3. A decision analysis of options to rebuild the New Orleans flood control system

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INTRODUCTION

The levees and floodwalls protecting New Orleans from hurricanes and floods were designed to withstand a Saffir–Simpson category 3 hurricane (see US Army Corps of Engineers – USACE, 1984). When making landfall on 29 August 2005, Hurricane Katrina was designated a category 4 hurricane; later, it was downgraded to a severe category 3. The devastation that followed was more extensive than predicted by the USACE in 1984, but it was close to predictions made by scientists and emergency managers in more recent years (see Maestri, 2002; Laska, 2004). When examining the analyses conducted to support the 1984 decisions to fortify the levees and floodwalls, von Winterfeldt (2006, p. 31) concluded:

> In summary, there were several problems with the analyses and decisions regarding the development of levees and floodwalls in the New Orleans area: 1) probabilities and consequences of extreme hurricane events were underestimated; 2) alternatives that provided a higher level of protection were not explored; 3) the preferred alternative was implemented slowly and with many funding delays.

Subsequent reports (for examples, Interagency Performance Evaluation Task Force – IPET, 2006; Seed et al., 2006) came to similar conclusions.

More than a year later, the United States was again facing decisions about how to fortify and upgrade the flood protection system of New Orleans. In a previous paper (von Winterfeldt, 2006), we developed a simple decision tree analysis comparing two alternatives: rebuilding the levees and floodwalls to a 100-year flood protection level or building a new system that has a higher 1000-year protection level. Using a parametric analysis, the previous paper showed that a higher level of protection can be cost-effective. The previous paper also described improvements to be implemented in a more complete and comprehensive analysis.

This chapter makes another step in this direction by developing a decision analysis of options for the levee and floodwall system in and around New Orleans. Like the previous paper, we assume that substantial portions of New Orleans will be rebuilt and require protection. Moreover, we consider a comprehensive list of options for flood mitigation, of the possible types of events in terms of precipitation-, overtopping- and breach-induced floods, and of the consequences of these types of events. We use historical data to develop realistic estimates of flood frequencies and consequences and combine these estimates with a parametric analysis of events for which little historic data is available (for example, breaches, sabotage) or for which consequences are uncertain (for example, fatalities as a function of evacuation speed). We developed this analysis framework in the form of an influence diagram, a well-established modeling tool in risk and decision analysis (Clemen, 1997).

NEW ORLEANS'S SYSTEM OF LEVEES AND FLOODWALLS

The levees and floodwalls developed by the USACE in the 1970s and 1980s reduced the risks of flood damage and provided economic development opportunities. At the time the USACE designed the system, its analysts believed that it protected New Orleans against a 100-year flood (that is, a flood of such magnitude that would occur, on average, only once in 100 years). However, due to many optimistic assumptions (for example, no levee breaches, rapid evacuation and resettlement, no consideration of fatalities), the analysts overestimated the level of protection and underestimated the consequences of such a major flood. In fact, the New Orleans area had experienced two near misses of category 3 hurricanes (Betsy in 1965 and Camille in 1969) which suggested that the probability of a category 3 or more severe hurricane (which would induce a '100-year' flood event) was much higher than one in 100 years.

Furthermore, the levels of protection decreased over time due to natural and man-made changes. Natural changes included continuing subsidence, lack of sedimentation and declining vegetative growth. Land use changes such as road building and increased residential densities induced hydrologic changes (including faster run-off) that reduced the level of protection provided by levees and floodwalls. And, while these levees and floodwalls required regular and extensive maintenance, their record of maintenance quality was spotty.

Over time, New Orleans's levees and floodwalls became structurally deficient and presented an increased risk to public safety and to the region's economic infrastructure. Minimum standards to regulate and to enforce the design, placement, construction and maintenance of levees and floodwalls had been and are critical to the built environment of New Orleans and its reconstruction. Indeed, the structural integrity and protection level of southeastern Louisiana's floodwall and levee system will strongly influence the extent of resettlement in New Orleans and influence the probability and consequences of future catastrophic hurricanes and floods.

In urban areas, the federal government has typically designed levees and other flood damage reduction projects with a 100-year flood threshold as the minimum standard for identifying, mapping and managing flood hazards. Participating National Flood Insurance Program (NFIP) communities are required to adopt building codes and other types of activities that reduce losses posed by a 100-year flood as a result of mandates by the Federal Emergency Management Agency (FEMA) and in order to maintain eligibility for ~~this program~~. ~~The~~ FEMA also requires levees and floodwalls protecting flood-prone areas to be certified for structural soundness and proper maintenance to a 100-year flood level. The USACE performs most of these certifications. However, its current process does not assess the geotechnical or hydrological conditions of the levees, and neither the areas to be protected nor the structures built behind the protection of 100-year levees are classified as within 'designated floodplains'.

The accuracy of maps used by the FEMA to define flood hazard areas is also problematic, as more than three-quarters of these maps are more than a decade old, raising concerns that hydrologic data has changed since the maps were last reviewed and updated.

MODEL OVERVIEW

In modeling future floods and their expected consequences in New Orleans, many input quantities can only be estimated, and, as such, they have an inherent degree of uncertainty. A model that explicitly specifies the range of uncertainty in its inputs can provide more realistic and informative estimates than deterministic assessments. Influence diagrams are a useful tool in mapping out the decisions, events, and variables that influence the potential consequences of decisions and events (see, for example, Clemen, 1997). In this analysis, we use a software tool, Analytica (see www.lumina.com), to assist in modeling an influence diagram that represents the interrelationships among approximately 58 variables that include data for wind, rain, wave action, geology, engineering, demographics and the potential for negative consequences of hurricanes and floods in the New Orleans area.

At the highest level, we use a NOLA Flood Control Risk Analysis System with two major ~~locational~~ submodels: Mississippi River flood frequency modeling (Model A) and Lake Pontchartrain flood frequency modeling (Model B), plus additional submodels that incorporate land use and mitigation options and demographic and consequence valuations for the New Orleans area. The submodels aggregate the expected frequencies of floods with their expected severities and present their expected costs as a function of their mitigation options. This model–submodel hierarchy of influence diagrams within Analytica serves as its key organizational tool. Because the visual layout of this influence diagram is intuitive, ~~its readers~~ are able to learn about ~~the model's~~ structure and organization quickly through ~~its~~ visual paradigms.

The influence diagram also serves as a tool for communication. An understanding of how the results are obtained and of how the various assumptions impact the results is often more important than the specific input and output numbers. In addition to communicating high-level findings, stakeholders can examine lower levels of modeling when more detail is desired, aided by the visual aspects of the model's structure. As stakeholders are able to understand this model easily, debate and discussion can focus more directly upon specific assumptions and lead to more productive results. Thus, the influence diagram serves as a tool to help to make the model accessible.

Following is a brief description of the influence diagram structure, followed by a description of the model inputs and calculations.

The Mississippi flood submodel is shown in Figure 3.1. Floods are divided into two classes of chance nodes based on cause: overtopping and breaches caused by overtopping floods (which include upstream Mississippi River floodwaters compounded by sinking floodwalls and design errors as well as downstream Mississippi River surges compounded by sinking floodwalls and design errors); and breaches caused by anything other than overtopping (this includes terrorist acts, poor workmanship or materials, and design errors).

Figure 3.2 shows the Lake Pontchartrain submodel. Once again, floods are divided into two classes based on cause: overtopping and breaches caused by overtopping ~~floods~~ (which include Lake Pontchartrain surges, seiches and waves compounded by sinking floodwalls and design errors) and breaches caused by anything other than overtopping (this includes terrorist acts, poor workmanship or materials, and design errors).

The land use submodel includes the options considered in this analysis for improvements of the levee and floodwall system:

- Restoring levees and ~~floodwall to the current (base) levels~~
- Increasing the levees and floodwalls by 5 feet.
- Increasing the levees and floodwalls by 10 feet.

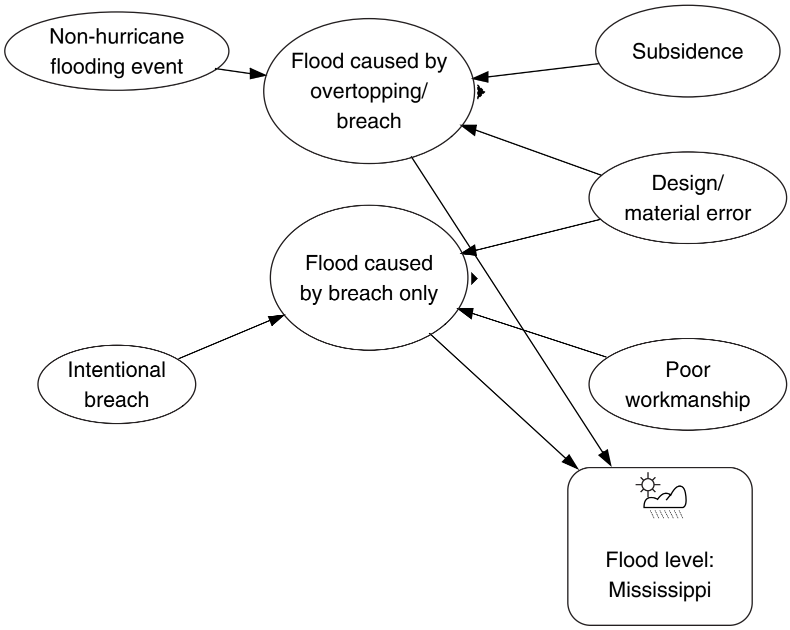


Figure 3.1 Mississippi flood submodel

Other options that can be explored with this model are improved levee maintenance and improved pumping systems and channels.

The demographics submodel contains the information representative of the housing stock and population in the New Orleans areas subject to possible flooding. This demographic information is used in the loss calculations, which determine, for each flood level, two consequences: lives lost and economic impacts. Lives lost are converted to economic equivalents by using a value of life of either $5 million or $10 million.

The analysis submodel (Figure 3.3) shows three decision nodes (rectangles). From the land use submodel, floodwall and levee heights can be selected. In addition, an option to allow the use of river flow cut-offs, such as the use of partial rechanneling of the Mississippi River down the Atchafalalya River during severe floods, is introduced. Attenuated by these choices, the products of flood and hurricane severities and frequencies return expected annual flood and hurricane losses and costs (net losses plus mitigation costs) for the New Orleans area. The uncertain quantities are specified using probability distributions. When evaluated, the distributions are sampled using Monte Carlo sampling, and the samples are propagated through the computations to the expected annual flood consequences (in

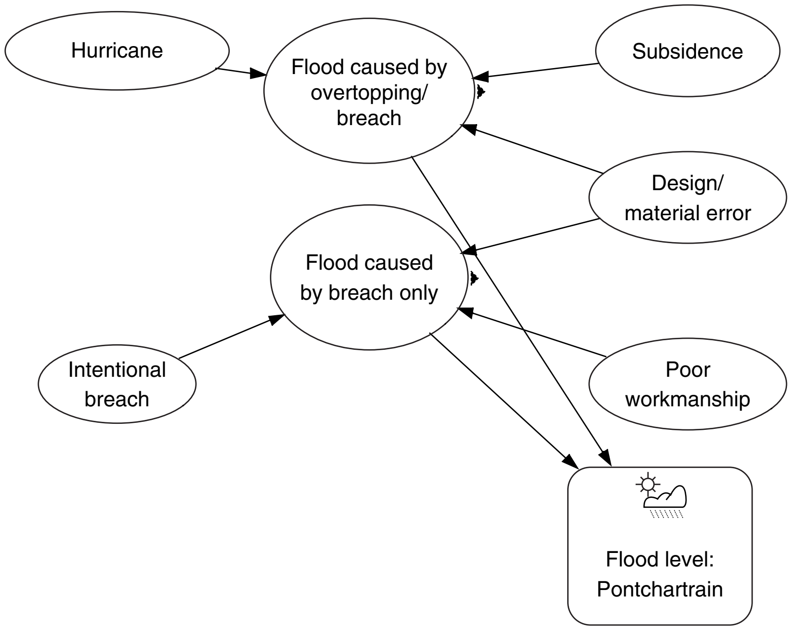


Figure 3.2 Lake Pontchartrain flood submodel

terms of lives lost and economic impacts). These distributions of consequences can then be analyzed in light of various mitigation strategies to evaluate the expected costs and benefits of these strategies.

FLOOD FREQUENCY RISK ANALYSIS

The frequency distributions of potential floods in the New Orleans area were based on historical data. As a starting point, we assumed that catastrophic floods could inundate New Orleans through two major pathways: one primarily from the south and east via hurricanes as occurred with Hurricane Katrina, and the other primarily from the north via Mississippi River basin flood flows as in the extreme example of the Great Mississippi Flood of 1927 (see Barry, 1997).

In an attempt to capture accurate historic records of floods along the east side of New Orleans (that is, the Lake Pontchartrain shoreline and similar areas) and along the banks of the Mississippi River, we used ~~the~~ United States Geological Survey (USGS) flood gauge data of peak annual flood discharges from a flood gauge station on Lake Pontchartrain and from two Mississippi River gauges, one upstream in Baton Rouge, Louisiana, and one

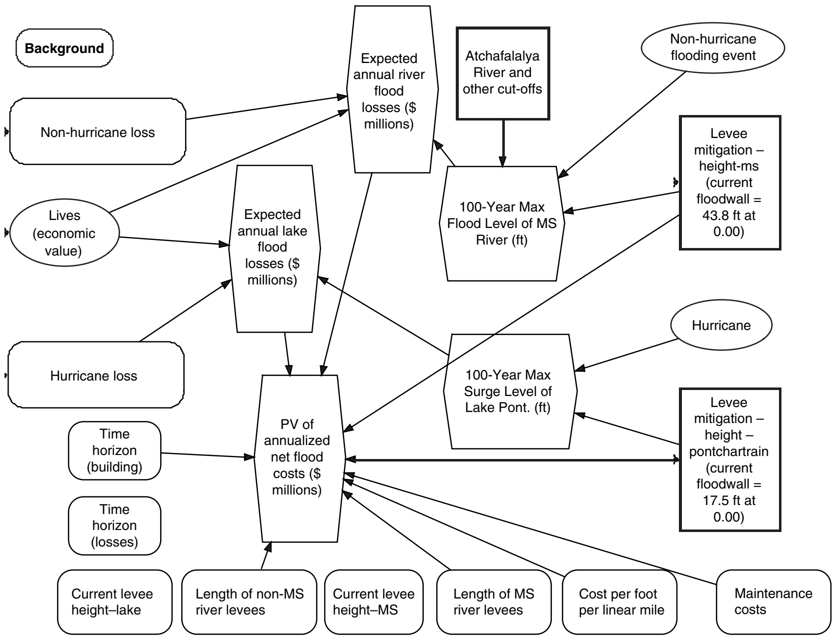


Figure 3.3 Analysis submodel

downstream in West Pointe a La Hache, Louisiana. For the Mississippi River, two gauges were selected to represent maximum flood waters along the Mississippi River in New Orleans because, historically, cut-offs and intentional levee breaches have been used to temper rising waters along the banks of the Mississippi in New Orleans. The Baton Rouge station, then, was used as a proxy for maximum flood potential from Mississippi basin floods that are resultant from upstream run-off, and the West Pointe a La Hache station was used as a proxy for downstream surge from approaching hurricanes.

Table 3.1 shows the relationship between storm categories, wind speed, minimum surface pressure and storm surge. Minimum pressures and surge heights are important in associating floods with the Saffir–Simpson scale of hurricane intensities (Simpson, 1974; also see http://www.ncdc.noaa.gov/oa/satellite/satelliteseye/educational/saffir.html).

For bodies of water with water-level gauges such as Lake Pontchartrain, a standard flood frequency analysis procedure is used. This procedure is promulgated from guidelines, known as *Bulletin 17* (U.S. Interagency Advisory Committee on Water Data, 1982), that are the official procedures of federal agencies in the United States. *Bulletin 17* characterizes flood

Table 3.1 Relationships between storm categories, wind speed, minimum surface pressure and storm surge

Saffir-Simpson Category	Wind speed		Minimum surface pressure mb	Storm surge ft
	mi/h	m/s		
1	74–95	33–42	greater than 980	3–5
2	96–110	43–49	979–965	6–8
3	111–130	50–58	964–945	9–12
4	131–155	59–69	944–920	13–18
5	155+	69+	less than 920	18+

frequency at a given location as a function based on the sequence of annual data points known as the 'peak annual flood discharges' that are defined as the annual maximum water levels at the flood gauge location. These magnitudes are assumed to be independent random variables that are represented by log-Pearson Type III (gamma) probability distributions. These distributions give the annual exceedence probabilities, the probability that a flood will exceed a given magnitude in an annual period.

Bulletin 17 defines the annual peak flows for a site and describes the calculations in detail. Its steps include data collection, outlier detection and adjustment, skew adjustment, curve computation, plotting and confidence ~~limits~~ calculation. A flood frequency curve is typically formulated for each type of hazard that is applicable, for example, upstream rainstorm, snowmelt run-off and hurricanes. As such, each hazard curve is a conditional probability curve. The unconditional probability distribution is obtained by weighting the conditional probability curves in proportion to the chance that a flood will be of each respective type. A means of expressing the magnitude of an expected flood is through the use of a term known as a 'return period' or probability of exceedence. The exceedence probability is not a random event, but a quantile of the flood frequency distribution. Thus, the probability of an exceedence next year for a 100-year return period is 1 percent, regardless of this year's outcome; the probability of exceedence in the year after next is 0.99×1 percent, and so forth, such that the average time to the next exceedence is 100 years.

The choice of a simple functional form for flood frequency distributions is problematic. Three of the more common choices for flood frequency are the extreme value distribution, the logistic distribution, and the lognormal distribution. We chose the logistic to represent the flood–surge exceedence curves for the Lake Pontchartrain floods and surges because it represents a reasonable fit to both the hurricane-induced and non-hurricane-induced floods, it is an available and flexible option within the Analytica modeling software, and its problematic tails are censored and truncated in the analysis. The logistic distribution's cumulative distribution function (cdf) is defined as follows:

$$F(x,\mu,s) = 1/(1 + e^{-(x-\mu)/s})$$

The probability density function (pdf) of the logistic distribution is given by:

$$f(x,\mu,s) = e^{-(x-\mu)/s}/[s(1+e^{-(x-\mu)/s})^2]$$

The μ (mean) for the selected distribution is 10.487, and its s (shape) is 6.988. The fitted cdf was based on hurricane flood frequency calculations derived from standard project hurricane (SPH) frequency analyses for Lake Pontchartrain. This distribution represents the expected range of maxima of lake depths plus surge heights in feet over a return period equivalent to the number of years of data. An adjustment factor was used to convert the 32 available, annual data points to a distribution of measurements whose return period is 100 years (according to the formula, adjustment factor = (1 − [1/selected interval])/{1 − [1/actual interval]} or 1.021935484).

In addition to expected surge, seiche or wave maxima, the probability of non-overtopping-related breaches due to design errors, poor workmanship, improper materials and intentional sabotage as well as the gradual sinking of existing levees and floodwalls due to subsidence were incorporated. Design errors, poor workmanship and improper materials were estimated to cause catastrophic structural failure (without floodwater assistance) an average of once in 10 000 years. A Poisson distribution represents this failure rate. Intentional sabotage was estimated at a fixed probability of 1 in 10 000 per year, due to a lack of specific threat information. Average subsidence was estimated at 0.081 ft per year based on the estimates of subsidence as much as 0.162 ft per year (see Westerrint, 2003). We also assumed that, once cumulative subsidence reaches 1 ft, mitigation occurs.

The product of these distributions returned a distribution of peak water levels for Lake Pontchartain (see Figure 3.4). The current average height of the levees and floodwalls above the lake's water level was estimated at 17.5 ft. From this measure, we constructed levee heights for different mitigation options at 17.5 ft, 22.5 ft and 27.5 ft. Floods are expected when peak water levels exceed the levee heights.

We determined the cumulative distribution function over flood levels in the Mississippi River in a similar manner. For purposes of this analysis, we selected the logistic function to represent the flood-surge exceedence curves for ~~the~~ Mississippi River floods. The μ (mean) for this selected distribution is

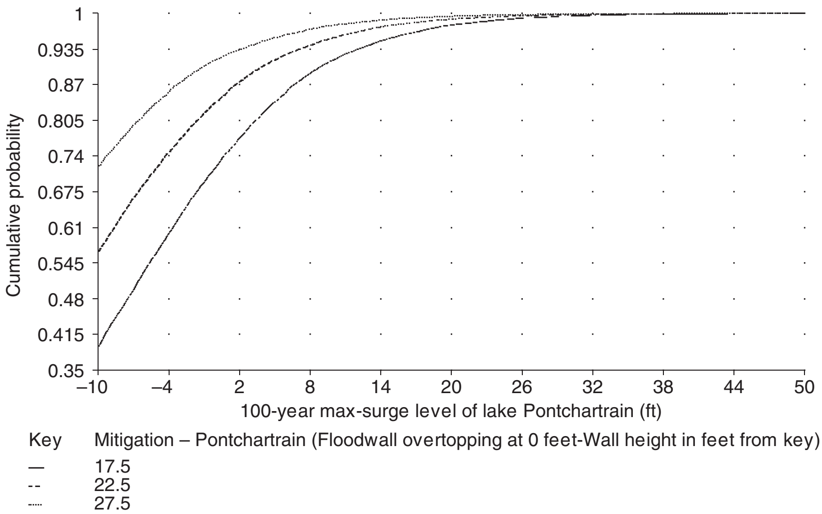


Figure 3.4 Cumulative distribution functions of 100-year flood levels for Lake Pontchartrain for different levels of protection

23.483, and the *s* (shape) is 15.708. The fitted cdf was based on the distribution using non-hurricane flood frequency calculations starting with a standard log-Pearson Type III analysis for the Mississippi River at New Orleans, Louisiana representing river depth in feet over return period in years. This distribution represents the expected range of maxima of river depths over a return period equivalent to the number of years of data. An adjustment factor of 0.998182 was used to convert these 122 available annual data points to a distribution of measurements whose return period is 100 years.

In addition to expected floodwater maxima, the probability of non-overtopping-related breaches due to design errors, poor workmanship, improper materials and intentional sabotage as well as the gradual sinking of existing levees and floodwalls due to subsidence were incorporated. Design errors, poor workmanship, and improper materials were estimated to cause catastrophic structural failure (without floodwater assistance) an average of once in 10 000 years. A Poisson distribution represents this failure rate. Intentional sabotage was estimated at a fixed probability of 1 in 10 000 per year. Average subsidence was estimated at 0.081 ft per year based on the estimates of subsidence as much as 0.162 ft per year. We also assumed that, once cumulative subsidence reaches 1 ft, mitigation occurs.

The product of these distributions returned a distribution of peak water levels for the Mississippi River. The current average height of the levees and floodwalls above the river's bottom near its banks was estimated at 43.8 ft. From this measure, we constructed theoretical levee or floodwall heights at 43.8 ft, 48.8 ft and 53.8 ft (see Figure 3.5a). Floods are expected when peak water levels exceed the floodwall heights (represented as ~~flood =~~ 0.00 ft in the graph).

EVALUATION OF THE CONSEQUENCES OF FLOODS AND HURRICANES

We estimated both economic consequences of floods and the number of lives lost, depending on surge and flood levels, breaches and evacuation times. For the expected flood level for hurricanes, economic (excluding the value of lives) consequences were estimated in this analysis by utilizing historic economic consequences data collected by the National Oceanic and Atmospheric Administration (NOAA) (see Blake et al., 2006 and Landsea et al., 2003) adjusted to current levels (see Pielke et al., 2002). Historic hurricane losses were trended to current loss expectation levels by adjusting past losses for the cumulative effects of economic inflation, the growth of infrastructure and population change. The economic inflation adjustment was accomplished by using the annual Consumer Price Indices (CPI) from the US Bureau of Labor Statistics (see www.bls.gov). Infrastructure changes were quantified by using the annual indices measuring investments in fixed assets available from the US Bureau of Economic Analysis (see www.bea.gov). Finally, annual population estimates were derived from the US Bureau of the Census (see www.census.gov). The adjusted losses (from 1955 to current) were then fitted to a cumulative size-of-loss distribution as a gamma distribution (Figure 3.6) with an α of 0.1305 and a β of 62 500.

For non-hurricane floods, we estimated the non-hurricane flood economic (excluding the value of lives) consequences by utilizing historic economic ~~consequences~~ data collected by the National Weather Service (NWS, a part of the NOAA) (see Pielke et al., 2002) adjusted to current levels (Figure 3.7). Historic flood losses were trended to current loss expectation levels by adjusting past losses for the cumulative effects of economic inflation, the growth of infrastructure and population change similar to the hurricane consequences' data. The adjusted economic losses (from 1955 to current) were then fitted to a cumulative loss distribution fitted as a log-logistic distribution (Figure 3.8) with a μ (mean) of 3.622 and an *s* (shape) of 2.996 (see Figure 3.8). In addition, we included an option for the use of cut-offs, such as the Atchafalaya River, during floods to decrease the peak flows. When the use of cut-offs is allowed, it was assumed to reduce the floodwater peaks by 50 percent and vastly reduce the potential for a

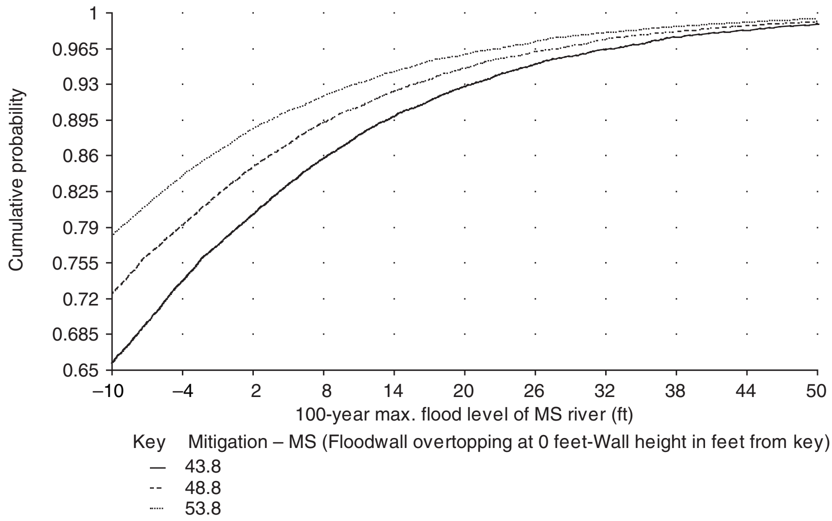


Figure 3.5a *Cumulative distribution function of 100-year flood levels at the Mississippi River for different protection levels and assuming no use of cut-offs*

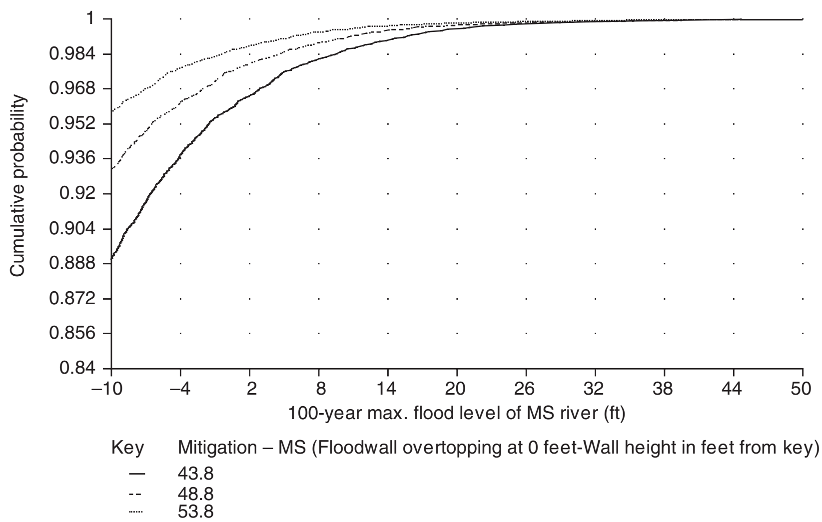


Figure 3.5b *Cumulative distribution function of 100-year flood levels at the Mississippi River for different protection levels and assuming use of cut-offs*

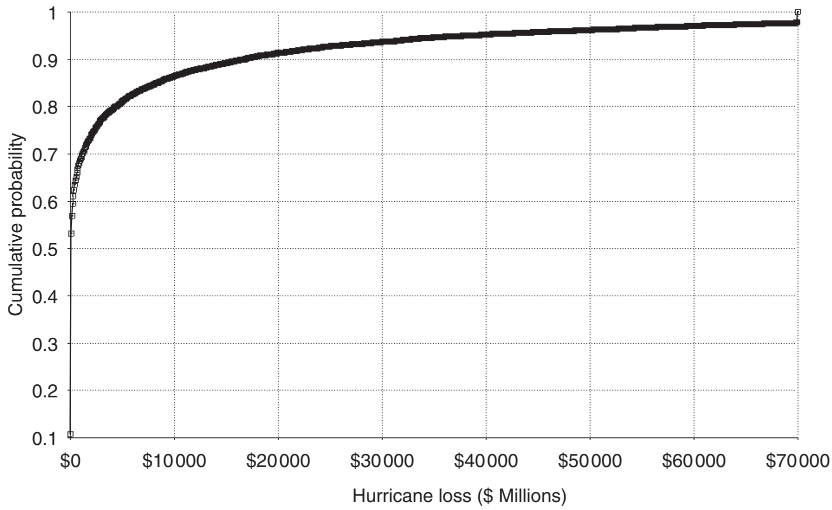


Figure 3.6 Cumulative severity distribution of hurricane losses (in $ millions and excluding value of lives)

Mississippi River inundation in the city of New Orleans (see, for example, Figure 3.5b).

The economic value of losses of lives for both hurricane and non-hurricane floods was estimated in this analysis as a function of the population at risk, the evacuation time, and the assigned economic value of a lost life, namely, the economic value of lives lost equals the selected value of life times the estimated lives lost where the estimated lives lost is assumed to be the ratio of the population at risk of dying to the product of the estimated number of hours of evacuation time (before the flooding event) and 36.236466 (from Brown and Graham, 1988; also see Stedge et al., 2006). Figure 3.8 uses $10 million as the value of a life and displays the economic values of lives lost as a function of evacuation time. Note that this is independent of the type of flooding event.

The aggregate economic value of an event, then, is derived simply as the products of the frequencies of these events and the sums of their independent economic severity distributions and the value of life distributions.

SOME PRELIMINARY RESULTS

We consider first a base case analysis, comparing the expected costs of several options to reduce the risk of floods in the New Orleans area,

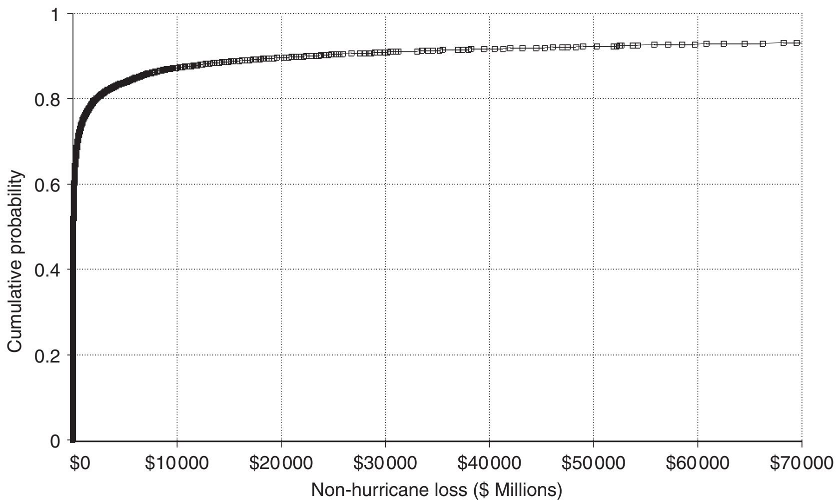


Figure 3.7 Cumulative severity distribution of non-hurricane flood losses (in $ millions and excluding value of lives)

followed by several sensitivity analyses. Figure 3.9 shows, in the form of bar charts, how the expected costs compare to one another. There are three major messages conveyed by this figure. First, the expected consequences of a flood are dominated by the economic impacts rather than by the potential fatalities; second, the mitigation costs are commensurate with the economic costs of floods; and, third, there appear to be three contenders that minimize the total expected costs: the status quo with cut-offs, increased levee heights at the Mississippi with cut-offs, and increased levee heights at Lake Pontchartrain with cut-offs. Note that all three options include cut-offs.

Lake Pontchartrain mitigation options are substantially more expensive than Mississippi River options, but the savings in terms of economic losses avoided tend to more than make up for the expense. In this analysis, mitigation of floodwalls and levees by increasing height is assumed to cost $3 265 000 per vertical foot per mile. The Mississippi side of the levee and floodwall system is approximately 100 miles long; the Lake Pontchartrain side (including the interior fortifications), about 250 miles.

Interestingly, the Atchafalaya River and other potential 'relief valves' that serve as flood flow cut-offs in the event of upstream flooding provide an estimated mitigation value of as much as $2.3 billion annually. Indeed, New Orleans has depended on such cut-offs historically to avoid Mississippi River inundations. In the future, given the physical characteristics of the upstream region that is home to the Old River Control Structure and similar upstream

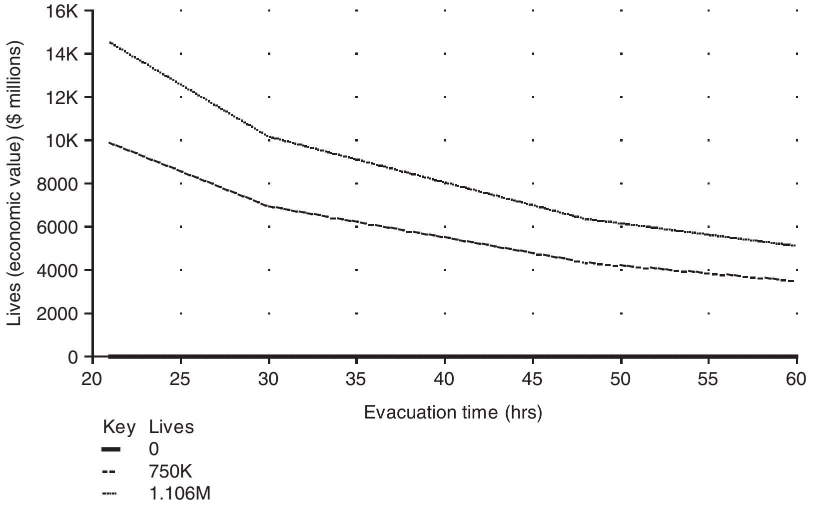


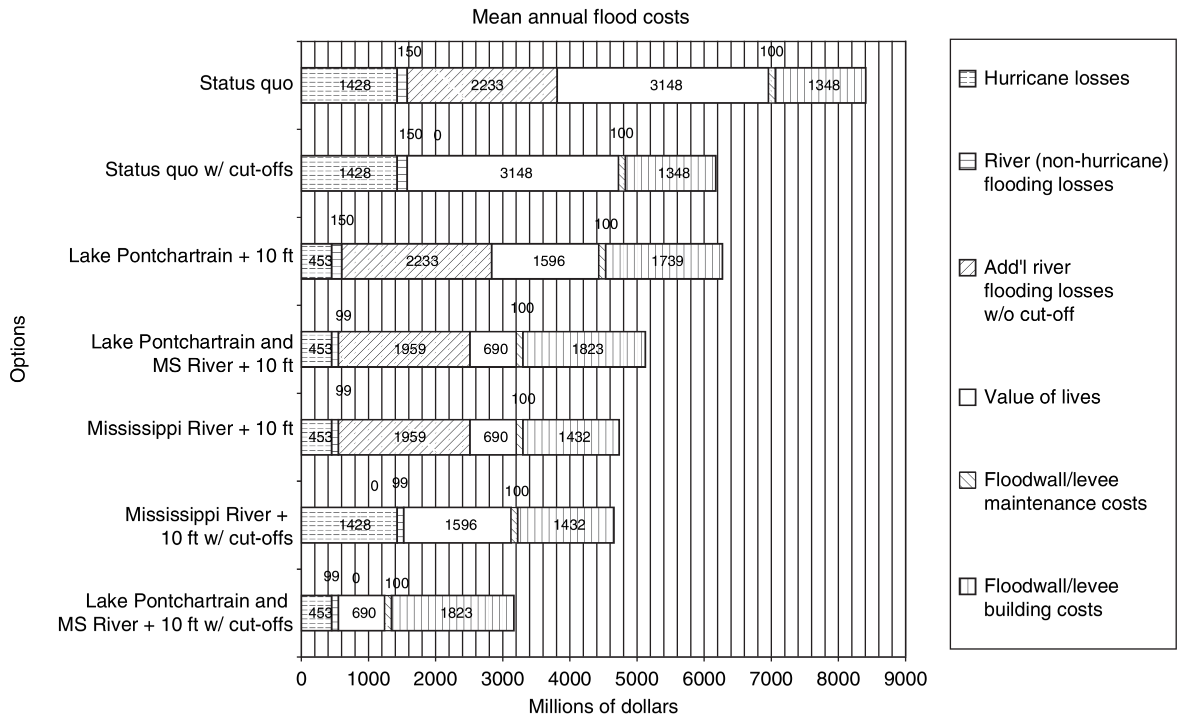
Figure 3.8 Cumulative severity of lives (in $ millions) as a function of evacuation time

areas with significant sandy deposits and gradients steeper than the current Mississippi River bed, it may be prudent to consider carefully this traditional mitigation strategy. Potentially, its use could catalyze the necessary initial conditions for the avulsion of the Mississippi to the Atchafalaya. An avulsion of the Mississippi River has the potential to doom irreparably the economy and future welfare of New Orleans and Baton Rouge.

This analysis is most sensitive, respectively, to the economic value we impute to a human life, to mandatory evacuation time, and to the combined levee or floodwall height on the Lake Pontchartrain side of New Orleans. Simply stated, the most immediate, significant flood and hurricane mitigations in New Orleans can be accomplished by increasing minimum, mandatory evacuation times for hurricanes to 48 hours or more and by giving first priority to repairs and fortifications of levees and floodwalls on the Lake Pontchartrain side of New Orleans.

CONCLUSIONS

To avoid repeating the mistakes of the past, this analysis can serve as an example of being more realistic about the assessment of probabilities of these future extreme events and about their consequences. Some preliminary results include the following:



Note: These are from all causes assuming a population of 750 000, 48-hour evacuation time, mitigation costs for levee and floodwall fortification and maintenance, 7 percent interest, \$3.265 million per vertical foot per mile construction costs, and an imputed value of \$10 million per life.

Figure 3.9 Net annual flood costs

- Increasing the floodwall and levee heights by 10 feet can be cost-effective.
- Continuing to provide a Mississippi River cut-off option seems to be very cost-effective.
- Increasing mandatory hurricane evacuation periods to at least 48 hours and, on a prescribed basis, for up to 60 hours can be very cost-effective and save many lives.

This analysis can be improved in several important ways:

- Improving the breach and overtopping model.
- Using formal expert judgment methods to improve the assessment of probability distributions and their parameters.
- Using uncertainty analysis to account for changes in frequencies and severities of flooding due to climate change phenomena.
- Using uncertainty analysis to assess the impacts of subsidence and the benefits of subsidence mitigation options.
- Using uncertainty analysis to assess the feasibility and effects of varying evacuation times.
- Developing and analyzing a more complete set of consequence measures, including impacts on the ecology, habitat, environmental justice, and so on.
- Involvement of stakeholders in the design and modification of the analysis and in the interpretation and communication of the results.

In addition, it may be worthwhile to consider other options, for example:

- Assigning floodplains that are enclosed by levees and floodwalls within prescribed bounds the status of 'designated floodplain', regardless of the engineering standards of the levees and floodwalls.
- Reworking floodplain maps on a regular basis to reflect more accurately elevation changes due to natural (for example, subsidence, erosion) and man-made impacts (for example, global warming, subsidence caused by oil and gas extraction, hardscaping effects).
- Addressing floodwall and levee improvement in creative ways (for example, considering use of slurry walls in levees, trading-off additional floodwall height for marsh restoration – for example 1 ft of floodwalls is approximately equivalent to 2.7 miles of restored marshlands – or other sustainable improvements).
- Considering the probable avulsion of the Mississippi River in considering the refortification and rebuilding of New Orleans.

Perhaps an optimal allocation would incorporate a multiple-lines-of-defense strategy that incorporates the principles and lessons of integrated coastal zone management (ICZM) and includes the combined buffering impacts of the offshore shelf within the Gulf of Mexico, the Louisiana barrier islands, the Louisiana sounds, marshland bridges, natural ridges, man-made soil foundations, floodgates, flood protection levees, flood protection pumping, elevated homes and businesses, and enhanced and more timely evacuation procedures (IPET, 2006).

Hurricane Katrina was a major natural disaster, the impacts of which were exacerbated by a poorly performing flood protection system due to engineering and institutional failures, questionable judgments, and errors involved in the design, construction, operation and maintenance of the system. The organizational and institutional problems associated with the response and recovery efforts for this combined natural and man-made disaster resulted in one of America's most severe catastrophes.

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