustrated in Fig. 1, the rivers flow through multiple communities. Hence, we measured neighborhood characteristics such as population density, median household income, and visible minority at the dissemination area level from Statistics Canada. A dissemination area (DA), equivalent to a Census block group in the US, is a small and stable geographic unit with an average population of 400 to 700 persons. The Census Canada defines that a visible minority is "persons, other than Aboriginal peoples, who are non-Caucasian in race or non-white in color."

3.3. Spatial hedonic model

The hedonic pricing model estimates the implicit value of attributes of differentiated goods (Lancaster, 1966; Rosen, 1974). We incorporated structural features, location, neighborhood characteristics, and transportation accessibility into our models (see Table 1) (Chau & Chin, 2003).

Ordinary Least Squares (OLS) are commonly employed to estimate housing prices in traditional hedonic price models. One of the basic assumptions of OLS is the independence of observations, which is often violated due to spatial dependence in the data. This violation can lead to biased estimations of standard errors and misleading significance tests (Bajat et al., 2018; Osland, 2010). This study employed a spatial regression model to account for spatial autocorrelation (Anselin & Bera, 1998). For each data subsets described above, we first developed an OLS multivariate regression model using a log-transformed Housing Sales Price as the dependent variable. Second, regression residuals from the fitted OLS model were used to calculate Global Moran's I statistic to determine the presence of spatial autocorrelation. When spatial autocorrelation was detected, a spatial regression model was fitted. The selection between the two commonly used approaches—spatial lag regression and spatial error regression—was made based on the Lagrange Multiplier test. The equation for all models in this study is as follows:

$$\begin{aligned}\text{Price} &= c + \text{STRUCTURE} + \text{GEOGRAPHIC} + \text{NEIGHBOR} + \text{HEIGHT} \\ &\quad + \text{YEAR} + \lambda \text{Wu} + \varepsilon,\end{aligned}$$

where STRUCTURE is the structural characteristics (e.g., living area and walkout), GEOGRAPHIC is the geographic features (i.e., proximity to amenities and transportation accessibility), NEIGHBOR is the neighborhood characteristics (e.g., population density), HEIGHT includes the relative height and flood elevation; YEAR is the dummy variable representing the year of transaction; λ is the spatial autoregressive coefficient; W is the spatial weight matrix; u is the spatially dependent error term; and ε is the random error term (Kim et al., 2003; Osland, 2010).

To evaluate the effect of the relative height difference for various temporal and spatial ranges, this study divided the single-family residential property sales transactions data into 18 subsets based on temporal as well as spatial criteria. The temporal criterion split the data into two groups: pre and post the 2013 flood (see Table 2). Based on the spatial range, these two groups were further subdivided into eight groups, where the spatial ranges were defined as the (i.e., the transactions occurred within certain ranges from the river, where the ranges include 0–200 m, 200–400 m, 400–600 m, 600–800 m, 800–1000 m,

Table 2
Model results by 3 years pre- and post-flood.

	Model 1 (pre-flood: 3 yrs)	Model 2 (post-flood: 3 yrs)
Relative Height (10 m)	**0.0103******** (0.0019)	**0.0115******** (0.0018)
Bedroom No.	**0.0140***** (0.0018)	**0.0069***** (0.0018)
Living Area (100sqft)	**0.0303***** (0.0004)	**0.0312***** (0.0003)
Building Age	**−0.0042***** (0.0003)	**−0.0013***** (9.20E−5)
Building Age (squared)	**2.37E−5***** (2.78E−6)	**5.74E−7***** (5.79E−8)
Basement Finished	**0.0691***** (0.0033)	**0.0632***** (0.0033)
Walkout	**0.0878***** (0.0058)	**0.0880***** (0.0054)
Cooling	**0.0406***** (0.0045)	**0.0419***** (0.0039)
View	−0.0094 (0.0053)	0.0060 (0.0035)
Proximity to Sports Facility (100 m)	**0.0059*** (0.0025)	**0.0049*** (0.0023)
Proximity to River	**−0.0160***** (0.0012)	**−0.0131***** (0.0012)
Proximity to Park (100 m)	**0.0072*** (0.0035)	**0.0092**** (0.0033)
Proximity to Commercial (100 m)	**−0.0036*** (0.0016)	**−0.0051**** (0.0016)
Proximity to School (100 m)	**−0.0083***** (0.0013)	**−0.0071***** (0.0012)
Flood Elevation	**0.0019***** (0.0002)	**0.0020***** (0.0002)
Population Density (1000people/sqkm)	**0.0058**** (0.0020)	0.0038 (0.0020)
Visible Minority	−0.0002 (0.0004)	−0.0001 (0.0003)
Median Income (10,000 CAD)	**0.0148***** (0.0007)	**0.0115***** (0.0006)
Proximity to Major Road (100 m)	**0.0227***** (0.0021)	**0.0211***** (0.0020)
Proximity to LRT Station (100 m)	**−0.0057***** (0.0003)	**−0.0051***** (0.0003)
Proximity to Bus Stop (100 m)	**0.0330***** (0.0031)	**0.0306***** (0.0030)
Observations	**12,306**	**12,182**

Note. The dependent variable is log price of the property. Year of sale fixed effects. Standard errors are stated in parentheses. Significant coefficients are printed in bold.
*** $p < 0.001$.
** $p < 0.01$.
* $p < 0.05$.

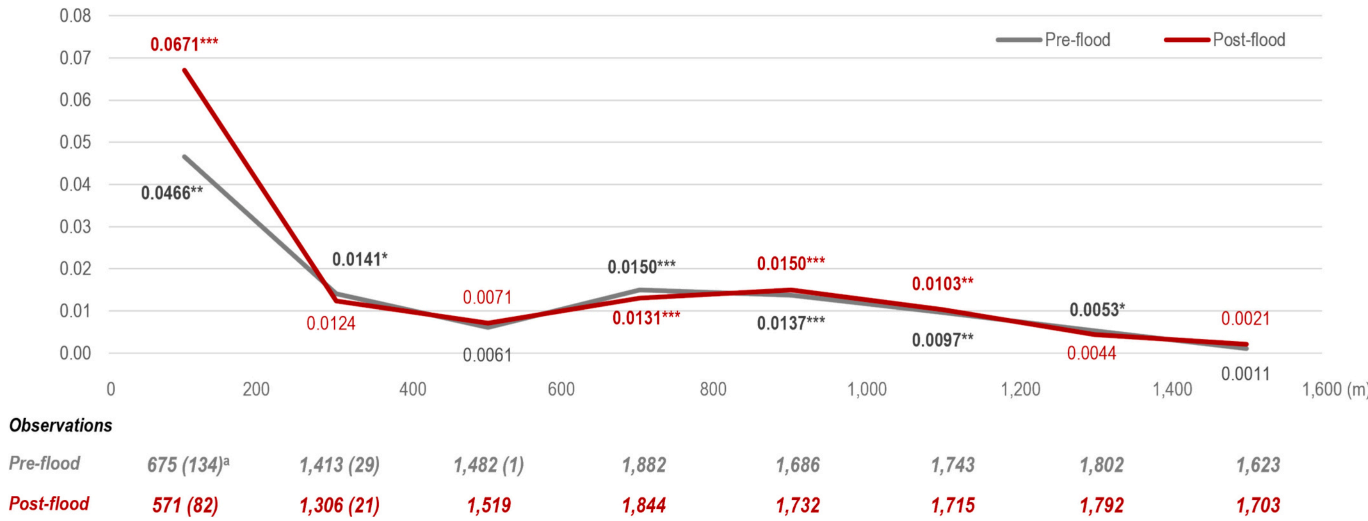

Fig. 3. Variations in coefficients of relative height along 200-m river distance intervals before and after the 2013 flood.

1000–1200 m, 1200–1400 m, and 1400–1600 m ranges; a pooled data from 0 to 1600 m range was also subsetted). This subdivision generated the total of 18 subsets ((8 subset data by the spatial ranges +1 spatially pooled data) × 2 temporal ranges) as illustrated in Fig. 3 and Table 1 in the Appendix. All models regress the log-transformed sold price in Canadian dollars on predictors listed in Table 1. We also included year of sale fixed effects to control for unobservable temporal differences in all models.

4. Results

4.1. Descriptive analysis

The descriptive statistics of variables are presented in Table 1. Among the selected samples, the average 3-year housing value was $611,749 before the 2013 flood event, increasing by 5.7 % over the following 3 years to reach $646,494. In both pre- and post-flood samples, the relative heights of properties range between −29 and + 173 m, reflecting Calgary's hilly geographic conditions. The average number of rooms and living areas indicates typical aspects of single-family houses, with 3.5 rooms and 1600 square feet, respectively. Despite the presence of new constructions, the average building age is 35 years. 65–68 % of sampled houses have finished basements, 10 % feature walkouts, and 8–17 % boast a view. Given Calgary's status as a winter city, 13–16 % of houses have cooling systems.

Other aspects, such as location, neighborhood characteristics, and transportation accessibility, exhibit similar values in both groups. The sampled areas encompass both suburban and downtown areas, resulting in a population density of 2800 people per square kilometer. In particular, the riverine areas encompass a wide range of neighborhood income levels, from $29,000 to $556,000. The percentage of visible minority individuals also varies widely, ranging from 0 % to 59 %. Flood elevations range from 990 to 1108 m, reflecting varying geographic conditions (with higher elevations upstream and lower elevations downstream).

4.2. Factors influencing housing prices: Insights from the hedonic model

Most variables concerning structural and other characteristics are consistent with earlier empirical studies. As shown in Table 2, these characteristics significantly influence the values of single-family housing units. Specifically, larger living areas are positively associated with higher housing values. Across the two models, three years pre- and post-flood in Table 2, the coefficients suggest that a 100-square-foot increase in living area leads to a selling price increase ranging from 3.05 % to 3.15 % (corresponding to coefficients of 0.030 and 0.031, respectively), equivalent to $18,658 to $20,365 at the mean. Exponentiating them gives percentage changes: a pre-flood coefficient of 0.0303 equals a 3.05 % increase in price per 100-square foot increase in living area, and a post-flood coefficient of 0.0312 equals a 3.15 % increase. The walkout feature, which arises from Calgary's hilly geography and enables the basement floor to have an outdoor entrance, is positively associated with an approximate 9.18 % (corresponding to coefficient of 0.0878) increase in housing prices (Model 1), or $56,159 at the mean.

In terms of geographic characteristics, proximity to rivers and schools is positively associated with housing prices. Since this study focuses on samples from riverine areas, being close to a river influences higher housing values. The distance to schools reflects the walking distance for Calgarians to reach the school. Proximity to LRT stations is positively associated with housing values, while proximity to bus stops and major roads is negatively associated. This indicates that single-family units located close to LRT stations may expect higher housing values, but those close to bus stops and major roads may have lower housing values. Flood elevation is positively associated with housing values. It may be incorrect to interpret this as higher flood elevation being beneficial to housing value; rather the flood elevation in this case is likely working as a proxy of elevation and therefore partly explaining the amenities associated with higher elevation, indicating that upstream areas with higher elevations offer more favorable geographic conditions, leading to higher property values.

In terms of neighborhood characteristics, while the percentage of visible minority population and population density tend to be associated with decreased housing prices, densely populated areas tend to be associated with increased housing values. Regarding neighborhood income level, higher-income neighborhoods are likely to be associated with increased housing values.

4.3. The influence of relative height on housing prices in the riverine areas, Calgary

The analytical results of spatial regression models in Table 2 support the idea that relative height significantly affects housing price after controlling for variables specified in the models, particularly flood elevation, view and location factors such as proximity to sports facility, river, park, and commercial. For single-family houses located within 1600 m from major rivers in Calgary, every 10-m increase in the property's relative height is associated with a positive housing price increase of 1.04 % (Model 1) before the event, and 1.16 % (Model 2) (corresponding to coefficients of 0.0103 and 0.0115, respectively) after the event. This measure suggests that both before and after the flood event, buyers may have recognized the risk of flooding, as indicated by relative height in the riverine areas. The flood elevation was statistically significant in both models, with higher flood elevations associated with higher housing price. While the relative height factor shows significance, the view factor showed insignificance in Model 1. However, for riverine properties, distance to the river (river accessibility) shows negative impact on housing prices with statistical significance: closer proximity to the river increases housing value.

4.4. The dynamics of relative height impact post-flood

Fig. 3 displays the results of spatial regression modeling, examining the relative height in 200-m intervals before and after the flood event. The relative heights in all 200-m interval models before and after the flood event are statistically significant up to 1400 m, except for the pre- and post-flood period in the 200–600 and 1200–1400-m intervals. When comparing the coefficients before and after the flood, housing units located within 0–200 m from the major rivers showed a 2.17 percentage point increase in value (from 4.77 to 6.94 %, corresponding to coefficients of 0.047 and 0.067, respectively), while controlling for other variables. Since the dependent variable is the log of housing price, coefficients indicate proportional changes. For instance, within this distance, the estimated value increase associated with every 10-m rise in ground elevation grew from $29,180 to $46,867 after the flood, with every 10-m rise in ground level. This result suggests that post-event, homebuyers were significantly more willing to pay a premium for properties at higher elevations.

However, beyond 200 m from the rivers, the coefficients significantly dropped and generally stabilized while maintaining statistical significance in most distance bands. Between 200 and 1200 m, the coefficients range from 0.6 % to 1.5 %, which is notably lower than the values observed within 200 m of the rivers. This shift suggests that the flood event significantly influenced the extent to which flood risk affects housing prices at a specific distance: the 200-m mark.

4.5. Trend of relative heights with distance pre- and post-flood in 200 m intervals

Fig. 3 also illustrates the trend of coefficients for relative height, examining variations within 200-m intervals before and after the flood event. The coefficients for relative height in all 200-m interval models before and after the flood event are statistically significant up to 1400 m, except for the pre-flood period in the 200–600-m and 1200–1400-m intervals. Although the coefficients of intervals between 200 and 600 m are lower than those between 600 and 1000 m, the overall trend suggests a decreasing effect with increasing distance. This pattern indicates that homebuyers are concerned about flood risks and are willing to pay more for a vertical premium, though the extent of that willingness varies with distance.

5. Discussion

The study conducted comprehensive analysis to understand the dynamics of housing prices in Calgary, particularly in riverine areas affected by the 2013 flood event. The research provides a nuanced understanding of how housing prices fluctuate over time, offering valuable insights for both academics and policymakers. This research marks the pioneering application of a hedonic model incorporating the relative height of houses based on actual flood elevation, rather than solely ground elevation, in a flood-prone riverine area. It provides valuable insights for estimating housing prices and managing floodplains. The findings demonstrate that relative height significantly impacts housing prices, with its effect decreasing as distance increases.

Consistent with prior research, structural characteristics such as living area, and features like building age and cooling system, exhibited significant impacts on housing prices (Zhang & Leonard, 2019). Larger living areas were consistently associated with higher selling prices, with an increase of 100 square feet translating to a 3.1 % rise in value across the models in Table 2. Moreover, the presence of certain features, such as walkouts, positively influenced housing prices, reflecting the geographical nuances of Calgary. In addition to structural attributes, the study also found the influence of location and neighborhood characteristics on housing prices, which aligns with previous empirical studies (Choi et al., 2021, 2023). The positive associations identified between proximity to amenities like rivers, schools, and public transportation, particularly LRT stations, highlight the significance of accessibility and convenience in driving property values. Conversely, the negative impact of proximity to bus stops and major roads underscores the importance of considering both positive and negative externalities associated with location when evaluating housing prices. Moreover, the study's exploration of neighborhood income levels further enriches our understanding of how socio-economic factors interact with housing dynamics, emphasizing the role of income disparities in shaping local housing markets.

5.1. Significance of relative height before and after the 2013 flood

The findings indicate that relative height significantly influences housing transactions, both three years prior to and following the 2013 flood event in Calgary. This result is likely due to home buyers' heightened awareness of flood risk in the riverine area, a crucial factor in shaping housing market dynamics. Relative height could serve as a proxy for flood risk, encompassing both projected or experienced riverine flood risk before the 2013 flood and confirmed flood risk after the event. The coefficient of relative height slightly increased after the flood compared to pre-flood levels, as shown in Table 2, and remained statistically significant, which is consistent with the patterns observed in Fig. 3 at the 200-m intervals. As illustrated in Fig. 3, the coefficients for relative height were statically significant up to 1400 m.

When comparing 200-m intervals before and after the flood, a notable increase in the apparent flood risk near the rivers can be observed up to a certain distance. Specifically, within 200 m from the rivers, there was an observable increase of buyers' awareness of flood risk after the event, as reflected in the heightened coefficients within this range. This finding (see Fig. 3) is consistent with previous research indicating that risk awareness tends to increase after a flood event (Jung & Yoon, 2018; Zhang & Leonard, 2019), leading to an increased willingness among buyers to pay premium prices for higher-ground houses (McKenzie & Levendis, 2010). However, it somewhat contradicts previous studies such as Rajapaksa et al.'s (2017), which suggest that amenities may outweigh flood risk in relation to river distance and elevation. While our study also confirms the significance of amenities, particularly river accessibility, it underscores the additional importance of relative height as a positively significant factor, possibly due to distinct geographic conditions and variable selections. Particularly, the relative heights in the riverine area of Calgary range between −28.88 and 173.30 m, whereas a previous study conducted in Brisbane, Australia, found absolute ground elevations ranging between 3.68 and 66.55 m (Rajapaksa et al., 2017). This disparity underscores the distinct geographic characteristics between the two regions and highlights the variability in elevation ranges within flood-prone areas. In addition, it highlights the complex relationship between elevation and flood risk. While elevation may represent flood risk, properties proximate to rivers indeed exhibit a higher premium for relative height after controlling flood elevation, emphasizing the complex interplay between geographic features and housing market dynamics in flood-prone areas like Calgary. It is also worth noting that floodplains and flood zones do not always align precisely with contour lines, and the extent of flooding can vary significantly across different locations, as mentioned earlier in Fig. 2. Absolute ground elevation may reflect flood risk only when flood elevations are consistent across the entire study area. Therefore, the higher premium associated with relative height, rather than absolute ground elevation, for properties near rivers further emphasizes the intricate nature of flood risk assessment in urban areas.

5.2. Relative height as a proxy of flood risk

Furthermore, as illustrated in Fig. 3, within 200 m from the rivers, the effectiveness of relative height increased after the flood. However, after 200 up to 1400-m intervals, the coefficients dropped significantly before and after the flood. This change may reflect a shift in perceived flood risk. Prior to 2013, past flood events in 1932 and 2005 had raised concerns about vulnerability in this zone. However, the 2013 flood, significantly more severe than earlier events (City of Calgary, 2022; Noad & Energy, 2014), revealed that areas especially between 200 and 400 m were relatively less affected, potentially reinforcing a sense of safety and reducing the perceived importance of elevation in this range. In contrast, within 200 m, the marked increase in the coefficient after the flood suggests that buyer's concerns about flood risk were confirmed by the 2013 event, increasing the relevance of relative height in property valuation in the most flood vulnerable areas. Similarly, Kousky (2010) confirmed this pattern by comparing housing prices before and after floods: prices remained stable for expected flood zones within the 100-year floodplain but declined for unexpected flood zones within the 500-year floodplain.

5.3. Modeling property values in riverine zones

This study represents the first examination of relative property height in relation to actual flood elevations, considering it as a factor affecting housing price in apparent flood risk. A hedonic property function is widely used to estimate the value of a product based on its characteristics, environmental, and amenities. Previous studies on housing prices have considered elevation as a factor alongside views and accessibility to amenities (Nicholls & Crompton, 2018). Additionally, other flood-related housing price studies have utilized flood risks (e.g., 100-year or 500-year floodplain), distance from flood zones, or ground elevation as indicators of flood risk affecting housing prices (Jung & Yoon, 2018; Kousky, 2010; Zhang & Leonard, 2019). These studies have often assumed that elevation increases gradually as distance from flood zones increases. Notably, this assumption may not hold true in areas with diverse topography and fluctuating flood elevations, such as hilly regions. Furthermore, designated floodplains or actual flood extents do not uniformly correlate with elevation, and even within the same neighborhood, floodwater elevation can vary significantly (see Fig. 2). Therefore, distance from flood risks and ground elevation may not adequately explain the vertical aspect of the real flood risks. Employing the relative height approach enables a more precise hedonic model for flood-prone riverine areas while also controlling for factors such as flood elevation, views and accessibility to amenities. Incorporating relative height as a variable enables more precise property assessments and more accurate estimations of flood insurance, especially for the National Flood Insurance Program in the US, although Canada does not require homeowners in floodplains to purchase flood insurance.

5.4. Policy implications for floodplain management

The City of Calgary has been actively sharing flood-related information with the public through its Open Data Portal, including the 2013 flood extent, 100-year and 500-year floodplains, flood history, flood preparedness, and other relevant data. In relation to the 2013 flood, the City also provides satellite flooding maps and GIS data online. After the event, the City developed and launched Calgary's Flood Resilience Plan, along with flood protection projects to mitigate future risks. Additionally, the City of Calgary and its residents commemorate the flood every June.

Identifying the vertical premium and its spatial variance in riverine areas would offer policymakers meaningful insights to formulate housing elevation strategies for flood-prone areas and floodplain management. The City of Calgary has recently updated its flood zones and is presently involved in the rezoning process for floodplain development (City of Calgary, 2024). Currently, within the 100-year floodplain, which includes floodway, flood fringe, and overland flow zones, regulations dictate that no new buildings can be constructed in the floodway area, except for the replacement of existing buildings on the same footprint (City of Calgary, 2007). However, new construction is allowed in the flood fringe and overland flow areas, subject to building setback requirements and base floor elevation above flood levels.

Our research highlights the significant impact of relative height on housing prices, which consequently influences on tax amounts. Building on this insight, the importance of the vertical premium in riverine areas suggests that implementing elevated base floor elevations for floodplain development, incentivized through construction subsidies, tax breaks, or density bonuses, holds promise for enhancing safety and mitigating the need for post-disaster recovery assistance. While flooding is not a frequent event in Calgary, proactive adaptation to extreme rainfall induced by climate change warrants expanding these measures to encompass the 500-year floodplain. The Houston case, where new homes are required to be elevated two feet above the 500-year flood elevation (City of Houston, 2018), underscores the importance of such measures. Additionally, this relative height enables insurance companies to accurately calculate insurance premiums based on the relative height, rather than solely on whether a property is in a flood zone, such as a 100-year or 500-year floodplain.

5.5. Limitations

While this research represents significant findings in utilizing a spatial hedonic model that incorporates relative elevation to evaluate housing prices and manage floodplains in riverine areas, it is important to acknowledge its limitations. First, generalizing the results may be challenging due to Calgary's specific geographic and flooding conditions. Calgary's hilly geography may differ from that of other flood-prone areas or coastal regions with flat ground elevation or constant flood elevation. Second, the study's hedonic model may not account for other potential factors influencing housing prices, such as socio-economic changes, housing market dynamics, or policy interventions. Third, the spatial distribution of samples in 200-m intervals from rivers may introduce biases, potentially affecting the observed effects of relative height on housing prices. Finally, using a dummy variable to approximate viewscapes presents a limitation, as it does not capture their full complexity and variation. However, it was selected for its credibility and consistency. Although alternative methods, such as those using street-level imagery, were considered, they were not employed since they typically fail to reflect interior-facing views relevant to housing valuation.

To address these limitations, future research should examine how relative height influences housing prices across diverse geographic settings, including low-lying areas with gradually increasing elevations that are prone to flooding. Additional attention should be given to socio-economic dynamics and policy changes that may affect this relationship. Future studies could also explore the evolution of flood risk perception over time, particularly in the aftermath of flood events, by employing survey-based approaches to directly measure flood-related perceptions and their influence on housing prices. In addition, adopting more advanced techniques that better capture the views experienced from within residential spaces could improve the model's accuracy. Such investigations will contribute to a more comprehensive understanding of how relative height, risk perception, and property value interact across various spatial and social contexts.

6. Conclusion

This study marks a significant advancement in understanding the impact of flood risk awareness on housing prices in riverine areas. By incorporating relative height from actual flood levels into a hedonic model in flood-prone areas, it provides valuable insights for estimating housing prices and managing floodplains effectively. The findings underscore the substantial influence of relative height on housing transactions, both before and after the 2013 flood event in Calgary. Specifically, our analysis reveals that the relative height factor exhibited a positive significance on housing prices in riverine areas, translating to an average increase of 1.1 % for every 10-m rise in height. This indicates that homebuyers in Calgary are willing to pay a premium for properties with higher elevations in the riverine areas. Moreover, following the flood event, within a distance of 0 to 200 m from the rivers, this impact intensifies to 6.94 % for every 10-m increase in height, highlighting the heightened importance of relative height in close proximity to rivers. This knowledge underscores how relative height significantly shapes the sense of safety from flood risks, thereby influencing housing prices. Furthermore, our study underscores the necessity of considering relative height alongside other factors such as flood elevation, amenities and distance from flood zones when accurately modeling housing prices in flood-prone regions. These insights are particularly relevant for floodplain management and urban planning efforts, as demonstrated by the potential for elevated base floor elevations to mitigate flood risks and enhance community resilience.

CRediT authorship contribution statement

Youjung Kim: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bon Woo Koo:** Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Sungmin Lee:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization.

Funding

None.

Declaration of competing interest

We have no conflicts of interest to disclose.

Acknowledgements

The authors sincerely thank Ann-Marie Lurie of the Calgary Real Estate Board (CREB), Shane Griffin and Ryan Fortier of Pillar 9™, and Renna Truong of Spatial and Numeric Data Services (SANDS) at the University of Calgary for generously providing the essential datasets used in this research. They are also grateful to Dr. John Park at the University of Maryland for his invaluable support and guidance. Finally, they appreciate the anonymous reviewers for their constructive feedback, which helped improve the quality of this manuscript.

Appendix A

Table 1
Model results of pre- and post-flood in 200-m intervals.

	0–200 m		200–400 m		400–600 m		600–800 m		800–1000 m		1000–1200 m		1200–1400 m		1400–1600 m	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Relative Height (10 m)	0.0466**	0.0671***	0.0141*	0.0124	0.0061	0.0071	0.0150***	0.0131***	0.0137***	0.0150***	0.0097**	0.0103**	0.0053*	0.0044	0.0011	0.0021
	(0.0145)	(0.0151)	(0.0057)	(0.0060)	(0.0046)	(0.0041)	(0.0033)	(0.0032)	(0.0035)	(0.0035)	(0.0035)	(0.0033)	(0.0025)	(0.0023)	(0.0025)	(0.0026)
Bedroom No.	0.0103	0.0243*	0.0066	−0.0045	0.0100	0.0180**	0.0196***	−0.0034	0.0116*	0.0043	0.0194***	0.0083	0.0278***	0.0143**	0.0087	0.0059
	(0.0110)	(0.0120)	(0.0062)	(0.0060)	(0.0059)	(0.0055)	(0.0047)	(0.0048)	(0.0050)	(0.0051)	(0.0049)	(0.0049)	(0.0047)	(0.0045)	(0.0049)	(0.0046)
Living Area (100sqft)	0.0278***	0.0308***	0.0318***	0.0319***	0.0317***	0.0330***	0.0339***	0.0333***	0.0338***	0.0328***	0.0319***	0.0328***	0.0301***	0.0294***	0.0298***	0.0288***
	(0.0017)	(0.0018)	(0.0011)	(0.0011)	(0.0012)	(0.0010)	(0.0092)	(0.0096)	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0011)	(0.0010)	(0.0012)	(0.0011)
Building Age	−0.0067***	−0.0018***	−0.0066***	−0.0035***	−0.0032***	−0.0030***	−0.0046***	−0.0029***	−0.0042***	−0.0029***	−0.0043***	−0.0020**	−0.0024**	−0.0028***	−0.0037***	−0.0045***
	(0.0014)	(0.0005)	(0.0008)	(0.0008)	(0.0008)	(0.0007)	(0.0006)	(0.0006)	(0.0007)	(0.0007)	(0.0008)	(0.0008)	(0.0008)	(0.0007)	(0.0008)	(0.0007)
Building Age (squared)	4.72E−5***	8.43E−7***	4.33E−5***	2.01E−5**	2.03E−5*	2.81E−5***	3.61E−5***	2.03E−5***	3.13E−5***	2.70E−5***	3.77E−5***	1.90E−5*	2.99E−6	1.98E−5**	1.99E−5*	3.45E−5***
	(1.32E−5)	(2.29E−7)	(8.06E−6)	(7.41E−6)	(7.98E−6)	(6.51E−6)	(6.47E−6)	(6.00E−6)	(7.16E−6)	(7.00E−6)	(8.02E−6)	(7.57E−6)	(7.19E−6)	(6.31E−6)	(8.10E−6)	(6.85E−6)
Basement Finished	0.1022***	0.0730**	0.0911***	0.0959***	0.0810***	0.0742***	0.0636***	0.0729***	0.0833***	0.0682***	0.0756***	0.0649***	0.0461***	0.0507***	0.0516***	0.0616***
	(0.0230)	(0.0243)	(0.0119)	(0.0116)	(0.0106)	(0.0102)	(0.0084)	(0.0089)	(0.0088)	(0.0092)	(0.0085)	(0.0084)	(0.0080)	(0.0076)	(0.0082)	(0.0076)
Walkout	0.1355***	0.0963**	0.0596***	0.1219***	0.0656***	0.0855***	0.0629***	0.0616***	0.0954***	0.0914***	0.0879***	0.0977***	0.0950***	0.0783***	0.0516***	0.0654***
	(0.0312)	(0.0316)	(0.0185)	(0.0180)	(0.0190)	(0.153)	(0.0147)	(0.0141)	(0.0156)	(0.0149)	(0.0148)	(0.0144)	(0.0151)	(0.0138)	(0.0152)	(0.0138)
Cooling	0.0714**	0.0741**	0.0575***	0.0508***	0.0224	0.0318**	0.0316	0.0481***	0.0512***	0.0366***	0.0307**	0.0591***	0.0419***	0.0167	0.0078	0.0470***
	(0.0258)	(0.0264)	(0.0139)	(0.0127)	(0.0136)	(0.0113)	(0.0116)	(0.0103)	(0.0122)	(0.0110)	(0.0112)	(0.0100)	(0.0113)	(0.0095)	(0.0118)	(0.0099)
View	−0.0005	−0.0003	−0.0304	0.0198	0.0197	0.0064	−0.0227	0.0014	0.0013	−0.0147	0.0096	0.0014	−0.0105	0.0045	0.0143	0.0001
	(0.0357)	(0.0262)	(0.0182)	(0.0123)	(0.0169)	(0.0106)	(0.0128)	(0.0098)	(0.0145)	(0.0098)	(0.0143)	(0.0093)	(0.0128)	(0.0082)	(0.0126)	(0.0082)

(continued on next page)

Table 1 (*continued*)

	0–200 m		200–400 m		400–600 m		600–800 m		800–1000 m		1000–1200 m		1200–1400 m		1400–1600 m	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Proximity to Sports Facility (100 m)	0.0051	0.0042	**0.0122***	**0.0203*****	0.0068	0.0035	−0.0002	**0.0114****	0.0001	**0.0119***	−0.0012	−0.0011	−0.0038	**−0.0108****	0.0046	−0.0039
	(0.0085)	(0.0086)	(0.0054)	(0.0052)	(0.0061)	(0.0050)	(0.0050)	(0.0044)	(0.0050)	(0.0049)	(0.0048)	(0.0045)	(0.0049)	(0.0040)	(0.0052)	(0.0050)
Proximity to River	**−0.1539*****	**−0.0899*****	**−0.0344****	−0.0178	−0.0047	−0.0038	0.0041	0.0003	−0.0082	−0.0147	−0.0204	−0.0161	−0.0098	−0.0125	−0.0155	−0.0093
	(0.0273)	(0.0271)	(0.0119)	(0.0118)	(0.0115)	(0.0097)	(0.0091)	(0.0088)	(0.0090)	(0.0091)	(0.0091)	(0.0090)	(0.0092)	(0.0082)	(0.0090)	(0.0085)
Proximity to Park (100 m)	0.0158	0.0176	−0.0039	−0.0024	−0.0074	0.0010	**0.0188***	**0.0148***	**0.0284*****	0.0053	**0.0218****	**0.0214****	**0.0334*****	**0.0252*****	0.0057	0.0137
	(0.0157)	(0.0156)	(0.0095)	(0.0098)	(0.0095)	(0.0097)	(0.0077)	(0.0071)	(0.0074)	(0.0074)	(0.0070)	(0.0072)	(0.0079)	(0.0073)	(0.0081)	(0.0073)
Proximity to Commercial (100 m)	−0.0007	−0.0023	0.0050	−0.0025	**−0.0106****	**−0.0084***	**−0.0104****	**−0.0082****	−0.0011	−0.0049	**−0.0066***	**−0.0062***	**−0.0068***	**−0.0052***	−0.0003	−0.0014
	(0.0064)	(0.0072)	(0.0038)	(0.0038)	(0.0038)	(0.0034)	(0.0035)	(0.0031)	(0.0033)	(0.0033)	(0.0027)	(0.0025)	(0.0028)	(0.0026)	(0.0031)	(0.0031)
Proximity to School (100 m)	**−0.0108***	−0.0045	**−0.0164*****	**−0.0149*****	**−0.0136*****	**−0.0080*****	**−0.0102*****	**−0.0078*****	**−0.0049***	**−0.0064****	**−0.0082*****	**−0.0060***	**−0.0079****	**−0.0072****	−0.0021	−0.0008
	(0.0046)	(0.0048)	(0.0029)	(0.0029)	(0.0028)	(0.0024)	(0.0023)	(0.0019)	(0.0023)	(0.0020)	(0.0021)	(0.0020)	(0.0026)	(0.0022)	(0.0034)	(0.0035)
Flood Elevation	**0.0022***	0.0014	**0.0015****	**0.0017****	**0.0032*****	**0.0027*****	**0.0028*****	**0.0027*****	**0.0022*****	**0.0020*****	**0.0018*****	**0.0017*****	**0.0016*****	**0.0017*****	**0.0010***	0.0008
	(0.0010)	(0.0009)	(0.0005)	(0.0005)	(0.0005)	(0.0004)	(0.0003)	(0.0003)	(0.0004)	(0.0003)	(0.0003)	(0.0003)	(0.0004)	(0.0003)	(0.0004)	(0.0004)
Population Density (1000people/sqkm)	−0.0060	0.0118	0.008	0.0028	0.0097	**0.0085**	0.0022	0.0053	**0.0137****	**0.0121***	0.0084	−0.0062	**0.0120***	0.0048	**0.0200*****	0.0025
	(0.0101)	(0.0110)	(0.0061)	(0.0063)	(0.0055)	(0.0046)	(0.0045)	(0.0041)	(0.0044)	(0.0050)	(0.0052)	(0.0049)	(0.0049)	(0.0043)	(0.0048)	(0.0046)
Visible Minority	−0.0020	0.0091	**0.0037****	**0.0042*****	**0.0025***	0.0010	**−0.0016*****	**−0.0025*****	**−0.0016***	−0.0009	0.0006	**−0.0018****	−0.0011	0.0003	−0.0004	−0.0003
	(0.0021)	(0.0019)	(0.0012)	(0.0011)	(0.0010)	(0.0009)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0007)	(0.0007)	(0.0007)	(0.0006)	(0.0007)	(0.0007)
Median Income (10,000 CAD)	**0.0168*****	**0.0122*****	**0.0019*****	**0.0014*****	**0.0184*****	**0.0125*****	**0.0163*****	**0.0188*****	**0.0219*****	**0.0229*****	**0.0241*****	**0.0228*****	**0.0297*****	**0.0243*****	**0.0381*****	**0.0263*****
	(0.0021)	(0.0019)	(0.0001)	(0.0001)	(0.0013)	(0.0012)	(0.0013)	(0.0014)	(0.0017)	(0.0017)	(0.0019)	(0.0018)	(0.0023)	(0.0021)	(0.0027)	(0.0027)
Proximity to Major Road (100 m)	**0.0335*****	**0.0242****	**0.0179*****	**0.0180*****	**0.0218*****	**0.0241*****	**0.0272*****	**0.0241*****	**0.0202*****	**0.0147*****	**0.0090***	**0.0117****	**0.0167*****	**0.0105****	**0.0199*****	**0.0175*****
	(0.0078)	(0.0081)	(0.0044)	(0.0044)	(0.0042)	(0.0037)	(0.0039)	(0.0036)	(0.0040)	(0.0040)	(0.0042)	(0.0041)	(0.0043)	(0.0039)	(0.0049)	(0.0048)
Proximity to LRT Station (100 m)	**−0.0081*****	**0.0101*****	**−0.0092*****	**−0.0083*****	**−0.0048*****	**−0.0050*****	**−0.0047*****	**−0.0045*****	**−0.0046*****	**−0.0048*****	**−0.0042*****	**−0.0040*****	**−0.0037*****	**−0.0040*****	**−0.0046*****	**−0.0052*****
	(0.0015)	(0.015)	(0.0009)	(0.0009)	(0.0008)	(0.0007)	(0.0006)	(0.0005)	(0.0006)	(0.0005)	(0.0006)	(0.0005)	(0.0005)	(0.0005)	(0.0006)	(0.0006)
Proximity to Bus Stop (100 m)	−0.0077	−0.0054	**0.0430*****	**0.0427*****	**0.0637*****	**0.0437*****	**0.0340*****	**0.0275*****	**0.0256*****	**0.0144***	**0.0194****	**0.0142***	**0.0239*****	**0.0333*****	0.0078	0.0122
	(0.0108)	(0.0114)	(0.0071)	(0.0070)	(0.0083)	(0.0074)	(0.0069)	(0.0062)	(0.0070)	(0.0067)	(0.0061)	(0.0066)	(0.0072)	(0.0066)	(0.0073)	(0.0072)
Observations	**675** (134)[a]	**571** (82)	**1413** (29)	**1306** (21)	**1482** (1)	**1519**	**1882**	**1844**	**1686**	**1732**	**1743**	**1715**	**1802**	**1792**	**1623**	**1703**

Note. a. Housing numbers within the 2013 flood extent in each interval are stated in parentheses in the 'Observations' section. The dependent variable is log price of the property. Year of sale fixed effects. Standard errors are stated in parentheses. Standard errors are stated in parentheses. Significant coefficients are printed in bold.

*** $p < 0.001$.

** $p < 0.01$.

* $p < 0.05$.

Data availability

The authors do not have permission to share data.

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