Analysis of the New Orleans Levee System

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Topics Covered

- Introduction
- Cause of Floods
- Facts
- Requirements
- Risk Mitigation
- Country Benchmarking
- Stakeholders
- Cost
- Lessons Learned
- New Orleans was built on a delta marsh
- Half of the city sits below sea level
- The city is surrounded by the Mississippi River to the south, Lake Pontchartrain to the north, Lake Borgne to the east.
- Due to poorly designed levees and the worst civil engineering failure in United States history, most of the city experienced flooding similar to a direct hit of a tsunami.
New Orleans Bowl Shape

New Orleans Area Map

Floodwall Along Mississippi River

- 23 FT
- 18 FT Project Flowline
- Avg Annual Highwater 14 FT

Hurricane Protection Levee & Floodwall

- 17.5 FT
- SPH Design Elevation 11.5 FT
- Normal Lake 1.0 FT Level

Elevations in Feet NGVD

- 30
- 20
- 10
- 0
- -10
- -20

Gentilly Ridge

City of New Orleans Ground Elevations
From Canal St. at the Mississippi River to the Lakefront at U.N.O.
Facts

- Hurricane Katrina was the greatest natural disaster in the history of the United States

- 80% of New Orleans flooded, that's an area equal in size to SEVEN Manhattan Islands

- Nearly 124,000 jobs were lost which crippled the region’s economy

- Approx. 1,500 people died; 134 were still missing two years after the storm

- Nearly half the population never returned

- Over 800,000-plus citizens were forced to live outside of their homes
Why New Orleans is Vulnerable To Floods and Hurricanes?

- Location near Gulf of Mexico, and other bodies of water
- Low elevation (near sea-level)
- Sea-level rise due to global warming
- Petroleum Extraction - When oil and natural gas are extracted from the subsurface, sediment that once held the oil in the pore spaces, compacts, resulting in subsidence.
- Inadequate, poorly designed, & incomplete hurricane protection system and population expanding into lower lying areas
What Went Wrong And Why

- The I-walls failed because the margin of safety used in the design process was too low — especially considering that the hurricane protection system was a critical life-safety structure.
- The engineering design did not account for the variability in the strength of soft soils beneath and adjacent to the levees.
- The designers failed to take into account a water-filled gap that developed behind the I-walls as they bowed outward from the forces exerted by the floodwaters.
What Went Wrong And Why

- The risks were not well understood or communicated effectively to the public, the importance of evacuating people and protecting property was under-estimated
- The projects were constructed as individual pieces — not as an interconnected system
- Levee builders used an incorrect datum to measure levee elevations — resulting in many levees not being built high enough
- No single agency was in charge of protecting New Orleans
- Lack of inter-agency coordination led to many adverse consequences from Hurricane Katrina
- The supposedly systems was funded on a project-by- project basis over many years. As a result, the system was constructed in a piecemeal fashion
- The designs were not subject to the rigorous external review by senior experts that is often conducted for similar life-safety structures and systems

The first of American Society of Civil Engineers (ASCE) Seven Fundamental Canons Code of Ethics states, “Engineers shall hold paramount the safety, health and welfare of the public....”
Replace fragile I-wall barriers with more robust T-walls, which use three rows of foundation pilings that can withstand pressure generated by hurricane-force floodwaters. A wide concrete slab, or "skirt," on the protected side deflects overflowing water that could otherwise wash away supporting soil. T-walls held throughout Katrina without a leak.
The Evidence

New Orleans protection system has been under-developed, under-planned, and constructed over the span of forty years; without a true holistic and robust systems engineering approach or integration. The first line of defense in the protection system includes levees and floodwalls to hold back the high water from a storm surge, yet it failed catastrophically at more than 50 different locations during Hurricane Katrina. It lacked “redundancy” If one component failed, there was no back-up component or strategy to take its place to reduce the risk or damage. The “system” was not a system.
Hurricane System Requirements

- Construct all levees to withstand a category 5 hurricane
- Replace I-walls with T-walls
- Ensure that all pump stations are outfitted to remain operable during and after future storm events.
- Armor the canal with concrete in the backside so that overtopping will not erode the backside of the levees
- The levee has adequate freeboard (e.g., the levee height is at least three feet above design flood state)
Hurricane System Requirements

- Monitor & Maintain subsidence rates individually and not as an average

- SIDE SLOPES: Riverside embankments shall have a minimum slope of 2:1 (h:v). Landside embankments shall have a minimum slope of 2.5:1. Overtopping sections shall have a minimum of 5:1 on the landside.

- The levee has adequate freeboard (e.g., the levee height is at least three feet above design flood state)

- DESIGN ELEVATION: With the exception of the freeboard standard, levees shall not be built higher than the levels specified

- Armor floodwall to prevent gaps between the base and the soil
Risk Overview

- Brainstormed Risks and Causes
- Researched
  - Used consequence, likelihood, severity, classification definitions
  - Researched mitigation plans
- Decided which risks are higher priorities based on classifications
Failures of risk assessment and risk management

The risks (likelihoods and consequences) associated with hurricane surge and wave induced flooding were seriously underestimated. Deficient risk management methods were used to allocate resources and impel action to properly manage risks. Risk management failed to employ continuing improvement, monitoring, assessment, and modifications in means and methods which were discovered to be ineffective.
## Risk Events

### Risk Event

- **Pumping Station Shut-down (Inoperable)**

### Consequence

- **Massive Flooding**

<table>
<thead>
<tr>
<th>Causes</th>
<th>Likelihood (0-1)</th>
<th>Severity (1-10)</th>
<th>Classification</th>
<th>Must Avoid/Reduce</th>
<th>Should Avoid/Reduce</th>
<th>Mitigation</th>
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</thead>
<tbody>
<tr>
<td>Operators Evacuate</td>
<td>0.7 (1)</td>
<td>10</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Controlled by NOAA via satellites</td>
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<tr>
<td>Loss of Power</td>
<td>0.93 (1)</td>
<td>10</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Back-up Generators</td>
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<tr>
<td>Loss of Cooling water</td>
<td>0.4 (1)</td>
<td>10</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Inspection</td>
</tr>
<tr>
<td>Pumps back-up</td>
<td>0.3 (1)</td>
<td>10</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Inspection by monitoring system</td>
</tr>
</tbody>
</table>

![Likelihood vs Severity Grid](image)
Likelihood

- P (quantitative, used for cost analysis): Scale of 0.01 to 0.99
- Probability, P (aka Likelihood):
  - Recommend scale of 0.01 to 0.99 (most intuitive)

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>P</th>
<th>Pquantitative</th>
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<tbody>
<tr>
<td>Negligible</td>
<td>1</td>
<td>&lt; 0.10</td>
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<tr>
<td>Unlikely</td>
<td>2</td>
<td>0.10 to 0.40</td>
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<tr>
<td>Likely</td>
<td>3</td>
<td>0.41 to 0.65</td>
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<tr>
<td>Highly Probable</td>
<td>4</td>
<td>0.66 to 0.90</td>
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<tr>
<td>Near Certainty</td>
<td>5</td>
<td>&gt; 0.90</td>
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</table>

From EN-01-00-31 Risk and Opportunity Management Best Practices
Fishbone Diagram

Forced Winds

Flooding

Operators Safety during Storm

Loss of Power

Loss of Cooling Water

Pumping Station Risk
Risk Mitigation

Nearby safe rooms are being strengthened to withstand hurricane force winds up to 250 MPH, wind-driven water, and loss of power. Storm proofing pump stations will ensure that pumps remain operable and that station operators can safely stay on the job during a storm event.

Does not require human operator and float

![Diagram showing a pump station with a diesel engine, gate, grate, and propeller.]

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
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</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
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</tbody>
</table>

Consequence

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
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<td>Low</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Medium</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
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</tbody>
</table>

Consequence
Architecture View (OV-1)
Before

Subsystems that aren’t linked together
What other countries are doing

**Venice:** The MOSE project is designed to eliminate flooding in Venice. It involves huge, submerged gates that will rise out of the water and block the rising water from entering the lagoon and flooding the city.

**Japan:** This flood control system is called the G-Cans Project. The underground waterway has five massive concrete silos tunnels sitting 50 meters beneath the surface.

**The Netherlands:** Natural sand dunes and man-made dikes, dams and floodgates and a complicated system of drainage ditches, canals and pumping stations.
**I-Wall Levees**

I-walls do not work because they rely on the passive pressure of the soil, which is the horizontal pressure of the soil. The passive pressure of the soft soils in the New Orleans area is not very strong.

The force of the storm surge is exerted on the top of the wall and the bottom is not supported by the soft soil. In addition, the height to which an I-wall can be built is limited, and overtopping scour out the soil supporting the backside. Seepage is also a major problem.

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**Earthen Levees**

They are good at channeling and holding back water under relatively constant hydrostatic pressure where the height of the water is not rapidly changing. An example would be a river at flood stage. The soil and water reach equilibrium.

One of the dangers is a rapid fall of water against a levee system. A rapid fall destabilizes the soil. The factor of safety is reduced. A subsequent rise could cause levee failure, such as back-to-back storms.

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**T-Wall Levees**

**PROS**
- Very strong
- Will absolutely work

**CONS**
- Very expensive
- Not cost effective
- A breach below the T-Wall is difficult to repair during an emergency situation. The Army Corp of Engineers estimated cost is $14,000 to $19,000 per linear foot. That comes to $75 million to $100 million per mile.
Cost of Levees

- Clay Levee: $4k-$8k
- Double-Wall Levee: $5k-$6k
- T-Wall Levee: $14k-$19k

* Unknown cost for the expropriation of private property necessary to facilitate a 750-foot wide right of way—which could add hundreds to thousands more per linear foot.

Estimated Levee Construction Costs, Per Linear Foot
## Trade Criteria

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Relative Weight (0-1)</th>
<th>Levees</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Earthen</td>
</tr>
<tr>
<td>Cost</td>
<td>0.7</td>
<td>$4k - 8k plus cost for expropriation</td>
</tr>
<tr>
<td>Standards compliance</td>
<td>0.9</td>
<td>Medium - High</td>
</tr>
<tr>
<td>Risk</td>
<td>1</td>
<td>Medium</td>
</tr>
<tr>
<td>Operations</td>
<td>0.5</td>
<td>Low</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.3</td>
<td>High</td>
</tr>
<tr>
<td>Schedule to construct</td>
<td>0.3</td>
<td>High</td>
</tr>
<tr>
<td>Structure Safety</td>
<td>0.8</td>
<td>Medium - High</td>
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</table>

Preferred
Ethical / Societal Issues

Mayor Nagin gave a mandatory evacuation order on August 28, before the storm hit, they did not make sufficient prevention and provisions to evacuate the homeless, the poor, the elderly, the infirm, or the car-less households. Hospitals, nursing homes, group homes, were supposed to have pre-determined evacuation and/or refuge plans in place.
Ethical / Societal Issues

According to the Louisiana Evacuation plan, evacuation was mainly left up to individual citizens to find their own way out of the city. It was known that many residents of New Orleans lacked cars. It is also believed that many citizens, having survived previous hurricanes, did not anticipate the impending catastrophe and chose to ride out the storm. Even so, a 2000 census revealed that 27% of New Orleans households, amounting to approximately 120,000 people, were without privately owned transportation. Additionally, at 38%, New Orleans has one of the highest poverty rates in the United States. These factors may have prevented many people from being able to evacuate on their own. Consequentially most of those stranded in the city are the poor, the elderly, and the sick.
Ethical / Societal Issues

- many people were separated from their family members
- lack of water, food, shelter, and sanitation facilities
- facing months without income
- severely damaged or destroyed homes
- permanently resettle elsewhere
- health problems for those who remained in the hurricane-affected areas
Stakeholders / Role & Responsibilities

- Congress: Authorization and funding
- Sewerage and Water Board
  Levee Board: Operates and maintains all drainage pump stations and is responsible for waterways’ trash pick-up and grass cutting
- U.S. Army Corps of Engineers (USACE): guidance and oversight
- Levee districts: Maintain and operate flood protection and levee systems
Stakeholders / Role & Responsibilities

- U.S. Army Corps of Engineers Development Center: research new designs, design,
- Pump Stations / drainage: Administration, direction, coordination, and implementation of major drainage and flood control
- National Oceanic and Atmospheric Administration (NOAA): weather predictions, Control floodgates, floating barriers, and pump stations via remote satellite
- Home / Business Owners: end users and economy stimulators
The actual cost of Hurricane Katrina's damage was between $96-$125 billion

$40-$66 billion in insured losses

An estimated 300,000 homes were destroyed

It struck the heart of Louisiana's sugar industry, with an estimated $500 million annual crop value.

Hurricane Katrina affected 19% of U.S. oil production

The city's tourism industry created $9.6 billion annually before Katrina, and has only recently returned to attracting 7.1 million visitors each year, up from 2.6 million in 2006.
# Hurricane Katrina Compared to Hurricanes Ivan, Andrew, and Camille

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Homes Damaged or Destroyed</td>
<td>22,008 Homes</td>
<td>70,663 Homes</td>
<td>27,772 Homes</td>
</tr>
<tr>
<td>Property Damage</td>
<td>$5 Billion</td>
<td>$33 Billion</td>
<td>$14.5 Billion</td>
</tr>
<tr>
<td>Deaths</td>
<td>35 Deaths</td>
<td>61 Deaths</td>
<td>57 Deaths</td>
</tr>
<tr>
<td>300,000 Homes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$905 Billion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,330 Deaths</td>
<td></td>
<td></td>
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</table>
New Orleans Drainage System

- 80% of the city flooded.
- The hurricane itself did not flood the city. A series of failures in mis-designed levees and floodwalls allowed water from the Gulf of Mexico and Lake Pontchartrain to flow into the city.
- In areas of town far from the breaches, flood water came not in through the streets, but up from the storm drains beneath the street.
- In March 2006, it was revealed that temporary pumps installed by the USACE were defective.
Recommendations

Movable Barrier
Built to protect London from floods, the Thames Barrier is a series of 10 flood-gates with openings that allow the water like an architectural fantasy.

Gates themselves are held in the riverbed, so water flow and river traffic are not blocked in normal conditions. But during storms they can be raised to make a steel wall across the river more than 60 feet high.
Among the many projects in the $10 billion restoration of New Orleans' 133-mile levee system, three in particular will play key roles in protecting the city from its next big hurricane.

1. **Seabrook Floodgate**
The centerpiece of this $165 million complex is a barrier with two 50-foot-wide gates that can be lowered to keep water from Lake Ponchartrain out of the shipping channel. Water from that channel caused some of the worst damage during Katrina, including the inundation of the Lower Ninth Ward.

2. **Lake Borgne Surge Barrier**
The world's longest surge barrier, dubbed "the Great Wall of Louisiana," is nearly two miles wide and can close off the west entrance of the channel. During Katrina, water from this overflowing channel blew out 4,000 feet of levee.

3. **West Closure Complex**
The massive pumping station across the Gulf Intracoastal Waterway is the largest of its kind. When its 225-foot gate is closed, its 11 pumps can churn out nearly 150,000 gallons per second of water coming from smaller stations along the Harvey and Algiers canals.

The Army Corps indicates that it has protected the area inside of this green line from a 100-year flood event (1 percent chance of occurring in any given year). Katrina was considered a 400-year flood event.

**Audubon Village homes were built by Crown Team Texas**

**House Frame**
- every piece of the wood is secured using metal straps.
- The entire structure is bolted to the concrete columns below

**Concrete and Steel Columns**
- Reinforced concrete columns more than a foot square lift the house more than 25 ft above the ground

**Grade Beam**
- Reinforced concrete beams, 2 ft thick and a 4 inch concrete slab link the underground support columns and distribute the weight of the house equally

**Underground Support Columns**
- Concrete and steel 18 inch support columns are 10 ft into the ground

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**Hurricane Resistant Homes that withstood Hurricane IKE at its worst Gilchrist Texas**

**Roof**
- Secured to the house frame with metal straps, and shingles are attached with six inch nails
Lessons Learned

- Place safety first.
- Learn from experiences
- Poor project planning and Flawed designs
- Reassess priorities
- Establish direct lines of communications for use during an emergency (include a clear definition of the role of the governor and staff)
- Recognize the importance of maintaining and testing emergency response plans on a regular basis and secure approval for the resources needed for those tasks
- Assess the risk / impact of both short and long term disruptions (Quantify the risks)
- Communicate the risks to the public and decide how much risk is acceptable.
- Rethink the whole system
- Correct the deficiencies.
- Put someone in charge.
- Improve inter-agency coordination.
- Upgrade engineering design procedures.
- Bring in independent experts.
Conclusion

There was far too little priority or urgency given to this undeveloped system by political leaders at all levels of government. There are flaws in the way the system was conceived, budgeted, funded, designed, constructed, operated, and managed. Overcoming the deficiencies in the New Orleans hurricane protection system and instituting real change in its engineering, management, and governance will require leadership, courage, conviction, and funding.

Public health, safety, and welfare should be placed at the forefront of priorities.
Thank You!!!