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## Dynamic Modelling of Local Government Wealth when Shocked by Natural Disasters

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# DYNAMIC MODELLING OF LOCAL GOVERNMENT WEALTH WHEN SHOCKED BY NATURAL DISASTERS

A Thesis

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Master of Science

in

The Department of Agricultural Economics and Agribusiness

by  
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B.S., Louisiana State University, 2011  
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To my parents Ingrid Ferrari Paz and Roberto Brevé Reyes. Every single step I take is to honor you, for with your love and support I have been able to overcome it all.

*Para mis padres Ingrid Ferrari Paz y Roberto Brevé Reyes. Cada paso que doy es para honrarles. Gracias a su amor y apoyo es que he podido contra todo.*

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## **ABSTRACT**

Hurricane Katrina struck the Gulf Coast as a Category 3 storm on August 29th of 2005. It is the costliest natural disaster in U.S. history. Communities across the country are increasingly at risk of being affected by natural and environmental disasters. The Public Assistance Grant Program (PA Program) administered by the Federal Emergency Management Agency (FEMA) is available for states and communities that have received a major or emergency disaster declaration. Most of Emergency Management (EM) research has focused on preparedness and mitigation activities; considerably less research has studied post disaster response. Two of the initial and most important aspects of disaster response and recovery operations are the removal and disposal of debris from the disaster-affected area. This study assesses local government's debris removal management decisions and how they impact their net wealth in the long run by using local government financial data from audited financial statements and post disaster data from the Louisiana Public Assistance database. Variables from transaction cost theory and similarity hypothesis are included as right hand side variables to explain the choice of outsourcing versus internal procurement of debris removal. A System Dynamics model is then built using the regression results and it incorporates debris removal decisions in the context of assumptions about future storm characteristics (i.e. frequency and severity) as well as the current capital and debt financial accounts of a rural parish government in Louisiana.

# **CHAPTER 1: INTRODUCTION**

## **1.1 Background**

Hurricane Katrina struck the Gulf Coast as a Category three storm on August 29, 2005. It is one of the most powerful and costliest natural disasters in U.S. history (Knabb, Rhome, & Brown, 2005). After levees and flood walls protecting the city of New Orleans failed, about 80% of the city was underwater (Graumann et al., 2006). While rising sea levels from global warming are putting coastal areas at greater risk, studies predict that powerful storms may occur more frequently this century (Bister & Emanuel, 1998). After the devastation incurred by Hurricane Katrina, it was evident that the United States' public-private system for addressing risk was very weak. The federal aid being received was not coordinated effectively, and a vast majority of the residents were not willing to commit to rebuilding (Gosselin, 2006). During Hurricane Katrina, there were many steps to take and the response was slow. Lessons learned from Katrina resulted in many changes to disaster management policy in the country.

The Stafford Disaster Relief and Emergency Assistance Act (2013) has been continuously amended and today serves as a guide for local governments to be more resilient to disasters. The Public Assistance Grant Program (PA Program) administered by the Federal Emergency Management Agency (FEMA) is available for states and communities that have received a major or emergency disaster declaration. A major disaster declaration is requested by a governor based on the disaster assessment in his or her state, and an agreement is submitted to commit state funds and resources to the long-term recovery. FEMA evaluates the request and recommends action to the White House based on the severity of the disaster and the local community and state's ability to recover.

In some instances, the costs taken may exceed the minimum federal threshold of damages required for federal financial assistance, but the opposite could also be the case. There is a state threshold and a county threshold, both determined by applying a per capita cost factor. For 2015, the state cost factor (for all 50 states) was \$1.41 per capita, which gives Louisiana (4.7 million population) a threshold of about \$6.6 million. Only if costs exceed this amount will the state qualify for public assistance. Once the state meets the threshold, the county threshold is then taken into consideration. After the most recent devastating tornadoes (2017), Louisiana did not meet the state threshold, and as a result, could not receive public assistance. The county threshold for 2015 was \$3.56 per capita (Louisiana Governor's Office of Homeland Security and Emergency Preparedness, 2015). The same process for state is applied at the county level. For example, East Baton Rouge Parish, Louisiana, with 440,171 population (U.S. Census Bureau, 2015), will have a threshold of \$1.6 million.

Communities across the country are increasingly at risk of being affected by natural and environmental disasters. In recent research it has been found that warmer ocean temperatures, caused by climate change, may be fueling stronger hurricanes, while at the same time, creating fewer storms (Kang & Elsner, 2015). Coastal communities, businesses, farmers, fisheries, and local governments across Louisiana struggled to recover financially from Hurricanes Ivan, Katrina, Rita, Gustav, Ike and Isaac, the 2011 Mississippi River flooding, and the 2016 North and South Louisiana Floods. Local governments must be better prepared to finance a larger percentage of their own cleanup and recovery costs that climate change induced natural disasters create (Fannin, Mishra, & Franze, 2014).



## **1.2 Problem Definition**

The PA Program was most recently amended by the Sandy Recovery Improvement Act of 2013 (Division B of P.L. 113-2, SRIA). FEMA is now able to implement a Public Assistance Alternative Procedures (PAAP) Pilot Program. These procedures revise a different set of elements of the PA Program, such as increasing the federal share of eligible costs when debris is removed in less than 90 days and retaining recycling revenues (Federal Emergency Management Agency, 2016b). Focusing on the Debris Management Pilot program available through June 27, 2017, the Sandy Recovery Improvement Act of 2013 (SRIA) (P.L. 113-2) authorized FEMA to provide a different set of incentives to state, tribal, or local governments, or owner or operator of a private nonprofit facility to have a debris management plan in place and accepted by FEMA prior to the declaration of a major disaster or emergency declaration (Federal Emergency Management Agency, 2016b). The content of each plan will vary depending on state, tribal, and local ordinances. The disaster management plan has to include the following twelve elements: debris management overview, events and assumptions, debris collection and removal plan, debris disposal location and management sites, debris removal on private property, use and procurement of contracted services, use of force account labor, monitoring of debris operation, health and safety requirements, environmental regulations and other regulatory requirements, public information, and identification of one or more prequalified debris removal contractors (Federal Emergency Management Agency, 2016b, p. 7). Once the plan is approved, there is a possibility for the cost share adjustment to increase for the first 90 days of debris removal activities. If debris is removed in the first 90 days then the federal share of 75% increases by 5% or more (Federal Emergency Management Agency, 2016b) as can be seen in Fig.1.1. Accurate coordination of debris removal activities is then an important factor to consider when constructing these plans.

The pilot program also provides incentives to recycle by allowing local governments to retain revenue from the sale of disaster debris. The income from this activity can only be used to increase resiliency to future natural disasters. Another major incentive is use of a public jurisdiction's own labor force to perform all or part of removal operations. FEMA will reimburse at the appropriate cost share level, the base and overtime wages for existing employees and hiring of additional staff (Federal Emergency Management Agency, 2016b, p. 6).

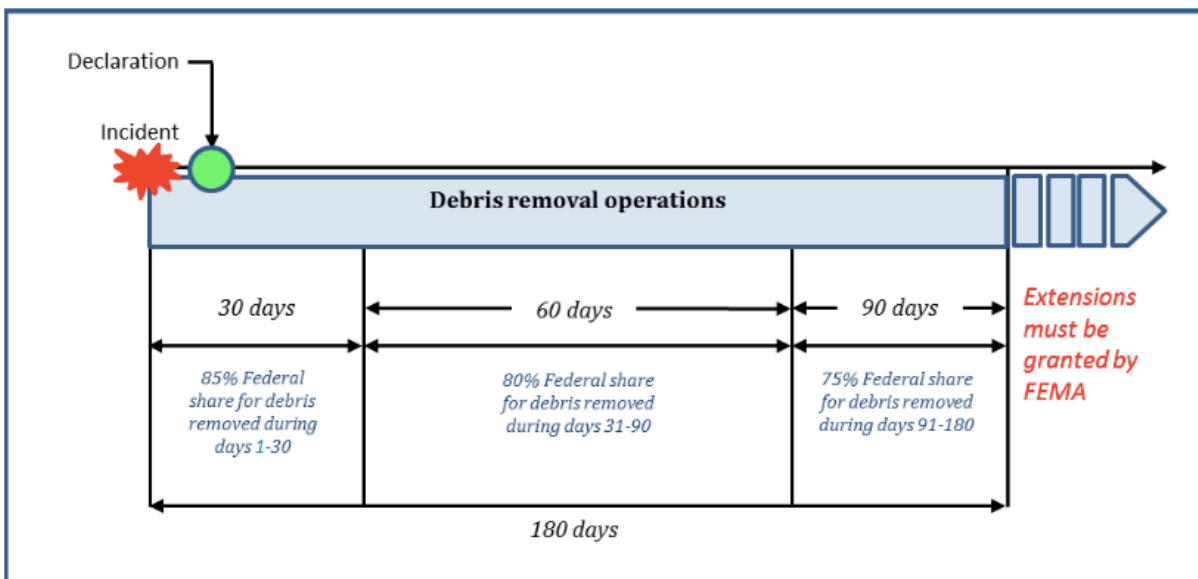


Figure 1.1 FEMA Pilot Program Debris Removal Reimbursement Timeline.

Note: Reprinted from Public Assistance Alternative Procedures Pilot Program Guide for Debris Removal (Federal Emergency Management Agency, 2016, p.5)

It is a problem then that most local governments in Louisiana have not completed or received approval for their debris management plans and are not actually obliged to follow it in case a disaster strikes (Jones, 2015). A local government may rely on their own resources to clean up debris, but when facing an overwhelming debris-creating disaster, they will need other private firms to complete the task. If the debris cleanup, removal, and disposal are not properly planned, the transition between public and private management can cause significant problems and result in increased costs associated with the overall debris operation (Swan, 2000).

On average, debris removal accounts for about 27 percent of the incurred costs during disaster relief from federally declared storms (Federal Emergency Management Agency, 2007, p. 43). In the case of less severe disasters that are not federally declared, there are still debris removal costs that are incurred and must be paid. Unfortunately, 100% of these costs must be covered by the respective state, tribal and/or local government jurisdiction in which the debris is located.

Although disaster and debris management plans may seem complete, there are always some factors that are very difficult to incorporate. There is a need of coordination among all public and private entities to insure appropriate plan implementation (Harrington, 2006). In the case of a vulnerable region like Louisiana, it is difficult to understand why some local governments and communities underprepare for hazards with measurable risk. Humans learn by experience and in the case of high consequence, low probability disasters, this learning method can be extremely costly. A reason might be that as Meyer (2006) discusses, people tend to underestimate consequences from disasters that they have not yet experienced. Even if they do experience catastrophic damages, they will try to forget about it and move on, expecting the event will never happen again.

The public sector needs a more systematic approach to debris management to improve decision making around disasters and increase the financial resilience of these local jurisdictions. As they do, they will be able to make progress in addressing the compelling slate of issues that challenge their viability.

### **1.3 Research Questions**

The following research questions will be addressed in this study:

- (1) What is the optimal debris removal method based on resources available and community attributes?

- (2) How can local governments (parishes) efficiently analyze the impact of debris management policies on their public wealth?

#### **1.4 Objectives**

This study assesses the resiliency of local governments in Louisiana when shocked stochastically by natural disasters, addressing specifically optimal debris management procedures. This will be achieved through the following specific objectives.

- (1) Estimate a regression model for optimal local government debris management decisions using post-disaster expense data.
- (2) Evaluate the implications of optimal debris management decision making applying a systems dynamics (SD) modeling framework.

#### **1.5 Accomplishment of Objectives**

Chapter 2 is focused on estimating a regression model for optimal local government debris management decisions using post-disaster expense data from Hurricane Katrina (2005), Hurricane Rita (2005), Hurricane Ike (2008), Hurricane Gustav (2008), and Hurricane Isaac (2012). It includes a review of literature of post disaster response and recovery procedures. The main debris management decision of interest is that of outsourcing debris expenses. The analysis will be accomplished through applying the theoretical frameworks of Transaction Cost Theory (Williamson, 1996) and the Similarity Hypothesis (Barnes, 2005). Williamson highlights that specific attributes of the outsourcing transaction (asset specificity, frequency, and uncertainty) condition the decision to outsource. Barnes argues that past outsourcing decisions determine if a local government outsources in the present. The empirical model presented analyzes the conditioning effect of past outsourcing decisions, landfill ownership, parish characteristics, and storm attributes on percent outsourced in the future. The regression results are then used in Chapter

3 to project the percent outsourcing of debris for a given local government in a given future tropical disaster scenario.

Chapter 3 evaluates the implications of optimal debris management decision making applied to a system dynamics (SD) model. An optimal debris management policy, in this case, is the one that allows the local government to recover public wealth levels to original conditions in the least amount of time. Literature suggests that SD is an efficient sensitivity tool for planning (Forrester, Mass, & Ryan, 1976; Roberts, Andersen, Deal, Garet, & Shaffer, 1983). It has been applied to model disaster event scenarios as flooding, and earthquakes (Ramezankhani & Najafiyazdi, 2008; Rivera-Royero, Galindo, & Yie-Pinedo, 2016).

The SD model built in this research assesses relationships between local government 's wealth and specific debris management policies through time. The model incorporates debris removal decisions in the context of assumptions about future storm characteristics (i.e. frequency and severity) as well as the current capital and debt financial accounts of a rural parish government in Louisiana.

## **1.6 Arrangement of Thesis**

The remainder of this thesis will be organized into the following sections. Chapter 2, “Optimal Debris Management”, accomplishes the first objective. Chapter 3, “Using System Dynamics for Optimal Debris Management”, undertakes the second objective of this thesis. Finally, Chapter 4 provides a summary that highlights the main findings and policy implications.

## **CHAPTER 2: OPTIMAL DEBRIS MANAGEMENT**

### **2.1 Introduction**

The National Response Framework (NRF) was created in response to the terrorist attacks of September 11, 2001. The NRF includes all processes from prevention to recovery of an emergency situation. To more effectively respond to a disaster, the NRF establishes the overall guidelines and procedures to respond to life threatening emergencies and establish a safe and secure environment moving toward recovery (U.S. Department of Homeland Security, 2013, pp. 1-4).

As response activities are ongoing, recovery operations must begin as established by the NRF (U.S. Department of Homeland Security, 2013). An important but often largely overlooked phase among the post-disaster activities is managing the resulting debris. The current trend in disaster management policy is for local governments to be more independent at mitigating, responding and recovering from a disaster. Federal Emergency Management Agency (FEMA) encourages state and local governments, tribal authorities, and private non-profit organizations to include a proactive debris management plan as part of their overall emergency management plan. Communities with a well-structured debris management plan should be able to more efficiently restore public services and ensure the public health and safety after a disaster.

The core components of a comprehensive debris management plan incorporate the best practices in debris removal as suggested by FEMA, reflect FEMA public assistance eligibility criteria, and are built to meet the needs and unique conditions of each applicant (Federal Emergency Management Agency, 2007). The objective of this research is to identify the main factors that condition debris management, specifically that of outsourcing or using own resources for debris cleanup operations. This analysis aims to identify optimal debris removal strategies from

different scenarios that a local government could face when affected by a debris-creating natural disaster.

In the remainder of the paper, an outsourcing model is constructed based on literature from the Similarity Hypothesis (SH) and Transaction Cost Theory (TCT). The SH argues that decisions made in the past condition those made in the present and TCT explains that specific contract attributes (asset specificity, frequency, and uncertainty) determine the type of transaction to be made. An empirical model is then constructed based on proxies for variables in the theoretical model as well as for storm and community characteristics. Empirical results and implications for future research and policy are finally discussed. Results from this chapter will be used to model different dynamic policy scenarios in Chapter 3.

## **2.2 Literature Review**

Most of Emergency Management (EM) research has focused on preparedness and mitigation activities. Considerably less research has studied post disaster response. Fetter (2012) discusses that initial and most important aspects of disaster response and recovery operations are the removal and disposal of debris from the disaster-affected area. Moreover, the problems and challenges of debris management have been explored in the literature mostly through case studies of specific events. For example, Roper (2008) examines debris and waste management activities and policies involving the cleanup from Hurricane Katrina. Through very detailed research, he confirms the importance of debris disposal planning and cleanup operations in order for optimal resource allocation. Others have observed or studied debris and waste management surrounding earthquakes, hurricanes, landslides, and wars, also emphasizing the importance and the need for debris management planning (Emerson, 2004; Roper, 2008; Wei, Hu, Cui, & Guan, 2008). As societies become more complex, so does the type of debris created from disaster events. Debris

types range from usual vegetation and construction materials to very hazardous waste (e.g., industrial chemicals). Brown et al. (2011) reviewed a vast amount of disaster waste management literature and concluded there is a gap between all the different proposed debris planning guides and the possible impacts. Their review addresses planning, waste management and treatment phases, social considerations, environmental impacts, economics, organizational legal framework, and funding of more than thirty disaster events. They urge for more comprehensive disaster waste management research.

Quantitative studies involving disaster debris management as it affects the public wealth of a local government are few. Most of the literature refers to mitigation efforts that do not necessarily address wealth shocks. For example Wei et al. (2008) propose a hazard mitigation decision support system using simulation to predict debris flow movements in the event of a landslide. On the other hand, Fetter and Rakes (2012) address specific disaster relief procedures which could be linked to financial effects on local governments. In their research, they incorporate recycling into post disaster debris disposal plans to potentially earn income as established by the Debris Removal Pilot Program. Most recently Lorca et al. (2016) created an optimization-based decision support tool for post-disaster debris operations that is similar to the model proposed by Fetter and Rakes, but also includes decisions on specific steps from sorting and processing capacity. Similar to Lorca et al. (2016), this research is an initial effort to create a user friendly interface that allows policy makers to be more informed about the possible financial implications of debris management decisions based on a retrospective analysis on past debris management decision making.

A lack of planning for disaster relief operations can have a toll on a local government's public wealth. Current literature on the economic impact of disasters shows contradictory results.



Some suggest that major storms cause temporary disruptions in economic activity followed by a short-term boom period as the region engages in rebuilding efforts (West & Lenze, 1994). This positive effect in economic activity can be attributed to reconstruction financed largely from extra regional sources, such as insurance claim payments and federal disaster funds (Burrus Jr, Dumas, Farrell, & Hall Jr, 2002). However, it is important to recognize that affected local governments in some cases do not meet the disaster fund threshold to be considered beneficiary of federal disaster funds (Fannin & Detre, 2012). In this case and others studied by Burrus et al. (2002), even a ‘low intensity’ hurricane may still be able to cause substantial damage.

Natural disasters have a negative impact on wealth as studied by Guimaraes et al. (1993), although major surges in construction, retail, and other sectors were perceived. In one of the most affected sectors of South Carolina, agriculture and forestry, the income gained remained below the unreimbursed wealth loss. Impacts of disasters on local governments are then very dynamic and dependent on several factors. The major goal of local governments after being shocked by a disaster is to fully recover to original conditions. Baade et al. (2007) suggest that public money will still be necessary especially in areas where insurance settlements will be slow to return.

## **2.3 Conceptual Framework**

A basic premise of public economic analysis is that a local government seeks to efficiently allocate resources (Atkinson & Stiglitz, 2015). Further, Transaction cost theory (TCT) explains how local governments may efficiently coordinate economic transactions. When the external transaction costs (outsourcing) are higher than the internal transaction costs (self-procurement), a firm will self-procure. If the internal transaction costs are higher than the external transaction costs, the firm will outsource. TCT assumes that firms pursuing a transaction choose the optimal arrangement that minimizes transaction costs (Williamson, 1996). Those costs include ex-ante

costs of contract negotiation as well as ex-post costs of monitoring and enforcement of the contract. Based on the behavioral assumptions of imperfect knowledge and opportunistic behavior by one or both parties, the attributes of the contract (asset specificity, frequency, and uncertainty) will result in a specific form of the transaction being chosen (Fannin et al., 2014, p. 4).

Alternatively, the similarity hypothesis (SH) argues that if one had organized contracts of similar types in the recent past, one is more likely to use similar procurement arrangements in future transactions (Barnes, 2005). The primary reason for use of a similar procurement arrangement is that the organizations are familiar with the contract structure, development and costs (Fannin et al., 2014, p. 4).

This study is an attempt to estimate the self-procurement versus outsourcing decision based on the behavioral assumptions of TCT and SH as described by Equation 2.1.

(Eq. 2.1) *Outsourcing* =  $f(\text{asset specificity, historical outsourcing, storm and community shifters})$

It is expected that parishes and municipalities that maintain large investments in assets specific for disaster debris removal will more likely self-procure. SH suggests that local governments that developed debris removal contracts with outsourced third party contractors are more likely to use outsourced third party contractors in the future (due to reduced costs of re-writing and enforcing similar contracts). If the parish has historically outsourced, it is more likely they will also outsource in the present disaster event. These contract-specific theoretical variables are hypothesized conditional on community and storm level shifters. For instance, the more severe storms in highly populated regions could create considerable amount of debris that would surpass the parish's capacity to self-procure that may require higher levels of outsourcing for all levels transaction specific assets.

## 2.4 Empirical Model

This study uses the Transaction Cost Theory (TCT) and the Similarity Hypothesis (SH) to model debris removal and cleanup management decisions. The empirical model is shown in Equation 2.2.

$$(Eq. 2.2) O_{rj} = f(P_j + O_{aj} + O_{pj} + W_{rj} + AV_{rj} + SC_j)$$

In Equation 2.2,  $O_{rj}$  is the percent total debris outsourced in the most recent storm ( $r$ ) by parish  $j$ . In reality, many parishes use a combination of internal debris removal procurement and contracted services. For example, many parishes will internally procure vegetative and constructive debris removal from roadways, but may outsource the removal of stumps or the “reduction” of debris through composting or incineration. Further, local governments, due to the amount of debris removal, may externally contract for a portion of these services. This dynamic scenario will be analyzed in Chapter 3.

The variable  $P_j$  (public landfill) is related to the transaction attribute of asset specificity as explained by TCT.  $P_j$  is a binary variable that identifies if the closest landfill to the parish ( $j$ ) core is publicly owned. If the parish owns the public landfill, then they are required to be certified in the processing of different types of disaster emergency debris. The sunk cost associated with this certification should make it more likely for local governments to self-procure the processing and disposal of their own post disaster debris in their own landfills to compensate for these sunk costs.

In the case of the SH, the variables  $O_{aj}$  and  $O_{pj}$  are proxies to the effect of historical disaster expense decisions on the most recent case. All parishes affected by at least one storm were included in the study. The %  $O_{aj}$  variable is the percent outsourced by parish  $j$  in all past storms (prior to storm  $r$ ). The higher the percentage outsourced in previous storms, it is expected that a parish will outsource high percentages of debris removal in future storms based on the SH. The binary variable

“no past storm”,  $O_{pj}$ , is used as an indicator variable to determine if the parish ( $j$ ) observation has a past record<sup>1</sup>.

The most recent disaster characteristics were used in Equation 2.2 for the storm attributes. Max wind,  $W_{rj}$ , is the maximum wind reading during storm  $r$  in the observed parish  $j$ . The highest measured wind speed was used assuming that at that instant, debris is most likely created. The higher the wind speed, the more debris/destruction will be created, and as a result, the parish might not have the capacity to clean up to initial conditions in a timely manner. As a result, the parish government is more likely to outsource.

For community attributes  $AV_{rj}$  is the per capita assessed-value of parish  $j$  during the year of storm  $r$ . Per capita assessed valuation is an estimate of the per capita financial value of the private and public utility assets of a parish. High per capita assessed value could be related to more industrial development that could lead to different types of debris creation (hazardous and construction). Debris that requires special processing might require third party involvement. Also, higher per capita assessed value may be associated with physical assets that generate higher economic returns. Consequently, high opportunity costs associated with reduced economic returns may result in desiring a more rapid debris removal typically affiliated with outsourcing.

Social capital,  $SC_j$ , as constructed by Rupasingha et al. (2006) serves as a proxy of community engagement when affected by disaster events. Social capital has been perceived in recent research as having an important influence on the ability of a community to prepare and respond to disasters. Following Hurricane Katrina, Hawkins and Mauer (2009) studied the different types of social capital (bonding, bridging and, linking) using a qualitative approach by

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<sup>1</sup> Chetty et al.(2014) also use this technique to control for the absence of past information in their dataset.

examining 40 families in New Orleans, Louisiana. They identified bonding as important for immediate support, but bridging and linking offered longer term assistance. In the case of post disaster debris management, higher social capital might suggest that the local community will be the first to respond and engage in the initial stages of debris clean up. An extension of that immediate response is that parishes with high social capital might also prefer using their own labor and equipment to process and dispose debris as opposed to outsourcing to private debris removal contractors that are more likely to come from outside the parish.

Finally, Rurality,  $R_j$  is the percentage of the population of parish  $j$  that live in rural areas. This variable is used as a control for other unknown or unmeasurable characteristics that rural areas have that might influence the debris removal outsourcing decision. A summary of expected signs of the variables are presented in Table 2.1.

Table 2.1 Summarized expected effects of the explanatory variables

Variable	Symbol	Expected Sign
Transaction Cost Theory		
Public Landfill	$P_j$	(-)
Similarity Hypothesis		
Past Outsource	$O_{aj}$	(+)
No Past Storm	$O_{pj}$	Indicator
Storm and Community Attributes		
Max Wind	$W_r$	(+)
Rurality	$R_j$	No Exp.
Per capita assessed value	$AV_j$	(+)
Social Capital	$SC_j$	(-)

## **2.5 Methods and Procedure**

### **2.5.1 Data**

The data requirements of this research primarily include post disaster expense data extracted from Louisiana Public Assistance database assisted by the Louisiana Governor's Office of Homeland Security and Emergency Preparedness (LAGOHSEP). The expense data of each federal declared disaster includes parish information, applicant (institution), project category (A-H), type of expense (contract work summary, invoice, force account labor, force account equipment, material invoice, rented equipment or unknown), eligible amount, work status, and other more general details. For the purpose of this research, only category A (debris removal) projects were extracted. The other PA project categories are: Emergency protective measures (B), roads and bridges (C), water control facilities (D), public buildings and contents (E), public utilities (F), and parks, recreational, and other facilities (G). The different types of expenses for debris management were identified as either outsourcing, self-procurement or unknown. Contract work summary, invoice, and rented equipment were in general classified as outsourcing expenses and force account labor, force account equipment, invoice<sup>2</sup>, and material invoice as self-procurement. Some of the unknown data and other observations that had no classification could be identified as either outsourcing or self-procurement by accessing more specific descriptive elements in the project's worksheet. Each of the applicants must submit substantial information regarding need of public assistance and detailed proof of expense in the project worksheets. All projects from the different applicants were aggregated by parish of origin. Altogether 98 observations pooled across multiple storms of debris removal expense data were collected from a subset of federally declared

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<sup>2</sup> In several cases it was necessary to extract more information on the type of expense from the project worksheets, even if it already had an identification.

disasters in Louisiana. The storms covered included Hurricanes Katrina and Rita (2005), Gustav and Ike (2008), and Isaac (2012). The parishes affected had a larger variance of impact within the same storm, that is, some local governments had high amounts of debris to be disposed while others had less.

Data for the maximum winds were extracted from publicly available data from the H\*Winds project of the Hurricane Research Division. The H\*Winds<sup>3</sup> project conducted an ex-post analysis of wind fields of active storms that made landfall in the United States between 1993 and 2014 (Hurricane Research Division, 2014) . Shape files<sup>4</sup> were available as free downloads from which one square mile grid maximum wind speeds for given named storms can be estimated. These data were used to calculate the max wind speeds recorded for each of the parishes.

Per capita assessed value (CPI adjusted to 2011) was calculated using the parish assessed value extracted from the Louisiana Tax Commission Annual Report (2012) for the years of 2005, 2008, 2011 and 2012 and its respective population estimates from U.S. Census Bureau (2010). Parish landfill ownership came from solid waste landfill information extracted from Louisiana Department of Environmental Quality (Louisiana Department of Environmental Quality, 2015) online database. The parish level social capital indices used are the ones constructed by Rupasingha et al. (2006). This particular measurement has become more popular as a proxy for social capital among economists such as the work by Chetty et al. (2014). Population living in rural areas and rurality, was extracted from the U.S. Census Bureau (2010) for 2008. The

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<sup>3</sup> Most analyses were conducted in real-time. As a result, the storm positions are typically extrapolated from earlier data and therefore not accurate. There are known error in some of the data coverage, mapping and gridded products. This data set is still considered reliable by the industry standard.

<sup>4</sup> Appendix A shows an example of the maximum 1-min sustained surface winds (kt) map constructed by h\*winds.

measurement of rurality for 2008 more accurately describes the population in rural areas for each of the studied events (2005, 2008, and 2012). Because of minimum variation in this variable, it was chosen not to be varied across time.

### 2.5.2 Descriptive Statistics

The 98 observations came from 40 of the 64 total parishes in Louisiana. These data only include parishes that have approved debris removal expenses from Hurricanes Katrina, Rita, Gustav, Ike and/or Isaac. For best track positions for the studied hurricanes see Appendix B.

Past outsourced is the aggregated percent outsourced from all past events<sup>5</sup>. Table 2.2 shows the case of East Baton Rouge parish with debris expenses from Hurricanes Isaac, Gustav, and Katrina.

Table 2.2 Percent Outsourcing calculation for East Baton Rouge Parish<sup>6</sup>

% Outsourced Recent Storm		% Outsourced Aggregated Past Storms		
		No	Katrina	Gustav
Hurricane Katrina	18.16	No	-	-
Hurricane Gustav	96.54	-	18.16	-
Hurricane Isaac	97.60	-	75.51	

Each of the storms at one point can be considered the most recent storm. In the case of Hurricane Katrina (the first disaster in the dataset), there is no past storm recorded for all observations affected by this disaster event. The Public Assistance Program does not have

<sup>5</sup> Using this aggregated outsourcing percentage from past storms assumes there is no depreciation of knowledge about contracting from previous storms. However, without knowledge of the turnover of finance and emergency response personnel in these parishes, it would be difficult to estimate a depreciation rate on historical disaster contracting knowledge. Given that the time window between the last storm in the model (Isaac) and the first storm (Katrina) was only seven years, it can be argued that this is likely a reasonable assumption.

<sup>6</sup> Table created using debris expenditure data from Louisiana Public Assistance Platform.



federally declared expenses reported on their LouisianaPA.com platform before Hurricane Katrina. There were a total of 41 of the 98 observations that did not have a past storm debris expense.

Table 2.3 describes the storms included in this research as published in each of the tropical cyclone reports (Knabb, Brown, & Rhome, 2005) . All of the storms had high winds for at least some regions of the state that created substantial damage. In this research, the maximum wind speed recorded at each of the observed parishes was included in the model. It is assumed that the most debris were created at this maximum wind reading.

Table 2.3 Description of Hurricanes Impacting Louisiana from 2005-2012

Hurricane	Date of formation to dissipation	Federal Declaration	Maximum Sustained Surface Winds <sup>7</sup>	Category
Katrina	08/23/2005 – 08/31/2005	08/29/2005	127 mph	C3
Rita	09/18/ 2005-09/26/2005	09/24/2005	127 mph	C3
Gustav	08/25/2008 - 09/07/2008	09/02/2008	97 mph	C2
Ike	09/1/2008 - 09/14/ 2008	09/13/2008	109 mph	C2
Isaac	08/21/2012 - 09/1/ 2012	08/29/2012	80 mph	C1

Note: Data retrieved from respective Tropical Cyclone Reports created by the National Hurricane Center team (Berg, 2009, 2013; Beven II & Kimberlain, 2009; Knabb, Brown, et al., 2005; Knabb, Rhome, et al., 2005).

Table 2.4 shows the descriptive statistics of the dependent and independent variables for Equation 2.2. On average, the affected parishes by major hurricanes outsourced approximately 67% of debris expenditures.

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<sup>7</sup> Maximum sustained surface winds are estimated from observations from selected land stations and other weather data collected during the disaster event. These values may vary significantly from the real time measurements from the H\*Winds project database.

Table 2.4 Descriptive Statistics

Variable	Mean	Std. Deviation	Min	Max
<b>Dependent Variable</b>				
Outsourced Recent Storm %	67	40.27	0	100
<b>Independent Variables</b>				
Public Landfill	0.35	0.48	0	1
Past Outsourced %	43.97	46.05	0	100
No Past Storm	0.41	0.49	0	1
Max Wind (mph)	62.91	17.45	27.44	113.03
Rurality (%)	36.16	27.66	0.59	100
Per capita assessed value (\$)	10,376.19	7,546.897	3019.35	40378.34
Social Capital	-0.74	0.54	-1.81	0.25

There were 66 observations where more than 50% of debris removal was outsourced. The studied parishes had on average 36.16% of their population residing in rural areas. For parishes in Louisiana, the social capital index ranged from -1.8 (St. Bernard) to 0.25 (St. James). Figure 2.1 shows the Social Capital Index for 2009 in Louisiana. The parishes in the Northern region of the state tended to have higher social capital as compared to the South. Social capital is not homogeneously distributed at one particular value throughout the state of Louisiana. There are some parishes with high social capital located in the North as well as in the South. Additionally, in South Louisiana, large urban parishes (e.g. East Baton Rouge and Orleans) have very high social capital and so do some more rural parishes (e.g. Cameron and Franklin).

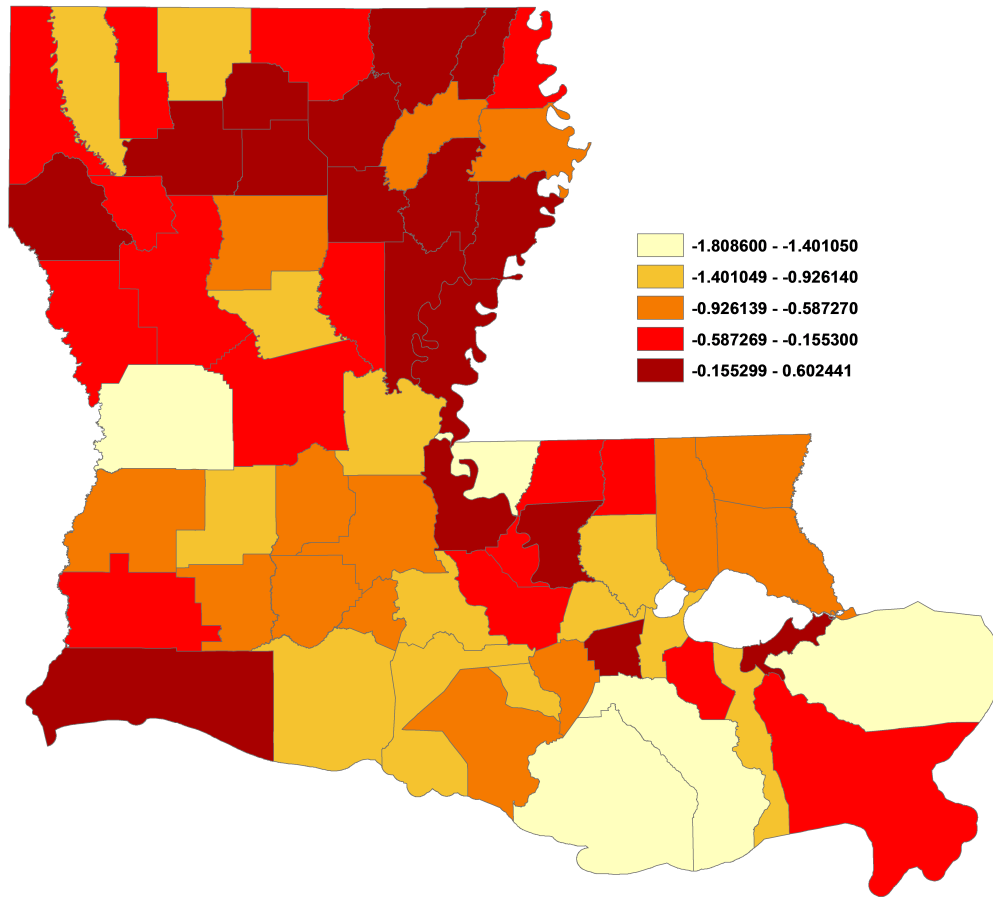


Figure 2.1 2009 Social Capital Index for Louisiana. Data from Rupasingha et al. (2009)

The correlation factor between the social capital index and rurality is 0.197 (Table 2.5) suggesting little relationship between social capital and rurality within the Louisiana parishes studied. Rural places are not necessarily a homogenous group of places that act similarly. They should be thought of as a collection of functional characteristics as described in the wealth creation framework. Hence, scholars should focus on controlling for specific functional characteristics in addition to adding a rural indicator for accounting for unknown or unmeasurable characteristics (T. G. Johnson, Raines, & Pender, 2014).

Table 2.5 Pairwise Correlation Matrix of Explanatory Variables

	Public Landfill	Past Out	No Past	Max Wind	Ruralit y	Per Capita Value	Social Capital
Public Landfill	1						
Past Outsourced	-0.016	1					
No Past	-0.038	-0.797	1				
Max Wind	0.102	0.008	-0.028	1			
Rurality	0.111	-0.293	0.2207	-0.162	1		
Per Capita Value	-0.317	0.240	-0.215	0.1530	-0.081	1	
Social Capital	-0.236	-0.216	0.079	-0.222	0.1972	0.406	1

The full econometric model is presented in Equation 2.5.

$$(Eq. 2.5) O_{rj} = \beta_1 + \beta_2 P_j + \beta_3 O_{aj} + \beta_4 O_{pj} + \beta_5 W_{rj} + \beta_6 R_j + \beta_7 AV_j + \beta_8 SC_j + e$$

In Equation 2.5, the percent outsourced in the most recent storm  $O_{rj}$  regressed against the explanatory variables using Ordinary Least Squares (OLS) method with heteroskedastic robust standard errors. Given there is no previous literature or theory suggesting a specific functional form, a linear relationship was applied.

## 2.6 Results

Results of the OLS regression are summarized in Table 2.6. Models 1-4 are included to observe the different interactions among the variables when more covariates are added. Model 5, the full model, is the model which includes the hypothesized relationships and is interpreted in the following section.

As can be seen in models 1 and 2, when both storm and parish characteristics are excluded, transaction cost theory and the similarity hypothesis are weakly supported.

Table 2.6 OLS Regression Results for Percent Outsourcing

Explanatory Variable	Model 1	Model 2	Model 3	Model 4	Model 5
<i>Similarity Hypothesis</i>					
Past Outsourced	0.307* (0.139)	0.315* (0.138)	0.263+ (0.145)	0.261+ (0.145)	0.166 (0.152)
No Past	9.248 (14.16)	10.58 (13.65)	10.15 (14.41)	10.23 (14.58)	5.818 (14.86)
<i>Transaction Cost Theory</i>					
Public Landfill	-5.694 (8.741)	-8.628+ (8.068)	-6.661 (8.160)	-6.351 (8.928)	-7.820 (9.207)
<i>Storm Characteristics</i>					
Max Wind		0.810** (0.194)	0.734** (0.192)	0.729** (0.201)	0.589** (0.207)
<i>Parish Characteristics</i>					
Rurality			-0.279+ (0.167)	-0.280 (0.169)	-0.244 (0.164)
Per Capita Assessed Value				0.0000569 (0.000479)	0.000641 (0.000471)
Social Capital					-16.52* (8.427)
Constant	51.71** (12.71)	0.867 (17.58)	17.53 (19.75)	17.20 (20.14)	12.95 (20.14)
F- test <i>p-value</i>	2.96 (0.0364)	7.31 (0.000)	6.32 (0.000)	5.21 (0.000)	5.05 (0.000)
N	98	98	98	98	98
Adjusted R <sup>2</sup>	0.049	0.166	0.190	0.182	0.204
Robust standard errors in parenthesis +p<0.1, *p<0.05, **p<0.01					

However, when including storm and parish characteristics in the complete model (Model 5), they are not statistically significant. There is no evidence that supports the Similarity Hypothesis (SH) (*Past Outsourced*). Past outsourcing decisions do not significantly increase the percent of debris expense to be outsourced in the present, when also accounting for parish and storm characteristics. The same is the case for Transaction Cost Theory (TCT).

Further, results suggest that the wind-severity of the storm and social capital (parish attributes) have a more significant effect on determining the percent of debris expense to be

outsourced. As expected, maximum wind is highly significant with a p-value of less than 0.01. If the storm's maximum winds were to increase by 10 mph from the mean, the local government would outsource debris removal about 5.89% more, other factors constant. In the case of the 40 parishes analyzed in this research, their community characteristics condition the decision to outsource. The social capital index is of high significance with a p-value of less than 0.05. It shows that as social capital increases the percent outsourced decreases, consistent with the hypothesis of increased social capital reducing outsourcing and increasing internal procurement.

In summary, Transaction Cost Theory (TH) and the Similarity Hypothesis (SH) appear to explain the debris management decision of local governments affected by federally declared disasters. Asset ownership is not significant in determining whether the local government will outsource debris management and disposal activities. There is no significant evidence suggesting that local governments that had developed debris removal contracts with outsourced third party contractors in the past are more likely to use outsourced third party contractors in the future. The factor that explained the greatest amount of the variation in the model was storm severity with other community level characteristics also explaining the parish government debris management decision.

## **2.7 Conclusion and Policy Implications**

Recovery operations can be potentially as important as mitigation efforts for disasters. In the case of debris accumulation, it has been shown that it can pose a severe threat to public health and safety (Brown et al., 2011; Roper, 2008). Debris must be collected and appropriately disposed of following all environmental and health regulations. Local governments are required to have a debris management plan along with the main disaster management plan (Federal Emergency Management Agency, 2007). It is impossible to exactly plan the necessary step-by-step procedure

after a disaster event. All storms studied in this research had different trajectories and unique characteristics. Nevertheless, local governments can be better prepared for future disaster events by doing a retrospective analysis of past policies and apply other decision support tools to understand best practices for future decision making.

Based on the estimation results, neither Transaction Cost Theory (TH) or the Similarity Hypothesis (SH) explain the debris management decision of Louisiana local governments affected by federally declared disasters. Ownership of transaction specific assets is not significant in determining whether a local government will outsource debris management and disposal activities. There is no significant evidence showing that local governments that had outsourced high proportions of debris removal activities in previous disasters are more likely to use outsourced third party contractors in future disasters.

The storm and parish attributes significantly condition the local government's debris management decision after federally declared disasters. Parishes are more likely to outsource a higher percentage of the debris cleanup activities after severe storms with high wind speed. It can be possible that the debris accumulated is beyond the capacity of the parish in these high wind speed disaster events. In more extreme cases, the storms could also take a toll on the local government's labor and equipment assets limiting their ability to leverage their own assets for clean-up.

Parishes with higher social capital were shown to reduce the use of outsourced debris removal contracts. The higher the bonding social capital, the more likely that local governments preferred to use their own resources to collect and dispose of debris.

The relative significance of some community characteristics as opposed to theoretical factors influencing transaction structure may point to assumptions inherent in both sets of factors.

Both TCT and SH assume decision makers have cost minimization as an objective. If parish governments are choosing to internally procure because there are more economic benefits (including multiplier effects) that create greater revenue for the local economy, local government officials may choose higher local economic benefits over slightly lower costs to local government coffers. Alternatively, Johnson, Raines, and Pender (2014) point out that factors such as social capital are a part of a larger portfolio of wealth creation assets (capitals) in individual places. Communities that are sustainable long-term are ones that increase their overall wealth over time. A large quantity of a rural location's wealth outside of its people are often in non-marketable assets that are not measured. These often include natural amenities, cultural capital, and some forms of social capital. To the extent these unmeasurable characteristics are showing up in the rural proxies, they could simply be revealing that public sector decision makers are acting rationally toward maintaining or improving the sustainability of their communities. The importance of social capital may be an indicator that these parish governments are not attempting to minimize economic costs but to maximize comprehensive community wealth.

## **2.8 Future Research**

There is limited amount of debris expense data regarding disaster recovery management. Severe hurricanes are not an everyday event, therefore there is a scarce amount of data available. The observations included in this research only provide information on public assistance reimbursement funds and not costs of other disasters that are not federally declared, but still require debris removal management. More data regarding specific debris management decisions should be collected from each local government to more efficiently identify explanatory variables that could better represent the Transaction Cost Theory and the Similarity Hypothesis. This study was limited to aggregating all types of debris removal transactions. Disaggregating the types of debris



removal expenses such as vegetative debris removal from monitoring may also reveal alternative contracting strategies.

## **CHAPTER 3: USING SYSTEM DYNAMICS FOR OPTIMAL DEBRIS MANAGEMENT**

### **3.1. Introduction**

The National Response Framework and the National Disaster Recovery Framework are two of the five core documents included in the National Planning Frameworks (Prevention, Protection, Mitigation, Response and Recovery). Response activities take place immediately before, during, and in the first few days after a disaster event. Recovery involves all activities needed to help communities recover from a disaster (Federal Emergency Management Agency, 2016a). Studying all processes involved in disaster response and recovery is a very complex challenge. First, disasters tend to vary greatly in their attributes (i.e. trajectory, wind speed, storm surge, and precipitation). Although both frameworks can assist local governments in planning before a disaster event, the specific effects of the disaster response and recovery decisions are unknown. Local governments cannot study the quality of their disaster management plans through immediate and direct physical experimentation. They need to efficiently formulate strategic plans based on objective evidence that brings them closer to bridging the gap between “predictions” and real life. A well-crafted strategic disaster management plan will quickly present available options for a local government and project the consequences of these decisions on both short and long-term time horizons.

System Dynamics (SD) modeling can be an efficient sensitivity analysis tool when planning disaster response and recovery operations. As proposed by Pender et al. (2012), it allows communities to be able to identify proper strategies taking into account their own resources. Debris removal is one of the first steps taken by response and recovery operations. The cleanup of access roads is essential for first responders to assist those who need immediate help. Debris management

continues past the response period into the recovery stage. Debris removal is a critical task for the community to recover to near its original state prior to the storm.

In this chapter, literature is first reviewed on the applications of SD that shows evidence of its ability in explaining the effects of alternative decisions/policies. A system dynamics model is then constructed to understand the implications of various disaster scenarios on the public wealth of local communities. Scenarios based on historical hurricane probabilities for a rural Louisiana Parish are constructed and applied to the SD models. Finally, implications of these models for future research and policy is discussed.

### **3.2. Literature Review**

The system dynamics approach to studying systems is concerned with the various parts that constitute a whole and their connections. Much of the studied systems have the main purpose of keeping some value within narrowly defined limits under a wide range of possible disturbances. Once all relationships are established, the last step involves tracking them simultaneously. The more objects involved in the system, the more rigorous it becomes to keep track of the relationships (Roberts et al., 1983, pp. 3-10). System Dynamics (SD) relies heavily on computer software to carry out these calculations. A system is a set of elements that interact with each other for some main purpose. For example, the different systems in the human body (cardiovascular, digestive, endocrine, integumentary, lymphatic, muscular, renal and nervous) each have a specific purpose. All the integrated elements in these systems work together establishing feedback relationships. A necessary condition for good practice in system dynamics modeling is to identify closed, causal feedback loops to more effectively keep track of relationships (Roberts et al., 1983). Figure 3.1 shows an example of a negative feedback loop that helps the body reach necessary homeostatic levels.

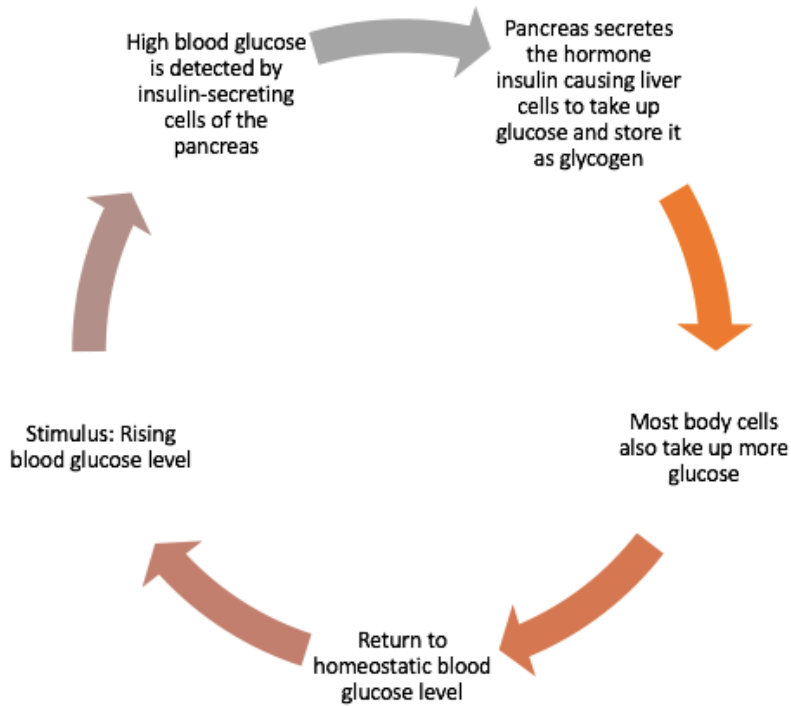


Fig. 3.1 The process of homeostasis for blood glucose levels.

System dynamics (SD) was first introduced by Jay W. Forrester in the 1950s as a problem-solving tool. At the time, Forrester used technological simulations to solve managerial problems (Forrester, 1995). In his first SD application, he identified the endogenous forces that determined employment instability at General Electric (GE). Initially, people at GE thought unfavorable business cycles (economy contracting, decrease of sales and personal incomes) were the reason why half of the staff at their household appliance plant had been fired. By using early SD modeling methods and hiring and inventory decision information, Forrester could model the unstable system that was entirely internally determined. The field has grown at a rapid pace due to its ability to represent complex real world scenarios. It has been applied in all areas of study from business management to biological pathway analysis as well as fiscal policy to climate change effects. SD models all relationships that take place in a system and how their specific relationships affect the system over time.

As studied by Dyson and Chang (2005) computer simulation applications using SD models rely on the use of market-available software, such as Stella®, Dynamo®, and Venisim®. These software programs have user friendly interfaces that make it easy to develop complex models. SD is a collection of interconnected difference equations that allow for numerical approximation of complex equations that would be difficult to solve analytically. Once the model is constructed and all relationships are established, the simulation can be applied over a specific length of time in the system. Some of the variables can be modified depending on the policy or scenario set to be tested.

### **3.2.1 System Dynamics Approach to Model Disaster Management Policies**

Research suggests that efficient use of SD modeling could significantly improve real world planning. Studies that use a SD approach to model disaster management are few. Dynamic models of disaster events should be considered an invaluable learning tool because they provide valuable information without having a disaster occur. Ahmad and Simonovic (2000) coupled SD modeling to disaster management to model flood management policies. Their model provides a platform to evaluate various policy alternatives for flood management applied to the Shellmouth reservoir on the Assiniboine River in Canada. The policies are related to operating rules used to decrease flooding during the high flow/flood years. Ramezankhani and Najafiyazdi (2008) looked into the importance of disaster response teams in the decrease of casualties after an earthquake. They used a SD approach to simulate the activities before and after the devastating Bam earthquake in Iran. The time factor in this type of disaster event is very important. They identified that the total debris removal ability of the city increases the rate of saving people buried by debris.

More recently Rivera-Royero et al. (2016) used a combination of optimization programming and a SD approach to solve the problems faced when distributing relief supplies after a disaster event. They first minimized the level of unsatisfied demand, which is the most

urgent demand that is not received in the appropriate timing. The optimization results were then used in a SD model of a real disaster event (2010 flooding in Colombia). The authors identified several of the involved variables as varying continuously through time and identified a SD modeling approach as the most effective way to better solve the obstacles of distribution of relief supplies.

### **3.2.2 System Dynamics Applied to an Economic Framework**

Use of SD in Economics has become increasingly popular since its first application in 1969. Hamilton (1969) used a SD approach to determine the needs and economic consequences of additional dam construction by the Susquehanna River Basin (Hamilton, 1969). At the 2003 System Dynamics Conference, Forrester presented an overview of the possible contributions of SD to Economics. He identified SD as being a useful tool in tying economic theory to real life economic behavior (Forrester, 2013). Today there is a vast amount of literature that applies widely accepted economic theories to observations of the real world. For instance, there is a significant amount of literature that addresses dynamic economic systems as it relates to natural resources (Dissanayake, 2016; Guo et al., 2001; Portela, 2004; Ruth & Hannon, 1997).

SD has also been used to model policy impacts on economic development. Bryden et al. (2011) used a SD model to examine how agricultural multifunctionality affects the sustainable development of rural regions, and how different policy changes might influence this relationship. The authors created alternative scenarios, reflecting the objectives of policymakers and then compared them to the baseline outcome. In the same context of rural development, Johnson et al. (2008) used SD to model the interactions of rural social, economic and environmental interaction of Agricultural Policy in the European Union.

In this research, the proposed SD model features the relationship between the public wealth of a local government, the debris management, and disaster fund relief. The different policy scenarios will be compared to the baseline outcome similar to the study made by Bryden et al. (2011).

### 3.3. System Representation

The SD building blocks are stocks, flows and converters as described in Figure 3.2. Stocks represent the accumulating component (i.e. public assets, cash, bonds); flows are the actions at which the factor flows in or out of the stock, and converters modify rates of change and unit conversions (Dyson & Chang, 2005).

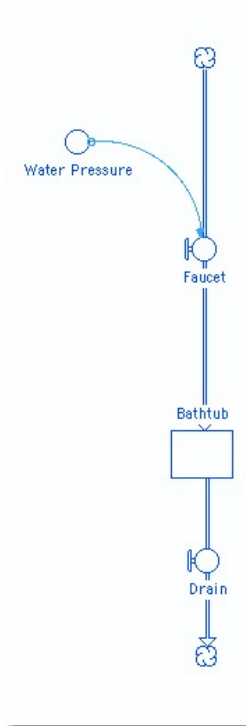


Fig. 3.2 Stella® diagram showing a stock, flows and a converter using a bathtub example.

In more simple terms, the flow can be viewed as a water faucet, that when opened, water flows into a bathtub at a certain pressure. The water accumulating in the bathtub is then the “stock”;

it will fill up until the water flows down the drain. The water pressure is the converter conditioning the rate at which the water flows into the bath tub.

### 3.4 Model

The model created features three sub-models or modules: the wealth of local governments, the debris management operations (disaster accumulated liabilities) and a disaster reserve fund. The wealth module's stock of public assets will be shocked with the various debris management policy scenarios. Only the basic idea of each one of the modules will be presented in this section. Fig. 3.3 shows the positive and negative feedback loops in the model.

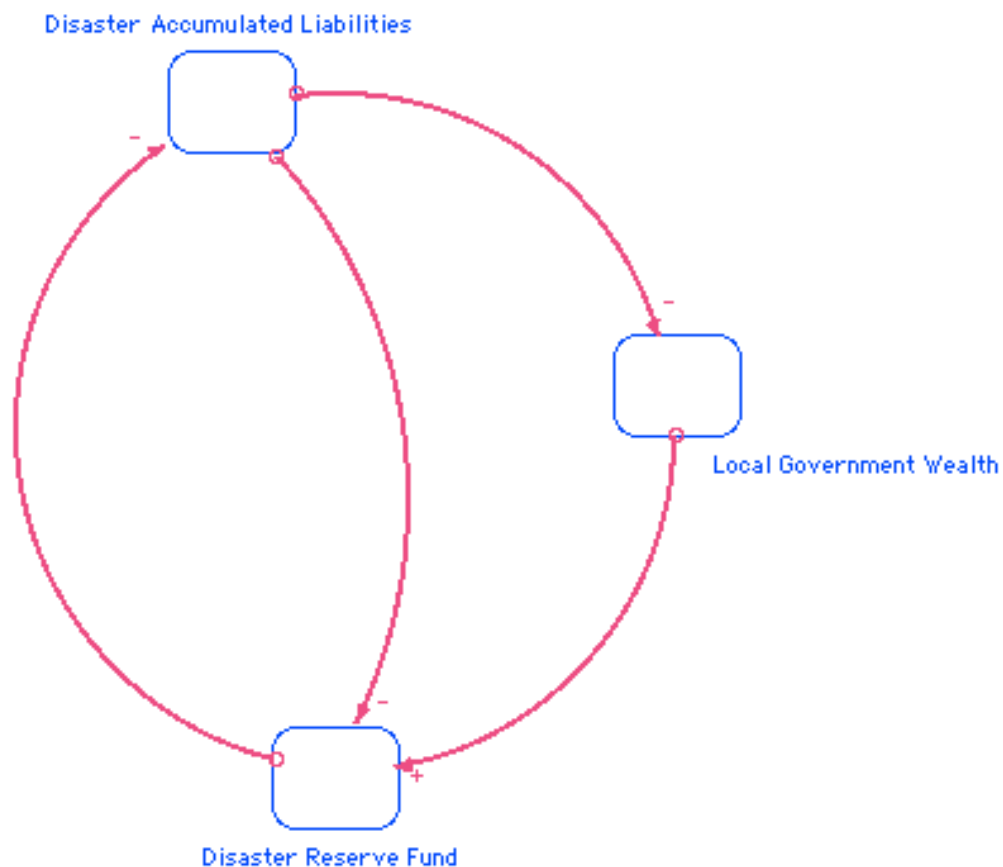


Fig. 3.3 Causal-loops in debris management.



This causal-loop suggests that disasters negatively affect the local government's wealth due to the costs of debris cleanup. An increase in disaster reserve funds from local government disaster relief taxing policy would decrease the disaster accumulated liabilities and therefore the disaster shock to the local government wealth would not be as profound as if the disaster reserve fund did not exist.

The disaster accumulated liabilities negatively affects the amount of disaster reserve fund available. There are different scenarios that could be modeled using the described relationships. The more complex modules that include all the converters can be seen in Appendix D.

### **3.4.1 Wealth Module**

The wealth module was built from the rural wealth creation framework proposed by Pender et al. (2012). In the first section (1) of Fig. 3.4, public (capital) assets are created by investments made through bond capital financing and/or cash capital financing. The assets depreciate and decrease the public asset value at a yearly depreciation rate.

In the second section (2), cash is accumulated by an inflow of tax revenues at a yearly economic growth rate. Cash is depleted when paying for services, interest on bonded indebtedness or cash capital financing.

In the third section (3), bonds increase due to borrowing decisions based on the current cash levels or willingness to invest on public assets (long term liabilities). The bonds decrease when they are paid according to the different payments schedules (principal pay off) using cash. There is another bond stock that accounts for new bonds being created.

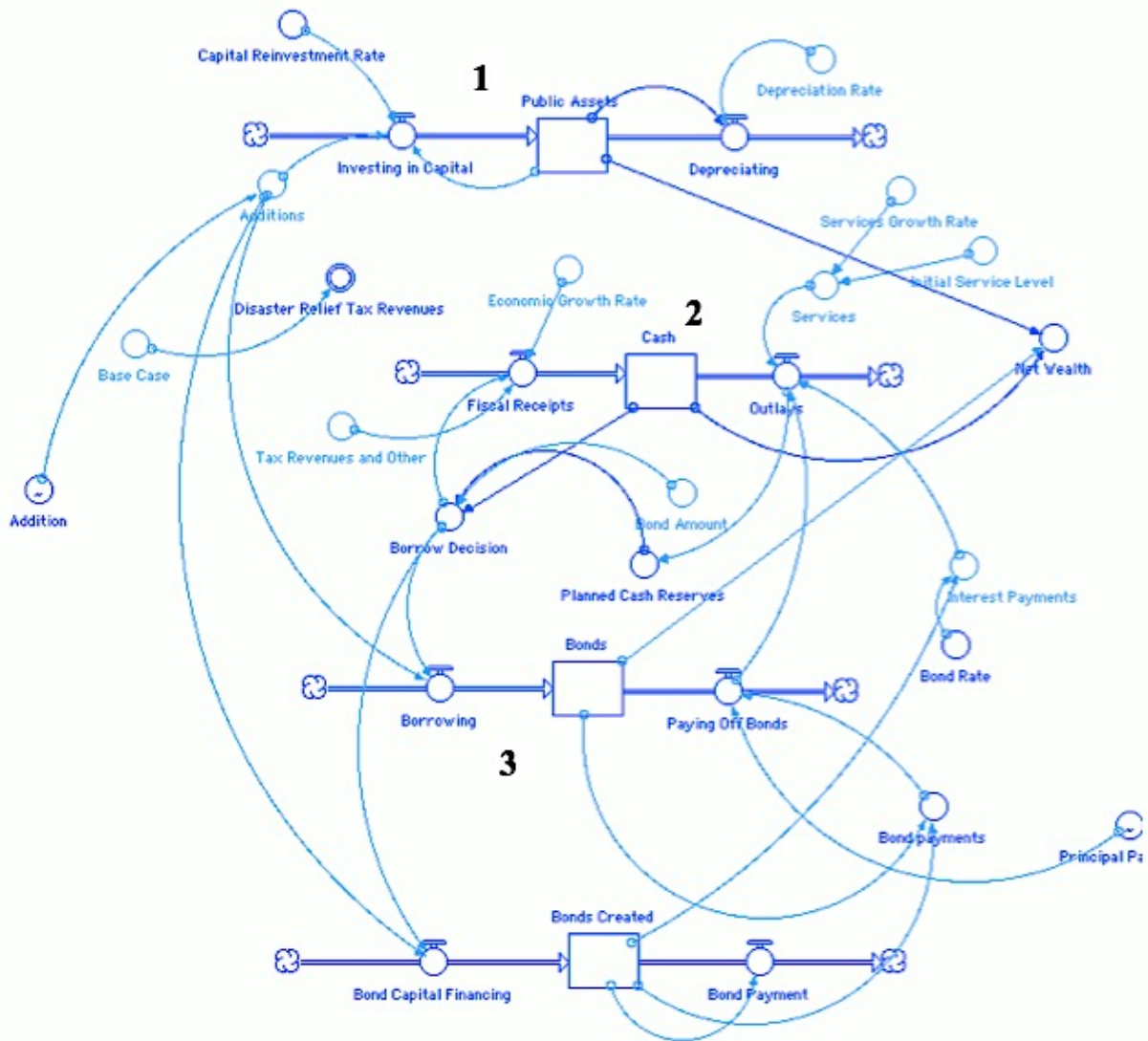


Fig 3.4 Stella® diagram showing the financial activities of a local government. Data from the local government's financial reports.

Some general capital stock and bond assumptions (Table 3.1) will be added into the model so that the stocks, flows, and converters that use specific data of the selected parish will connect and run the simulations. A disaster event shocks the financial system at different points. It destroys infrastructure (loss of public assets); it creates disaster response and recovery expenses that need to be paid (cash outlays), and through recovery, it measures investments on capital that will be needed (loans/bonds).

Table 3.1 Variable descriptions for the local government financial module

Variables	Descriptions
<b>Capital Assumptions</b>	
Depreciation	5%
Re- Investment	3% or \$1.5 million investment when capital stock falls below 75% of initial value.
<b>Bond Assumptions</b>	
Bonds	Bonds sold at 3.5% interest rate
<b>Cash</b>	
Tax growth rate	Different estimated tax growth rate can be selected based on the level of desired revenue. Assumptions range from 1.5% to 5.30%
Services growth rate	Assumed ranges from 1.00% to 1.50%. The selected growth rate will be based on the type of scenario modeled.
Re- Investment	\$1.5 million investment when cash stock falls below 25% of outlays.
<b>Disaster Reserve Fund Policy</b>	
Yearly deposit rate	Based on the parish income and interest. A yearly amount will be withdrawn from the cash account and placed in the disaster reserve fund.
<b>Debris Clean-up</b>	
Cash account shock	Cash account stock will be shocked by an outflow of cash to pay debris removal and cleanup operations when the event happens. It will depend on how the reimbursement rate of Public Assistance (PA) program and the Disaster Relief Fund balance.
<b>Disaster Capital Assets Loss</b>	
Infrastructure will be destroyed	The public assets stock will be shocked by a loss of infrastructure. Assumed ranges are from \$1 million - \$5 million. Depends on the severity of the storm.

Note: Assumptions are based on current and historical averages of the selected parish.

### 3.4.2 Debris Management

Debris removal is one of the first steps taken by response and recovery operations. This module shows the process starting from debris creation to debris removal. The main goal is to show the resulting outcomes from debris management. These include decisions such as outsourcing vs self-procurement of debris removal and the resulting impacts to finances. Another important scenario is to analyze the implication of not qualifying for public assistance. Fig. 3.5. shows the foundation of the debris management process.

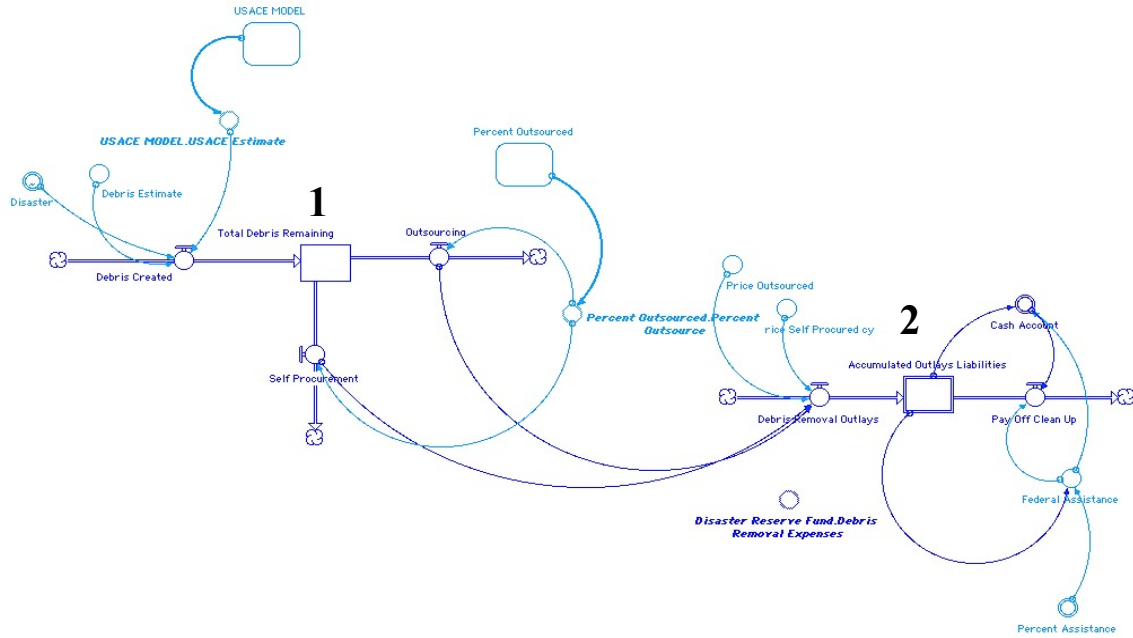


Fig 3.5 Stella® diagram showing the foundation of debris management process. Data for debris creation from local government's attributes, for accumulated outlay liabilities from debris expense data from Louisiana Public Assistance platform.

In the first section of Fig 3.5 (1) debris is created using the debris estimation (Eq. 3.1) built by the U.S. Army Corps of Engineers (USACE) as published by FEMA (2007).

$$(Eq. 3.1) Q=H(C)(V)(B)(S)$$

Let Q be the quantity of debris in cubic yards, H the number of households, C the storm category factor in cubic yards (cy), V vegetation characteristic multiplier, B business use multiplier and S is the storm precipitation multiplier. Detailed description of the variables can be found in Appendix C. The total quantity created flows into the “total debris created” stock. It has two outflows based on two possible decisions: outsourcing conditional on the results of Chapter 2. Both decisions will assist in removing debris that had been created and will convert it into a financial cost for the organization. The debris management process (Fig. 3.6) itself has many steps that are not taken into consideration in this study since the expense data aggregates all debris expenses.

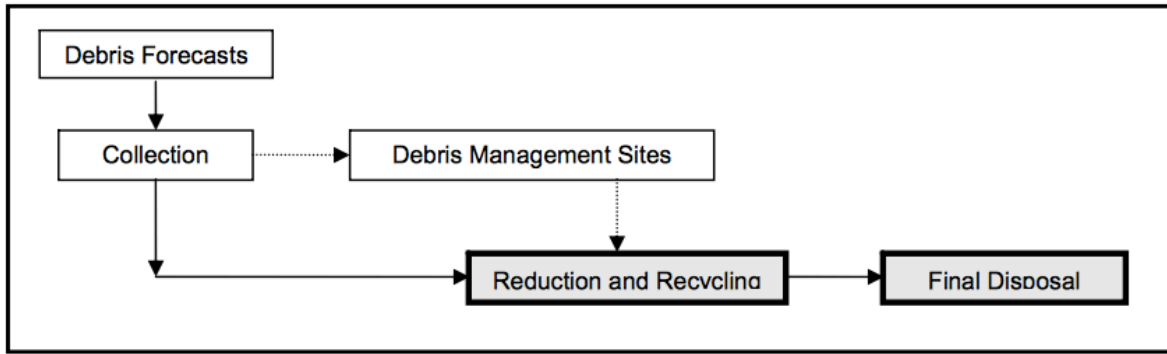


Fig. 3.6 Debris Reduction/ Recycling and Final Disposal Component.  
Reprinted from the Public Assistance Debris Management Guide (Federal Emergency Management Agency, 2007, p. 83)

In the second (2) section, the stock of “Accumulated Outlay Liabilities” has as outflow “pay off” made either by Federal Assistance, “Disaster Reserve Funds” or cash outlays. The general variable descriptions are summarized in Table 3.2.

Table 3.2 Dynamic variables for the debris management module

Dynamic Variable	Description
<b>Storm Characteristics</b>	
Storm Category	Used in the USACE debris estimation and ranges from Category 1- Category 5.
Max Wind	Cat 1 (74- 95 mph), Cat 2 ( 96 – 110 mph), Cat 3 (111- 129 mph), Cat 4 (130 – 156 mph), and Cat 5 (157 or higher )
Precipitation	Used in the USACE debris estimation and it is set at either none, light, or medium to heavy.
<b>Federal Assistance</b>	
Reimbursement	Reimbursement ranges from 75% to 90% (extreme cases) or 0% if the costs do not meet with the state and county thresholds.
<b>Percent Outsourcing Calculation</b>	
Past Outsourced	Used historical past outsourcing aggregated percentage from expense data.
No Past	If there is no past observation, assigned 1 and 0 otherwise.
Public Landfill	Determines if the closest landfill is publicly owned, assigned 1 if “yes”, and 0 otherwise.
Rurality	Percent of the population living in rural areas
Per Capita Assessed Value	Per capita assessed value of the parish studied.

The exact amounts are based on the current public assistance policy and the amount of public assistance conferred is dependent on the time of clean up and designation threshold. The price of cubic yards (cy) outsourced vs. price of cy self-procured will vary depending on the specific scenario.

### 3.4.3 Disaster Reserve Fund

This Disaster Reserve Fund module was created to model a possible policy implemented in which a designated monthly amount is deposited from cash outlays. All formulas used for this module (as well as other modules) can be found in Appendix D. Figure 3.6 shows the “Disaster Reserve Fund,” which has a connection between the Wealth Module and the Debris Management Module. In the first section (1), the disaster reserve fund is increased by a mitigating decision. This is where the “Disaster Reserve Fund” is connected to the “Wealth Module.” The mitigation dollars come from outlays of the cash stock to the disaster reserve fund. In the second section (2), the disaster reserve fund is decreased when used for paying disaster accumulated outlay liabilities based on the percent of public assistance. An initial level for the disaster reserve fund can be assumed for scenario purposes.

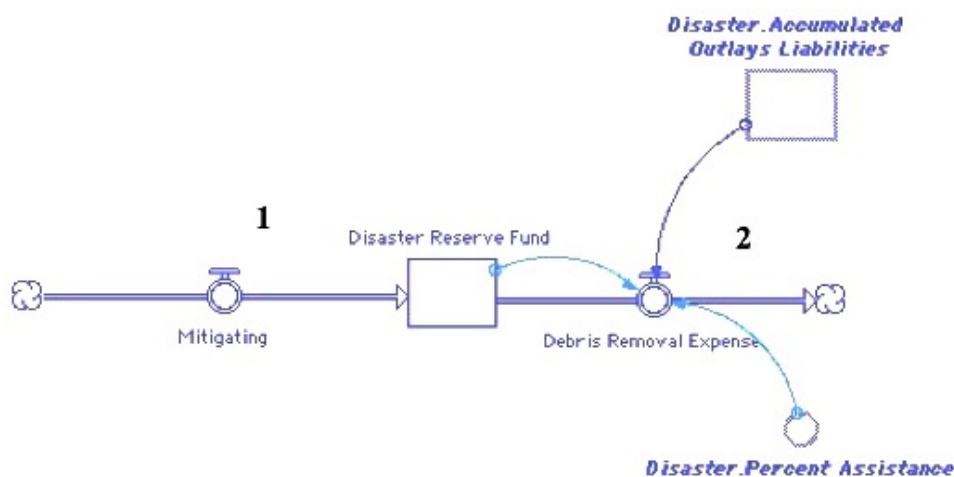


Fig. 3.6 Stella ® diagram showing the foundations of the Disaster Reserve Fund. Data from model calculations.

The debris removal expense (2) can also be conditioned on the amount that could be financed by using cash to control the amount of the fund depleted.

### 3.5 Data

The data required for the system dynamics model includes the regression estimates calculated in Chapter 2 and summarized in Table 3.3. These parameter coefficients will be used to estimate the “total percent outsourced” in the debris management module. The data on past outsourced, no past, public landfill, max wind, rurality, and per capita assessed value variables are the same as in Chapter 2. These values were applied to the appropriate converters, flows, and stocks for the financial module. Other data sources for this model were extracted from the parish’s comprehensive annual financial report that can be found on the Louisiana Legislative Auditor’s website (2013, 2014, 2015) . The data can be set static throughout all the different scenarios or could be modified according to forecasted economic changes.

Table 3.3 OLS Regression Results for Percent Outsourcing

Explanatory Variable	Estimates
Similarity Hypothesis	
Past Outsourced	0.166
No Past	5.818
Transaction Cost Theory	
Public Landfill	-7.820
Storm Characteristic	
Max Wind	0.589
Parish Characteristics	
Rurality	-0.244
Per Capita Assessed Value	0.000641
Social Capital	-16.52
Constant	12.95

Adapted from Chapter 2, Table 2.6.

Amount of debris created was estimated using the method provided by the U.S. Army Corps of Engineers (USACE) as published by FEMA (2007). The detail description of all the variables used in this formula can be found in Appendix C.

### 3.6 Case Study

Cameron parish is the largest parish in Louisiana in terms of geographical area, with a size of 1,932 square miles, of which 1,313 square miles are land and 619 square miles (34 %) are water. Cameron Parish is located in the southwestern coast of Louisiana as can be observed in Figure 3.7.

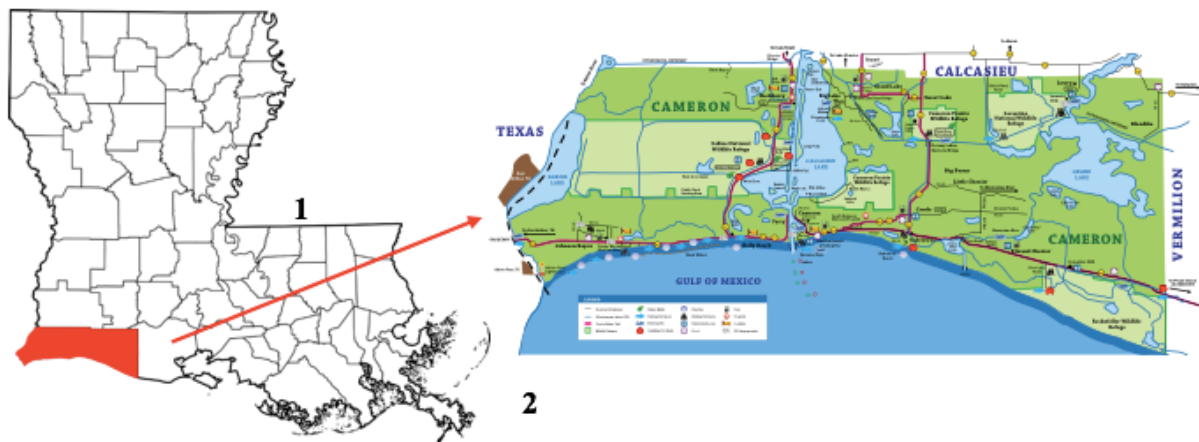


Fig. 3.7 Cameron Parish, Louisiana.

Adapted from the Cameron Parish Tourism Commission and the State of Louisiana website <http://visitcameronparish.org/info/maps> and [http://louisiana.gov/Government/Parish\\_Cameron/](http://louisiana.gov/Government/Parish_Cameron/)

It is bordered north by Calcasieu and Jefferson Davis parishes, east by Vermilion parish, and south by the Gulf of Mexico. Due to its location, Cameron Parish is extremely vulnerable to tropical weather systems. Cameron has been catastrophically affected by natural disasters in the past, including Hurricane Audrey (1957), Rita (2005), and Ike (2008). The population has been steadily decreasing since Hurricane Rita from about 9,576 in 2005 to an estimated 6,839 in 2015. The unincorporated towns of Creole, Cameron, Grand Chenier, Johnson Bayou, and Holly Beach were catastrophically devastated after both severe storms. The financial system of Cameron Parish can



be easily modeled using a SD approach. It doesn't have complex factor relationships as compared to other parishes in Louisiana.

Keim et al. (2007) estimated the average return periods for tropical storms and hurricanes for coastlines from Texas to Maine. On average, the tropical cyclone return period is once every three years for Cameron Parish. For all hurricanes, the return period is once every 15 years, and for more severe hurricanes (category 3, 4, and 5), once every 52 years. Storms can still happen in back to back years. These estimates are based on historical events that have affected the studied locations.

The local government is actively seeking to be more resilient to natural disasters by constructing better disaster management and recovery plans. At this time, Cameron parish has a Long-Term Community Recovery Fund with the main purpose of the fund to finance capital projects. The fund is usually used to finance hurricane recovery efforts using Community Development Block Grant (CDBG) funds.

### **3.6.1 Base Case**

For the initial base case, only the most current financial conditions were modeled using average data from the Cameron Parish Police Jury audited financial statements from 2013, 2014, and 2015. These statements do not include other public sector entities in the parish such as the school board or special purpose districts. The model ran for 10 years with no disaster events occurring nor a disaster reserve fund policy in place. The base case can be compared to what Cameron parish has been experiencing since Hurricane Ike (2008). There have been no major tropical cyclones impacting Cameron Parish between 2009 and 2016. Table 3.5 summarizes the estimated initial values for this base case.

Table 3.5 Initial (starting) Values for the Case Study of Cameron Parish

Financial Variables	Unit	Value	Description <sup>8</sup>
(Stock # 1) Capital Assets Transactions			
Federal Assistance Recovery Fund (Initial Value)	\$ millions	20	Funding from recovery grants
Capital Assets (Initial Value)		124	For 2016
Capital Funds		2.74	For 2016
Ad Valorem Tax		2.5	Average yearly funding for capital investments (2013-2015)
Capital Reinvestment	%	10	Average from (2013-2015)
Depreciation Rate		5	
(Stock # 2) Cash Transactions			
Cash	\$ millions	16.6	For 2016
Revenue : Tax and Other		14.77	2015
Initial Services		12.45	2015
Economic Growth Rate	%	1	Average from (2013-2015)
Services Growth Rate <sup>9</sup>		1	Assumption
(Stock # 3) Bond Transactions			
Bond Rate	%	2.5	Average (2013-2015)
Bonds	\$ millions	3.5	Bond amount pending to be paid
Interest Payments		-	Bonds * Bond Rate
Bond –Pay Off Principal – 10 year pay off		Bonds/10	Average from (2013-2015)
Net Wealth		143	Capital Assets + Cash - Bonds

A base case is first modeled to better visualize the net effects of the different disaster policies that could be implemented before and after a disaster event. The final value of net wealth will serve as the main output to be compared among scenario results. Cameron Parish is still undergoing recovery construction from Hurricanes Rita and Ike. From 2013 to 2015, there have been additions to capital assets on average of \$24 million per year. Some of the projects are scheduled to have been finished by December 2015 (Louisiana Legislative Auditor, 2015, p. 43).

<sup>8</sup> The financial data was extracted from the Cameron Parish financial statements from 2013-2015.

<sup>9</sup> Service expenses has been decreasing significantly from 2013 to 2015 (\$8.3 million - \$4.6 million) for this model, the assumption is being set at 1% to account for a modest level of inflation on the initial service level.

The list includes: Holly Beach Sewer, Big Burn Spillway, Clerk of Court Relocation, Cameron Courthouse Boiler, South Oak Grove Restoration, Courthouse Renovations, Channelview Waterline Extension and Cameron Main Library. The assumption for additions to public assets in this model is going to be estimated at a 10% capital reinvestment rate based on the recovery efforts.

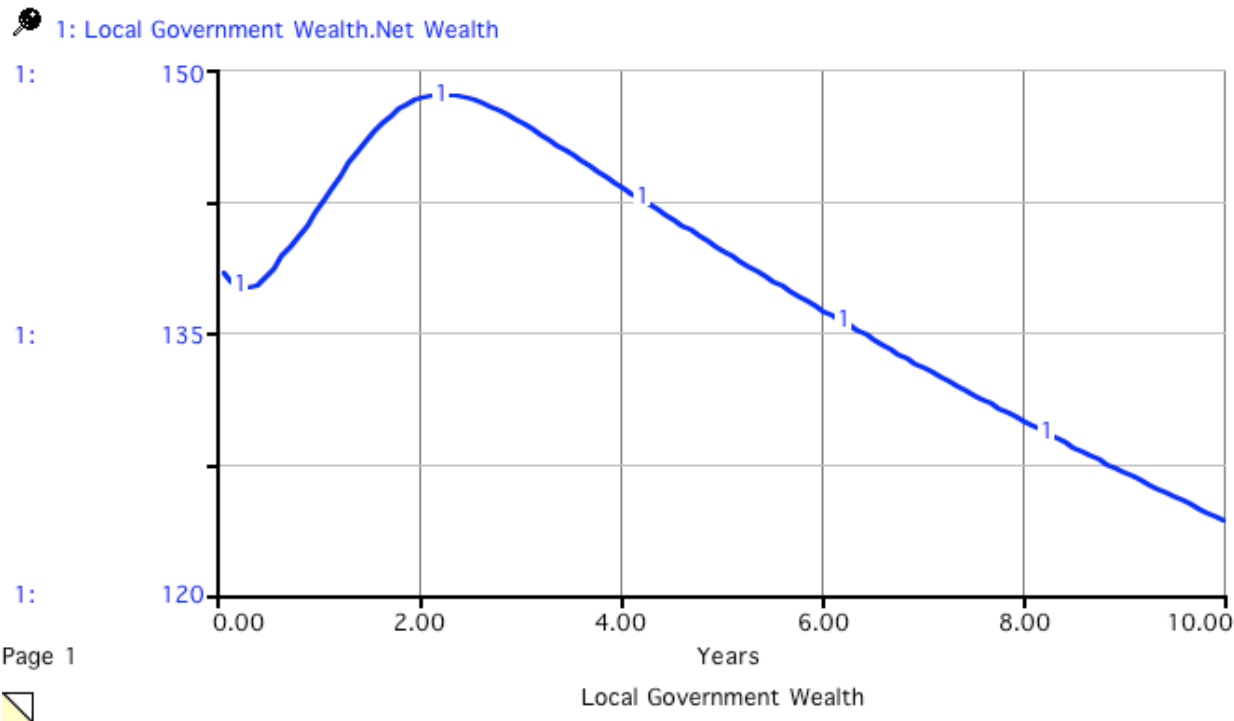


Fig. 3.8 Local government’s change in wealth under base conditions  
 Note: The vertical axis in millions of dollars.

The Cameron Parish Police Jury’s wealth position is estimated to decrease by \$31.98 million (23%) from January 1<sup>st</sup>, 2016 to December 31<sup>st</sup> 2025. The governmental activities are tied up in capital investments using recovery grants, ad-valorem tax revenue and paying off bonds during the first two years. Cameron Parish has been meaningfully planning to invest in public assets that are meant to favor public welfare. Once the Federal Grant Funds are depleted by year 2 the local government has to use its own resources to keep up with the depreciation pace of public assets. All three stocks are compared in Fig. 3.9. The cash account has been decreasing in the first years of the scenario due to principal and interest payments scheduled at that time. Then it

increases steadily getting close to its starting value. On the other hand, public assets are first increasing at an accelerated rate during years 1 and 2, but then starts to decrease. The decrease is related to not having any additional recovery grant investments as well as assets depreciating. Bonds are decreasing as can be expected because no borrowing is required.

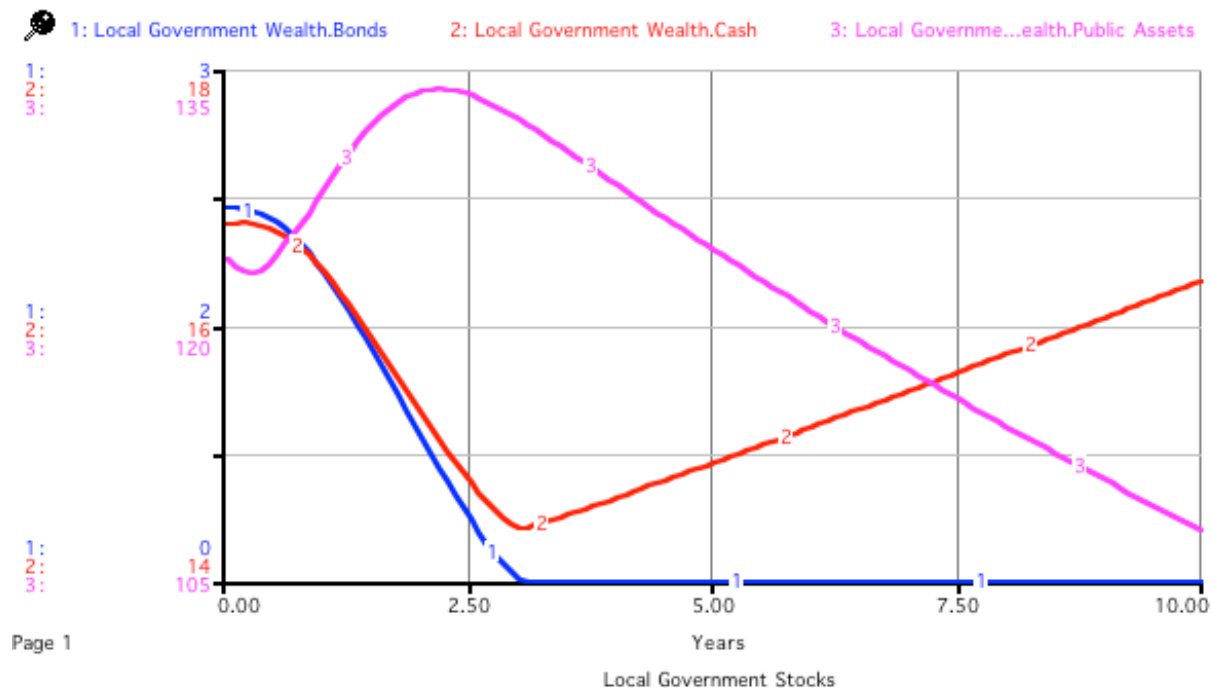


Fig. 3.9 Local government's change in stock values (Public Assets, Cash, and Bonds) under base conditions.  
Note: The vertical axis is \$ in millions

The advantage of this modeling strategy is that one can identify what factors are causing these interactions. For instance, what seems to be affecting the public asset stock is that depreciation is higher than investments once external funding is limited. Table 3.6 shows a comparison of the stocks from the starting value to the final value (after 10-year simulation period). While the overall financial wealth of the parish declines over the 10-year period, there is a tradeoff of reduced capital assets for liquidity.

Table 3.6 Stock Comparison

Stock	Starting Value (\$ million)	Final Value (\$ million)
Public Assets	124	107.97
Cash	16.6	16.27
Bonds	2.2	0
Net Wealth	143	124.24

### 3.6.2 Scenario 1.1: Category 3 Hurricane No Public Assistance

In this scenario, the financial conditions are kept the same as the base case. The cash and public asset accounts will be shocked by a Category 3 hurricane event similar to Hurricane Rita. The time to cleanup and process the debris is set to 3 months. The characteristics of the hurricane are described in Table 3.7.

Table 3.7 Disaster Event Characteristics

Hurricane Variables	Units	Initial Values
Percent Outsourced	%	100
Past Outsourced	%	50
No Past	-	0
Public Landfill	-	0
Rurality	%	100
Per Capita Assessed Value	\$	40,953.48
Social Capital	-	-0.904
Max Wind	mph	111
USACE debris estimate	cy	322,533.12
Household Multiplier	-	2,272
Vegetation Multiplier	-	1.5
Commercial Density	-	1
Hurricane (3) Multiplier	cy	26
Precipitation Multiplier	-	1.3
Cameron Parish Multiplier <sup>10</sup>	-	2.80

<sup>10</sup> Cameron Parish Multiplier is an adjustment factor that accounts for the specific characteristics of the parish. It was calculated from the comparison between the estimated debris created from a storm like Hurricane Rita and the observed amount.

The calculated amount of debris created from a storm with the described characteristics is estimated at 322,533.12 cy. The estimated percent outsourced was set at 100% and the price per cy is estimated to be \$20 per cy<sup>11</sup>. The storm will take place in 2023(Year 7) based on the average return estimates of Keim et al. (2007), considering that the last hurricane impacting Cameron Parish occurred in 2008 and the assumed year 1 is 2016. This disaster creates damages to infrastructure of about \$5 million<sup>12</sup>. The estimated percent outsourced will be calculated using the estimated parameters obtained from Chapter 2.

Table 3.8 Disaster Shock to Net Wealth

Date (2023)	Total Debris Remaining (cy)	Outsourcing (cy)	Self-Procurement (cy)	Pay Off (\$)	Cash (\$)
Aug	322,533.12	107,511.04	0	0	0
Sept	215,022.08	107,511.04	0	2,150,220.80	2,150,220.80
Oct	107,511.04	107,511.04	0	2,150,220.80	2,150,220.80
Nov	0	0	0	2,150,220.80	2,150,220.80
Dec	0	0	0	0	0
Total	-	322,533.12	0	6,450,662.40	6,450,662.40

This storm shocks the cash account with \$2.15 million per month with a total net effect of \$6.45 million. The storm shocks the system at a point in time in which cash accounts are increasing after having paid for bonds. There is a reduction on the net wealth curve as can be observed in Fig. 3.11. The shock to net wealth is a result of the combined effects of the \$5 million shock to public assets and the \$6.45 million shock to cash. Net wealth decreases at a faster rate.

<sup>11</sup> The price for debris removal varies considerably depending on the amount, type and location. The estimated \$20/cy assumption is based on the review of several project worksheets submitted to the Louisiana Public Assistance platform.

<sup>12</sup> Capital asset loss estimated from the difference in capital assets from the Financial Statements before Hurricane Rita (2004) and after Hurricane Rita (2005) (CPI adjusted to 2015).

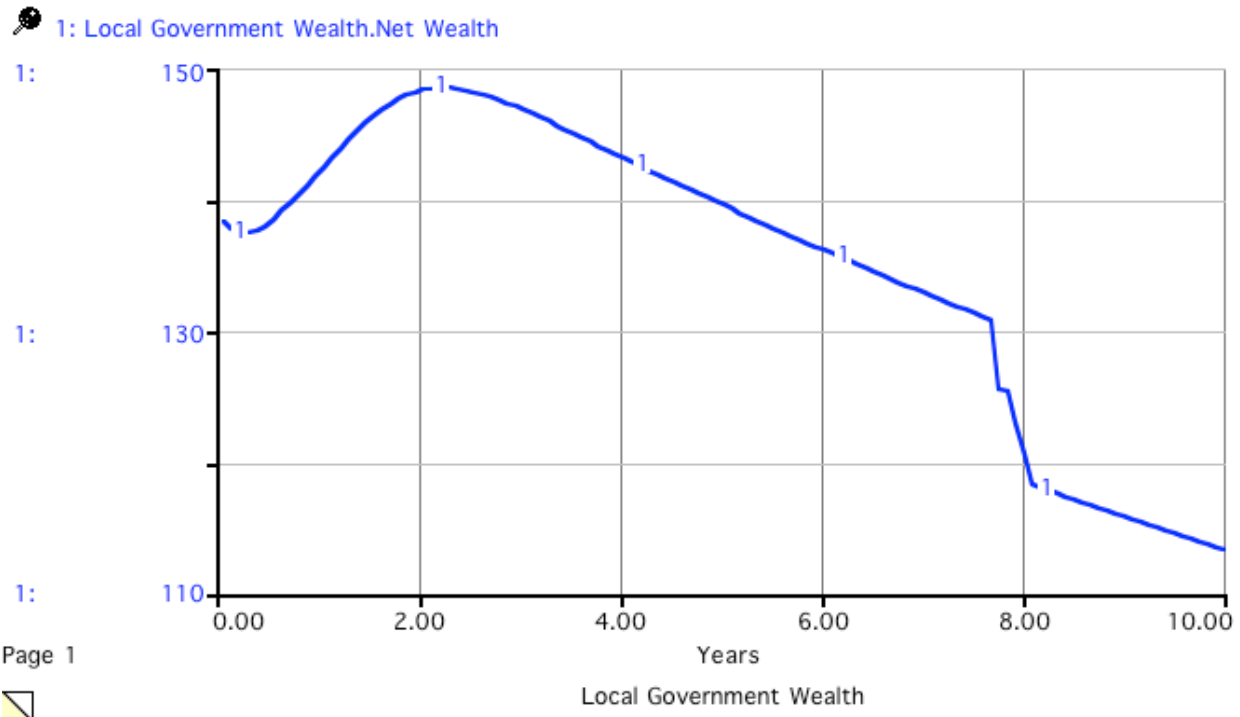


Fig. 3.10 Local government's change in wealth when shocked by a category 3 hurricane  
 Note: The vertical axis is \$ in millions

The last financial statements available only include bonds to be paid by 2017. It could be the case that they borrow money to fund other projects in the future and continue to pay bonds throughout the rest of the studied time frame making the reduction even deeper. The comparison between the base case and this scenario is summarized on Table 3.9.

Table 3.9 Stock Comparison

Stock	Starting Values (\$ million)	Base Case (\$ million)	Scenario #1 (\$ million)
Public Assets	124	107.97	103.51
Cash	16.6	16.27	9.82
Bonds	2.2	0	0
Net Wealth	138.4	124.24	113.32

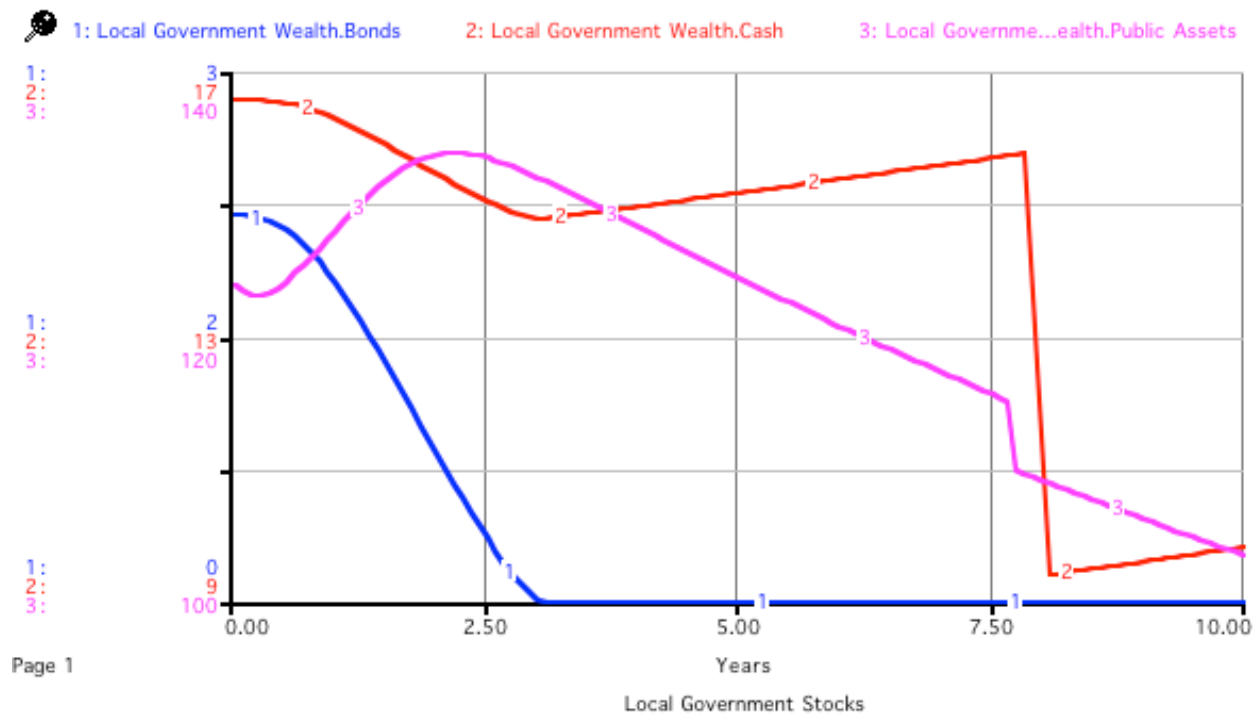


Fig. 3.11 Local government change in stock values (Bonds, Cash, and Public Assets) when shocked by a category 3 hurricane  
 Note: The vertical axis is \$ in millions

There are other disaster response and recovery expenses that are not being included in the model (i.e. disaster relief emergency assistance, temporary housing) and revenue will also decrease.

### 3.6.3 Scenario 1.2: Category 3 Hurricane with Public Assistance

In this scenario, the financial conditions are kept the same as the base case. The cash and public asset accounts will be shocked by a Category 3 hurricane event similar to Hurricane Rita. The time to cleanup and process the debris is set to 3 months. The characteristics of the hurricane are described in Table 3.10. The calculated amount of debris created from a storm with the described characteristics is estimated at 322,533.12 cy. The estimated percent outsourced was set at 100% and the price per cy is estimated to be \$20 per cy.



Table 3.10 Disaster Event Characteristics

Hurricane Variables	Units	Initial Values
Percent Outsourced	%	100
Past Outsourced	%	50
No Past	-	0
Public Landfill	-	0
Rurality	%	100
Per Capita Assessed Value	\$	40,953.48
Social Capital	-	-0.904
Max Wind	mph	111
USACE debris estimate	cy	322,533.12
Household Multiplier	-	2,272
Vegetation Multiplier	-	1.5
Commercial Density	-	1
Hurricane (3) Multiplier	cy	26
Precipitation Multiplier	-	1.3
Cameron Parish Multiplier <sup>13</sup>	-	2.80

The storm will take place in 2023 based on the average return estimates of Keim et al. (2007), considering that the last hurricane impacting Cameron Parish occurred in 2008 and the assumed year 1 is 2016. The first assumption is that due to the severity of the storm, Cameron Parish will be eligible for (90%) public assistance for debris management. This disaster also creates damages to infrastructure of about \$5 million. The estimated percent outsourced will be calculated using the estimated parameters obtained from Chapter 2.

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<sup>13</sup> Cameron Parish Multiplier is an adjustment factor that accounts for the specific characteristics of the parish. It was calculated from the comparison between the estimated debris created from a storm like Hurricane Rita and the observed amount.

Table 3.11 Disaster Shock to Net Wealth

Date (2023)	Total Debris Remaining (cy)	Outsourcing (cy)	Self-Procurement (cy)	Pay Off (\$)	Cash (\$)	PA (\$)
Aug	322,533.12	107,511.04	0	0	0	0
Sept	215,022.08	107,511.04	0	2,150,220.80	215,022.08	1,935,198.72
Oct	107,511.04	107,511.04	0	2,150,220.80	215,022.08	1,935,198.72
Nov	0	0	0	2,150,220.80	215,022.08	1,935,198.72
Dec	0	0	0	0	0	0
Total	-	322,533.12	0	6,450,662.40	645,066.24	5,805,596.16

It is important to note that even though the parish meets the requirements for public assistance, there is still some higher percentage of the costs that might need to be covered by the local government. For instance, it could be the case that not all debris removal activities fit into what FEMA establishes as a potential hazard to public safety.

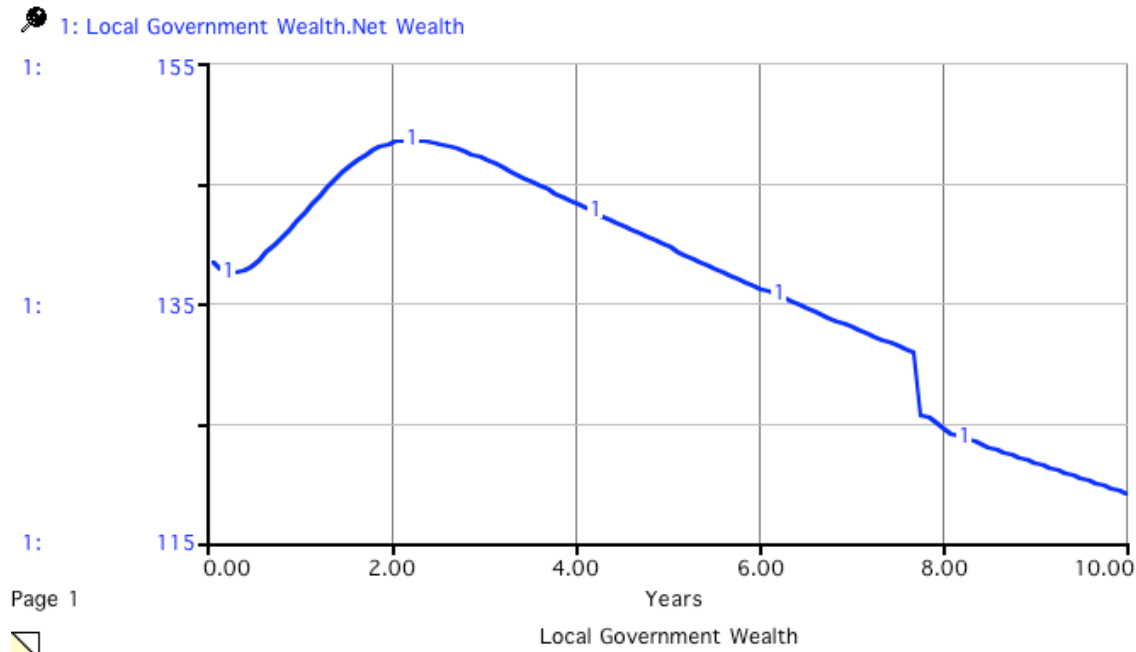


Fig. 3.12 Local government change in wealth when shocked by a category 3 hurricane and receiving 90% PA

Note: The vertical axis is \$ in millions

As can be observed in Fig. 3.12 there is a reduction around the last months of year 7 (2023). Under this circumstance, the local government has lost infrastructure (\$5 million) due to the severity of the storm and had to pay for debris removal operations (\$645,066.24). This takes into account that the local government will receive the Public Assistance funds immediately after the disaster event. The Police Jury's wealth position is estimated to decrease by \$19.27 million (13.9%) from January 1<sup>st</sup>, 2016 to December 31<sup>st</sup> 2025. This is \$5.81 million less than in Scenario #1 in which the wealth position was estimated to decrease by \$25.08 million (18%).

The Federal Government Public Assistance Program offers financial support for local governments when facing extremely devastating disasters when they are not able to recover using their own resources. Just for Hurricane Ike, Cameron received an estimated \$118.3 million (Louisiana Recovery Authority, 2008, p. 11) that only includes rebuilding. Most of the rebuilding efforts had the intention to make public structures more resistant to disasters which increases construction costs. Figure 3.13 shows the value of the local government stocks throughout time.

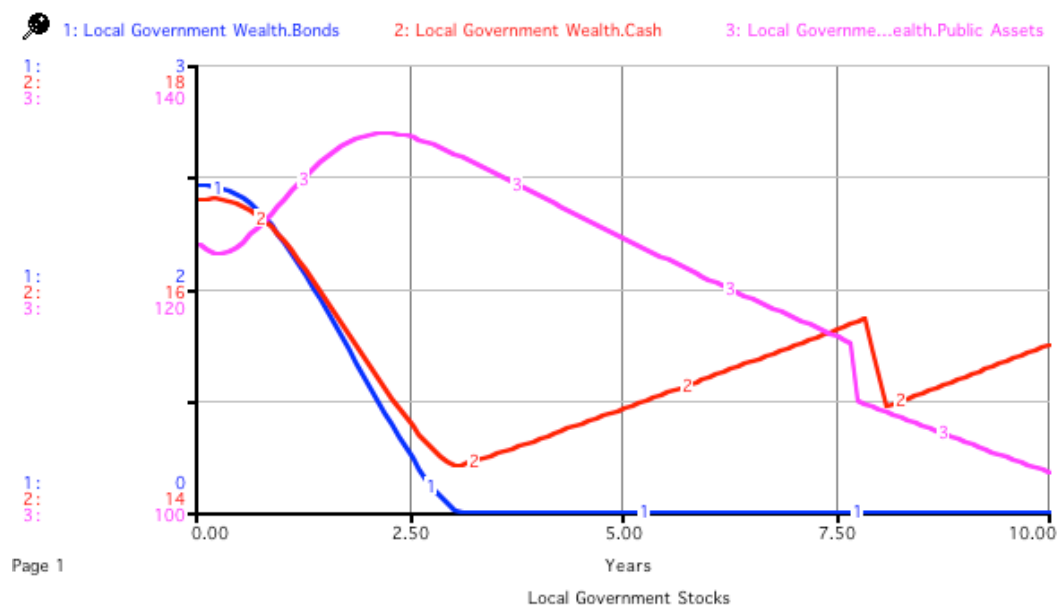


Fig. 3.13 Local government change in stock values (Bonds, Cash, and Public Assets) when shocked by a category 3 hurricane and receiving 90% PA.  
Note: The vertical axis is \$ in millions

Around the time of the storm it can be observed that the local government's public assets are shocked with the loss of infrastructure. The cash account is also affected by the disaster. The difference in stock values from the base case to this scenario is summarized in Table 3.9. Public Assistance does what it is intended to do, which is to alleviate the burden of a severe disaster on the local government's wealth.

Table 3.12 Stock Comparison

Stock	Starting Value (\$ million)	Base Case (\$ million)	Scenario #1 (\$ million)	Scenario #2 (\$ million)
Public Assets	124	107.97	103.51	103.51
Cash	16.6	16.27	9.82	15.62
Bonds	2.2	0	0	0
Net Wealth	138.40	124.24	113.32	119.13

### 3.6.4 Scenario 1.3: Category 3 Hurricane with Public Assistance and Disaster Relief Fund

In this scenario, the financial conditions are in general kept the same as in the base case with the addition of a disaster relief fund. The disaster relief fund policy aims to raise enough money to cover the possible debris removal cost (\$595,440.00) related to a category 2 storm hitting the parish in year 15 and receiving 70% from the PA Program. The cash and public asset accounts will be shocked by a Category 3 hurricane event similar to Hurricane Rita. The time to cleanup and process the debris is set to 3 months. The characteristics of the hurricane are described in Table 3.13. The calculated amount of debris created from a storm with the described characteristics is estimated at 322,533.12 cy. The estimated percent outsourced was set at 100% and the price per cy is estimated to be \$20 per cy<sup>14</sup>.

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<sup>14</sup> The price for debris removal varies considerably depending on the amount, type and location. The estimated \$20/cy assumption is based on the review of several project worksheets submitted to the Louisiana Public Assistance platform.

Table 3.13 Disaster Event Characteristics

Hurricane Variables	Units	Initial Values
Percent Outsourced	%	100
Past Outsourced	%	50
No Past	-	0
Public Landfill	-	0
Rurality	%	100
Per Capita Assessed Value	\$	40,953.48
Social Capital	-	-0.904
Max Wind	mph	111
USACE debris estimate	cy	322,533.12
Household Multiplier	-	2,272
Vegetation Multiplier	-	1.5
Commercial Density	-	1
Hurricane (3) Multiplier	cy	26
Precipitation Multiplier	-	1.3
Cameron Parish Multiplier <sup>15</sup>	-	2.80

The storm will take place in 2023 based on the average return estimates of Keim et al. (2007), considering that the last hurricane impacting Cameron Parish occurred in 2008 and the assumed year 1 is 2016. Different assumptions of funding will be modeled. The first assumption is that due to the severity of the storm, Cameron Parish will be eligible for (90%) public assistance for debris management. The second assumption is that the remaining 10% will be covered by the disaster relief fund if sufficient funds are available. This disaster also creates damages to infrastructure of about \$5 million. The estimated percent outsourced will be calculated using the

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<sup>15</sup> Cameron Parish Multiplier is an adjustment factor that accounts for the specific characteristics of the parish. It was calculated from the comparison between the estimated debris created from a storm like Hurricane Rita and the observed amount.

estimated parameters obtained from Chapter 2. Table 3.14 summarizes the disaster shock to net wealth.

Table 3.14 Disaster Shock to Net Wealth

Date (2023)	Total Debris Remaining (cy)	Outsourcing (cy)	Pay Off (\$)	Cash (\$)	PA (\$)	Disaster Reserve Fund (\$)
Aug	322,533.12	107,511.04	0	0	0	0
Sept	215,022.08	107,511.04	2,150,220.80	129,013.25	1,935,198.72	86,008.83
Oct	107,511.04	107,511.04	2,150,220.80	129,013.25	1,935,198.72	86,008.83
Nov	0	0	2,150,220.80	129,013.25	1,935,198.72	86,008.83
Dec	0	0	0	0	0	0
Total	-	322,533.12	6,450,662.40	387,039.75	5,805,596.16	258,026.49

By year 7 the Disaster Reserve Fund had about \$300 thousand. To avoid depleting the fund 4% will covered by the “Disaster Reserve Fund” and 6% by the “Cash Account”. Fig. 3.14 shows the shock to the overall net wealth.

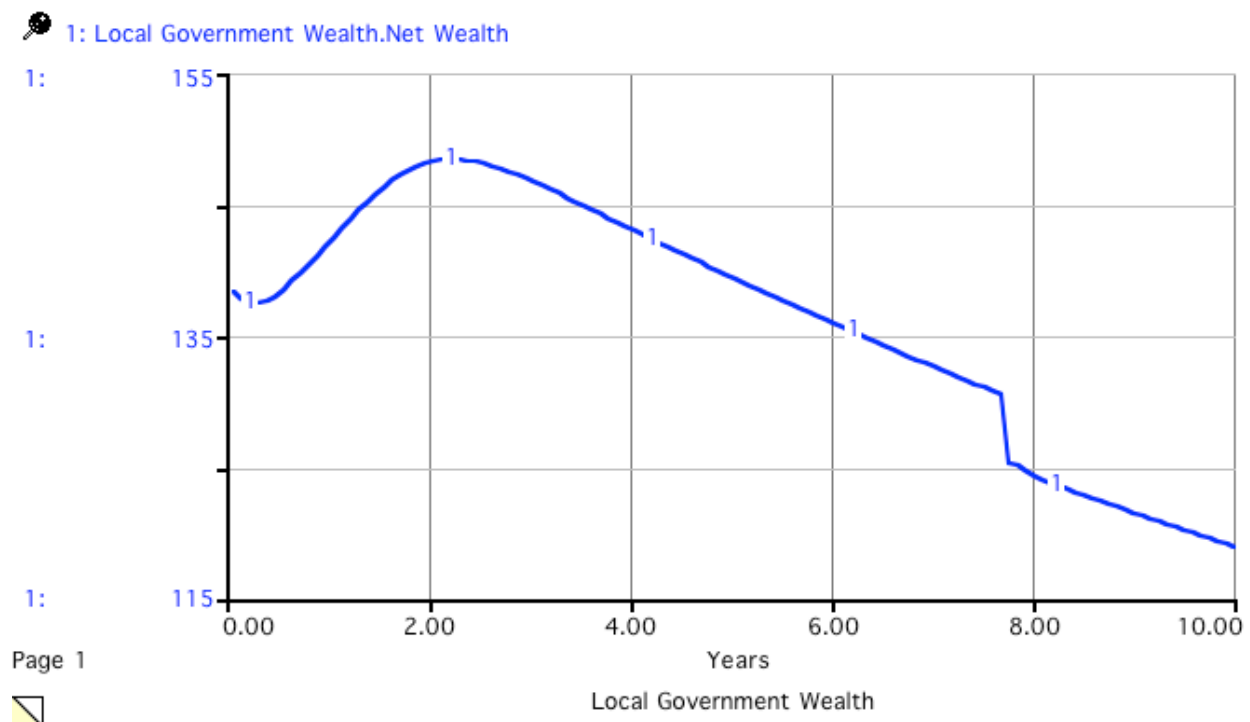


Fig. 3.14 Local government’s change in wealth when shocked by a category 3 hurricane receiving 90% PA and covering 4% of costs with disaster reserve funds  
Note: The vertical axis is \$ in millions

Under this circumstance, the local government loses infrastructure (\$5 million) due to the severity of the storm. The parish had to pay for debris removal operations from cash account (\$387,039.75) and disaster reserve fund (\$258,026.49). This also takes into account that the local government will receive the Public Assistance funds immediately after the disaster event. The Police Jury's wealth position is estimated to decrease by \$19.27 million (13.9%) from January 1<sup>st</sup>, 2016 to December 31<sup>st</sup> 2025. This is \$5.81 million less than in Scenario #1, but the same for Scenario #2. The Disaster Reserve Fund as it is being modeled is decreasing the cash available and in the long run affecting the net wealth. The Disaster Reserve Fund is collecting \$40,000 per year.

Table 3.15 Stock Comparison

Stock	Starting Value (\$ million)	Base Case (\$ million)	Scenario #1 (\$ million)	Scenario #2 (\$ million)	Scenario #3 (\$ million)
Public Assets	124	107.97	103.51	103.51	103.51
Cash	16.6	16.27	9.82	15.62	15.48
Bonds	2.2	0	0	0	0
Disaster Relief Fund	0	-	-	-	0.142
Net Wealth	138.40	124.24	113.32	119.13	119.13

As can be observed in Fig. 3.15 not all of the Disaster Reserve Fund was used to cover the debris management costs. At the time of the disaster shock, the funds were not sufficient to cover all costs. In that case, 4% of the accumulated liabilities was covered by the Disaster Reserve Fund and 6% by the Cash Account. The Disaster Relief Fund ending balance is of \$142,000 by year 10. A more realistic scenario would include a decrease of tax revenue at the time of the disaster shock as well.

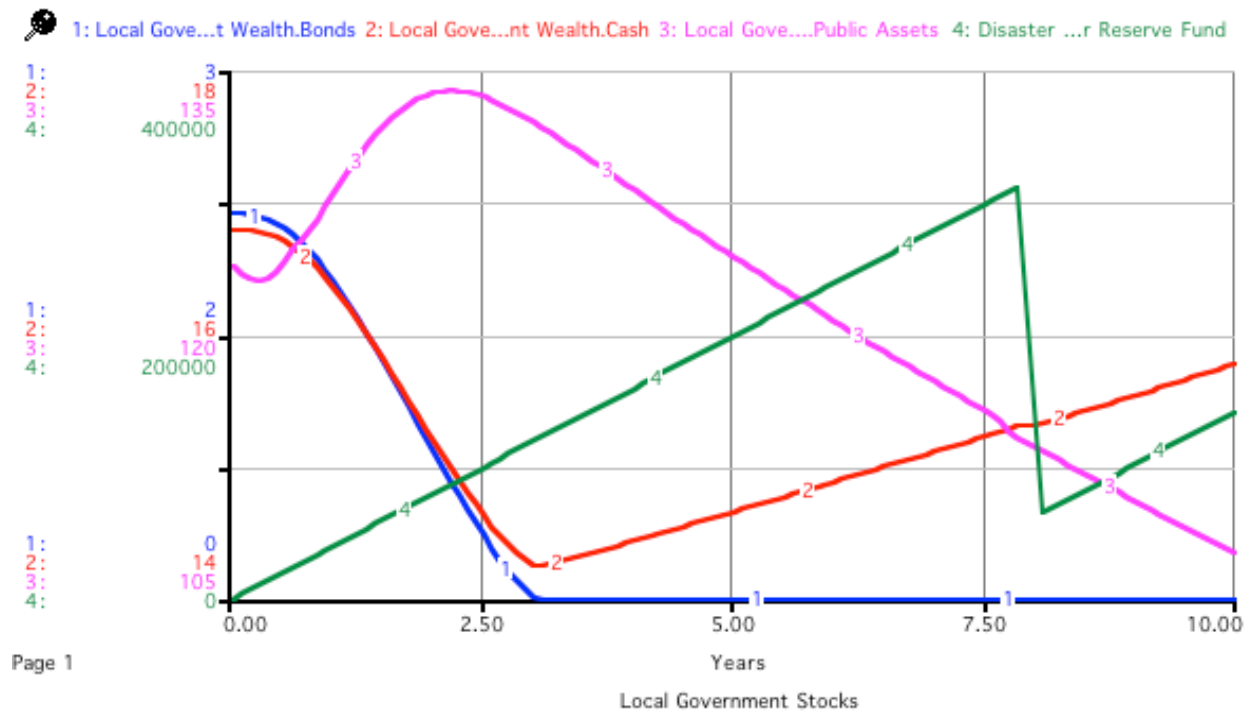


Fig. 3.15 Local government's change in stock values (Bonds, Cash, Public Assets, Disaster Reserve Fund) when shocked by a category 3 hurricane and receiving 90% PA  
 Note: The vertical axis for bonds, cash, and public assets is \$ in millions and for disaster reserve fund is in \$.

### 3.6.5 Scenario 2.1: Category 2 Hurricane

In this scenario, the financial conditions are kept the same as the base case. The cash and public asset accounts will be shocked by a disaster event similar to Hurricane Ike (Category 2). The time to cleanup and process the debris is set to 3 months. The characteristics of the hurricane are described in Table 3.16. The amount of debris created from this type of storm is estimated at 99,240.96 cy which is 223,292.16 cy less than a Category 3. The estimated percent outsourced was set at 100% and the price per cy is \$20 per cy<sup>16</sup>. The parish doesn't receive any type of Public Assistance in this scenario.

<sup>16</sup> The price for debris removal varies considerably depending on the amount, type and location. The estimated \$20/cy assumption is based on the review of several project worksheets submitted to the Louisiana Public Assistance platform.



Table 3.16 Disaster Event Characteristics

<b>Hurricane Variables</b>	<b>Units</b>	<b>Initial Values</b>
Percent Outsourced	%	100
Past Outsourced	%	50
No Past	-	0
Public Landfill	-	0
Rurality	%	100
Per Capita Assessed Value	\$	40,953.48
Social Capital	-	-0.904
Max Wind	mph	100
USACE debris estimate	cy	99,240.96
Household Multiplier	-	2,272
Vegetation Multiplier	-	1.5
Commercial Density	-	1
Hurricane (2) Multiplier	cy	8
Precipitation Multiplier	-	1.3
Cameron Parish Multiplier <sup>17</sup>	-	2.80

The storm will take place in 2023 based on the average return estimates of Keim et al. (2007), considering that the last hurricane impacting Cameron Parish occurred in 2008 and the assumed year 1 is 2016. This disaster creates damages to infrastructure of about \$1 million<sup>18</sup>. This storm shocks the cash account with \$662 thousand per month with a total net effect of \$1.99 million.

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<sup>17</sup> Cameron Parish Multiplier is an adjustment factor that accounts for the specific characteristics of the parish. It was calculated from the comparison between the estimated debris created from a storm like Hurricane Rita and the observed amount.

<sup>18</sup> Capital asset loss estimated from the difference in capital assets from 2004 and 2005 (CPI adjusted to 2015) and the assumption that the hurricane is Category 2.

Table 3.17 Disaster Shock to Net Wealth

Date (2023)	Total Debris Remaining (cy)	Outsourcing (cy)	Pay Off (\$)	Cash (\$)
Aug	99,240.96	33,080.32	0	0
Sept	66,160.64	33,080.32	661,606.40	661,606.40
Oct	33,080.32	33,080.32	661,606.40	661,606.40
Nov	0	0	661,606.40	661,606.40
Dec	0	0	0	0
Total	-	99,240.96	1,984,819.20	1,984,819.20

The storm shocks the system at a point in time in which cash accounts are increasing after having paid for bonds. There is a small dent on the net wealth curve as can be observed in Fig. 3.16. The shock to net wealth is a result of the combined effects of the \$1 million shock to public assets and the \$1.99 million shock to cash. Net wealth decreases at a faster rate.

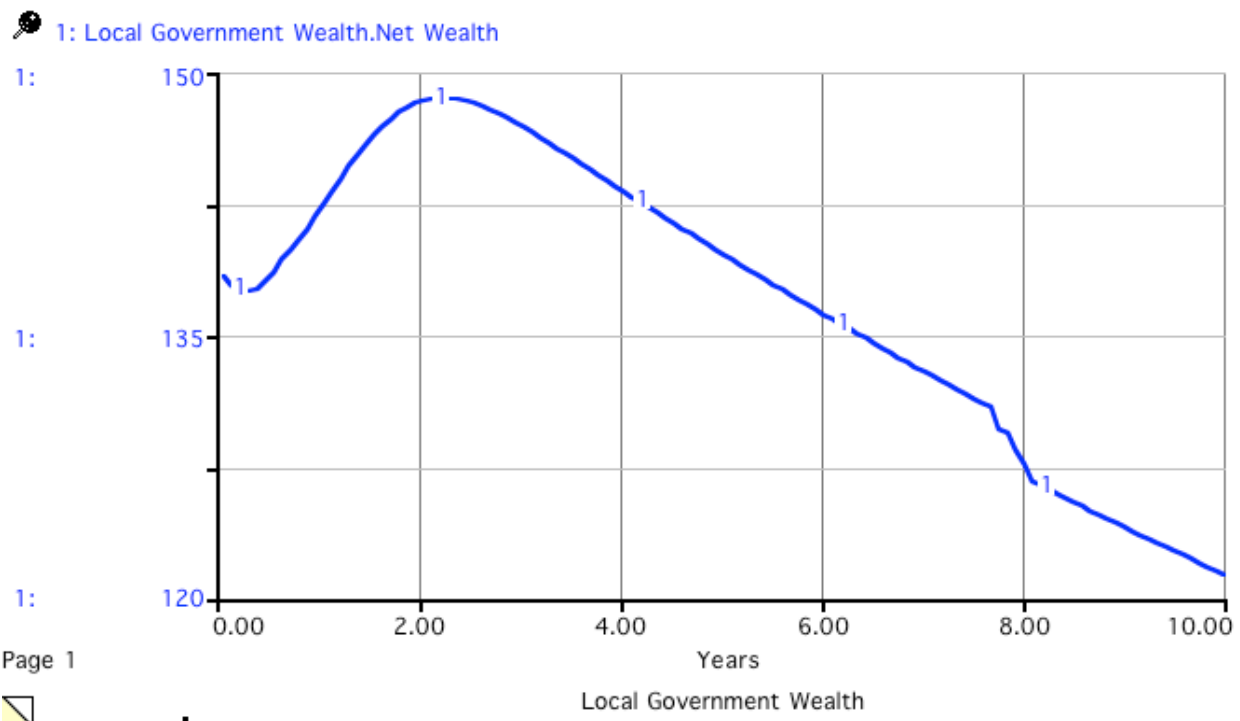


Fig. 3.16 Local government's change in wealth when shocked by a category 2 hurricane  
Note: The vertical axis is \$ in millions

Table 3.18 shows the comparison between the Base Case and Scenario # 1 of the different storms analyzed. As can be expected, a higher category storm causes greater damage to the local government's wealth. The parish's net wealth is estimated to decrease by \$17.04 million (12.3%) as compared to \$14.16 million (10.23%) of the base case. Fig. 3.17 shows Bonds, Cash and Public Assets through time.

Table 3.18 Stock Comparison

Stock	Starting Value (\$ million)	Base Case (\$ million)	Scenario # 1 (\$ million)	
			Cat.2	Cat. 3
Public Assets	124	107.97	107.08	103.51
Cash	16.6	16.27	14.28	9.82
Bonds	2.2	0	0	0
Net Wealth	138.40	124.24	121.36	113.32

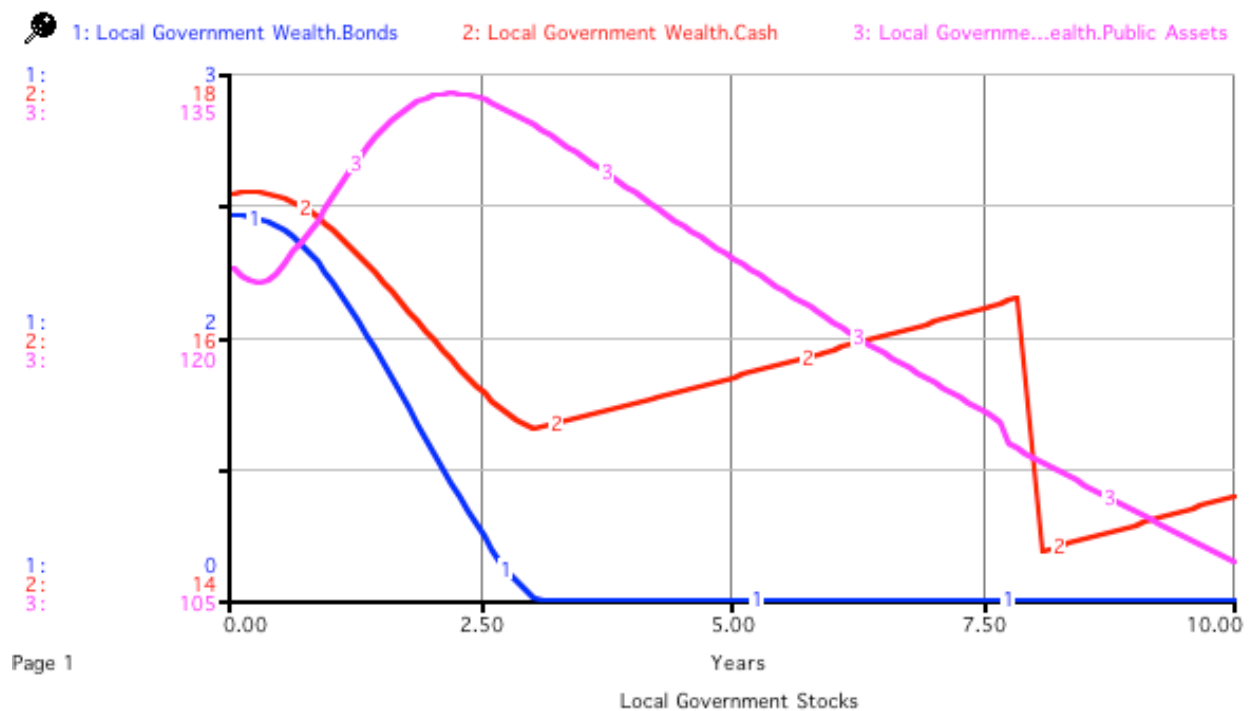


Fig. 3.17 Local government's change in stock values (Bonds, Cash, Public Assets) when shocked by category 2 hurricane

Note: The vertical axis is \$ in millions

### 3.6.6 Scenario 2.2: Category 2 Hurricane with Public Assistance

In this scenario, the financial conditions are kept the same as the base case. The cash and public asset accounts will be shocked by a disaster event similar to Hurricane Ike (Category 2). The time to cleanup and process the debris is set to 3 months. The characteristics of the hurricane are described in Table 3.19. The amount of debris created from this type of storm is estimated at 99,240.96 cy which is 223,292.16 cy less than a Category 3. The estimated percent outsourced was set at 100% and the price per cy is \$20 per cy<sup>19</sup>. The parish receives 70% of Public Assistance and 30% of the costs will have to be financed using own funds.

Table 3.19 Disaster Shock to Net Wealth

Date (2023)	Total Debris Remaining (cy)	Outsourcing (cy)	Pay Off (\$)	Cash (\$)	PA (\$)
Aug	99,240.96	33,080.32	0	0	0
Sept	66,160.64	33,080.32	661,606.40	198,481.92	463,124.48
Oct	33,080.32	33,080.32	661,606.40	198,481.92	463,124.48
Nov	0	0	661,606.40	198,481.92	463,124.48
Dec	0	0	0	0	0
Total	-	99,240.96	1,984,819.20	595,445.76	1,389,373.44

This storm shocks the cash account with \$199,000 per month with a total net effect of \$595,000. The storm shocks the system at a point in time in which cash accounts are increasing after having paid for bonds. There is a small dent on the net wealth curve as can be observed in Fig. 3.18. The shock to net wealth is a result of the combined effects of the \$1 million shock to public assets and the \$595,445.76 million shock to cash. Net wealth decreases at a faster rate.

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<sup>19</sup> The price for debris removal varies considerably depending on the amount, type and location. The estimated \$20/cy assumption is based on the review of several project worksheets submitted to the Louisiana Public Assistance platform.

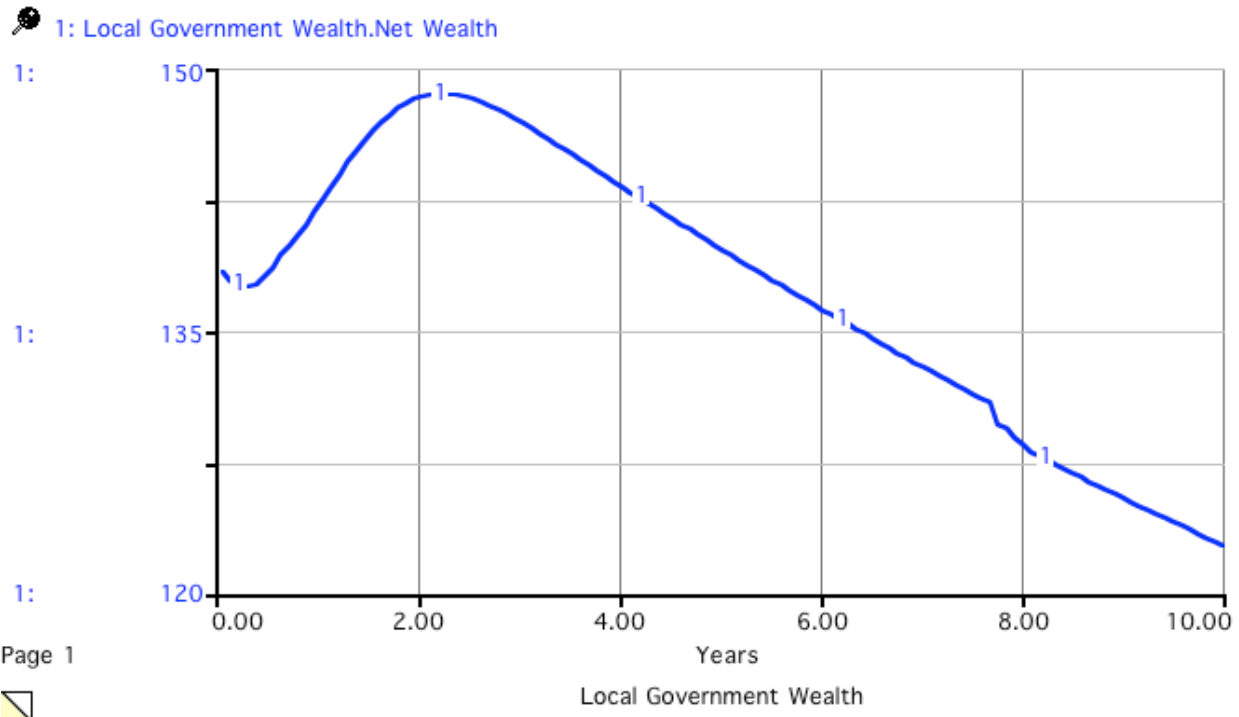


Fig. 3.18 Local government's change in wealth when shocked by a category 2 hurricane and receiving 70% PA

Note: The vertical axis is \$ in millions

This scenario assumes that the local government will receive the Public Assistance funds immediately after the disaster event. If there is a delay in receiving the funds the dent to the Local Government Wealth should be steeper. Table 3.20 compares the stocks of interest in the different scenarios that have been modeled.

Table 3.20 Stock Comparison

Stock	Starting Value (\$ million)	Base Case (\$ million)	Scenario # 1 (\$ million)		Scenario # 2 (\$ million)	
			Cat.2	Cat. 3	Cat.2	Cat. 3
Public Assets	124	107.97	107.08	103.51	107.08	103.51
Cash	16.6	16.27	14.28	9.82	15.67	15.62
Bonds	2.2	0	0	0	0	0
Net Wealth	138.40	124.24	121.36	113.32	122.75	119.13

The Cameron Parish Police Jury's wealth position is estimated to decrease by \$14.28 million (10.3%) from January 1<sup>st</sup>, 2016 to December 31<sup>st</sup> 2025. This is about \$120 thousand less than the first scenario with no Public Assistance. Fig. 3.19 shows the stock values through time.

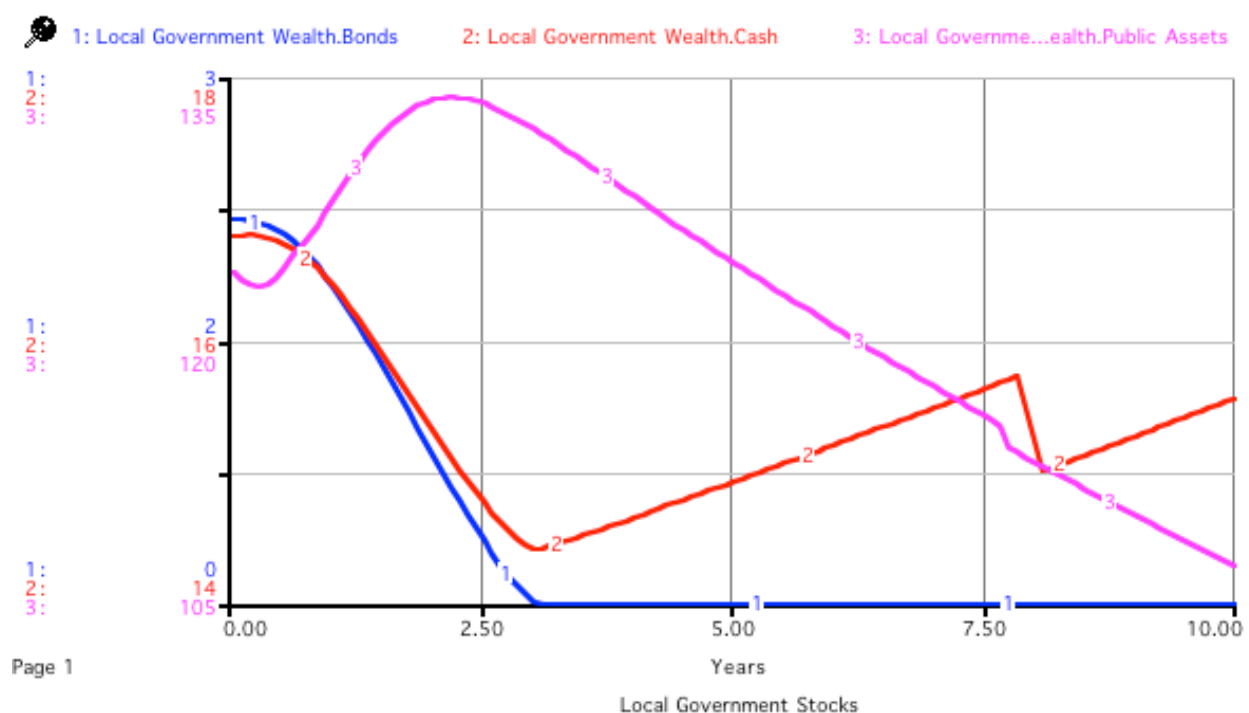


Fig. 3.19 Local government's change in stock values (Bonds, Cash, Public Assets) when shocked by a category 2 hurricane and receiving 70% PA  
Note: The vertical axis is \$ in millions

### 3.6.7 Scenario 2.3: Category 2 Hurricane with Public Assistance and Disaster Relief Fund

In this scenario, the financial conditions are in general kept the same as in the base case with the addition of a Disaster Relief Fund. The Disaster Relief Fund policy aims to raise enough money to cover the possible debris removal costs (\$595,440.00) related to a Category 2 Hurricane making landfall in 15 years and receiving 70% of Public Assistance. Table 3.21 summarizes the shocks to Net Wealth.

Table 3.21 Disaster Shock to Net Wealth

Date (2023)	Total Debris Remaining (cy)	Outsourcing (cy)	Pay Off (\$)	Cash (\$)	PA (\$)	Disaster Relief Fund (\$)
Aug	99,240.96	33,080.32	0	0	0	0
Sept	66,160.64	33,080.32	661,606.40	119,089.15	463,124.48	79,392.77
Oct	33,080.32	33,080.32	661,606.40	119,089.15	463,124.48	79,392.77
Nov	0	0	661,606.40	119,089.15	463,124.48	79,392.77
Dec	0	0	0	0	0	0
Total	-	99,240.96	1,984,819.20	357,267.45	1,389,373.44	238,178.31

There were not enough funds available from the “Disaster Reserve Fund” to cover the 30% remaining from Public Assistance. In this case 12% is covered by the “Disaster Reserve Fund” and 28% by the “Cash Account.” Fig. 3.20 shows the shock to the overall net wealth. Under these conditions, the Net wealth is not affected as much as in the other scenarios.

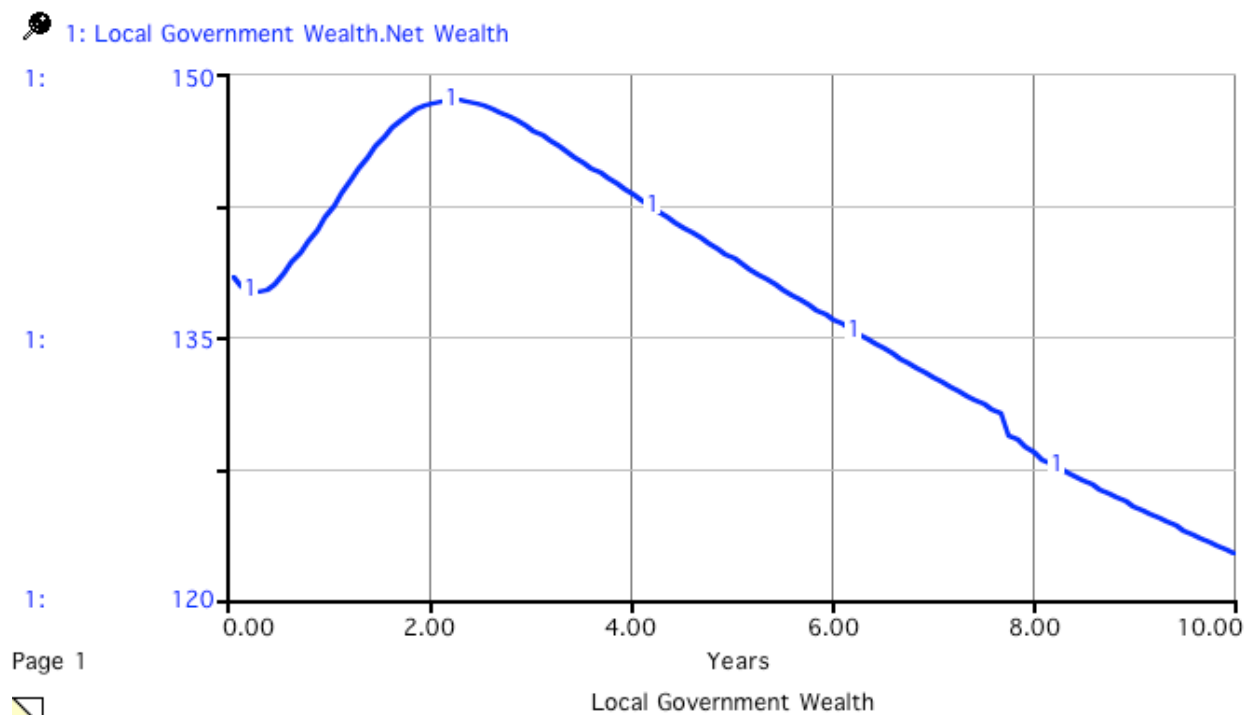


Fig. 3.20 Local government’s change in wealth when shocked by a category 2 hurricane and receiving 70% public assistance  
Note: The vertical axis is \$ in millions

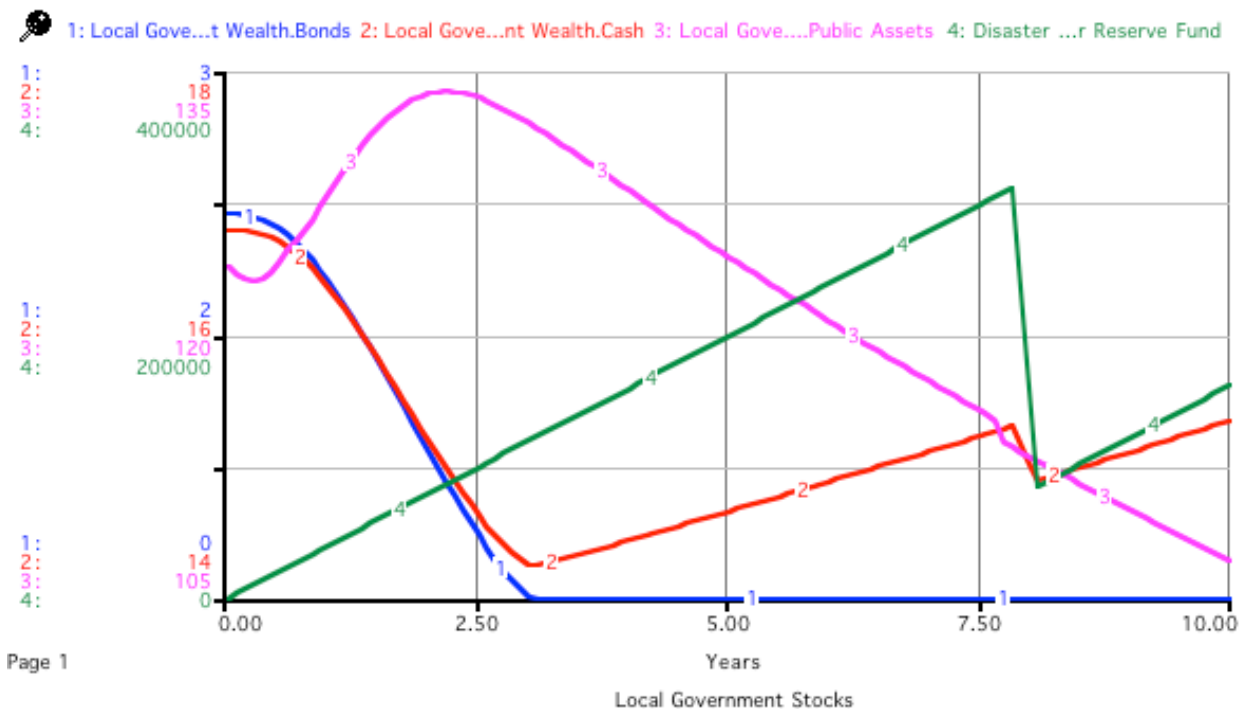


Fig. 3.21 Local government's change in stock values (Bonds, Cash, Public Assets, Disaster Reserve Fund) when shocked by a category 2 hurricane receiving 70% of PA and using Note: The vertical axis for bonds, cash, and public assets is \$ in millions and for disaster reserve fund is in \$.

Under this circumstance, the local government loses infrastructure (\$1 million) due to the severity of the storm. The parish had to pay for debris removal operations from cash account (\$357,267.45) and disaster reserve fund (\$238,178.31). This also recognizes that the local government will receive the Public Assistance funds immediately after the disaster event. The Cameron Parish Police Jury's wealth position is estimated to decrease by \$15.65 million (11.3%) from January 1<sup>st</sup>, 2016 to December 31<sup>st</sup> 2025. The Disaster Reserve Fund as it is being modeled is decreasing the cash available and in the long run affecting the net wealth. The Disaster Reserve Fund is collecting \$40,000 per year. Table 3.22 summarizes the different scenarios modeled.



Table 3.22 Stock Comparison

Stock	Starting Value (\$ million)	Base Case (\$ million)	Scenario # 1 (\$ million)		Scenario # 2 (\$ million)		Scenario # 3 (\$ million)	
			Cat.2	Cat. 3	Cat.2	Cat. 3	Cat. 2	Cat. 3
Public Assets	124	107.97	107.08	103.51	107.08	103.51	107.08	103.51
Cash	16.6	16.27	14.28	9.82	15.67	15.62	15.51	15.48
Bonds	2.2	0	0	0	0	0	0	0
Disaster Relief Fund	-	-	-	-	-	-	0.162	0.142
Net Wealth	138.40	124.24	121.36	113.32	122.75	119.13	122.75	119.13

### 3.7 Conclusion

After a severe disaster event, a local government needs to look beyond the early stages of recovery to measure the long-term effects of disaster management policies. Optimal disaster management planning should consider many possible “what if” scenarios. What if in the next ten years a hurricane category 3 makes landfall? What if the Public Assistance reimbursement program is changed to reduced assistance levels? What if economic growth declines? There are many conditioning factors that can only be truly understood if modeled through time. System Dynamics (SD) allows policy makers to identify the effects of policies at different moments in time. In this research, it could be observed that accounting for a model’s amount of the most recent financial activities (2013-2015) of a local government, a model could be built that projects dynamic changes in net wealth over a multi-year period.

Cameron parish has been affected by destructive storms in the recent past (Hurricane Rita and Hurricane Ike). The population has also been steadily decreasing in the past 10 years. After Hurricane Rita (2005), the initial efforts of recovery were slowed by the impact of Hurricane Ike in 2008. The local government has been actively investing in recovery projects to bring the parish

to a new normal. It has been estimated that on average a hurricane could make landfall in the next 15 years in this region. Using SD modeling could assist local governments in better planning recovery operations after a major disaster based on their resources. It could also better inform a local population and make them more engaged in disaster mitigation activities. The Cameron Parish Police Jury has recently depended on the recovery funds from federal assistance and other grant projects to invest in much needed infrastructure. The dependence on grant money does not give the local government security in being able to recover for a future disaster event if the grants are not available to them. Cameron Parish should analyze alternate sources of funding that will provide the liquidity needed to finance a severe disaster (i.e. lines of credits).

### **3.8 Future Research**

System dynamics modeling is a practical tool when the goal is to model continuous events (i.e. population growth and biological pathways). In the case of this research, shocking the local government system with a discrete event in time, such as a natural disaster occurrence, creates additional challenges, but also opportunities for SD modeling to assist in decision making. The process from debris collection to disposal requires a series of different mandatory steps. It is of great importance to figure out the timing to be able to link the process to the timing of necessary financial resources required to fund debris removal response to communities they can address long-run recovery needs.

It is also important to extend the application of this model to local governments with more complex financial systems. Cameron parish is actually undergoing disaster recovery and much of its financial decisions are oriented towards investments on capital assets. Parishes that have more financial interactions (i.e. Ascensions Parish, East Baton Rouge Parish, Orleans) are the ones that in the end might require extensive disaster preparedness planning.

## **CHAPTER 4: SUMMARY**

This research studied the post-disaster debris management decisions based on historical expense data from Hurricane Katrina (2005), Hurricane Rita (2005), Hurricane Ike (2008), Hurricane Gustav (2008), and Hurricane Isaac (2012) gathered from the Louisiana Public Assistance (PA) platform. The Public Assistance Grant Program (PA Program) administered by the Federal Emergency Management Agency (FEMA) is available for states and communities that have received a major or emergency disaster declaration. A major disaster declaration is requested by a governor based on the disaster assessment in his or her state, and an agreement is submitted to commit state funds and resources to the long-term recovery. An important but often largely overlooked phase among the post-disaster activities is managing the resulting debris. Debris accumulation can pose a severe threat to public health and safety (Roper, 2008). This study had two main objectives: estimate a regression model for optimal local government debris management using post-disaster expense data and evaluate the implications of optimal debris management decisions.

Chapter two addressed the first objective based on the assumption that local government seeks to efficiently allocate resources (Atkinson & Stiglitz, 2015). In the case of debris management activities, there is the option of self-procuring or hiring a third party to process post-disaster debris. Williamson (1996) argues that specific attributes of the outsourcing transaction (asset specificity, frequency, and uncertainty) condition the decision to outsource (Transaction Cost Theory). Barnes (Barnes, 2005) suggests that past outsourcing decisions determine if a local government outsources in the present (Similarity Hypothesis). The empirical model built sets the decision to outsource as a function of asset specificity, historical outsourcing levels, storm and community “shifters”. The OLS econometric regression results suggested that storm and parish

characteristics significantly condition the local government's debris management decision after federally declared disasters. Parishes are more likely to hire a third party to process and dispose debris after more severe storms. It can be possible that the debris accumulated is beyond the capacity of the parish in these higher category disaster events. In more extreme cases, the storms could also take a toll on the local government's labor and equipment assets limiting their ability to clean-up themselves. Parishes with a higher index of community involvement referred to as social capital (number of associations, voter turnout, census response rate, and number of non-profit organizations) were shown to reduce the use of debris removal contracts. The higher the social capital, the more likely that local governments preferred to use their own resources to collect and dispose of debris. There is no statistical evidence from the analyzed data that local governments take into account historical debris outsourcing decisions when deciding how to manage debris in the present. Minimizing debris removal costs may be less an objective of local government decision makers; rather, the goal may be to allow economic returns to physical, human, and social capital redevelop quickly after the disaster. Based on these results, a local government should have an idea of what to expect in the future and build recovery scenarios accounting for their capacity and specific community characteristics.

Chapter three used a System Dynamics (SD) model to evaluate the implications of possible debris management decisions applied to a local rural government in Louisiana. SD modeling can be an efficient sensitivity analysis tool when planning disaster response and recovery operations; it seeks to bridge the gap between forecasting and taking real world decisions. A well-crafted strategic disaster management plan should quickly present available options for a local government and project the consequences of these decisions on both short and long-term horizons. In this section, Cameron Parish was selected for modeling different debris management decisions that a

rural government might address. The limitations of using SD in modelling a discrete event such as a natural disaster is that the model assumes continuous relationships. It is a challenge, but there are methods to go beyond it even though they might not represent the precise reality of the system. After running the model scenarios over 10 year windows of time, it was easy to see how present period interactions affect the overall net wealth in the future. The model had three different modules: The local government's wealth module, the debris management module, and the disaster relief fund module. Three different disaster scenarios for hurricanes category 2 and 3 were modeled and the results compared to the base model output. For the base scenario, the system is not affected by any disaster shock and the financial activities run like they have been in the past three years. The first scenario looks at the total effect on net wealth if the parish receives no public assistance nor has a disaster relief fund in place. The net effect on wealth (10-year period) for a category 3 hurricane is about \$25 million (18%) and for a category 2, \$17.04 million (12%). Both amounts are significantly different from the usual decrease in wealth due to factors as depreciation and government expenses (\$14.16 million). The second scenario highlights the PA program, in the case of a category 3 event the percent reimbursement is assumed to be set a 90 and the rest of the costs were financed by the parish. A hurricane of this category can create as much as 330 thousand cy of debris and could cost about \$6.5 million to remove and process. PA funding significantly decreases the burden of disaster recovery activities (debris removal). It is expected that under PA funding, the net effect of a category 3 hurricane on wealth is about \$19.27 million (13.9%) which is \$5 million less than without PA (scenario #1). A category 2 hurricane produces about 30% of the debris created under a category 3 event. The costs of debris removal are less, but still affect the net wealth of the parish in the long term. In the case of a category 2 hurricane, it is assumed the PA percent reimbursement will be 70 percent and the rest of the costs were financed by the parish.

In the long run, the net wealth of the parish decreases by \$15.65 million (11%) compared to a 12% under opposite funding conditions. The last scenario models a tentative disaster reserve policy that aims to raise enough funds to be able to cover all costs (\$595,440.00) associated with a possible category 2 storm 15 years from today. The net wealth effects were the same as with only covering costs with PA and Cash. The Disaster Fund pulls a yearly amount (\$40,000) from the cash account, and has a similar impact as when paying all remaining debris removal costs with cash only.

The purpose of this research was to identify the optimal debris removal method and analyze the impacts of debris management policies. Optimal debris removal is not strictly minimizing a cost function. In disaster response and recovery operations, what is optimal is not necessarily the inexpensive option. Many of the disaster events studied were extremely devastating and debris removal operations were essential.

Understanding the implications of recovery and response policy, specifically when facing constraints as lack of federal assistance funding, should help local governments become more resilient as they face a future of uncertainty. SD modeling visualizes all of the tentative effects of different activities that take place in a complex financial system as it is shocked by a disaster. If tools, like SD were integrated more in the formation of policies, local governments could be able to better analyze the long run effects of decisions made today.

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## APPENDIX

### A. H\*winds Hurricane Katrina Max-1 sustained surface winds (kt)

#### Hurricane Katrina 0000 UTC 29 AUG 2005

Max 1-min sustained surface winds (kt)

Valid for marine exposure over water, open terrain exposure over land

Analysis based on AFREC from 0105 - 0259 z; SFMR43 from 2100 - 0120 z;

CMAN from 2100 - 0300 z; FCMP\_TOWER from 2109 - 0255 z;

ASOS from 2105 - 0259 z; BACKGROUND\_FIELD from 0000 - 0000 z;

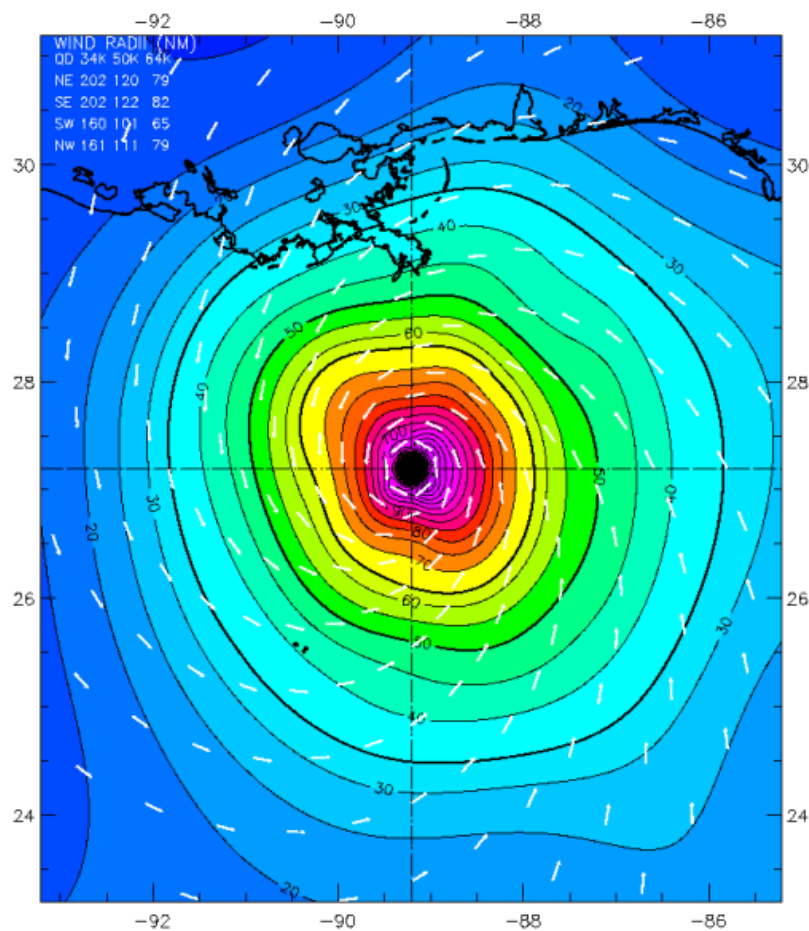
QSCAT from 2349 - 2351 z; SHIP from 2118 - 0300 z;

GPSSONDE\_WL150 from 2103 - 0239 z; METAR from 2105 - 0255 z;

MOORED\_BUOY from 2100 - 0300 z; TAIL\_DOPPLER43 from 2231 - 2326 z;

MESONET from 2100 - 0300 z;

0000 z position interpolated from 2326 Army Corps; mslp = 904.0 mb



Reprinted from h\*winds Hurricane Katrina wind data [http://www.rms.com/perils/hwind/legacy-archive/storms/data/PostAnalysis/2005/AL122005/0829/0000/AL122005\\_0829\\_0000\\_contour08.png](http://www.rms.com/perils/hwind/legacy-archive/storms/data/PostAnalysis/2005/AL122005/0829/0000/AL122005_0829_0000_contour08.png)

## B. Tropical Cyclone Report Best Track Positions

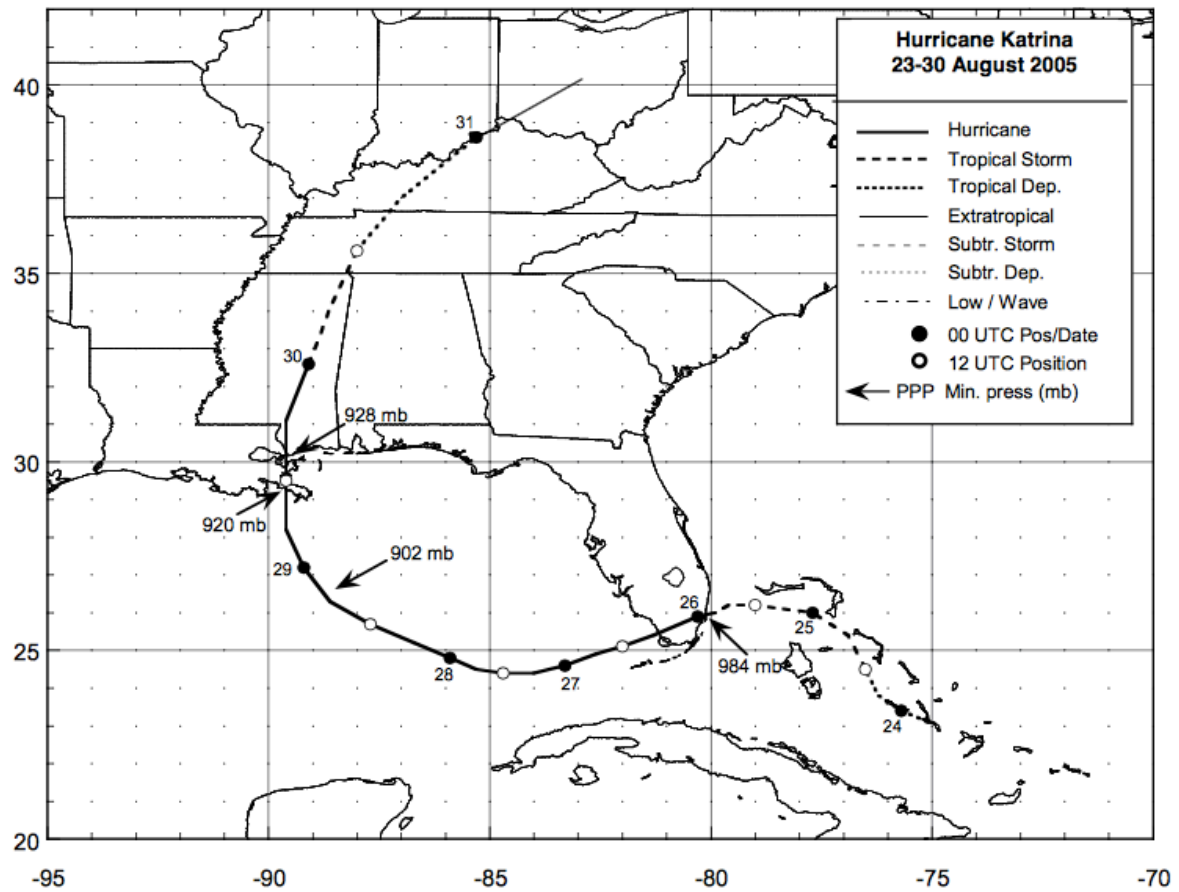


Fig. B.1 Best track positions for Hurricane Katrina, 23-30 August 2005. Reprinted from Tropical Cyclone Report Hurricane Katrina by NHC, 2005, p.37.

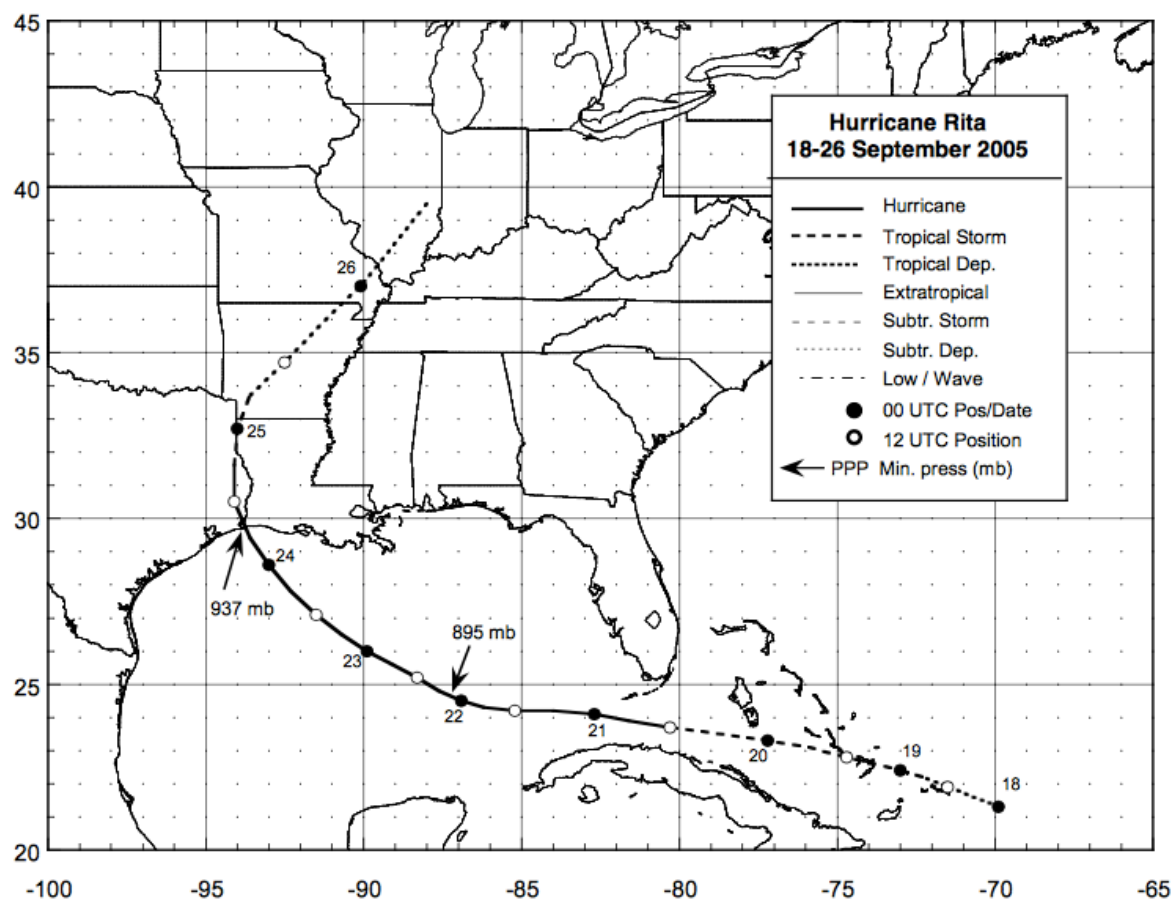


Fig.B.2. Best track positions for Hurricane Rita, 18- 26 September 2005. Reprinted from Tropical Cyclone Report Hurricane Rita by NHC, 2006, p.30.



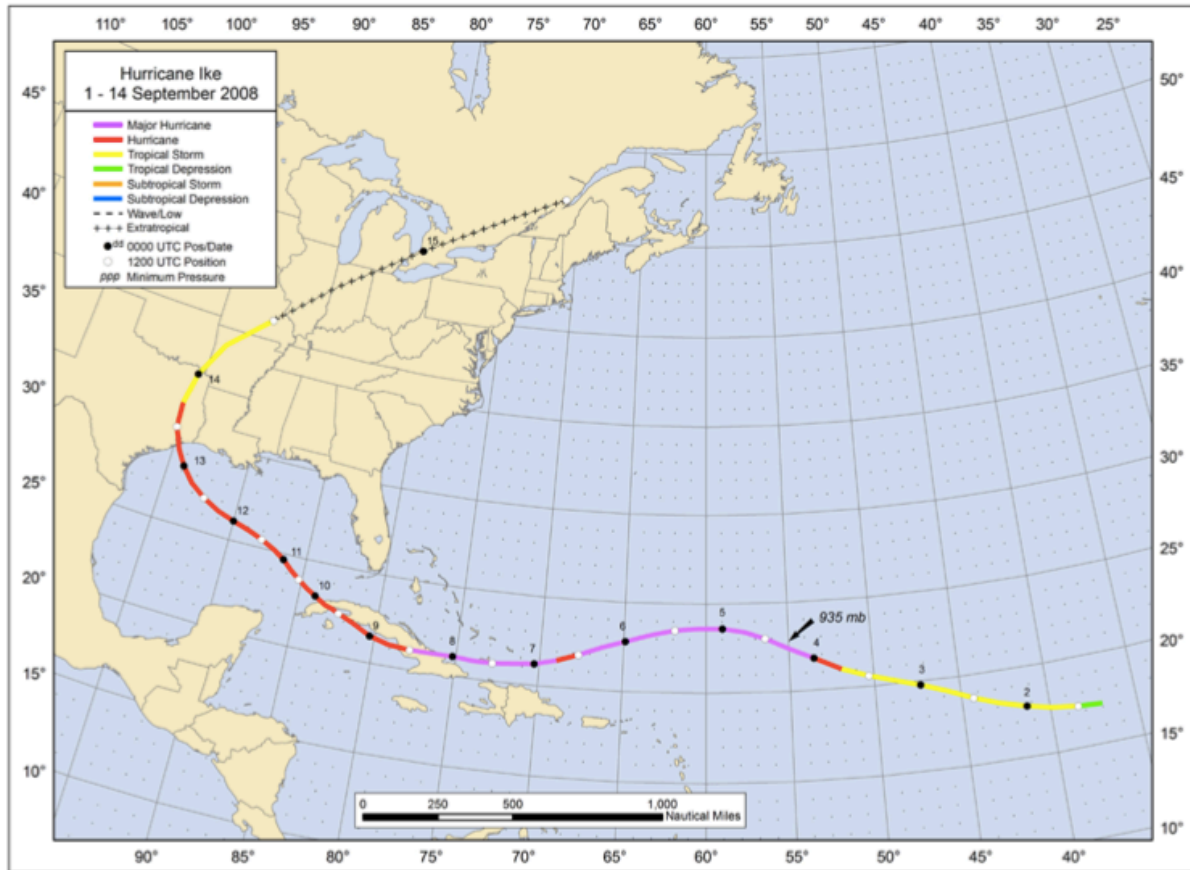


Fig. B.3. Best track positions for Hurricane Ike, 1 – 14 September 2008. Track during the extratropical stage is based on analyses from the NOAA Hydrometeorological Prediction Center and Environment Canada. Reprinted from Tropical Cyclone Report Hurricane Ike by NHC, 2009, p. 43.

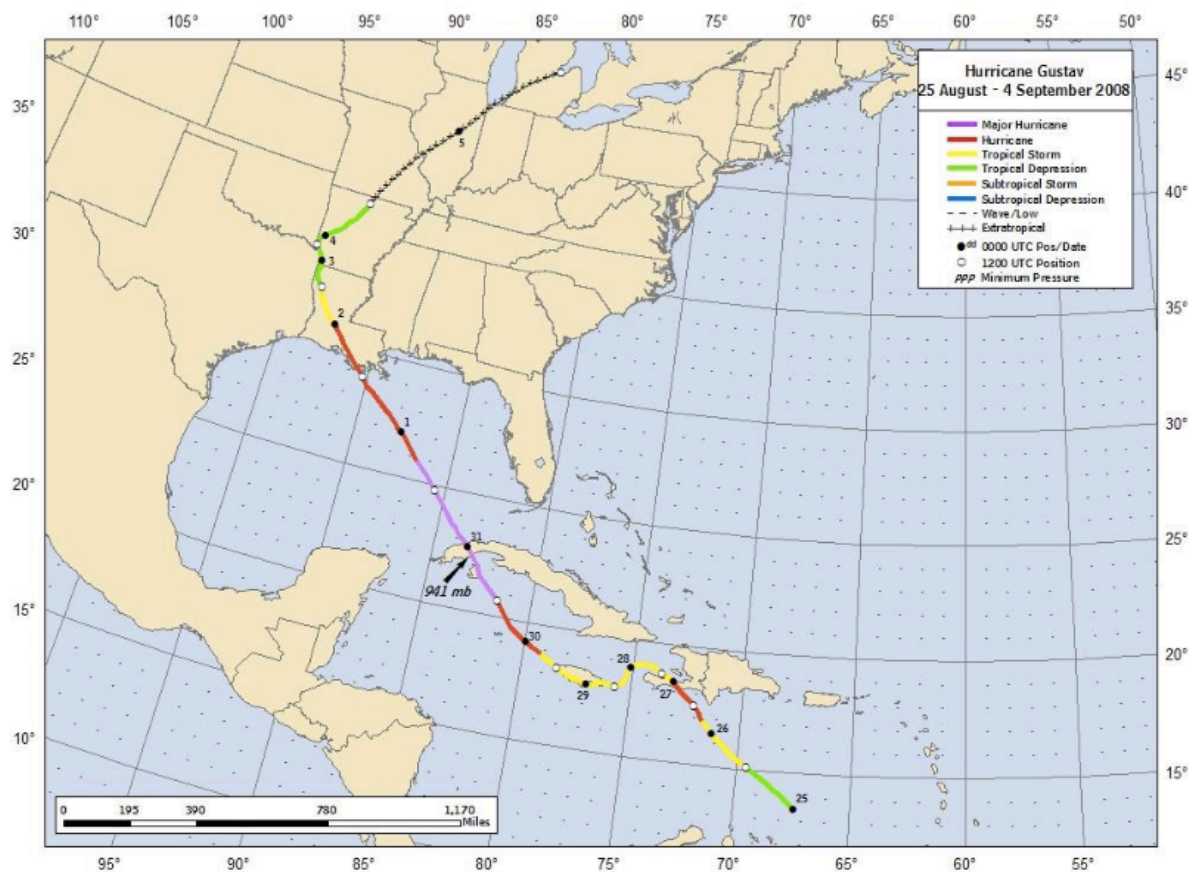


Fig. B.4. Best track positions for Hurricane Gustav, 25 August – 4 September 2008. Track during the extratropical stage is based on analyses from the NOAA Hydrometeorological Prediction Center. Reprinted from Tropical Cyclone Report Hurricane Gustav by NHC, 2009, p.43.

### **C. U.S. Army Corps of Engineers Debris Estimation Formula**

The information was adapted from the Public Assistance Debris Management Guide published July 2007.

Formula:  $Q = H(C)(V)(B)(S)$  where

Q is the quantity of debris in cubic yards

H is the number of households

C is the storm category factor in cubic yards

- (1) 2cy
- (2) 8cy
- (3) 26cy
- (4) 50cy
- (5) 80cy

V is the vegetation characteristic multiplier

- Light (1.1)
- Medium (1.3)
- Heavy (1.5)

B is the commercial/business multiplier

- Light (1.0)
- Medium (1.2)
- Heavy (1.3)

S is the storm precipitation characteristics multiplier

- None to Light (1.0)
- Medium to Heavy (1.3)

## D. STELLA® Models and Equations

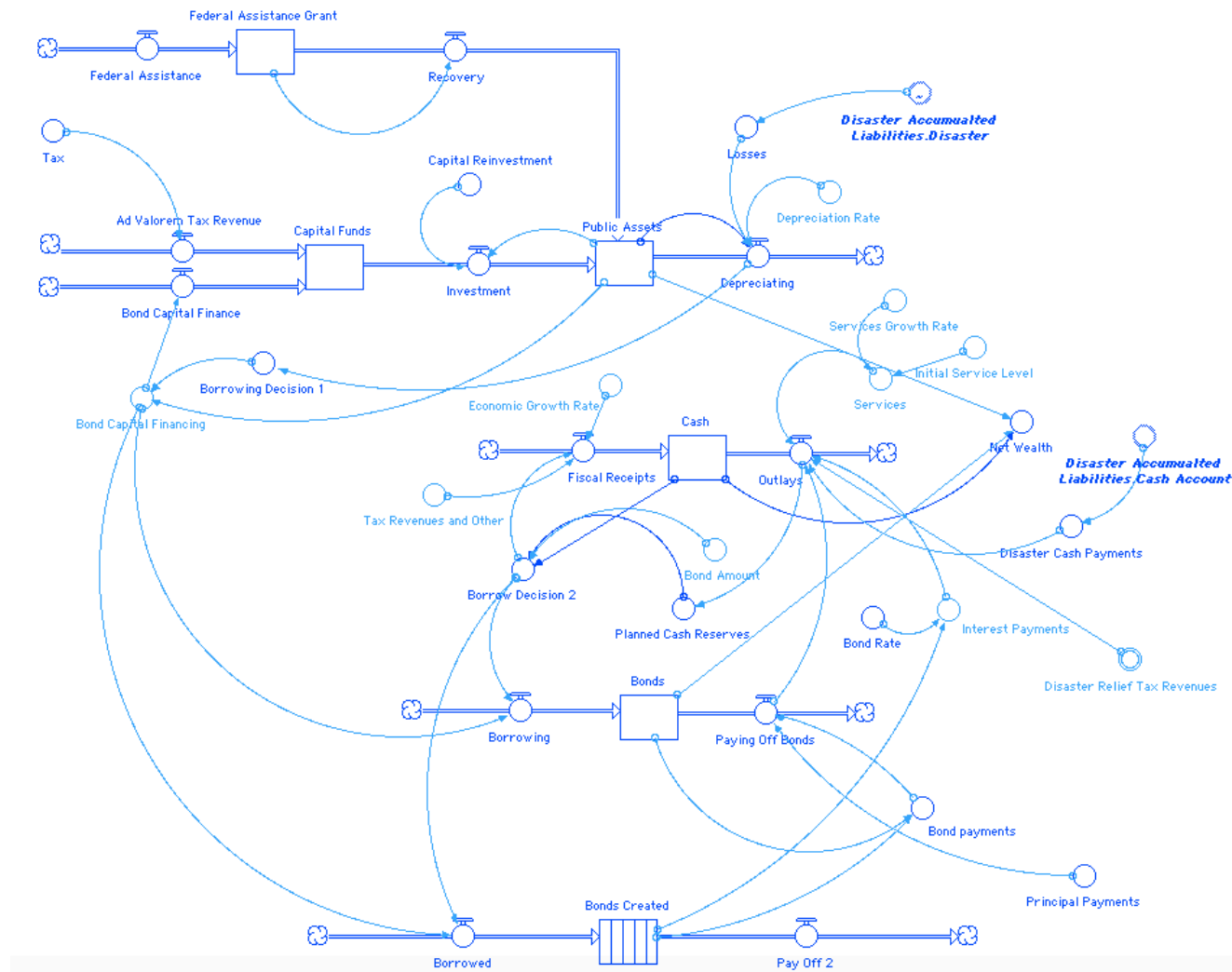


Fig. D.5 Local Government Wealth Module

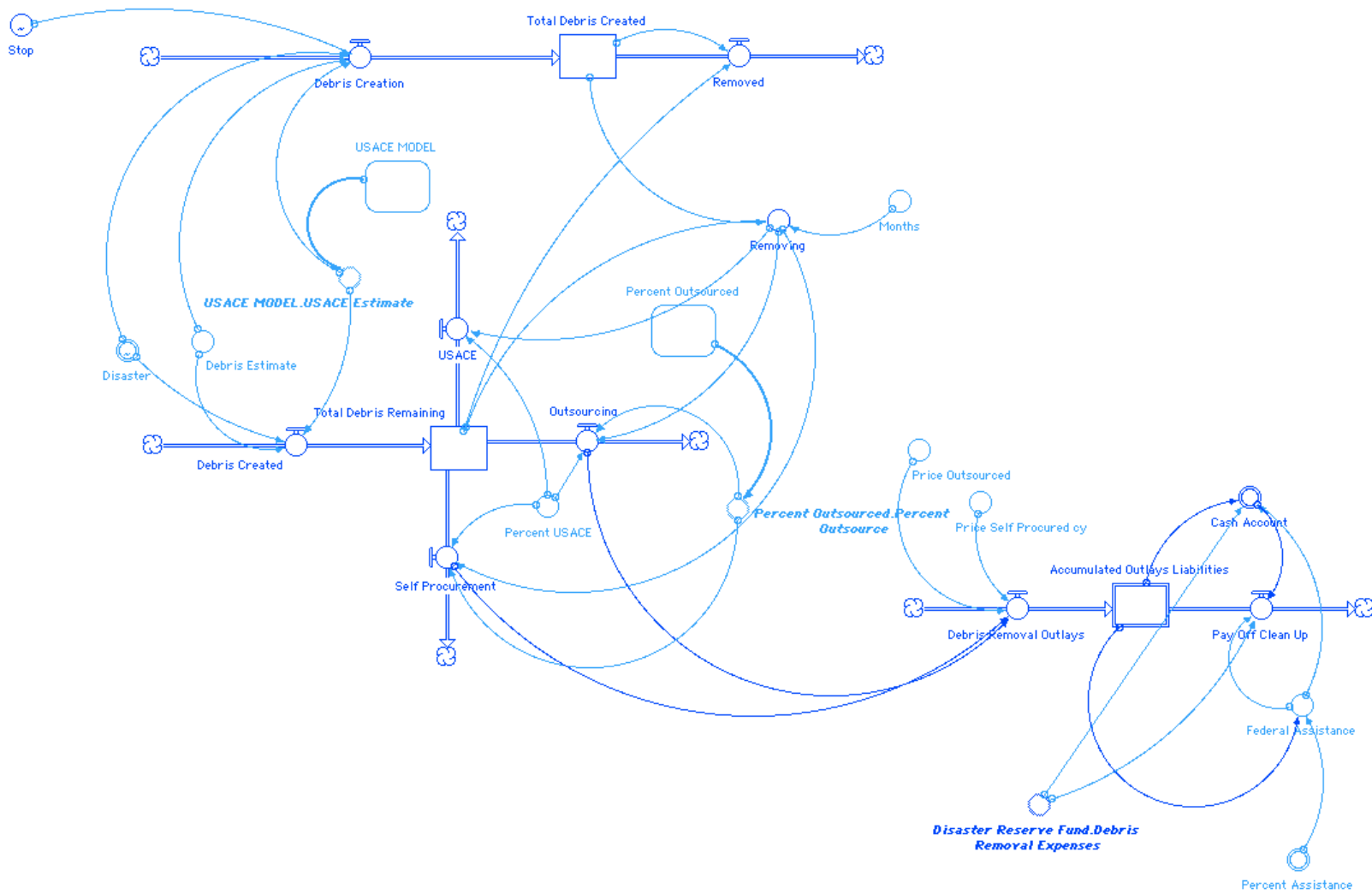


Fig. D.6 Debris Management Module

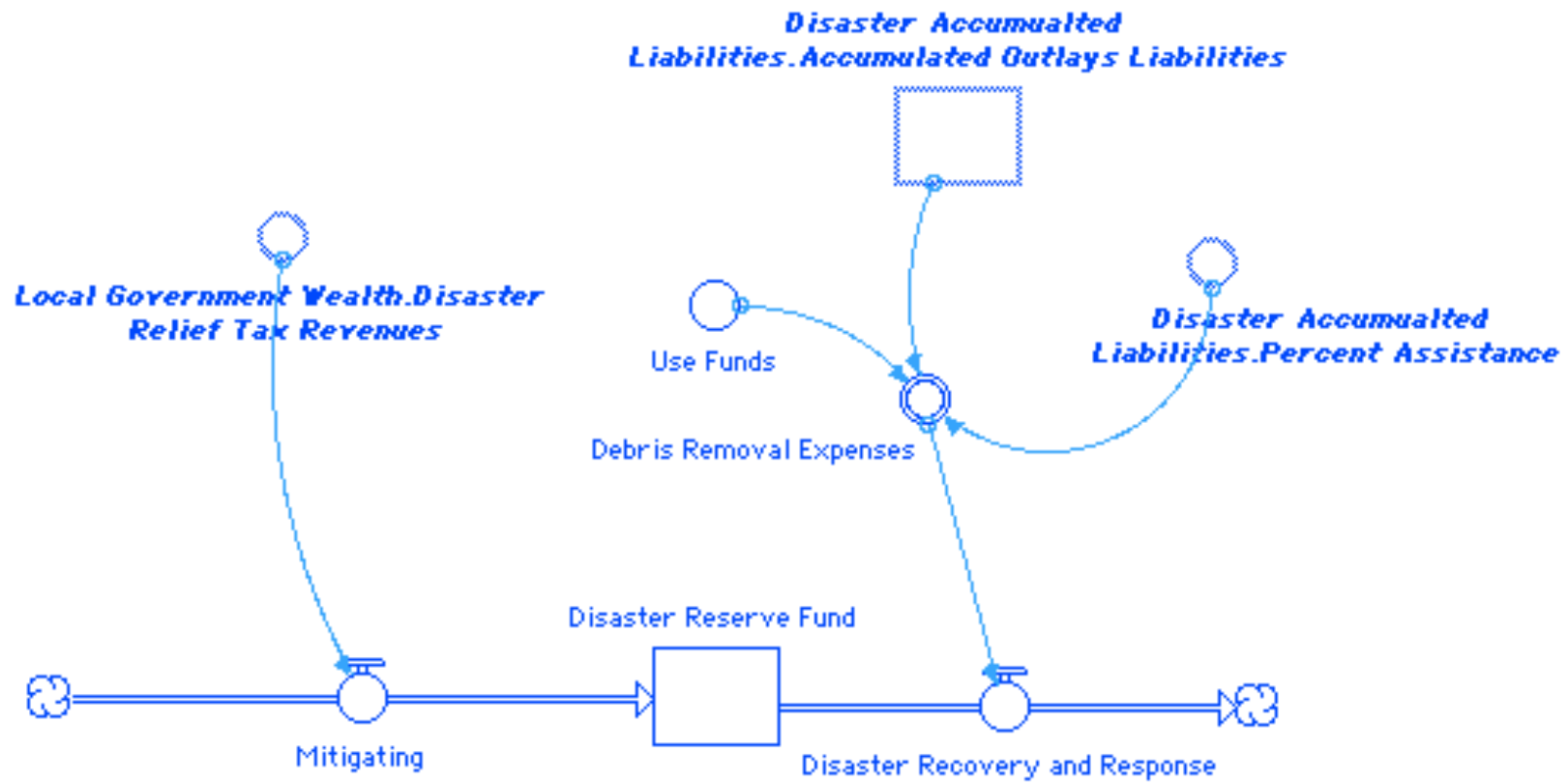


Fig. D.7 Disaster Relief Fund Module

☐  $\text{Accumulated\_Outlays\_Liabilities}(t) = \text{Accumulated\_Outlays\_Liabilities}(t - dt) + (\text{Debris\_Removal\_Outlays} - \text{Pay\_Off\_Clean\_Up}) * dt$   
 INIT  $\text{Accumulated\_Outlays\_Liabilities} = 0$

INFLOWS:

☐  $\text{Debris\_Removal\_Outlays} = ((\text{Self\_Procurement} * (\text{Price\_Self\_Procured\_cy})) + (\text{Outsourcing} * (\text{Price\_Outsourced})))$

OUTFLOWS:

☐  $\text{Pay\_Off\_Clean\_Up} = (\text{Federal\_Assistance}) / DT + \text{Disaster\_Reserve\_Fund} . \text{Disaster\_Recovery\_and\_Response}$

☐  $\text{Total\_Debris\_Created}(t) = \text{Total\_Debris\_Created}(t - dt) + (\text{Debris\_Creation} - \text{Removed}) * dt$   
 INIT  $\text{Total\_Debris\_Created} = 0$

INFLOWS:

☐  $\text{Debris\_Creation} = (((\text{USACE\_MODEL} . \text{USACE\_Estimate} + \text{Debris\_Estimate}) / DT) * \text{Disaster}) * \text{Stop}$

OUTFLOWS:

☐  $\text{Removed} = \text{IF } \text{Total\_Debris\_Remaining} = 0 \text{ THEN } \text{Total\_Debris\_Created} / DT \text{ ELSE } 0$

☐  $\text{Total\_Debris\_Remaining}(t) = \text{Total\_Debris\_Remaining}(t - dt) + (\text{Debris\_Created} - \text{Self\_Procurement} - \text{Outsourcing}) * dt$   
 INIT  $\text{Total\_Debris\_Remaining} = 0$

INFLOWS:

☐  $\text{Debris\_Created} = ((\text{USACE\_MODEL} . \text{USACE\_Estimate} + \text{Debris\_Estimate}) / DT) * \text{Disaster}$

OUTFLOWS:

☐  $\text{Self\_Procurement} = ((\text{Removing}) * (1 - \text{Percent\_Outsourced} . \text{Percent\_Outsource})) / DT$   
☐  $\text{Outsourcing} = (\text{Removing} * \text{Percent\_Outsourced} . \text{Percent\_Outsource}) / DT$

☐  $\text{Cash\_Account} = ((1 - \text{Percent\_Assistance}) * \text{Accumulated\_Outlays\_Liabilities}) * 0$   
☐  $\text{Debris\_Estimate} = 0$

Fig. D.8 Formulas for Debris Management System Dynamics Model

☐  $Bonds(t) = Bonds(t - dt) + (Borrowing - Paying\_Off\_Bonds) * dt$   
 INIT Bonds = 2.2  
 INFLOWS:  
      $Borrowing = (Borrow\_Decision\_2 + Bond\_Capital\_Financing) * DT$   
 OUTFLOWS:  
      $Paying\_Off\_Bonds = (Bond\_payments) + (Principal\_Payments * TIME)$

☐  $Capital\_Funds(t) = Capital\_Funds(t - dt) + (Ad\_Valorem\_Tax\_Revenue + Bond\_Capital\_Finance - Investment) * dt$   
 INIT Capital\_Funds = 0.3  
 INFLOWS:  
      $Ad\_Valorem\_Tax\_Revenue = Tax$   
      $Bond\_Capital\_Finance = Bond\_Capital\_Financing * DT$   
 OUTFLOWS:  
      $Investment = (Capital\_Reinvestment * Public\_Assets) * TIME$

☐  $Cash(t) = Cash(t - dt) + (Fiscal\_Receipts - Outlays) * dt$   
 INIT Cash = 16.6  
 INFLOWS:  
      $Fiscal\_Receipts = (Economic\_Growth\_Rate * Tax\_Revenues\_and\_Other * TIME) + Tax\_Revenues\_and\_Other + Borrow\_Decision\_2$   
 OUTFLOWS:  
      $Outlays = Paying\_Off\_Bonds + Services + Interest\_Payments + (Disaster\_Cash\_Payments / DT) + Interests + Disaster\_Relief\_Tax\_Revenues$

☐  $Federal\_Assistance\_Grant(t) = Federal\_Assistance\_Grant(t - dt) + (Federal\_Assistance - Recovery) * dt$   
 INIT Federal\_Assistance\_Grant = 20  
 INFLOWS:  
      $Federal\_Assistance = 0$   
 OUTFLOWS:  
      $Recovery = Federal\_Assistance\_Grant * TIME$

☐  $Public\_Assets(t) = Public\_Assets(t - dt) + (Recovery + Investment - Depreciating) * dt$   
 INIT Public\_Assets = 124  
 INFLOWS:  
      $Recovery = Federal\_Assistance\_Grant * TIME$   
      $Investment = (Capital\_Reinvestment * Public\_Assets) * TIME$   
 OUTFLOWS:  
      $Depreciating = (Depreciation\_Rate * Public\_Assets) + (Losses / DT)$

Fig. D.9 Formulas for Public Wealth System Dynamics Model



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☐  $\text{Disaster\_Reserve\_Fund}(t) = \text{Disaster\_Reserve\_Fund}(t - dt) + (\text{Mitigating} - \text{Disaster\_Recovery\_and\_Response}) * dt$   
 INIT Disaster\_Reserve\_Fund = 0  
 INFLOWS:  
      Mitigating = Local\_Government\_Wealth.Disaster\_Relief\_Tax\_Revenues\*1000000  
 OUTFLOWS:  
      Disaster\_Recovery\_and\_Response = Use\_Funds/DT  
☐ Disaster\_Reserve = Disaster\_Reserve\_Fund/1000000  
☐ Use\_Funds = (0.3)\*Disaster\_Accumualted\_Liabilities.Accumulated\_Outlays\_Liabilities

Fig. D.10 Formulas for Debris Management System Dynamics Model

## **VITA**

Alejandra Rebeca Brevé Ferrari is a native of Tegucigalpa, Honduras. She received her Bachelor of Science in Animal Science with concentration in production from Louisiana State University in May of 2011. Thereafter, she spent three years in Honduras working on several development projects. She along with her family started the non-profit association ASOPAZH. They assist at risk children and previously incarcerated women from the village of San Matias located 40 minutes from the capital city of Tegucigalpa. She entered the Master of Science in Agricultural Economics program at Louisiana State University in 2014. She plans to transition into the PhD program after graduation.