ENHANCING COMMUNITY RESILIENCE TO FLOODING THROUGH THE SPATIAL EVALUATION OF PLANS, POLICIES, AND REGULATIONS

A Dissertation

by

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ABSTRACT

Flooding is among the most deadly and destructive of all natural hazards, both in the United States and around the world. As human and economic costs from flooding continue to rise – driven by a changing climate and increasing urbanization, as well as local land use decisions – communities are being forced to reevaluate their planning and development management practices. Land use planning is frequently cited by academic and government sources as one of the most important factors in mitigating (or exacerbating) flooding hazards. Communities that plan for growth and management in a coordinated, proactive way are shown to be more *resilient*—with infrastructure that continues to function during and after a hazard event; critical facilities and residential communities located away from the most hazardous areas; building standards based on actual hazard risk; and natural environments prized and protected for the critical ecosystem services they provide.

Unfortunately, integrative planning is currently the exception, rather than the rule, in many places, especially in the U.S., and unwise development persists. A single community is often guided by multiple plan documents constructed by various 'siloed' departments and organizations, each in pursuit of its own interests and goals. The resulting *network of plans* – which typically includes comprehensive, hazard mitigation, and various sector- and place-specific plans – guides future land use and development patterns, including in hazardous areas. Poor coordination of these documents can lead to conflicting policy guidance, reduced efficacy, and increased hazard vulnerability.

Research also suggests that community resilience can be affected by policies or recommendations located anywhere in this network of plans, including in documents seemingly unrelated to hazards.

Emerging concepts and techniques focused on a *spatial* understanding of plan, policy, and regulatory coordination present a compelling new direction for research and practice aimed at improving integration and, ultimately, strengthening community resilience. This work consists of three related studies, designed to continue the development of such approaches and push them into new conceptual and methodological territory. Results suggest that the *spatial evaluation of plans, policies, and regulations* has significant potential as a means of enhancing community resilience to flooding.

DEDICATION

For my family. And for the future.

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The data in Chapter 2 were produced in collaboration with Dr. A.D. Brand of Delft University of Technology, as necessitated by the tenets of best practices for plan evaluation and content analysis (see Stevens, Lyles, and Berke, 2014). Data in Chapter 3 were produced in collaboration with Dr. Sierra Woodruff of the Department of Landscape Architecture and Urban Planning at Texas A&M University, for the same reason.

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1. INTRODUCTION

1.1. Research Problem and Background

Flooding is among the most deadly, destructive, and costly of natural hazards. In the United States, floods caused an average of 82 fatalities and $7.96 billion in damages per year in recent decades (National Weather Service, 2019). Worldwide, flooding affected nearly 2 billion people over the past 20 years, annually accounting for over 7,000 deaths and $32 billion in economic losses (United Nations Office for Disaster Risk Reduction, 2018). These costs continue to rise – driven by climate change, an increasingly urbanized and coastal population, and local land use decisions (Reidmiller et al., 2017; Kousky, 2014; Moser et al., 2014) – and are forcing communities to reevaluate their planning and development management practices as they struggle to adapt to this new reality.

Land use planning is frequently cited by academic and government sources as one of the most important factors in mitigating (or exacerbating) flooding hazards (Brody, Highfield, & Kang, 2011; Godschalk, 2003; National Research Council, 2014). Communities that plan for growth and management in a coordinated, proactive way are shown to be more *resilient* (Berke et al., 2015; Kim & Rowe, 2013; Burby, 1998), meaning that they have infrastructure that can continue to function during and after a hazard event; critical facilities and residential communities located away from the most hazardous areas; building standards based on actual hazard risk; and natural environments protected for the critical ecosystem services they provide to human communities, such as flood attenuation (Godschalk et al., 1998).

Unfortunately, integrative planning is currently the exception, rather than the rule, in many communities, and unwise development persists (Macintosh, 2013; Burby et al., 1999). A single community may be guided by multiple plan documents constructed by various ‘siloed’ departments and organizations, each in pursuit of its own interests and goals (Hopkins & Knapp, 2018). This ‘network of plans’ – which often includes comprehensive, hazard mitigation, and various sector- and place-specific plans – guides future land use and development patterns, including in hazardous areas. Poor coordination of these documents can lead to conflicting policy guidance, reduced efficacy (Finn, Hopkins, & Wempe, 2007), and increased vulnerability to hazards (Berke et al., 2015). Current research also suggests that a community’s resilience can be affected by policies or recommended actions located anywhere in its network of plans, including in documents seemingly unrelated to hazards (Kashem et al., 2016; Berke et al., 2018; Fidelman, Leitch, & Nelson, 2013). This problem extends into the domain of implementation when future land use guidance and zoning regulations are misaligned with one another or with hazard risk (Talen et al., 2016; Salkin, 2005).

The specific nature of these conflicts is not well understood, however, and more systematic evaluations of community networks of plans, policies, and regulations are needed. Emerging concepts and techniques focused on a spatial understanding of plan, policy, and regulatory coordination present a compelling new direction for research and practice toward improving integration and, ultimately, resilience. In 2007, Finn, Hopkins, and Wempe introduced an 'information system of plans' (ISoP) to help integrate community plans, regulations, and resource data through a GIS-linked online database, suggesting that geocoded policies and actions would facilitate focused comparisons, easier access to information, and detection of gaps and conflicts in plans. While they were correct to recognize the potential of using spatial aspect of plans and policies to enhance decision-making, the ISoP approach requires significant time and technological inputs and focuses almost exclusively on project-level conflicts.

Berke and colleagues (2015) responded more directly to the problems that plan conflicts pose to community resilience with the *Plan Integration for Resilience Scorecard* (PIRS) method. A PIRS enables the 'spatial evaluation' of plans and their constituent policies at the neighborhood (or other sub-jurisdictional) scale by assigning a score to each relevant policy, based on its likely effect on hazard vulnerability, and then indexing and comparing scores across different plans (also see Malecha et al., 2019). It can reveal conflicts within a community's network of plans and areas where policies may be increasing vulnerability. For example, while a hazard mitigation plan may prohibit new construction in or near a floodplain, a comprehensive plan that mentions increased development in the same area would be in conflict and might increase vulnerability to flooding. On the other hand, a comprehensive plan that is coordinated and contains policy language similar to that of the hazard mitigation plan would likely reduce vulnerability by minimizing the number of people and structures in harm's way. By demonstrating the advantage of a spatial perspective when assessing the integration of plans and policies vis-à-vis hazard mitigation, the PIRS represents a valuable way forward in the effort to elucidate the relationship between land use planning and flooding hazards.

Recognizing this potential, I have designed three studies to further develop the PIRS approach and spatial evaluation, more generally, pushing it into new conceptual and methodological territory. First (in Chapter 2 of this dissertation), I test the PIRS method's generalizability by applying it in a cultural, planning, and hazard context markedly different from that in which it was developed and originally tested, thereby demonstrating its utility even in a place famous for sophisticated planning and water management: Rotterdam, the Netherlands. I then (in Chapter 3) spatially evaluate a large, multi-tier network of plans that was in place and guiding land use decision-making in Houston, Texas, at the time Hurricane Harvey struck the city in August 2017, revealing how and where plans and policies may have exacerbated the storm's impact. Finally (in Chapter 4), as step toward extending core spatial plan and policy evaluation concepts into the regulatory realm, I develop a method for evaluating the *suitability* and *alignment* of zoning and land use planning, and then demonstrate it in the vulnerable coastal city of Tampa, Florida.

1.2. Conceptual Diagram

The diagram below (Figure 1.1) situates these three studies conceptually within the broader set of relationships between natural hazards (with a specific focus on *flooding*), urban/regional planning (especially *land use planning*), and policy implementation (emphasizing *land use regulation*).

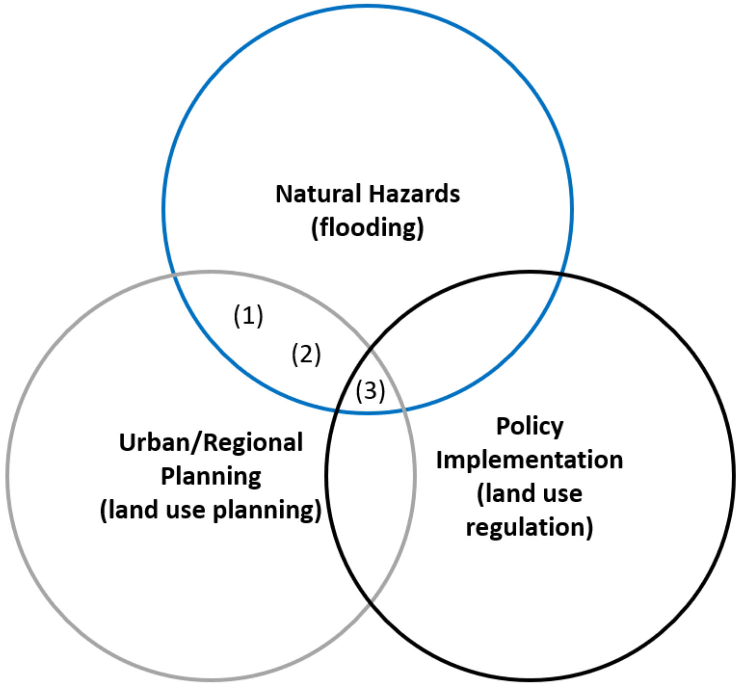

Figure 1.1 Conceptual diagram showing relationships between natural hazards (flooding), urban/regional planning (land use planning), and policy implementation (via land use regulation) and the locations of the studies that comprise this dissertation.

A PIRS evaluation reveals how networks of land use plans are integrated with respect to threats posed by natural hazards, such as flooding. My first two studies – represented by locations (1) and (2) in Figure 1.1 – keep the focus on this relationship, aiming to advance the PIRS concept and its capabilities by investigating its application and potential for scientific and practical contribution in two novel contexts: first, in a city renowned for progressive planning and flood safety practices (Rotterdam, the Netherlands); second, in a city (in)famous for its supposed *laissez faire* attitude toward land use.

The third study expands the reach of several core PIRS concepts – notably, *spatial evaluation* and an *emphasis on the nexus between land use and hazard* *vulnerability* – into the domain of policy implementation. I develop and test a method to simultaneously evaluate the relative suitability of land use planning and land use regulation in flood-hazard areas, as well as the degree to which prescriptions in land use plans and regulations align in this respect. This study is conceptually situated in the area of overlap between hazards, planning, and policy, at location (3) in Figure 1.1.

Thus, the three studies in this dissertation contribute, individually and collectively, to the ongoing exploration of whether and how the spatial evaluation of plans, policies, and regulations can enhance resilience in communities as they confront natural hazards like flooding.

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2. SPATIALLY EVALUATING A NETWORK OF PLANS AND FLOOD-VULNERABILITY USING A PLAN INTEGRATION FOR RESILIENCE SCORECARD: A CASE STUDY IN FEIJENOORD DISTRICT, ROTTERDAM, THE NETHERLANDS*

2.1. Introduction

Damages and costs associated with flood events are mounting as a result of a changing climate, an increasingly urbanized and coastal populace, and local land use and development decisions (Kousky, 2014; Moser et al., 2014). National and international governmental organizations have responded with calls for research and implementation of climate change mitigation, adaptation, and resilience-building measures (Intergovernmental Panel on Climate Change [IPCC], 2014). In 2012, the United States National Research Council (NRC) recommended development of a “resilience scorecard” to help communities “track their progress toward resiliency” (NRC, 2012, p. 12). As part of the 2015 Sendai Framework, the United Nations (UN) declared that consistent integration of hazard mitigation policies is critical to effecting resilience, and that the failure of many communities to do so is a critical international concern (United Nations General Assembly, 2015).

* Reprinted with permission from “Spatially evaluating a network of plans and flood vulnerability using a Plan Integration for Resilience Scorecard: A case study in Feijenoord District, Rotterdam, the Netherlands” by Matthew Malecha, A.D. Brand, and Philip Berke, 2018. *Land Use Policy*, vol. 78, pp. 147-157, Copyright 2018 by Elsevier.

Berke and colleagues (2015) developed and tested a resilience scorecard that focuses on the integration and responsiveness of a community's *network of plans* vis-à-vis physical and social vulnerability and coastal flooding hazards in the United States. Communities often adopt multiple plans (which together constitute a 'network') that guide future development patterns, including in hazardous areas. A network of plans frequently includes a master plan (also referred to as a comprehensive plan or a general plan), which serves as the community's primary guiding and coordinating policy document (Berke et al., 2006; Kim & Rowe, 2013). It may also include plans that focus on a particular sector of the urban system such as land use, housing, or transportation. With increasing frequency, communities are also preparing and adopting hazard mitigation plans and/or climate change adaptation plans in anticipation of future risks (Klein et al., 2005; Woodruff & Stults, 2016).

The *Plan Integration for Resilience Scorecard* (formerly known as the *resilience scorecard*) enables the spatial evaluation of community network of plan documents, giving planners and decision-makers a new perspective regarding the coordination and efficacy of their policy responses to coastal flooding (Berke et al., 2015). The development of this method is an important step toward answering the calls of the NRC and UN for greater resilience and plan coordination—goals long advocated by hazard planning specialists (Godschalk et al., 1998b). Plan Integration for Resilience Scorecards offer planners and researchers a new way to simultaneously evaluate community vulnerability, policy response, and plan integration. Areas of the community demonstrating vulnerability–policy discrepancies or inter-plan conflict can be targeted by policymakers.

By way of expanding and validating that approach, this study applies the Plan Integration for Resilience Scorecard methodology in an international setting, specifically to a relatively vulnerable district in the port city of Rotterdam, the Netherlands. While an internationally acknowledged leader in flood safety (Ward et al., 2013), Rotterdam is nevertheless highly exposed to flood hazards, particularly as climate change begins to alter patterns of precipitation and glacial melt (City of Rotterdam, 2013; IPCC, 2014). The city has also produced multiple spatial plans, including the pioneering Rotterdam Climate Change Adaptation Strategy (*Rotterdamse Adaptatiestrategie*), making it a suitable candidate for the novel perspective offered by the Plan Integration for Resilience Scorecard technique.

Although contextual differences necessitate slight modifications, the core evaluation process and measurements of integration are retained, thus providing support for the generalizability and utility of the Plan Integration for Resilience Scorecard analytical method beyond the United States. Furthermore, application of the scorecard analysis in the Netherlands allows a nuanced exploration of the ways natural hazard planning and governance affect plan quality and efficacy, adding to the important and growing body of knowledge on this subject (cf. Berke, 1996; Burby et al., 1997; Brody, 2003; Ward et al., 2013).

The next section provides a brief literature review to situate this study within the evolving hazard resilience and plan integration discourses. Contextual information will then be presented regarding the Dutch traditions of flood risk management and land use planning, followed by an introduction to the study area and its network of plans. The Plan Integration for Resilience Scorecard method, as generalized and applied in the Netherlands, will then be described. The paper concludes with a discussion of research findings, potential implications, and considerations for this and future research.

2.2. Literature Review

Despite its recent popularity, the concept of *resilience* has been criticized for being ambiguous and difficult to operationalize (Klein et al., 2003; Alexander, 2013). Authoritative publications now define the term relatively consistently, if abstractly, as "[t]he capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation" (IPCC, 2014, p. 5).

A resilience approach to urban planning relies on a more straightforward and pragmatic interpretation, derived primarily from the field of hazard mitigation (Berke & Stevens, 2016). Godschalk and colleagues (1998a) were among the first to describe, succinctly and in practical terms, what it means to be a resilient community. Resilient places have infrastructure that can continue to function during and after a hazard event; critical facilities and residential communities located away from the most hazardous areas; building standards based on actual hazard risk; and a natural environment prized and protected for the ecosystem services it provides, such as flood attenuation (Godschalk et al., 1998a; Berke & Stevens, 2016). Social factors, such as income and education, have also been shown to affect community capacity and response to hazards (Van Zandt et al., 2012).

Achieving and maintaining resilience is contingent, in large part, on a community's ability to coordinate the plans and policies that guide its growth. Current research suggests that resilience can be affected by policies located anywhere in a plan network, including in documents seemingly unrelated to hazards (Berke et al., 2015; Kashem et al., 2016). Strong integration throughout the entire network of plans, including those not focused on hazards, is a critical part of building community resilience (Fidelman et al., 2013). Research has also shown that communities that plan for hazard mitigation through proactive land use policies are more resilient (Burby et al., 1997; Kim & Rowe, 2013).

Unfortunately, integrative hazard planning is currently the exception, rather than the rule, in many communities around the world (Burby et al., 1999; Macintosh, 2013). Policy coordination has often been included as part of the broader discussion of plan evaluation (Alexander & Faludi, 1989; Baer, 1997; Hopkins, 2001; Berke & Godschalk, 2009), but has only recently become the subject of more focused investigations (Woltjer & Al, 2007; Di Gregorio et al., 2017); the specter of climate change has increased the sense of urgency regarding the integration of mitigation and resilience policies and actions—often referred to as 'mainstreaming' (Klein et al., 2005; IPCC, 2014).

Recognizing the challenges communities face as they attempt to integrate multiple plans (which are often produced in isolation), planning researchers have developed new approaches and tools for plan assessment and coordination. Finn, Hopkins, and Wempe (2007) introduced an ‘information system of plans’ (ISoP) to help integrate community plans, regulations, and resource data through a GIS-linked online database. They geocoded policies and actions containing spatial attributes in a GIS, allowing more focused comparisons, easier access to information, and detection of gaps and conflicts in plans. Finn and colleagues were correct to recognize the potential of using the spatial aspect of plans and policies to aid decision-making, though their approach is focused almost exclusively on project-level deliberations and requires significant time and technological inputs.

Berke and colleagues (2015) responded more directly to the problems that plan conflicts pose to community resilience with their ‘resilience scorecard’. By assessing community plans and measures of vulnerability at the planning district scale, the resilience scorecard method helps identify incongruities within a community’s network of plans and with respect to areas of vulnerability. The scorecard allows planners and decision-makers to better focus their efforts on areas of greatest need and keep track of their progress toward integration and resilience goals. The authors tested their method by applying it to the small, vulnerable community of Washington (2015 population estimate: 9,788), located in coastal North Carolina. Although their initial proof-of-concept was successful, the authors did not explore the method further (or test it) with respect to generalizability, explanatory power, or utility for praxis. Still, the resilience scorecard method holds great potential for advancing planning practice and the scientific understanding of community resilience by allowing planners to more effectively recognize areas of policy discord, ‘hot spots’ of vulnerability, and their spatial associations.

The primary goal of this paper is to test the generalizability of the Plan Integration for Resilience Scorecard[1] and its methodological value in a dissimilar planning and policy context. To that end, a somewhat extreme example has been selected: Feijenoord District in Rotterdam, the Netherlands. Like Washington (North Carolina), Feijenoord is river-adjacent and is relatively vulnerable. Unlike Washington, Feijenoord is a densely populated urban district, located in a city and country famous for advanced planning and flood risk management. Successful application of the Plan Integration for Resilience Scorecard method in Feijenoord, with its dramatically different governance and hazard circumstances, will provide evidence for the external validity of Berke and colleagues’ method.

2.3. Context: Planning in the Netherlands

2.3.1. Flood Risk Management and Networks of Plans

Flood risk management has existed for centuries in the Netherlands and relatively strict land use planning regulation is generally accepted as a social good, integral to the maintenance of safety and a high standard of living (Van der Valk, 2002; Wiering & Winnubst, 2017). Despite their relative sophistication, however, flood risk management

[1] Renamed so as to differentiate it from the multiplicity of ‘resilience scorecards’ in existence worldwide – e.g. Disaster Resilience Scorecard for Cities (United Nations Office for Disaster Risk Reduction, 2015), Community Disaster Resilience Scorecard (Torrens Resilience Institute, 2015), Resilient Communities Scorecard (Vermont Natural Resources Council, 2013) – which approach the concept of resilience more generally. The Plan Integration for Resilience Scorecard method is focused on the integration, or lack thereof, in a community’s network of plans and its relationship to community vulnerability and resilience.

and local planning practice in the Netherlands developed in separate silos, which have only recently begun to integrate (Woltjer & Al, 2007; Neuvel & van den Brink, 2009).

In many ways, the advanced state of Dutch flood risk management is a consequence of the country's long and complicated history with water (Wiering & Winnubst, 2017). The Dutch were draining wetlands for agricultural purposes at least as far back as the 11th century, and protecting this investment has required significant and continuous engineering and planning efforts ever since (Wesselink, 2007). Still, with 60% of its surface area of 34,000 km^2 located below sea level and/or adjacent to water (Van Alphen, 2015), the Netherlands is one of the most exposed countries in the world with respect to coastal and riverine flooding, especially in an era of increasing climatic uncertainty (City of Rotterdam, 2013); approximately two-thirds of the country's population lives below sea level (PBL, 2010). The Netherlands also has a troubled history of floods, including an epic 1953 event that devastated the country's southwest and precipitated the modern era of Dutch water management, in which flood risk is a fundamental driver of policymaking (Jonkman et al., 2008; Correljé & Broekhans, 2015).

Today the small, densely populated nation of 16.8 million inhabitants (500 persons/km^2) (2014 values; Centraal Bureau voor de Statistiek [CBS], 2016) is world-renowned for its advanced spatial planning and flood risk management (Ward et al., 2013). Since the second half of the 20th century, flood prevention has been the primary policy target of Dutch national water management. However, projected changes in climate and land use threaten to upset this delicate balance, and the official 'resistance' strategy of attempting to prevent all flooding has begun to give way to a more flexible ‘resilience’ approach, which seeks to minimize the consequences of flooding (Klijn et al., 2004; Van Buuren et al., 2016) as part of a multi-layer water safety approach (Kaufmann et al., 2016). The full scope of effects of this policy shift is presently unknown, as multi-layer safety has yet to be implemented beyond several initial pilot projects (STOWA, 2014; Van Buuren et al., 2015).

Comprehensiveness and integration of land use planning are viewed as paramount in Dutch planning (Nadin & Stead, 2008; Buitelaar & Sorel, 2010). Consistency in decision-making between the three tiers of government is formally regulated, to be achieved through required communications aimed at consensus-building and mutual adjustment of planning proposals (Van der Valk, 2002). Planning and building regulations in the Netherlands are centrally authorized, but powers are distributed among various administrative bodies working at multiple scales (Hobma & Jong, 2016). The country’s 12 provinces and 390 municipalities share spatial planning obligations, with the latter responsible for approving and enforcing the land use plan (*bestemmingsplan*), a fundamental neighborhood-scale document that simultaneously regulates planning and acts as a vision statement and development guide (Hobma & Jong, 2016). Municipalities are required to have up-to-date land use plans for their entire territory, and to follow a standardized national format (Needham, 2005) which requires acknowledgement of all related plans and policies, contributing (in theory) to a well-integrated network of plans.

Twenty-one regional Water Authorities, which possess regulatory and taxing powers, plan and manage the country's complex relationship with water; each produces a water plan (*waterplan*) that addresses water quantity, quality, and safety issues (Hobma & Jong, 2016). Although spatial planning and flood risk management developed separately in the Netherlands, with local decision-makers and regional Water Authorities pursuing their own independent policies, concerns about drainage have led to mandated collaboration (Woltjer & Al, 2007; Neuvel & van den Brink, 2009). The now-standard 'water assessment' (*watertoets*) legally binds land use and water planning by requiring municipalities to "consult with Water Authorities where the preparation of land-use plans is concerned" (Hobma & Jong, 2016, p. 8). Thus, flood-hazard-related policies are found today in many parts of a Dutch community's network of plans.

The relatively recent acknowledgement of spatial planning as an instrument to reduce flood consequences in the Netherlands (Neuvel & van den Brink, 2009) suggests, however, that even in a country labeled 'a planner's paradise' (Faludi & van der Valk, 1994; Roodbol-Mekkes et al., 2012), the coordination and efficacy of policy responses to flood hazards may not be self-evident. Runhaar and colleagues (2012) indicate that Dutch planners find climate change and related adaptation measures challenging to confront due to deficiencies in knowledge, resources, and urgency, as well as unclear legal obligations in *unembanked areas* (which are located outside the city's protective dike system; see Section 2.3.2). This applies to Rotterdam as well, despite the city's recently elevated international profile as a leader in water management—a consequence of its ambitious 'Climate Proof' program (Runhaar et al., 2012; City of Rotterdam, 2013). Therefore, applying the Plan Integration for Resilience Scorecard method in the City of Rotterdam is important both in terms of testing the method's generalizability and as a new perspective on plan integration and responsiveness as Rotterdam adjusts to new planning and water management challenges.

2.3.2. Study Area: Feijenoord District, Rotterdam, the Netherlands

The Plan Integration for Resilience Scorecard is applied in the district (*wijk*) of Feijenoord, located south of the Nieuwe Maas River in central Rotterdam, the second largest city in the Netherlands (2016 population: 616,260 [CBS, 2016]) and the largest port in Europe (Figure 2.1). Feijenoord is a densely populated urban district with more than 70,000 residents (CBS, 2016) that is exposed to both storm surge and riverine flooding, though engineering works reduce flood risk (City of Rotterdam, 2013; de Moel et al., 2014b). Feijenoord's nine neighborhoods (*buurten*), shown in Figure 2.1, are among Rotterdam's most vulnerable (CBS, 2016).

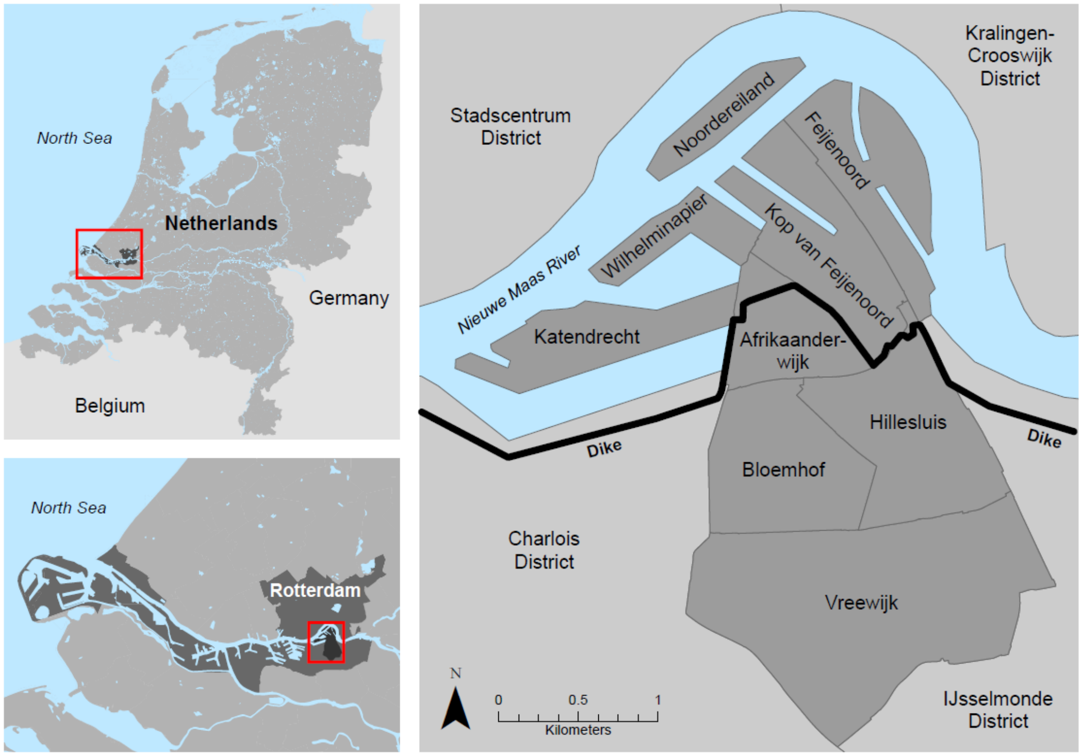

Figure 2.1 Neighborhoods in Feijenoord District, with locator maps of the Netherlands and Rotterdam environs. Reprinted with permission from Malecha, Brand, & Berke (2018).

Like much of Rotterdam, the majority of southern Feijenoord District is located below sea level (indicated by blue coloring in Figure 2.2) but is *embanked*, or protected from riverine flooding by an extensive dike system (City of Rotterdam, 2013; Ward et al., 2013). More than half of Feijenoord’s land area – including the neighborhoods of Vreewijk, Bloemhof, the majority of Afrikaanderwijk, and all but a small portion of Hillesluis – is located behind the south bank dike (Figure 2.1). These largely residential neighborhoods are almost entirely built-out. Figure 2.3 shows the appearance of the dike in the Afrikaanderwijk neighborhood. Flood safety in embanked areas is the responsibility of the regional Water Authority, which produces the required water plan and maintains the dikes to prevent overtopping or failure (Correljé & Broekhans, 2015). A very high safety standard has been set by the Dutch national government, and thus annual flood risk in the embanked part of Feijenoord District is estimated at 1 in 4,000 (Jonkman et al., 2008). In the unlikely event of a dike breach or extraordinarily high river levels, however, damage to the low-lying neighborhoods would be catastrophic (City of Rotterdam, 2013).

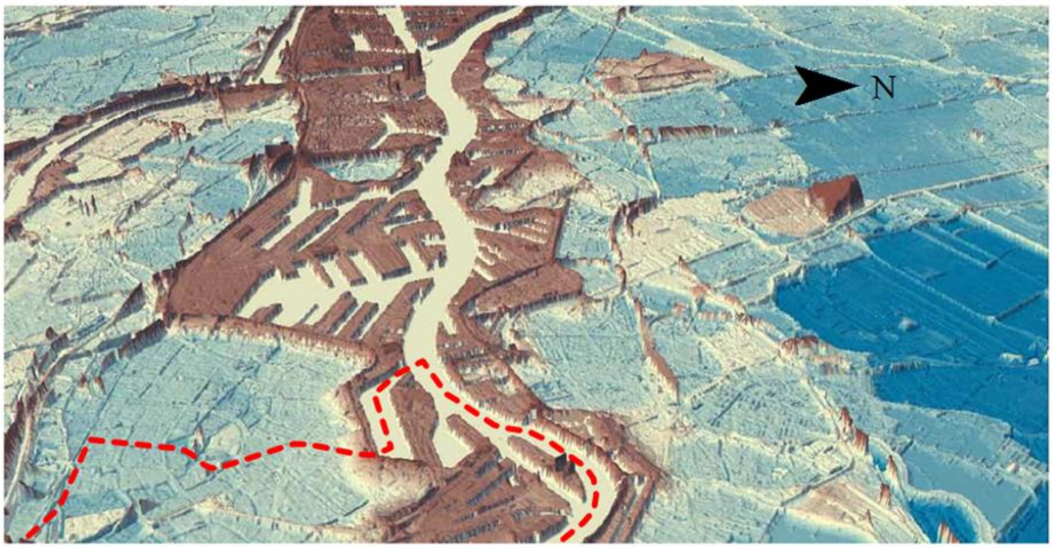

Figure 2.2 3D model showing land elevation in central Rotterdam (looking west, down the Nieuwe Maas River; brown = higher elevation; blue = lower elevation). Most of Feijenoord District is shown in the left-central foreground (red dotted line). The island in the river is the Noordereiland neighborhood. The sharp border between light blue and brown areas along the river generally indicates the presence of a dike. [Source: I. Bobbink, TU Delft, via City of Rotterdam (2013)]. Reprinted with permission from Malecha, Brand, & Berke (2018).

The remainder of the district – including Noordereiland, Feijenoord, Kop van Feijenoord, and the rapidly redeveloping Wilhelminapier and Katendrecht neighborhoods, as well as parts of Afrikaanderwijk and Hillesluis – is located on higher ground but is *unembanked*. Being directly exposed to the river (see Figure 2.4), these neighborhoods have a greater probability of flooding compared to the embanked neighborhoods, though inundation and damages are mitigated by higher elevation and by the Maeslant storm surge barrier (*Maeslantkering*), which prevents storm surges from the North Sea (City of Rotterdam, 2013). In sharp contrast with the embanked areas, where flood safety (through prevention) is the sole responsibility of the regional Water Authority, responsibilities in unembanked areas are relatively ambiguous. According to Dutch national policy regarding the riverbeds (*Beleidslijn Grote Rivieren*), individual developers are responsible for damage to new developments, whereas the municipality is in charge of public spaces and *may* contribute to flood response through provisions included in spatial and evacuation plans (Neuvel & van den Brink, 2009; Runhaar et al., 2012; Ward et al., 2013).

Although current Dutch safety standards are very high, some uncertainty and vulnerability remain, particularly with respect to unembanked areas (de Moel et al., 2014a). Additionally, while Rotterdam's policy professionals appear to be aware of the threats posed by an ever more unpredictable climate, including changes in the intensity and seasonality of rainfall (City of Rotterdam, 2013), the ways this concern is borne out in planning and policy across the network of plans is not yet well understood. High standards and cognizance of climate change notwithstanding, how well-integrated are the city's plan documents with respect to flood resilience? The Plan Integration for Resilience Scorecard method is used to explore this issue, beginning with Feijenoord District and its constituent neighborhoods.

Figure 2.3 Street scene in Afrikaanderwijk neighborhood, Feijenoord, Rotterdam. Part of the dike dividing the neighborhood into *embanked* and *unembanked* sections is shown in front of the buildings (grass knoll, short brick wall). (Photo by author.) Reprinted with permission from Malecha, Brand, & Berke (2018).

Figure 2.4 Aerial view of northern Feijenoord District and the Nieuwe Maas River, looking west, showing the unembanked neighborhoods of Noordereiland (center), Feijenoord (bottom left), and Kop van Feijenoord (middle left). (Source: City of Rotterdam [2013]). Reprinted with permission from Malecha, Brand, & Berke (2018).

2.4. Methods: Plan Integration for Resilience Scorecard Analysis in the Netherlands

The resilience scorecard method proffered in Berke et al. (2015) is adjusted to fit the cultural and hazard context in Feijenoord District, Rotterdam. Creating a Plan Integration for Resilience Scorecard entails the (1) delineation of planning and hazard zones and (2) evaluation of the community's network of plans for integration and responsiveness to flood vulnerability.

2.4.1. Step 1: Delineate Planning and Hazard Zones

Delineating 'planning zones' divides the city into smaller units that can be individually evaluated and compared, allowing for a finer-grained spatial analysis than is possible by evaluating plans at the community-wide scale (cf. Piantadosi et al., 1988). The existence of neighborhood-level land use plans in the Netherlands, and their importance for guiding land use and planning policy, makes the neighborhood the ideal planning zone in Feijenoord District.

'Hazard zones' are then delimited and intersected with the neighborhoods to create a new layer of '*neighborhood hazard zones*', which are the ultimate unit of analysis for the study. Flood hazard areas are often tied to natural features (e.g. 100-year floodplain adjacent to a river). In Rotterdam, however, decades of altering the local landscape by elevating land and constructing dikes has greatly influenced the circumstances of neighborhood flood exposure (Ward et al., 2013). Thus, following the Dutch conceptualization of flood risk, which is a function of both elevation and responsibility for water management (Jonkman et al., 2008; de Moel et al., 2014b), the hazard zones used for the examination of Feijenoord District are the previously described *embanked* and *unembanked* areas (see Section 2.3.2). Within this framing, the entire district (along with most of the city and much of the country) can be understood as existing within a flood hazard zone, even if the risk is relatively low. Embanked areas are protected by flood defenses but, due to their low elevation, are at risk of catastrophe in the event of a collapse or overtopping. The low elevation also poses a unique risk due to the lack of natural drainage for floodwaters. Unembanked areas, located between the dike and the river, are at greater risk of riverine flooding, though the land has been elevated to mitigate the effects (City of Rotterdam, 2013).

Dividing Feijenoord District into culturally relevant neighborhood hazard zones facilitates improved analysis of its network of plans. The ways plans and policies differ in their approach to flood hazards, as well as how these differences play out spatially and according to risk type, can be documented and evaluated. All Feijenoord District neighborhoods are located in at least one hazard zone, with Afrikaanderwijk and Hillesluis the only neighborhoods in both zones (Figure 2.1). In total, there are 11 spatially distinct neighborhood hazard zones in the study area.

2.4.2. Step 2: Evaluate Network of Plans and Generate Plan Integration for Resilience Scorecard

The study area's network of plans is then spatially evaluated. Policies that influence land use and development are identified in each of the community plan documents. The policies are then spatially assigned to neighborhood hazard zones and scored according to their effect on flood vulnerability. Policies that increase vulnerability receive a score of "-1", while those that reduce vulnerability receive a "+1" score. Table 2.1 contains examples of policies used in the analysis of Feijenoord District. Scores are totaled for each neighborhood hazard zone to create a policy score index. Higher scores indicate greater policy focus on reducing vulnerability. Negative scores suggest that the plan may actually increase flood vulnerability in a neighborhood hazard zone.

Table 2.1 Examples of policies included in the Feijenoord District scorecard. Reprinted with permission from Malecha, Brand, & Berke (2018).

Policy	Plan (year, page)	Effect on Vulnerability
"Within land use 'Power of amendment 1' (*wro-zone - wijzigingsgebied – 1*) a maximum of 173 residential units are allowed (Bloemfonteinstraat/ Joubertstraat), as long as the municipality and the public owners of the property have reached an anterior agreement to do so."	Afrikaanderwijk Land Use Plan (2011, p. 103)	Policy allows construction of many new residential units, increasing residential density and vulnerability to flood events; the affected neighborhood receives a score of -1 for this policy
"The houses in the Leeuwenkuil-site north in the Afrikaanderwijk will be demolished, and the site is suited to contain water."	Sub-municipal Water Plan for Charlois & Feijenoord (2010, p. 23)	Policy directs reduction of residential population density through demolition of housing and acknowledges suitability of site for water storage; the affected neighborhood receives a score of +1 for this policy
"In all new developments in outer-dike Rotterdam the risk of flooding will continue to be taken into account when determining the construction elevation."	Rotterdam Climate Change Adaptation Strategy (2013, p. 36)	Language directs new developments in the unembanked part of the city to consider flood risk during planning, reducing vulnerability to flooding; all affected neighborhood hazard zones receive a score of +1 for this policy

Consistent with Berke et al. (2015), this analysis focuses on local and municipal plans. In the Netherlands, mandatory standardized acknowledgement of plans produced by larger governmental units (provinces, the central state) is designed to reduce plan conflict (Neuvel & van den Brink, 2008; Buitelaar & Sorel, 2010), and thus a high degree of 'vertical plan integration' can be assumed. The network of plans for

Feijenoord District includes ten neighborhood land use plans (Katendrecht has two), the Sub-municipal Water Plan for the districts of Charlois and Feijenoord (*Deelgemeentelijk waterplan Charlois en Feijenoord 2011-2016*), and Rotterdam's Climate Change Adaptation Strategy (*Rotterdamse Adaptatiestrategie*).

Established content analysis procedures (Berke & Godschalk, 2009) were followed, with policies scored independently by two researchers. The resulting intercoder agreement (0.84) falls above the suggested coefficient threshold for acceptable plan evaluation. Each case of coder disagreement was reconciled through reexamination of the policy in question and assignment of a final score. This resulted in a final, consensus scorecard.

2.5. Findings and Discussion

This section demonstrates the viability of the scorecard method in a non-U.S. context by examining (1) overall composite policy scores, (2) scores for the individual plans, and (3) the spatial distribution of plan scores across neighborhoods in Feijenoord District, Rotterdam. The discussion is structured around the district's two hazard zones – the *embanked* and *unembanked* areas – given their demonstrated salience to flood risk and policy approaches in the city. To facilitate comparison and description, neighborhood hazard zones have been assigned numbers and, in the case of neighborhoods in both hazard zones, letters (e.g. '6u for the unembanked portion of Afrikaanderwijk, '7e' for the embanked portion of Hillesluis; see Figure 2.5).

2.5.1. Overall Policy Scores

When scores are summed across all three plan categories, all neighborhood hazard zones receive positive overall policy scores (overall mean = 10.4; unembanked mean = 10.4; embanked mean = 10.3), indicating that the network of plans emphasizes vulnerability reduction across Feijenoord District (Figure 2.5; also see Appendix A for district hazard zone plan scores and descriptive statistics). When compared to the application of the scorecard method in the small city of Washington, North Carolina (Berke et al., 2015) – which produced mixed results and identified multiple areas of high plan conflict – this suggests that plan integration is stronger in Feijenoord, a result consistent with known differences between the two communities in terms of planning capacity and flood mitigation priorities.

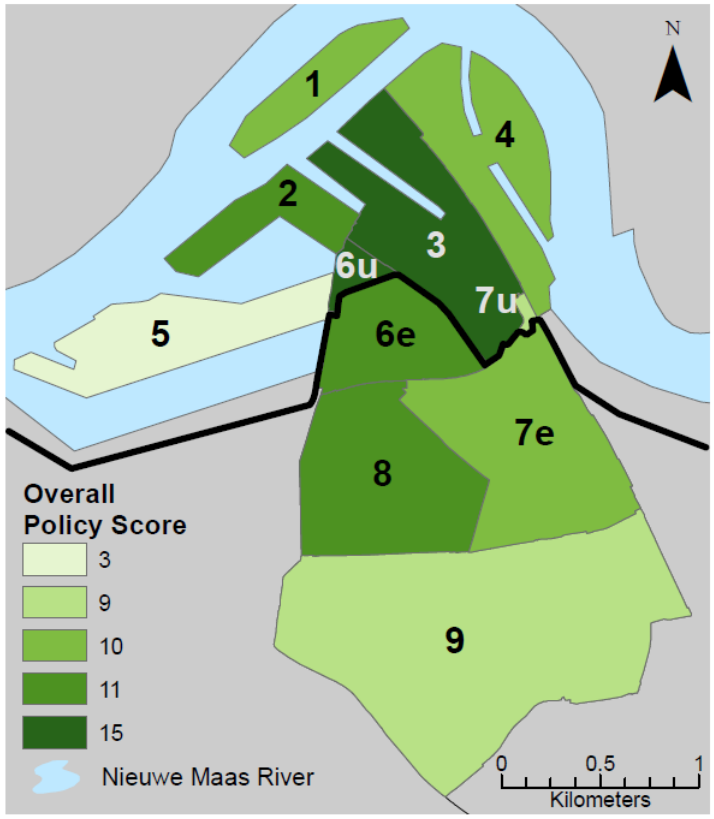

Figure 2.5 Overall (composite) policy scores in Feijenoord District neighborhoods. Neighborhoods have been numbered to facilitate discussion: (1) Noordereiland; (2) Wilhelminapier; (3) Kop van Feijenoord; (4) Feijenoord; (5) Katendrecht; (6u) Afrikaanderwijk – unembanked portion; (6e) Afrikaanderwijk – embanked portion; (7u) Hillesluis – unembanked portion; (7e) Hillesluis – embanked portion; (8) Bloemhof; (9) Vreewijk. Reprinted with permission from Malecha, Brand, & Berke (2018).

The Dutch planning system mandates vertical and encourages horizontal integration of spatial plans (Van der Valk, 2002). Combined with deliberate municipal (and national) prioritization of flood resilience, this is reflected in high plan scores, especially when compared to the U.S. example. The overall policy score results thus provide support for the scorecard method's validity, and are also a testament to the advanced state of planning and flood risk management in Rotterdam.

Despite the generally positive results, however, overall policy scores vary considerably from the mean in Feijenoord's unembanked neighborhoods (std. dev. = 3.8); they are more consistent in the embanked part of the district (std. dev. = 0.8). This suggests differences in both the goals and the spatial foci of the individual documents in the network of plans. These variations and their significance are the subject of the remainder of this discussion.

2.5.2. Policy Scores by Type of Plan and Hazard Zone

Disaggregating the scorecard results by type of plan and hazard zone (Table 2.2) allows a deeper look at the policy approach to flood vulnerability in Feijenoord District. Land use plans have the lowest mean neighborhood score (0.5) as a result of their focus on land use, including (re)development. They also display the highest standard deviation (3.3), likely reflecting their hyper-local focus—each neighborhood has its own land use plan according to its particular needs and goals.

Table 2.2 Policy score statistics, by plan type and hazard zone. Reprinted with permission from Malecha, Brand, & Berke (2018).

	Plan Type					
	Land Use Plans		Water Plan		Adaptation Strategy	
Hazard zone	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Unembanked	0.3	3.7	0.7	0.7	9.4	1.0
Embanked	0.8	2.6	2.5	1.8	7.0	0.0
Overall	*0.5*	*3.3*	*1.4*	*1.5*	*8.5*	*1.4*

Not surprisingly, the adaptation strategy has the highest mean neighborhood score (8.5) across Feijenoord's network of plans. It is clearly focused on increasing flood resilience throughout the district, though somewhat more so in the unembanked neighborhoods. Scores for the water plan are more modest (mean = 1.4), and are considerably higher in the embanked part of the district than in the unembanked areas.

2.5.3. Spatial Distribution of Individual Plan Scores

Observing the scorecard results disaggregated by plan type *and* at the individual neighborhood scale permits an even more nuanced analysis of the network of plans. Scores are a window onto both existing conditions and spatial differences in plan emphasis. In Feijenoord, land use plans reflect current development pressures as well as individual neighborhood goals, which vary widely across the district (Figure 2.6a). The sub-municipal water plan (Figure 2.6b) and climate change adaptation strategy (Figure 2.6c) both broadly reduce flood vulnerability, but affect Feijenoord's constituent neighborhoods in different ways. As demonstrated below, assessment of neighborhood-level disparities using the Plan Integration for Resilience Scorecard enables a richer understanding of the dynamics of the community's network of plans.

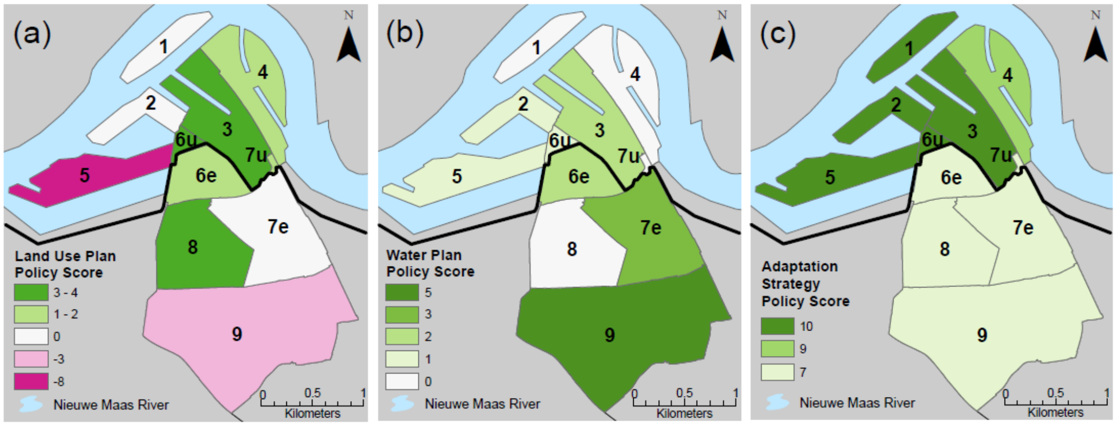

Figure 2.6 Policy scores by plan type in Feijenoord District neighborhoods (pink = negative; green = positive[2]): (a) Land Use Plans (all shown on one map); (b) Sub-municipal Water Plan; (c) Rotterdam Climate Change Adaptation Strategy. Reprinted with permission from Malecha, Brand, & Berke (2018).

2.5.3.1. Land Use Plan Scores

The unembanked portion of Feijenoord District is currently the focus of substantial public and private attention as part of a city-led push to attract middle- and upper-income residents. Several neighborhoods are undergoing a transition that includes redevelopment and infill as their abandoned port-related facilities are converted to modern residential districts, and this is reflected in their land use plan scores (Figure 2.6a). In some places, development pressures challenge the attention given to flood resilience, resulting in land use policies that may increase flood vulnerability. The Katendrecht neighborhood (#5) exemplifies this conflict as it evolves from an industrial brownfield site to a residential and mixed-use community. Katendrecht's two land use

[2] Selected instead of the conventional red-to-blue color scale (red = bad; blue = good) which, though preferred in social science research for its ease of understanding and colorblind-safe status, is problematic when illustrating flood vulnerability due to the intuitive connection between shades of blue and depth of water (see colorbrewer2.org).

plans (one for the ‘core’, or *kern*, and one for the ‘wrist’, or *pols*) include multiple policies aimed at increasing density on the peninsula, often noting the proximity of the harbor basins for their amenity value, but not acknowledging the potential hazard (e.g. ‘[T]he Pols-site is to be … transformed into a mixed, urban residential, working and leisure-district, using the recreational potential of the vicinity of the water’ [*Bestemmingsplan Katendrecht-Pols*, 2011, p. 17]).

Development pressure is less intense in Feijenoord’s more established embanked neighborhoods, where opportunities for infill and redevelopment are limited. Variations in land use plan policy scores there are more often driven by priorities for how to improve spatial quality and the built environment. Neighborhoods like Bloemhof (#8) and Afrikaanderwijk (#6e) are made more resilient by policies focused on modernization and the improvement of public spaces and drainage (e.g. ‘Sites where green is permitted are to be used for parks, public utilities, playgrounds … and other necessities of water management, like embankments and revetments’ [*Bestemmingsplan Bloemhof*, 2007, p. 62]). However, with its ‘conservative’ land use plan, Vreewijk (#9) is less affected by this positive attention, and several redevelopment-related policies are actually likely to raise vulnerability in the event of a flood (e.g. ‘Dordtsestraatweg 603-611, a mixed-use site, will be redeveloped into 20 apartments divided over four floors, with a new underground parking lot’ [*Bestemmingsplan Vreewijk*, 2010, p. 27]).

2.5.3.2. Sub-Municipal Water Plan Scores

Results from the scorecard analysis indicate that Feijenoord District’s water plan (Figure 2.6b) accomplishes its mandated objective – and even strives to do more. Water

Authorities are enabled by Dutch law to produce plan documents in collaboration with municipalities that manage water availability, movement, and quality in their jurisdictions (Tromp et al., 2014). With regard to flood resilience, these plans are mainly concerned with water drainage and retention. Unembanked parts of the city have been designed to allow precipitation to drain to the river directly, and thus policies aimed at improving water storage are generally not needed in these areas. Rotterdam's water plans are progressive, however, expanding beyond the mandated intent and pooling staff and fiscal resources; even unembanked neighborhoods are positively affected by some water plan policies.

Still, because the task of managing water is more complicated in areas that cannot naturally drain to the river, Feijenoord's progressive water plan focuses more on the embanked neighborhoods. A greater number of resilience-building policies in the water plan apply to Vreewijk (#9) and the embanked part of Hillesluis (#7e) than anywhere else (e.g. 'The site of the former hospital [*Zuiderzeeziekenhuis*] in [the Vreewijk neighborhood of] Feijenoord will be redeveloped; during development, opportunities to address water challenges are to be included' [*Deelgemeentelijk waterplan Charlois en Feijenoord 2011-2016*, 2010, p. 23]). This may indicate that the water plan is working to fill policy gaps in the land use plans related to flooding—compare Figure 2.6b to Figure 2.6a for these embanked neighborhoods.

2.5.3.3. Climate Change Adaptation Strategy Scores

Finally, it is apparent from the scorecard results that Rotterdam's citywide climate change adaptation strategy (Figure 2.6c) offers many innovative approaches for building flood resilience throughout Feijenoord District (again, mean policy score = 8.5), but especially in unembanked neighborhoods (mean = 9.4). Like the water plan, the adaptation strategy is generally concerned with flooding, but it is more focused on the threats posed by impending climate change and from the Nieuwe Maas. Hence, greater policy attention is given to the unembanked part of the district (e.g. 'In order to be able to design and build robust waterproof constructions [in Kop van Feijenoord and Noordereiland], new building regulations are being developed' [City of Rotterdam, 2013, p. 70]). This emphasis on unembanked neighborhoods again represents an attempt to fill policy gaps; Rotterdam is using the adaptation strategy to strengthen flood resilience in the increasingly vulnerable unembanked areas, which receive relatively little attention from the water plan.

2.6. Conclusions and Implications

The scorecard findings reveal conflicts and patterns in Feijenoord's network of plans that have implications for flood resilience in the district and in Rotterdam, more generally. Despite positive overall policy scores, the neighborhood- and plan-specific results are inconsistent. Some neighborhoods focus on development with insufficient attention to flood safety—to such a degree that their land use plan scores are negative. This mirrors findings from the U.S. (Berke et al., 2015; Berke et al., 2018) and reflects tensions between development and flood mitigation, which often lead to increases in population and building density in vulnerable areas without adequate focus on resilience. Resolving such tensions is critical to reducing vulnerability.

The larger-scale plans unsurprisingly score higher on average and are more consistent—evidence of their strong focus on flood risk and an indication that they may, in fact, be making up for policy gaps in some of the land use plans. The strategy of water plans assuming greater responsibility for water resilience, particularly in embanked neighborhoods (and of the adaptation strategy doing the same in unembanked areas) may be expedient, as long as the plans and agencies are truly working together. When this is not the case, though, which plan's guidance will win out? It is thus advisable to integrate resilience-building policies as thoroughly as possible, 'mainstreaming' them in the most influential plans. This is especially true for policies in the adaptation strategy, which is more of a visionary than a regulatory document. Integrating its many progressive recommendations in the more prescriptive elements of the network of plans – the water plans and, especially, the land use plans – will help Rotterdam reach its ambitious resilience goals.

From a research perspective, completing a Plan Integration for Resilience Scorecard analysis in a new policy and hazard context, quite unlike that in which the scorecard method was originally developed, provides support for its external validity. Methodological adjustments (e.g. delineating planning districts and hazard zones, determining which plans and policies to include) were relatively straightforward and should also be in future studies, provided that local experts are involved in the design and conduct of the research. The scorecard permitted an in-depth assessment of plan integration for flood resilience in Feijenoord District and offered new insight into the dynamics of its network of plans.

Finally, the scorecard evaluation of Feijenoord raised unanticipated questions about flood resilience in Rotterdam. Ambiguity appears to exist with respect to responsibility for flood safety in unembanked areas. Given the non-committal nature of national requirements like *Beleidslijn Grote Rivieren*, it seems that Dutch municipalities are still trying to identify their obligations in unembanked areas. The extent of their responsibility for flood damages and spatial provisions in land use plans remains unclear—a problem resulting in part from (and exacerbated by) a lack of experience with large flood events over recent decades. This is somewhat troubling, especially when combined with the policy inconsistencies identified using the scorecard. Whether existing provisions will suffice in the case of a very large flood event remains to be seen.

2.7. Limitations

This process was limited in several ways that should be improved in future applications, which may include evaluations of additional locations, comparative analyses, and translation to planning and flood risk management practice. As in Berke et al. (2015), this initial proof-of-concept scorecard evaluation was conducted in a community with a relatively small number of sub-jurisdictional districts (neighborhoods), which limited the statistical power for analysis of spatial relationships. A larger study area with more individual neighborhood hazard zones would provide a higher n-size, greater confidence, and better insight. Thus, having been demonstrated at the scale of the district (Feijenoord), small city (Washington, NC), and large city (Berke et al., 2018), the scorecard process may benefit from testing at the regional or even national scale.

Another way to strengthen the potency of conclusions, with respect to both Feijenoord's network of plans and the efficacy of the scorecard method, would be to repeat the study after some time has elapsed. A longitudinal study would track changes in the integration and responsiveness of the network of plans. It would allow greater insight regarding, for example, whether the suggestions in the adaptation strategy are eventually mainstreamed and whether low land use plan scores for Katendrecht and Vreewijk merely reflect an uncharacteristically development-centric time period. It should be emphasized, however, that sufficient consideration should always be given to flood resilience, regardless of what other policy drivers exist.

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3. PLANNING TO MITIGATE, OR TO *EXACERBATE*, FLOODING HAZARDS? EVALUATING A HOUSTON, TEXAS, NETWORK OF PLANS IN PLACE DURING HURRICANE HARVEY USING A PLAN INTEGRATION FOR RESILIENCE SCORECARD

3.1. Introduction

On August 25, 2017, Hurricane Harvey made landfall along the Texas Coastal Bend. For the next four days the storm stalled over southeastern Texas, dropping historic amounts of rainfall—including over 50 inches in the city of Houston (Blake & Zelinsky, 2018; City of Houston, 2018a). These rains caused catastrophic flooding. More than 8,500 calls were made to 911 to request water rescues and over 37,000 families were displaced in Houston, alone. Over 200,000 properties were damaged across southeastern Texas, including over 65,000 structures in Houston (Texas General Land Office, 2019; Sebastian et al., 2017). Harvey is the second costliest hurricane in United States history, behind only Hurricane Katrina in 2005 (Blake & Zelinsky, 2018).

Although the Harvey event produced record amounts of rain, flooding has been a persistent and growing problem in the Houston area. The Houston Hazard Mitigation Plan (2018) documents 57 flood events over 21 years. In 2015, the city experienced severe flooding on Memorial Day and on Halloween weekend; both events received a presidential disaster declaration (City of Houston, 2018a). Again in 2016, two flood events were declared presidential disasters (City of Houston, 2018b). [Even at the time of this writing, Tropical Depression Imelda is causing catastrophic flooding in parts of

Houston and southeastern Texas, with precipitation totals of up to 40 inches in some places.] Since 1973, Harris County has received 28 federal disaster declarations related to floods and storms and, as a result, has been classified as a repetitive loss community (Harris County, 2013; Federal Emergency Management Agency [FEMA], 2019).

Rapid development in risky and greenfield locations throughout the Houston region exacerbates the flooding problem. In Harris County, over 100,000 homes and businesses are currently located in the 100-year floodplain (which has a 1% annual chance of flooding), designated by the Federal Emergency Management Agency (FEMA) as the Special Flood Hazard Area (SFHA) (Harris County Flood Control District [HCFCD], 2018a). Across the region, poorly controlled development has replaced natural ecosystems like wetlands and prairies with great expanses of impervious surface, nullifying their ability to attenuate stormwater (Sebastian et al., 2017; Brody, Highfield, & Kang, 2011). Consequently, excessive rainfall frequently overwhelms drainage systems, resulting in overland and sheet flow flooding outside of mapped floodplains (Harris County, 2013). The growing problem of flood damage occurring beyond the commonly acknowledged and comparatively well-managed SFHA has been documented in recent research (Blessing, Sebastian, & Brody, 2017; Brody et al., 2014, 2012).

Land use planning is a key factor in this equation, and can either mitigate or exacerbate flood risk (National Research Council, 2014; Brody, Highfield, & Kang, 2011; Godschalk, 2003). Planning for growth in a coordinated, proactive way has been shown to lead to greater resilience (Kim & Rowe, 2013; Burby, 1998). Unfortunately, planning efforts are increasingly fragmented in many U.S. communities, leading to weak coordination between the various plans that guide development and land use (Hopkins & Knapp, 2018; Berke et al., 2015). As a result, hazard mitigation and wise land use practices are often poorly integrated across a community's network of plan documents. Such disjointed planning raises vulnerability and the potential for loss, leaving many communities ill-prepared for the magnitude and frequency of flood events with which they must contend (Burby et al., 1999; Macintosh, 2013).

In this study, I spatially evaluate a network of community plans, with respect to its integration and responsiveness to flooding hazards, in the context of a large-scale flood event. Using the *Plan Integration for Resilience Scorecard* (PIRS) method (Berke et al., 2015, 2018, 2019), I evaluate the integration of a network of 18 plans that were guiding land use and development in a section of western Houston that experienced dramatic flooding during Hurricane Harvey, revealing how that guidance aligned and conflicted across plans and across the community. These findings are discussed after a review of relevant literature and explanations of the study context and methods. Conclusions and potential implications are then presented, and the paper closes with an acknowledgement of study limitations and a look ahead to future research directions.

3.2. Literature Review

Resilience, the concept at the center of the PIRS method, is defined as "[t]he capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation" (Intergovernmental Panel on Climate Change [IPCC], 2014, p. 5). A resilience approach to urban planning is more pragmatic, and traces its origins to the field of hazard mitigation. Resilient communities are comprised of infrastructure that is able to successfully function during and after a hazard event; critical structures and residential areas that are not located in the most hazard-prone locations; building standards that incorporate true hazard risk; and natural areas that are preserved for the 'ecosystem services' they provide, like serving as buffer zones or attenuating flooding (Godschalk et al., 1998).

Achieving and maintaining community resilience in the face of disturbances (e.g. flood events) is closely linked with the effective coordination of the various plans that guide development and land use management (Di Gregorio et al., 2017; Kim & Rowe, 2013; Woltjer & Al, 2007; Berke & Godschalk, 2009; Burby et al., 1997). Emerging scholarship suggests that policies and recommended actions found in plans not focused overtly on hazards may still affect resilience (Berke et al., 2015, 2018; Kashem et al., 2016). Integrating hazard awareness and mitigation throughout the network of plans is therefore crucial for building and enhancing community resilience (Fidelman, Leitch, & Nelson, 2013).

In the U.S., local and regional planning rarely achieve the integration required to effectively mitigate hazards. Poor coordination of a community's multiple plans – which are often developed by disparate, 'siloed' departments and organizations, each pursuing its own goals (Hopkins & Knapp, 2018) – may result in ineffective guidance, conflicting policies, and increased hazard vulnerability (Berke et al., 2018; Finn, Hopkins, &

Wempe, 2007). Recognizing this challenge, planning researchers developed new concepts and tools to analyze and coordinate plans. Finn, Hopkins, and Wempe (2007) geocoded community action items and policies that included spatial attributes in a GIS-linked online database, enabling more effective comparisons and detection of conflicts between policies and actions in various plans. Berke and colleagues (2015) developed the PIRS methodology to evaluate policies at the sub-jurisdictional scale. Employing metrics to score applicable policies, based on their geographic focus and likely effects on hazard vulnerability, facilitates the indexing and comparison of scores across a network of plans and across a community. By revealing policy gaps or conflicts, and highlighting places where policies may effectively increase vulnerability to hazards, the PIRS allows planners and decision-makers to better understand their communities and more effectively focus efforts on strengthening integration and resilience across the network of plans.

It remains unknown, however, what such a method might reveal if applied against the backdrop of an actual flood event and in a 'heavily planned' community (at least in terms of quantity; the direction and coherence of said planning a primary objective of a PIRS evaluation). A resilience scorecard evaluation can add to the larger hazard mitigation and plan coordination discourses, providing a new empirical perspective and evidence regarding (a) how different levels of hazard risk (e.g. 1% vs 0.2% chance of flooding) manifest in plans for land use and the built environment (see Butler, Deyle, & Mutnansky, 2016; Correljé & Broekhans, 2015); (b) the effects of larger structures and dis/incentives on hazard and development policy (see National

Research Council, 2014; Moser et al., 2014; Brody, Highfield, & Kang, 2011; Burby, 2006); or (c) how plans are coordinated across administrative scales, with respect to hazard mitigation and resilience (see Woodruff, 2018; Berke, Smith, & Lyles, 2012). These issues are especially pertinent, of course, in the city of Houston, Texas, which experiences more than its share of flooding disasters—many of which are likely related to planning and management decisions.

The tragedy of Hurricane Harvey still weighs on the city and its inhabitants, yet provides an opportunity to better understand the circumstances that contributed to it, in hopes of reducing the impact of future events. Given the critical role of land use planning in flood-hazard mitigation (or exacerbation), lessons from a resilience scorecard evaluation may prove useful. To that end, I spatially analyze a network of 18 plans in a cluster of 4 'super neighborhoods' and 3 'municipal management districts' in western Houston, addressing the following related questions:

(1) How integrated is the network of plans with respect to its influence on flood vulnerability, and how do plan policies affect different parts of the study area?

(a) How do plans at different administrative or geographic scales (e.g. regional, city, neighborhood) affect flood vulnerability across the study area?

(b) How do different types of plans (e.g. transportation, parks and recreation, small area master plan) affect flood vulnerability across the study area?

(c) How does the network of plans affect flood vulnerability in the FEMA SFHA (100-year floodplain), the FEMA 500-year floodplain, and the parts of the study area that experienced flooding during Hurricane Harvey?

(2) What are the implications for long-term flood mitigation in Houston, in light of climate change and an increase in the frequency of extreme flood events?

3.3. Context

The analysis is focused on a cluster of four super neighborhoods – *Briar Forest*, *Eldridge / West Oaks*, *Memorial*, and *Westchase* – and three municipal management districts – *Energy Corridor*, *Memorial*, and *Westchase* – in western Houston (Figure 3.1). The former denotes an administrative and planning division unique to the city, while the latter comprise special districts created by the Texas legislature to coordinate and promote development and the public welfare (State of Texas, 2005). The 47.3-square-mile area is home to approximately 200,000 residents (City of Houston, 2019). Neighborhoods here have higher than average median household incomes and percentages of white residents, compared to the city as a whole (City of Houston, 2019). The study area is also home to headquarters or regional offices of numerous energy companies, including Shell and BP, making it the second largest employment center in the region (Energy Corridor District, 2015).

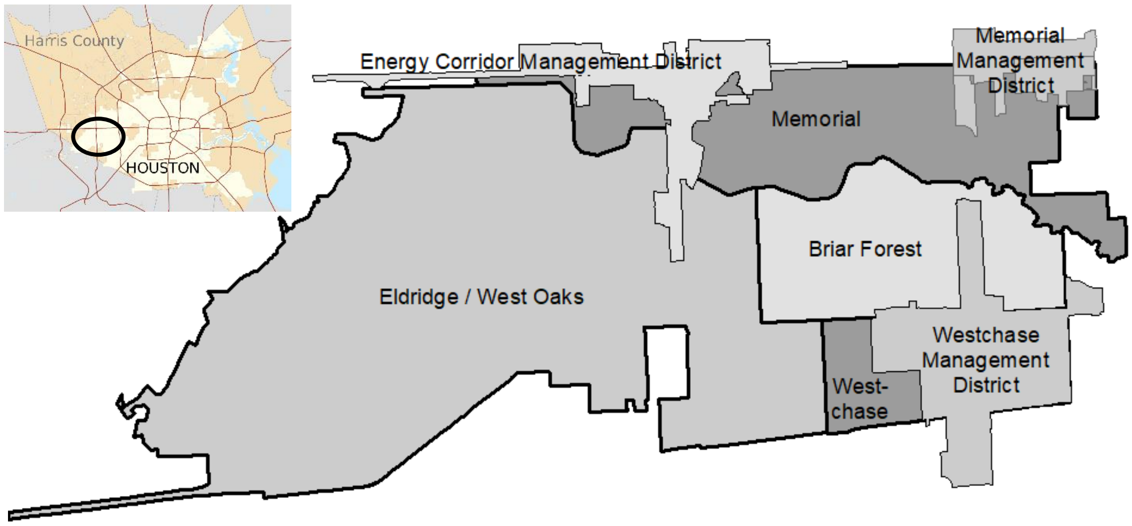

Figure 3.1 Study area: a cluster of four super neighborhoods and three municipal management districts in western Houston, Texas. The Barker Reservoir (including George Bush Park) comprises the western half of the Eldridge / West Oaks super neighborhood. The Addicks Reservoir is located just to the north of the Energy Corridor Management District.

Despite its relative affluence, this part of the city suffered extensive damage during Hurricane Harvey. Located immediately downstream from the Addicks and Barker Reservoirs, the area was inundated not only by the unprecedented rainfall accumulation, but also as a result of controlled releases from the reservoirs to prevent catastrophic dam failure (Blake & Zelinsky, 2018). Releases began August 28 and continued until September 20; only then did floodwaters begin to recede from the study area (HCFCD, 2018b).

Following catastrophic flooding in the 1930s, the Addicks and Barker Reservoirs were built to protect downtown Houston from flooding (United States Army Corps of Engineers [USACE], 2009). The reservoirs are designed to collect excessive rainfall and then release water into Buffalo Bayou at a controlled rate. Although releases from the reservoir devastated downstream neighborhoods during Harvey, the dams successfully protected downtown Houston, the Houston Ship Channel, and Port Houston (HCFCD, 2018b).

Flooding below the dams in this part of Houston has become a greater threat as urban development has continued to intensify (USACE, 2009). Continued development downstream has placed more people and property in risky locations, while development upland, near the western edges of the rarely-filled reservoirs (USACE, 2009), has resulted in additional pressure and less room for the reservoirs. Thus, it is critical that the plans guiding this development are coordinated and that hazard-awareness is integrated throughout the entire network.

Unlike many parts of this notoriously planning-averse city, this prominent section of Houston received a great deal of policy attention from plans at multiple administrative scales. Development in the western Houston super neighborhood cluster study area is guided by 18 separate plans, developed by regional, city, and neighborhood entities (and combinations thereof). Municipal management districts, which are empowered to promote economic development and public welfare, have also developed numerous plans to guide future development. This enables a robust exploration of the relationship between plans, including at different administrative scales (also see Woodruff, 2018), as well as of the potential effects of policies that apply to one area but affect another—e.g., policies encouraging new development in an upland location increasing flood risk in downstream areas (Brody, Highfield, & Kang, 2011).

3.4. Method

The examination of the network of plans in the western Houston super neighborhood cluster generally follows the standard PIRS evaluation methodology (Berke et al., 2015; Malecha et al., 2019), though with several adjustments as necessitated – as *permitted* – by the unique circumstances. The study proceeds in two steps: (1) delineation of planning districts and hazard zones, and (2) evaluation of the study area's network of plans for integration and effects on flood vulnerability.

3.4.1. Step 1: Delineate Planning Districts and Hazard Zones

The western Houston study area is first subdivided to facilitate spatial analysis of plans and improved understanding of the heterogeneity of policy effects across the community. For this analysis, *planning districts* consist primarily of U.S. Census tracts—statistical and geographic units of roughly 4000 inhabitants which are "designed to be relatively homogeneous … with respect to population characteristics, economic status, and living conditions" (United States Census, 2019). Census tracts are preferred to super neighborhoods as a scale of analysis because they are significantly smaller than the latter, which enhances the quality of spatial plan and policy analysis that can be performed. Moreover, despite official recognition by the city, super neighborhoods generally play a relatively minor role in local planning. To the U.S. Census tracts are added the three legislatively established municipal management districts, included because of their significance to planning in the region; many plans and policies reference management districts as their specific areas of geographic focus. Together, the U.S.

Census tracts and management districts yield a set of 38 total planning districts, outlined in black and numbered/labeled in Figure 3.2.[3]

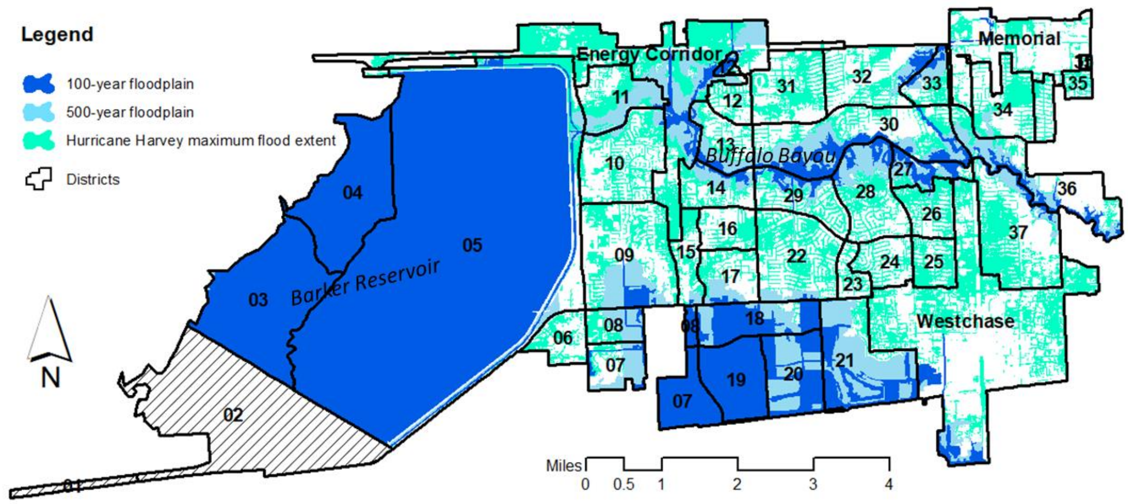

Figure 3.2 Map of the western Houston super neighborhood cluster study area, showing numbered/labeled planning districts (38 in total, excluding districts '01' and '02', which contain no population and are outside Harris County) and hazard zones (3 in total). These combine to subdivide the study area into 97 mutually exclusive district-hazard zones. To enable more useful comparisons, the 'Hurricane Harvey maximum flood extent' hazard zone only covers areas that flooded *outside* the other hazard zones, despite significant overlap.

Three separate hazard zones are used in the analysis, each of which is significant for planning and policy in the Houston region. First, given its central role in driving food-related land use policy over many decades (National Research Council, 2014), the current FEMA SFHA (100-year floodplain) is used as the primary hazard zone.[4,5] Its

[3] Note: Districts '01' and '02' are excluded from the analysis for lack of residential population and location outside Harris County.
[4] Data retrieved from Harris County Flood Control District (HCFCD): https://www.hcfcd.org/interactive-mapping-tools/
[5] For discussions of why and how the 100-year floodplain has been a problematic standard for flood risk, see National Research Council, 2014; Brody, Highfield, & Kang, 2011; Burby, 1998.

spatial extent, which corresponds to the part of the study area ostensibly subject to a 1% chance of flooding in a given year, is displayed in dark blue in Figure 3.2.

The 500-year floodplain (the area with a 0.2% chance of flooding in a given year) is included as a second hazard zone.[6,7] It is shown in light blue in Figure 3.2. The 500-year floodplain is particularly suitable as an analytical frame in the study area due to its prominence in the post-Hurricane Harvey planning and policymaking discourse. Authoritative voices in Houston and Harris County[8] have suggested replacing the current 100-year-floodplain-based development standards in Houston and Harris County with similar standards based on the 500-year floodplain. Even before Hurricane Harvey, the recent spate of large floods had suggested that the current 100-year floodplain was an inadequate measure of flood risk.

A third and final hazard zone is created based on the actual maximum extent of flood waters during Hurricane Harvey, derived from post-event analysis by FEMA.[9] This is an especially salient hazard zone, given the geographic and temporal context of this

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[6] Data retrieved from Harris County Flood Control District (HCFCD): https://www.hcfcd.org/interactive-mapping-tools/

[7] Because the study area is located approximately 40 miles from the nearest coastline, a secondary hazard zone incorporating a projection of sea-level rise – preferred in several prior PIRS studies (Berke et al., 2015, 2019) as a way of evaluating spatial differences in policy focus – is not appropriate.

[8] Documented in contemporary local news articles, e.g.: https://www.bizjournals.com/houston/news/2019/07/10/harris-county-approves-tougher-interim-floodplain.html; https://communityimpact.com/houston/city-county/2019/07/17/new-harris-county-floodplain-rules-draw-concern-over-development-costs/; https://www.freese.com/blog/new-city-houston-floodplain-regulations-post-harvey

[9] Derived from 3m^2 continuous food depth raster grid for entire Harvey-impacted area (FEMA Region 8: https://data.femadata.com/Region8/Mitigation/Data_Share/). Geoprocessing performed to collapse all depths into a single polygon layer, such that standing water of any depth constituted flooding. Though potentially a limitation, given recent studies focused on the impact of water depth on flood damage (Jenkins et al., 2018), this method parallels the depth-related aspects of delineating FEMA floodplains.

study. It is the most extensive, affecting every planning district in the study area. It overlaps large portions of the SFHA and 500-year floodplain hazard zones and extends beyond them to include much of the land located outside the FEMA-recognized flood hazard areas. For the purpose of this evaluation, however, the parts of the layer outside the other hazard zones, shown in teal in Figure 3.2, will be isolated and analyzed as a third mutually exclusive hazard zone. This hazard zone represents the parts of the community thought to be quite safe, but which nevertheless flooded during the hurricane.

The planning districts and hazard zones are combined using GIS to form *district-hazard zones*—the unit of analysis for this study. In total, the 38 planning districts and 3 hazard zones combine to form 97 mutually exclusive district-hazard zones (some districts do not include all 3 hazard zones) that may be differentially affected by policies in the network of plans.

3.4.2. Step 2: Evaluate Network of Plans

After deriving the district-hazard zones, the study area's network of plans is acquired[10] and spatially evaluated using the PIRS method (see Malecha et al., 2019). Relevant policies are assigned to appropriate district-hazard zones and scored according to their likely effects on flood vulnerability. Policies likely to increase vulnerability receive a "-1" (negative) score, while those likely to reduce it receive a "+1" (positive)

[10] Plans are acquired from online outlets of various local governments (e.g., Harris County, City of Houston, Houston-Galveston Area Council), management districts (e.g., Energy Corridor District, Memorial Management District) and non-profit stakeholder groups (e.g., Houston Stronger, West Houston Association, Gulf-Houston Region).

score. Scores are then totaled to create policy score indexes for every district-hazard zone. The resulting scorecard is analyzed to provide insight into how and where policy guidance aligns and conflicts with respect to flood vulnerability in the study area.[11]

The large network of plans evaluated for the western Houston study area is shown in Table 3.1. It includes 18 plans, across 4 administrative scales, which were in place and directing land use and development at the time Hurricane Harvey made landfall in August 2017. Regional plans are the broadest in scope, generally focusing on the Greater Houston metropolitan area, but sometimes containing quite precise guidance. Given the size of Harris County and Houston, proper, the county- and city-scale plans also have relatively broad geographic scopes, whereas the district and small area plans are much more narrowly focused. Along with differences in the purpose(s) for which plans are produced, variations in scope can influence the focus of their policies, including the attention they pay to flood hazards.

[11] Additional sources for data to assist in spatial plan evaluation acquired from Houston-Galveston Area Council: http://www.h-gac.com/gis-applications-and-data/datasets.aspx; City of Houston: https://cohgis-mycity.opendata.arcgis.com/; and Harris County Open Data: http://geo-harriscounty.opendata.arcgis.com/

Table 3.1 Network of plans in the western Houston super neighborhood cluster study area.

Regional Plans [4 in total]

- Our Great Region 2040 (including the 'Strategy Playbook') (2014)
- Houston Stronger (*undated*)
- Gulf-Houston Regional Conservation Plan (2017)
- 2040 Houston-Galveston Regional Transportation Plan (RTP) + 2017-2020 Transportation Improvement Plan (TIP)

County Plans [1]

- Harris County Flood Control District 2017 Federal Briefing

City of Houston Plans [3]

- City of Houston Hazard Mitigation Plan Update (2017)
- Plan Houston (2015)
- Houston Parks & Recreation Department Master Plan (2015)

District and Small Area Plans [10]

- The Energy Corridor District Unified Transportation Plan, 2016-2020
- The Energy Corridor District 2015 Master Plan
- Energy Corridor Livable Centers Plan (2010)
- Energy Corridor Bicycle Master Plan (2010)
- Memorial City Management District 2014-2024 Service & Improvement Plan & Assessment Plan
- Westchase District Long Range Plan (2006)
- West Houston Plan 2050: Envisioning Greater West Houston at Mid-Century
- West Houston Trails Master Plan (2011)
- West Houston Mobility Plan (2015)
- 2009 Master Plan, Addicks and Barker Reservoirs, Buffalo Bayou and Tributaries, Fort Bend and Harris Counties, Texas

Well-established content analysis procedures were followed (Stevens, Lyles, and Berke, 2014). Two trained researchers worked independently to code and score policies across the entire network of plans, resolving instances of disagreement to produce a final, consensus scorecard. The intercoder agreement score (0.88) falls above the acceptable plan evaluation coefficient threshold.

3.5. Findings and Discussion

3.5.1. Overview (Study-area-wide Findings)

Results from the spatial plan evaluation indicate that the network of 18 plans that was in place and guiding development and land use management in western Houston at the time Hurricane Harvey struck generally supported a reduction in flood vulnerability. Of the 152 land use policies and actions across the network of plans that were likely to influence vulnerability, many more were focused on reducing it (90) than were likely to increase it (62) (Table 3.2). Across the entire study area (Figure 3.3), not a single district-hazard zone received a negative index policy score, which would indicate that the mix of policies affecting it were, on the whole, guiding it in a more vulnerable direction. This positive overall picture, however, belies hidden patterns within the network of plans and across hazard zones, including apparent conflicts between policies in some areas, which are discussed in greater detail below and then illustrated in a 'case study' of the Energy Corridor District.

Table 3.2 Scorecard results: policy counts and total index policy score statistics by administrative scale, plan type, and hazard zone.

	Policy counts			**Total index policy score statistics***		
	Likely to reduce vulnerability	Likely to increase vulnerability	Total	Composite	Average	Std. dev.
Administrative scale**						
'Larger' (regional, county, and city plans)	51	5	56	1834	229.3	163.3
'Smaller' (district and small area plans)	39	57	96	268	26.8	66.9
Total	*90*	*62*	*152*	*2102*		
Plan type						
Environmental	35	1	36	853	213.3	176.3
Hazard mitigation	22	0	22	841	210.3	160.1
Transportation	3	14	17	-84	-28.0	11.5
'Comprehensive plan'-style	30	47	77	492	70.3	96.0
Total	*90*	*62*	*152*	*2102*		
Hazard zone						
100-year floodplain (1% annual chance)	*[Direction of policy influence very rarely differs across hazard zones]*			956	53.1	72.0
500-year floodplain (0.2% annual chance)				629	34.9	47.7
Hurricane Harvey maximum flood extent				517	28.7	44.5
Total				*2102*		

*Total index policy score statistics are calculated slightly differently for each sub-group. Inputs for *Administrative scale* statistics include total index policy scores by plan (all hazard zones combined), regardless of plan type. Inputs for *Plan type* statistics include total index policy scores by plan (all hazard zones combined), regardless of administrative scale. *Hazard zone* statistics are calculated by totaling index policy scores by hazard zone for each plan, resulting in averages that are lower than in the other sub-groups. Composite total index policy scores reflect the total number of policies in an administrative scale, plan type, or hazard zone; their likely direction of influence (reducing or increasing vulnerability); and their geographic range.

**Administrative scale groupings are based on geographic scope (larger than study area vs. smaller than study area) and scorecard results.

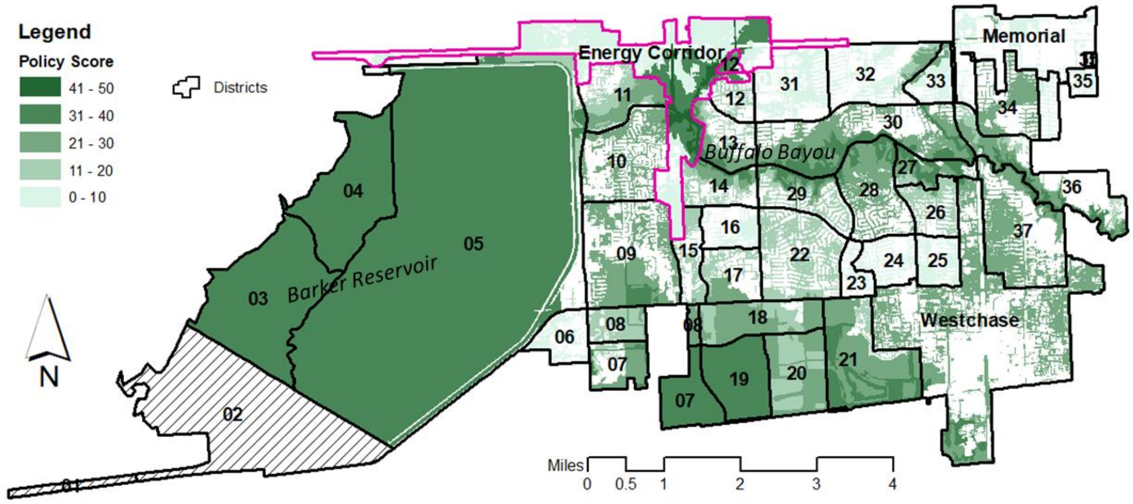

Figure 3.3 Scorecard results: index policy scores by district-hazard zone in the western Houston study area. Darker shades indicate stronger and more positive policy attention, while lighter shades suggest less attention (and potentially more policy conflict). Districts 03, 04, and 05, located inside the Barker reservoir, are positively affected by policies aimed at preserving and enhancing it as a parkland and water detention facility.

3.5.2. Results by Administrative Scale

Analysis of the index scores for the western Houston network of plans by administrative scale reveals stark differences between 'larger scale' and 'smaller scale' plans (Table 3.2). The eight regional-, county-, and city-scale plans are significantly more positive and wider ranging (affecting more district-hazard zones) than are the ten neighborhood and small area plans, though the latter include more total policies likely to affect vulnerability. Of the policies in the larger-scale plans, 91% (51 of 56) are likely to reduce flood vulnerability, while only 41% (39 of 96) of the neighborhood and small area plan policies guide the community in a less vulnerable direction. This is likely due to the prominence of development and transportation policies in the smaller-scale plans (see Section 3.5.3), whereas the city, county, and regional plans are mainly focused on environmental, safety, and connectivity issues. Being 'closer to the action', neighborhood and small area plans are also frequently affected by the need to balance many competing needs – including the classic development-vs.-preservation challenge – while larger-scale plans generally avoid such issues. 'Total index policy scores' (calculated by summing the index policy scores across all district-hazard zones in a plan) average 229.3 per plan for the larger-scale plans and 26.8 for the smaller-scale plans.

3.5.3. Results by Plan Type

Regardless of administrative scale, plan type has a major influence on policy guidance with respect to flood resilience. Table 3.2 indicates that plans with an environmental emphasis (*Gulf-Houston Regional Conservation Plan*, *Houston Parks & Recreation Department Master Plan*, *West Houston Trails Master Plan*, *Energy Corridor Bicycle Master Plan*) or a focus on hazard mitigation (*Houston Stronger*, *Harris County Flood Control District Federal Briefing*, *City of Houston Hazard Mitigation Plan Update*, *Addicks and Barker Reservoirs Master Plan*) contain many policies aimed at strengthening flood-resilience (35 and 22, respectively).

Total index policy scores are also very high for these plans, on average (213.3 and 210.3, respectively). Policies in transportation plans (*Houston-Galveston Regional Transportation Plan / Transportation Improvement Plan*, *Energy Corridor District Unified Transportation Plan*, *West Houston Mobility Plan*) are much more are likely to raise vulnerability (14 of 17) than to reduce it (3 of 17), typically by guiding development toward hazard-prone locations. Total index policy score averages per plan are negative (-28.0) for transportation plans. Results are mixed for 'comprehensive plan'-style documents (*Our Great Region*, *Plan Houston*, *Energy Corridor District*

Master Plan, Energy Corridor Livable Centers Plan, Memorial City Management District Service & Improvement Plan, Westchase District Long Range Plan, West Houston Plan 2050), reflecting the diversity of policies often contained in such documents—from increases in development intensity, on one hand, to preservation of critical habitat or scenic areas, on the other.

3.5.4. Results by Hazard Zone

Table 3.2 also compares total policy index scores for the three hazard zones examined in this study. It reveals that the strongest and most positive policy attention is paid to the to the 100-year floodplain (the FEMA SFHA). The floodplain surrounding Buffalo Bayou, in particular, is the focus of significant attention aimed at reducing vulnerability (Figure 3.3). The total index policy score for the 100-year floodplain averages 53.1 per plan across the network of plans. Scores are significantly lower for the 500-year floodplain (34.9 per plan, on average), and even lower for the Hurricane Harvey maximum extent hazard zone (28.7 per plan). This suggests that the network of plans was heavily focused on mitigating flooding in the FEMA SFHA, the flood-hazard zone that was most familiar, most strongly regulated, and for which proactive planning was best incentivized. At the time of Harvey's impact, such institutional drivers were far weaker with respect to the 500-year floodplain, though this is changing (see Section 3.4.1). The lowest index policy scores by plan – as well as many of the lowest index policy scores by district-hazard zone (e.g. Districts 6, 16, 18, 24, 25, 31, 33, 35, Energy Corridor [see Figure 3.3]) – are found in the Hurricane Harvey maximum extent hazard zone, reinforcing the claim that policy attention is contingent, in large part, on perceived hazard risk and the institutionalization of hazard awareness. Policies likely to increase vulnerability were more likely to target such areas, given their location outside the FEMA-designated flood zones. However, as Hurricane Harvey and other recent flood events have shown (and research has documented), flooding does not always respect predetermined hazard zones—and relative safety during most conditions means little during a catastrophe.

3.5.5. Case Study: Energy Corridor District

Houston's Energy Corridor District – established in 2001 by the Texas Legislature to "promote, develop, encourage, and maintain employment, commerce, economic development, and the public welfare" (Energy Corridor District, 2015; State of Texas, 2005) – is the most heavily planned part of the western Houston study area (outlined in pink in Figure 3.3). More than 100 policies across 14 plans are likely to affect flood vulnerability in the Energy Corridor District (see Appendix B). Straddling Interstate 10 and Buffalo Bayou and bordering the Addicks and Barker Reservoirs (which double as regionally significant parks), the Energy Corridor is a leading employment center in the city, with designs for continued growth as a high-amenity mixed-use destination (Energy Corridor District, 2015). The abundance of flood-vulnerability-related policies in the Energy Corridor District enables a 'deep dive' to investigate some of the drivers behind the scorecard results, including examples of how polices across the network of plans align, conflict, and affect different parts of the community in different ways.

Findings generally reflect those observed for the wider study area: more policies affecting the Energy Corridor District are likely to strengthen resilience (65) than to raise vulnerability (52); scores are generally better for plans at higher administrative scales and for those that focus on environmental or hazard issues; and more positive policy attention is given to the parts of the district in the 100-year floodplain (index score: +44) than to those in the 500-year floodplain (+30) or Hurricane Harvey maximum flood extent hazard zone (+1). A closer look at the policies behind these scores reveals patterns, including conflicts between plan documents, that are often relevant to the broader study area, and perhaps even to Houston and the wider region. They help illustrate the story of how the existing network of plans influenced flood vulnerability in this part of Houston at the time of Hurricane Harvey's impact in August 2017.

A majority of policies affecting flood vulnerability in the Energy Corridor District are likely to have a positive effect—from promoting conservation subdivision design, preserving wetlands and riparian zones, and developing an integrated regional storm defense system (*Our Great Region 2040, West Houston Plan 2050*); to land acquisition and conservation easements (*Gulf-Houston Regional Conservation Plan*); to buyouts of flood-prone homes (*Houston Stronger*), regulatory measures that ensure safety in future development (*City of Houston Hazard Mitigation Plan Update*), and improvement of reservoir outlet structures (*Harris County Flood Control District Federal Briefing*). Extensions and enhancements of park and trail networks, especially along drainageways, are also suggested in multiple plans (*Houston Parks & Recreation Department Master Plan, Energy Corridor District Bicycle Master Plan, West Houston*

Trails Master Plan). However, many policies directed at the very same part of the city encourage intensification of development near transit (*Plan Houston*), large-scale redevelopment and infill (*Energy Corridor District Master Plan*, *Energy Corridor Livable Centers Plan*, *Energy Corridor District Unified Transportation Plan*), and new transportation corridors to induce development (*West Houston Plan 2050*, *West Houston Mobility Plan*), even suggesting financial incentives to help accomplish it all (*Our Great Region 2040*). While appropriate in less hazardous places, such density- and development-focused policies potentially raise vulnerability if implemented in flood-hazard areas without sufficient attention to mitigation. They also conflict with the direction of much of the other guidance – toward reducing flood-vulnerability – and make no mention of this potential discord or how to resolve it (e.g. 'hazard mitigation should take precedence in flood-hazard areas'). Also note the distribution of these policy examples among plan scales and types: following the broader trends seen throughout the study area, policies aimed at reducing vulnerability are found most often in plans at higher administrative scales and focusing on environmental or hazard issues, whereas policies likely to raise vulnerability are typically found in the more localized plans and those that focus on transportation or development.

The Energy Corridor District also exemplifies the disparity in policy attention with respect to the three hazard zones. A higher index policy score for the district's 100-year floodplain (SFHA) is the result of many policies focused on protecting riparian and other flood-prone areas from development (*City of Houston Hazard Mitigation Plan Update*, *Our Great Region 2040*), as well as conserving or expanding existing parkland

(*West Houston Trails Master Plan*, *Houston Parks & Recreation Department Master Plan*), much of which coincides with the SFHA. Fewer such policies apply in the 500-year floodplain, which is also the focus of a number of policies aimed at increased development (*Energy Corridor District Unified Transportation Plan*, *Energy Corridor District Master Plan*). Policy conflict is even more apparent in the Hurricane Harvey maximum flood extent hazard zone; many parts of the district that flooded during the storm but are located outside the 'acknowledged' floodplains were also the focus of intense development pressure and related policies (*Energy Corridor Livable Centers Plan*, *West Houston Mobility Plan*), in direct conflict with policies aimed at district-wide flood mitigation. The results of the spatial plan evaluation therefore suggest that planning in the Energy Corridor District at the time of the impact of Hurricane Harvey was proceeding with *some* awareness of flood risk, but that this was aimed much more toward the established, regulatory SFHA.

This may go some way toward explaining the massive destruction that occurred in this otherwise relatively well-planned and prosperous part of the city. A much stronger focus on the 'known' floodplain – almost as if it was the only hazard area worth worrying about, despite the recent trend toward larger-than-expected flood events – appears to have exacerbated the consequences from Hurricane Harvey. This is, in many ways, a stark example of the 'safe development paradox' (Burby, 2006): focusing on large structural interventions to 'safeguard' new development from disasters inadvertently increases the human and economic costs of disasters when those systems fail or are exceeded. In the Energy Corridor District, located immediately downstream from the Addicks and Barker Reservoirs (which flow into Buffalo Bayou), planners and decision-makers appear to have recognized the need to restrict development in the *most* flood-prone area (100-year floodplain), but were also guiding new and/or intensified development toward proximate parts of the city, many of which are at only slightly higher elevation. Thus, when Hurricane Harvey's relentless rainfall necessitated the opening of the Addicks and Barker Reservoirs – so as to prevent additional flooding and their potential rupture and collapse – much of the community was inundated, leading to more catastrophic damage than would otherwise have occurred had the area not been deemed 'safe' and thus intensely developed without adequate mitigative measures.

Plan conflict is also observed in the notable case of several regional plans with policies spatially focused on 'upstream' areas that are nevertheless likely to affect flood vulnerability along Buffalo Bayou and in the Energy Corridor District. The *Gulf-Houston Regional Conservation Plan* aims to preserve upland Katy Prairie as part of a broader Prairie Conservation Initiative, likely reducing pressure on the Addicks and Barker Reservoirs and retaining or enhancing resilience along Buffalo Bayou. However, the *West Houston Plan 2050* discusses the need for a new "Prairie Parkway" in the same area to accommodate future growth. Unless the development induced by such a major roadway addition proceeds extremely cautiously (dubious in Houston), the likely result is reduced storage area for storm water, thereby increasing downstream vulnerability to flooding.

3.6. Conclusions and Implications

The spatial plan evaluation in this study shows that the existing network of plans was generally guiding the western Houston neighborhood cluster in a more resilient direction leading up to Hurricane Harvey. However, more – and more positive – policy attention was paid to the 100-year floodplain (SFHA) than to other parts of the study area. Policies likely to reduce vulnerability were also more often located in the plans further removed from neighborhood-scale decision-making. That is, plans focused on small areas often contained development- or density-focused policies likely to increase vulnerability, whereas those at higher administrative scales were more consistently aimed at reducing flood vulnerability.

A closer look at the scorecard results reveals that, despite positive overall index scores and many instances of sound planning, policies in many plans were guiding the community toward increased flood-vulnerability—especially in areas outside the SFHA but still at some risk for flooding. In the drive to accommodate and encourage new development, some plans and policies paid insufficient attention to actual flood risk. This may indicate an inability for plans to keep up with a rapidly changing reality; after all, the plans suggest an awareness of the need for flood mitigation, albeit aimed primarily at the SFHA. Given the recent increase in large flood events in Houston and mounting evidence of the SFHA's inadequacy as an accurate indicator of flood risk (Blessing, Sebastian, & Brody 2017; National Research Council 2014; Brody et al. 2014, 2012), some of the plan guidance at the time of Hurricane Harvey's impact appears to have been outdated. The problem may also have been amplified the false sense of security provided by ostensibly strong flood control measures, including the massive Addicks and Barker Dams. Intensifying development in areas just below a dam is a classic example of the *safe development paradox*, and had the effect of making the area even more vulnerable to cascading effects from a massive and sustained precipitation event like Harvey.

If Houston is to reverse the worrying trend of annual (or even more frequent) flooding catastrophe – with Hurricane Harvey as a massive exclamation point – a concerted effort must be made to build resilience across the city, and especially in the city's expanding flood-hazard zones. Much of this begins with sound planning, underlain by an acknowledgement of the new paradigm of relatively frequent and extensive flooding. Plans and policies must be adjusted to reflect this reality. The empirical evidence provided by a PIRS evaluation can help decision-makers identify policy gaps and conflicts, more effectively focus attention and resources, and strengthen resilience through better-integrated and more hazard-aware plan guidance. For the western Houston super neighborhood cluster study area, the focus on the SFHA must be broadened to include other parts of the community at risk for flooding. Policies aimed at intensifying development should also be reconsidered, given the reality flood risk, even if limited to incorporating site-level flood mitigation, such as building elevation, wet-proofing, or dry-proofing. A more unified and resilient policy direction across the network of plans will not only help prepare the area for the inevitable next flood event, but will also likely make it more attractive to development, in the long run.

3.7. Limitations and Future Applications

This study represents a first attempt at applying the concept of spatial plan evaluation (using the PIRS method) in the context of an actual flood event. As such, it was deliberately limited in scope. Time and resource constraints prompted a decision to focus the evaluation on a portion of the city, rather than the entire municipality or an even larger area. Prior studies (Malecha et al., 2018) have shown that such limitations do not negatively impact the efficacy of a PIRS evaluation, as long as the geographic parameters are acknowledged and remain clear throughout the process. Still, a broader examination would certainly provide additional insight – particularly if focused on real flood events, which are often regional in nature – and would be warranted in the right circumstances (such as a municipal or regional organization using it to systematically evaluate its network of plans and policies to improve resilience [see Malecha et al. 2019 for examples]). In this case, an analysis of the entire city, or even of Greater Houston, might prove informative with respect to the differential effect of plans and policies on flood vulnerability and impacts. Alternatively, a comparison with another part of the city – one that shares some characteristics (e.g. level of damage from the flood event) but not others (e.g. socioeconomics, plan/policy attention) – might offer similar insight in a more focused way.

Another consequence of the deliberate limitation is that the analysis was not tied or compared to actual flood damage or hardship, beyond the inclusion of the Hurricane Harvey Maximum Flood Extent as a hazard zone. Exploring the links between policy scores and reported flood losses or hardship would not only provide new insight into the circumstances 'on the ground', but could also be used to better understand the utility (and limitations) of the PIRS method in a hazard context. These are exciting new avenues to be explored in the near future.

3.8. References

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4. PLANNING *AND* REGULATING FOR RESILIENCE? A METHOD FOR EVALUATING THE SUITABILITY AND ALIGNMENT OF ZONING AND LAND USE PLANNING IN FLOOD-HAZARD AREAS

4.1. Introduction

Flooding is one of the most deadly, destructive, and costly natural hazards that affects the United States (Moser et al., 2014), causing dozens of fatalities and billions in damages every year (National Weather Service, 2019). Driven in large part by the continued urbanization and expansion of cities in flood-prone locations, especially in coastal areas (National Research Council, 2014), this problem is further complicated by the real and growing threats posed by climate change (United States Global Change Research Program [USGCRP], 2018), which are forcing communities to reevaluate many things, including the ways they plan and manage the use of their land. The growing climate crisis has increased the frequency and cost of heavy precipitation and coastal storm surge events in many places, as well as the spatial extent of the areas they inundate (USGCRP, 2018). Although some cities are beginning to plan for and adapt to this new reality, most are not doing so as quickly or effectively as needed.

Land use is frequently cited by academic and government sources as among the most important factors in determining community resilience (Godschalk, 2003; Brody et al., 2011; National Research Council, 2014; Berke et al., 2015). In the U.S., urban planning and zoning are used to guide and regulate land use, respectively, including in flood-prone areas. However, even when both approaches are employed (this varies, as there is no federal requirement for communities to have both planning and zoning), the land use prescriptions they produce do not always align (Hoch et al., 2000; Talen et al., 2016). Development may thus be allowed in a location or manner that increases vulnerability, despite well-intentioned plans to the contrary.

Furthermore, some land uses are more suitable than others in areas susceptible to flooding. Parks and open spaces, for example, are significantly less vulnerable than dense housing developments to floods, and are therefore more appropriately located in a floodplain than the latter. If similar logic is applied across the spectrum of land uses in a community, a conceptual hierarchy may be constructed of land uses based on their *suitability* for location in flood-prone areas. Such a framework can then be applied to adopted future land use and zoning categories as a way of understanding how a community is planning and managing land in flood-hazard zones though the lens of suitability. Assigning ordinal scores to the standardized categories then facilitates analysis of the *alignment* of land use planning and regulations, revealing how they compare to one another and to existing land uses, as well as the direction the community is heading with respect to land use in potentially hazardous places.

This paper presents a method for evaluating the suitability and alignment of zoning and land use planning in flood-hazard areas. First, a review of the literature and context is presented to situate the concept and method within the broader academic and popular discourses surrounding land use suitability and the relationship between planning and zoning in the United States. This is followed by explanations of the concept and methodology. I then demonstrate the method in the vulnerable coastal city of Tampa, Florida, and discuss the findings and broader implications. The paper concludes with a discussion of study limitations and potential avenues for further research and applications.

4.2. Literature Review: Flooding and Land Use, Planning and Zoning, Consistency and Conflict

The relationship between flooding and land use in the U.S. has long been the subject of academic attention and practical guidance. Scholarly investigation traces its origins at least as far back as the writings of geographer Gilbert White (1945), who detailed the risks and costs of developing in floodplains. Decades later, alarmed at the continuation of development in unsafe areas – and the accompanying rise in human and economic costs – hazards researchers produced pioneering edited volumes like *Disasters by Design* (Mileti, 1999), which recast disasters as largely human-caused, and *Cooperating with Nature: Confronting Natural Hazards with Land-use Planning for Sustainable Communities* (Burby, 1998), which offered a compelling way forward through smarter land use planning. Federal agencies have also produced guidance about land management in flood-prone areas, including the suitability of different land uses (Waananen et al., 1977), and have incentivized land-use-based risk avoidance through programs like the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP) and Community Rating System (CRS) (Brody et al., 2011; Highfield et al., 2014). Meticulous benefit-cost analyses have empirically substantiated flood mitigation techniques and program, which are shown to return an average of $6 in savings for every $1 invested (National Institute of Building Sciences, 2018; Godschalk et al., 2009). Despite known risks and clear guidance, however, property owners and local governments are often loathe to forego development in flood-prone areas, citing the opportunity costs of not developing (Olshansky & Johnson, 2015).

Unlike many countries, the United States does not have a unified, national (federal) planning department; most land use planning and regulation is conducted at the local scale, legally authorized via statutory language (Hoch, 2000; Hirt, 2015). Plans by themselves are instruments to guide the community's long-term approach to land use and development, gaining legal 'teeth' when paired with a zoning ordinance as part of an implementation-oriented development management program (Berke et al., 2006; Norton, 2008; Jourdan & Strauss, 2015). All 50 states have some degree of planning and/or zoning enabling legislation, though many have just one or the other (Jourdan & Strauss, 2015). However, localities often create and adopt both comprehensive plans (typically including a land use element) and zoning ordinances, which together guide land use decision-making in the community (Meck et al., 2000). Policies and regulations in these documents connect to specific areas of the community through the future land use map and zoning map.

Some states require *consistency* between planning and zoning, such that zoning must follow the plans and policies set forth by the adopted comprehensive plan (DiMento, 1980; Norton, 2008). In Florida, for instance, land use regulations are required to "be based on, be related to, and be a means of implementation for an adopted comprehensive plan" (State of Florida, 2019). As with many rules in the U.S., however, this requirement differs from state to state (Jourdan & Strauss, 2015). Despite this, the normative concept of consistency continues to be a significant driver of land use decision-making in many places that engage in both comprehensive planning and zoning, and the authority of comprehensive plans to set a community's regulatory framework is widely recognized (Brody et al., 2014; Jepson & Haines, 2014; Hoch et al., 2000).

Consistency between planning and zoning is especially critical with respect to flood-hazard mitigation. The power of the comprehensive plan to foster resilient communities by guiding development away from the most hazardous locations, promoting resilient design standards, and otherwise integrating mitigation within the broad spectrum of community goals has been persuasively demonstrated (Godschalk, 2003; Burby et al., 1999; Godschalk et al., 1998b). As the most important regulatory instrument by which communities effect their land use plans (Norton, 2008; Berke et al., 2006), zoning is a vital conduit for implementing a holistic, considered approach to hazard mitigation. Conflicting guidance between planning and zoning or toward inappropriate land uses may increase risk, whereas strong alignment toward suitable, hazard-aware land uses is likely to reduce community vulnerability to flooding.

4.3. Toward a Systematic Evaluation of the Suitability and Alignment of Zoning and Land Use Planning in Flood-hazard Areas

Despite renewed interest in the links between land use and flood risk – and new guidance to that effect (see USGCRP, 2018; Associated Programme on Flood Management, 2016) – relatively little attention has been paid to assessing the plans and regulations that influence community land use, let alone to identifying *where* their prescriptions may be increasing vulnerability and where they may, in fact, conflict. The method presented in this paper is a first step toward filling that gap. It builds on key concepts first explored by Berke and colleagues (Berke et al., 2015, 2018) as part of the *Plan Integration for Resilience Scorecard* (PIRS), a method for spatially evaluating networks of plans with respect to flood hazards. A PIRS analysis helps reveal where and how a community's plans are coordinated or in conflict, and where opportunities exist to strengthen resilience, but makes no connection to regulation and implementation.

Linking these concepts to land use regulation is crucial, given the central role zoning plays in implementing plans in the United States. Often characterized as relatively weak or, at best, highly variable, plan implementation and its associated problems – increasingly tied to environmental concerns – have garnered significant attention from planning scholars (Lyles et al., 2016; Brody & Highfield, 2005, Laurian et al., 2004; Talen, 1996). Methods to systematically understand the disconnects between planning and implementation remain scarce, however.

The *suitability and alignment of zoning and land use planning* (SAZLUP) method directly addresses this issue by extending core PIRS concepts – spatial plan evaluation, comparison of policy documents based their likely effects on hazards – into the regulatory realm. Concentrating on the community's officially adopted zoning map and future land use map, the spatial manifestations of its zoning ordinance and future land use plan, the SAZLUP method introduces two new concepts (both of which are explained in greater detail below): (1) a hierarchy of land uses by suitability in flood-hazard areas and (2) the alignment of planning and zoning prescriptions, based on that suitability. This may prove timely as the effects of climate change prompt communities to reevaluate the ways they plan for and regulate the use of their land.

Informed by theoretical and practical guidance from both academic and government sources, the SAZLUP method compares the relative suitability of adopted zoning and future land use plan prescriptions in flood-hazard areas to provide new perspective on a community's regulatory land use categories, proposed future land uses, and the spatial relationships between the two. It can reveal where zoning or future land use maps may be 'paving the way' for increased vulnerability through unsuitable density or development intensity without adequate mitigative measures. It may also show places where the ordinance or land use plan incorporates hazard information and regulates or guides for reductions in intensity (e.g. converting developed parcels to open space), thereby reducing vulnerability. Finally, it can reveal where the mapped land use prescriptions are inconsistent or in conflict. The SAZLUP method may potentially help address a multitude of questions, with applications for both research and practice. In this paper, I focus on the following:

(1) Is a community's future land use plan *guiding* it in a more suitable (less vulnerable) direction, with respect to land use in flood-hazard areas? That is, compared with existing land uses, are future land uses more suitable for locating in flood-hazard areas (all else being equal)?

(2) Is a community's zoning ordinance *regulating* for more suitable (less vulnerable) land uses in flood-hazard areas, compared to existing land uses?

(3) How well do the future land use plan and zoning ordinance align with respect to land use suitability in flood-hazard areas, based on the prescriptions in their associated maps?

4.4. Method

Addressing the research questions requires the standardization and comparison of land use designations defined in a community's adopted zoning ordinance and comprehensive or land use plan—including, if available, its existing land uses[12]. Analysis of the suitability and alignment of zoning and land use planning in flood-hazard areas is accomplished in three steps (Figure 4.1), aided by Geographic Information Systems (GIS) software.

(1) First, shapefiles and supporting documentation (e.g. plans, ordinances, definitions, metadata) are acquired for the community's zoning designations, future land uses, and existing land uses. They are then clipped to the flood-hazard zone(s) of interest, such as the 100-year (1% annual chance) floodplain.

(2) Land use categories in all three layers are standardized using the *land use suitability ladder* (see Section 4.3.2) and each parcel is assigned an ordinal value corresponding to its *land use suitability class*.

[12] Unlike policy statements – the plan components evaluated in the PIRS method – which have inherent temporality and directionality (e.g. "Encourage high-density residential redevelopment of Area A" suggests a future increase in residential population density in Area A, likely raising its vulnerability in the event of flooding, all else being equal), an evaluation of zoning regulations and future land use designations for hazard vulnerability necessitates a baseline condition and normative framework against which the static regulations and designations can be judged. Provided they are known (and mapped), existing land uses should serve as this baseline condition.

(3) Finally, calculations and geoprocessing are performed to determine a *land use suitability change* score for each parcel, indicating the relative change in land use suitability should regulatory or planning prescriptions be followed.

Tables and maps may then be produced to display the resulting data and help answer questions about the community's planning and regulatory direction and alignment in flood-hazard areas.

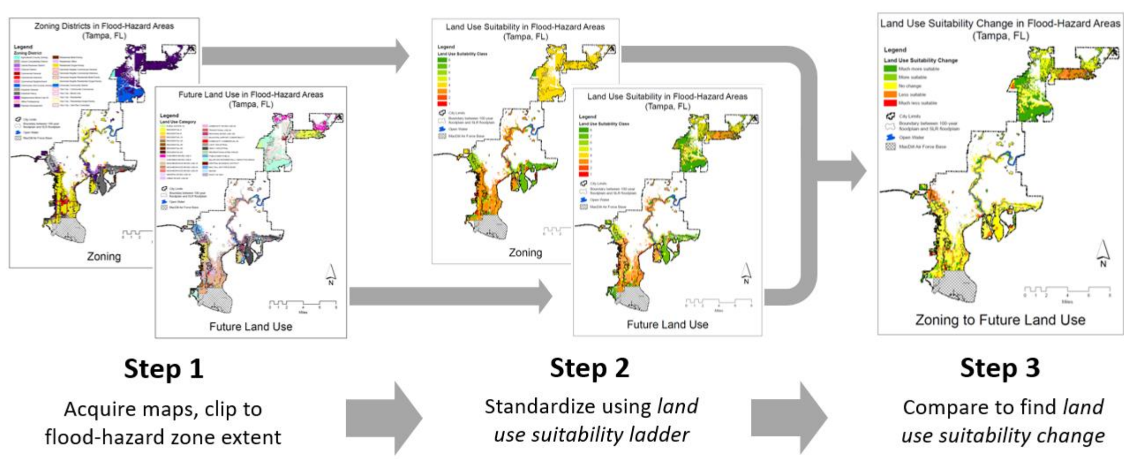

Figure 4.1 Illustration of steps in the *suitability and alignment of zoning and land use planning* (SAZLUP) method.

4.4.1. Data

Data sources for the SAZLUP evaluation include official community land use and zoning maps and corresponding GIS shapefiles, as well as adopted comprehensive or land use plans and zoning ordinances, which provide definitions and context to inform the standardization. The analysis should be performed at as detailed a scale as allowed by the data. In the case study of Tampa, Florida (see Section 4.5), data are available for all three layers – zoning, future land use, and existing land use – at the individual parcel scale. Shapefiles may also be collected from FEMA or other sources to help delineate the desired hazard zone(s). For the case study, I use the current FEMA Special Flood Hazard Area (SFHA), also known as the 100-year (or 1% annual chance) floodplain, as the flood-hazard zone. Including additional hazard zones, such as a future floodplain that incorporates a projection of sea-level rise, may enable a new set of research questions to be addressed (see Section 4.7).

4.4.2. Land Use Suitability Ladder (Land Use Suitability Class)

A conceptual hierarchy, based on the relative suitability of locating different types of land use in areas subject to flooding hazards, is used to develop a *land use suitability ladder* and assign *land use suitability class* scores (Table 4.1). The placement of land use categories within the hierarchy is grounded in academic and government publications (Burby, 1998; Godschalk et al., 1998a; Burby et al., 1999; Brody et al., 2011, 2014; Moser et al., 2014; National Research Council, 2014; Geneletti & Zardo, 2016) and is consistent with leading examples from practice (City of Dubuque, 2015; Tulsa County, 2018; Snohomish County, 2013; Minnesota Department of Natural Resources, 2013; Wisconsin Department of Natural Resources, 2017). The logic of minimizing the number of *person-hours* in harm's way – that is, minimizing the number of individuals in harm's way and the amount of time they are there[13] – is utilized to supplement the guidance from these sources.

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[13] Depending on a community's goals and priorities, however, other logical frames might be substituted (or incorporated) to determine suitability. For instance, if limiting the total area of structures exposed to

The land use suitability ladder is a normative framework that enables the surfeit of land use designations that may be found in municipal zoning ordinances and land use plans, including those unique to an individual locale, to be simplified and standardized for comparison. Each land use category found in a community's zoning or land use map is assigned to an appropriate 'rung' on the land use suitability ladder, based on its similarity to one of eight conceptual categories. Table 4.1 summarizes this step. Conceptual categories are shown on the left, followed by examples of existing land use, zoning, and future land use categories (from actual land use documents) that might be included on the same rung in the hierarchy. Corresponding land use suitability classes – ordinal values assigned for the purpose of standardization – are shown on the right. A higher land use suitability class score indicates that the land use is relatively suitable for location in a flood-hazard zone, while a lower score indicates that the specified land use is less appropriate.

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flooding is desired, flood-area-ratio (FAR) or setback limits might be more effective measures and might thus reorder or expand the categories. If the potential for toxic contamination is identified a high-priority risk, the *Industrial* category might be adjusted down a few 'rungs' on the land use suitability ladder.

Table 4.1 Land use suitability ladder, indicating relative suitability of land uses in flood-hazard zones; includes conceptual categories, examples of actual categories from zoning and land use maps, and land use suitability class scores (ordinal scale).

Conceptual Category	Examples of Existing Land Use Categories	Examples of Zoning Categories	Examples of Future Land Use Categories	Land Use Suitability Class
Open Space	"Parks / open space" "Vacant developable"	"Open space" "Agricultural"	"Parks / open space / natural" "Agriculture reserve"	8 (most suitable)
Industrial*	"Light industrial" "Industrial"	"Limited industrial" "Industrial heavy"	"General industrial" "Heavy industrial"	7
Commercial	"Light commercial" "Heavy commercial"	"Commercial general" "Office/ commercial"	"Community commercial" "Auto-dominant commercial"	6
Institutional**	"Government/medical/ educational" "Public/quasi-public"	"Public and semipublic" "University community district"	"Public/semi-public" "Public, Institutional"	5
Mixed-use	"Mixed use" "Commercial/residenti al mix"	"Neighborhood mixed use" "Planned unit development"	"Suburban village" "Commercial mixed use"	4
Low-density residential	"Single family residential" "Large lot residential"	"Low-density suburban residential RSF-10" "Suburban residential"	"Rural estate residential" "Residential low"	3
Medium-density residential	"Duplex/triplex area" "Townhomes"	"Medium-density residential RSF-5" "Residential multi-family"	"Enhanced auto-dominant residential" "Residential medium"	2
High-density residential	"Multi-family residential" "Mobile home park"	"High-density multi-family residential RMF-1.2" "Multi-family high"	"Residential multi-family" "Residential high"	1 (least suitable)

*Category subject to 'toxic facilities caveat'
**Category subject to 'critical facilities caveat'

Hazards and planning literatures (Burby, 1998; Burby et al., 1999; Godschalk, 2003) and government guidance (e.g. State of West Virginia, 2015; Snohomish County, 2013) are nearly unanimous in suggesting *residential* land uses as the least suitable of all for flood-prone areas. They also fare poorly when using the aforementioned person-hours logic: a comparatively large population is present in residential areas for a large proportion of the day—especially during the mornings, evenings, and overnight, though also a reduced number during normal working hours. These categories are therefore placed at the bottom of the ladder, according to intensity (see Federal Emergency Management Agency [FEMA], 2019; Urban Floods Community of Practice [UFCP], 2017), with an ordinal score of '1' for *high-density residential* land use, '2' for *medium-density residential* and '3' for *low-density residential*.

On the opposite end of the spectrum, and thus occupying the highest rung of the land use suitability ladder (score of '8'), is the category of *open space*, broadly defined as including parks, recreation areas, and natural and vacant lands. These areas are less likely to contain permanent residential populations or large numbers of vulnerable structures, and are universally regarded as the most appropriate of all urban uses for areas likely to be impacted by flooding (UFCP, 2017; FEMA, 2017; Schwab et al., 2016; Burby & French, 1981). Additionally, many open spaces provide important ecosystem services by attenuating flood waters, preventing erosion and runoff, or acting as buffers (Burby, 1998; Brody et al., 2011).

Based on a combination of examples from practice (Snohomish County, 2013; Tulsa County, 2018) and the person-hours logic, *industrial* land uses occupy the second highest rung on the suitability ladder (‘7’). Given their typically low residential population density, all else being equal, industrial uses are preferred to most others in an area likely to be flooded. However, the potential for flood waters to spread toxins or other hazards following inundation of industrial sites is a significant consideration, and thus industrial areas in flood hazard zones should be viewed with caution, despite their relatively high land use suitability class. A ‘toxic facilities caveat’ may also be applied. When land parcels containing toxic facilities (or likely to contain them in the future) can be identified and isolated, they should be assigned a land use suitability class score of ‘1’ (the equivalent of being placed on the lowest rung of the ladder), reflecting their status as among the least suitable uses for land a flood-hazard zone.

Commercial, *institutional*, and *mixed-use* land use categories form the central portion of the land use suitability ladder. Less direction exists in the scholarly or advisory literature for these categories. However, state and local requirements are often less strict for non-residential land uses (see FEMA, 2017; Tulsa County, 2018; FEMA, 2019), implying greater suitability. Like industrial areas, places with predominantly commercial land uses (‘6’) are unlikely to have large residential populations or numbers of people unable to evacuate to avoid flooding. Commercial structures are also often less vulnerable to flooding than residential structures due to their building materials (National Institute of Standards and Technology [NIST], 2016; City of Dubuque, 2015).

The mixed-use category (‘4’) is located just above the residential categories but below commercial, given its combination of functions and greater potential for full-time residents (Xiao & Van Zandt, 2012). Though a relatively high residential population may be present in such areas, the residences, themselves, are often elevated, and thus less vulnerable to flooding than residential areas with similar densities (UFCP, 2017).

The area in between, occupying the ‘5’ rung on the ladder, is reserved for institutional land uses, which include government, medical, or educational facilities and publicly owned lands.[14] These uses suggest the need for a second important caveat – a ‘critical facilities caveat’ – which should also be applied when possible. If parcels that contain (or are likely to contain) critical facilities can be identified, they (like the parcels identified as containing toxic facilities) should be assigned a low score. Examples of such critical facilities may include hospitals, fire stations, schools, and even critical commercial facilities, such as pharmacies (see NIST, 2016; UFCP, 2017). These uses often ‘hide’ in broader categories used in zoning or land use maps, such as ‘public/semipublic’ or ‘government/medical/educational’, but are often referenced as among the least suitable land uses in an area that is likely to flood (Snohomish County, 2013; City of Dubuque, 2015).

After each existing land use, zoning, and future land use category has been assigned to a land use suitability class, it may be informative for maps and tables to be produced that indicate the relative suitability (all else being equal) of the various land uses in the community’s flood-hazard zones.

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[14] The *institutional* land use category, perhaps more than the others, illustrates the challenges of standardizing complex land use and zoning systems for comparison. In many communities, institutional land uses include vacant or reserved parcels, which would otherwise be placed at the top of the ladder. However, critical facilities (e.g. fire/police stations, hospitals, schools) are also located in areas demarcated with this land use category. As with the PIRS evaluation, the scores provided as part of a SAZLUP analysis requires further consideration (which is facilitated by the method’s organizational attributes).

4.4.3. Land Use Suitability Change

With land use suitability classes thus assigned, the community's existing land use, zoning, and future land use designations can be compared. *Land use suitability change* results reveal the relative change in suitability for a given parcel if its zoning regulation or future land use prescription is followed. Changing from a less suitable to a more suitable land use category ('ascending the ladder') results in a positive score, whereas moving from a more suitable to a less suitable category ('descending the ladder') results in a negative score. For parcels with the same (or very similar) land uses, the resulting score is neutral.

Particularly when mapped (see Section 4.5, below), land use suitability scores are useful in illustrating the differences between land use suitability in a community's zoning and planning documents. When compared to existing land uses, this reveals the direction of their guidance—toward greater or lesser suitability. It can also indicate how well aligned zoning and planning are, with respect to land use in flood-hazard areas. Table 4.2 illustrates this concept, comparing existing land use and future land use suitability in several hypothetical parcels located in a floodplain. Land use suitability change scores can similarly be derived to show the differences between existing land use and zoning, and between zoning and future land use.

Table 4.2 Examples of *land use suitability change* for parcels in a flood-hazard area, if future land use prescriptions are followed. The same method is also applied to reveal changes from existing land use to zoning, and from zoning to future land use.

Parcel	Existing Land Use Suitability Class (and Category)	Future Land Use Suitability Class (and Category)	Land Use Suitability Change score	Explanation
A	3 (Low-density residential)	1 (High-density residential)	-2	Negative change. The future land use map suggests densification in Parcel A, from existing low-density residential land use to even less suitable (more vulnerable) high-density residential land use.
B	8 (Open space)	1 (High-density residential)	-7	Strongly negative change. The future land use map suggests replacing the most suitable land use (open space) with the most vulnerable land use (high-density residential) in Parcel B.
C	6 (Commercial)	6 (Commercial)	0	No change (or lateral change). The future land use map suggests maintaining current commercial land use in Parcel C.
D	4 (Mixed-use)	8 (Open space)	+4	Positive change. The future land use map suggests replacing the existing, relatively vulnerable land use (mixed-use) in Parcel D with a far less vulnerable use (open space).

4.5. Case study: Tampa, Florida

The SAZLUP method is demonstrated in the flood-vulnerable city of Tampa, on Florida's Gulf Coast (Figure 4.2), using the current FEMA SFHA, or 100-year (1% annual chance) floodplain, as the flood-hazard zone of interest.[15]

4.5.1. Context

Tampa, Florida, is a city of 392,000 people (2018 estimate; U.S. Census Bureau, 2019) located on a low coastal plain along the large, shallow bay that shares its name.

[15] The SAZLUP evaluation was also conducted for a 'future floodplain', incorporating a projection of sea-level rise in the year 2100 ('SLR floodplain' extent indicated in Figure 4.2). In the interest of clarity and brevity, however, results were omitted from this chapter.

The county seat of Hillsborough County, Tampa is a large and diverse social and commercial center and the hub of a major metropolitan area of more than four million people (U.S. Census Bureau, 2019). Hurricanes, thunderstorms, and other flooding events resulted in nearly $500 million in property damage between 1993 and 2008 (Hillsborough County, 2015).

A significant proportion of Tampa's land area (39.4 square miles, or 34%) and residential population (54,240 people, or 16%) is located in the 100-year floodplain (Hillsborough County, 2015). Tampa's low-lying coastal and riverine areas are currently dominated by mixed-use (7,363 acres, or 37%), residential (6,500 acres, or 32%), and industrial (4,613 acres, or 23%) land uses.

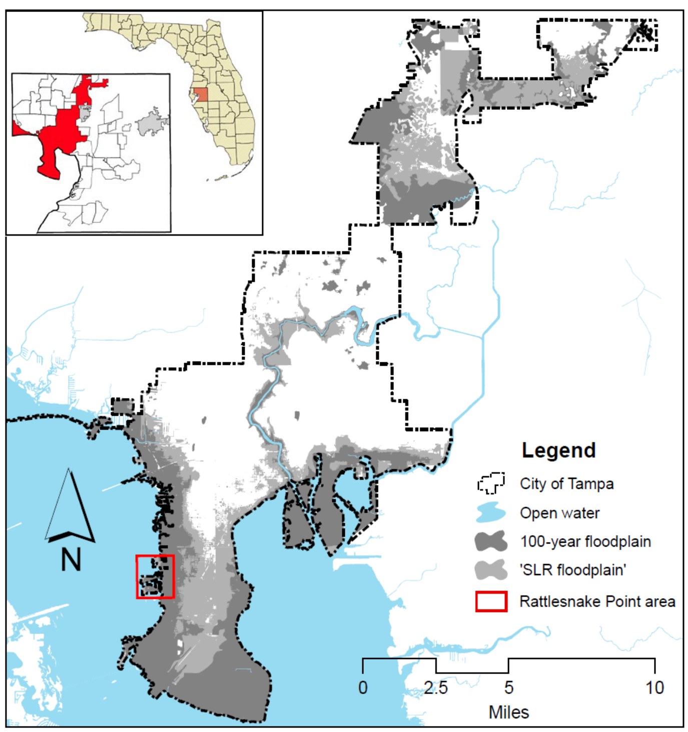

Figure 4.2 Tampa, Florida, with flood-hazard areas indicated. This analysis focuses on the 100-year floodplain, but could be extended to the 'SLR (sea-level rise) floodplain' to address additional research questions. (Locator map source: wikipedia.org)

4.5.2. Findings and Discussion

Zoning and future land use designations in the 100-year floodplain differ from existing land uses in Tampa – and from each other – in important ways, perceptible at both citywide and parcel-level scales of analysis. This discussion sheds light on the 'story' of the suitability and alignment of zoning and land use planning in Tampa's flood-hazard areas, helping address the research questions posed above. The SAZLUP evaluation illuminates the relationships between two key components of the city's development management program and flood vulnerability, and provides new perspective and empirical data to help planners and policymakers reevaluate their plans and regulations. Due to space constraints, the discussion focuses exclusively on results from the *land use suitability change* evaluation—the final step in the SAZLUP process. Maps and tables related to the previous steps, can be found in Appendix C.

4.5.2.1. Citywide Findings

Citywide results are computed using the total area of parcels in Tampa's 100-year floodplain in each land use suitability class (following standardization via the land use suitability ladder). They help address questions about how the city is being guided by its land use planning and regulatory documents – and how well this guidance lines up – with respect to the most flood-prone areas. Figures 4.3 and 4.4 illustrate and summarize the land use suitability change from *existing land use to future land use*, *existing land use to zoning*, and *zoning to future land use*, assuming the stated prescriptions are followed.

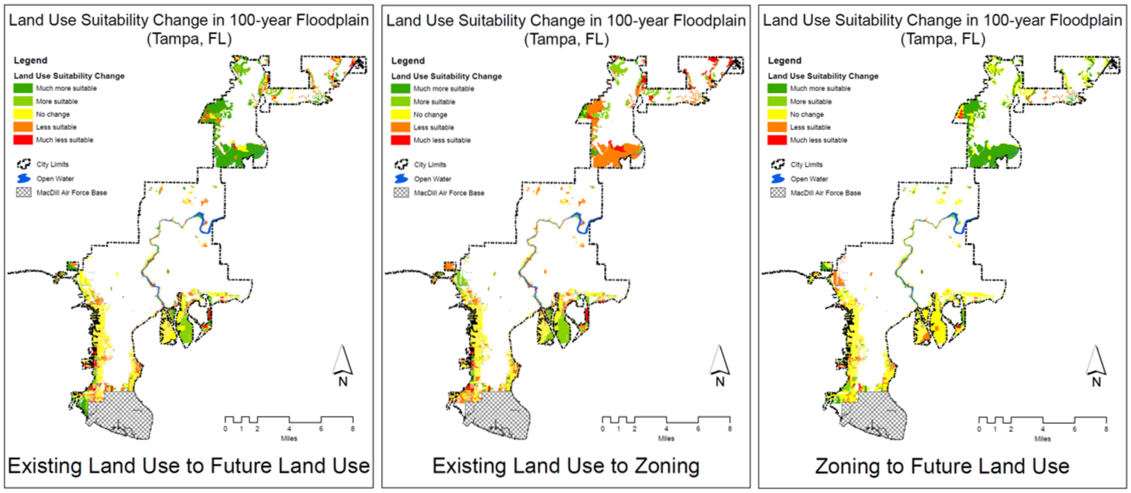

Figure 4.3 Maps illustrating *land use suitability change* for parcels in flood-hazard zones in Tampa, Florida. ‘Much more suitable’ and ‘Much less suitable’ indicate changes of three or more land use suitability classes.

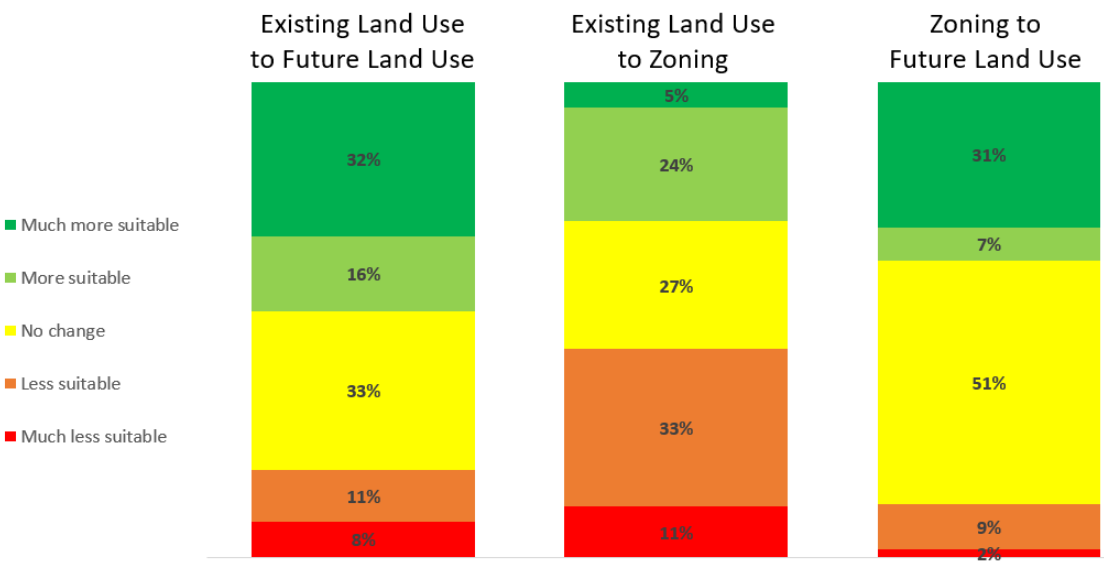

Figure 4.4 Bar charts summarizing *land use suitability change* in the 100-year floodplain in Tampa, Florida. ‘Much more suitable’ and ‘Much less suitable’ indicate changes of three or more land use suitability classes.

Results suggest that Tampa is moving in the right direction with respect to long-term planning of land use in the 100-year floodplain, while regulated land uses in the same area are generally less suitable than what currently exists. The *existing land use to* *future land use* map and bar (left-most sections of Figures 4.3 and 4.4, respectively) provide a ‘snapshot’ of the direction that Tampa’s future land use plan is guiding the community vis-à-vis land use suitability in flood-hazard areas. Around half (48%) of the land in Tampa’s 100-year floodplain shows positive land use suitability change, indicating that nearly half the land area in the current floodplain is being guided toward land uses more suitable than what occupy them at present. Notably, the majority of this change – nearly a third of all the land in the 100-year floodplain – is characterized as ‘much more suitable’ (rising three or more land use suitability classes). This suggests that Tampa is generally *planning* for a more suitable future in its known flood-hazard area.

An opposite trend is shown in the *existing land use to zoning* map and bar (center of Figures 4.3 and 4.4). Much of the land in Tampa’s 100-year floodplain is zoned for less suitable uses than presently exist (44%), while less than a third (29%) is zoned for more suitable uses. This finding may belie an ill-advised permissiveness with respect to the regulation of flood-vulnerable land uses in the city’s flood-hazard areas. Despite the strong trend toward planning for greater suitability in the 100-year floodplain, *zoning regulations* are substantially less focused toward that end. As the legally-binding ‘teeth’ by which future land use prescriptions are to be implemented, this divergent direction signals a lack of conformity which may be problematic.

Finally, the *zoning to future land use* analysis (right side of Figures 4.3 and 4.4) gets at the question of consistency, describing the alignment of (and discrepancies between) current regulations and long-range plans with respect to suitable land uses in flood-hazard areas. The citywide statistics are notable for several reasons. First, as alluded to above, future land use prescriptions are much more suitable than zoning regulations. In fact, over three times as much land area in the 100-year floodplain is in the direction of greater suitability (38%) than lesser suitability (11%). And second, that despite such a wide disparity and strong trend, more than half of the land in Tampa's 100-year floodplain actually shows no change in land use suitability category when comparing zoning regulations to future land use guidance.

Taken together, these findings suggest (1) that the future land use plan shows greater awareness than current zoning regulations of the need for appropriate land uses in the floodplain, and (2) that zoning aligns reasonably well with the direction set in the future land use map, showing a relatively high degree of consistency. Neither of these is particularly surprising, especially for a large city in Florida, which has a robust history of progressive planning (Burby et al., 1997; Jourdan & Strauss, 2015). Both attest, however, to the validity of the SAZLUP method. That planning is shown to be more 'progressive' than zoning is in line with expected norms; it is a purposely aspirational 'visioning' document. That Tampa's zoning is generally consistent with the future land use plan more often than it deviates is also unsurprising, given that Florida is one of the few places in the U.S. where consistency is enshrined in state law (State of Florida, 2019). This finding suggests, however, that the city may indeed begin to regulate for greater suitability in the future, should the zoning evolve to conform more fully to the future land use plan.

4.5.2.2. Parcel-scale Findings

Spatial data from the SAZLUP evaluation may also be examined in greater detail. Parcel-scale findings reflect some of the citywide trends, but add additional nuance to the 'story' of suitability and alignment of zoning and land use planning in Tampa. The port area surrounding Rattlesnake Point in southern Tampa (Figures 4.2 and 4.5) is selected as a demonstration. Located on the western side of Tampa's Interbay Peninsula, the area is comprised primarily of industrial and vacant land uses, with some residential and mixed-use development as well. It is entirely within the current 100-year floodplain, including areas subject to storm surge.

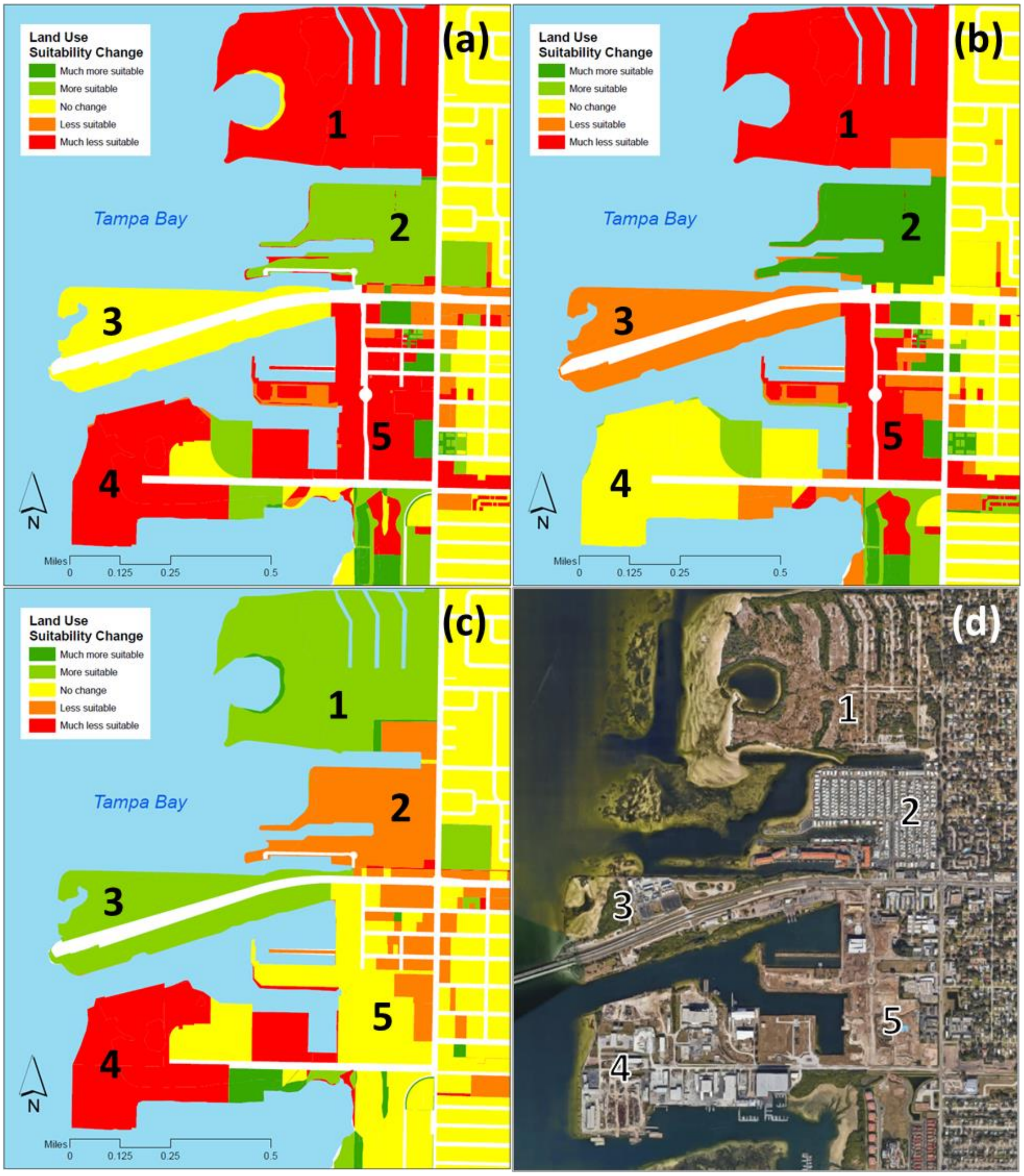

Figure 4.5 Land use suitability change in the Rattlesnake Point port area: (a) existing land use to future land use; (b) existing land use to zoning; (c) zoning to future land use; (d) aerial view (source: www.google.com/maps).

Five parcels are tracked across the three land use suitability change evaluations to illustrate the diversity of relationships between Tampa's existing land uses, zoning regulations, and planned future land uses in the coastal floodplain (Figure 4.5 and Table 4.3). This close-up view, and the data behind it, demonstrates the utility of the SAZLUP method for helping identify and understand ‘hot spots’ that may warrant further consideration (during future zoning and plan updates) if the city wishes to improve land use suitability and resilience in the community.

Table 4.3 Land use categories for select parcels in Rattlesnake Point port area, Tampa, Florida.

Parcel No.	Existing Land Use	Zoned for…	Planned for…
1	Vacant	High-density residential	Medium-density residential
2	High-density residential	Mixed-use	Medium-density residential
3	Institutional	Low-density residential	Institutional
4	Industrial	Industrial	Mixed-use
5	Vacant	Mixed-use	Mixed-use

Despite the broadly positive trend shown in citywide statistics, closer inspection reveals a more mixed story with regard to land use suitability changes from existing to future land uses in the Rattlesnake Point area (Figure 4.5, map [a]). In an otherwise largely land-use-suitability-conscious future land use plan, several parcels in this part of the city indicate a planning direction that may increase vulnerability through less suitable land use. Parcels (1) and (5) currently sit vacant, but are planned for medium-density residential and mixed-use development, respectively. Similarly, parcel (4) is designated for mixed-use redevelopment, though its current use, industrial, is one of the most suitable for an area likely to flood, ‘toxic facilities caveat’ notwithstanding (see Section 4.4.2). A reduction in development intensity is planned for parcel (3); despite plans for continued residential occupation, this is at least a ‘step in the right direction’. The city plans for parcel (3) to remain in institutional use for the foreseeable future.

The mixed story at the parcel scale continues when comparing zoning designations with current land use (Figure 4.5, map [b]). In addition to being planned for future development, parcels (1) and (5) are respectively zoned for high-density residential and mixed land uses. Parcel (4) is zoned for its current occupied use, and thus receives a ‘yellow’ color, indicating no land use suitability change. Parcel (3) is zoned for residential use, likely less suitable than its current status (institutional), critical facilities caveat notwithstanding. Parcel (2) is actually zoned for somewhat less intensive use than exists currently.

The Rattlesnake Point area showcases several of the consistency (alignment) issues common across the Tampa floodplain (Figure 4.5, map [c]), even as it reflects the key points from the citywide findings. The relative conformity of zoning regulations to the future land use plan in Tampa, at least with respect to land use categories in the floodplain, is highlighted in parcel (5), which is both zoned and planned for mixed use development. Zoning is also consistency with planning regarding the established neighborhoods along the right edge of each map. The green color of parcels (1) and (3) are indicative of zoning lagging somewhat behind the future land use plan—a pattern even more apparent elsewhere in the city. Land use prescriptions are somewhat less suitable, however, in parcel (2), with the future land use plan guiding toward medium-density residential uses and zoning favoring a somewhat more suitable mixed-use approach. Finally, parcel (4) is zoned industrial, which reflects the current dominant land use of this working port, but the future land use plan envisions a mixed-use redevelopment—a much less suitable use with respect to placing people and structures in harm's way.

This close-in snapshot of land use suitability and alignment in a transitioning port area illustrates the complex relationships between planned and zoned land uses, adding significant nuance to the broader citywide trends. Areas where planning and zoning are not consistent and do not align – and the direction of that misalignment – can easily be recognized and investigated.

4.6. Conclusions and Implications

The SAZLUP method offers a new perspective and empirical data to help researchers and practitioners better understand relationships between community land use planning and zoning vis-à-vis flooding hazards. Like the Plan Integration for Resilience Scorecard (PIRS) method from which it is derived (Berke et al., 2015, 2018), it focuses on the costly and growing threat of flooding, using it as a lens by which to evaluate land use policy decision-making. It utilizes widely available data and a straightforward evaluation process to facilitate reevaluation that can lead to more suitable land use in flood-hazard areas. Thus, the SAZLUP method can be characterized as a first step toward extending the core PIRS concepts into the regulatory realm—concentrating as much on regulations as on plans, but with the same attention to resilience, land use, and spatial evaluation. As with the PIRS analysis, 'low' scores should be seen not as negatives, but as opportunities for communities to better understand and adjust their future land use planning and zoning toward greater suitability and resilience.

As demonstrated in a case study of the flood-vulnerable city of Tampa, Florida, the method can be used to address questions about the direction that a community's future land use plans and adopted zoning regulations are guiding and regulating it with respect to flood vulnerability, as well as the degree to which these are (mis)aligned. Land in Tampa's 100-year floodplain is generally being guided toward greater suitability by the future land use plan; a large proportion is planned for more suitable uses than exist at present. The opposite is true, however, with respect to zoning regulations, evidence of at least some inconsistency between land use plans and regulations. While such dynamics are perhaps unsurprising, given the more progressive and visionary purpose of a future land use plan, and despite zoning being shown to align relatively well with the future land use plan, they suggest a need for some reconsideration for the city to remain on a path toward improved suitability.

Parcel-scale findings provide an additional level of detail. In a place like the Rattlesnake Point port area, many kinds of relationships exist with respect to suitability of existing land uses, zoning, and future land uses—including some that diverge from the broader citywide trends. This indicates that the SAZLUP method has additional value as a means for identifying problematic 'hot spots' of low suitability for further investigation and, potentially, rectification.

4.7. Limitations and Future Applications

The SAZLUP method, as presently conceived and described, includes several potential limitations. These primarily relate to its dependence on the availability, accuracy, precision, and comprehensiveness of data—including the *plans*. Although this is hardly a novel limitation – 'garbage-in-garbage-out' is a well-worn expression in research – it is especially critical, here. Communities lacking well-defined future land use or zoning maps (and corresponding plans and ordinances) will find it very challenging, if not impossible, to evaluate land use suitability or spatial alignment. Similarly, the accuracy and precision, and therefore the usefulness, of the results are directly correlated to that of the data inputs; plans or maps with less detail will produce less helpful end products.

Potential limitations also exist with respect to the land use suitability ladder concept. First, it should be noted that the concept assumes non-hierarchical zoning; that is, the zoning category indicated on the official zoning map was assumed to be the land use 'as regulated'. Second, assigning land use categories to the appropriate rung (conceptual categories) can be challenging, as zoning and land use definitions are, in the United States, anything but uniform. They are often subject to local drivers and can be somewhat esoteric, making assignment for standardization difficult. Therefore, for the best results, it is advised that this critical task be performed with the benefit of local expertise, and preferably in consultation with a team.

Despite these challenges, the SAZLUP method has potential to help communities more effectively align their land use and zoning in flood-hazard areas to achieve greater suitability and resilience—particularly if applied in combination with a PIRS analysis of a community's network of plans (though it can, as demonstrated, provide benefits as a standalone tool). The methods are set up to accommodate such a combined approach. Although SAZLUP results are likely to be at an even finer grain (parcel) than those from the PIRS (district-hazard zone), they can easily be scaled up to facilitate comparison. Additionally, potential exists to expand the SAZLUP concept to additional scales (e.g. county, region, state), hazard zones (e.g. projected future flood zones incorporating sea level rise), or even other hazards, if they are sufficiently spatial and predictable (e.g. wildfire, earthquakes). Continuing urbanization and occupancy of flood-vulnerable areas – to say nothing of the potential complications to be wrought by climate change – magnify the need for effective coordination of resilience-focused, hazard-aware land use planning and regulation.

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5. CONCLUSIONS AND IMPLICATIONS

The three studies presented in this dissertation demonstrate the potential of *spatial evaluation* of plans, policies, and regulations as a conceptual and methodological foundation for addressing issues of plan conflict and land use decision-making with respect to flood hazards. This need is driven by a recent proliferation of plan documents that are often poorly integrated and guiding communities toward vulnerable land use decisions, and is made significantly more urgent by parallel increases in population and the built environment in flood-prone areas—as well as by the growing climate crisis. Spatial evaluation adds useful perspective and empirical data across varying planning and hazards contexts. It may also be used to guide post-disaster evaluation, revealing the ways plans and policies may act as drivers of flood-vulnerability, and how they may contribute to disasters. Spatial evaluation theory and techniques may also offer a way forward in better understanding the critical nexus between land use planning, land use regulation, and flooding hazards.

The first study – ***Spatially evaluating a network of plans and flood vulnerability using a Plan Integration for Resilience Scorecard: A case study in Feijenoord District, Rotterdam, the Netherlands*** – demonstrated the external validity of the Plan Integration for Resilience Scorecard (PIRS) method by applying it in a planning and hazard context quite unlike that in which it was originally developed. Slight methodological adjustments (e.g. delineating planning districts and hazard zones, determining which plans and policies to include) were relatively straightforward. The resilience scorecard permitted an in-depth assessment of plan integration for flood resilience in Feijenoord District and offered new insight into the dynamics of its network of plans, revealing conflicts and patterns that may have otherwise gone unnoticed. Of particular note, it was discovered that the larger-administrative-scale plans affecting the district (e.g. the Rotterdam Climate Change Adaptation Strategy) scored higher on average and were more consistent—evidence of their strong focus on flood risk and an indication that they may, in fact, be making up for policy gaps in some of the neighborhood-scale land use plans. A similar dynamic was also found during the second study.

The second study – ***Planning to mitigate, or to* exacerbate*, flooding hazards? Evaluating a Houston, Texas, network of plans in place during Hurricane Harvey using a Plan Integration for Resilience Scorecard* –** used the PIRS technique to organize an investigation of a complex network of plans that was in place and guiding development in the city of Houston, Texas, at the time of Hurricane Harvey's impact in 2017. It provided empirical evidence that planning in the western Houston super neighborhood cluster study area, while relatively strong (particularly in a planning-averse city), focused mitigation efforts overwhelmingly on the Special Flood Hazard Area (SFHA). Policies in many plans were guiding the community toward increased flood-vulnerability, especially in areas outside the SFHA but nevertheless at some risk for flooding, even as the city experienced a rise in the frequency of (and costs from) large flood events. In the drive to accommodate and encourage new development, it appears, some plans and policies paid insufficient attention to actual flood risk. The problem may also have been amplified a false sense of security provided by ostensibly strong flood control measures, including the existence of the Addicks and Barker Dams—a classic example of the 'safe development paradox' that effectively made the area even more vulnerable to a massive and sustained precipitation event like Harvey.

Finally, the third study – ***Planning* and *Regulating for Resilience? A Method for Evaluating the Suitability and Alignment of Zoning and Land Use Planning in Flood-Hazard Areas*** – presented and demonstrated a new method for expanding spatial evaluation into the regulatory realm. The suitability and alignment of zoning and land use planning (SAZLUP) method offers a new perspective and data to help researchers and practitioners better understand relationships between community land use planning and zoning vis-à-vis flooding hazards. Like the PIRS method from which it was conceptually derived, it focuses on the costly and growing threat of flooding, using it as a lens by which to evaluate land use policy decision-making. As demonstrated in a case study of the flood-vulnerable city of Tampa, Florida, the method can be used to address questions about the direction that a community's adopted zoning regulations and future land use plans are guiding and regulating it with respect to flood vulnerability, as well as the degree to which these are (mis)aligned. Parcel-scale findings provided an additional level of detail, indicating that the SAZLUP method has additional value as a means for efficiently identifying problematic 'hot spots' of low suitability for further investigation and, potentially, rectification.

By focusing on several heretofore unexplored aspects of the spatial evaluation of plans, policies, and regulations, this dissertation contributes to what may, with continued development, come to represent a new paradigm for plan integration, hazard mitigation, and the strengthening of community resilience. The value of an overtly spatial and explicitly hazard-aware approach to understanding land use planning, policy-making, and regulation is demonstrated by the many instances of conflict and misalignment revealed by the PIRS and SAZLUP analyses which, if they led to reconsideration by policymakers, could result in critical adjustments that strengthen community resilience. Such tactics need not, however, be limited to post hoc analysis; indeed, they ought to be central to the holistic approach to planning necessitated (now, perhaps, more than ever) by an increasingly hazardous and unpredictable climate. If deliberate consideration of the spatial focus of policies and regulations, as well as of their potential effects on hazard vulnerability, became standard practice – even, perhaps, making its way into planning pedagogy – such a shift could help stem the growing problems associated with poor land use guidance highlighted throughout this dissertation and across the planning and hazards literatures.

Like much of planning scholarship, all three of the studies in this dissertation were designed to advance scientific understanding while also being oriented toward praxis and real-world outcomes. Though actively working with communities was outside the scope of this document, such efforts have been pursued in parallel. A practitioner-oriented PIRS guidebook – *Plan Integration for Resilience Scorecard Guidebook: Spatially evaluating networks of plans to reduce hazard vulnerability* – is currently in its second iteration (found online at http://mitigationguide.org/wp-content/uploads/2018/03/PIRSGuidebook2.0_FullDraft_March2019.pdf) and has been applied to useful effect in the cities of Norfolk, Virginia; Nashua, New Hampshire; and Rockport, Texas. Staff in these communities have followed the PIRS Guidebook to evaluate their plans and policies with respect to their likely effects on flood-vulnerability, and then used the information gained to make integration- and resilience-focused and spatially-aware adjustments to their plans, policies, and, in the case of Norfolk, ordinances. In Rockport, which is still in the process of rebuilding after Hurricane Harvey, a version of the PIRS that emphasizes disaster recovery (a 'PIRS-*DR*') was used to evaluate the city's draft comprehensive plan with respect to hazard resilience and the rest of the network of plans. Post-application case studies of these communities are also underway, to document additional outcomes. These successful practical applications suggest that the spatial evaluation of plans, policies, and regulations may, with continued conceptual and methodological development, come to play an increasingly prominent role in helping communities strengthen resilience to flooding.

APPENDIX A

Table A.1 Policy scores and descriptive statistics for Feijenoord District, by plan type and hazard zone.

		Plan Scores			
	Neighborhood	**Land Use Plan**	**Water Plan**	**Adaptation Strategy**	**Total**
Unembanked	(1) Noordereiland	0	0	10	**10**
	(2) Wilhelminapier	0	1	10	**11**
	(3) Kop van Feijenoord	3	2	10	**15**
	(4) Feijenoord	1	0	9	**10**
	(5) Katendrecht	-8	1	10	**3**
	(6u) Afrikaanderwijk (Unembanked)	4	1	10	**15**
	(7u) Hillesluis (Unembanked)	2	0	7	**9**
	Unembanked Neighborhoods Mean	*0.3*	*0.7*	*9.4*	***10.4***
	Unembanked Neighborhoods Std. Dev.	*3.7*	*0.7*	*1.0*	***3.8***
Embanked	(6e) Afrikaanderwijk (Embanked)	2	2	7	**11**
	(7e) Hillesluis (Embanked)	0	3	7	**10**
	(8) Bloemhof	4	0	7	**11**
	(9) Vreewijk	-3	5	7	**9**
	Embanked Neighborhoods Mean	*0.8*	*2.5*	*7.0*	***10.3***
	Embanked Neighborhoods Std. Dev.	*2.6*	*1.8*	*0.0*	***0.8***
	Overall Mean	*0.5*	*1.4*	*8.5*	***10.4***
	Overall Standard Deviation	*3.3*	*1.5*	*1.4*	***3.1***

APPENDIX B

Table B.1 Policies from the western Houston study area network of plans affecting flood vulnerability in the Energy Corridor District.

Plan Policy (location or page #)	<u>**Policy score**</u> **100-year floodplain**	**500-year floodplain**	**Hurricane Harvey max. flood extent**
Our Great Region 2040 (including the 'Strategy Playbook') (2014)			
Direct Development to Existing Communities Directing development away from sensitive ecosystems and into areas already served by adequate infrastructure (roads, utilities, etc.), protects rural lands while reducing the cost of building and maintaining public facilities. (Playbook, 36)	**1**	**-1**	**-1**
Promote Conservation Subdivision Design Conservation subdivision design aims to conserve natural areas and reduce impervious cover by clustering development on a small portion of the site, leaving the remainder undisturbed (Playbook, 36)	**1**	**1**	**1**
Provide financial incentives, such as tax foreclosure property programs or property lien dismissals, for developers to build diverse housing types near jobs, transit centers, and services, including mixed-use developments and housing at a variety of price points (12)	**-1**	**-1**	**-1**
Develop and enforce local housing codes and standards to ensure owner-occupied and rental housing is safe and healthy. (12)		**1**	**1**
Encourage Use of Low Impact Development (LID) Practices LID practices aim to replicate the pre-development hydrology of local watersheds. On-site detention and infiltration is achieved by preserving natural areas, minimizing impervious cover, and utilizing small-scale hydrologic controls that mimic natural processes. (Playbook, 36)	**1**	**1**	**1**
Develop an integrated regional storm defense system, which includes both structural and non-structural elements. (16) [Structural elements, including dikes, flood gates, levees, building adaptations, and other physical improvements, could help protect key assets, but their high cost means that this approach must be carefully targeted. Non-structural elements are policies and actions that reduce risk, such as protecting coastal wetlands, limiting development in flood-prone areas, and educating the public about flood risk. An integrated approach can reduce potential losses in a cost-effective way, protecting both existing communities and fragile ecosystems. (Playbook, 176)]	**1**		**1**
Conserve natural assets through multi-benefit green infrastructure projects and designing with nature, such as Low Impact Development and expanding Our Region's network of open space and trails along waterways. (8) • The Harris County Low Impact Development and Green Infrastructure Design Criteria for Stormwater Management (2011) describes how developers may use LID practices to meet local stormwater management requirements. • The Bayou Greenways Initiative is a multi-organizational effort to create a continuous open space network with walking and biking trails along bayous and creeks throughout the greater Houston area. When complete, the region's greenway network will include 300 miles of	**1**	**1**	**1**

trails within a 4,000-acre ribbon on open space. • Several land trusts, including the Bayou Land Conservancy and the Katy Prairie Conservancy, are working to protect environmentally-sensitive lands throughout the Houston-Galveston area. (Playbook, 38)			
Preserve wetland and riparian zones, which provide natural flood protection and improved water quality processes. (Playbook, 194)	**1**	**1**	**1**
Houston Stronger (*undated*)			
STRATEGIC BUYOUT OF EXTREME FLOOD-PRONE HOMES Long overdue project to buyout homes and remove people from harm's way. The additional land will be used for improved conveyance as well widening bayous and streams. COST: $8.5 Billion	**1**		**1**
CONSTRUCT 3rd RESERVOIR Following devastating floods in Houston during the 1930's, the U.S. Corps of Engineers (USACE) called for a third reservoir to be built in north Houston. Time to get this done and it should be built on Cypress Creek. COST: $500 million	**1**	**1**	**1**
RESTORE BARKER & ADDICKS RESERVOIRS Restore and add to the capacity of both Barker & Addicks reservoirs. The two reservoirs should be excavated so that all private property currently subject to inundation upstream of the reservoirs would never be at risk of inundation again. The overflow weirs for the reservoirs should be lowered and placed on government-owned land at elevations that would never allow flooding to occur on private property. COST: $2.5 Billion	**1**	**1**	**1**
INCREASE BAYOU CONVEYANCE The HoustonStronger flood plan calls for doubling the amount of floodwater conveyance for drainage systems in Harris County. Plain and simple…controlling flooding is about getting as much water possible into the drainage systems, out to the bayous and into Galveston Bay as quickly and effectively as possible. Again, this portion of the HoustonStronger plan doubles the amount of floodwater conveyance. COST: $23.20 Billion	**1**	**1**	**1**
CITY OF HOUSTON DRAINAGE COST $6 Billion	**1**	**1**	**1**
Gulf-Houston Regional Conservation Plan (2017)			
Support local county/city bond referendums and other funding sources for additional nature-based infrastructure and open land acquisition projects (Action Agenda)	**1**	**1**	**1**
Encourage land-use projects to secure the floodway, floodplain and wetlands as buffer for at-risk waterways in our region (including Armand Bayou & Cypress Creek) (Action Agenda)	**1**	**1**	**1**
Support use of private land conservation easements and *acquisitions* that allow for additions to 24% by 2040 (Action Agenda)	**1**	**1**	**1**
Buffalo Bayou Partnership is seeking $5 million to expand its land acquisition and ecosystem services efforts. If funded, properties that would otherwise fall victim to development will be protected for open space, and enhanced with native trees, vegetation and wetlands. As a result of this restoration, the bayou's water and air quality will be improved, habitat protected, quality of life enhanced, and eco-tourism and economic development opportunities created. The funds requested will be used for land acquisition and restoration projects that are "shovel ready." With escalating property values, it is critical that property is acquired as soon as possible! (Working List of Projects -- Riparian Corridor Protection Initiative)	**1**	**1**	**1**
Support regional "buy-out" and "waterway land expansion" programs that allow for additions to the 24% by 2040 (Action Agenda)	**1**		**1**

Support use of private *land conservation easements* and acquisitions that allow for additions to 24% by 2040 (Action Agenda)	**1**	**1**	**1**
[ACQUISITION OF REMAINING UNDIVIDED INTEREST IN THE WARREN RANCH (WARREN RANCH BUYOUT PROGRAM)] (Working List of Projects -- Prairie Conservation Initiative)	**1**	**1**	**1**
[HCFCD & KPC - CYPRESS CREEK OVERFLOW] (Working List of Projects -- Prairie Conservation Initiative)	**1**	**1**	**1**
[KATY PRAIRIE ACQUISITION AND RESTORATION PROJECT - PHASE 1 & 2] (Working List of Projects -- Prairie Conservation Initiative)	**1**	**1**	**1**
[KATY PRAIRIE PROJECT (PHASE 3)/ PRESERVE SYSTEM ACQUISITION PROJECT] (Working List of Projects -- Prairie Conservation Initiative)	**1**	**1**	**1**
[WARREN RANCH PRESERVATION PROJECT] (Working List of Projects -- Prairie Conservation Initiative)	**1**	**1**	**1**
[PRAIRIE CONSERVATION INITIATIVE: ACQUISITION FOR KATY PRAIRIE AND DAMON PRAIRIE CONSERVATION] (Working List of Projects -- Prairie Conservation Initiative)	**1**	**1**	**1**
Support Comprehensive Regional *Maintenance* & Enhancement of 9.2% in nature-based infrastructure to improve water storage, and conveyance needs (Action Agenda)	**1**	**1**	**1**
Harris County Flood Control District 2017 Federal Briefing			
New Outlet Structures for Addicks and Barker [Reservoirs] … (105)	**1**	**1**	**1**
City of Houston Hazard Mitigation Plan Update (2017)			
Enact and enforce regulatory measures to ensure that future development will not put people in harm's way or increase threats to existing properties. (142)	**1**		
Adopt ordinance to require retention ponds in all new developments, and to validate retention ponds in existing high risk flood areas. (167)	**1**	**1**	**1**
Promote beneficial uses of hazardous areas while expanding open space and recreational opportunities (144)	**1**		
Create and Implement reconstruction program to bring buildings up to code and protect from hazardous events. (166)	**1**		**1**
Reduce the danger to, and enhance protection of, high risk areas during hazard events. (142)	**1**		
Elevation or Mitigation reconstruction of Flood-prone Structures. (185)	**1**		**1**
Implement flood risk reduction projects identified through the Harris County Flood Control District's (HCFCD) ongoing Capital Improvement Program (CIP). Flood control measures will include cost effective structural drainage improvements as well as acquisition/demolition projects. (162)	**1**	**1**	**1**
Develop and implement program to clean and clear ditches in existing neighborhoods to improve drainage capacity. (168)	**1**	**1**	**1**
Analyze the current storm sewer system, then design and implement an improved storm sewer system that will convey the current contributing drainage areas runoff flows adequately to discharge point. Storm sewers will be increased in size to adequately convey the minimum City design storm event (2-year event). In addition, an analysis of sheet flow will be performed to assess what design measures are necessary to adequately convey a more significant (i.e., 100-year) storm event to the discharge point in a manner that minimizes structural flooding. (180)	**1**	**1**	**1**
Plan Houston (2015)			
Encourage compact, pedestrian-friendly development around transit. (12)	**-1**	**-1**	**-1**

Preserve open space for recreation, habitat, and other uses. (16)	**1**	**1**	**1**
Maintain a comprehensive plan for acquiring, developing and maintaining parks and open space. (16)	**1**	**1**	**1**
Encourage development of green infrastructure and low impact development. (10)	**1**	**1**	**1**
Coordinate with partners to improve drainage. (8)	**1**	**1**	**1**
Houston Parks & Recreation Department Master Plan (2015)			
In this Park Sector 401 acres of parkland are needed. Even though the need analysis for parkland shows a great need for parkland, this analysis only accounts for Pocket, Neighborhood and Community parks. This Park Sector is unusual in that it is served by four Regional Harris County parks: Terry Hershey Park, George Bush Park, Art Storey Park and Archbishop Joseph A. Fiorenza Park. Nonetheless there is still a need for smaller scale parks in areas of need. This is the second most populous Park Sector that carries 11.3% of the total population in the City of Houston. There are areas of need throughout almost the entire Park Sector. (397)	**1**	**1**	**1**
The Eldridge Spine Trail (from Briar Forest south to Bellaire) proposed by the (WHTMP) connects Brays Bayou, the Energy Corridor and gives access to single-family, multi-family, retail and restaurants in the area. (407)	**1**	**1**	**1**
additional connections for accessibility to Cullen Park from the neighboring residential areas are necessary. There are 13 miles of trails in Park Sector 19. With the extension of Terry Hershey trail north of I-10 and the trail to Cullen Park there are more opportunities for connectivity and additional trails around the Reservoir. (419)	**1**		**1**
The Energy Corridor District Unified Transportation Plan, 2016-2020			
The Energy Corridor District will install transit stop amenities including shelters, benches and crosswalks at various METRO bus stops throughout the District. By enhancing the safety and comfort of transit stops, the user's waiting experience and overall public transit experience is improved, making it a more attractive alternative to driving a passenger vehicle. (10)	**-1**	**-1**	**-1**
The implementation of The Energy Corridor Circulator will require the installation of additional bus stops throughout the District in order to attract and retain ridership. Many new transit stops will include amenities that enhance the "waiting experience" such as shelters and benches. (10)	**-1**	**-1**	**-1**
The District will coordinate with METRO, the City of Houston, Memorial District and Westchase District the planning and acquisition of grant funds to install Bike Share stations at Addicks Park & Ride, Terry Hershey Park and Kendall Library. The District will also encourage the construction of end-of-trip facilities, such as bicycle racks, lockers and storage, showers and changing rooms at private properties and public places. (10)	**-1**	**-1**	**-1**
The redevelopment of the Addicks Park & Ride lot into a high-capacity transit hub for West Houston will further the transformation of The Energy Corridor into a more urban environment. The District will coordinate with METRO and support the development of a signature transit center facility and urban plaza that includes a multi-modal main street. (10)			**-1**
Pedestrian Bridge from Woodbranch to Addicks Dam Trail: The District will coordinate with the Houston Parks Board and the City of Houston Parks and Recreation Department for the design and construction of a pedestrian bridge and trail connections over Turkey Creek connecting the Woodbranch area with the Addicks Dam Trail.		**-1**	**-1**

The Energy Corridor District 2015 Master Plan			
The Central District of The Energy Corridor, north and south of I-10 from Highway 6 to Eldridge Parkway, presents the opportunity to rethink the conventional development model and instead introduce a street and block structure that prioritizes multiple route options, pedestrian and bicycle infrastructure, and better movement of all modes through the neighborhood. With very little existing development but significant future potential, this area can be the model livable community in The Energy Corridor.		**-1**	**-1**
The proposed network introduces multiple new streets to maximize mobility and create walkable places. Smaller block sizes are proposed at the three social centers (Terry Hershey Park core, The Energy Corridor Transit Center, and Grisby Square) with slightly larger blocks planned for the neighboring areas. This will allow flexibility within the majority of parcels while creating the desired pedestrian spaces at the social centers. (50)			
[Expanding] Park Row (for detail, see Park Row section) (145)	**-1**	**-1**	**-1**
[Expanding] Grisby Road extension through Langham Park (145)	**-1**	**-1**	**-1**
[Expanding] Grisby Road extension from Langham Park to Eldridge Parkway (145)	**-1**	**-1**	**-1**
The landscape zones along the street [Eldridge Parkway] should all be designed to capture stormwater and reduce the amount of runoff going into the city system. In addition, landscape should consist of native species that do not require regular irrigation minimizing potable water use. (119)	**1**	**1**	**1**
As a component of development projects, require/incentivize developers to create publicly accessible open space that serves the needs of on-site employees and residents while contributing to The Energy Corridor's overall coordinated open space network. (148)	**1**	**1**	**1**
Incorporate small-scale parks in new development projects, as informed by the West Houston Parks Master Plan (see planning recommendation above). (148)	**1**	**1**	**1**
Construct the street parallel to Eldridge Parkway along the west side of Langham Park from Enclave Parkway to Interstate 10. This new street will provide improved routing options for all road users, in addition to providing the ability to restore Eldridge Parkway to four-lanes and make it a complete street between I-10 and Memorial Drive. (144)		**-1**	**-1**
Connecting parks and open spaces together enhances the overall parks system and serves both the community and wildlife. Building on the Terry Hershey Park and Buffalo Bayou linear parks, a system of smaller linkages should be introduced into the network. Neighborhood parks can link to the larger community and regional parks to form a robust park network. (36)	**1**	**1**	**1**
Major elements of the new park (henceforth Langham Park) would include the following: • Refinement of the Langham Creek channel and riparian landscape to enhance the environmental values of the creek corridor for local flora and fauna • An event and lawn space with a pond and large open space along Langham Creek just north of Memorial Drive serving as a destination for informal recreation, public art, concerts, and festivals • A spillway park below Addicks Dam with boardwalks, scenic overlooks, and an archeological preservation area to showcase the natural and cultural history of The Energy Corridor • Additional pedestrian bridges over Langham Creek as well as boardwalk bike trails to enhance connectivity for pedestrians and bicyclists to entry points along the neighborhood	**1**	**1**	**1**

• A neighborhood park for residents and families with community gardens, playgrounds, and picnic areas, complete with barbecue grills east of the creek
• A comprehensive landscape strategy that integrates environmental systems to better manage stormwater and urban runoff within the park and adjacent properties. (86)

Energy Corridor Livable Centers Plan (2010)
[Note: Policies in this plan consist primarily of public and private capital improvement project line items, elaborated throughout the plan document. All are found on pp. 46-47, unless otherwise noted.]

2011 A1 Terry Hershey Extension from I-10 to Park & Ride Road	**-1**
2013 A3 Wolfe School (via Katy ISD Bond)	**-1**
2013 A4 Lone Wolfe Office	**-1**
2012 A5 Lone Wolfe Parking Garage & Retail	**-1**
2012 B1 Purchase Park Row R.O.W. (600k sf @ $8/sf)	**1**
2013 B2 Build Park Row Extension with required utilities	**-1**
2013 B3 Houston Area Energy Education Center	**-1**
2014 B4 Addicks-Howell Road & Grisby Trail Enhancements	**1**
2014 B5 METRO Park Row service Addicks to Dairy Ashford	**-1**
2014 C1 Transit Center, 2,000 Car Metro Garage, Street Improvements	**-1**
2014 C2a Lined Bridge (Bridge & Approaches Only, Bridge: 800' x 100')	**-1**
2014 C2b Lined Bridge Retail & Incubator Office Space (120k sf)	**-1**
2014 C3 Addicks Park & Ride Public Street Network & Infrastructure	**-1**
2015 C4 Livable Center Park	**1**
2015 C5 Bridge Approach Park	**1**
2015 C6a East of Park & Ride Residential & Parking (75 du)	**-1**
2016 C6b East of Park & Ride Residential & Parking (100 du)	**-1**
2017 C6c East of Park & Ride Residential & Parking (75 du)	**-1**
2015 C7a Addicks Office Development & Parking (350k sf office, 12k sf retail)	**-1**
2017 C7b Addicks Office Development & Parking (750k sf office, 10k sf retail)	**-1**
2019 C7c Addicks Office Development & Parking (250k sf office, 6k sf retail)	**-1**
2018 C8 Central Garage & Mixed-use (160k sf office, 42k sf retail, 110 du, 2700 sp)	**-1**
2018 C9 IH-10 Mixed-use Liner (21k sf office, 22k sf retail, 140 du)	**-1**
2020 D1a Bernstein/Perwien Development Office & Parking (400k sf office)	**-1**
2020 D1b Bernstein/Perwien Development Hotel (150 rooms)	**-1**
2016 D2a North of Park Row Residential High Density (200 du)	**-1**
2017 D2b North of Park Row Residential Townhomes (200 du)	**-1**
2016 D3 North of Park Row Roads & Infrastructure	**-1**
2017 E1 Post Office integration (Public/Private Swap, 15k sf)	**-1**
2017 E2b BP West of Bridge Retail/Movie (105k sf Retail/Entertainment	**-1**
2017 E2a BP West of Bridge Retail/Parking (40k sf Retail, 530 sp)	**-1**
2018 E3a BP East of Bridge Hotel & conference (250 rooms, 15k sf Retail, 500 sp)	**-1**
2020 E3b BP East of Bridge Retail/Parking I (60k sf Retail, 150 sp)	**-1**
2020 E3c BP East of Bridge Office I (350k sf Office, 12k sf Retail, 1100 sp)	**-1**
2020 E3d BP East of Bridge Retail/Parking II (30k sf Commercial, 15k sf Retail, 120 sp)	**-1**
2020 E3e BP East of Bridge Retail/Parking III (50k sf Retail, 150 sp)	**-1**

2020 E3f BP East of Bridge Office II (350k sf Office, 12k sf Retail, 1100 sp)			**-1**
2018 E4 Other Trail Upgrades			**1**
Adding a new east-west hike and bike trail on a pipeline corridor between Park Row and IH-10 to serve workplaces and residences west of SH-6 (38)			**1**
Creating additional high-quality neighborhood connections to Addicks-Howell Road, Grisby Road, and Gracie Lane to support walking and bicycling trips by residents of the Barker's Landing and Fleetwood neighborhoods (38)			**1**
Energy Corridor Bicycle Master Plan (2010)			
Trailville Buffalo Bayou Bicycle/Pedestrian Bridge. Between SH 6 and Langham Creek connecting Fleetwood subdivision to Terry Hershey Park Trail (25)	**-1**	**-1**	**-1**
Coordinate with Harris County Flood Control District to provide multifunctional uses along drainageways for recreation and transportation purposes. (8)	**1**	**1**	**1**
West Houston Plan 2050: Envisioning Greater West Houston at Mid-Century (+ "2010 Update")			
Prairie Parkway -- We believe our westward growth will require a new, major roadway linking US 290 and the Westpark corridor west of Katy… (7)	**-1**	**-1**	**-1**
Regional amenities in GWH such as conservation and open spaces provide a premium to the quality of living and amplify neighborhood level amenities. Regional conservation and open space areas have a cost component but also provide a significant economic benefit in addition to their contribution to the sustainability of our region's environment. The identification and development of regional conservation areas and open spaces is progressing with several governments and organizations working to make individual projects a reality long before mid-century. Regional connectivity of hike and bike trails is a priority and will allow access across the 1,000 square mile GWH. (2010 Update, last page)	**1**	**1**	**1**
The toll-revenue financed Grand Parkway will largely be completed in GWH within the next 5 years. Design is completed on Segment E and starting on Segment F. With nal environmental clearance, construction could begin as soon as right of way is acquired.	**-1**	**-1**	**-1**
Westpark Tollway is currently being extended west from the Grand Parkway to Fulshear and will eventually link to the elements of the planned Prairie Parkway, GWH's third major north-south backbone artery.	**-1**	**-1**	**-1**
The Frontier Channel concept being developed by the HCFCD envisions a series of riparian corridors (250-700 feet wide) that combine flood control, water quality, wildlife habitat and recreational potential. … This would expand current protection for residential and commercial properties downstream on Buffalo Bayou and would also allow Buffalo Bayou to remain in its current native state, providing a scenic natural source for Greater West Houston. (10)	**1**	**1**	**1**
… we should explore expanding the detention capacity of the Barker and Addicks reservoirs to enable them to meet possible future drainage demands under extreme events. This would expand current protection for residential and commercial properties downstream on Buffalo Bayou and would also allow Buffalo Bayou to remain in its current native state, providing a scenic natural source for Greater West Houston. (10)	**1**	**1**	**1**

New System Designs: GWH area flood control systems are becoming a model for addressing growing suburban locations. Harris County Flood Control District (HCFCD) has implemented the “Frontier Channel” flood control program on Langham Creek, with the best characteristics of quality growth meeting a critical public need in a cost-effective manner. South Mayde and Little Cypress Creek are the next watersheds to be addressed. The concept institutes “linear”, “on-line” detention as opposed to traditional “off-line” systems and will be finance through development impact fees. The system will include active open space and park land in addition to performing their drainage function. (2010 Update)	**1**	**1**	**1**
City System Rebuilding: City of Houston drainage systems are recognized as old and in need of updating. A proposal for a City Charter Amendment has been advanced as a ballot measure in November, 2010 that would establish a dedicated fund for drainage and roadway improvements. If passed, this fund would include a drainage fee on existing residential and commercial properties in the City of Houston and an impact fee on new development in the City of Houston in addition to capturing a portion of the City’s ad valorem tax currently servicing debt on bonds for these improvements after existing bonds are paid off. (2010 Update)	**1**	**1**	**1**
West Houston Trails Master Plan (2011)			
Develop recreational-use easements on all open and accessible areas currently slated as public maintenance easements. This recommendation is already a current practice of Harris County Flood Control District, holder of the majority of maitenance easements for flood management purposes, but it shoud become a policy of any entity needing to obtain easeements for utilities, maintenance or flooding purposes. (61)	**1**	**1**	**1**
Patterson/N. Eldridge Spine Trail (30)			**1**
Eldridge/Energy Corridor Spine Trail (32)	**1**	**1**	**1**
Terry Hershey Park Spine Trail (56)	**1**	**1**	**1**
Evaluate vegetation management policies that surround drainage and riparian corridors to encourage appropriate vegetation growth, reforestation of the upper banks and habitat restoration, improved water quality and reduced maintenance costs. (61)	**1**		**1**
West Houston Mobility Plan (2015)			
Add all roadways shown in the MTFP map to the MTFP Hierarchy Table (Section 5.1) (124)			**-1**
Add the list of nominated collector streets to the MTFP (Section 5.1) (124)			**-1**

APPENDIX C

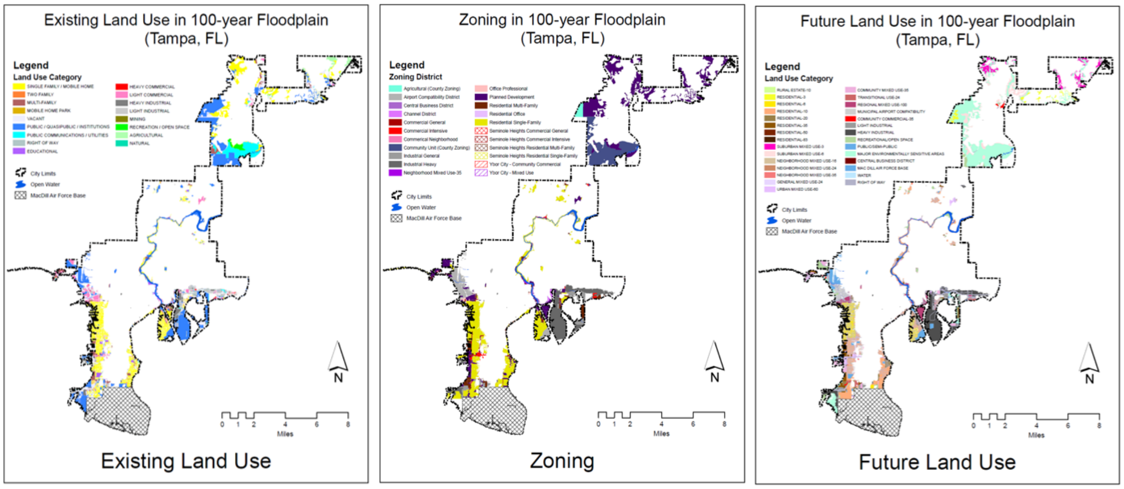

Figure C.1 Land use and zoning designations in flood-hazard zones – Tampa, Florida.

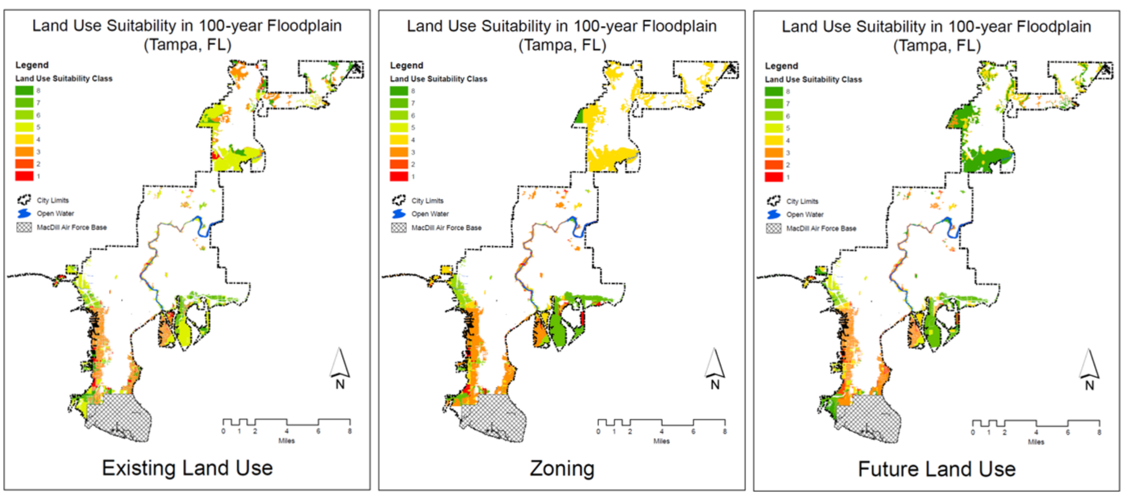

Figure C.2 Land use and zoning suitability class in flood-hazard zones – Tampa, Florida.

Table C.1 Suitability ladder for land use and zoning categories in flood-hazard zones in Tampa, Florida.

Conceptual Category	Existing Land Use Category	Zoning Category	Future Land Use Category	Land Use Suitability Class
Open Space	Natural Recreation / open space Vacant Mining Agriculture	Public Park Agricultural	Major environmentally sensitive areas Recreational / open space	8 (most suitable)
Industrial	Light industrial Heavy industrial	Industrial general Industrial heavy	Light industrial Heavy industrial	7
Commercial	Light commercial Heavy commercial	Commercial general Central business district Airport compatibility district Commercial intensive Office professional Residential office Seminole Heights residential office Seminole Heights commercial general Seminole Heights commercial intensive Ybor City central commercial core Ybor City community commercial Ybor City general commercial	Community commercial Central business district Municipal airport compatibility	6
Institutional	Educational Public / quasi-public / institutions Public communications / utilities	University community district Ybor City Hillsborough Community College	Public / semi-public	5

Conceptual Category	Existing Land Use Category	Zoning Category	Future Land Use Category	Land Use Suitability Class
Mixed-use		Channel District Commercial neighborhood Seminole Heights commercial neighborhood Commercial neighborhood / Residential single family Neighborhood mixed use Planned development Planned development alternative Seminole Heights planned development Ybor City mixed use Ybor City mixed use redevelopment Ybor City site plan controlled	General mixed use Urban mixed use Neighborhood mixed use Suburban mixed use Community mixed use Regional mixed use Transitional use	4
Low-density residential	Single family / mobile home	Residential single-family Seminole Heights residential single-family Ybor City residential single-family	Rural estate Residential (≤ .35 FAR)	3
Medium-density residential	Two family	Residential multi-family Ybor City residential	Residential (.50 ≤ .60 FAR)	2
High-density residential	Multi-family Mobile home park	Residential multi-family Seminole Heights residential multi-family	Residential (.65 ≤ 1.0 FAR).	1 (least suitable)

*Individual land use and zoning categories were assigned to rungs on the suitability ladder as a demonstration of the underlying concept, and are based on definitions found in Tampa's plan and ordinance documents and metadata, where available. While every effort was made for correct placement, the author makes no definitive claims regarding accuracy.