Factors that influence household decision-making on property-level flood protection investment: Insights from a stated preference study

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Extreme rainfall events have been increasing in severity and frequency, posing a greater flood risk to Canadian homeowners than ever before. As a result, the expected benefits of property-level defensive actions to protect against flooding are growing, particularly in older and high-risk homes. This study aimed to understand the decision-making process concerning household investment in property-level flood protection (PLFP) measures, analyze whether specific PLFP devices were beneficial from a household perspective, and learn which factors were most salient to household choice. Data were collected through a household survey in mature neighbourhoods in Edmonton, Alberta, Canada. The principal method used was stated preference to elicit homeowners' willingness-to-pay (WTP) for two PLFP devices: backwater valves and sump pump systems. The design included varying monetary incentives to understand their impact on consumer choice. In addition to preferences, the survey collected information on several factors deemed likely to influence choice, including risk perceptions and prior flood experience. Results showed average market cost to purchase and install these devices was higher than average WTP of households in our sample. Through econometric analysis we found choice to purchase PLFP was influenced by monetary incentives, risk perceptions, and the belief that protective measures will work to protect a home from flooding.

JEL: L95, Q25, Q53

Keywords: Stated Preference, Willingness-to-Pay, Monetary Incentives, Risk Perceptions, Flood Protection

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Acknowledgements: We gratefully acknowledge the funders of this research: Mitacs (via an Internship with the Institute for Catastrophic Loss Reduction) and the Social Sciences and Humanities Research Council. We would like to thank John Parkins (University of Alberta), Evan Davies (University of Alberta), Brandon Katz (KatRisk), and Susan Ancel (EPCOR) for their support and sharing their expertise. We also thank Huma Pabani and TD Insurance for their support and connections to the Showcase Homes Initiative.

Disclosure statement: The authors declare no conflicts of interest. The data that support the findings of this study are available from the corresponding author upon reasonable request. This study received ethics clearance on June 10, 2022, under the ID Pro00111805.

Manuscript received: 9 May 2025; final version accepted: 16 Jan 2026; available online: 16 Feb 2026.

Available at https://www.journalofwatereconomics.com.

1 Introduction

Floods are the costliest natural hazard in Canada, causing on average $1.2 billion CAD in losses annually to homes and businesses across the country (Swiss Re, 2016). While some areas face risk of flooding from overflowing rivers or coastal storm surges, almost all areas in Canada are at risk of potential flood damage from sudden and severe rainfall events (pluvial flooding). In recent decades, extreme rainfall events have been increasing in their severity and frequency (Actuaries Climate Index, 2023; IBC, 2019), posing a greater risk to Canadian homeowners than ever before. Urban areas are particularly vulnerable due to various factors including aging sewer and stormwater infrastructure that cannot accommodate excess flow, the increase in impermeable surfaces associated with densification, and the increase in homes with finished basements (CCA, 2022; IBC, 2019; CIRC, 2019). Therefore, the benefits associated with property-level defensive action to limit homeowners' exposure to flooding are becoming more pronounced. The costs associated with flooding are also borne by local governments and insurers, which underscores the public value in reducing household exposure. Consequently, numerous municipalities and few insurers across Canada offer programs with monetary incentives to assist homeowners in implementing property-level flood protection (PLFP). However, many homeowners do not participate in risk-reducing actions, despite the availability of incentives to do so (Sandink, 2016). The overall objective of this study was to better understand the decision-making process concerning homeowner investment in PLFP measures, to analyze whether specific PLFP devices were beneficial from a household cost perspective, and to learn which behavioural factors were most salient to household choice.

2 Literature

Previous research examining the behavioural drivers of protective action against flooding has been grounded in the Protection Motivation Theory (PMT) framework. PMT suggests that protective behaviours are shaped by two key cognitive processes: 1) threat appraisal – an individual's perceived vulnerability (i.e. risk perception) and perceived severity of consequences, and 2) coping appraisal – an individual's assessment of self-efficacy as well as the efficacy and cost of protective action (Grothmann and Reusswig, 2006). The literature has generally found coping appraisal as a stronger and more consistent predictor of whether an individual will take protective action compared to threat appraisal (Weyrich et al., 2020; Bubeck et al., 2018; Babcicky and Seebauer, 2019; Poussin et al., 2014; Bubeck et al., 2013; Terpstra and Lindell, 2012; Grothmann and Reusswig, 2006). However, there is considerable variability regarding which PMT elements are found to be significant across the literature (Bubeck et al., 2012a). This inconsistency is likely attributable to methodological differences across studies, but there are also notable limitations inherent to the PMT framework. Grahn and Jaldell (2019) suggested that PMT's explanatory power may be constrained by existing knowledge of the issue, since individuals must first recognize and understand the threat they face before they can adequately appraise it. Weyrich et al. (2020) highlighted that PMT does not consider the heterogeneity of the public and how individuals may respond differently to the various elements of threat and coping appraisal. Lastly, several studies suggest that PMT does not sufficiently account for relevant factors that may influence threat and coping appraisal including experience, psychological characteristics, social environment, and incentives, which can also influence behaviour (Weyrich et al., 2020; Bubeck et al., 2018; Poussin et al., 2014; Zaalberg et al., 2009).

Empirical studies on willingness-to-pay (WTP) for flood protection – whether through insurance, public infrastructure, or PLFP – indicate that it is most strongly associated with risk perceptions (Netusil et al., 2021; Withey et al., 2019; Oulahen, 2015; Botzen and van den Bergh, 2012), prior flood experience (Thistlethwaite et al., 2018; Owusu et al., 2015), and income (Netusil et al., 2021; Owusu et al., 2015; Brouwer et al., 2008; Zhai et al., 2006; Clark et al., 2002). While WTP for flood protection has been examined in various contexts, empirical research focusing specifically on the drivers of WTP for PLFP remains limited. Thistlethwaite et al. (2018) found most Canadian households in their survey were willing to pay under $1,000 CAD for non-specific PLFP to protect against flood damage. Their results indicated that income, ownership, and house type were most significantly linked with WTP and adoption of PLFP. Joseph et al. (2015) found that the average WTP of households in the United Kingdom to avoid intangible flood impacts was approximately $1,222 CAD (£653), annually, for non-specific property level flood risk adaptation. Their results indicated that WTP was most influenced by stress of flood, worrying about loss of house value, and worrying about future flooding. Owusu et al. (2015) found that households in the United Kingdom were willing to pay an average of approximately $1,550 CAD (£795) for various PLFP to prevent damage to their homes from river flooding. Their results indicated that household income, age, employment status, prior PLFP expenditure, and prior financial and social flood impacts were all positively associated with WTP. They also reported that the majority of households in their survey were unwilling to pay for flood protection, citing affordability as the primary reason.

The literature on financial incentives, specifically for PLFP adoption to reduce flood risk and damage, is also limited. Botzen et al. (2009) surveyed households in the Netherlands on their willingness to undertake flood mitigation actions in exchange for an $8-16 CAD (€5-10) annual discount on their flood insurance premium. These actions included: purchasing twenty sandbags for $32 CAD (€20), relocating laundry machines to a higher floor, and relocating the central heating boiler to a higher floor when it needed replacement. Their results found that incentives were effective in motivating the purchase of sandbags, but not the relocation and re-installation of household equipment, suggesting that financial incentives may be most effective when the required action is relatively inexpensive, convenient, and easy to implement. Poussin et al. (2014) investigated the impact of financial incentives for the adoption of flood protection measures in France. The study found that insurance discounts were significant for households implementing structural or non-structural (avoidance) measures, while municipal subsidies were only significant for emergency preparedness. Finally, using an experimental game, Mol et al. (2020) found that financial incentives, in the form of insurance premium reductions, significantly increased household self-insurance (i.e. investment in flood mitigation measures).

Despite these contributions, there is room for further exploration of factors that influence PLFP uptake. Building on PMT, our research explicitly links threat and coping appraisals with a household WTP study, allowing us to examine how much individuals value PLFP and also how perceptions of risk and efficacy also shape their decisions. In addition, we combine the analysis of WTP for PLFP with the role of financial incentives to assess whether such incentives are a significant motivator for action. To reduce the hypothetical bias often present in stated-preference studies, our design embeds WTP questions within realistic scenarios for both the PLFP measures and the incentives being offered, thereby providing results that are more directly relevant to policy and practice.

3 Methodology

3.1 The Devices

Using stated preference methods, this study assessed household WTP for two PLFP devices: backwater valves and sump pump systems. These devices are both private goods for which homeowners bear the costs of purchase, installation, and maintenance. The primary function of a backwater valve is to protect against sewer backup by blocking the reverse flood of wastewater, while sump pump systems are designed to remove excess groundwater from around the foundation of the home, reducing the potential for infiltration (i.e. seepage). Sewer backup occurs when heavy rainfall overwhelms the municipal sewer system, causing rainwater and sewage to flow into a home through an input source, such as a floor drain, toilet, or shower. Infiltration (seepage) occurs when heavy or prolonged rainfall saturates the soil surrounding a home's foundation or raises groundwater levels to a point where water enters the home through cracks in the foundation floors or walls.

The two devices were chosen to be the focus of the study for several reasons. First, their installation in new homes has been required in the study city, Edmonton, since 1988 (City of Edmonton, 2020), thus they reflect what the municipality considers effective PLFP. Second, these devices are easily defined goods in terms of their price, implementation, and maintenance and are relatively consistent across properties, unlike other PLFP measures (i.e., lot grading, window well installation, etc.). The ability to clearly define the good is fundamental to achieving accurate results using stated preference. Third, the study aimed to understand the impact of monetary incentives on homeowners' WTP for flood protection. The installation of these two devices as retrofits in older homes is already incentivised by municipalities and insurance companies, making them realistic choices. The City of Edmonton, for example, offers a one-time $800 CAD subsidy for the installation of backwater valves to households that own homes built before 1980 and have undertaken their free inspection program. While not as common, some insurance companies integrate protective measures that reduce risk of flood damage, such as backwater valves, into their calculation for premiums at the time of enrollment.

Detailed descriptions of the devices were provided to homeowners before being presented with the stated preference questions to ensure all respondents had a clear and consistent understanding of the proposed PLFP. These descriptions included an explanation of how the device works to prevent flooding, the installation process, and maintenance requirements.

3.2 Stated Preference Design

Stated preference methods are commonly used to value non-market goods, such as environmental quality; however, these methods can also be employed to estimate WTP for private goods and are used in marketing research to understand factors that drive product demand (Doyon et al., 2015). These methods are used to understand WTP when revealed data is not readily available and can also be used to determine preferences for new attributes or characteristics of private goods that are non-existent or uncommon in the market. Through the use of stated preference, our objective was to determine whether homeowners' WTP for PLFP is comparable to the real market cost and whether the addition of clear financial incentives has an impact on WTP.

The stated preference method employed in this study combines elements of contingent valuation (elicitation of responses from a "yes/no" purchase decision), choice experiments (presenting scenarios where attributes of the options vary), and stochastic payment cards (elicitation of how likely an individual would be to purchase a good under different price scenarios). We used this combination to best address concerns with hypothetical bias, while also generating more information than a simple binary contingent valuation question.[1] This modified stochastic payment card approach, as outlined in Wang and Whittington (2005), was used in the questionnaire to present the WTP questions for the two devices. The choice for each homeowner was whether or not they would purchase each device at 11 different price points presented on the payment card (from $0 to $2500 CAD, in $250 CAD intervals) to reduce their risk of flooding from their perceived risk levels (asked in an earlier question) to almost zero. Homeowners were given four choice options for each price point (definitely yes, probably yes, probably no, definitely no). To minimize hypothetical bias the stated preference questions were only presented to respondents who might realistically consider purchasing the device. Eligible respondents met all three of the following criteria: (1) the respondent stated that they were a homeowner; (2) the respondent stated that they did not already have (or did not know if they had) these specific devices; and (3) the respondent would have indicated a perceived percentage risk above zero for sewer backup and/ or infiltration. A one-time subsidy from the City of Edmonton's public utility company and a discount on insurance premiums were also incorporated and varied across respondents using a split sample design. These were included to assess whether financial incentives had an impact on WTP. Both upfront and net cost were presented on the payment card, therefore the subsidy was a contextual factor that reflected the municipality's "stake" in the scenario (see Figure 1).

As shown in Table 1, each device had 16 different incentive combinations possible, consisting of one of four subsidies and one of four insurance premium discounts, which were randomly assigned to each respondent. These incentives were hypothetical; however, the municipal subsidies were based on an actual range of subsidy values offered across Canadian municipalities for PLFP. Since the study city, Edmonton, has a municipal subsidy,

[1] Although single binary choice is a more widely adopted approach in valuation studies, it has been shown that this method is not incentive compatible with private good valuation (Johnston et al., 2017; Carson and Groves, 2007). Additionally, since our study had a relatively small number of observations, a single binary choice method would provide limited information. The stochastic payment card approach was chosen for this study as it provides more information per observation and has been used in recent environmental valuation studies where private goods are involved (Ingram et al., 2023; Adamowicz et al., 2019).

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Earlier in this survey, you stated that your chance of flooding from sewer backup was **20%**

Assume installing a backwater valve in your home will **reduce your chance of sewer backup flooding to almost 0%** (with proper maintenance of the device).

Also assume that, with the installation of a backwater valve:

- The City of Edmonton/EPCOR will give you a **one-time $600 subsidy (rebate)** for the installation.
- Your insurance company will give you an **annual $25 discount** off your home insurance premium.

To get the subsidy you will need to have your home inspected, fill out paper work, and book a contractor for installation (approx. 2 hours). You will also need to be home for the installation of the device and a follow-up inspection (approx. 4-12 hours).

The subsidy will be given to you *after* the installation is complete, which means you will have to pay the full cost of the device and installation upfront. This is shown in the chart below as the **upfront cost**. The final cost to you, after you receive the subsidy, is shown in the chart below as the **final net cost**.

Upfront Cost	Final Net Cost	**How likely are you to install a backwater valve if the total cost to you is....?** *Please select one choice per row.*			
		Definitely Yes (100% Likely)	Probably Yes (51-99% Likely)	Probably No (1-49% Likely)	Definitely No (0% Likely)
$600	**$0**	○	○	○	○
$850	**$250**	○	○	○	○
$1,100	**$500**	○	○	○	○
$1,350	**$750**	○	○	○	○
$1,600	**$1,000**	○	○	○	○
$1,850	**$1,250**	○	○	○	○
$2,100	**$1,500**	○	○	○	○
$2,350	**$1,750**	○	○	○	○
$2,600	**$2,000**	○	○	○	○
$2,850	**$2,250**	○	○	○	○
$3,100	**$2,500**	○	○	○	○

Figure 1: Example of Payment Card Used to Elicit WTP in Questionnaire

a $0 incentive option was not included to reduce hypothetical bias. Some insurance companies in Canada provide premium discounts for existing PLFP when signing a new insurance policy; however, the amount reduced is typically not advertised, it is instead included as part of their calculation when considering all elements of risk to a home. The values chosen for the insurance premium discounts were informed by a partner insurance company.

Table 1: Financial Incentive Levels Incorporated into Stated Preference Design (CAD $)

Backwater Valve		**Sump Pump System**	
One-Time Subsidy	Annual Insurance Discount	One-Time Subsidy	Annual Insurance Discount
$600	$25	$1,200	$25
$800	$50	$1,400	$50
$1,000	$75	$1,600	$75
$1,200	$100	$1,800	$100

The upfront and net costs included in the payment card were developed using data collected from local plumbers. The plumbers were asked to provide either a low-high range or average cost of the device and its installation as retrofits in older homes. If a plumber provided a low-high range, the mid-point was taken to calculate the average. The costs varied substantially from plumber to plumber. Overall, the average reported cost of a backwater valve was $2,137 CAD, while the average cost for a sump pump system was $2,868 CAD (see Table 2). Using the low and high ranges provided by local plumbers, we were able to construct subsidy amounts that, when combined with the net cost to households, would equal realistic total costs for these devices and their installation.

Table 2: Average Cost of Flood Protection Devices and Installation, Reported by Local Plumbers (CAD $)

	Backwater Valve (n=19)	**Sump Pump System** (n=14)*
Average Cost	$2,137	$2,868
Lowest Average Cost	$950	$1,300
Highest Average Cost	$3,000	$4,600

*One outlier was removed from the calculations.

There are several criticisms of stated preference methods, the most common of which is the susceptibility to hypothetical bias (i.e., the difference between what a person indicates they would pay and what a person would actually pay in a non-hypothetical scenario). The existence of hypothetical bias has led to evidence of overstatement of WTP (List and Gallet, 2001). As a result, there has been a substantial amount of literature that has examined ways to reduce hypothetical bias (Johnston et al., 2017; Loomis, 2014; Arrow et al., 1993). Several recommendations from these studies were incorporated into our design, including a clear and thorough description of the devices and payment vehicle, acknowledgment of hypothetical bias prior to presenting the WTP question as well as reminders of budget constraints and substitutes (cheap talk script), and the inclusion of debriefing questions designed to identify bias and/ or strategic behavior.

3.3 Survey Overview

The household survey was conducted in four mature neighbourhoods in Edmonton, Alberta, Canada (see Figure 2). These neighbourhoods pre-date several mandatory development bylaws related to current techniques used for public and private management of extreme rainfall, indicating a higher-than-average flood risk. Although survey recruitment was conducted door-to-door, the questionnaires were issued to households using the online survey software Qualtrics.

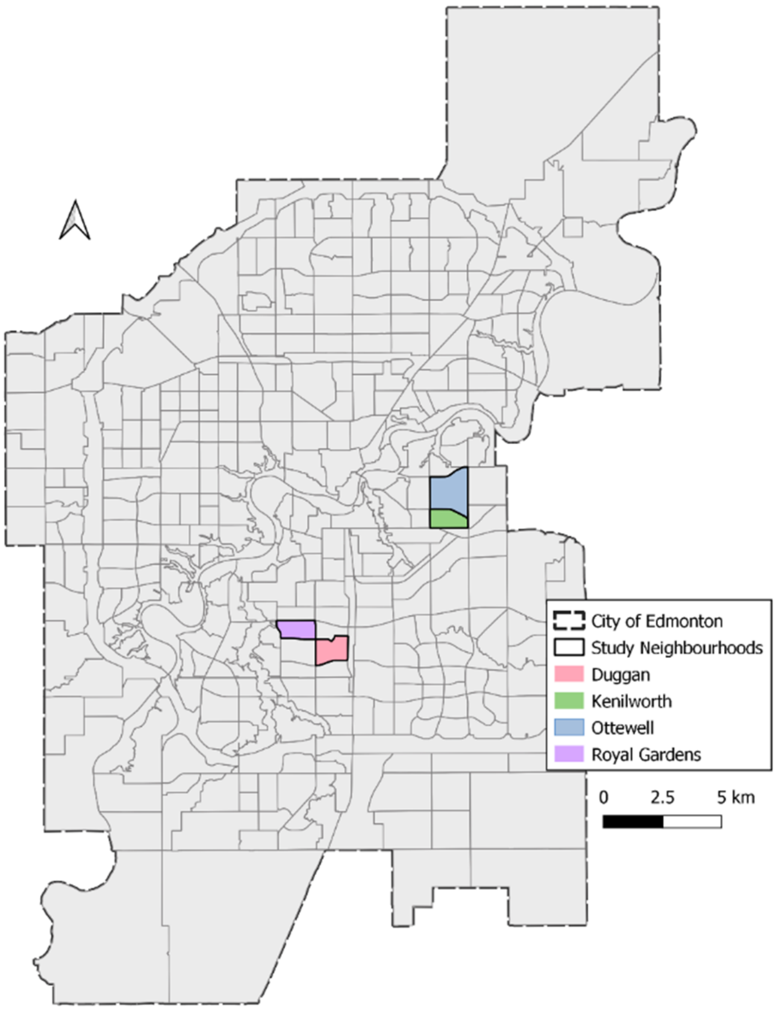

Figure 2: Map of Study Neighbourhoods in Edmonton

A small pilot survey was conducted between May 31 and June 1, 2022, to assess question clarity and any technical difficulties with the survey software. Given project time constraints, the pilot was conducted by going door-to-door to randomly selected households in the selected neighbourhoods, until a household agreed to complete the online questionnaire and provide feedback within the week. In total, 18 questionnaire access letters were distributed and four completed questionnaires were received (22% response rate). The questionnaire was then adjusted following suggestions from the pilot households and academic colleagues.

The main survey was conducted from June 13 to July 12, 2022. To increase the response rate, the survey consisted of two visits to each home – the initial contact visit and the follow-up visit as a reminder. Homes in each neighbourhood were selected using a systematic random sampling method of the City of Edmonton's Property Assessment data. The sample was 752 households out of a total population of 4,998. Of the 752 households included in the survey sample, 196 completed the questionnaire. The overall response rate was 26% and the response rate between the four neighbourhoods was consistent – between 25 and 27%.

4 Descriptive Results

Of the 200 respondents (196 survey households and 4 pilot households), 94% were homeowners. Homeowners were the primary target of the survey, as they are best positioned to make financial decisions regarding PLFP. The average length of homeownership was 25 years, while the average length of homeownership in their current home was 19 years. Furthermore, 96% of homes surveyed were built before 1980, i.e., before the Edmonton bylaw that required new homes to have backwater valves and sump pump systems. Summary statistics can be found in Appendix A.

Households were asked a variety of questions about flooding and protection (see Table 3). The descriptive results revealed numerous gaps in awareness about the topic. Over 80% of households were unaware of municipal programs aimed at flood risk reduction, including the City of Edmonton's free inspection program to determine property-level flood risk and the City's existing subsidy program towards the installation of a backwater valve. Approximately 30% of households were unaware of whether they had any insurance against flooding. Lastly, 33% of households were unaware of how backwater valves protect against flooding, while 39% were unaware of how sump pump systems protect homes.

Analysis of flood risk perceptions also showed the potential for information failure. On average, households stated a 20% probability of experiencing sewer backup from a storm event over the next 10 years (2.0% chance annually) and a 24% probability of experiencing infiltration (seepage) over the next 10 years (2.4% chance annually). A pairwise correlation analysis was conducted between household risk perception for infiltration and lot-level flood risk scores modelled by KatRisk[2], to assess whether risk perceptions were aligned with objective risk levels.[3] The results showed no correlation between the two, suggesting that households may not know their objective risk levels or choose to inform their flood risk perceptions using other factors.

5 Econometric Analysis and Results

The econometric analysis employed McFadden (1973) Random Utility Model (RUM) framework; a framework used for analyzing discrete choice behaviour using a linear-in-

[2]KatRisk is a catastrophe modelling firm based in the United States of America and is one of three firms the Government of Canada is consulting with to create nationwide flood maps for Canada (Public Safety Canada, 2022).

[3]The lot-level flood risk scores produced by KatRisk only evaluated surface/ground flood potential, therefore risk of sewer backup could not be compared.

Table 3: Flooding and Protection Results of Responding Households (n=200)

Question	Statistic	Percentage of Total Sample
Awareness ("Do you know of any ...?" Answered 'yes')	Local Programs to Reduce Flood Risk	18.0%
	Financial Incentives or Subsidies to Install PLFP	17.0%
Flood Insurance ("What type of flood damage is covered under your home insurance policy?")	Sewer Backup	56.0%
	Infiltration	27.0%
	Overland	36.0%
	Don't Have Flood Coverage	7.5%
	Don't Know	29.5%
Existing PLFP ("Do you have ... at your current home?" Answered 'yes')	Backwater Valve	37.5%
	Extended Downspouts	88.5%
	Landscaping	67.0%
	Rainwater Collection	33.5%
	Sump Pump	15.5%
	Foundation Drain	35.5%
Moderately Knowledgeable or Very Knowledge About PLFP (Likert scale for each device. Answered 'I know what the device is and I know how it works to prevent flooding')	Backwater Valve	67.0%
	Extended Downspouts	87.0%
	Landscaping	84.0%
	Rainwater Collection	67.5%
	Sump Pump	61.5%
	Foundation Drain	58.0%
Flood Experience ("Have you experienced water entering your home due to a flooding event?" Answered 'yes')	Flood Experience in Current or Previous Home	58.5%
	Flood Experience in Current Home Only	42.0%
Level of Damage of Last Experience ("What was the severity of damage of your most recent incident?" – only asked of those with flood experience)	Clean Up Only	41.9%
	Minimal	26.5%
	Moderate	28.2%
	Severe	3.4%
Risk Perception for Sewer Backup Over Next 10 Years ("What is the percentage chance you will have water enter at least once over the next 10 years due to sewer backup?")	No Chance (0%)	10.7%
	Low (1-24%)	56.3%
	Med-Low (25-49%)	22.3%
	Med-High (50-74%)	7.1%
	High (75-99%)	2.0%
	Certain (100%)	1.5%
Risk Perception for Infiltration Over Next 10 Years ("What is the percentage chance you will have water enter at least once over the next 10 years due to infiltration?")	No Chance (0%)	7.6%
	Low (1-24%)	53.8%
	Med-Low (25-49%)	21.8%
	Med-High (50-74%)	9.6%
	High (75-99%)	6.1%
	Certain (100%)	1.0%

parameters functional form. The framework assumes individuals are making choices that would provide them with the highest utility (welfare), while incorporating observed and unobserved factors into their decision-making process. The inclusion of unobserved factors, such as behavioural elements, makes the RUM more flexible than traditional models. In the RUM approach each individual responds "yes" or "no" to each price level on the payment card and the responses are treated as discrete responses by bid. The RUM specification is:

$$U_{ij} = V_{ij} + \epsilon_{ij},$$

where i represents the decision maker, j represents the alternatives, U_{ij} represents the utility of an individual under each alternative, V_{ij} represents the utility of observed (systematic) factors, and ε_{ij} represents the utility of unobserved (random) factors. Two models were estimated:

$$\begin{aligned} U_{ij} = {} & \alpha_0 + \beta_1\,\text{Cost}_{ij} + \beta_2\,\text{Device}_{ij} + \alpha_1\,\text{Subsidy}_{ij} \\ & + \alpha_2\,\text{InsurancePremiumDiscount}_{ij} + \alpha_3\left(\text{Device}_{ij} \times \text{Subsidy}_{ij}\right) \\ & + \alpha_4\left(\text{Device}_{ij} \times \text{InsurancePremiumDiscount}_{ij}\right) \end{aligned} \tag{M.1}$$

$$\begin{aligned} U_{ij} = {} & \alpha_0 + \beta_1\text{Cost}_{ij} + \beta_2\text{Device}_{ij} + \alpha_1\text{Subsidy}_{ij} \\ & + \alpha_2\text{InsurancePremiumDiscount}_{ij} + \alpha_3\left(\text{Device}_{ij} \times \text{Subsidy}_{ij}\right) \\ & + \alpha_4\left(\text{Device}_{ij} \times \text{InsurancePremiumDiscount}_{ij}\right) \\ & + \beta_3\text{RiskPerception}_{ij} + \beta_4\left(\text{Device}_{ij} \times \text{RiskPerception}_{ij}\right) \\ & + \beta_5\text{ExpectedLosses}_{ij} + \beta_6\text{Irr.Belongings}_{ij} \\ & + \beta_7\left(\text{ExpectedLosses}_{ij} \times \text{Irr.Belongings}_{ij}\right) + \beta_8\text{SelfEfficacy}_{ij} \\ & + \beta_9\text{ResponseEfficacy}_{ij} + \beta_{10}\text{FloodExperience}_{ij} + \beta_{11}\text{HomeownerYears}_{ij} \end{aligned} \tag{M.2}$$

The first model (M.1) was a simple specification that incorporated cost and the experimental design variables (i.e. device, subsidy amount, and insurance premium discount amount). The second model (M.2) was an extended specification that incorporated cost, the experimental design variables, and additional variables connected to PMT and flood experience. Interactions between the device and the variables specific to the devices (i.e. subsidy, insurance premium discount, and risk perception) were used to differentiate the effect between backwater valves and sump pump systems. Table 4 describes the variables included in each model.

Additional variables were considered for inclusion in the model based on the literature, including respondents' level of pre-existing knowledge of the devices, level of trust in government, level of responsibility felt towards flood mitigation action, and demographic characteristics such as age, education, and income. However, incorporating these variables presented issues. Given the small and highly heterogeneous sample, adding additional predictors risked overfitting the model and reducing the robustness of the estimates of interest. Furthermore, the survey results exhibited high non-response rates for the demographic questions, particularly household income, with 21% of respondents declining to provide information. Including these variables would have resulted in a loss of observations from the model and corresponding reduction in statistical power. These variables were tested, but did not improve the fit of the model, and thus were not included in the final analysis.

Table 4: Variable Description

Variable	Type	Description	Model
Device	Binary	1 = Backwater Valve (BWV) 0 = Sump Pump System (SPS)	M.1, M.2
Cost (PMT Coping Appraisal: Response Cost)	CAD $ Value (Payment Card)	$0, $250, $500, $750, $1000, $1250, $1500, $1750, $2000, $2250, $2500	M.1, M.2
Subsidy Offered	CAD $ Value, Random	BWV: $600, $800, $1000, $1200 SPS: $1200, $1400, $1600, $1800	M.1, M.2
Insurance Premium Discount Offered	CAD $ Value, Random	BWV: $25, $50, $75, $100 SPS: $25, $50, $75, $100	M.1, M.2
Risk Perception of Flooding Over 10 Years (PMT Threat Appraisal: Perceived Vulnerability)	% Chance	BWV: Sewer Backup (0–100%) SPS: Infiltration (0–100%)	M.2
Expected Value of Belongings in Basement Vulnerable to Flood	CAD $ Value (Midpoint)	$0, Under $5000, $5000–$9999, $10000–$14999, $15000–$19999, $20000–$24999, $25000–$30000, Over 30000	M.2
Has Irreplaceable Belongings in Basement Vulnerable to Flood	Binary	Yes = 1, No = 0	M.2
Severity of Losses from Flood (PMT Threat Appraisal: Perceived Severity)	Interaction	Expected Losses x Irreplaceable Belongings	M.2
Feels Capable of Implementing Measures to Protect Home and Belongings from Flood (PMT Coping Appraisal: Perceived Self-Efficacy)	Binary	Yes = 1, No = 0	M.2
Feels Protective Measures Could Protect Home from Flood (PMT Coping Appraisal: Perceived Response Efficacy)	Binary	Yes = 1, No = 0	M.2
Flood Experience	Binary	Yes = 1, No = 0	M.2
Homeowner Years	Number	Number of Years	M.2

Although risk perception has been shown in the literature to be an important aspect of protective behaviour, including it as an explanatory variable in regression analysis can lead to endogeneity concerns (Lloyd-Smith et al., 2018). For example, if respondents have other measures in place to protect against flooding, this may lower both their risk perceptions as well as their WTP for another PLFP measure. This is often referred to as a feedback effect in the literature (Richert et al., 2017; Poussin et al., 2014; Bubeck et al., 2012b). Not testing and controlling for this potential endogeneity can lead to a substantial underestimation in the value of risk reduction (Lloyd-Smith et al., 2018). For this reason, we also conducted instrumental variable (IV) regressions. The instrumental variable used in the IV regressions was the respondent's stated probability of experiencing a power outage (lasting more than a few hours) over a 10-year period. In order for this variable to serve as a valid instrument it must be correlated with the suspected endogenous variable (i.e., risk perception of sewer backup and risk perception of infiltration) and uncorrelated with the error term. The correlations were statistically significant (99% confidence level); however, the correlations were weaker than expected (coefficients of 0.24 and 0.31, respectively) and therefore the IV was unlikely to be valid.

Conditional logit regressions with clustered standard errors were estimated using the Apollo package in R (Hess and Palma, 2019). Of the 200 households that responded to the survey, and after applying the exclusion criteria described in the methodology, 138 valid responses were used in the regression for M.1 and 131 valid responses were used in the regression for M.2.[4] The majority of the excluded observations were due to households already having the devices. The results of the estimations can be found in Table 5. All coefficients are interpreted as marginal utilities.

The cost of the device was highly statistically significant (99.9% confidence level) with a negative effect, which is expected – as the cost increased, the probability of purchase of either device decreased. Device type was also highly significant (99.9% confidence level), reflecting a stronger preference for purchasing backwater valves over sump pump systems. When interaction effects were taken into account, financial incentives and flood risk perception were not statistically significant for increasing the probability of backwater valve purchase (see Table 6). Conversely, these variables were significant for sump pump systems. The subsidy offered was marginally significant (90% confidence level) for the device, meaning that the higher the subsidy amount, the more likely the respondent would purchase a sump pump system. Similarly, the insurance premium discount offered was significant in increasing the probability of purchasing a sump pump system (99% confidence level). Risk perception was highly significant (99.9% confidence level), indicating that the respondents who perceived higher infiltration flood risk over the next 10 years were more likely to purchase sump pump systems. Having high expected losses and having irreplaceable belongings vulnerable to flooding were not statistically significant in the purchase of either device. However, the interaction variable between the two, described as severity of loss, was marginally statistically significant (90% confidence level) and negatively associated with the probability of purchase. Feeling capable to implement protection (i.e. self-efficacy) was also not statistically significant, however, feeling that protective measures would be effective against flooding (i.e. response efficacy), was marginally statistically significant in motivating PLFP purchase (90% confidence level).

In addition to the discrete choice modelling, WTP was estimated using the Delta method. For the simple model (M.1), WTP was analyzed for each device, using the mean values for subsidy and insurance premium discount. On average, respondents were willing to pay $1,040 CAD for a backwater valve and $652 CAD for a sump pump system (see Table 7). In the extended model (M.2) WTP was analyzed for each device as well as response efficacy, using the mean values for all other variables (i.e. subsidy, insurance premium discount, risk perception, expected losses, and number of years as a homeowner). Furthermore, it was assumed that the average individual had experienced floods before, felt capable of implementing protection, and had irreplaceable belongings vulnerable to flooding. On average, respondents were willing to pay $1,145 CAD for a backwater valve and $798 CAD for sump pump systems if they perceived protective measures as being

[4]Seven respondents were dropped from M.2 due to missing information in added variables.

Table 5: Conditional Logit Regression Results

Variable	M.1		R-SE	M.2		R-SE
Intercept	-1.125		(1.268)	-2.486	·	(1.496)
Cost	-0.002	***	(0.000)	-0.002	***	(0.000)
Device (BWV=1, SPS=0)	4.497	**	(1.410)	5.581	***	(1.573)
Subsidy	0.001		(0.001)	0.001	·	(0.001)
Subsidy x Device	-0.002	·	(0.001)	-0.002	*	(0.001)
Insurance P. Discount	0.018	**	(0.006)	0.018	***	(0.006)
Insurance P. Discount x Device	-0.023	**	(0.008)	-0.024	**	(0.008)
Risk Perception				0.034	***	(0.007)
Risk Perception x Device				-0.020	*	(0.010)
Expected Losses				-0.006		(0.015)
Irreplaceable Belongings (Y=1, N=0)				0.610		(0.530)
Severity of Losses (EL x IB)				-0.049	·	(0.029)
Self-Efficacy (Y=1, N=0)				0.476		(0.499)
Response Efficacy (Y=1, N=0)				0.580	·	(0.300)
Flood Experience (Y=1, N=0)				0.067		(0.303)
Years as Homeowner				-0.012		(0.009)
Number of Respondents	138			131		
Number of Observations	2376			2277		
Adjusted Rho^2	0.30			0.35		
AIC	2252			2010		
BIC	2292			2102		

Significance Levels: *** 0.001, ** 0.01, * 0.05, · 0.10. Robust standard errors in parenthesis.

Table 6: Device Specific Impacts of Factors (Delta Method to Test Interaction Effects)

Variable	Value	R-SE	T-Ratio
Subsidy, Backwater Valve	-0.0010	(0.0009)	-1.07
Insurance P. Discount, Backwater Valve	-0.0062	(0.0071)	-0.87
Risk Perception, Backwater Valve	0.0138	(0.0096)	1.43

The values reported represent marginal utilities for the interaction effects associated with the backwater valve device (BWV) estimated in Table 5. Robust standard errors in parenthesis.

effective in reducing flood impacts on their homes. If protective measures were perceived as ineffective, WTP decreased by approximately $258 CAD for each device.

Additional follow-up questions were asked to better understand respondents' intentions to purchase or not purchase the devices.[5] The most selected reasons for not wanting the devices included: the risk reduction was not worth the expense (33%), they could not afford the upfront cost (23%), they required more information to make a decision (23%), and they already felt protected (21%). Since this is an optional private good purchase and not a mandatory tax, we were not concerned that these were protest responses, but legitimate feelings towards the value of the product for these individuals. Among respondents

[5]The results follow a similar pattern for both devices; therefore, they have been aggregated for this discussion. Respondents could choose multiple reasons in their responses.

Table 7: Average Willingness-to-Pay for the Devices Using Delta Method (CAD$)

Variable	Value	R-SE	T-Ratio
M.1, WTP 1: Device = 1	1040.06	(162.54)	6.40
M.1, WTP 2: Device = 0	651.78	(128.01)	5.09
M.2, WTP 1: Device = 1, Response Efficacy = 1	1145.27	(195.14)	5.87
M.2, WTP 2: Device = 1, Response Efficacy = 0	887.49	(215.36)	4.12
M.2, WTP 3: Device = 0, Response Efficacy = 1	798.61	(158.87)	5.03
M.2, WTP 4: Device = 0, Response Efficacy = 0	540.83	(164.93)	3.28

Device 1 = Backwater Valve, Device 0 = Sump Pump System. Robust standard errors in parenthesis.

willing to pay $250 CAD or more for a device, the majority (80%) indicated that the city subsidy offered was part of their reason for doing so. The second most selected reason was the desire to avoid the inconvenience and stress of damage and repairs (74%) and the third was the risk reduction was worth the additional expense (70%).

6 Discussion

The overall objective of this research was to explore factors that affect household investment in property-level flood protection (PLFP), including awareness, risk perception, flood experience, financial incentives, and cost.

Our descriptive results revealed gaps in awareness regarding flood risk and protective measures. The vast majority of respondents (80%) had not heard of existing local programs for flood risk reduction, suggesting that households were not accessing available information or financial support to evaluate and reduce their risk. Moreover, nearly one-third of the respondents were uncertain whether their insurance would cover flood damage, and over a one-third did not understand how the PLFP devices examined in this study worked to protect their homes. Follow-up questions to the payment card revealed that many respondents who were not interested in purchasing the PLFP devices expressed the need for more information before making a decision. Finally, the flood risk perception of respondents was not correlated with objective levels of flood risk, implying that perceptions were shaped by other factors. Collectively, these results point to an information failure potentially driven by the low salience of flood risk as a low-probability, high-consequence hazard. The literature has documented that when individuals perceive their flood risk as below a threshold of concern, or when they perceive the urgency of the threat is low, they are less likely to have an awareness about flood risk information and may exhibit reduced responsiveness to risk communication (Botzen et al., 2015; Terpstra and Gutteling, 2008).

This study analyzed different elements of threat appraisal and coping appraisal from Protection Motivation Theory (PMT), including perceived vulnerability (i.e. risk perception), perceived severity, perceived self-efficacy, and perceived response efficacy. Results from the econometric analysis indicated that heightened risk perception was statistically significant to the purchase of sump pump systems. This finding aligns with some of the previous research suggesting that individuals who perceive themselves to be at higher risk are more likely to engage in protective behaviours (Weyrich et al., 2020; Oulahen, 2015; Grothmann and Reusswig, 2006) and/or pay for protective measures (Netusil et al., 2021; Withey et al., 2019). However, our findings contrast with those of Thistlethwaite et al. (2018) who reported that risk perception was not a significant factor in the adoption of backwater valves or sump pump systems among Canadian households surveyed. This discrepancy may support the idea that households are highly heterogeneous in the flood mitigation context. Severity of consequence, defined by the interaction of expected losses from a basement flood and whether or not irreplaceable belongings were stored in the basement, was marginally significant to the probability of PLFP purchase, but the effect was negative. Similar findings were reported by Weyrich et al. (2020) and (Poussin et al., 2014), where the severity of expected damage acted as a negative predictor of undertaking structural measures to reduce flood risk. Although counterintuitive, both studies suggest that this may reflect a feedback effect; households expecting high losses may have already implemented protective measures they consider sufficient and therefore perceive no need for an additional investment. Self-efficacy, i.e. feeling capable of implementing measures to protect one's home from flooding, was not significant to the probability of purchase. This result was surprising, given that several studies reviewed on the topic identify self-efficacy as a key determinant of adopting structural flood mitigation measures (Botzen et al., 2019; Poussin et al., 2014; Bubeck et al., 2013). However, as Weyrich et al. (2020) suggested, when protective measures cannot be easily implemented by households – as is the case with the devices examined in our study – self-efficacy may be less relevant. Lastly, response efficacy, i.e. belief that protective measures can prevent the impact of a flood on one's home, was found to be marginally significant to the probability of PLFP purchase. This result is aligned with most research that has found that response efficacy was significant to household intentions to implement flood protection measures (Weyrich et al., 2020; Botzen et al., 2019; Poussin et al., 2014; Zaalberg et al., 2009).

Our results show that flood experience was not statistically significant to the purchase of PLFP. Although the significance of flood experience is mixed in the PMT literature, it has been shown to be an important determinant of WTP for flood protection (Thistlethwaite et al., 2018; Owusu et al., 2015). This result was therefore unexpected, particularly given that approximately 60% of households in the sample reported having experienced basement flooding at least once in the past. One possible explanation lies in the severity of these events. Among respondents with flood experience, approximately 42% reported that only clean-up was required, i.e. no actual damage to the home or belongings, while approximately 27% indicated that they experienced only minimal damage. If most encounters with flooding have been relatively minor, the data may not provide sufficient variation to draw a strong conclusion about flood experience as a notable factor in the probability of PLFP purchase.

Financial incentives were statistically significant, having a positive effect on the probability of purchase of sump pump systems. Although the effects of the incentives were small and the subsidy was only marginally significant to purchase, the majority of respondents who were willing to purchase either device stated in the follow-up questions that the subsidy made it worth the additional expense to them, which may reflect household interest in government contributing to a solution. Other studies have also found that financial incentives have a positive impact on motivating household level action against natural hazard risk (Botzen et al., 2019; Chatterjee et al., 2019; Hudson et al., 2016).

In terms of cost, the willingness-to-pay (WTP) for these devices was lower than their market prices, a finding consistent with previous literature on PLFP (Thistlethwaite et al., 2018, 2020; Owusu et al., 2015) as well as studies on flood insurance (Netusil et al., 2021; Roder et al., 2019). Average WTP was notably lower than the average cost to install a backwater valve ($2,137 CAD) or sump pump system ($2,868 CAD) as stated by local plumbers (see Table 2). Overall, only 10% of households that were presented with the backwater valve payment card were willing to pay the average market price or more for the device, while only up to 7% that were presented with the sump pump system payment card were willing to pay the average market price.

An interesting result of the analysis was that although backwater valves were the preferred device, only the purchase of sump pump systems was influenced by flood risk perception and the financial incentives offered. This may suggest that households did not require heightened risk perceptions or incentives to recognize the value of backwater valves, perceiving them as beneficial or necessary regardless of external factors. A related explanation is that these devices address different types of flooding – backwater valves are currently the only household-level measure designed to prevent sewer backup, whereas sump pump systems are just one of several methods (e.g. lot grading, extending downspouts, etc.) available to manage groundwater infiltration. Therefore, the perceived value of a sump pump system, as a substitute among other, often less costly options, may be more sensitive to financial incentives and perceptions of risk.

There were several limitations with this study that may influence the interpretation of the results. First, the relatively small number of questionnaire responses, given the heterogeneity of the sample, constrained the complexity of the modelling. Having a limited sample size restricted our ability to explore more nuanced relationships between variables and may affect the robustness of the resulting inferences. Second, there was a high non-response rate for demographic questions, particularly household income. Consequently, in order to preserve statistical power, key demographic variables that are commonly included in similar studies could not be incorporated into the model. Finally, there are potential concerns regarding endogeneity, particularly in relation to the risk perception variable. To mitigate this issue, OLS and instrumental variable (IV) regressions were estimated; however, the instrument employed was likely insufficient to ensure validity.

7 Conclusion

The factors influencing households in their investment decisions for property-level flood risk reduction are numerous and complex. Nevertheless, our findings point to specific barriers to protective action that policymakers could address.

First, the salience of flood risk is critical. As a low-probability, potentially high-consequence hazard, the issue may not be a priority for households to understand or address. The City of Edmonton already offers programs to assess and communicate the risk households face from flooding; however, these services were not well known to respondents. While information alone is unlikely to be sufficient in motivating protective action, it is an essential prerequisite for households to accurately evaluate whether the cost of protection is justified for the potential risk they face. Therefore, greater effort is needed to make flood risk information relevant, accessible, and engaging to households to ensure informed decisions can be made about protective measures.

The second barrier that could be addressed is cost. If policy makers and insurance providers are interested in the public benefit of PLFP, then consideration should be given to increasing and or restructuring incentive programs to improve their uptake. For example, most financial incentives are provided after installation, which can prevent households from adopting PLFP. This barrier was reflected in the study results; the inability to pay the upfront cost of the device and installation was one of the main reasons respondents were not interested in purchasing PLFP, even when the net cost to them was $0. Therefore, alternative delivery mechanisms could help households overcome these cost barriers. Examples include providing subsidies to households upfront, sending the subsidy amount directly to contractors before installation, or the municipality paying for the device and installation directly and allowing for re-payment through property tax.

Finally, consideration should be given to the heterogeneity of households in both their PLFP preferences and exposure to flood risk. This study revealed a stronger preference for backwater valves over sump pump systems, even though financial incentives were only significant for the latter. Given the wide range of available PLFP, it is important for policymakers to understand household preferences when designing and targeting financial incentives. Furthermore, because flood risk varies considerably at the property level, offering flexible incentives that allow households to select the PLFP measures best suited to their specific property-level risk – rather than prescribing support for specific PLFP – may help increase overall PLFP uptake.

This research contributes to the empirical literature on property-level climate adaptation and resilience, the effectiveness of incentives for private goods with public externalities, and the economic efficiency of PLFP (specifically backwater valves and sump pump systems). Future research could more closely examine how the uptake of property-level risk reduction measures is influenced by enhanced information provision, trust in risk communicators, household self-efficacy, and flexible financial incentives. It could also explore the broader social and public benefits and costs associated with PLFP compared to alternative approaches, such as infrastructure investments.

Appendix A: Summary Statistics

Table A1: Summary Statistics: Demographic Results of Responding Households with Corresponding Population Statistics (n=200)

Variable	Statistic	Count	Sample	Population (2022)*
Gender	Male	113	56.5%	49.6%
	Female	82	41.0%	50.4%
	Prefer Not to Say	5	2.5%	NA
Age	20-29	6	3.0%	14.4%
	30-39	33	16.5%	15.4%
	40-49	41	20.5%	12.2%
	50-59	27	13.5%	12.7%
	60-69	48	24.0%	10.7%
	70-79	30	15.0%	8.0%
	80+	11	5.5%	6.7%
	Prefer Not to Say	4	2.0%	NA
	Avg Age of Respondent/ Household Maintainer	NA	53	NA
Education	Grade 1-11	6	3.0%	13.0%
	High School Diploma	23	11.5%	25.3%
	Trade Cert/ Apprenticeship	16	8.0%	9.4%
	College Diploma or Cert	43	21.5%	21.3%
	Bachelor's Degree	62	31.0%	21.1%
	Above Bachelor's Degree	43	21.5%	10.1%
	Prefer Not to Say	7	3.5%	NA
Household Income (CAD$)	<$20,000 (including Losses)	2	1.0%	6.7%
	$20,000-$39,999	8	4.0%	15.0%
	$40,000-$59,999	13	6.5%	16.6%
	$60,000-$79,999	25	12.5%	13.8%
	$80,000-$99,999	26	13.0%	11.7%
	$100,000-$149,999	36	18.0%	20.0%
	$150,000-$199,999	26	13.0%	8.2%
	>$200,000	22	11.0%	8.0%
	Prefer Not to Say	42	21.0%	NA
Ownership Status	Owner	187	94.0%	66.0%
	Renter	8	4.0%	34.0%
	Other	4	2.0%	NA
Age of the Home (Era Built)	Built in the 50s or Earlier	17	8.5%	17.0%
	Built in the 60s or 70s	171	87.0%	65.4%
	— Built in the 60s	136	68.0%	NA
	— Built in the 70s	38	19.0%	NA
	Built in the 80s	4	2.0%	6.5%
	Built in the 90s	0	0.0%	4.4%
	Built in the 00s or Later	1	0.5%	6.7%
	Don't Know	4	2.0%	NA
Years as Homeowner (Over Lifetime)	Less Than 1	5	2.5%	NA
	Between 1-5	25	12.5%	NA
	Between 6-10	14	7.0%	NA
	Between 11-15	22	11.0%	NA
	Between 16-20	22	11.0%	NA
	Between 21-30	29	14.5%	NA
	Between 31-40	32	16.0%	NA
	Between 41-50	25	12.5%	NA
	Over 50	14	7.0%	NA
	Not Applicable	12	6.0%	NA

*Population statistics were sourced from SimplyAnalytics using census tract data for the four neighbourhoods.

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