Exploring U.S. Flood Mitigation Policies: A Feedback View of System Behavior

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Abstract:
Despite the availability of policy tools to mitigate property damage, relief costs for disasters continue to rise. This paper presents a framework for analyzing flood mitigation policies and policy design challenges in the United States. The system dynamics model prepared for this research was developed from qualitative data collected from over 300 sources, including the extant literature on natural disasters, statements made by disaster experts, government documents, policy analyses, and federal disaster mitigation policies. The generic structure developed for this research, the flood-1 model, explains the dynamics of major pressures in any flood-prone community. Eleven policies were analyzed against three scenarios to show the benefits and burdens of several types of mitigation policies. The policies selected in this analysis reflect the incentives established in the federal government's Community Rating System (CRS). In this paper, I show how the system dynamics model was used as a theoretical framework and policy analysis tool to explain the policy design challenges in every flood-prone community.

Key words: vulnerability, natural hazard, flood mitigation, disaster management, agenda setting, public policy analysis, policy process, sustainable development

1. Introduction

This research takes a continuous view of the factors influencing disaster mitigation policies. Natural hazards research has changed its focus over the years, moving from a linear disaster "stages" model (Haas, Kates et al. 1977, chapter 2) to a more dynamic decision-making process (Rubin 1995; Mileti 1999; Birkland, Burby et al. 2003) that more clearly reflects how preparedness, response, recovery, and mitigation are interrelated. The effectiveness of any one phase affects and is affected by the other phases (Rolfe and Britton 1995). Following the lead of this research, I have developed a model that represents an endogenous complex system of interactions between stakeholders who participate in several continuous processes.

The purpose of this paper is to show the policy design challenges for federal flood mitigation policies. In this paper I present the results of an exploratory study funded by the National Science Foundation (CMS#0408994). The model was developed from qualitative data collected from over 300 sources, including: the extant literature on natural disasters, statements made by disaster experts, government documents, policy analyses, and federal disaster mitigation policies. I developed a generic structure that represents the pressures in a flood-prone community. This community is called flood-1a and the model is called flood-1. Eleven policies were analyzed against three scenarios to show the benefits and consequences of several types of mitigation policies. The policies selected in this analysis reflect the incentives established in the federal government's Community Rating System (CRS). This is a rating system established to provide NFIP flood insurance discounts to residents whose communities take an active role in flood mitigation activities.

2. Model Overview

This section will proceed in the following manner. First, I will present the reference mode for an important indicator variable in this system, vulnerable property. Then, I will use the structure of the model, represented in the form of a causal map, to explain the behavior of this reference mode. The purpose of section two is to ground the reader in the important feedback structures in the model. Additional information pertaining to model structure and behavior has been provided in the supplemental documents. The information provided in section two should provide the reader with enough background on the problem to understand and enjoy the analysis in section three.

2.1 Reference Mode

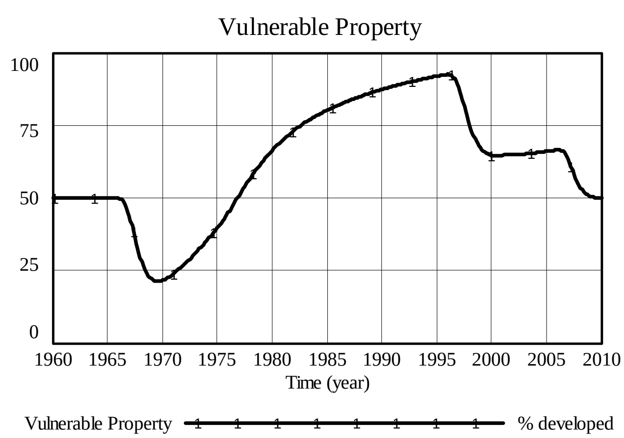


Figure 1 Reference Mode: Vulnerable Property

Figure 1 shows the dynamic behavior of total vulnerable property in the base run. Total vulnerable property is at equilibrium in 1960, the first year of the simulation. The first major event in the simulation occurs in 1965. During this event, a large number of vulnerable properties in the community experience some damage. Vulnerable property decreases in the years immediately following the event. Over time, the total vulnerable property rises above its level in the first year of the simulation. When hazard meets vulnerability in 1995, the level of damage is greater than the damage incurred during the first flood event in 1965. Between 1995 and 2005 the number of vulnerable structures declines. At the end of the base run simulation, the number of vulnerable properties levels off to its initial value.

Disaster experts provide explanations for the dynamics of vulnerability in hazard-prone communities. These explanations have been analyzed to construct the reference mode for *vulnerable property.* The reference mode of vulnerable property for the Flood-1a community illustrates the unintended consequences of rational decisions to control the hazard. The New Orleans case provides a generic example of the unintended consequences of decisions made by federal, state and local stakeholders (Pielke and Landsea 1997; Burby, Beatley et al. 1999). As a result of policy choices made by local governments - influenced by federal incentives- the experts argue that New Orleans had become more vulnerable to flooding over time. The formal model developed for this research replicates the behavior described in this reference mode. The model provides a theoretical framework of the endogenous feedback structures explaining vulnerability in this complex system.

The New Orleans example represents how human actions affect vulnerability in hazard-prone communities. After Hurricane Betsy contributed to 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, which resulted in 520 miles of levees, 270 floodgates 92 pumping stations, and hundreds of miles of drainage canals. The added protection spurred additional development in flood-prone areas, but did not eliminate vulnerability to flooding, which has remained extraordinary (Burby, Beatley et al. 1999). In a Category 5 hurricane, New Orleans was predicted to incur over $30 billion in property damage and more than 25,000 deaths from drowning (Pielke and Landsea 1997).

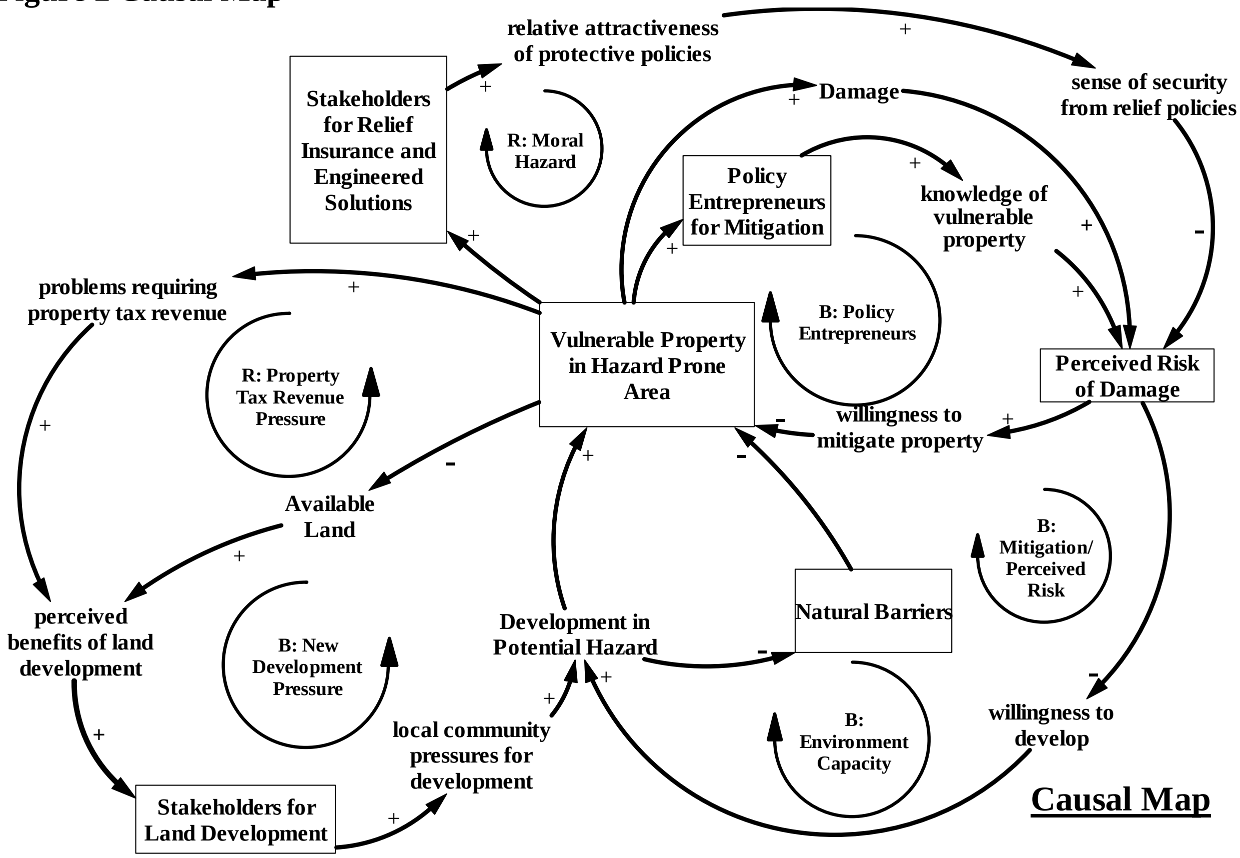
The model developed for this research is a generic structure of the problems creating vulnerability in a community like New Orleans. It is important to note this research is not a case study on New Orleans or any other flood-prone community. The stock and flow feedback structure developed for this research represents the problems any flood-prone community must cope with to eliminate, reduce or share the risks of flooding.

2.2 The Causal Loop Diagram

System dynamics models are designed to address problems in complex systems, where delays, accumulations and feedback explain the unintended consequences of well-intended policies. The size of the model is proportional to the scope and size of the problem. The problem definition for this research recognizes a high degree of complexity in this system: *despite the availability of policy tools to mitigate property damage, relief costs for disasters continue to rise*. The model developed for this research addresses the complexity identified in this problem definition. Figure 2 is a causal map representing key features of the model developed for this research. The full model addresses the problem in more detail and contains approximately 300 variables. [1] With that said, the causal map delineates the feedback structure of the full model simply and accurately without underplaying the complexity of the system.

[1] The full model developed for this research is rather large and still pending final approval as part of my dissertation requirement. Therefore, I will provide the structure of the model in a supplemental file. If the reader wishes to see the model equations, please contact me directly. In this paper, I may reference variables listed in the full model that are not in the causal diagram. In those cases, please see Appendix E, which shows model views of the major loops in the flood-1 model.

Figure 2 Causal Map



The data were coded for themes explaining the rise in property damage despite the availability of mitigation policy tools. These themes were analyzed using system dynamics tools to produce a theoretical framework for studying the impact of federal and state incentives to reduce damage in flood-prone communities. The full model represents a generic structure of a local community prone to flooding. The causal map in figure 2 represents a summary of the accumulations, delays and feedback presented in the full model. The model is a dynamic hypothesis of a generic flood-prone community; the structure of model explains the behavior of important indicators in the system.

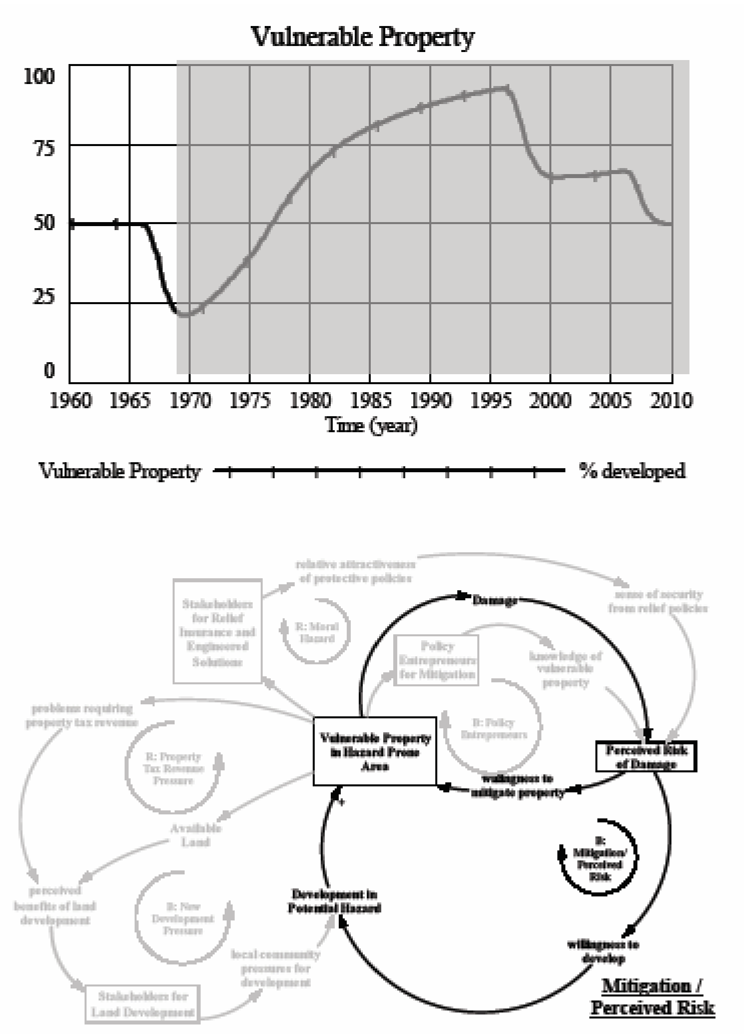
The causal map contains six major feedback loops: flood mitigation, policy entrepreneurs, moral hazard, development pressure, property tax pressure, and natural barrier protection. These feedback loops are casual stories used to explain the behavior over time of key indicators in this system. At different periods of time some loops become active and dominant over other loops in the system. The concept of loop dominance is a way to communicate the endogenous structures explaining the dynamics in model behavior.

2.3 Structure Explains Behavior

A system dynamics model is a dynamic hypothesis of the problem; the structure of the model is used to explain the behavior of key indicators in the system. The model prepared for this research has been grounded in the extant literature of disaster experts. The casual loop diagram is a summary of the full model structure, which represents six major feedback loops that explain the behavior of vulnerable property in the base run of the simulation.

In the flood-1 model, major feedback loops become active and dominate the system at different periods of time. Shifts in loop dominance and their implications for policy can be described and explained in terms of nonquantitative causal-loop diagrams (Richardson 1995). The reference mode behavior of vulnerable property can be analyzed using the feedback structure of the causal-loop diagram. The model behavior for vulnerable property is explained in four phases: (1) hazard meets vulnerability, (2) recovery with development pressures, (3) moral hazard and the property tax pressure, and (4) policy entrepreneurs for mitigation. In each diagram that follows, the base run for vulnerable property is shaded to highlight the phase in the discussion. The feedback loops that explain the behavior for the given phase are highlight directly below the base run illustration.

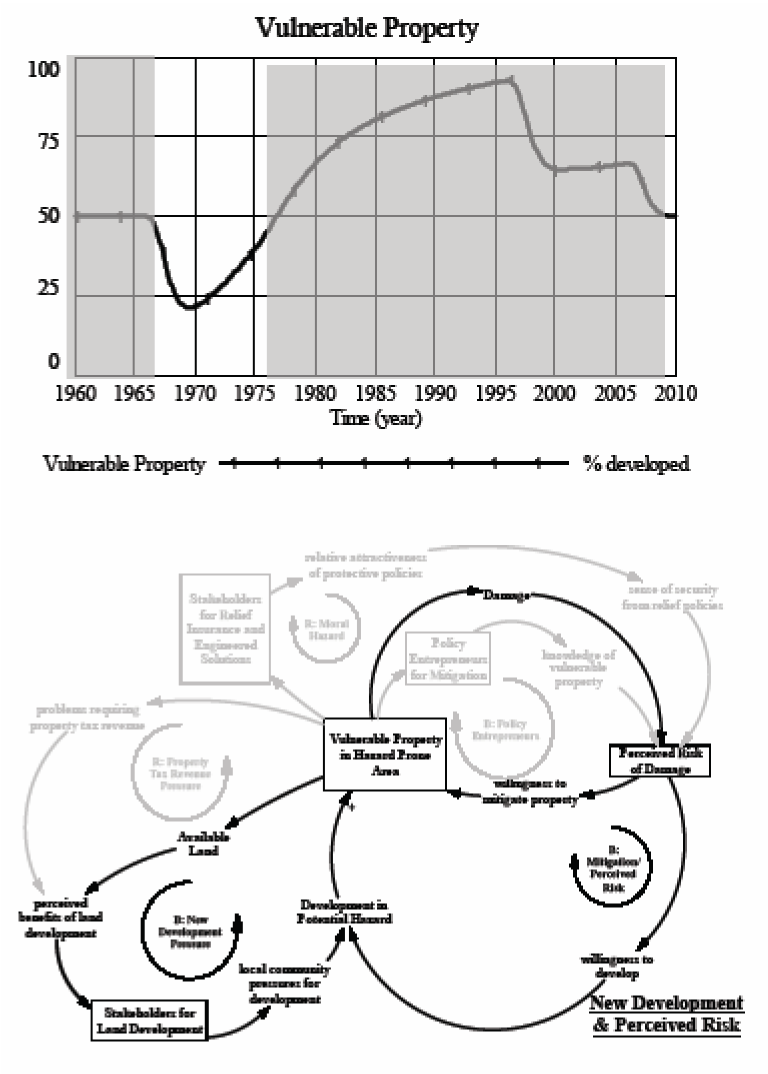
Figure 3 Hazard meets Vulnerability



In phase one, hazard meets vulnerability, vulnerable property is at equilibrium in the Flood-1 community. The dominant feedback loop is the mitigation/ perceived risk balancing loop. When this balancing loop is active there is an implicit goal of acceptable vulnerable property.

Approximately fifty percent of the flood-prone property is developed during phase one. It is assumed that the public perceives investment for development in the remaining fifty percent to be a risky decision. There are no major events in phase one and the perceived threat of future damage in the developed area is relatively low.

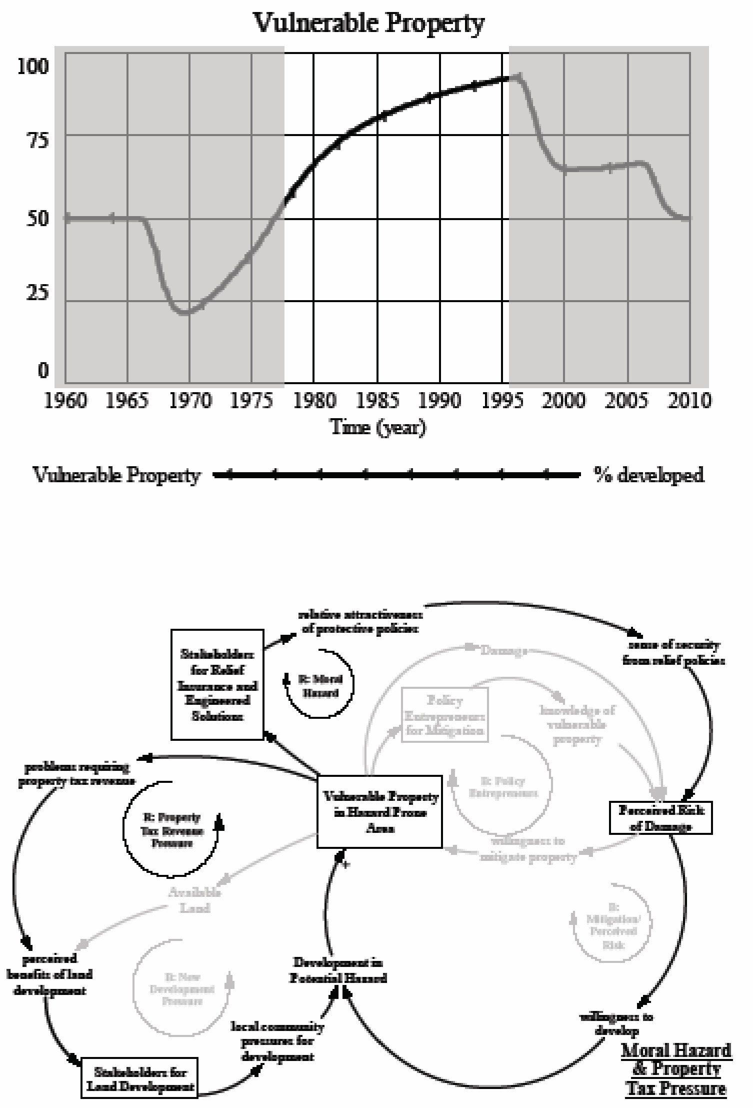
Figure 4 Recovery with Development Pressure



The Flood-1 community experiences a flood at the beginning of phase two, recovery with development pressures. The damage incurred during the event increases perceived risk in the community and activates the mitigation/ perceived risk loop. As a result, some of the structures are moved from harm and some are redeveloped with mitigation. Thus, the level of vulnerable property decreases immediately following the event.

As the memory of damage fades and perceived risk decreases, the mitigation/ perceived risk loses its strength. During the second half of phase two, the increase to available land activates the development pressure loop. The stakeholders for development place pressure on decision-makers to return the community to its original level of development. At the end of phase two, the level of vulnerable property is equivalent to its initial value.

Figure 5 Moral Hazard and Property Tax Pressure



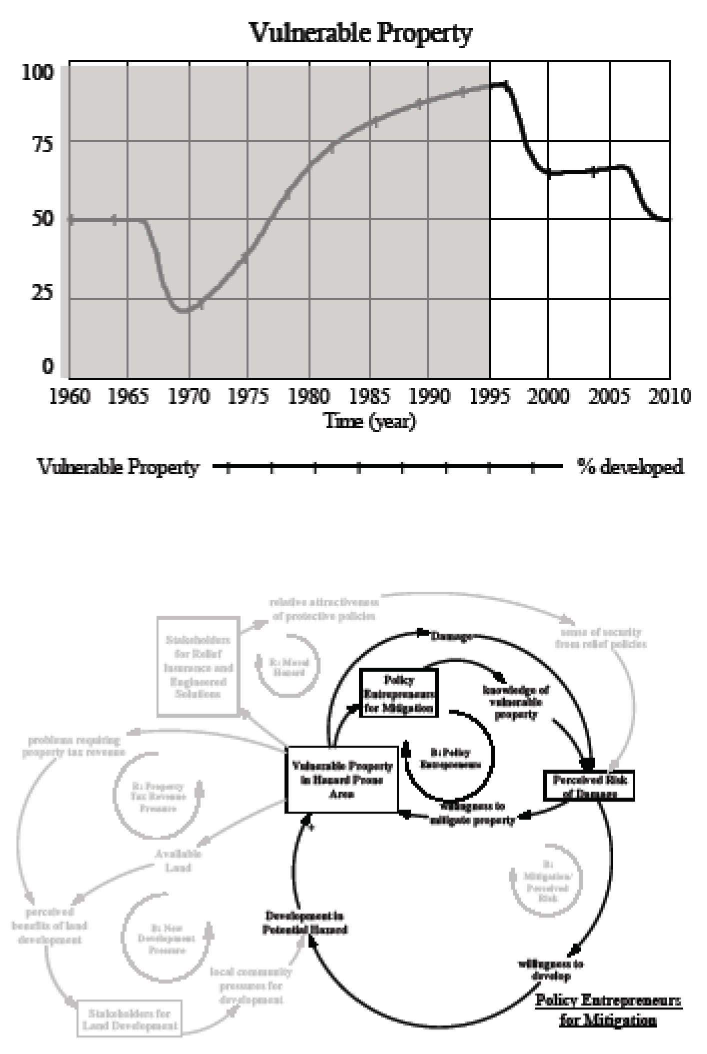
In phase three, two reinforcing loops combine to increase vulnerable property in the Flood-1 community above its initial value. The moral hazard and property tax pressure feedback loops are dominant during phase three. The two reinforcing processes lower the community's commitment to long term mitigation policy alternatives.

The availability of federal and state resources for relief and structural mitigation projects builds a sense of security in the community, which results in additional development. At this point, the moral hazard loop has been activated.

The additional development brings new problems that require a strong property tax base. Stakeholders for maintaining this tax base begin to accumulate and the property tax pressure becomes active.

Vulnerable property continues to rise when supporters for protective policies and continued development lower the perceived risk and the local commitment for zoning and wise land-use management. As a result of these pressures, the Flood-1 community is more vulnerable than it was at the beginning of the simulation.

Figure 6 Policy Entrepreneurs for Mitigation



At the beginning of phase four the Flood-1a community experiences a disaster that damages much of the vulnerable property. The damage to public and private structures builds a perception of risk and activates the perceived risk/ mitigation feedback loop. In addition, the potential focusing event activates policy entrepreneurs for mitigation.

When the policy entrepreneur feedback loop becomes active, the agenda for mitigation builds quickly. Policy entrepreneurs use the policy window to build commitment for wise land use management. These efforts reduce the level of vulnerable property in the Flood-1a community. At the end of the simulation, the level of vulnerable property has returned to its initial value. The structure of this model would suggest that vulnerable property would most likely rise again, as the pressures in the Flood-1a community will resurface and challenge the long-term success of mitigation policies in the future.

3. Model Analysis 1: The Policy Space

The policy space is a matrix of policies and scenarios, which show model run behavior for important indicators in the system. The matrix is used to analyze the performance of policies under various scenario conditions. The flood-1 model addresses several “what if” questions in this analysis. In fact, each scenario and policy run in section three leads off with one of these “what if” questions. In addition to the base condition, there are three scenarios and 11 policies tested and discussed in this section.

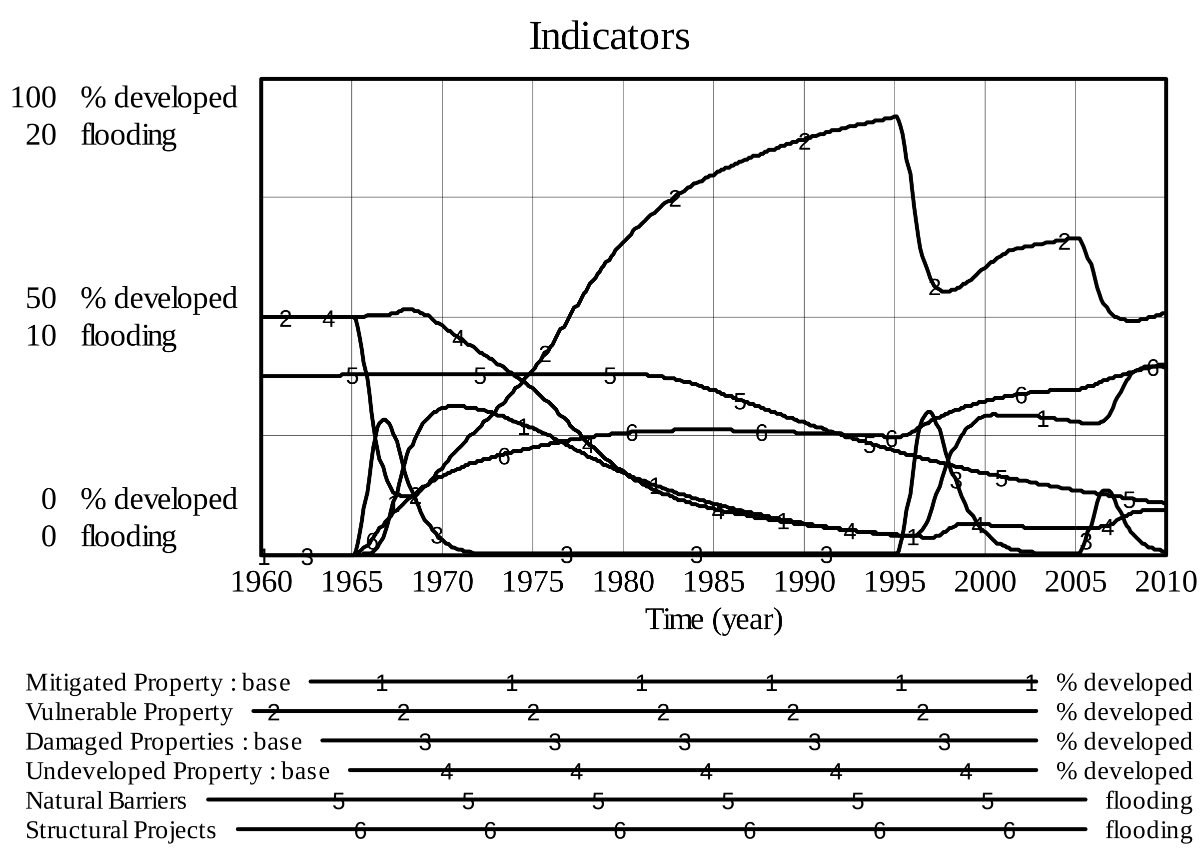
3.1 Base Run Indicators

The model developed for this research is the generic structure of a flood-prone community in the United States. Flooding in the flood-1a community is not a new problem. Solutions to the problem have been available for many years. The base run behavior represents the commitment and capacity for policy responses that develop over time. Policies in the flood-

1a community result from pressures in the system from an accumulation of unsolved problems (e.g., damage) and the preferences of stakeholder interest groups. The flood-1a base run is a benchmark to evaluate the effectiveness of different policies under various scenarios.

There are six indicator variables used to evaluate the model behavior in the flood-1a community: *mitigated property, vulnerable property, damaged properties, undeveloped properties,* natural barriers (*total environment capacity*), and structural projects (*mitigation capacity of engineered solutions).* Figure 7 shows the behavior of the six indicator variables that will be used to compare policy runs in this section of the paper.

Figure 7 Base Run for Indicator Variables



Land in the flood-1 model can exist in one of four states: undeveloped property (open space), vulnerable property, property with mitigation, or damaged property. The behavior of these variables is presented in figure 7. In the base run scenario, five hazards meet vulnerable properties three times and the level of damage for each event is different. The mitigated property stock increases after the first disaster, then slowly decreases over time and increases in the final years to its highest level at the end of the base run. Vulnerable property is not constant in the base run; it begins at equilibrium, decreases after the first major event, becomes greater than its initial value over time, and returns to a level close to its initial value. Undeveloped property steadily decreases after the first event, with the exception of minor increases after each of the damaging event. The natural barriers hold for half the run and steadily decline, as overdeveloped erodes the environment's capacity to protect against flooding. Structural mitigation projects increase after each damaging event.

3.2 Scenarios

Frequency and severity of flood events are two types of scenarios analyzed in the flood-1a policy space. It is assumed the frequency and severity of a flood for any given year is very difficult to predict. Moreover, the purpose of this research was to develop a model to address human responses to flood events. Therefore, these scenarios are exogenous to the system and their parameters can be changed to answer several types of "what if" questions. The model was used to analyze three scenarios: high frequency, low frequency and one severe event.

3.2.1 Frequency

The period between events may affect the commitment and capacity for mitigation in flood-prone communities. Disaster experts argue that frequent floods that result in damage build a strong memory and perception of risk. As this perception of risk builds, property owners may be more willing to partake in floodproofing and elevation, or buyout incentives provided by the government. There are two types of frequency scenarios presented in this analysis: high frequency and low frequency. Other frequency patterns were tested and analyzed, such as regular vs. irregular frequency. However, the most interesting results could be explained with the two scenarios discussed in this section.

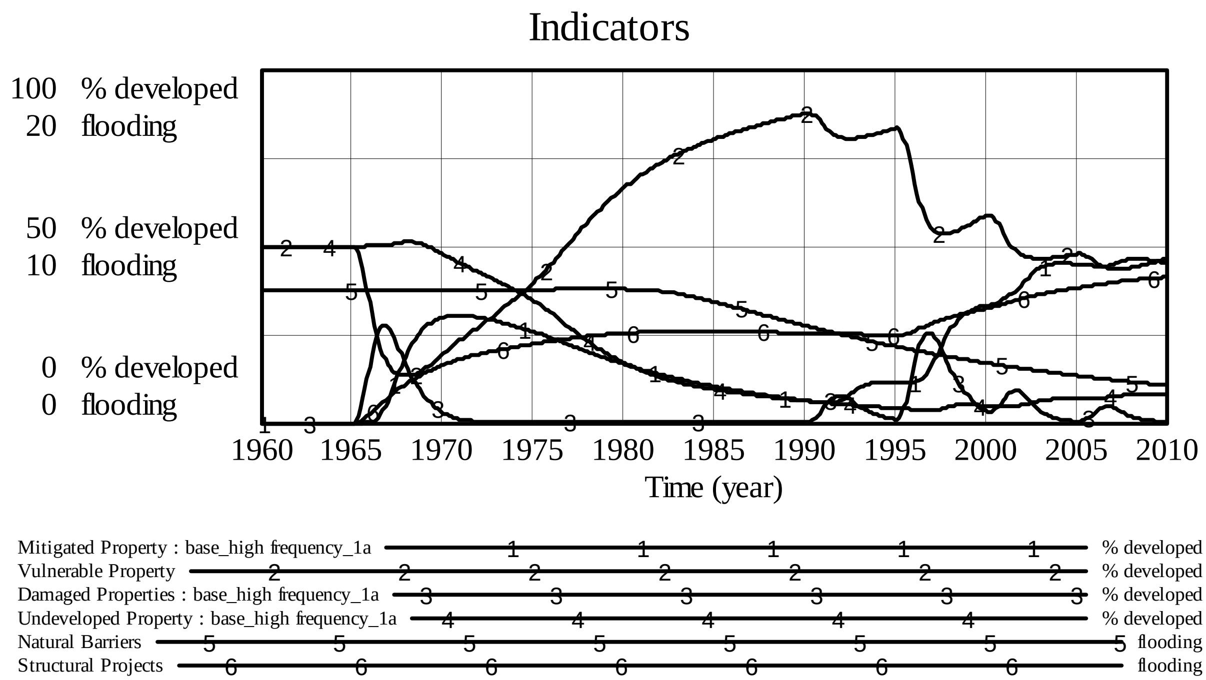
3.2.1.1 **High Frequency**

The flood-1a community experiences a moderate flood event once every ten years. The vulnerable property exposed to flooding is damaged during these events. The severity of damage is relative to the capacity of the natural environment and the capacity of structural engineering projects to divert the high waters. The flood-1 model represents frequency in the flood-1a community with the parameter *frequency*, which is set at 10 years. The first event occurs in the same year as the base run, in 1965.

What if the flood-1a community experiences flooding on a more frequent interval?

The flood-1 model answers this question by changing the *frequency* parameter to show flooding on an interval more frequent than once every ten years. The "high frequency" scenario is a model run where the time in between floods is less than the base run. The *frequency* was set to 5 years to represent a high frequency scenario. Based on the base run analysis, a hypothesis can be made about the expected behavior in the high frequency scenario. *High Frequency Hypothesis:* More frequent events should activate the memory of damage/perceived risk feedback loop, which would increase perceived risk and reduce vulnerability in the flood-1a community. The *high frequency* run behavior in the flood-1a community is provided in Figure 8.

Figure 8 Floods with High Frequency



Model behavior for vulnerable property in the high frequency scenario is the same as the base run behavior until the 1990 event, where vulnerable property decreases below the base run value from 1990 to 1995. Between the years 1995-2000, vulnerable property has the same behavior as the base run and then falls below the base run from 2000 to 2010. Damage occurs during five events in the high frequency run, with the largest amount of damages in 1965 and 1995. The recovery period during the 1995 event is longer than the base run recovery for the same event. Mitigated property is greater than the base run between 1992 and 2010. Undeveloped property is approximately the same value in the high frequency and base run. The natural barriers are identical in both runs as well. Structural mitigation is slightly higher from 2002 to 2010, but is otherwise the same in both runs.

The 1990 event is the key event in the analysis of the high frequency run. Structures do not increase after the damaging event 1990. Instead, the community pursues a “recovery with mitigation” strategy following the 1990 event. However, the indicator of perceived risk is unchanged until the 2000 event. Therefore, the recovery with elevation and floodproofing after the 1990 event is the result of local incentives and regulations, as the community uses taxpayer resources in the recovery effort. The 1990 recovery is a relatively small recovery, which means the local government would be responsible for the recovery and the pressure to “return to normalcy” would be greater.

If the 1990 event caused more damage and federal resources were used in the recovery, there may have been more pressure to create open space. The flooding ratio is greater during the 1995 event; more vulnerable properties are damaged and structural engineering solutions increase during the recovery. The 1995 exceeds local capabilities and federal resources are used to return the community to normal. The federal response creates some open space. Since the level of damage in the high frequency run is not as great as the base run, the local portion of recovery is large and thus, the amount of open space is relatively small.

In 2000 and 2005 the damages are perceived to be minor and therefore, structural mitigation solutions are not pursued. The recovery strategy in these events is similar to the 1990 event, where local resources are used as incentives for floodproofing and elevation. Policy entrepreneurs for mitigation are relatively high in the high frequency run and become active at an earlier (in 1992) point in the run. The mitigation policy entrepreneurs promote mitigation policies that require individual resources over mitigation policies that require taxpayer resources. This provides some explanation for the low commitment to structural mitigation at the end of the run, but the agenda density for nonstructural mitigation is no substantially different from the base run behavior.

The *high frequency* hypothesis suggested that more frequent flood events would increase perceived risk and lower vulnerable property. The perceived risk in the high frequency run is only greater than the base run during the last five years. However, vulnerable property does finish lower in the high frequency run. More frequent flood events do not significantly change the behavior of the indicator variables but does change the numeric value of these indicators.

3.2.1.2 **Low Frequency**

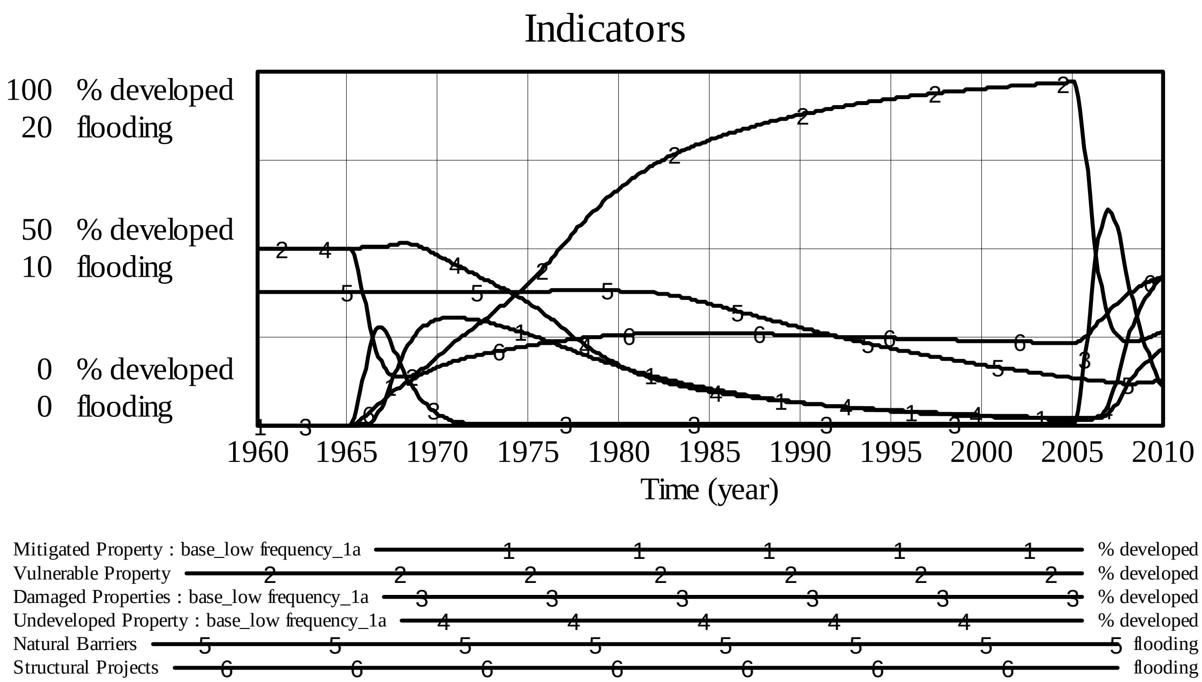
The moderate flooding that occurs every 10 years in flood-1a provides a reminder of potential risks and vulnerabilities in the community. In the base run, the community reacts to the first event with structural engineered solutions (e.g., seawalls, dams) that protect against high water for several years and provide a sense of security during the base run. In the high frequency scenario, awareness of the potential threat activated feedback loops in favor of mitigation. A second scenario could be generated to address low frequency flooding.

What if the flood-1a community experiences flooding on a less frequent interval?

The flood-1 model answers this question with a change to the *frequency* parameter to reflect flooding on an interval less frequent than once every ten years. The “low frequency” scenario is a model run where the time between floods is less than the base run. The *frequency* was set to 20 years between events to reflect a low frequency scenario. Therefore, an event will shock the system in 1965, 1985, and 2005. The *low frequency hypothesis* is stated as follows: Less frequent events will reduce the memory of damage and the impact of the damage/perceived risk feedback loop, which will reduce perceived risk and increase vulnerability in the flood-1a community. As a result, the level of accumulated damage in the *low frequency* run should be greater than the level of damage in the base run. Figure 9 shows the *low frequency* run behavior in the flood-1a community.

The accumulation of vulnerable property increases to a high level between 1980 and 2005, surpassing the level achieved in the base run. By contrast, mitigated property is much lower than base run until the 2005 event. The amount of open space is very low for most of the *low frequency* run, but increases at the run above the level of open space in the base scenario. Natural barriers are equal to the base run, but increase slightly after the 2005 event. Structural mitigation projects hold constant from 1980 to 2005, where they increase after the damaging event in that year.

Figure 9 Floods with Low Frequency



The analysis for the high frequency run follows a similar logic as the base run analysis. After the 1965 event, structural mitigation projects protect the flood-1a community. The memory of damage fades and the agenda for nonstructural mitigation decreases over time. Knowledge on vulnerable properties in the community decreases, as the policy entrepreneurs for mitigation have found other problems to champion. Since the 1985 event resulted in no significant level of damage, the sense of security fueled development in the floodplain. By the time the 2005 hits flood-1a, nearly all of the land is developed without proper insurance or mitigation above the base flood elevation level. As a result, the accumulated level of damage incurred in the *low frequency* run is greater than the total damages incurred in the base run.

The *low frequency* hypothesis suggested that a longer period between events would increase vulnerability and total accumulated damage in the flood-1a community. The analysis of the *low frequency* run partially supports this claim, as total accumulated damage is greater than the base run. However, despite the very high level of vulnerable property for most of the *low frequency* run, the sharp decline in vulnerable property at the very end of the run suggests the flood-1a community may be turning towards nonstructural mitigation.

3.2.2 Severity

As stated earlier, a disaster occurs when hazard meets vulnerability. This research has focused on the human response to floods that affect vulnerability. The base run controlled for the hazard by keeping the frequency and severity of the event constant. Over a period of time, a flood-prone community may experience one or more events that exceed normal or moderate flooding levels. The flood-1 model accounts for this possibility as a “what if” scenario. That is, a Katrina-like event would be analyzed with the flood-1 model as a *severity* scenario test.

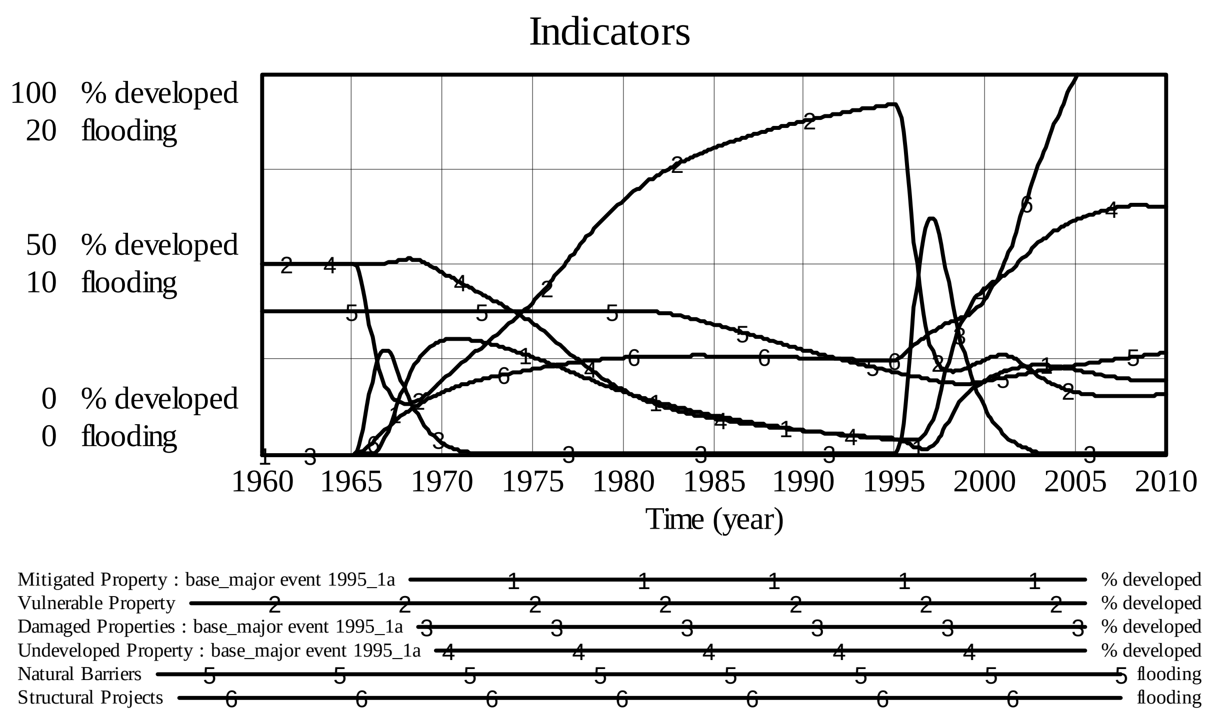
3.2.2.1 **Major event in 1995**

In the base run, the severity of each event exceeds the natural environment capacity. Each event would result in flooding and damage if no mitigation measures were taken. The severity of each event is identical in the base run. That is, the flood-1a community does not deal with any Katrina-like events in the base run. Therefore, an extreme condition test should evaluate the indicators against one or more events with greater severity than any of the "normal" events in the base run.[2]

What if the flood-1a community experiences a severe flood?

The flood-1 model has variables called *year of first major event* and *severity of major event* to address this what if scenario. The *year of first major event* is set for 1995 and the *severity of major event* is set 1.5 times greater than a normal event.[3] The year was selected to allow for an analysis of pre-event and post-event conditions. Essentially, this scenario creates a simulated environment for a pre-test/post-test analysis. The *major event in 1995* hypothesis is stated as follows: A major event will result in more total damage than the base run, which will activate several loops that increase perceived risk and lower vulnerable property in the second half of the run. The *major event in 1995* behavior in the flood-1a community is provided in Figure 10.

Figure 10 Severe Event



Vulnerable property drops below 25 percent during the 1995 recovery period. Perhaps

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[2] A "one severe event scenario" is reported in this research but several tests were conducted. The insights from more than one event scenarios were not significantly different than the single major event.

[3] The severe event occurs in the same year as a normal event. Therefore, total flooding in the 1995 severe event scenario (adding these events together) is 2.5 times the flooding of the 1995 base run event.

due to the size of the damage, this recovery is longer than the recovery in the base run. Mitigated property, on the other hand, finishes lower than the base run value. As predicted, damaged property is very high in 1995, which results in total damages much greater than the base run. The level of undeveloped property increases after the 1995 event. Compared with the base run, there is far more open space at the end of the *major event in 1995* run. The increase to open space results in more natural barriers from 1999 to the end of the run. Structural mitigation projects increase after the 1995 event, but the behavior of this variable is interesting. There is a period right after 1995 where structural mitigation projects increase slowly and then in 2000 these projects increase dramatically.

The structural mitigation gap is very high in 1995 but the response is relatively weak. Local resources have been spent on recovery, which leaves very little for any mitigation activity. After the recovery is complete and local resources are available for structural mitigation projects, the level of effort for structural mitigation increases in 2000. The local capability to address flooding during the 1995 event is exceeded and the federal government assists in the recovery. This explains why there is more open space and less mitigated property at the end of the *major event in 1995* run. The indicator of perceived risk rises above the initial value between 2001 and 2007 and changes the behavior of several variables. Individuals in the community are willing to retrofit and relocate existing vulnerable property.

There is an interesting contrast between the behavior of the severe event scenario and the base run. In the second half of the base run, policy entrepreneurs were responsible for setting the agenda to promote mitigation policies. However, in the second half of the severe event scenario, the direct experience of damage influences the decisions made by property owners in the community. While the agenda density for nonstructural mitigation and number of policy entrepreneurs for mitigation are only slightly higher than the base run levels, the direct experience of damage, failed protective policies, and low agenda activity for relief directly influence the indicator of perceived risk in the severe event scenario. The contrast between this scenario and the base case is very interesting because it shows how similar behavior results with different feedback loops becoming active in the second half of the run.

The hypothesis proposed for this scenario stated accumulated damages would be greater than the base run and the level of vulnerability would finish lower than the base case. It appears this hypothesis is supported in the flood-1 model. The total accumulated damage is greater than the base and several feedback loops become active to reduce vulnerable property in the second half of the run.

3.3 Policies[4]

The community rating system provides incentives for local mitigation activities in four categories: public information, mapping and regulations, flood damage reduction, and flood preparedness. The flood-1 model was designed to address policies in these four areas. This exploratory research revealed additional policies that could lead to improved mitigation outcomes. The existing policy alternatives and the "new" policies alternatives were used in this policy analysis. Eleven policy mixes have been tested against the base case and three scenarios

[4] Due to the 30 page-limit constraint, several graphs were not able to fit into this paper. I have attached four appendices as supplemental documents to show the reader how the model runs were analyzed. Appendix B shows policy runs vs. the base case for several indicator variables mentioned but not shown in section 3.3. Appendix C shows how the policies performed against each scenario listed in section 3.2. Appendix D shows the database output of my notes for each policy run listed in section 3.3.

described earlier. The results of those policy tests are described in this section and the summary of the analysis is discussed in section 3.4.

Policy mix[5]	**Description**
Structural mitigation	Build levees, seawalls and other engineered solutions that requires collective action and taxpayer resources
Public Information	Raise awareness of future flood risks and provide reminders of previous damaging events.
Policy entrepreneurs for mitigation	Increase the administrative capacity (research and implementation) and political commitment to encourage wise land use, floodproofing, and elevation.
Hazard Mapping and Vulnerability Assessment	Learning about the community's risk to flooding through more frequent hazard mapping and vulnerability assessments
Less Relief and Government Subsidies	Reduce the incentives for stakeholders to promote policies that subsidies overdevelopment or development without mitigation.
Public Information on Structural Protection	Reduce the levee effect from structural mitigation by downplaying the actual protection or providing reminders of recent structural failures.
Zoning Restrictions	New development can be prevented with proper implementation of zoning ordinances.
Reduce Property Tax Pressure	Assistance from state and federal government to reduce property tax pressures (e.g., cost to protect infrastructures with new development).
Recovery with Open Space	Policies that address repetitive loss by requiring open space provisions each time taxpayer dollars are used in recovery.
Restore Natural Barriers	Allocate resources for wetland restoration and beach replenishment activities.
Community Rating System (CRS) Policy Mix	A policy mix that included all four activities in the community rating system: public information, mapping and regulations, flood damage reduction, and flood preparedness.

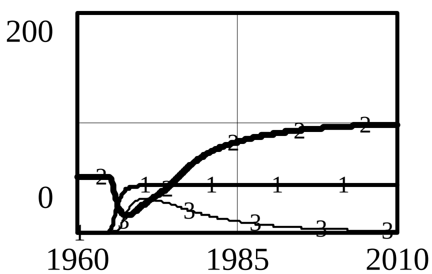
[5] Appendix A provides the model parameter changes for each policy mix listed in this table.

3.3.1 Structural Mitigation Protection[6]

Levees, dams, seawalls and other structural mitigation projects were the preferred solution to flooding problems in the United States for many years. Flood experts have warned against policies that control the hazard without addressing property owner vulnerability, as they tend to encourage unwise land development. The flood-1a community uses taxpayer dollars for structural mitigation projects to protect its residents after the 1965 event. In the base run, the desired level of structural mitigation protection is base on a parameter called *levee increase multiplier*. Essentially, this parameter is the perceived worst case flooding scenario in a flood-prone community. It is the level of desired protection, based on recent flooding beyond the natural environment and existing engineered solutions. In the base run, the *levee increase multiplier* is set at two. This means the flood-1a community desires protection against a flood twice as great as its most recent event. However, a worst case scenario of two might not be enough protection if the community prefers an engineered solution approach to the problem, which was the case in New Orleans following Hurricane Betsy. The *levee increase multiplier* was increased from 2 to 4 to reflect this policy change. Figure 11 shows the model run behavior for the *more levees* policy run.

What if communities responded to events with more structural mitigation projects?

Figure 11 Structural Mitigation Protection



1= total damage
2= vulnerable property
3= mitigated property

The indicators presented in figure 11 tell a very interesting story. In the first half of the *more levees* policy run, *Mitigated Property* has the same behavior as the base run. In the second half of the run, *mitigated property* decreases to zero. Vulnerable property is 50 percent higher than the base level at the end of the run. The 1965 event is the only event to result in damage. All of undeveloped property is developed by 2010. Natural barriers follow the same behavior as the base run. The mitigation capacity of engineered solutions is where this policy is focused, and it produces an interesting result (see Appendix B1). After the 1965 event, this capacity increase quickly and remains above the base run. However, the capacity of engineered solutions in this policy run is only slightly greater than base run value at the very end of the run. Where the base run follows an incremental increase to engineered projects, the *more levee* policy run increases quickly and levels off over time.

Depending on the performance indicator or criteria used to evaluate the policy, the *more levees* policy performs better than the base run under some circumstances. The mitigation capacity of engineered solutions contains the flood waters in 1975, 1985, 1995 and 2005. The major benefit of this policy is that it reduces the total damages under the base scenario conditions. However, the indicator of perceived risk remains very low through most of the run

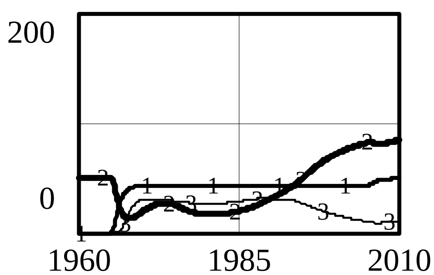
[6] Note to reader: Please open "Appendix B: Policy Analysis Indicators" as you read the policy descriptions in this section. The page-limit prevents me from providing these diagrams in the main text. However, if you use the diagrams in Appendix B, I think the analysis in this section will be clear (and more interesting!).

and finishes less than half the value of the base run in 2010. When the 1995 event results in zero property damage, the policy entrepreneurs for mitigation are not activated, the agenda density for mitigation remains low, and knowledge never rises above zero throughout the final years of the run. While structural mitigation for this policy ends at nearly the same value as the base run, the community is more vulnerable. *Vulnerable Property* occupies nearly 100 percent of the total land and development with mitigation is virtually zero. In the base run, the policy entrepreneur loop is active and dominant and active in the final period. In the *more levees* policy run, the sense of security / moral hazard loop is dominant. This policy could be viewed as a success in terms of the relatively low total damage under base scenario conditions. However, this policy could also be viewed as a failure, since it increases the number of vulnerable properties that would be exposed to damage during a severe event.

3.3.2 Public Information

What if public information campaigns used existing damage as reminders to keep the memory of damage alive?

Figure 12 Public Information on Damage



1= total damage
2= vulnerable property
3= mitigated property

The public information campaign policy performs very well in the middle years of the run (Appendix B2). Mitigated property stabilizes from 1970 to 1995, but declines steadily in the final period of the run. Vulnerable property stays below the base run from 1970 to 1995. However, it too finishes worse than the base in the final years of the run. There are no damaged properties in 1995 and very few damaged properties in 2005; total accumulated damage is half the level of the base run. The behavior of undeveloped property is very interesting; it increases from 1973 to 1980 and remains above the base run until 2005. However, in the final years of this policy run, the level of undeveloped property is less than the base run level. Natural barriers remain strong until 2000, but still finishing above the base run value in 2010. The capacity of structural mitigation projects ends at only half the value of the base run. This policy produces more individual effort towards mitigation after the 1965 event, but the effect is short-lived. Overall, the behavior could be characterized as a “better before worse” policy run.

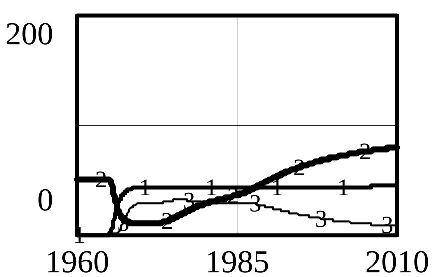
When analyzing this policy run, I experienced a challenge that all mitigation policy analyses face. This public information policy mix outperforms the base run on all of the indicators during the first half of the run. If the temporal boundary was thirty years, this policy would be the optimal solution. However, the temporal boundary is fifty years, which allows five events to “test” the system. In addition, the long temporal boundary shows how policies play out as development pressures build and properties transfer ownership.

The most notable difference between the base run and the public information policy mix run is the increase to *knowledge on vulnerable property* between 1970 and 1995. The increase to knowledge during this period creates a reinforcing loop with *policy entrepreneurs for mitigation*. Policy entrepreneurs stay active from 1975 to the end of the run. While finishing lower than the base run, their early activity in the policy process increases the agenda for nonstructural mitigation during the middle years of the run. As property development shifts from vulnerable to mitigated and undeveloped, *stakeholders for protective policies* are lower than their base level for most of the policy run. The intended effect of the policy produces a greater *memory of damage* after the first event. An interesting benefit of this policy is that the increased knowledge and agenda activity to nonstructural mitigation increases the *indicator of perceived risk* above the initial value for part of the run and a value much greater than the base run from 1970 to 1995. Since this policy mix is unable to detract *stakeholders from land development*, these stakeholders are active in the policy process for a longer period of time. This explains why the policy run ends with more vulnerable development. The public information policy mix effectively reduces vulnerability in the first half of the policy run. In addition, this policy run has less total accumulated damage than the base run. However, the vulnerable property development in the latter half of the run raises some concern about this policy. The public information policy mix produces "better before worse" behavior for the model variable indicators.

3.3.3 Policy Entrepreneurs

What if incentives were provided to attract policy entrepreneurs and keep them active in the policy process?

Figure 13 Policy Entrepreneurs



1= total damage
2= vulnerable property
3= mitigated property

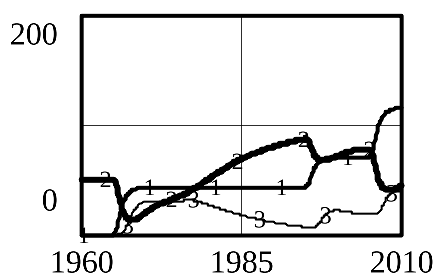
The policy entrepreneur policy mix results in similar behavior as the public information policy mix (see Appendix B3). Mitigated property is greater than the base run from 1970 to 1987. Then, it declines slowly and finishes at 25% of the base run value in 2010. This run produces less vulnerable property than the base between 1970 and 1997. However, vulnerable property steadily increases during this time and finishes 25% greater than the base. There are no damage during the 1995 and 2005 event and thus, the total accumulated damage finishes much lower than the base run. After the 1965 event, there is a long period where open space is created and maintained, but this level decreases over time and finishes at the base value in 2010. Natural barriers hold until 2000 and slowly decline thereafter; the natural defense of the land is more than double the base level in the final year. Finally, structural mitigation protection is lower than the base run value from 1970 to the end of the run. These projects are approximately one-half the strength of the base case in the final years of the policy run. The indicators in the policy entrepreneur policy mix show a commitment to nonstructural mitigation in the first half of the run, but like the public information policy mix, the commitment fades and the community is left vulnerable to flooding in the final years of the run.

If efficiency was the criteria used to evaluate policy runs in this policy analysis, then the policy entrepreneur policy mix would be the preferred solution. This solution is less coercive than other policies and provides the spark that starts a reinforcing process in the system. The policy entrepreneurs rise quickly and remain active for the duration of the run. Their presence increases agenda density for nonstructural mitigation and fuels knowledge of vulnerable property. In fact, the *knowledge of vulnerable property* stock reaches 80 properties by 2010; the highest level in any policy run. In addition, protective policy stakeholders are lower between 1970 and 2000, which keep the agenda for relief lower than the base until 2005, where both are equal to the base run values. Despite having a lower value than the base run, structural projects do not fail in the policy entrepreneur policy run and total damage is half the value of the base case. The indicator of perceived risk is very high after the 1965 event and does not fall below .4, but finishes at the same level as the base in 2010. Since damages are very low in this run, the community does not have a constant reminder of the flood threat. As a result, mitigated property slowly becomes vulnerable, as people stop taking proper insurance and there are more NFIP violations. In the second half of the run there is more vulnerable development, as stakeholders for land development remain active and apply pressure to relax zoning and mitigation requirements. Overall, this is a good policy run with very low damages. The results are very efficient and not coercive. However, this community is vulnerable to flooding in the second half of the run. If total damage is main criterion for evaluation, this is a very successful policy run. If vulnerable property is criterion for evaluation, this is policy exhibits "better before worse" behavior.

3.3.4 Hazard Mapping and Vulnerability Assessment

What if maps were updated more frequently and vulnerability assessments were made regardless of political commitment for mitigation?

Figure 14 Hazard Mapping and Vulnerability Assessment



1= total damage
2= vulnerable property
3= mitigated property

The mapping and vulnerability assessment policy mix performs only slightly better than the base run (Appendix B4). This policy performs well for a brief period following the 1965 event. In the second half of the run, the flood-1a community returns to its status quo strategy. Between 1970 and 1978 mitigated property is above the base, at 30 percent of development. After 1978, mitigated property declines and falls below the base between the 1995 and 2005 events, finishing at the base run level in 2010. The analysis for vulnerable property follows a similar trajectory. It is lower than the base from 1972 to 2000; rises above the base value between 2000 and 2005 and finishes at approximately the same value as the base in 2010. The behavior for *damaged properties* reveals another interesting issue with policy analysis for disasters. The total accumulated damages are identical to the base run but the magnitude of damages in 1995 and

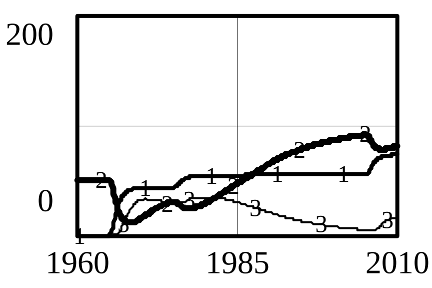
2005 are reversed. If the community were to apply a discount rate to future benefits and costs, it would prefer to have damages occur later rather than sooner. However, if property owners in the future are valued in the same way as property owners in the present, then this would be a moot point. The discount rate is one of many issues that come under fire during a disaster mitigation policy analysis (see Ganderton 2006). Undeveloped property mirrors the base run until the final years, where it increases slightly above the base. Natural barriers and structural mitigation projects are very similar to the base run, with the natural environment performing slightly better than structures, relative to the base.

The "research only" approach has limited benefits, as shown by the performance of the indicators in figure 14. The major difference between the base run and the hazard mapping and vulnerability assessment policy mix run is the behavior for the level of *knowledge of vulnerable property*. Between 1970 and 2000, the level of knowledge on vulnerability increases to a peak of 30 properties in 1980and slowly declines thereafter. The increase to knowledge creates a reinforcing loop with policy entrepreneurs. The interesting result is that agenda density for mitigation is considerably higher in the middle of the run, despite having the same level of policy entrepreneurs during this period. The indicator of perceived risk reflects the increase to knowledge as well, which is higher than the base at the end of the run. Overall, the hazard mapping and vulnerability assessment policy is a good idea with limited benefit. It performs well to raise awareness and ensure the community develops with mitigation. This appears to be a policy mix that delays the problem, rather than solve it. Total damages are the same as the base run and vulnerability is still an issue. Essentially, researchers and vulnerability experts need help from other policy levers to accomplish their goals.

3.3.5 Moral Hazard / Protective Policies

What if incentives reduced the number of active stakeholders for relief and protective policies in the policy process?

Figure 15 Less Relief and Government Subsidies



1= total damage
2= vulnerable property
3= mitigated property

The less relief and government subsidies policy mix has rather odd behavior against the base conditions (Appendix B5). Mitigated property performs very well after the 1965 event but steadily declines from 1985 to the end of the run and finishes 50 percent lower than the base run. Vulnerable property follows a similar behavior by performing better than the base run in the first half but over time finishes 25 percent higher than the base. The behavior of damaged property is interesting. This is the first run where damage is incurred in the 1975 event and yet, there is no damage in 1995. As with the previous runs, there is more open space in the first half of the run but the situation slowly erodes during the latter stages. Perhaps the most interesting result is the behavior of structural mitigation projects. As the policy is designed, there is less commitment to structural mitigation projects, which explains why these projects are low after the

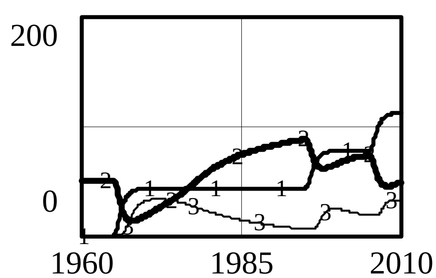
1965 event. However, when the 1975 event causes damage, mitigation projects stay constant until 1982 and then increase quickly and finish almost at the base run level.

By reducing the number of stakeholders for government subsidies, the agenda density for protective policies is low. Thus, the policy discussion shifts towards nonstructural mitigation policies, despite no change in the number of active policy entrepreneurs for mitigation. This creates what I would label a "quiet" agenda for mitigation, where research on knowledge on vulnerable property (see Appendix B5) increases between 1970 and 1985. During this period, the local government communicates knowledge to property owners, which increases perceived risk. Overall, this is an interesting run for several reasons. The middle of the run looks very good, almost all variables show signs of commitment towards mitigation between 1975 and 1995. However, as soon as this commitment fades, the stakeholders for land development apply pressure on local decision makers and the indicator of perceived risk finishes 50 percent below the base run. While total damages are approximately 20 percent lower than the base in this policy run, vulnerable property is higher and mitigated property and open space are lower. Despite strong results in the middle years, the less relief policy mix run does not produce optimal results. The property development variables show "better before worse" behavior, while the damage indicator reveals worse before better behavior.

3.3.6 Moral Hazard from structural mitigation

What if public information campaigns increased the memory of levee breaks and play down the level of structural protection?

Figure 16 Public Information when structures fail to protect



1= total damage
2= vulnerable property
3= mitigated property

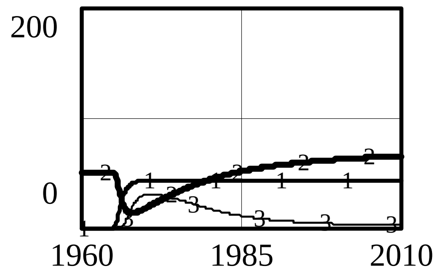
The behavior in the "structures fail" policy mix is very similar to the base run behavior (Appendix B6). Mitigated Property and Vulnerable property follow the same behavior pattern as the base run. The information campaign to play down the importance of structural projects increases perceived risk, especially after engineered solutions fail to divert flood waters in the 2005 event.

The benefit of the "structures fail" strategy is that it requires very little effort. However, this is primarily a reactive policy, as structures need to fail in order to activate feedback loops in this system. Therefore, it is relatively efficient, in that it requires little effort but not very effective, as reactive policies do not fit the tone of recent mitigation legislation (e.g, DMA 2000 and the 2004 amendment to the NFIP). However, this strategy could work if combined with another strategy that was designed to increase perceived risk. For example, when structures fail in 2005, perceived risk increased above its initial value and commitment to open space policies increased as well (see Appendix B6).

3.3.7 New Development Pressure

What if zoning regulations made land development stakeholders less active and less effective in the policy process?

Figure 17 Zoning Regulations



1= total damage
2= vulnerable property
3= mitigated property

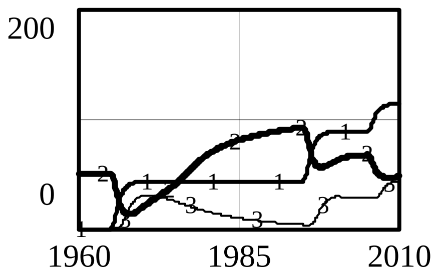
The zoning regulation policy mix addresses a very important issue in the National Flood Insurance Program. By restricting stakeholder pressure for development in flood-prone areas, local governments work towards several goals in the program. The flood-1 model replicates the behavior of a policy mix disaster experts have been supporting for the last 40 years. However, as with all regulatory policies, the zoning regulation policy mix is coercive and requires constant monitoring to sustain successful mitigation outcomes. Mitigated property and vulnerable property show similar behavior patterns as the base run (Appendix B7) but perform slightly better than the base levels. There is only one event that results in damage in this policy run. Total level accumulated damages are 50 percent less than the base run. Natural barriers remain strong for the entire run but the capacity of structural mitigation projects finishes 50 percent lower than the base.

The zoning regulation policy mix was difficult to analyze. This is one of those policies whose performance is relative to the criteria selected in the analysis. This policy mix performs very well when total damage is the basis of the analysis. However, this policy does not eliminate the problem; it only slows down the rates of development. Stakeholders for land development and stakeholders for government subsidies are less active during this run. The analysis shows some potential problems if this policy is used as a long term strategy. The indicator of perceived risk finishes 50% below the base run level. Knowledge of vulnerable property is zero for the entire run. The agenda density for mitigation is actually lower than the base run from 1980 to the end of the run. Overall, this policy is very effective. However, since this is a coercive policy it might not be the most efficient approach to mitigation. The community relies on the natural barriers as protection more than its engineered solutions. While there is still plenty of open space in the final years of this run, it appears development is steadily increasing. In this policy run, individual mitigation (i.e., floodproofing and elevation) is supplanted by zoning and open space. Overdevelopment could lead to very dangerous consequences for this policy strategy. With that said, the zoning regulations policy mix produces very effective results.

3.3.8 Property Tax Revenue Pressure

What if resources were provided to lower infrastructure costs and local problems associated with growing communities?

Figure 18 Property Tax Revenue Pressure



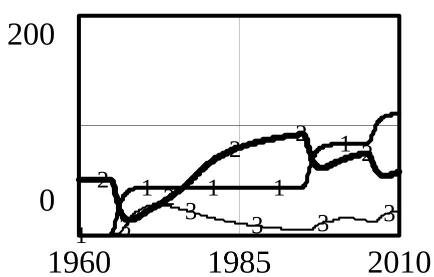
1= total damage
2= vulnerable property
3= mitigated property

The reduce property tax pressure policy mix has very little effect in the flood-1a community. In fact, the behavior of the indicator variables is nearly identical to the base run behavior (see Appendix B8). The flood-1a community is a community that does experience financial difficulty in the base run. The parameters in the flood-1 model can be reset to reflect financial trouble in poor communities (e.g., New Orleans). This run is included in this policy analysis to see where the flood-1a might benefit from additional resources. This policy mix might work best for the flood-1a community if used in conjunction with the structural mitigation policy mix, as this required additional local resources to maintain projects. With that said, the reduce property tax pressure mix is not very efficient in the flood-1a community, since the results are the same as the base run.

3.3.9 Tax Revenue for Recovery

What if recovery that used federal resources was required to redevelop with open space?

Figure 19 Recovery with Open Space



1= total damage
2= vulnerable property
3= mitigated property

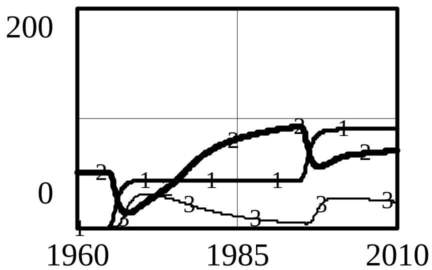
The recovery with open space policy mix is another reactive policy. It reflects the tone of government policies before the recent changes emphasizing pre-disaster mitigation. According to the GAO and FEMA, the NFIP is comprised of approximately 25% of policies with structures constructed Pre-FIRM (before the hazard maps). Many of these properties receive subsidized flood insurance, which decreases their incentive to relocate. Moreover, policy analyses conducted over the last 40 years show these structures to be the major category of RLPs (repetitive loss properties).

The behavior of the recovery with open space policy mix is similar for most indicators until the 1995 event. While the level of vulnerable property is approximately the same, the recovery after 1995 creates more open space, but less mitigated property. With that said, total damages in this policy run are equal to the base run. It appears that the total environment capacity of natural barriers finishes the run slightly better than the base run. Therefore, if this run were to be extended another 10 years we may see more positive results. Since this is a reactive policy, it does not restrict new development, which means the vulnerable property issue is not resolved. Overall, this policy mix performs slightly better than the base case by creating open space at the end of the run. This is a policy mix that would work better if it was combined with a pre-disaster mitigation strategy.

3.3.10 Natural Barriers

What if mitigation resources were used to replenish wetlands, beaches and other natural barriers that erode when land has been overdevelopment?

Figure 20 Restore Natural Barrier Protection



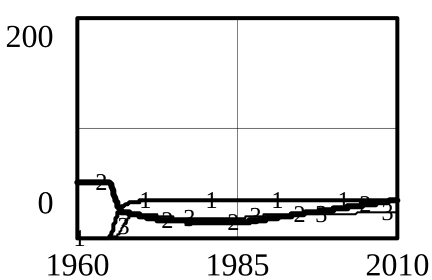
1= total damage
2= vulnerable property
3= mitigated property

Beaches and wetlands provide natural barriers for flood-prone communities. Overdevelopment on and near these barriers reduces their flood-protection capacity. The restore natural barrier protection policy mix includes beach replenishment and wetland restoration. This policy mix is somewhat controversial, as it often encourages unwise development in flood-prone areas. In the flood-1a community, the restore natural barriers policy mix has obvious benefits and potentially harmful unintended consequences. A damaging event in 1995 brings attention to problems with the natural barriers. While total development in this policy run is actually greater than the base run, the natural barriers are 150 percent stronger than the base in the final years of the run. In some ways, this policy resembles the structural mitigation strategy. Total accumulated damages are lower; there are no damages in the 2005 event. The benefits associated with this policy are measurable and clear. However, this policy mix creates another type of moral hazard. Perceived risk is lower at the end of the run and vulnerable property is greater than the base run value (Appendix B10). Overall, this policy is very dangerous, as it creates a sense of security in the community that may be false in a flood of record. The additional development also activates a reinforcing loop of spending; the community spends money to repair natural barriers that become damaged from development spurred on by the sense of security those barriers produce. Overall, this is a “proceed with caution” approach to mitigation; a controversial strategy according to most disaster experts.

3.3.11 Community Rating System (CRS) Policy Mix

What if the community enacted and implemented policies in all four categories promoted by FEMA in the community rating system?

Figure 21 CRS Policy Mix



1= total damage
2= vulnerable property
3= mitigated property

The CRS policy mix implements activities in the four main CRS categories: public information, mapping and regulations, flood damage reduction, and flood preparedness. This policy mix performs very well against the base run on every indicator used in this analysis (see Appendix B 11). While mitigated property finishes below the base level in 2010, its behavior is relatively consistent for most of the run. In fact, it is the only policy mix where mitigated property ends in equilibrium. Vulnerable property stays below the base run for the entire run and open space is well above the base in 2010. Most importantly, the natural barriers never erode during the CRS policy mix run.

This policy mix achieves its intended results. Policy entrepreneurs for mitigation are active and stay active; they promote the agenda for nonstructural mitigation and help produce knowledge on vulnerability. Stakeholders for protective policies are less active. The memory of damage from the 1965 event fades at a much slower pace, which helps maintain the indicator for perceived risk. Despite there being more stakeholders for land development, none of the events in the latter half of the run result in damage.

Overall, the CRS policy mix is the most effective policy tested in this analysis. However, the question remains whether it the most efficient policy mix. Several parameters must be changed in order to achieve the desired mitigation outcomes. With that said, the benefits are very clear. The flood-1a community does not overdevelop and the natural barriers are preserved. Enough attention is paid to structural mitigation projects to ensure they are maintained periodically. Damages are lower than any other run; the total accumulated damage is 25% of the base run total. In the final analysis, the flood-1a community resembles the ideal NFIP community.

3.4 Policy Analysis Summary

There are two policy analysis summaries provided in this section. The policy space summary shows the model behavior for 11 policies performing under base conditions and three scenarios. The second summary is a policy analysis “scorecard” that evaluates the policies based on a set of criteria.

3.4.1 Summary #1: The Policy Space

Figures 22, 23 and 24 show model behavior for total damage, vulnerable property, and mitigated property. The policy space expands beyond the analysis provided in section 3.3; these diagrams show model behavior for policies across all three scenario tests. It is beyond the scope of this paper to show the analysis for each scenario. However, it is interesting to note that several policy runs produce similar behavior, despite affecting different policy levers in the system. This summary was coded to compare model runs across scenarios. Section 3.4.2 shows the result of this analysis.

Figure 22 The Policy Space (page 1)

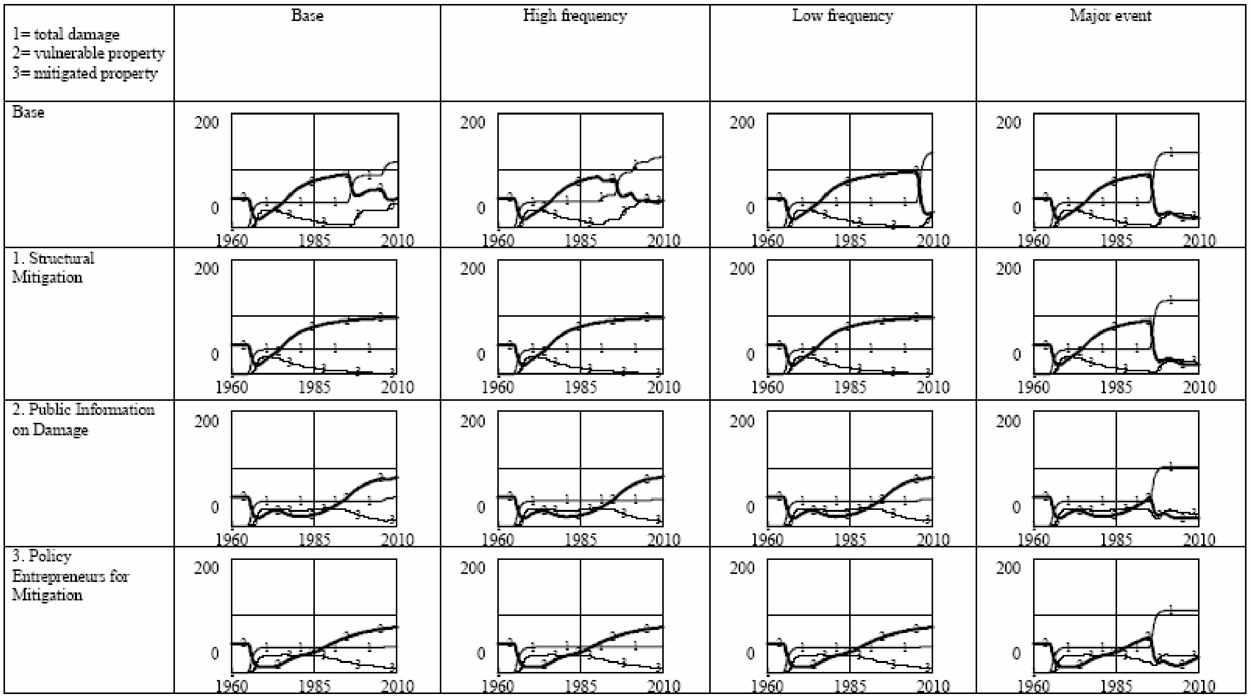


Figure 23 The Policy Space (page 2)

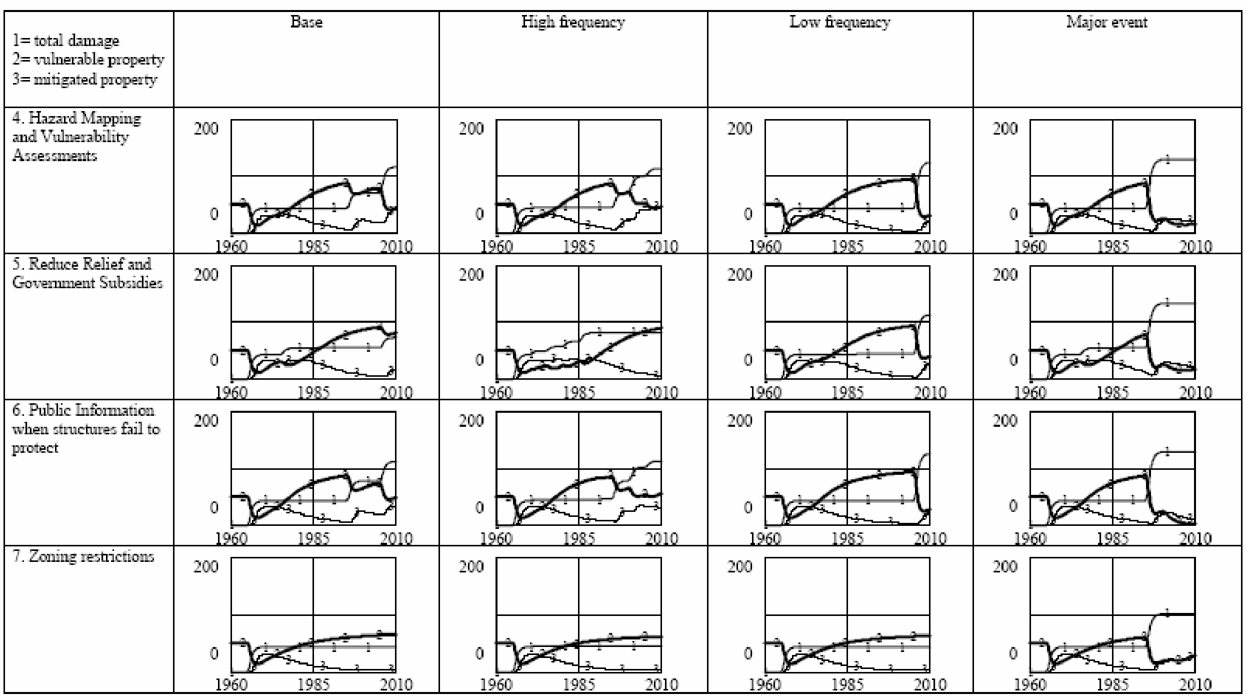
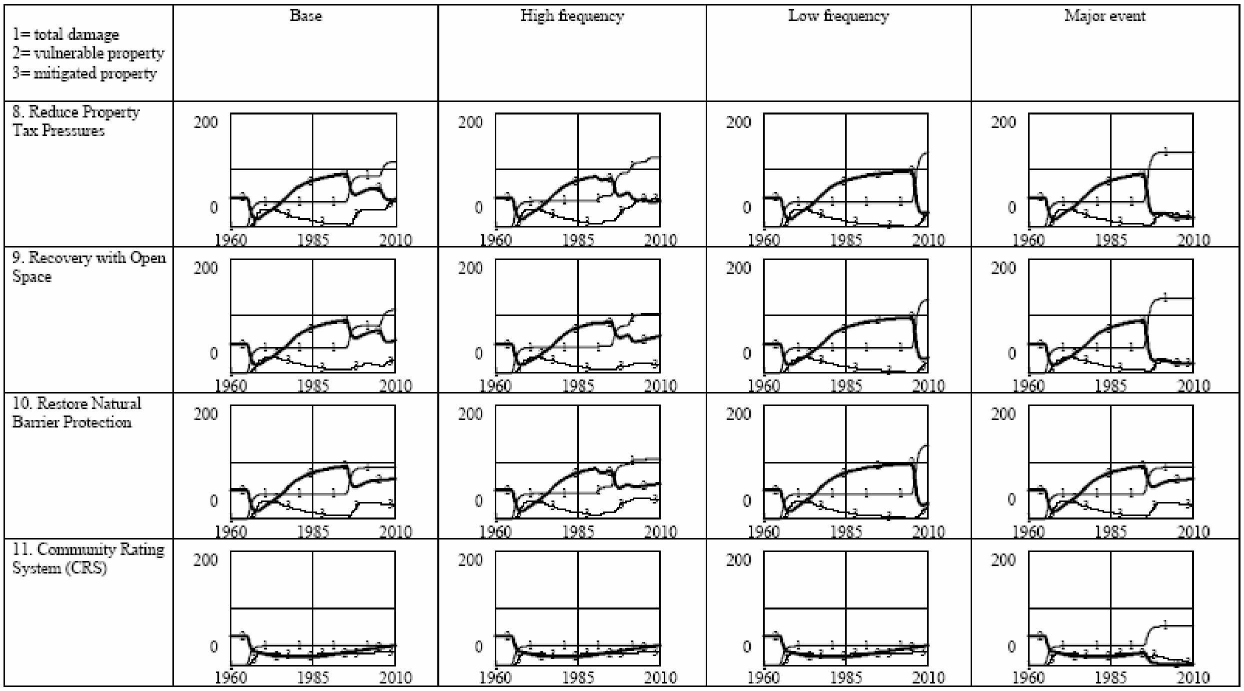


Figure 24 The Policy Space (page 3)



3.4.2 Summary #2: The Policy Analysis Scorecard

As I analyzed the behavior in the model, I noticed several instances where policies performed well in the first half of the run and poorly in the second half of the run. In addition, I observed there to be some policies that controlled vulnerability very well but resulted in relatively high damage and other policies that controlled damage but resulted in high vulnerability. Therefore, I created a two-by-two matrix for each policy run. The analysis produced four scores for the following categories: vulnerability in the 1st half of the run, vulnerability in the second half of the run, damage in the first half of the run, damage in the second half of the run. The policy runs were coded against the base run using the following coding scale:

+	policy run results were better than the base run
0	policy run results were equal to the base run
-	policy run results were worse than the base run
++	policy run was one of the best overall runs
--	policy performed very poorly relative to the base

Of course, some policies performed in ways that did not fit this scale accurately on the first pass. In some cases the policy had a "better before worse" behavior in one half of the run. This was identified with a +/- symbol. If the policy was only marginally better than the base case, it received a 0+ and if marginally worse it received a 0-. The table below shows the results of this coding.

Policy Analysis Scorecard for Flood-1a Model Runs	Base **1^{st} / 2^{nd}**		High Frequency 1^{st} / 2^{nd}		Low Frequency 1^{st} / 2^{nd}		Major Event 1^{st} / 2^{nd}	
Base **Property**	0	0	0	0	0	0	0	0
----------- **Damage**	0	0	0	0	0	0	0	0
1 Structural Mitigation	0	- -	0	- -	0	- -	0	0
	0	++	0	++	0	++	0	0
2 Public Information on Potential Damage	++	-	+	-	+	+/0	+	+
	0	+	0	+	0	+	0	+
3 Policy Entrepreneurs for Mitigation	+	-	+	-	+	+/0	+	+
	0	++	0	++	0	+	0	+
4 Hazard Mapping and Vulnerability Assessment	+	-/0	+	-/0	+	0	+	0
	0	0	+	0+	0	0	0	0
5 Less Relief / Government Subsidies	+	-	+	- -	+	0-	+	0/+
	-	+	-	+	0	0+	0/-	0
6 Public Info / Structures	0	0	0	0-	0	0	0	0+
	0	0+	0	0	0	0	0	0
7 Zoning Restrictions	0	+/-	+	+/-	0	+/-	0/+	+/0
	0	++	0	++	0	++	0	+
8 Reduce Property Tax	0	0	0	0	0	0	0	0

Policy Analysis Scorecard for Flood-1a Model Runs	**Base** **1st**	**/ 2nd**	High Frequency 1st	/ 2nd	Low Frequency 1st	/ 2nd	Major Event 1st	/ 2nd
Pressures	0	0	0	0	0	0	0	0
9 Recovery with Open Space	0	0-	0	0-	0	0	0	0
	0	0	0	+	0	0	0	0
10 Restore Natural Barriers	0	0-	0	0-	0	0	0	+/-
	0	+	0	+	0	0	0	+
11 Community Rating System (CRS) Policies	+	+	+	+	+	+	+	0+
	+	++	+	++	0+	++	0+	++

3.5 Conclusions

This paper shows how a system dynamics model can be used to analyze flood mitigation policies for a generic flood-prone community. In this paper, I have shown how the model structure explains the reference mode behavior for vulnerable property. I have shown how the model runs were analyzed and highlighted some of the interesting behavior I discovered in these runs. In addition, I presented a method for comparing policy runs across scenarios in a policy space. In the generic community designed for this research, the flood-1a community, the policy mix that used all four categories of CRS incentives performed very well against the base run condition. With that said, other policies achieved results in a more efficient manner. For example, the policy entrepreneur for mitigation policy mix and the zoning restrictions mix perform quite well and do not require as many policy levers to achieve their outcomes.

System dynamics compliments the policy analysis techniques used in disaster mitigation studies. The advantage of using system dynamics is that by looking at behavior over time the policy analyst can use several different types of criteria in the analysis. In the final analysis for this paper, I was able to evaluate vulnerability and damage across the early and late states of the policy run. By coding the results in this manner, my results can be compared with other studies that observe mitigation outcomes over time.

References

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