Received: 18 June 2019 | Revised: 16 August 2019 | Accepted: 21 August 2019

DOI: 10.1002/wat2.1387

OVERVIEW

WIREs WATER WILEY

Cost–benefit analysis of flood-zoning policies: A review of current practice

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Funding information

European Comission, Grant/Award Number: G.A.N. ECHO/SUB/2014/694469 H2020; the Netherlands Organisation for Scientific Research, Grant/Award Number: VIDI Grant (452.14.005)

Abstract

One commonly proposed method to limit flood risk is land-use or zoning policies which regulates construction in high-risk areas, in order to reduce economic exposure and its vulnerability to flood events. Although such zoning regulations can be effective in limiting trends in flood risk, they also have adverse impacts on society, for instance by limiting local development of areas near the water. In order to judge whether proposed land-use or zoning policies are a net benefit to society, they should be accepted or rejected based on a societal cost–benefit analysis (CBA). However, conducting a CBA of zoning regulation is complex and comprehensive guidelines of how to do such an analysis are lacking. We offer guidelines for good practice. In order to assess the costs and benefits of zoning as a climate change adaption strategy, they should be assessed at a societal level in order to account for public good features of flood risk reduction strategies, and because costs in one area can be benefits in another region. We propose a multistep process: first, determine the spatial extent of the zoning policy and how interconnected the zoned area is to other locations; second, conduct a CBA using monetary costs and benefits estimated from an integrated hydro-economic model to investigate if total benefits exceed total costs; third, conduct a sensitivity analysis regarding the main assumptions; fourth, conduct a multicriteria analysis (MCA) of the normative outcomes of a zoning policy. A desirable policy is preferred in both the CBA and MCA.

This article is categorized under:

Engineering Water > Planning Water
Human Water > Value of Water
Science of Water > Water Extremes
Human Water > Methods

KEYWORDS

climate change adaptation, cost–benefit analysis, flood, risk reduction, spatial planning, zoning

1 | INTRODUCTION

Floods can have large societal impacts, which are expected to grow around the world (Alfieri, Dottori, Betts, Salamon, & Feyen, 2018; Winsemius et al., 2016). It is recognized that both climate change and socioeconomic development play a role in increasing the impacts of flooding (IPCC, 2012, 2014). This is because climate change can increase the frequency and intensity of flood events, while socioeconomic development leads to growth of people and assets in flood-prone areas. Therefore, these two drivers need to be controlled to limit negative flood impacts, and to produce more disaster resilient communities (Mysiak, Surminski, Thieken, Mechler, & Aerts, 2016).

Zoning, sometimes also called spatial or land-use planning, can be an ingredient in creating flood resilient communities. These policies can regulate the development of flood-prone areas, introduce building codes, convert built up areas to nature, relocate buildings, and raise public awareness, in order to lower flood risk (Botzen, Scussolini, et al., 2019; Burby, Deyle, Godschalk, & Olshansky, 2001). Zoning regulations can reduce flood risk by lowering vulnerability, defined as the susceptibility of people or assets to damage during a flood, for instance through requirements to flood-proof or elevate buildings. Moreover, zoning regulations can limit the exposure, defined as the number of people or value of assets that can be affected, through restricting development in flood-prone areas. Zoning regulations can also change the potential flood hazard, for instance by increasing space for rivers to enhance their discharge capacity. Although limiting flood risk is the primary aim, zoning regulations can also have other benefits, for example, by improving the local environment. Zoning polices can be applied to various scales by ranging from comprehensive land-use planning policies in a region to focusing on building code measures in specific local areas.

There are several examples of these regulations in practice. For example, France has zoning regulations via the *Catastrophes Naturelles* (CatNat) insurance scheme, which are employed through risk prevention plans, so-called PPRs (Poussin, Botzen, & Aerts, 2013). PPRs are led by local governments and approved by a governmental decree. A PPR is applied to a defined area, which can be the area affected by the largest known historical flood or the 1 in 100 year flood (a flood with a 1% annual occurrence probability). PPRs can define a set of compulsory and recommended property-level measures to lower flood risk, and limit new development in high flood risk zones. A second example is that in the United States the Federal Emergency Management Agency uses flood risk zoning in order to determine insurance premiums, insurance purchase requirements, and building regulations that are part of the National Flood Insurance Program. There are three broad flood risk zones: the Special Flood Hazard Area (SFHA) which has an annual flood occurrence probability of at least 1%; Zone B where the probability lies between 1 and 0.2%; and areas of lower probability which are not considered at risk. SFHAs have mandatory flood insurance purchase requirements and enforceable floodplain management regulations. These zoning regulations limit development in floodplains and require that newly constructed or substantially renovated homes must be elevated above the expected 1 in 100 year flood inundation-depth (Aerts & Botzen, 2011).

Despite the potential benefits of zoning regulations, society has limited resources for flood risk management and should make the best use of those available. Cost–benefit analysis (CBA) is the standard methodology for judging if a policy makes best use of available resources, by systematically comparing the total range of benefits and costs accruing to the policy (HMT, 2011; Kind, Botzen, & Aerts, 2016; NZT, 2014). Even though flood zoning regulations are not exempt from this requirement, there are few comprehensive CBA studies of zoning regulations. Conducting a CBA is important, because welfare losses can occur when zoning policies result in suboptimal economic activities in regulated areas, for instance. However, economic evaluations of proposed or on-going zoning regulations are hampered by the small literature dealing directly with flood zoning CBA. This is despite the recognition that zoning regulations requires an adapted CBA framework, because they are complex to evaluate (Whipple, 1969). The increased difficulty arises due to the need to assess flood risk as well as a range of interrelated environmental and social impacts of (potential) land-use changes. Moreover, these complexities are compounded by the need to estimate projected or counterfactual trends in impact categories with, or without, the zoning policies in place.

The main goal of this paper is to collate and synthesize the academic literature on CBA evaluation of zoning regulations. In conducting this synthesis, we aim to generate an overarching CBA framework in order to improve CBA methods for evaluating zoning policies. This is an important topic of study given the increasing threat posed by flooding across the world. This paper identified the current literature on CBA of flood zoning regulations through a systematic literature review (Section 2) to synthesize the employed CBA frameworks (Section 3) and to identify an agenda for future research on this topic (Section 4).

2 | LITERATURE REVIEW APPROACH

In order to synthesize the current literature on the CBA of zoning policies a systematic literature review was conducted in order to collate the current body of knowledge and practice. This section describes the review approach and is summarized in Figure 1.

Stage 1 consists of a literature search conducted between January 1, 2019 and January 31, 2019 using: *Web of Science*, *Google Scholar*, and *Google Search*. Multiple sources were used to reduce the likelihood of a biased sample of papers (Paez, 2017). The search was not constrained by publication dates. This means that in principle all recorded papers in the database were considered. The search terms were as follows:

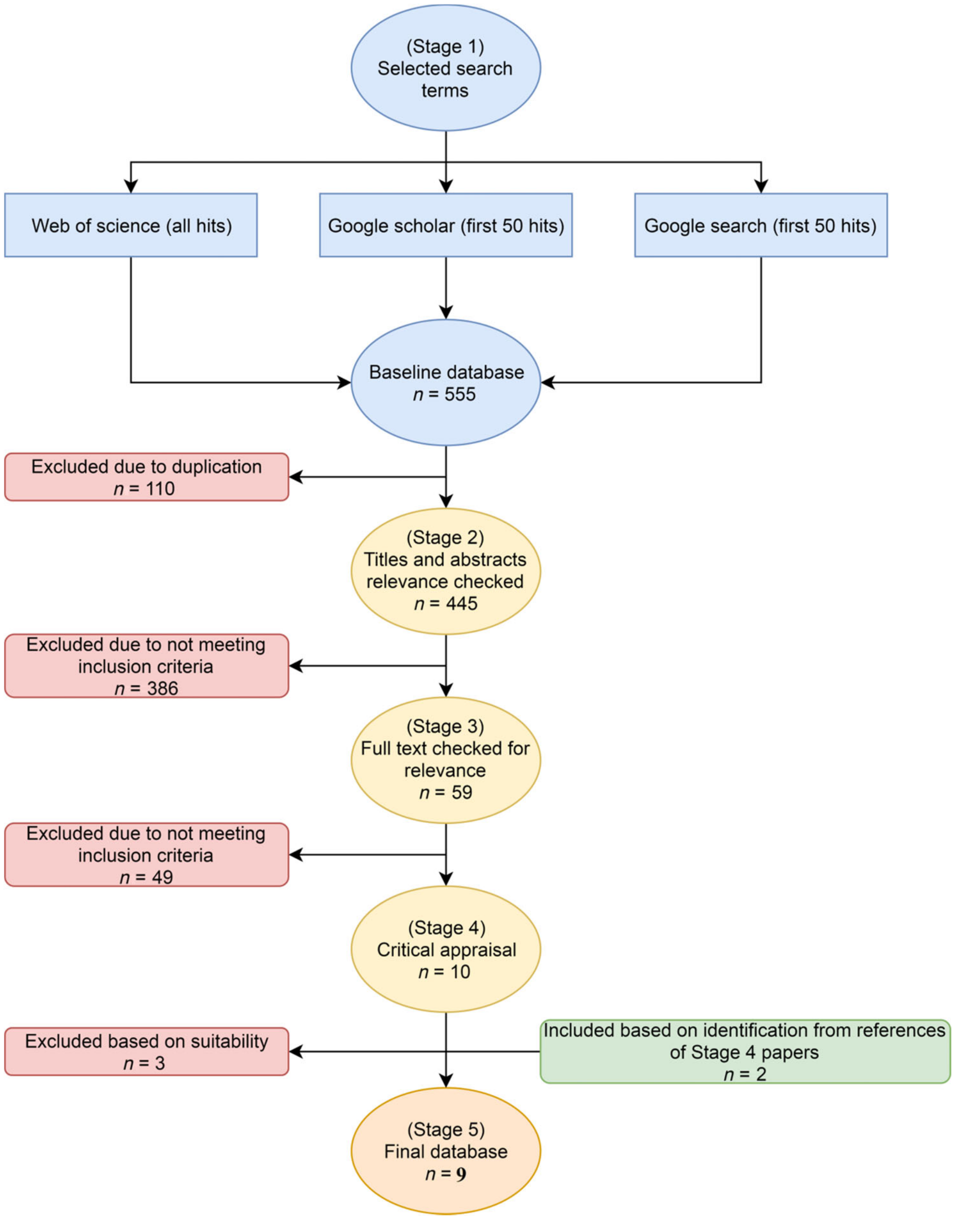

FIGURE 1 Overview of the literature review process

- Flood* & "Zoning" & "Cost Benefit Analysis"
- Flood* & "Zoning" & "CBA"
- Flood* & "Zoning" & "Cost Effective"
- Flood* & "spatial planning" & "Cost Benefit Analysis"
- Flood* & "spatial planning" & "CBA"
- Flood* & "spatial planning" & "Cost Effective"
- Flood* & "land-use" & "Cost Benefit Analysis"
- Flood* & "land-use" & "CBA"
- Flood* & "land-use" & "Cost Effective"

This variety of search terms represents the range of terminologies that can be used to describe zoning policies. At this stage of the literature search the only criterion was that the document was in English.[1]

In Stage 2, the abstracts and titles of documents found in Stage 1 were checked against the inclusion criterion for this stage, and, were forwarded to Stage 3 if relevant. The inclusion criterion was that the title and abstract/summary of the document indicated an assessment of both the costs and benefits due to a flood risk management strategy that includes zoning or spatial planning. This broad inclusion criterion was used since a zoning policy may not be explicitly framed as such in the document.

Not all abstracts and titles were sufficiently informative to judge if the inclusion criteria are met. These cases were forwarded to the next stage in which the document was studied in more detail. In Stage 3, the full document was read to confirm that the document presented both the costs and benefits of a zoning policy intervention. For instance, Porse (2014) provided a value for benefits of zoning, but not a clear value for costs, which is why it was excluded. This also applied to Poussin, Bubeck, Aerts, and Ward (2012).

In Stage 4 the documents were checked upon their overall suitability and quality. The first consideration was if the paper could be considered a CBA. For instance, Kousky, Olmstead, Walls, and Macauley (2013) were excluded because their comparison of costs and benefits is unclear, which hampers doing a CBA. The second consideration was a connection with flooding; one case was excluded because it focused upon coastal erosion rather than flooding. Finally, the references of the selected studies were examined, which identified two additional relevant papers.

Stage 5 compiled the final set of studies to be reviewed. A total of nine suitable documents were included: Whipple (1969), Leblanc and Ouellette (1988), Ouellette, Leblanc, El-Jabi, and Rousselle (1988), Millerd, Dufournaud, and Schaefer (1994), Brouwer and van Ek (2004), Rose et al. (2007), Aerts et al. (2014), de Bruin, Goosen, van Lerland, and Groeneveld (2014), and Aubé, Hébert, Wilson, Trenholm, and Patriquin (2016).

Leblanc and Ouellette (1988), Ouellette et al. (1988), Millerd et al. (1994), and Rose et al. (2007) evaluated known zoning programs: namely Federal Emergency Management Agency (FEMA) regulations across the United States (Rose et al., 2007), and zoning regulations in a few small Canadian communities (the remaining three studies). Aubé et al. (2016) conducted a CBA of a potential zoning policy against coastal flooding in a small Canadian community. Aerts et al. (2014) investigated a range of potential zoning policies via building codes in New York City. Brouwer and van Ek (2004) and de Bruin et al. (2014) evaluated potential changes to Dutch flood risk management strategies, including zoning regulations. In contract, Whipple (1969) did not study an explicit policy, but was the earliest attempt we found at developing a zoning CBA framework.

Overall, the studies adopted the CBA decision rule presented in Section 3.1 based on the variables discussed in Section 3.2. Nevertheless, the studies differed in the extent to which they assessed costs and benefits from zoning, as discussed in Section 3.3. Detailed study characteristics are presented in Tables 1 and 2, which are used for highlighting key features of the studies, and for making a comparison between variables that should be included in a zoning policy CBA and those that are actually included. The following section gives an overall synthesis of the common points of the nine identified studies, from which guidance on how to do a CBA of zoning policies can be drawn.

3 | FLOOD RISK ZONING CBA

This section describes the common elements of the CBA frameworks in terms of their methodological approach, commonly included benefit and cost categories, and main sources of uncertainties.

3.1 | CBA criteria

The purpose of a CBA of a zoning policy is to investigate whether the policy provides a net benefit to society (Brouwer & van Ek, 2004; Rose et al., 2007). The approach is summarized in Equation (1), which states that a project goes ahead if its life-time discounted benefits (B) are larger than its life discounted time costs (C). The benefit–cost ratio (BCR) may also be required to reach a predetermined ratio (x), which could be 1 or larger. Additionally, the net present value (NPV) could also be used as a decision rule. NPV is calculated as $B - C$, and as such if the NPV > 0 then the zoning project is beneficial. Most of the studies identified in Section 2 used the BCR as the decision rule, in which $x = 1$.

$$\text{CBA} = \begin{cases} \text{Yes if } \dfrac{B}{C} > x \\ \text{No if } \dfrac{B}{C} \leq x \end{cases}. \tag{1}$$

In Equations (2) and (3) are, respectively, the benefits $[b(.)_t]$ and costs $[c(.)_t]$ in year t of the zoning policy are the positive and negative impacts of the zoning policy. Both are relative to a baseline (NZT, 2014). The baseline differs in a forward or

TABLE 1 Overview of potential benefits and costs derived from studies measuring the costs/benefits of land-use modifications for reducing flood risk

	Benefits (positive impacts of the policy)	Costs (negative impacts of the policy)
Financial	• Reduced annual expected damage to physical property due to flooding ∘ Due to lower exposure (less valuable assets located in the area) ∘ Due to lower vulnerability (higher level of preparedness due to regulations) • Reduced annual expected flood losses due to business interruption caused by flooding ∘ Due to lower exposure (fewer businesses located in the area) ∘ Due to lower vulnerability (the businesses remaining are less likely to be heavily affected) • Reduced indirect economic impacts due to flooding • Fewer ripple effects into economic activity in other areas, that is, a factory must shut down because it cannot get input materials from a flooded factory	• Suboptimal land-use ∘ Lost income due to sub-optimal land-use ∘ Cost of purchasing land that does not meet zoning requirements • Loss of employment ∘ Average wage • Indirect economic impacts ∘ Indirect business losses due to sub-optimal land-use • Administrative/enforcement costs ∘ Cost of producing and maintain flood risk maps accounting for changing flood conditions ∘ Costs of hiring staff and transaction costs of enforcing the zoning policy ∘ Start-up and assessment costs ∘ Deadweight welfare loss due to increases taxation to finance the zoning department • Cost of employing risk management methods and maintenance costs • Change in tax revenue due to changes in economic activity
Societal	• Prevented human welfare impacts by flooding ∘ Dislocation of population ∘ Community disruption ∘ Fatalities and injuries suffered ∘ Intangible emotional impacts • Improved level of risk perception/awareness	• Increased risk awareness • Unequal distribution of impacts of land use change across stakeholders ∘ Differences in benefit/cost ratios for the government versus landowners versus. residents
Environmental	• Newly developed eco-system services due to changing land-use patterns (different land-use patterns can promote different eco-system services) ∘ New recreational uses ∘ New landscapes ∘ Increased bio-diversity	• Negative changes in the environment (e.g., habitat loss)

Note: Based on Aerts, Botzen, and de Moel (2013), Aerts et al. (2014), Aubé et al. (2016), Brouwer and van Ek (2004), de Bruin et al. (2014), de Loe and Wojtanoswski (2001), Godschalk, Rose, Mittler, Porter, and West (2009), Jonkman, Brinkhuis, and Kok (2004), Leblanc and Ouellette (1988), Millerd et al. (1994), Ouellette et al. (1988), Rose et al. (2007), SEPA (2015), and Tarig (2013).

backward looking CBA. The zoning regulations are not yet implemented in a forward looking CBA, so the baseline is the current status quo and is compared to the projected changes. The zoning regulations have been implemented in a backward looking CBA, which is why the current status quo is compared to the counterfactual of what would have happened if the zoning regulations were not implemented. In both cases the impacts of the policy which are measured on a variety of scales are put in monetary values, which provides a comparable metric across benefits and costs (Section 3.2).

$$B = \sum_{0}^{T} \left(\frac{1}{1+r}\right)^{t} b(.)_{t}. \tag{2}$$

$$C = \sum_{0}^{T} \left(\frac{1}{1+r}\right)^{t} c(.)_{t}. \tag{3}$$

Furthermore, lifetime benefits and costs are measured in inflation corrected present values for the project's lifetime. The time value of money concept implies that costs and benefits occurring at different times cannot be directly compared, because $100 today is worth more than $100 in the future. To correct for the time value of money and make values over time comparable, discount factors are used to estimate the present value of future costs and benefits (Rose et al., 2007). Present values are

TABLE 2 Features of flood zoning CBA studies, including cost and benefit variables

Study	Description of zoning policy	Discount rate	Time span	Financial		Environmental		Social		Result
				Benefit	Cost	Benefit	Cost	Benefit	Cost	
Whipple (1969)[a]	Provides a hypothetical description for conducting a CBA.	Not discussed	Not discussed	Avoided direct flood damage to existing property. Avoided increase in expected annual property loss due to development prohibitions.	Site income lost					Provides an artificial example to illustrate the methodological approach employed.
Leblanc and Ouellette (1988)	There is not a detailed description of the zoning policy, but implies it deterred development. The program in question occurred in the Outaouais region of Canada consisting of six communities. This study presents a general framework and an example analysis.	5 and 10%	30 years	Forgone flood damage.	The costs of developing and implementing the program.					BCR is 2.1 with a 5% discount rate. BCR is 1.02 with a 10% discount. The authors also calculate the probability that the expected benefits are larger than the implementation costs. They place this probability between 51 and 83%.
Ouellette et al. (1988)	Evaluates the zoning in the Outaouais region of Canada consisting of six communities, which started in 1977. This is a more detailed study than Leblanc and Ouellette (1988).	5 and 10%	30 years	Avoided direct flood damage to residential property.	The cost of developing risk maps and implementing the program.					The study employs a scenario approach for two different discount rates (5 and 10%), and rates of change in the value of the flood prone area and the total number of buildings.

(Continues)

TABLE 2 (Continued)

Study	Description of zoning policy	Discount rate	Time span	Financial		Environmental		Social		Result
				Benefit	Cost	Benefit	Cost	Benefit	Cost	
										The associated BCRs are between 1.12 and 20.2, with a mean BCR of 8.2.
Millerd et al. (1994)	Four examples of regulations in Canada from small communities.	10%	25 years	Forgone flood damage due to deterred development.	Engineering studies. Information campaign. Administration and overhead.	Improved, or maintained, environmental areas (not always monetized). Delayed flooding (not monetized).		Closer cooperative actions between stakeholders (not monetized). Better land use decision-making process (not monetized).		Two case studies had BCRs of 2.5 and 5.3, based solely on the benefits from forgone flood loses. The two remaining case studies did not have a BCR calculated as the major benefits are social and environmental which were not monetized.
Brouwer and van Ek (2004)	The objective of this paper is to evaluate in an integrated way the ecological, economic and social impacts of zoning like policies.	4%	100 years	Direct flood damage to property avoided. Increased recreational benefits. Positive effects of landscape and nature conservation. Positive effects on public safety.	Suboptimal land use. Compensation payments due to lost agricultural productivity. Costs of required risk reduction measures. Costs of developing new spatial infrastructure. Operation and maintenance costs.	Positive changes in vegetation.	Negative changes in vegetation.	None determined a priori. After expert judgment. Stakeholders perceptions of landscape change. Impact on functions performed in the area.	None determined a priori, after expert judgment. Stakeholder and public perception of risk. Communication efforts Possibilities to participate in the decision-making process.	Without including environmental benefits the BCR is 0.61. Including environmental benefits increases the BCR to 1.16.

(Continues)

TABLE 2 (Continued)

Study	Description of zoning policy	Discount rate	Time span	Financial		Environmental		Social		Result
				Benefit	Cost	Benefit	Cost	Benefit	Cost	
Rose et al. (2007)[b]	The paper seeks to assess the FEMA Hazard Mitigation Grants program. This program funds a range of activities that comprise the effective zoning requirements of the National Flood Insurance Program.	2%	Varied between 50 and 100 years depending on activities.	Reduced direct property damage. Reduced direct business interruption. Reduced indirect business interruption costs. Reduced nonmarket damage (e.g., to historical sites).	Size of FEMA Hazard Mitigation Grant issued.	Reduced environmental damage.		Reduced number of deaths, injuries, and homelessness.		BCR of 4.8 for the activities related to flooding, 99% confidence that the benefits exceed the costs.
de Bruin et al. (2014)	The study area is a region of the Netherlands which has a spatial planning master plan. The analysis then extends this plan to include flood risk adaptation due to climate change.	2.5% Declining 4%	100 years	Reduced property damages.	Investment costs (land purchases and upkeep costs).	Additional water storage capacity. Increased recreational benefits from the change from current land use to nature land use.				Total sum NPV of all four adaption options is 5.14 million euros at a 2.5% discount rate, but −24.12 million euros at a 4% discount rate. The option with a positive NPV under both 2.5 and 4% discount rates is focused upon the environmental benefits.
Aerts et al. (2014)	One aspect of the study is focused upon an analysis of building codes requiring that housing within specific flood risk zones of New York	4 or 7%	100 years	Reduced flood risk due to flood-proofing (elevation, or wet flood-proofing, or dry flood-proofing).	Investment costs of the various flood-proofing measures.					Across a range of climate, socioeconomic, and effectiveness scenarios, they find: *Elevation*

(Continues)

TABLE 2 (Continued)

Study	Description of zoning policy	Discount rate	Time span	Financial		Environmental		Social		Result
				Benefit	Cost	Benefit	Cost	Benefit	Cost	
	City are flood-proofed to a sufficient degree. These rules can apply to both existing and new buildings. This analysis was conducted with three climate scenarios.									Current buildings between 0.03 and 1.36 (1/100 year); 0.01 and 0.26 (1/500 year). New buildings between 0.28 and 61.16 (1/100 year); 0.03 and 3.68 (1/500 year). *Wet flood-proofing* Current buildings between 0.08 and 7.81 (1/100 year); 0.02 and 2.29 (1/500 year). *New buildings* between 0.13 and 10.87 (1/100 year); 0.01 and 1.59 (1/500 year). *Dry flood-proofing* Current buildings between 0.13 and 6.42 (1/100 year); 0.04 and 1.50 (1/500 year). New buildings between 0.14 and 8.18 (1/100 year); 0.02 and 1.1 (1/500 year).

(Continues)

TABLE 2 (Continued)

Study	Description of zoning policy	Discount rate	Time span	Financial: Benefit	Financial: Cost	Environmental: Benefit	Environmental: Cost	Social: Benefit	Social: Cost	Result
Aubé et al. (2016)	Concerns for Shippagan in Canada regarding storm surge flood risk management. The proposed scenario is the development of a "retreat zone", with no new development and "accommodation zone," which is the remaining area affected by the 1/100 year storm in which buildings must meet adaptation guidelines additionally, current protection infrastructures are maintained.	3%	25 years 50 years 100 years	Increase sense of safety (nonmarket). Protection value of adaptation for future properties.	Flood damage costs. Maintenance of retaining wall. Impacts on property values in the risk zones.	Loss of recreation avoided (nonmarket).	Habitat reduced.			Average BCR for a 25 year evaluation period is 0.7. Average BCR for a 50 year evaluation period is 0.75. Average BCR for a 100 year evaluation period is 1.92. In all cases the NPV of action is larger than not taking action.

Abbreviations: BCR, benefit–cost ratio; CBA, cost–benefit analysis; NPV, net present value.

[a]Modeling framework rather than an explicit CBA.

[b]Flood zoning enforcement and management is one use to which FEMA grants can be used.

produced by multiplying the benefits and costs occurring in a certain year with a discount factor $[(1/(1+r))^t]$ which is a function of time t and the discount rate (r). Higher discount rates give a relatively high weight to present compared with future values.

CBA guidelines suggest the use of the social discount rate as flood risk management CBA should take a societal perspective (ADB, 2013; European Comission, 2013; HMT, 2011; NZT, 2014). The mean (median) discount rate used in the studies identified is 5.5% (4.5%), as seen in Table 2. The majority of the identified studies used two discount rates in order to investigate the BCR's sensitivity to this assumption (Section 3.4).

The evaluation period T (see the superscript in the summation symbol of Equation 2 or Equation 3) should last as long as costs or benefits accrue from zoning (Rose et al., 2007). The papers identified had a median time horizon of about 60 years. In contrast, more recent studies tended to focus on longer time spans. The pre-2000 studies in Table 2 employed a ~30 year time period, while the post-2000 studies are clustered around 100 year time periods as modeling techniques to estimate future flood risk have improved.

The reviewed studies present final central values of BCRs of 0.03–8.2 across scenarios (using the mean value of reported BCRs). The median and mean central BCRs in Table 2 are 0.79 and 1.65, respectively. Focusing only on high-risk areas (the 1/100 year floodplain), the median and mean BCRs grow to 1.09 and 2.2, respectively. From the studies identified zoning regulations offer an overall benefit to society when focused on high-risk areas, as BCRs are larger than 1. This also holds when the exogenous impacts of climate change are taken into account (Aerts et al., 2014). Kousky et al. (2013) also find that targeted land-use strategies are more likely to offer a net benefit to society. Furthermore, the cases from North America conclude this was mainly due to the avoided flood impacts. In the Dutch cases, the projects were deemed worthwhile due to the additional inclusion of environmental improvements, which highlights the need for a comprehensive consideration of benefits and costs. However, it must be noted that only nine evaluations were identified which can raise questions about how robust our current knowledge base on the topic is. Therefore, additional evaluations of existing or proposed zoning policies need to be conducted to improve our overall understanding of the net benefits of zoning policies.

3.2 | Variable selection for a CBA

The reviewed studies emphasize that there are a range of benefits and costs, which can be broadly defined as function of financial (FIN), social (SOC), and environmental impacts (ENV). A CBA should account for all the benefits and costs that emanate from the policy in order to approximate the complete welfare impact on society from the zoning policy. This is formally represented in the following change to Equations (2) and (3).

$$b(.)_t = b(\mathrm{FIN}, \mathrm{SOC}, \mathrm{ENV})_t. \tag{4}$$

$$c(.)_t = c(\mathrm{FIN}, \mathrm{SOC}, \mathrm{ENV})_t. \tag{5}$$

Financial impacts are those that directly correspond to changes in flood damage (Aerts et al., 2014; Leblanc & Ouellette, 1988; Ouellette et al., 1988; Whipple, 1969) and changes in economic activity (Rose et al., 2007), for example. Social impacts are broader and correspond to other human impacts from zoning, for example communication activities that increase awareness (Brouwer & van Ek, 2004), and better governance capabilities (Millerd et al., 1994). Environmental impacts relate to how the environment changes, for example natural area restoration or protection (Aubé et al., 2016; Brouwer & van Ek, 2004; de Bruin et al., 2014). Moreover, not all costs or benefits are tangible, but can also represent opportunity costs. An opportunity cost is what must be forgone due to the policy and encompasses the loss of potential gains from alternative land uses. For instance, if a zoning policy converts industrial land into wet-lands, then the opportunity cost is the benefits of the forgone economic activity.

Table 1 lists a range of impacts that can be considered to be costs or benefits of flood risk zoning regulations. These variables are drawn from the academic literature on flood risk management CBA. The general description of variables in Table 1 serves as a guideline to determine key benefit and cost categories. The key variables to be included in the analysis according to Table 1 are likely to be: changes in direct expected flood losses to property and indirect economic impacts, like business interruption; changes in ecosystem service provision; changes in intangible welfare impacts; changes in land prices; changes in economic activity; and costs of mandated risk reduction measures. These variables capture most of the prime effects as well as the indirect ripple effects, or transfers between regions. This point of transfers was raised in de Bruin et al. (2014) who state that the effects of zoning in one area can have consequences on neighboring areas. For example, a city may ban industrial activity in a flood-prone area, which then relocates to a neighboring city. This implies that the lost jobs are a cost for a single administrative area, but a transfer benefit in another, in addition to changes in their local economies. A wider geographical perspective can account for these transfers, as we are more likely to capture such changes.

Initial variable selection involves selecting the important impacts on a case-by-case basis. This way a broad overview of possible relevant impacts can be obtained and narrowed to the most important categories using stakeholder engagement (Burby et al., 2001). It is important to have such a stakeholder engagement early on in the design of the CBA. The reason is that de Loe and Wojtanoswski (2001) observe there is a relatively high degree of agreement on what experts consider as policy benefits (23 out of 29 benefits had high expert consensus), which is not the case for the potential costs (only 2 out of 32 costs had high expert consensus). In particular, de Loe and Wojtanoswski report high expert agreement that various improvements in environmental quality count as a benefit, while there was a large disagreement if the costs associated with flood-proofing should be counted as a cost. The presented rationale was that some stakeholders understood flood-proofing costs as a financial burden for residents, while others argued it fell on property developers to include such measures as standard practice and is not an additional cost arising from the zoning policy. Therefore, one lesson learnt is that stakeholder engagement can overcome disputes about what should be considered costs and benefits and ultimately contribute to support for, and credibility of, the CBA.

However, by comparing Tables 1 and 2 it appears that the inclusion of impacts in current practice is less comprehensive. Table 2 indicates that the main focused upon zoning impacts are those within the financial domain, followed by the environmental domain, while the social impacts were not often included in the BCR calculations. The neglect of important variables in zoning CBA studies indicates that conducting a comprehensive societal CBA for zoning is hampered, because the full range of potential positive and negative impacts are open to different interpretations and not all have a preexisting market value (Rose et al., 2007).

In terms of costs, the majority of papers identified focus cost estimates on those required to implement the policy from the perspective of the policymaker (e.g., administration costs). An exception is Brouwer and van Ek (2004) who embrace a wider range of costs, including possible negative environmental and social impacts. The reason why this is often not done is the challenge to attribute these other costs to the zoning project. Moreover, environmental and societal impacts are nonmarket values, which are more difficult to monetize than changes in flood damage and direct government expenditures for implementing the zoning project. Nevertheless, given the importance of nonmarket impacts it is relevant to include such impacts in the overall evaluation (Brouwer & van Ek, 2004; de Bruin et al., 2014; Rose et al., 2007), even if only in a qualitative manner as in Millerd et al. (1994). For instance, Brouwer and van Ek (2004) base their CBA for flood-zoning in the Netherlands on expert judgment and qualitative or normative scoring in addition to a quantitative CBA. Therefore, it is important to combine both quantitative and qualitative results to gain a full understanding of the CBA outcome.

In addition to selecting a suitable set of variables, the spatial extent over which to consider impacts must be selected. This is because benefits and costs may cross an administrate border which complicates the CBA process. Societal level CBA studies that include impacts that cross-administrative borders are required in order to capture transfers between regions (Penning-Rowsell et al., 2013). The spatial extent of the CBA study will have to be defined based on the extent to which the to-be zoned area is interconnected to other areas in addition to the scope of the zoning project. However, the rationale of where to draw this spatial "line" was not often discussed in the CBA studies. Brouwer and van Ek (2004) consider entire river deltas, while Ouellette et al. (1988), Millerd et al. (1994), and Aubé et al. (2016) focus on small communities.

Moreover, the reviewed studies did not always explicitly discuss the rationale for a particular area to be zoned. Whipple (1969) argues that zoning should not be applied to all of the floodplain and that rather an optimization routine should be developed to optimally select the areas to be zoned. This is similar to the approach taken in Kousky et al. (2013). However, this increases the complexity of the modeling process without necessarily simplifying the determination of the spatial extent of the CBA. A common choice for the area to be zoned is the high-risk area, which is often defined as the 100 year flood-plain (Penning-Rowsell et al., 2013; Schwarze & Wagner, 2007). Aerts et al. (2014) study the impact of zoning the 100 or 500 year flood-plain, and they subdivide the 100 year flood-plain into a relatively higher risk zone and a relatively lower risk zone. They find that zoning regulations, via building codes, have higher BCRs when focused upon the 100 year flood-plain, and the higher risk zone in it. Another advantage of selecting this flood-plain is it provides a formal definition that can be consistently applied across regions.

Even though a formal definition is useful and the 100 year flood-plain is a relatively common choice, it also faces challenges. A challenge with using the 100 year flood-plain definition for determining the area to be zoned is that this area can change over time due to climate change. Constantly altering the size of the zoned area increases the administrative costs associated with the program. A solution could be to fix the area under the zoning regulations at the start of the program and account for a predicted change in future flood extents or to update the area under the zoning regulation in certain time intervals, such as every 20 years. However, in practice such updates may be political contentious as is shown by updates of flood risk maps and insurance regulations in the United States (National Research Council, 2015) and Canada (McClearn, 2019).

Finally, the temporal scale of the analysis must also be defined. Given the findings of the literature review, a time span of 50–100 years should be used to be in line with overall flood risk management assessments (Shreve & Kelman, 2014). While the more recent studies displayed in Table 2 focus on 100 year time periods, 50 years may also be viable due to the complexity in estimating r trends past this point using flood risk assessment methods (Saint-Geours, 2012).

3.3 | Assessing key benefits and costs

The assessment framework required can increase in complexity the more comprehensive the zoning policy implemented. For instance, Aerts et al. (2014) focused on assessing the (tangible) costs and benefits of mandated property-level measures in flood-prone areas, while Brouwer and van Ek (2004) focused on land-use changes and the integrated analysis of changes in flood and environmental impacts. Even though the complexity in assessing costs and benefits differs between the reviewed studies, the core impacts can be derived from Tables 1 and 2.

A common recommendation for assessing these impacts found across the studies was that the costs and benefits should not be considered independent of one another (Brouwer & van Ek, 2004; Burby et al., 2001; Rose et al., 2007). This was because a change in zoning requirements not only altered potential flood impacts, but also offered additional nonmarket benefits, such as increased biodiversity due to changes in local hydrology. Brouwer & van Ek and de Bruin et al. both clearly stated the importance of such benefits for the CBA's outcome. An integrated modeling approach can help to avoid unforeseen consequences of policy changes and can capture endogenous changes to the system, positive or negative, that influence the CBA's result. For example, the modeling-framework can jointly determine how the relevant outcomes change with, and without, the zoning policy. The outcomes of the two model runs can be compared and differences placed into the CBA ledger. Brouwer and van Ek (2004) presented such an integrated modeling approach. They used a hydrologic model to estimate the area that can be affected by flooding, the level of flood risk faced, and how changes in hydrology due to zoning altered environmental conditions.

The reduction in flood impacts is the primary benefit of zoning, which can be assessed with flood risk models (Burby et al., 2001; Ouellette et al., 1988; Rose et al., 2007). The flood risk models employed operate at many spatial scales and are highly adaptable to the available input data (de Moel et al., 2015). Flood risk models base their estimated impacts on a hazard module which simulates inundation extent and depth, an exposure module which estimate the values of exposed properties, and stage-damage curves, which provide a monetary value of property damage that occurs with a specific inundation depth. The stage-damage curves differ across land-use classes in terms of the rate of change of losses and the absolute value of losses. Zoning regulations alter the land-use classification to one that is less vulnerable or has a lower exposure value. Moreover, zoning policies may mandate the compulsory employment of risk reduction measures, as in Aerts et al. (2014), which also change the shape of stage-damage curves.

The reduction in indirect economic impacts from flooding, for example, business interruption losses, which can occur when industrial land is affected, requires a different modeling approach, because these are based on disruptions of consumption and production that are the result of interactions of economic agents (Koks & Thissen, 2016). Common methods for estimating indirect losses are input–output models of trade-flows between different economic sectors or general equilibrium models which are macroeconomic models of interconnected markets in equilibrium (Botzen, Deschenes, & Sanders, 2019; Koks et al., 2016). These models in general assume that a flood causes a loss in production capacity which then has ripple effects through the rest of the economy, for instance because of disruptions in trade flows. However many studies estimate indirect losses by assuming that they are equal to a certain percentage of direct property losses (Rose et al., 2007; Ward et al., 2017), which trades off simplicity with accuracy. Only Rose et al. (2007) included these indirect impacts as a potential cost or benefit. The other studies in Table 2 tended to focus on residential areas and as such indirect impacts may not be prominent if only residential land-uses are zoned.

There are a number of nonmarket impacts that must be converted into monetary values in order to be included in a CBA. For example, Brouwer and van Ek (2004) used willingness to pay (WTP) as an indicator to value the environmental benefits of zoning policies that create new wetland areas, as did de Bruin et al. (2014). HMT (2011) notes that WTP is the most accepted concept for measuring nonmarket values in monetary terms, because WTP represents how much an individual is, at most, willing to spend in order to gain a particular benefit. WTP can be derived from stated preference methods, such as contingent valuation that directly asks individuals about a maximum WTP amount for a particular (environmental) good, or choice experiments that ask individuals preferences for different (environmental) goods with stated attributes, including price, from which WTP values can be derived (Loomis, 2011). The choice experiment method is considered to be more reliable than the contingent valuation method, because the former closer reflects decision-making in actual markets in which consumers make choices between goods with given attributes and prices (Hoyos, 2010). The impact of zoning on the number of expected causalities from a flood can be monetized using the WTP value associated with a reduced probability of death/injury. This can be expressed as the value of a statistical life (VSL) which is the financial value society places on reducing the average number of deaths by one (Andersson & Treich, 2011).

A comprehensive societal CBA of flood risk management strategies should also include avoided intangible impacts caused by floods, like psychological impacts (Lamond, Joseph, & Proverbs, 2015). However, intangible impacts were neglected in the identified zoning CBAs, while several valuation approaches exist (Markantonis, Meyer, & Schwarze, 2012). Joseph, Proverbs, and Lamond (2015) employ contingent valuation to value intangible benefits of property-level flood adaptation via WTP. Navrud, Huu Tuan, and Duc Tinh (2012) also use this method for valuing the welfare loss of being flooded. Additionally, life-satisfaction or subjective well-being valuation approaches are an emerging field of research. The well-being approach establishes a relation between subjective well-being and flood (or other) impacts along with the relation between income and well-being, from which a monetary equivalent of flood impacts on well-being can be derived. See Hudson, Botzen, Poussin, and Aerts (2017), Hudson, Pham, and Bubeck (2019), Fernandez, Stoeckl, and Welters (2019), or Sekulova and van den Bergh (2016) for examples. A practical limitation of this method is that it can only be applied in an area with sufficient flood experience from which the impact on subjective well-being can be assessed, while the stated preference method is more broadly applicable.

In terms of costs, one of the main costs to be considered is that the land located in the area to be zoned is being transformed in a less economically optimal land-use. Land-use change often entails cost because current land-uses have developed to make best use of its comparative advantage, for example as a location for business activity (Whipple, 1969). This cost of zoning can be measured through the difference in projected income that accrues to the site (Whipple, 1969). In the absence of market frictions such as asymmetric information, transaction costs, or regulations, the value of land or property should be equal to the NPV of future income that accrues from the land or property. For instance, Stewart, Thomas, and Schauer (2015) state the value of agricultural land has been traditionally seen as approximating the value of crops that can be grow upon it. A practical approach that can be taken to value the suboptimal use of land is to take the difference in the price of the original land use type before it was subject to zoning and the price of the alternative land use type after zoning, or simply the fall in prices after the zoning policy has been declared. Ex ante a zoning policy is put in place, such price differences can be approximated by taking the difference of prevailing prices of the current land use type and the land use type that will be put in place after the zoning policy. Furthermore, administrative costs are also often considered important as the zoning policy is complex to design, monitor, and enforce over time.

The costs of the required risk reduction measures for flood-proofing can be inferred through contacting producers of the required risk reduction measures in order to produce an average price for a representative building, as was done for example, in Kreibich, Christenberger, and Schwarze (2011). However, producing an average price for a representative building might be difficult and differ substantially depending on where the houses are located. These potential local differences could limit the transferability of the average price of a representative building across regions without additional localization efforts. There is also a preexisting literature describing the unit costs of several risk reduction measures based on engineering estimates (e.g., Aerts, 2018) which can be used if the study area is similar enough. If needed, these values can be adapted to fit local context, for example, using purchasing power parity exchange rates to translate costs to local currency and construction cost indexes to put the cost figures in the correct price year, as in Botzen, Monteiro, Estrada, Pesaro, and Menoni (2017) or Unterberger, Hudson, Botzen, Schroeer, and Steininger (2019).

3.4 | Classifications of potential sources of uncertainty

The evaluation of a zoning policy requires that long-term changes regarding social and environmental conditions are anticipated. This produces uncertainty on how precisely the future will evolve with zoning regulations or how the past would have evolved in their absence. This uncertainty places limitations on the estimation of opportunity costs of the zoning policy or the monetized estimates of key impact categories (Hallegatte, Shah, Lempert, Brown, & Gill, 2013). There are different ways to cope with this uncertainty in zoning CBAs. Policymakers could favor “No-regret” strategies, which yield net benefits even if risk forecasts are wrong (Hallegatte et al., 2013). In establishing if a zoning CBA results in a “No regret” policy a starting point is to use input and outcome scenarios to model uncertainty and the zoning policy's desirability across scenarios. This was the approach taken in Ouellette et al. (1988) and Aubé et al. (2016). Alternatively, a CBA focused upon the most likely benefit and cost estimates can examine whether the CBA outcome is robust to using confidence intervals around these estimates, as in Aerts et al. (2014).

An important source of uncertainty is the estimated reduction in flood risk. Future flood risk estimates are uncertain and depend on scenarios of climate change and socioeconomic development. As an illustration, a global flood risk model estimates that by 2030 the annual expected urban damage due to fluvial flooding in Italy is $1.6bn under the combined shared socioeconomic pathway (SSP) 2 and representative concentration pathway (RCP) 4.5 scenarios for socioeconomic development and climate change (Winsemius, van Beek, Jongman, Ward, and Bouwman (2013) and Ward et al. (2013)). As a comparison, replacing RCP 4.5 with the higher end climate scenario RCP 8.5 results in a lower annual expected urban damage of $1.1bn because of dryer climate conditions. Another uncertainty is that these examples assume a flood protection standard of 1%, which means only floods with smaller occurrence probabilities cause damage, while in reality local flood protection standards may differ from this assumed level. This uncertainty can be mitigated by collecting detailed information on local protection standards, for instance using, and further developing, the Flood Protection Standard (FLORPOS) dataset (Scussolini et al., 2016). This dataset is intended to be an evolving and updatable dataset of flood protection standards across the globe.

Moreover, there is modeling uncertainty when the benefits of avoided flood damage from zoning policies are assessed using flood risk models (Rose et al. (2007). The hazard, exposure, and vulnerability model components produce uncertainty which propagates throughout the CBA. De Moel and Aerts (2011) estimated that in their application the total uncertainty surrounding the final damage estimate is a factor 5–6, which implies that the lower bound flood risk estimate could be 5–6 times smaller than the upper bound, depending on input data. It is advisable to account for uncertainty in avoided flood damage, due to model error, by using confidence intervals with lower and upper bounds of prevented annual flood damage, and to estimate these figures for different climate change scenarios to which probabilities cannot be firmly assigned. This way it can be examined whether the CBA outcome is robust to model error and climate uncertainty, as was for example done in the Aerts et al. (2014) CBA of flood-protection and building code policies in New York City.

The valuation of nonmarket impacts, like environmental impacts or VSL, is also an uncertainty source, especially if limited resources are available for conducting the valuation assessment. HMT (2011) recommends that a prestudy of the target area is conducted to value nonmarket impacts. However, resources for primary data collection may be limited, as was the case in for example, Brouwer and van Ek (2004) and Rose et al. (2007). In such cases, the value transfer methodology may be used which assumes that values from other studies can be used in the CBA. For example, Brouwer and van Ek (2004) used this method for estimating an economic value for wetlands created by zoning policies in the Netherlands, on the basis of average WTP estimates of wetlands obtained from studies in other countries. This can be done if the applied values are from a study that was conducted in a similar context or are adjusted to reflect the local context, because nonmarket values are highly context dependent (HMT, 2011; NZT, 2014). Care must be taken in using the value transfer approach as the introduced errors can be large. For instance, Brander, Florax, and Vermaat (2006) used a meta-analysis to show that these transfer errors are on average 76% for WTP values of wetland conservation. de Bruin et al. (2014) attempted to limit this error by using WTP estimates from an area close to the studied zoning area to maximize the degree of comparability. Additionally, preferences may change over time and the analysis of their stability would require the use of panel or longitudinal datasets rather than the more commonly employed cross-sectional datasets (Bubeck & Botzen, 2013; Hudson, Thieken, & Bubeck, 2019; Siegrist, 2013).

A further source of uncertainty to overcome regards assessing the counterfactual situation of how the region would have developed in the presence or absence of zoning regulations, depending on whether the status quo is a situation with zoning or not. The initial steps generate the policy context that allows the counterfactual situation to be clearly defined. Next, the effects of uncertainty of the counterfactual situation can be investigated by involving several trends of how land could be used and how productive such uses could be with zoning. For example, Ouellette et al. (1988) used the historical trend in the annual increase in housing stock and price as one scenario concerning the benefits from flood risk reduction. However, they note that this trend originates in a pessimistic economic environment and as such may not be a suitable trend if the economy picks up again. Therefore, they supplement this scenario with two more optimistic scenarios and its corresponding impact on the benefits of the risk reducing aspects of the zoning policy. Historical counterfactuals are hard to construct, because we do not have data records of observations to build upon, and this of course also applies to future projections.

To account for the main sources of uncertainty, when the lifetime benefits and costs have been calculated their associated confidence intervals should also be calculated in order to express the range to which the projects benefits and costs can stretch. Several scenarios of climate change and economic development should be used in order to fully explore the role that the various assumptions can play in determining the desirability of the zoning regulation. For each scenario a distribution of the NPV or BCRs can be produced via a Monte-Carlo approach, which in turn helps to capture overall uncertainty. An ensemble scenario outcome can be produced by aggregating the separate scenario outcomes into a single overall outcome. This method is similar to the approach taken with uncertainty in climate models, like is done in Winsemius et al. (2016). From the distribution of BCR or NPVs the expected (mean) value should be equal or larger than the desired threshold (x). Another criterion could be if the lower tail of the confidence interval (90%); and: BCR > 1 or NPV > 0. An approach similar to this was employed in a CBA of zoning by Leblanc and Ouellette (1988). The additional nuance provided by such an analysis is important as governments can be financially constrained when implementing zoning policies which means they aim to earn a positive return with a high enough degree of certainty.

Given the range of uncertainties it is important to consider if "some number is better than no number" (see e.g., the discussion in Diamond and Hausman (1994) regarding valuation approaches). One side of the argument is that it is better to have a value, despite the potential complexity and uncertainty, so that decision-making can be suitably facilitated. The counterpoint argument is that a sufficiently complex and uncertain analysis inhibits rather than facilitates decision-making. The CBA of zoning policies will need to take this into account when being designed. This is because the analysis can quickly grow in complexity when the scope of actions undertaken as part of the zoning policy widens. However, part of this complexity can be mitigated through the use of stakeholder consultation throughout the project to narrow down the focus of the CBA onto the most pertinent outcomes, scenarios, or suitable actions to consider in order limit unwarranted complexity.

3.5 | Initial stages of analysis

The above subsections indicate the first stages for evaluating zoning policies. The first stage determines the spatial extent of the study by assessing how interconnected the zoned area is to other locations. This determines the scale and scope of the economic and hydrological models required. This can be achieved via a prestudy of the affected areas to calibrate the models used for assessing and determining the main potential impacts of the zoning policy. The second stage conducts a CBA using monetary costs and benefits to investigate if the zoning policy's total discounted benefits exceed total discounted costs. The third stage consists of an extensive sensitivity analysis that checks whether the CBA results are robust to assumptions and uncertainties in the cost and benefit estimates. The final stage uses the multicriteria analysis (MCA) approach to evaluate the normative implications of the policy.

4 | EQUITY AND SOCIAL JUSTICE CONCERNS

The primary focus of a CBA is on monetary values, which has challenges with including equity and social justice concerns into the analysis. However, zoning policies can have substantial equity and social justice impacts which need to be accounted for in a full analysis.

One such implication is from the observation that CBA is often conducted from the perspective of risk neutrality. The result of which is that the benefit of avoided flood damage enters the CBA as the expected value of reduced flood damage. However, not all policymakers will display risk neutrality when faced with financial constraints. Moreover, the underlying assumption for assuming risk neutrality of individuals for whom flood risk is reduced is that they are fully compensated for flood damage either through insurance or the government, which may not be the case. Kind et al. (2016) discussed the adjustment of benefits and costs to account for risk aversion, which would imply adding a surcharge to the risk reduction benefits in a CBA. Another issue to consider is that impacts are felt differently across population subgroups. There are recent studies that allow for equity weighting in the CBA to account for unequal distributions of impacts between poor and rich households, which implies that a higher weight is given to benefits and costs for low-income households (NZT, 2014). A more detailed discussion of this approach is found in Kind et al. (2016). This discussion is relevant for zoning since whether impacts are valued equally when they accrue to poor or rich groups can influence the overall desirability of the zoning policy (Leblanc & Ouellette, 1988; Millerd et al., 1994).

Furthermore, when CBA studies are conducted there are often important issues regarding the fairness or other equity impacts that flood risk managements strategies can have, which are not necessarily captured by the monetized cost and benefit categories (NZT, 2014). These are important considerations as such concepts can have welfare implications for which risk management decisions should be made. For example, zoning policies may disproportionally affect certain stakeholders that use land near rivers, which may be seen as unfair. Additionally, the policy may have distributional implications, such as shifting employment between areas. An example is noted in Ouellette et al. (1988) who highlighted how the zoning policy studied had a BCR less than 1 for local governments, while the BCR was larger than 1 for land owners.

Despite theoretical advancements, equity concerns are difficult to include in a CBA as monetary values (NZT, 2014). Equity impacts are normative and therefore could be better integrated in the analysis via a supplementary MCA (Gamper, Thoni, & Weck-Hannemann, 2006; Gamper & Turcanu, 2007). In a MCA, different sets of outcomes for a given policy choice (e.g., zoning vs. no-zoning) are presented as the evaluation criteria, which are not necessarily monetized. The normative equity implications of the policy choice can enter the analysis as evaluation criteria, because in order to combine variables on different measurement scales they are standardized onto the same scale. Each of the evaluation criteria are then associated with separate weights to indicate their subjective importance to the stakeholders, for example, environmental impacts can be weighted at 0.1 if they are of small importance, social impacts at 0.25, and economics impacts at 0.65. The result for a given policy choice can then be summarized as a single score by the weighted sum of the criteria, and the highest scoring policy should be the preferred one.

Therefore, an evaluation of flood zoning policies can consist of two steps, as in Brouwer and van Ek (2004). The first step consists of the stages of a CBA examining if the monetized benefits of the project are (sufficiently) larger than its costs, see Section 3.5, and the second is if the distributional or equity impacts are acceptable via a MCA. This multistage process shows if a flood risk management decision is both welfare increasing and acceptable. Across both stages, stakeholders need to be actively engaged with, see Mercer, Kelman, Lloyd, and Suchet-Pearson (2008) and White, Kingston, and Barker (2010).

5 | CONCLUSION

Zoning regulations can be effective in reducing flood risk, in particular, by limiting economic exposure and vulnerability of properties in flood-prone areas. Several countries currently employ zoning regulations and there are examples of calls for a greater use of comprehensive zoning regulations to control current and future flood risk. However, it is rarely acknowledged in these calls that zoning regulations have costs and benefits that extend beyond those directly associated with flood risk reduction. Such policies need to be evaluated at the societal scale and include benefits and costs from the social, financial, and environmental domains. The impacts included in such evaluations are not always limited to the region directly being zoned, since there can be ripple effects that transfer economic activity from one area to another.

A CBA provides a systematic method for evaluating costs and benefits of these policies, providing important insights into the societal desirability of zoning policies. Our review has shown that there is only a small literature about societal CBAs of zoning and land-use policies for managing flood risk. Overall, the studies identified found that zoning policies tended to have a positive CBA outcome, meaning zoning policies are economically desirable, at least when both changes in financial and environmental impacts are considered. However, these results should be interpreted with some caution since many of the studies did not explicitly account for the full range of potential costs.

A potential explanation for the small number of CBA studies on this topic is the complexity involved in jointly assessing environmental, social, and economic impacts of a change in land-use and providing monetary values for both market and non-market impacts. The reviewed studies show the need for study specific frameworks because the needs of the analysis grow with the complexity of the policy. Nevertheless, we identify important benefit and cost categories and CBA guidelines that can serve as a starting point for future zoning CBA studies.

On the basis of our review we draw the following guidelines for conducting a CBA of flood zoning regulations: conduct the analysis at the societal level to capture transfers between regions; focus on zoning in a high-risk flood-plain, like the 1/100 year flood zone; develop an assessment framework that can account for changes in hydrology, flood impacts, economic activity, and environmental changes in a consistent manner; employ various scenarios of future or counterfactual projections; express the final cost–benefit ratio via a Monte-Carlo analysis to capture total uncertainty of benefit and cost values; engage stakeholders to ensure that the most important cost and benefit categories are captured by the CBA; and conduct a qualitative MCA of distribution or equity effects. While changes in the social domain are more difficult to include in a CBA, they may be more easily assessed in a MCA.

Taking these steps implies a full evaluation of zoning policies is a multistage process. The first stage determines the spatial extent of the study by determining how interconnected the zoned area is to other locations via a prestudy which is used to calibrate the models used for assessing impacts of the zoning policy. These impacts often encompass the hydrological, financial, social and environmental domains requiring a multidisciplinary approach. The second stage conducts a CBA using monetary costs and benefits to investigate if the zoning policy improves allocative efficiency, meaning total discounted benefits exceed total discounted costs. The third stage consist of an extensive sensitivity analysis that checks whether the CBA results are robust to assumptions and uncertainties in the cost and benefit estimates as well as the adopted discount rate. The final stage is to conduct a MCA to examine if the introduction of zoning regulations is preferred in terms of important normative factors, such as equity or fairness. A desirable policy should pass both evaluations.

Additionally, we suggest a future research agenda to aid in the overall development of CBA within the flood risk management or climate change adaptation literature. The first is to conduct systematic CBA evaluations of zoning policies that capture monetized societal impacts. This is hardly done currently, which means that policies can be employed or dismissed based on an incomplete understanding of their total impacts. This is important as several studies identified how moving beyond financial impacts significantly altered their final BCR. A related area of future research is on how to specifically account for inequalities arising from zoning regulation in a CBA of zoning using equity weighting or other mechanisms for example. This is an important extension of the analysis in order to judge the wider suitability of the policy and its potential acceptability. Finally, a systematic analysis of interconnected uncertainties, including climate change, should be conducted due to the complexity of the analysis of reductions in future flood risk from zoning. This is an important consideration since policymakers should have confidence that their decisions about zoning regulations make the best use of society's limited resources.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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ENDNOTES

[1] Additionally, between March 1, 2019 and March 8, 2019 an additional search was done using "building codes" which did not result in new relevant papers.

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How to cite this article: Hudson P, Botzen WJW. Cost–benefit analysis of flood-zoning policies: A review of current practice. *WIREs Water*. 2019;6:e1387. https://doi.org/10.1002/wat2.1387