Defining the Policy Space for Disaster Management: A System Dynamics Approach to U.S. Flood Policy Analysis

Michael A Deegan
Rockefeller College
University at Albany, State University of New York
Center for Policy Research, Milne Hall 300
135 Western Avenue
Albany, NY 12222
md7875@albany.edu

This paper defines a policy space for a natural hazard policy analysis using a system dynamics approach. In this paper, I present a dynamic hypothesis of problems faced by decision-makers in a flood hazard community. While current policy analysis for hazard mitigation focuses on benefit-cost analysis, I argue that system dynamics can be used to improve the quality of policy analysis and compliment the traditional approach. In this paper, I present a system dynamics model and policy space to illustrate the effectiveness of system dynamics in two respects. First, a system dynamics model designed to represent a policy space provides a way to systematically identify potential policy levers in the system. Second, by using structure to explain behavior in the policy space, the effect of potential policy levers is compared for several key indicators. The policy space constructed from the system dynamics model identifies both qualitative and quantitative differences in policy outcomes. Including a system dynamics model in a policy analysis provides a deeper understanding of the causal structures, which compliments the traditional benefit-cost approaches and improves the overall quality of the analysis.

Key words: policy analysis, natural hazard, flood, mitigation, extreme event, public administration, disaster management, agenda setting

1 Introduction

This paper shows how a system dynamics model can be used to identify policy alternatives and scenarios for a policy space in a natural hazard policy analysis. In this paper, I will present a system dynamics model of the problems faced by decision-makers in a community that experiences flooding. The model is a generic structure of a hazard-prone community and represents one part of a larger research project.[1]

While current policy analysis for hazard mitigation focuses on benefit-cost analysis, I argue that system dynamics can be used to improve the policy analysis and compliment the traditional approach. In this paper, I present a system dynamics model and policy space to illustrate the effectiveness of system dynamics in two respects. First, a system dynamics model designed to represent a policy space provides a way to systematically identify potential policy levers in the system. Second, by using structure to explain behavior in the policy space, the effect of potential policy levers is compared for several key indicators. The policy space constructed from the system dynamics model identifies both qualitative and quantitative differences in policy outcomes. Including a system

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dynamics model in a policy analysis provides a deeper understanding of the causal structures, which compliments the traditional benefit-cost approaches and improves the overall quality of the analysis.

The policy space is a matrix of outcomes for policy alternatives and anticipated scenarios. The analysis of the policy space compares the success of policies across different "what if" scenarios. Figure 1 illustrates an example of a policy space.

Figure 1: Defining the Policy Space: a generic example

	Base	*Scenario #1*	*Scenario #2*	*Scenario #3*	*Scenario n*
Base					
Policy Mix #1					
Policy Mix #2					
Policy Mix #3					
Policy Mix m					

The remainder of this paper is structured in following manner. First, the important problems and key stakeholders are identified using the current hazards research to guide the modeling effort. Second, initial policy alternatives, such as federal incentives to encourage hazard mitigation in local communities, are discussed to set the boundaries for the model. Then, the model is presented in stages, revealing several major loops in sequence.[2] Also in this section, policy options studied in the natural hazards literature are identified as potential leverage points in the system. In addition, this section identifies scenarios that could affect the strength of each major loop in the model. The paper concludes with a policy space, a matrix of policies and scenarios, showing how policy alternatives can be analyzed for their effect on relevant stakeholders in the system.

2 Problem Definition

Natural hazards are estimated to cost the citizens of the U.S. an estimated $500 million per week. In spite of large national effort to reduce the toll from natural disasters, both catastrophic and chronic losses have been rising rather than falling relative to

[2] For those who consider themselves "whole-part" learners, a causal map of the major feedback loops is presented in Appendix A.

increases in population and gross national product (Mileti 1999). The following problem definition results: *Despite the availability of policy tools to mitigate property damage, relief costs for disasters continue to rise*.

While it has been well known for many years that humans create the conditions that exacerbate natural disasters, the active encouragement of effective mitigation of all natural hazards is a relatively new feature of federal policy. Mitigation was stated as a goal in the Disaster Relief Act of 1974, but, beginning with the enactment of the Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended in 1988, 1993 and in 2000 (codified at 42 USC 5121 et seq.), the promotion of natural hazard mitigation has been a key element of federal law.

This research focuses on flood hazards for several reasons. First, the features of natural hazards and their mitigation are particularly evident in the flood hazard. Indeed, these principles were postulated by the prominent geographer Gilbert White to describe the flood hazard over fifty years ago (White 1945; 1958). Second, while these features of natural hazards in general, and floods in particular, are well known to professionals whose jobs engage questions of land use and risk, these principles are not uniformly applied. Indeed, in many areas of the nation, policies continue to be adopted that run contrary to these postulates. Because it is presumably true that community leaders do not willfully make their communities more vulnerable to hazards, it is important to understand the sometimes unintended consequences of community actions to mitigate hazards. Third, the risk of floods is widely distributed throughout the United States, occurs in both inland and coastal areas, is the most common and is the most damaging type of natural hazard on a yearly basis. Any findings from the application of this model to an actual case may therefore be generalizable in the United States.

The Stakeholders

The policy process literature argues that problem definition is political (Stone 1997) and the argument has been extended to the natural hazard policy domain. Problem definition affects the agenda activity and policy selection for policy solutions on prevention, mitigation, or recovery (Kreps 1984). In addition, interest groups influence issue framing for hazard policy problems. Therefore, any hazard policy analysis should begin with stakeholder identification.

The importance of stakeholders permeates across disciplines in varying degrees. Bryson (2004) describes how political scientists who focus on coalition building and management strategies recognize the importance of stakeholders to foster cooperation on important decision. In addition, public administrationists agree that stakeholders affect problem definition and policy identification. As Kettl (2004) argues, no organization fully contains the problem. Instead, many individual groups and organizations are involved or affected or have some partial responsibility to act.

With respect to natural hazards, varying values and perceptions among stakeholders makes it difficult, if not impossible, to reach consensus about appropriate mitigation policy (Petak 1984; Alesch and Petak 1986). There are several models to resolve stakeholder conflict and promote stakeholder participation in planning (Godschalk, Parham et al. 1994; Schwab, Topping et al. 1998). The nature of the hazard plays a role as well. Hazards, such as floods, which allow victims or potential victims to be easily recognized are more amenable to land use adjustments than hazards, such as earthquakes, where victims are more spatially diffuse (Graham 1982). Since problem identification varies between hazards, the role of stakeholders in the policy process becomes important yet difficult to determine.

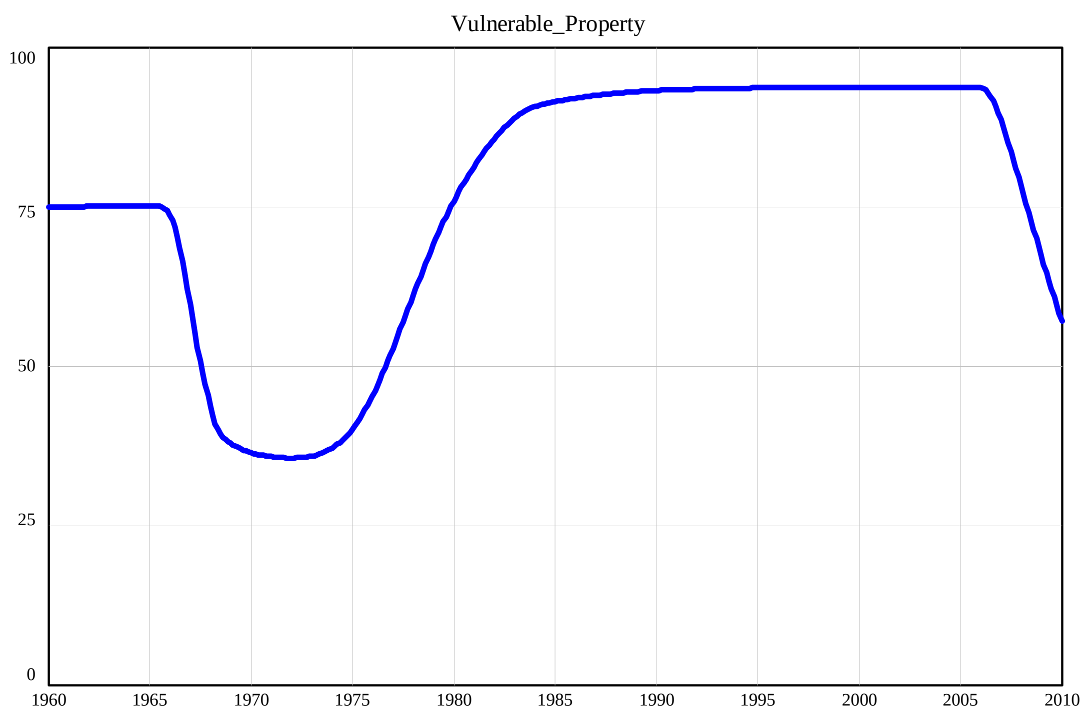
The current hazards literature identifies some of the important stakeholders, especially those necessary for building sustainable communities focusing on mitigation (Mileti 1999). A hazard prone community has several stakeholders. These stakeholder groups include: home owners, business owners, insurance companies, land developers, environmental groups, emergency managers, building inspectors, engineers, community planners and elected officials.

Reference Mode

In the natural hazards literature, Burby et al. (1999) provide an explanation for the unintended consequence of hazard policies, where pressures to develop land for property tax and other benefits increases the vulnerability of the property and residents in the community. The authors include the New Orleans case as an example. After Hurricane etsy caused one billion dollars in flood damage in 1965, federal taxpayers provided hundreds of millions of dollars in additional aid to augment the flood protection system. The added protection promoted additional development in flood-prone areas, but did not eliminate vulnerability to flooding. Research conducted by Pielke and Landsea (1997) predicted property damage during a category 5 hurricane in New Orleans to be over $30 billion and deaths from drowning at more than 25,000.

The qualitative data described in the natural hazards literature produces the following **reference mode**:

Figure 2: Reference Mode for Vulnerable Property



3 Initial Policy Alternatives

Natural hazard mitigation policies fall into two general categories: structural mitigation and nonstructural mitigation. Structural mitigation policies, such as levees, dams and seawalls, require collective action from the community and some assistance from the federal government (e.g., Hazard Mitigation Grant Program or technical assistance from the U.S. Army Corps of Engineers). Nonstructural mitigation policies, such as wise land use policies and retrofitting, involve incentives and regulations as means towards achieving better mitigation outcomes.

3.1.1 Structural Mitigation: Levees, Dams, Seawalls

Flood hazards may become disasters when vulnerable property is left unprotected and exposed to the hazard. While the rate of damage is affected by the severity and frequency of the event, damages occur only when vulnerable property is exposed to the hazard. Structural mitigation projects, such as levees, seawalls and dams, can reduce the severity and frequency of disasters in a hazard prone community.

Early efforts to prevent flood damage have focused on structural mitigation policies, such as levees, dams and floodwalls. The Army Corps of Engineers notes that its flood hazard mitigation efforts prevent billions of dollars in damage—$709 billion in constant dollars from 1928 to 2000 (United States Army Corps of Engineers 2001). Where structural solutions are available, communities will look toward them before pursuing land use adjustments to hazards (Burby, French et al. 1985; Burby, Bollens et al. 1988).

While the financial burden of these mitigation projects is shared between different levels of government, the cost of land use policies (e.g., lost tax revenue) falls mainly on the local government. State and local governments can request structural mitigation projects, but the final decision rests with the federal government. Benefit cost analysis provides necessary justification for structural mitigation projects. Projects may be accepted if the benefit/cost ratio of the project is greater than one (e.g., the value property protected is greater than the cost of the project). Therefore, structural projects may be politically attractive for local communities that wish to share mitigation costs with higher levels of government.

3.1.2 The National Flood Insurance Program

In addition to direct relief immediately following a disaster, the federal government also sponsors insurance relief through the National Flood Insurance Program (NFIP). The federal government is the only source of flood insurance, as flooding is not included on most homeowner's policies. There has been empirical research conducted on the efficacy of flood insurance as a tool for hazard mitigation (Kunreuther 1974), as well as empirical reviews of the federal program (Chivers and Flores 2002). While efforts to mitigate flood hazards have not been evenly applied throughout the United States, the idea of mitigation in general has been an important part of policy for nearly forty years. Federal flood mitigation policies date to the enactment of structural requirements in the

National Flood Insurance Program (NFIP) of 1968 and as modified by the Flood Disaster Prevention Act of 1973 and the National Flood Insurance Reform Act (NFIRA) of 1994 (Federal Emergency Management Agency 2002). The flood insurance policy was further amended in 2004 in the Flood Insurance Reform Act, which required flood insurance policy holders who have been flooded more than twice to accept a buyout of their flood prone property, or to lose all eligibility for flood insurance.

3.1.3 Nonstructural Mitigation: HMGP Grants for Buyouts and Relocation

After a disaster, communities may take advantage of the federal Hazard Mitigation Grant Program (HMGP) to aid in their recovery. Authorized under Section 404 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act, the Hazard Mitigation Grant Program (HMGP) administered by the Federal Emergency Management Agency (FEMA) provides grants to States and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the program is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster (Federal Emergency Management Agency 2005). These grants may be used for property acquisition (buyouts). Since 1993, participating communities have purchased more than 20,000 properties as part of this program (Federal Emergency Management Agency 2005).

3.1.4 Nonstructural Mitigation: HMGP for Floodproofing and Elevation

Communities may apply to the Hazard Mitigation Grant Program for funding for elevation projects. Homes can be elevated to a desired Flood Protection Elevation (FPE). Most often this desired protection level is at or above the Base Flood Elevation (BFE). The Base Flood is a flood having a 1 percent chance of being equaled or exceeded in a given year. Therefore, when a house is properly elevated, the living area will be above all but the most severe floods (such as the 500 year flood) (Federal Emergency Management Agency 2005).

3.1.5 Nonstructural Mitigation: Pre-Disaster Mitigation Grants

Without the HMGP for assistance, the local community can apply for Pre-Disaster Mitigation grants to assist with land development issues. Unlike the HMGP, these grants are awarded on a competitive basis, which therefore may require more “buy-in” from stakeholders in the community. Without such grants, communities can provide incentives (e.g., tax deductions and credits) for development away from hazard prone areas. These incentives may be more attractive as the public becomes better aware of the hazard risks in their community. In addition, the more nonhazardous sites available for development, the more likely communities are to adopt land use adjustments to natural hazards (Burby and French 1981; Burby, French et al. 1985; Godschalk, Brower et al. 1989).While much of the current hazards literature promotes land use away from hazard prone areas, the implementation of these policies can be very difficult.

3.1.6 Nonstructural Mitigation after Development: Retrofitting Structures

Rate setting for flood insurance in the National Flood Insurance Program depends on several factors, including the whether there is an enclosure at the base of the property, whether the building is elevated, and whether the home is a manufactured (mobile) home (Chivers and Flores 2002). The insurance incentive might be strong enough for property developed with new structures.

However, the incentive might not be as strong for older structures. In order to garner the votes for passage of the Flood Insurance Act of 1968, the supporters of the law included language that allowed insurance subsidies for millions of structures in the flood-prone areas (Burby, Beatley et al. 1999). Even today, the program subsidizes structures PRE-FIRM (i.e., before updates to the Flood Insurance Rate Map), thus providing less incentive for property owners to mitigate against hazards.

The acceptance of retrofitting incentives may be hindered by the rate at which memories of prior events fade, which may be affected by the rate of development in the community. That is, a “younger” community may have more opportunity to set incentives and restrictions. Some research suggests that faster growing communities are more likely to adopt hazard mitigation measures than slower growing communities (Burby, French et al. 1985).

3.1.7 Nonstructural Mitigation with Regulations: Building Code Enforcement

Building codes have an important role in flood mitigation. Structures built safely with the proper materials can reduce their vulnerability substantially. The adoption of this policy highlights a serious federalism challenge. Building codes established in the NFIP provide minimum requirements for building construction and a way for communities receive reduced rates on flood insurance. Since participation in the program is voluntary for most individuals, the incentive to adopt building codes at the local level varies across states and local communities. Enforcement of these policies are left to the local government (May 1997). This carries implementation problems for communities that do not have stakeholder support to maintain these policies over time.

3.1.8 Nonstructural Mitigation with Zoning: Preserving Open Space through planning

Land-use planning is the means for gathering and analyzing information about the suitability for development of land exposed to natural hazards, so that the limitations of hazard-prone areas are understood by citizens, potential investors, and government officials (Burby, Deyle et al. 2000). Land use management as a tool for hazard mitigation is favored by most scholars in the hazards research community. For example, the Second National Assessment on Natural and Related Technological Hazards concluded, “No single approach to bringing sustainable hazard mitigation into existence shows more promise at this time than increased use of sound and equitable land-use management” (Mileti 1999).

3.2 Defining the Scenarios

A natural disaster occurs when vulnerability meets hazard. The model is designed to address vulnerability at a local level. However, there are several scenarios which may fall beyond the control of the local community decision makers. A base run of the model might consider some of the most likely hazard parameter settings. Scenario runs should reflect the best, worst and most probably cases for communities experiencing flood hazards in the United States.

3.2.1 Severity of major floods

Since the impetus of this research focuses on social science aspect of disaster (i.e., vulnerability) rather than natural science aspect of disaster (i.e., the hazard), scenarios were generated to reflect different characteristics of a flood hazard. In the base run, there are several "normal" floods and one additional "major" flood in year 2005. This reflects the challenge for decisions makers in a location such as New Orleans, which had a 40 year gap between Hurricanes Betsy and Katrina. While the experts had predicted problems for New Orleans in a severe event (e.g., the simulated Hurricane Pam), the decisions made by the local, state, and federal government increased the city's vulnerability over time.

3.2.2 Political commitment for mitigation

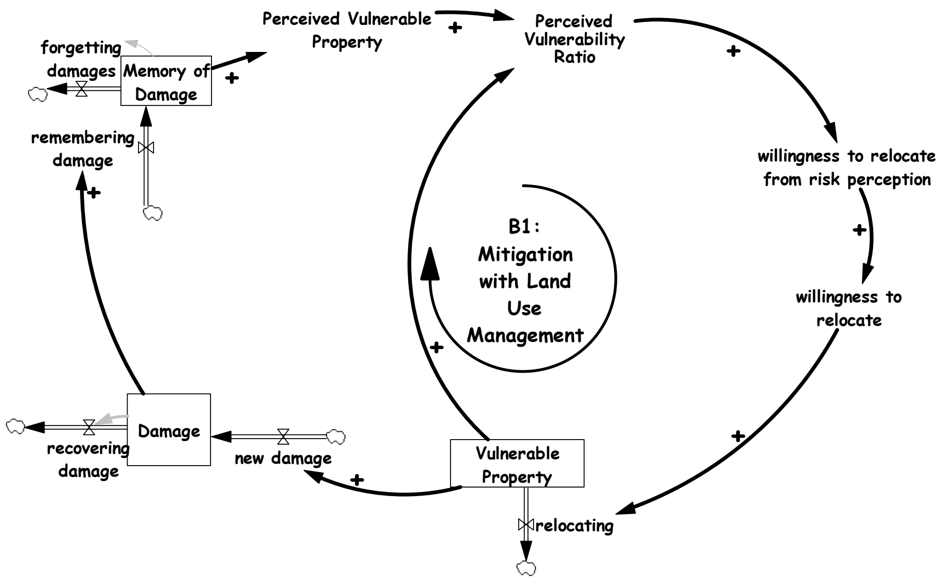
Natural hazard communities, especially those experiencing flood hazards, operate in different political settings. The political commitment and capacity of each state, as well as the incentives provided by the federal government, are to some degree beyond the control of local decision makers. The model can address this interaction between local and state governments. If the federal (or state) government wishes to move beyond the policy analysis rhetoric and take a real "bottom-up" approach, by developing commitment for mitigation, this would be represented by additional resources to support policy entrepreneurs (i.e., those with expert knowledge in the policy domain and the policy process). In the base run, commitment is set at a moderate level, where mitigation incentives from the state and federal governments only attract those individuals and community stakeholder who already have some willingness to participate in mitigation. Additional "what if" scenarios can show how strong commitment creates an institutional setting in favor of long-term mitigation outcomes.

3.2.3 Frequency of flood hazard

In addition to differences in severity and political commitment, communities may also be defined by the frequency of a flood hazard. In the base run, the model is shocked with an event every 5 years. It is reasonable to assume that some communities do not experience flooding on this interval. Scenarios runs can reflect longer or shorter periods in between events. In the policy space designed for this paper, a *low frequency* scenario run sets the period between events at 10 years. Some might argue that as the frequency of hazard events decreases, the potential for poor hazard mitigation decisions increases.

4 Model Presentation

4.1 [Mitigation with Land Use Management]



B1: Mitigation with Land Use

The presentation of this model begins with the *Mitigation with Land Use Management* loop. In recent years, the natural hazards literature has promoted effective land use management as the primary solution to disasters resulting from flood hazards. The three main stocks in this loop represent a focal point of the model: *vulnerable property*, *damage,* and *memory of damage*.

In some respect, all decisions related to natural hazard policy making are indirectly or directly related to a loop involving this stock. It is important to note that this model focuses on vulnerable property as a proxy for vulnerability. Whereas some of the hazard literature, especially in sociology, will define vulnerability in terms of race, gender or income, this model defines vulnerability in terms of property exposed to damage during a natural hazard event. As the discussion turns to mitigation, the conceptualization of vulnerability should become obvious. In this model, *vulnerable property* is in *property* units, which allows the modeler to distinguish between structures damaged and the value of such damage.

As the level of *vulnerable property* increases, the potential for damage also increases. During an event, a fraction of the vulnerable property will become damaged. This rate of *new damage* increases the level of *Damage* in a community. There is a tendency for communities to press for a swift "return to normalcy" after a disaster. In this model, a focus on recovery will reduce the recovery time, and thus increase the rate of *recovering damage*. Some of the early hazards research suggests that a quick return to normalcy may have some adverse unintended consequences (Haas, Kates et al. 1977). The recovery phase of disaster influences how mitigation efforts will be carried out in the future. As one might assume, the decisions made after disaster will depend on how well the event is remembered and what lessons (if any) were learned.

The *Mitigation with Land Use Management* loop continues with the *Memory of Damage* stock. A fraction of the *damage* incurred during a disaster will be remembered by decision makers in the community. The rate of *remembering damage* might be influenced by news reporters (the CNN effect) and information provided by policy entrepreneurs looking to advance solutions on the agenda.

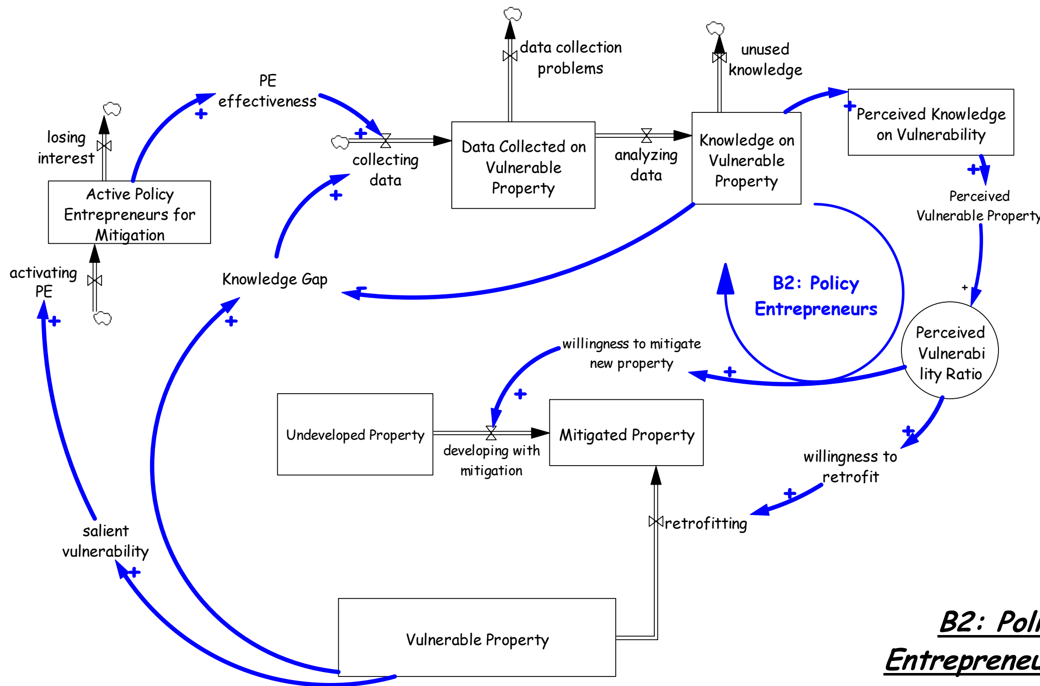
Despite the level of attention natural hazards gain immediately after an event, memories of damage fade quickly (Birkland 1997). As the time to forget damage decreases, the rate of *forgetting damage* will increase, thus reducing the *memory of damage*. Where perceived damage is lower, perceptions of actual problem will decrease for stakeholders and individuals in the community. With that said, policies can be implemented to keep the memory of recent events alive and allow individuals to understand the proper risk they are taking in a flood prone area. Successful policies in this area will encourage community leaders to make wise land use decisions.

There are two ways people perceive natural hazard risks: directly and indirectly. Direct experience with a hazard event can create a memory of potential harm. In addition, *perceived vulnerable property* might be influenced by knowledge about the hazard produced by other sources. As this knowledge increases, more property owners will have an accurate perception of risk in their community. The *perceived vulnerability ratio* is a ratio of perceived vulnerable property to actual vulnerable property. Whereas a ratio below one indicates a low risk perception on the part of property owners in the community, a ratio equal to or greater than greater would suggest a risk neutral or risk adverse population respectively, both of whom would be willing to consider well designed nonstructural mitigation incentives.

The most effective way to minimize damages during a flood event is to clear all properties away from potentially hazardous land. Under this policy alternative, the government may offer incentives to buyout properties in potential hazard and implement zoning laws to establish “open space,” where flood waters can flow naturally and without harm to the community. As the *willingness to relocate from risk perception* increases, individuals will have a greater *willingness to relocate* as well. While risk perception might be a major factor in the decision to relocate, other political factors may contribute as well. Since most local governments rely heavily on property tax as a source of revenue to address problems, they may not be willing to sacrifice potential revenue in the floodplain. Funding to provide incentives obtained from higher levels of government (e.g., through HMGP grants) can be used to encourage relocation decisions.

As the *willingness to relocate* increases, property owners will be more willing to relocate to safer locations, and thus, the level of *vulnerable property* will decrease over time, along with the potential for *new damage* during the next event. This completes the *Mitigation with Land Use Management* loop; a balancing loop that can have considerable strength when high levels of *damage* create a focusing event for the community.

4.2 Policy Entrepreneurs for Mitigation



B2: Policy Entrepreneurs for Mitigation

Every natural disaster is a potential focusing event that can create a window of opportunity for policy change. Policy entrepreneurs have expert knowledge in both the specific policy domains and the policy process. They can use these windows of opportunities to move their preferred problems or solutions on the agenda. A potential disaster can motivate policy entrepreneurs, preparing them to use such policy windows to promote nonstructural mitigation policies in a hazard prone community. The second balancing loop, *Policy Entrepreneurs for Mitigation*, operationalizes this concept in a stock and flow feedback structure.

There are two paths from *vulnerable property* that are important in this loop. In the first path, as people move resources into the floodplain and *vulnerable property* increases, the amount of vulnerable property salient to policy entrepreneurs increases as well. The *salient vulnerability* activates latent policy entrepreneurs for mitigation.[3] These *active policy entrepreneurs for mitigation* might be experts in emergency management or proponents of wise land use for environmental causes. As the size of this interest group for mitigation grows, their *policy entrepreneur effectiveness* increases as well. It is assumed that the effectiveness of their efforts has limits. As groups become too large, their efficiency decreases and some members become free riders who benefit from the group productivity without significantly increasing progress toward the group's goals. Despite this potential inefficiency, an effective group of experts who become active and mobilized support can build knowledge on the problem.

[3] In the most current hazards literature, the term mitigation is synonymous with nonstructural mitigation. Structural mitigation is often referred to as engineered solutions.

The second path from *vulnerable property* leads directly to the *knowledge gap*. This gap is simply the difference between what policy experts currently know about vulnerable property and the total vulnerable property developed without mitigation. Since mitigation plans are required to include vulnerability assessments, this knowledge becomes very important for local communities that wish to stay in compliance with federal and state guidelines.

The purpose for these two separate paths should make sense. Without active experts to study problems, these problems will remain unsolved. However, without something to study (i.e., vulnerable property), the knowledge accumulated on the problem reaches limits as well. This process is captured in a two stock aging chain structure. D*ata collection on vulnerable property* is collected (accounting for some data collection problems) and becomes *knowledge on vulnerable property* based on the rate, *analyzing data.*

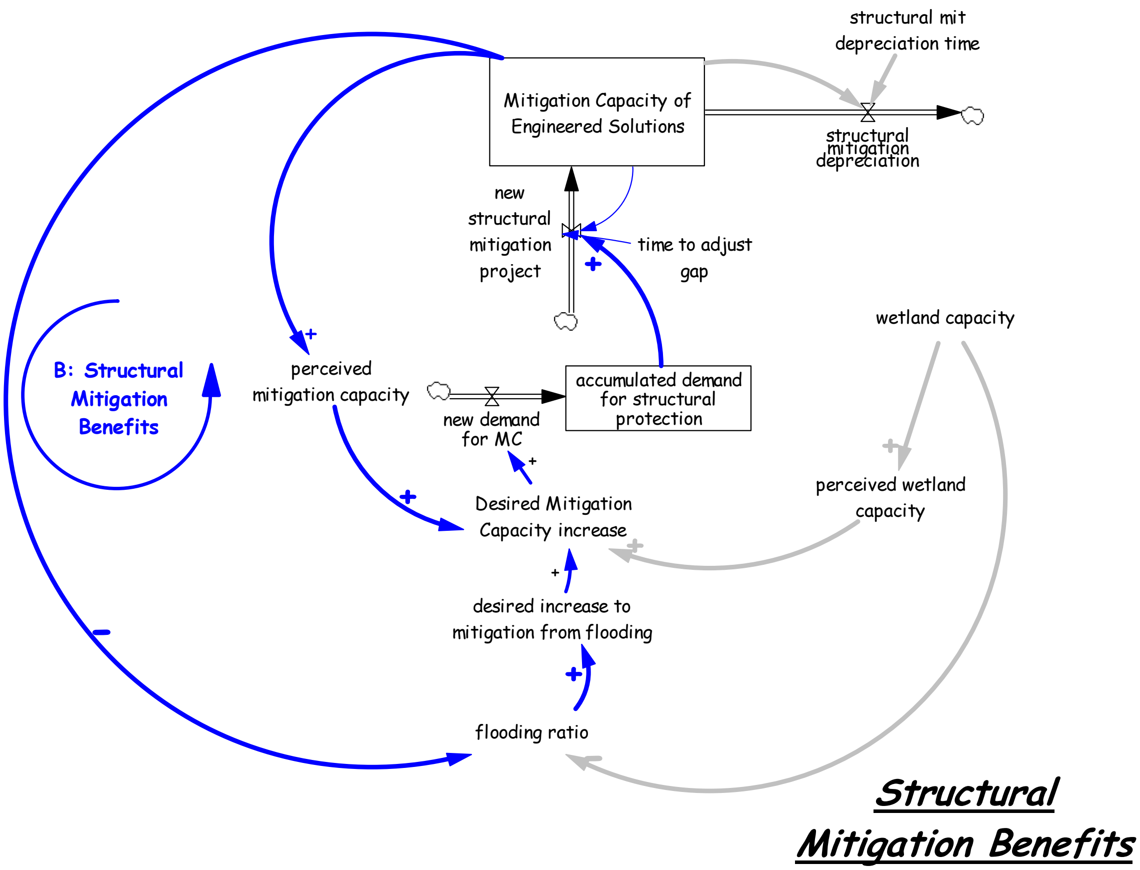
Perceived knowledge on vulnerability is a smooth of the *knowledge on vulnerable property* and a smoothing time equal to the time it takes to disseminate this knowledge. Resources can be used to promote effective risk communication, which would decrease the time it takes for people to understand their risk. As mentioned earlier, *Perceived Vulnerable Property* consists of two components: direct experience with a natural hazard, and, as explained in this loop, knowledge provided by experts.

The *Perceived Vulnerability Ratio* is a relative measure between *perceived vulnerable property* and threshold of acceptable damage, labeled here as *acceptable vulnerable property.* This threshold may increase as the *sense of security* in the community develops from successful structural projects and perceived protection from policies that promote relief and recovery over nonstructural mitigation [see moral hazard loop 4.4]. If the *perceived vulnerable property* is higher than the threshold, the *perceived vulnerable ratio* will increase, as will the willingness to take part in floodproofing and insurance programs such as the NFIP (i.e., *willingness to mitigate new property* and *willingness to retrofit)*. Individual willingness to support these activities, combined with community support for such measures, property owners will be *developing with mitigation* for new structures and *retrofitting* older structures.

The rates of *retrofitting* and *developing with mitigation* have two slightly different implications. *Retrofitting* deals with mitigation for existing structures, thus, it reduces *vulnerable property* in communities that have already developed on or near the floodplain. *Developing with mitigation* (i.e., floodproofing and elevation) deals with new development on or near the floodplain. While increases to this rate will reduce the amount of open space in a floodplain community, it is considered safe development in the natural hazards literature. In both cases, the community is developing with mitigation, which reduces potential damage during the next event.

The *Policy Entrepreneurs for Mitigation* feedback loop carries important implications for communities with multiple stakeholders. Policy entrepreneurs carry out an important role during times of entrepreneurial politics (Wilson 1989), when costs are concentrated to a small group (e.g., owners of property in potential hazard) and benefits are distributed among many people (e.g., all taxpayers in the community who pay the cost of recovery). This balancing loop may gain strength after a focusing event or as knowledge on hazard problems accumulates. However, as indicated by Wilson, government policies born out of entrepreneurial politics may be abandoned when the perception of the problem (i.e., vulnerable property) decreases over time.

4.3 Structural Mitigation Benefits



In most urban areas located on a floodplain structural mitigation projects (e.g., dams and levees) are the primary defense against flood hazards. Analyses of the 1993 Midwest Floods concluded that some structural efforts in large urban centers, such as St. Louis, created unintended consequences for smaller communities downstream. Moreover, many of the structural projects undertaken by small rural communities failed during the 1993 floods, as their levees were not up to federal guidelines set up by the U.S. Corps of Army Engineers. In the case of Hurricane Katrina, the levees protecting the city of New Orleans were not designed to handle storm surges in a hurricane with a category 4 magnitude.

With that said, engineered solutions and structural mitigation continue to be an important source of protection for communities during flood hazard events. The *Structural Mitigation Benefits* loop could also be labeled the structural mitigation demand loop, as it describes a pressure in the community for additional protection after a disaster. The important stock in this loop is *Mitigation Capacity of Engineered Solutions*, with units of water feet/year.

Structurally sound levees and engineered solutions will prevent excess water from flowing beyond the river or coastal waters. As the capacity of these solutions increases, the amount of flooding reaching the community during a storm or period of heavy rain decreases. The amount of heavy rain or storm surge is not affect by structural mitigation, but the amount that reaches the vulnerable property in the community is affected. In this model, the relative measure of storm surge or rain and structural capacity is the *flooding ratio*. When the *flooding ratio* is greater than one, the community experiences flooding and a potential for damage where property is vulnerable.

In this model, it is assumed that hazard experts who understand structural mitigation will be interested in flooding regardless of the damage incurred. That is, when the *flooding ratio* is greater than one, there will be some desire to improve structures or *increase mitigation*, based on an analysis of the flooding.

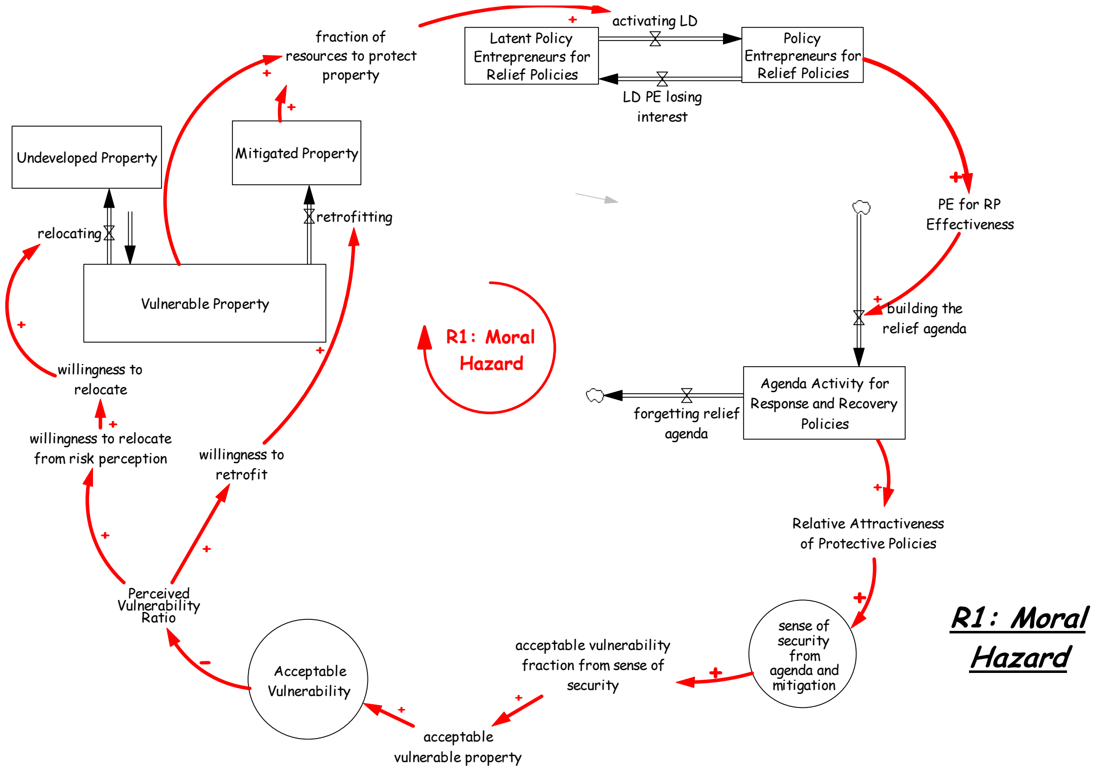
The natural environment provides another layer of defense against flooding. In the model this defense is labeled as *wetland capacity*. Realizing that wetlands are just one form of natural defense (e.g., beaches provide a natural barrier), wetland capacity is in reality any natural environment protection. Therefore, it becomes the experts' challenge to determine what fraction of the flood waters were blocked the natural environment or the engineered mitigation solutions.

The *perceived mitigation capacity* and *perceived wetland capacity* are smoothed stocks creating a goal/gap formulation for changes to structural projects. It is assumed that knowledge about these capacities is not perfect. The *time to perceive* in each smooth for these capacities could be the time for decision makers to learn about problems with the current structures and make informed decisions about funding approvals for structural improvements.

Historically, calls for levee and structural mitigation decreases are very rare. Therefore, in this model the goal/gap formulation is somewhat unique. The goal is an *accumulated demand for structural protection* that has an inflow of *new demand for mitigation capacity*. This rate is affected by *desired mitigation capacity increase* and also a *willingness to support structural mitigation*, as the agenda for these solutions reach the agenda. The accumulation of demand is simply the additional protection desired after a recent flood. The time to close the gap in current mitigation capacity and desired mitigation capacity may depend on political commitment or efficiency of the construction. For example, there has long been a demand for updates to the levees in New Orleans, but due to lack of funding and political commitment, these demands have not been met. Moreover, even if the levee updates had been approved, the project would not have been completed in time to prevent Hurricane Katrina.

Finally, another issue discussed in the post-Katrina analysis deals with the depreciation of engineered solutions. This could be most troublesome for older communities, especially if it takes a long time to perceive mitigation capacity changes. The *Structural Mitigation Benefits* balancing loop is a goal gap formulation, troubled by delays in perceptions, material delays in project completion, and political limitations when the presence of a problem is not apparent.

4.4 Moral Hazard



The initial disaster policy options discussed in this paper fall into two broad categories: policies that encourage individual action that protect their property and policies that use collective action to protect individuals in potential harm. As stated earlier, policy entrepreneurs who support nonstructural mitigation encourage individual action. These policy entrepreneurs have the difficult task of promoting policies in policy domains where costs are concentrated and benefits are dispersed. Interest groups bearing these costs might use their resources to advocate policies where costs are dispersed among many taxpayers. *Moral Hazard* is the first reinforcing loop, representing an important feedback structure in the model.

It is reasonable to assume that property owners in potential hazard, whether or not the property is vulnerable, are willing to mobilize some of their resources to minimize their direct costs recovering from the next flood event. Therefore, *vulnerable property* and *mitigated* property will increases the *resources to protect property*. These resources can be used to mobilize policy entrepreneurs for protective policies (e.g., response and relief policies), which reduce costs to property owners in the floodplain.

As the *policy entrepreneurs for relief policy effectiveness* increase, the number of reports, stories and general *agenda activity for response and recovery policies* increases as well. The *relative attractiveness of protective policies* is the relative measure of this agenda activity with the agenda activity for all other policy alternatives. A community that focuses on relief and recovery as a way to cope with potential disaster will be less likely to participate in nonstructural mitigation.

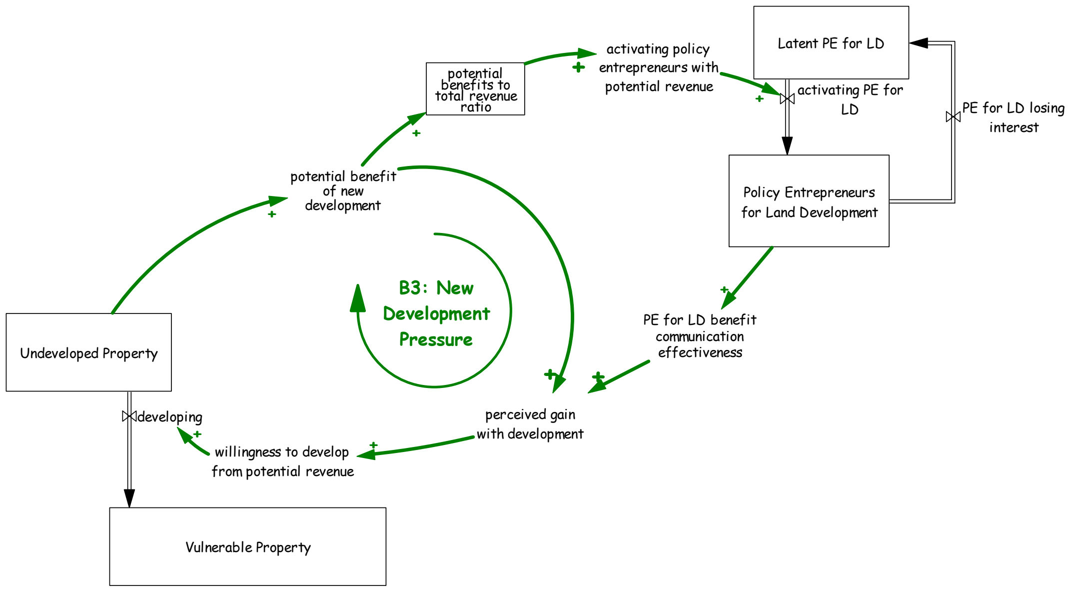
Recovery can take many forms. When the President declares a disaster, money and resources are provided to the affected areas to aid in response and recovery. Relief from the federal government may depend on the magnitude of the damage and number of people affected. Research shows that disaster declarations are political. In part, the president is able to exert such power because there has never been a clear definition of "disaster" or clear guideline to establish when disasters should be declared (Platt 1999).

The availability of relief policies combined with structural projects creates a *sense of security,* which attracts more investment and land development in the hazard prone community. The natural hazards literature suggests that protective policies and structural mitigation projects create a "false sense of security" for people living in the hazard prone community. While structural mitigation policies often protect a community during normal flood activity, there is potential for large damages in a flood of record; more than the community would experience if structural mitigation policy had not been pursued (Williams 1998).

A high *sense of security* increases the fraction of property individuals are willing to put at risk. The moral hazard loop can be offset by the policy entrepreneurs for mitigation loop. If the response and recovery agenda dominates and a higher sense of security prevails, the *acceptable vulnerability* increases. Whereas information provided by policy entrepreneurs for mitigation increases the perceived vulnerability, the effort of policy entrepreneurs for response and recovery policies reduces perceived vulnerability. With lower perceived vulnerability, the *willingness to retrofit* and the *willingness to relocate* decrease as well.

A combination of stakeholders converge in the policy process to develop an agenda for incentives and sanctions focusing on individual or collective action. Where policies encourage development and discourage nonstructural mitigation, a *moral hazard* exists. Since the *moral hazard loop* is reinforcing, the results could be favorable (e.g., when nonstructural policies control the agenda) or potentially dangerous (e.g., when the sense of security is very high). A solid argument can be made that New Orleans suffered from a false sense of security following hurricane Betsy. For a number of years the city relied on structural mitigation projects and relief and recovery policies to cope with potential disasters. These policies encouraged land development without proper nonstructural mitigation. Years of unsafe development resulted, coupled with an outdated levee system and a reliance on response and recovery over mitigation resulted in one of the nation's worst natural disasters in history.

4.5 New Development Pressure



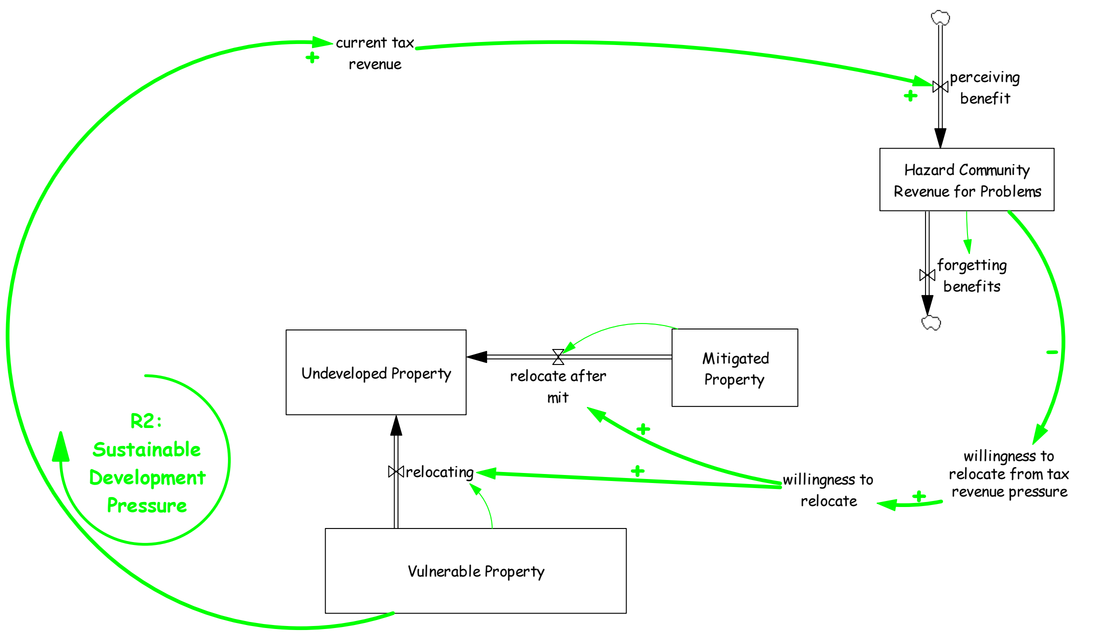
B3: New Development Pressure

Land development in a floodplain may occur for several reasons. Oftentimes, the common denominator rests in benefits (e.g., profits) the open space can generate for land developers. From the perspective of community decision makers, potential tax revenues influence decisions to relax zoning laws and allow such development. Whether or not the benefits outweigh the costs is moot. Since natural hazards are difficult to predict, their costs are difficult to measure. However, costs and benefits weighed over the life of the property (e.g., a 30 year mortgage) could establish reasonable estimates for a benefit/cost ratio of development. In some cases, this type of long term thinking is not politically feasible. Therefore, land development decisions are often based on limited information, perceptions of benefits and costs, and short-term thinking rather than long-term planning. The *New Development Pressure* loop describes these challenges for decision makers managing resources in the floodplain.

When *undeveloped land* is high, the potential benefits, or gains (e.g., from tax revenues) are high. These benefits can be compared to the benefits of land located away from the floodplain to create the *potential benefits to total revenue ratio*. When this ratio is high, latent policy entrepreneurs for land development may become active in the policy process. The *policy entrepreneurs for land development* would be experts in zoning regulations and other government tools that limit their interests' profits. As more of these policy entrepreneurs become active their interest group's *communication effectiveness* increases as well.

New property development in the floodplain also carries potential costs, or losses, over the average life of structures developed on the property. The perceived gain with development is a ratio determined by the *potential benefits of new development* compared with *the potential costs of new development.* When policy entrepreneurs are active, perceived benefits will be emphasized and perceived costs will be disregarded. This positive perception increases the *willingness to develop* and moves property from the *undeveloped property* stock to the *vulnerable property stock*. Depending on the communities preference for nonstructural policies (i.e., zoning and mitigation regulations) *vulnerable property* may also flow to the *mitigated property* stock. The *new development* loop is a balancing loop that may gain strength at two moments. First, the loop could be dominant in a community's early growth years when economic development pressures are strong. Second, this loop may gain strength several years following a disaster, when buyouts have created open space and the damage of the last event is all but forgotten.

4.6 Sustainable Development Pressure



R2: Sustainable Development Pressure

In the natural hazards research community, the term "sustainable development" has been used to describe communities that take part in wise mitigation practices (Mileti 1999). The academic research agrees the only way to guarantee zero damage for communities in a floodplain is to remove vulnerable property from the hazard-prone area. However, the pressure for economic development and the demand for tax revenue to solve problems in the community force community leaders to make difficult land use management decisions. In this model, this challenge has been identified in a reinforcing loop, *Sustainable Development Pressure.*

Development in any location, including development of *vulnerable property* in a hazard-prone area, increases the tax revenue for the solving local problems. Local governments depend on property tax as a main source of revenue. On average, seventy percent of local government tax revenue is generated by real estate (Burby, May et al. 2000). Therefore, fluctuations in this revenue stream make it difficult for local communities to sustain commitment and capacity for solving problems. Zoning policies and buyout programs alter the tax base and make difficult for local decision makers to effectively manage budgets in their community.

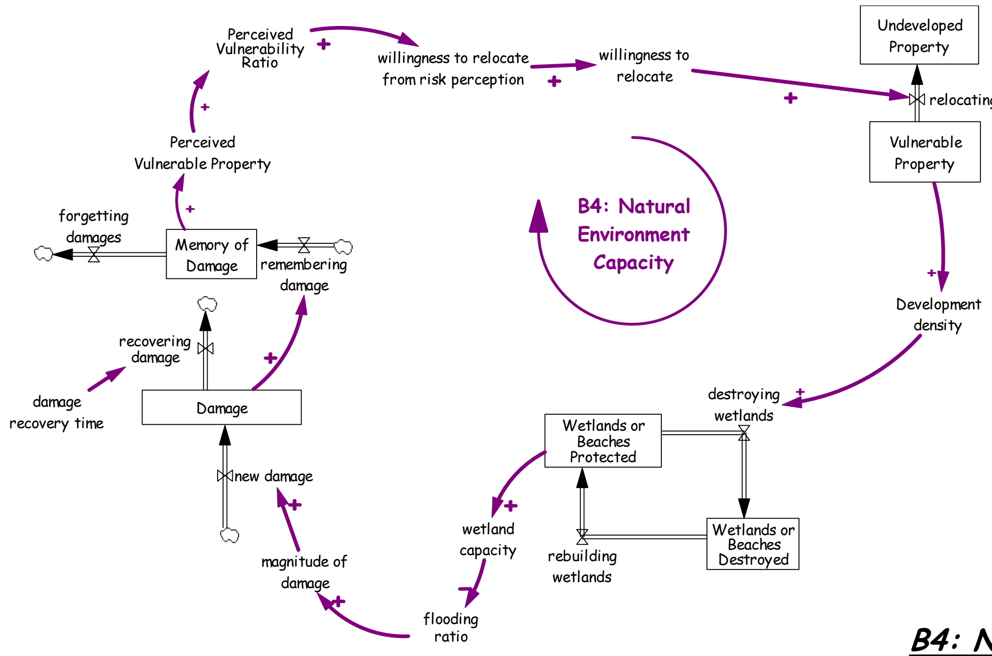
In this model, the *perceiv*ed *benefit* of having a stable tax base accumulates a stock of revenue (or confidence), where the community perceives it can handle long term problems. This stock is labeled *Hazard Community Revenue for Problems.* It is reasonable to assume that a portion of this revenue will be used to protect the community in the face of a natural hazard. It is also reasonable to assume that some of this revenue will be used to promote structural mitigation projects, coordinate response efforts, and provide relief for recovery after an event. The degree to which communities provide their own resources may depend upon the policy mix from state and federal governments.

As the level of confidence in *revenue for problems* increases, the community may be less willing to provide incentives for relocation or less committed to zoning policies for creating open space. As a result, less commitment from the community would decrease the individual's willingness to relocate.

As local incentives for mitigation decrease, resulting in a lower *willingness to relocate,* there will be fewer individuals relocating to safe locations. As a result, the *vulnerable property* stock remains high, especially if the community is perceived as a relatively attractive place to live.

Development pressures reinforce status quo policies, which tend to favor incentives that increase the level of *vulnerable property* over time. In the last two decades, homeowners associations in hazard-prone communities have gained considerable power. They have had success in winning court cases that favor development and limit the government's ability to exercise its constitutional authority under the 5th Amendment (Platt 1999). These limits on buyouts or "takings" combined with the tax revenue pressure to maintain development puts local governments in a position to be more reactive than proactive with respect to its hazard policies. This pressure may reinforce over time, as the community interest groups for development increase in power and create a *sustainable development pressure.*

4.7 Natural Environment Capacity



B4: Natural Environment Capacity

Development in hazard prone areas, on beachfront property or in the wetlands, reduces the capacity of the natural environment to protect the community during a hazard event. Research suggests that overdevelopment destroys wetlands and beaches that provide a natural defense against flooding. The *Natural Environment Capacity* loop explains how overdevelopment may result in dangerous long term effects on the environment and its capacity to minimize damage during a flood.

Either as a result of economic development pressures, agendas for protective policies, structural mitigation projects that produce a moral hazard, or other unintended consequences of policies at the local level, development of *Vulnerable Property* and Mitigated Property in flood prone areas may increase over time. Increased development reduces the available land for development, thereby creating a more densely populated area (identified as *development density* in the model*)*.

Where governments permit development in wetlands or on beachfronts, the capacity of *wetlands and beaches* as natural protection will be *destroyed*. The rate of this erosion will be affected by the rate of development. In addition, it is reasonable to assume that the rate for *rebuilding wetlands* (or beach replenishment) will slower than the rate at which these natural barriers can be destroyed. From time to time, the government has used incentives and resources to restore wetland and beaches. The commitment for these programs has not been constant over time.

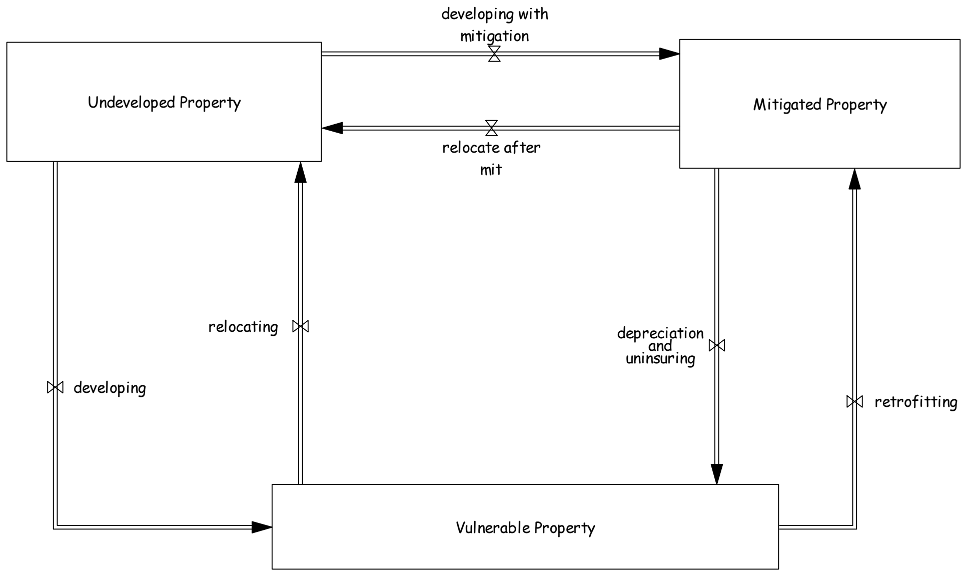
When a flood event threatens to damage property in a community, the capacity of the wetland will reduce the *magnitude of the damage*. However if overdevelopment has depleted these natural barriers, the *new damage* incurred during the event will be greater than originally perceived. If the public is made aware of or has direct experience with a flood event, the *Damage* accumulated creates a new *memory of damage*. These memories increase risk perception of vulnerable property, which can increase the individual's *willingness to relocate.* Therefore, as a potential leverage point, local governments can take advantage of federal funding (HMGP grants) for buyouts/relocation of *vulnerable property* immediately following a damaging flood event.

While the frequency and severity of the flood hazard affects the level of damage during an event, the *Natural Environment Capacity* loop shows how overdevelopment can increase damages during the next event. Development in the floodplain may vary considerably over time. The effects of rapid development have lingering effects for the natural barriers. That is, let's assume that new development destroys the natural barriers (i.e., wetlands or beaches). When an event strikes and people move away from the hazard-prone area there might be some time elapsed where the memory of the event fades. If it is difficult to perceive the time it takes to replenish theses barriers, it appear that the community is "safe" for redevelopment. After this delay, a period of redevelopment could make the community more vulnerable than it was before the first event. Relying on the *natural environment capacity* to protect against disaster may produce a false sense of security and another type of moral hazard.

5 The Policy Space

The policy space is a matrix of outcomes for policy alternatives against anticipated scenarios. The analysis of the policy space compares the success of policies across different "what if" scenarios. The indicator variables chosen for the matrix may reflect stakeholder interests or the concerns of underrepresented populations in the community. In section three, policy alternatives and scenarios were identified to show existing federal incentives. In section four, several policies were discussed in terms of their potential effect on important rates and decisions in the model.

Most of the initial policy option will have a direct or indirect effect on one (or more) of the important rates in the Land Development Sector:



Levels and Rates for Land Development

5.1 The Policy Space and Model Behavior[4]

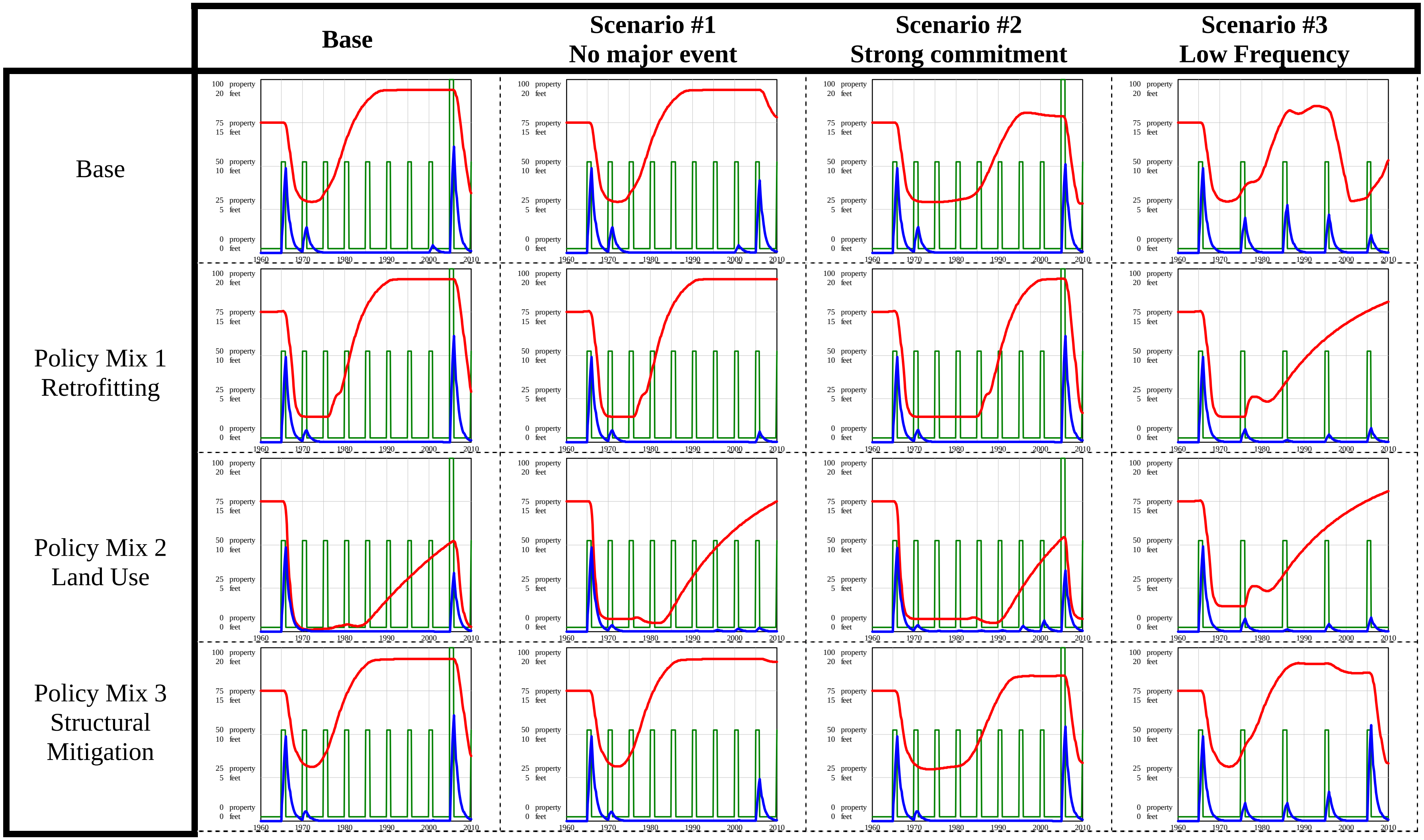
The policies and scenarios discussed during the last two sections of this paper define a "policy space" that can be analyzed and evaluated for qualitative differences in outcome behavior for key indicators in the system. The purpose of this paper is to show how a system dynamics model can be used to develop a policy space. Since it is beyond the scope of this paper to explore each possible outcome, it will be sufficient to show a policy space of the principal policies and scenarios. The policy space constructed for this section will consists of a 4 by 4 matrix: a base run and three policy mixes against base conditions and three scenarios. The policy space is presented with an outline of the policies followed by three charts. The first diagram, *Model Behavior: Changing the Parameters*, shows how the parameters were changed to operationalize the policies and scenarios for each cell. The second diagram, *Model Behavior: Vulnerable Property*, shows how one key indicator changes with respect to each change in policy and each scenario setting. The final chart, *Model Behavior: Multiple Indicators*, shows several important indicators in the system. This chart illustrates how a complex model might be used to analyze policies across scenarios for several indicators at one time. The presentation of model behavior in this section provides support to employ system dynamics as a powerful tool in any natural hazard policy analysis.

[4] Legend Key: Mitigated Property=blue, Vulnerable Property=red, Damage=green, Undeveloped Property=gray, Environment Capacity=black, Mitigation Capacity of Engineered Solutions=brown

Model Behavior: Changing the Parameters

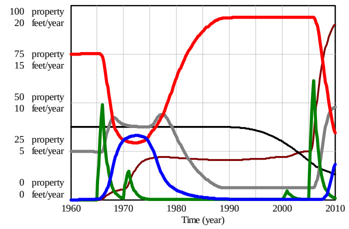
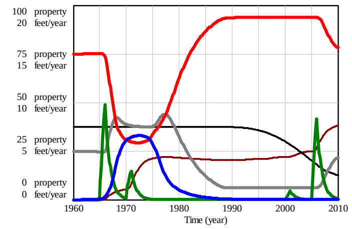
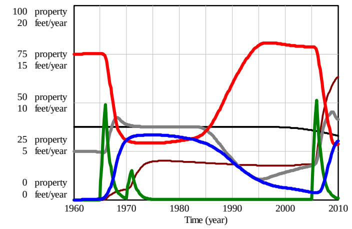
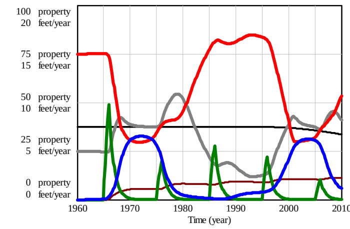
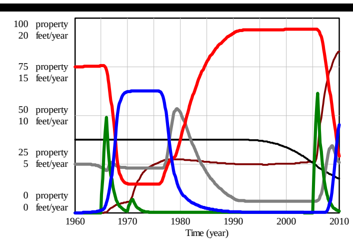
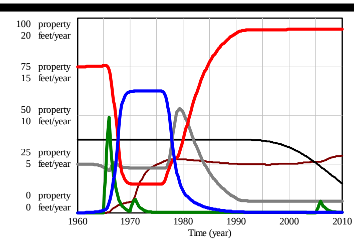
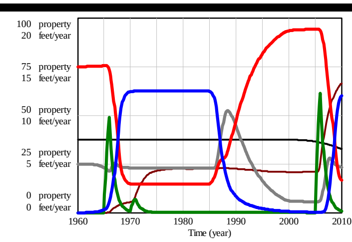
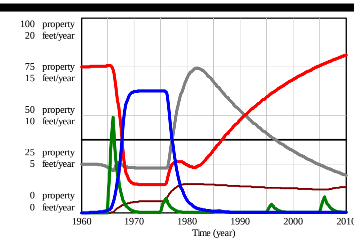
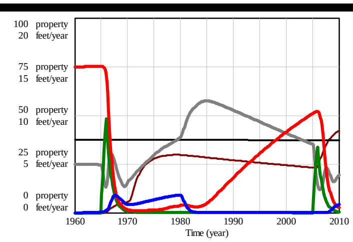
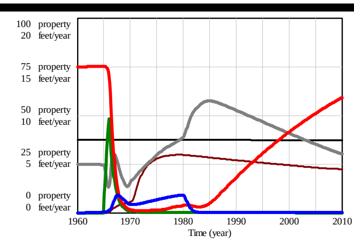
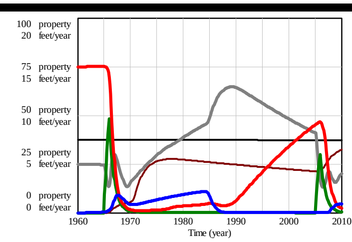
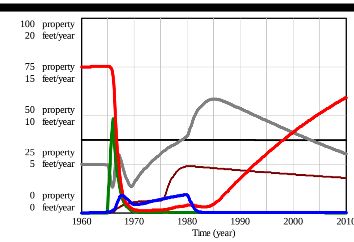
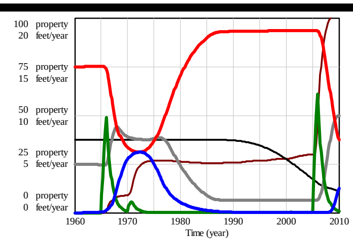
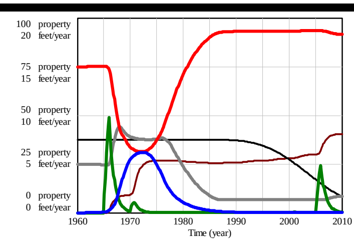
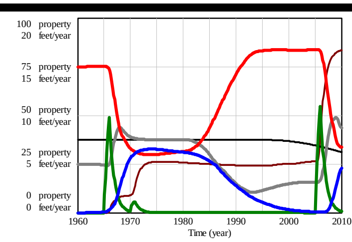
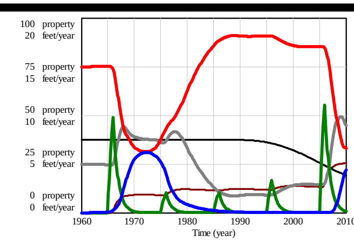
	Base	**Scenario #1** **No major event**	**Scenario #2** **Strong commitment**	**Scenario #3** **Low Frequency**
Base	-Initial conditions for a generic community - Policies are reactive, rather than proactive - Mitigation is not high on the agenda	- Base: major event occurs in year 50 (e.g., the time between Hurricanes Betsy and Katrina) -Scenario 1: The major event is removed completely	-Scenario 2: The time for policy entrepreneurs to forget (lose interest) is doubled - thus, increasing commitment for research and mitigation on the local agenda	- Base: A flood impacts the community once every 5 years. - Scenario 3: the events are spread out to once every 10 years - There is NO major event
Policy Mix 1 Retrofitting	- Base run Initial Conditions - Policy Mix 1: Increase the maximum willingness to retrofit AND build w/ mitigation to reflect better floodproofing incentives	- Scenario 1: No major event - Policy Mix 1: Increase max willingness to retrofit and build w/ mitigation to reflect better floodproofing incentives	-Scenario 2: The time for PE to forget (lose interest) is doubled - Policy Mix 1: Increase max willingness to retrofit and build w/ mitigation to reflect better floodproofing incentives	- Scenario 3: frequency is once every 10 years. NO major event - Policy Mix 1: Increase max willingness to retrofit and build w/ mitigation
Policy Mix 2 Land Use	- Base run Initial Conditions - Policy Mix 2: Increase willingness to relocate to reflect buyout incentives, limit the maximum developing in hazard to reflect zoning regulations	- Scenario 1: No major event - Policy Mix 2: Increase willingness to relocate and limit max developing in hazard	- Scenario 2: The time for PE to forget (lose interest) is doubled - Policy Mix 2: Increase willingness to relocate and limit max developing in hazard	- Scenario 3: frequency is once every 10 years. NO major event - Policy Mix 2: Increase willingness to relocate and limit max developing in hazard
Policy Mix 3 Structural Mitigation	- Base run Initial Conditions - Policy Mix 3: resources that reduce time to perceive mitigation and wetland demands. Incentives that increase time for structural PE to lose interest	- Scenario 1: No major event - Policy Mix 3: reduce time to perceive mitigation and wetland demands. Increase time for structural PE to lose interest	-Scenario 2: The time for PE to forget (lose interest) is doubled - Policy Mix 3: reduce time to perceive mitigation and wetland demands. Increase time for structural PE to lose interest	- Scenario 3: frequency is once every 10 years. NO major event - Policy Mix 3: reduce time to perceive mitigation and wetland demands. Increase time for structural PE to lose interest

Model Behavior: Vulnerable Property[5]



[5] Legend Key: Vulnerable Property=red, potential flooding=green, Damage=blue

Model Behavior: Multiple Indicators[6]

	Base	Scenario #1 No major event	Scenario #2 Strong commitment	Scenario #3 Low Frequency
Base				
Policy Mix 1 Retrofitting				
Policy Mix 2 Land Use				
Policy Mix 3 Structural Mitigation				

[6] Legend Key: Mitigated Property=blue, Vulnerable Property=red, Damage=green, Undeveloped Property=gray, Environment Capacity=black, Mitigation Capacity of Engineered Solutions=brown

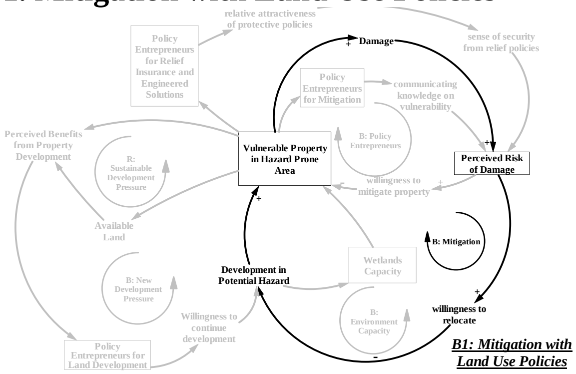
6 Conclusion

In this paper, I have shown how system dynamics can be used to define a policy space for a natural hazard policy analysis. The dynamic hypothesis for a flood hazard community was presented to illustrate potential leverage points in the system and important feedback structures affecting policy outcomes. By showing behavior over time graphs in the policy space, the analyst is able to identify both qualitative and quantitative differences in policy outcomes. The system dynamics model developed for this research provides insights to the causal structures which produce outcome behavior in the policy space. By providing such insights on behavior, the system dynamics model compliments the traditional benefit-cost approach and improves the overall quality of the analysis.

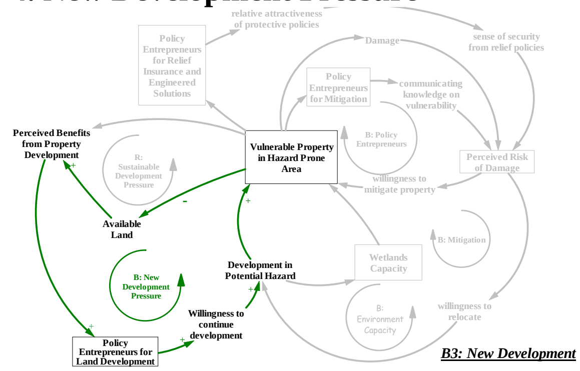
For future research: The paper presented at last year's conference in Boston was a conceptual model of the problems for a hazard prone community. That model linked structure and behavior for a base run and presented a dynamic hypothesis on the problem. The paper prepared for the conference in Nijmegen formalizes the conceptual model to link structure with policy alternatives and to create a policy space where alternatives can be evaluated under various scenarios. The final step in this research will apply the generic structure to specific case studies, where mitigation policies can be analyzed across stakeholder preferences and levels of political commitment and capacity for mitigation can be evaluated at each level of government.

Appendix A: The Causal Map

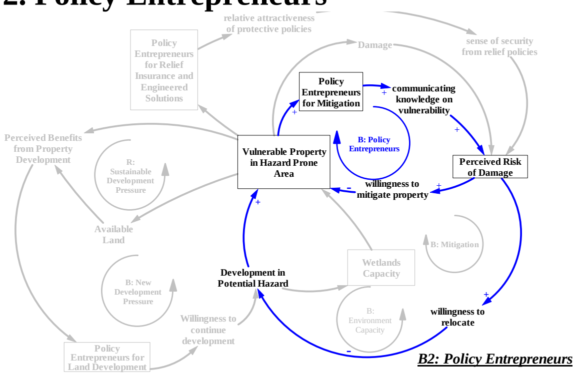
1. Mitigation with Land Use Policies



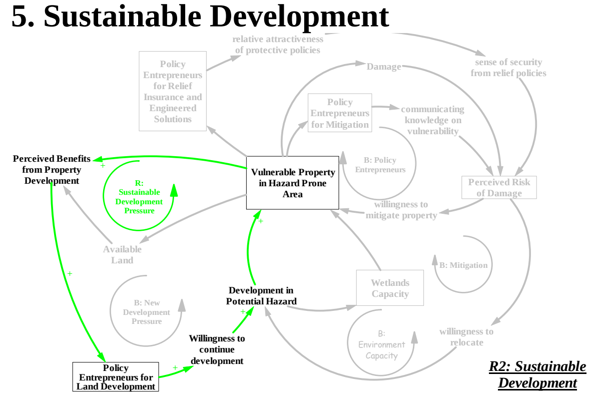
4. New Development Pressure



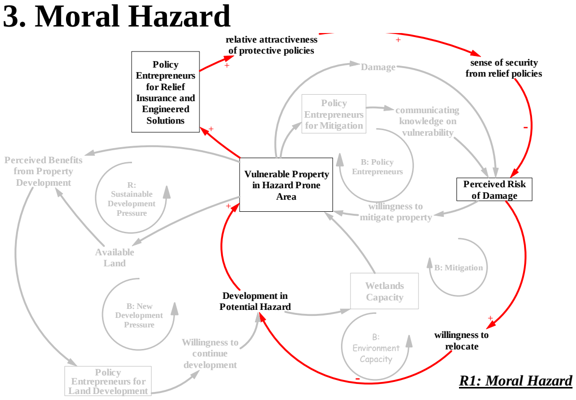
2. Policy Entrepreneurs



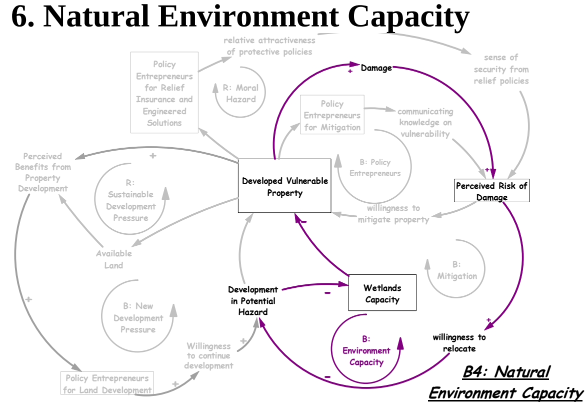
5. Sustainable Development



3. Moral Hazard



6. Natural Environment Capacity



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