Twenty Years After Katrina:

# Ten Fundamental Flood Re$ilience Lessons We Must Finish Learning






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## Overview

Flood Ri$k[1] management has witnessed astounding advances since the catastrophic inundation of New Orleans in August 2005. Nevertheless, there are ten fundamental lessons yet to be fully recognized and supported. Escalating climate change demands a broad and thorough adoption of basic principles regarding:

**Understanding Ri$k**

1. Hazard
2. Ri$k
3. Evolving Science
4. Uncertainty
5. Responsibility for Ri$k Information

**Re$ilience (Managing Ri$k)**

6. Insurance
7. Ri$k Mitigation
8. Limitations of Ri$k Mitigation
9. Nature-Based Mitigation
10. Assistance

This article addresses these ten fundamental lessons—recalling severe failures exposed during Hurricane Katrina and subsequent flood disasters, highlighting twenty years of progress, and emphasizing the remaining challenges. The subject follows up the author's previous **Louisiana Civil Engineer** articles on Hurricane Katrina and flooding: ***Managing Hurricane Surge in the Supercomputing Era Part I*** / ***Part II*** (2015) and ***Property-Specific Flood Risk, Part I*** / ***Part II*** (2021-2022).[2]

**Bonus Lesson**: the very same lessons have stood the test of time for other property hazards such as fire, ice, wind, soil/foundation, and legacy contamination. The ASTM E1528-14 Standard addressing environmental Ri$k has been in effect now for over 30 years.

## Lesson 1: **Hazard**

At the time of Hurricane Katrina, and still today, many officials and most of the public oversimplify flood hazard—using a single-line threshold or crude categories/factors and misrepresenting rarity. This severely distorts risk and leads to bad decisions. A proper understanding of flood hazard accounts for five basic principles.

### 1.1 Flood hazard is "how high, how often" at a specific location.

Risk management demands a fully quantitative hazard depiction—with detailed increments of flood elevation versus frequency, i.e., a **Full-ʃpectrum hazard curve**. Frequency is typically expressed as Annual Exceedance Probability (AEP): the odds (chance) over a single year. Flood hazard is location-specific, and the curve is better appreciated by converting flood elevation to flood height above ground. See Figure 1, light solid line.

### 1.2 Flood hazard encompasses a complete range of rare scenarios.

A location's Full-ʃpectrum hazard curve does not rely just on local history, but covers all applicable and remote river, coastal, flash, and compound exposures. A 1% (1-in-100) AEP and even a 0.2% (1-in-500) AEP are not that rare when regarded over longer timeframes and larger areas (see below). A 0.01% (1-in-10,000) AEP better addresses what is rare—and is often deemed a Probable Maximum Flood (PMF) if the hazard curve becomes nearly flat.

### 1.3 Flood hazard considers ongoing changes to probability.

Consideration of hazard must account for changing odds associated with climate trends (sea level and precipitation-frequency); landscape modifications (coastal subsidence/erosion and land-cover changes that raise or lower runoff rates); and mitigation improvement/degradation. A hazard curve can increase/decrease significantly over several decades. See Figure 1, light dashed line.

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[1] The "$" in the terms Ri$k, Re$ilience, and Su$tainability is used to reinforce the particular focus on financial risk, resilience, and sustainability. **Ri$k**, **Full-ʃpectrum**, **Re$ilience**, and **Su$tainability** are trademarks owned by **Real Flood Resilience L3C**.

[2] Reference links are active in the pdf version of this article available on the Louisiana Section website.

### 1.4 Flood hazard considers exposure duration.

Single-year odds are convenient and traditional for many purposes but are "rare-sounding." Converting single-year odds to multi-decadal odds better communicates hazard for long-term exposure planning, e.g., 30 years. Multi-decadal odds can also incorporate future hazard change (compare Columns 1, 3, and 4 in Table 1; also see Figure 1, dark solid line).

### 1.5 Flood probability over a large area considers multiple independent exposures.

Cumulative flood probabilities for several distant properties, extended regions with many watersheds, and along lengthy levee systems involve combining odds for independent exposures (compare Columns 1, 3, 4, and 6 in Table 1). **Thus, over a longer-time frame and a large area, a seemingly rare AEP flood is not that rare!**

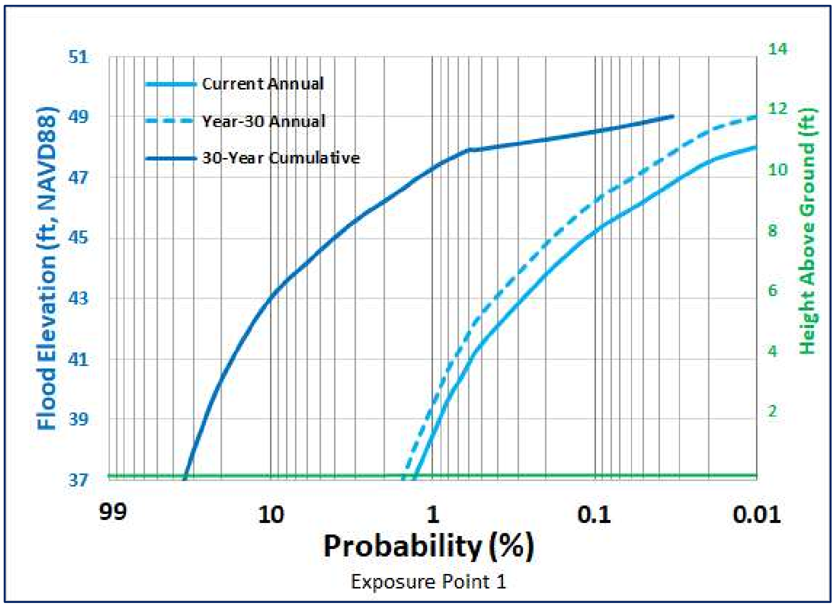


**Figure 1. Full-ʃpectrum Hazard Curve**

**Table 1. Comparison of Annual versus Multi-decadal Odds with Increasing Hazard and Multiple Independent Exposures**

| 1. Single Exposure Chance | 2. Exposure Duration | 3. Multi-decadal Chance | 4. With Increasing Hazard | 5. Number of Independent Exposures | 6. Cumulative Chance |
|---|---|---|---|---|---|
| **1% (1-in-100)** | 30 years | 26% | 33% | 3 | ***70%*** |
| **0.2% (1-in-500)** | 30 years | 6% | 8% | 5 | ***33%*** |
| **0.1% (1-in-1,000)** | 30 years | 3% | 4% | 10 | ***33%*** |
| **0.01% (1-in-10,000)** | 50 years | 0.50% | 0.70% | 20 | ***13%*** |

## Lesson 2: **Ri$k**

In addition to being one of the deadliest flood disasters in living memory—***with 341 direct*** and ***up to 829 indirect*** fatalities in Louisiana alone—Katrina was the most expensive flood disaster in US history, ***at over $200 billion in today's dollars***. There are four principles to keep in mind regarding flood Ri$k.

### 2.1 Flood Ri$k is "how expensive, how often."

**Ri$k** is priced risk for direct financial consequences. Like hazard it is quantitative, requiring detailed increments of property damage plus related expenses versus probability. A property-specific **Full-∫pectrum Ri$k curve** with Cost versus AEP (Figure 2) is directly determined by multiplying the Full-∫pectrum hazard curve times Fragility (given by a Fragility curve with cost versus hazard magnitude). Additional risk analyses are often required for consequences to life, safety, health, and non-priceable societal/cultural/personal assets.

### 2.2 Ri$k curve yields two crucial property-specific metrics. n

Metric 1 is **Expected Annual Cost** (EAC). Integrating the current Ri$k curve provides a current-year, probability-weighted "average" cost. Future EACs are derived using future Full-∫pectrum Ri$k curves.

Metric 2 is **Present Value**. A stream of future EACs is easily converted into Present Value. See Figure 3.

**Ri$k Present Value is the appropriate indicator of property-specific long-term flood Ri$k.**

### 2.3 Aggregation of property-specific Ri$k is straightforward.

Aggregate Ri$k is easily calculated for stakeholders with multiple properties and for whole watersheds and communities. A coarse approach relies on rudimentary hazard curves, property groupings, and generalized depth-damage correlations. A better, more rigorous granular approach sums property-specific EAC and Present Value. Community Ri$k can incorporate other economic losses.

### 2.4 Intensifying concern for property-specific flood Ri$k metrics is inevitable.

**With decades of over-development in floodplain margins, climate change, and accumulating exposure duration—we are experiencing more flood disasters and have a growing need to understand Ri$k**. In the past, appreciating and applying the metrics have been a challenge due in part to a natural cognitive bias that neglects a rare recurring expense, but more importantly due to a lack of data, models, and analyses to estimate the metrics—which is now no longer the case.

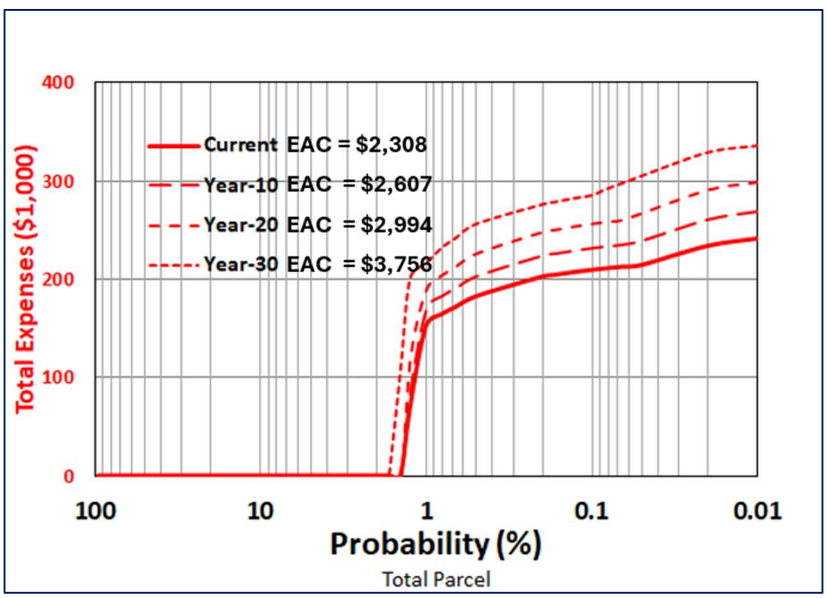


**Figure 2. Full-∫pectrum Ri$k Curve**

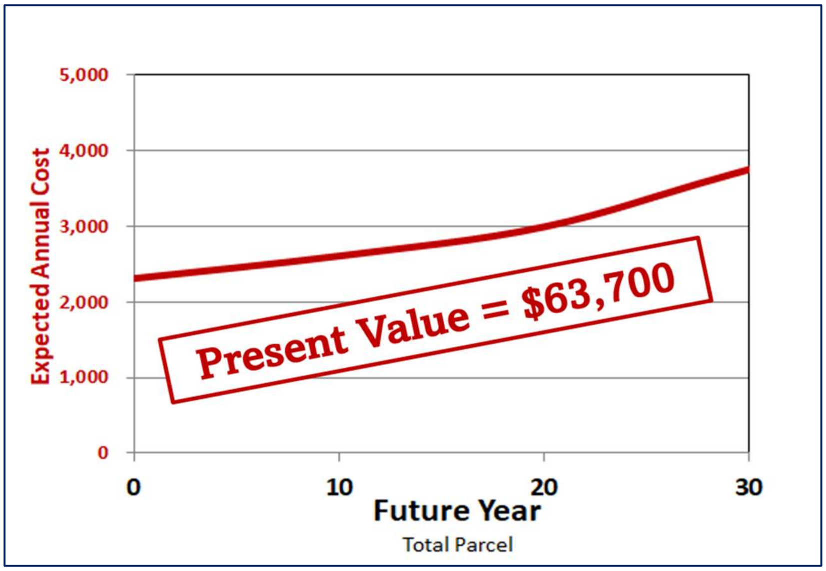


**Figure 3. EAC Stream**

## Lesson 3: **Evolving Science**

Katrina exposed antiquated reliance on peak wind category for "design storms." Over the following years, tens of millions of dollars were invested to accelerate application of special supercomputers to modeling an array of coastal surge scenarios. Future advances in estimating flood Ri$k involve four principles.

### 3.1 Intensifying Ri$k concern drives continuous improvement of estimates.

Today, there is mounting pressure to constantly leverage the latest advances in science and technology (S&T)—particularly those associated with increasing computer power—for better property-specific estimates. Crucially, the focus is on better **Median estimates**—not base (floor) or conservative (ceiling) estimates. Median estimates do not purposefully under- or over-represent anyone's property-specific flood hazard or Ri$k EAC/Present Value.

### 3.2 Dramatic S&T progress revolutionizes routine estimates.

Five notable ongoing advances are:

- **High-Definition** terrain, hydrography, conveyance-feature, and land-cover datasets, and flood inundation maps (FIMs)—exhibiting both **high-resolution** (1-meter) and **high-accuracy** (local, approaching parcel, scale).
- Terabyte-scale GIS raster processing and analysis. See the ***High-Definition FIM for the August 2016 Flood Amite River Basin*** with 2-foot resolution and 0.5-foot Root Mean Square Error by sub-basin.
- High-resolution 2D watershed flood models.
- Cloud resources for simulating hundreds of scenarios and extensive joint probability analysis.
- Assessments of local flood climatology (e.g., ***sea level rise*** and ***precipitation frequency***).

### 3.3 Accelerating S&T forces more frequent Professional Standard-of-Practice (SOP) updates.

The ***ASCE 24-24 Standard for Flood Resistant Design and Construction*** issued January 2025 contains significant changes from the 2014 version. A new ***ASTM E3429-24 Standard Guide for Property Resilience Assessments*** was issued October 2024. Both are likely to be outdated in the near future with S&T advances in Median estimates for hazard and Ri$k metrics.

### 3.4 Median estimates are highly volatile.

Frequent SOP updates together with changing forecasts for future conditions mean that data, modeling, and analyses have a short shelf-life (see Figure 4). Volatility and constant updating of Median Estimates are very challenging to individuals and organizations. Ri$k management requires all interested parties to join in institutionalizing continuous improvement for Median estimates.

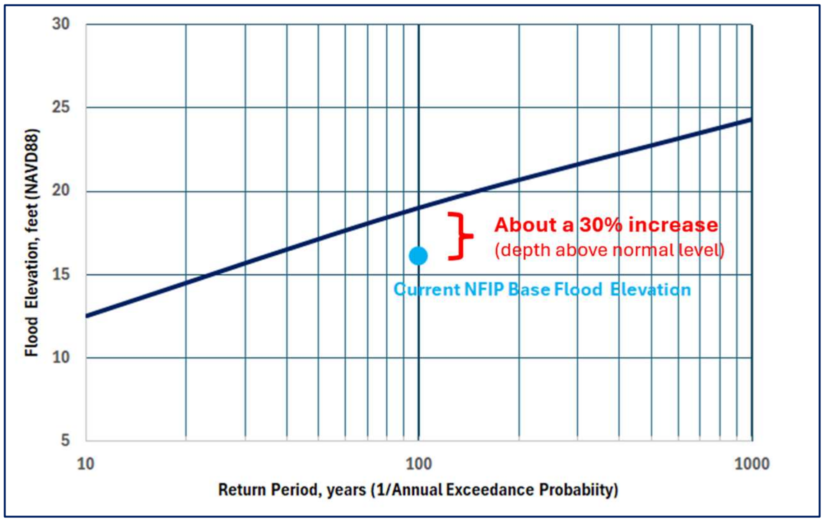


**Figure 4. Volatility of Flood Hazard Estimate, Amite River at Port Vincent**
*Compound Flood Transition Zone Pilot Study for the Amite River Basin, Final Report*

## Lesson 4: **Uncertainty**

In addition to volatility, flood hazard and Ri$k estimates have significant intrinsic uncertainty. Understanding Ri$k involves acknowledging and dealing with four principles on uncertainty.

### 4.1 The SOP delineates uncertainty bands around Median estimates.

Uncertainty bands are designated according to the desired width of a "confidence interval" for capturing a percentage of possible values; e.g., a 95% confidence interval is wider than a 90% interval, which is wider than an 80% interval. The lower and upper confidence levels (LCL/UCL) can serve as base (floor) and conservative (ceiling) limits where/when specifically needed. Non-exceedance level (NEL) refers to a percentage of values below a UCL; e.g., a 90%NEL corresponds to a 80%UCL.

### 4.2 The uncertainty magnitude can be very large.

Large uncertainty (see Figures 5 and 6) does not obviate the need for quantified hazard and Ri$k. At the same time, it is important to avoid implying over-precision—to admit that estimates are really *scientific guesstimates*. Transparency and clarity support credibility, discourage bias, and encourage improvement.

### 4.3 Uncertainty differences can also be very large.

At a given AEP, the difference between UCL-versus-Median flood elevation can vary widely by location. **The use of a uniform UCL as a contingency freeboard can create wide disparities in residual hazard referenced in Median AEP.** See Table 2 and Figure 7. The UCL for the 1%AEP surge still water level (SWL) might correspond to a Median AEP of 0.5% at one location versus 0.1% at another location.

### 4.4 Aggregate uncertainty is lower than property-specific uncertainty.

In aggregating Ri$k many property-specific uncertainties "cancel out" (per the Law of Large Numbers). This greatly facilitates many aggregate Ri$k management efforts. However, aggregate uncertainty is not appropriate for location-specific uncertainty. See Figure 8.

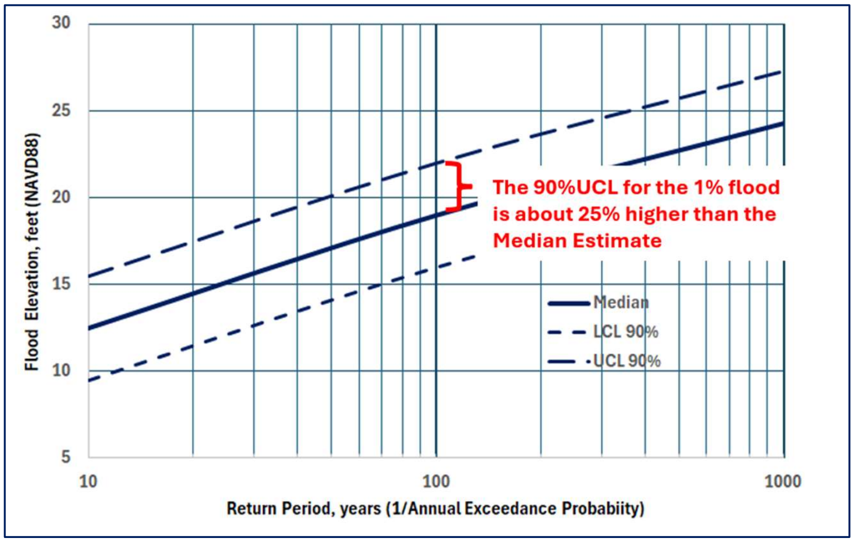


**Figure 5. Median Estimate with Uncertainty, Amite River at Port Vincent**
***Compound Flood Transition Zone Pilot Study for the Amite River Basin, Final Report***

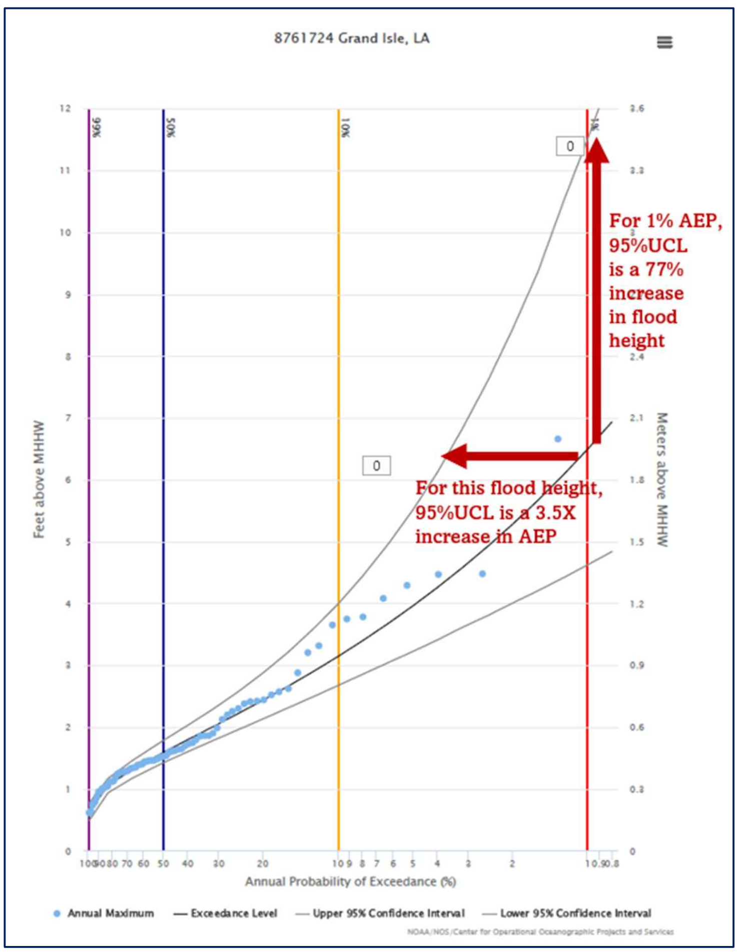


**Figure 6. Median Estimate with Uncertainty, Grand Isle, Louisiana, NOAA**

**Table 2. UCLs for the 1% AEP East-Bank Perimeter SWL**

(see Figure 7 for locations)

versus 1%AEP Median varies from 3 to 6 ft; versus 0.2%AEP Median varies from 0.2 to 1.7 ft

***NO East-Bank Hurricane Surge Residual Risk Reduction Report***

| **Location** | **1% AEP** | | | **0.2% AEP** | |
|---|---|---|---|---|---|
| | **Median** | **UCL** | **UCL – Median** | **Median** | **UCL – Median** |
| SC02-A | 12.1 | 16.0 | 3.9 | 15.6 | 0.4 |
| SC02-B | 11.6 | 15.3 | 3.7 | 15.1 | ***0.2*** |
| JL01 | 9.7 | 12.8 | 3.1 | 12.2 | 0.6 |
| NO01 | 9.6 | 12.7 | 3.1 | 12.2 | 0.5 |
| NO10 | 9.8 | 12.9 | 3.1 | 12.3 | 0.6 |
| NE01 | 9.4 | 12.4 | ***3.0*** | 11.7 | 0.7 |
| NE02 | 9.4 | 12.4 | ***3.0*** | 11.7 | 0.7 |
| NE10 | 11.2 | 14.8 | 3.6 | 14.2 | 0.6 |
| NE11A | 14.7 | 19.4 | 4.7 | 18.2 | 1.2 |
| NE11B | 16.2 | 21.4 | 5.2 | 19.9 | 1.5 |
| NE12A | 17.2 | 22.7 | 5.5 | 21.1 | 1.6 |
| NE12B | 18.2 | 24.0 | 5.8 | 22.3 | ***1.7*** |
| NE30 | 9.3 | 12.3 | 3.0 | 11.6 | 0.7 |
| NE31 | 9.5 | 12.5 | 3.0 | 12.0 | 0.5 |
| SB11 | 18.8 | 24.8 | ***6.0*** | 23.1 | ***1.7*** |
| SB12 | 17.6 | 23.2 | 5.6 | 21.7 | 1.5 |
| SB13 | 17.6 | 23.2 | 5.6 | 21.7 | 1.5 |
| SB15 | 14.9 | 19.7 | 4.8 | 18.2 | 1.5 |
| SB16 | 17.3 | 22.8 | 5.5 | 21.2 | 1.6 |
| SB17 | 18.2 | 24.0 | 5.8 | 22.6 | 1.4 |

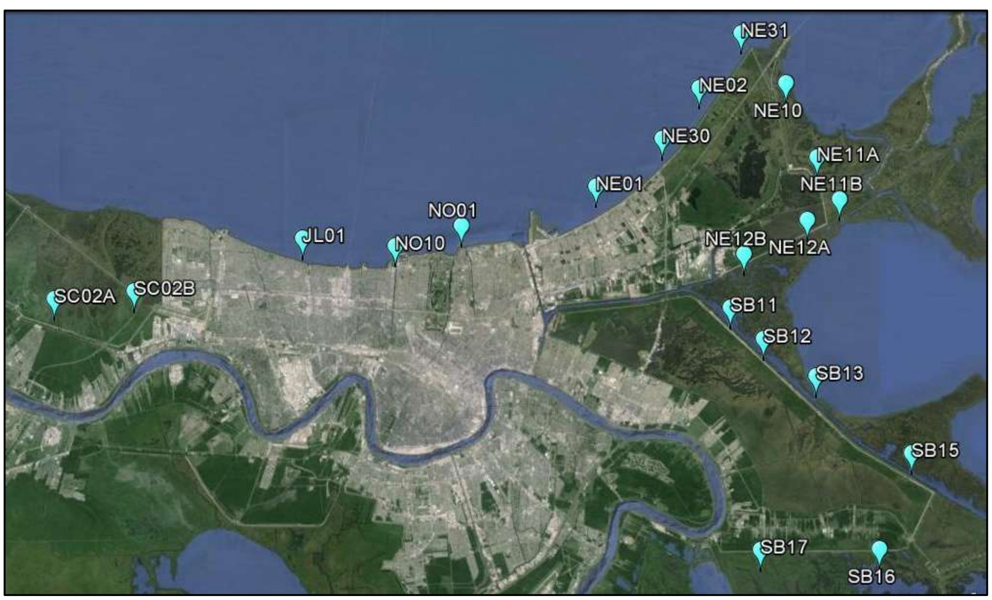


**Figure 7. Locations for Table 2.**

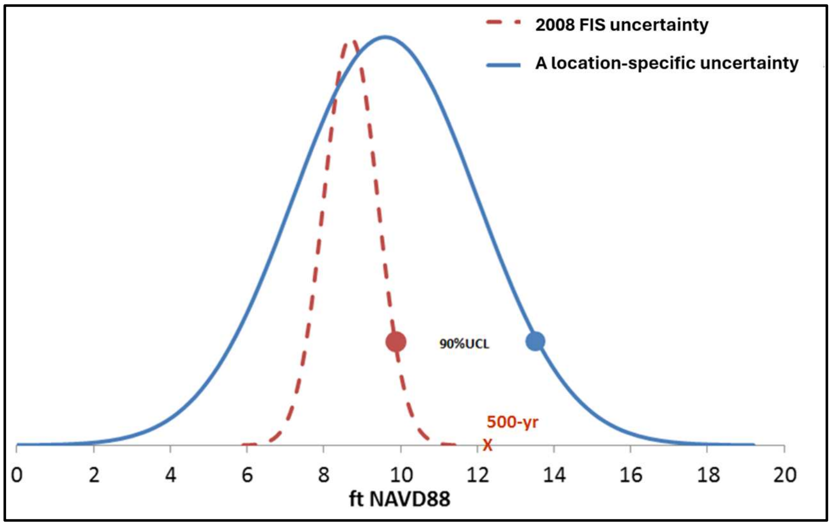


**Figure 8. Uncertainty in the 1%AEP Still Water Level at one HSDRRS reach.**
NFIP post-Katrina perimeter 1%AEP SWL estimates employed a standard deviation of 0.7 ft for Aggregate Uncertainty (dashed line); the standard deviation for one Location-Specific Uncertainty (solid line) was estimated at 2.4 ft.
***NO East-Bank Hurricane Surge Residual Risk Reduction Report***

## Lesson 5: **Responsibility for Ri$k Information**

Katrina and subsequent major floods underscore principles on the respective Ri$k information responsibilities for property-stakeholders, professionals, government officials, and the media.

### 5.1 Property-stakeholders own the Ri$k and have "due diligence" responsibility.

Every property-stakeholder—including developers, builders, owners, buyers, renters, investors, lenders, and private insurers—has flood hazard exposure and bears the brunt of obsolete and/or biased information, including from government sources.

Every property transaction demands flood Ri$k due diligence. *Due diligence is the property-stakeholder's legal obligation to obtain and address relevant information.* (Due diligence can also be regarded as a social duty, the neglect of which contributes to moral hazard.) Intensifying concern for Ri$k valuation stimulates more rigorous due diligence, which becomes a major driver of SOP improvement. Cycles of improvement start where/when Ri$k stakes are high. See ***ClimateScore Global*** from Jupiter Intelligence and ***The climate challenge for boards: Perspectives from the financial sector*** from Fathom, as well as ***Unpriced climate risk and the potential consequences of overvaluation in US housing markets***.

### 5.2 Private sector professionals have a fiduciary duty.

Property managers, agents, brokers, appraisers, inspectors, engineers, and planners assist clients with due diligence. They are exposed to significant liability given climate change, intensifying stakes, rapidly evolving SOP, and volatile Median estimates. See ***Oh the Tides They Are a Changin': Climate Change, Due Diligence, and How the Standard of Care Should Change to Reflect the Current Technologies in Flood Mapping***.

### 5.3 Government agencies have an obligation for integrity and currentness.

Elected and appointed officials, managers, staff, and contract researchers and professionals administer government Ri$k management programs for insurance, mitigation, and assistance. Ri$k information transparency, clarity, and accuracy/updating are essential to program effectiveness, efficiency, and fairness. Improving government programs and private-sector due diligence is synergistic. Both benefit from agencies being proactive in facilitating and leveraging private-sector SOP improvements. Examples include FEMA's ***Future of Flood Risk Data*** Initiative and Louisiana Watershed Initiative investment in ***Statewide Data and Modeling Program***.

### 5.4 The media has a duty for accurate reporting.

The media has a responsibility to address the facts of evolving SOP Median estimates; to call-out obsolete descriptions of hazard and Ri$k; and to question outdated/inadequate property-stakeholder, professional, and government practices. See ***Many Americans are buying homes in flood zones—and don't realize it***.

## Lesson 6: **Insurance**

Only 25% of Katrina-flooded homes, and less than 50% of Louisiana homes flooded in August 2016, had flood insurance. Nationally, only 30% of homes in the highest Ri$k areas currently have flood insurance. Three principles regarding flood insurance are crucial.

### 6.1 Flood insurance is the foundation for flood Re$ilience.

Flood **Re$ilience** is the financial capacity for disaster recovery.

Insurance is collectively self-funded Re$ilience by property-stakeholders per their specific Ri$k EAC. In this sense "insurance" is distinct from "assistance." Insurance addresses the cognitive bias discounting of a rare recurring expense, as well as uncertainty in guesstimates. Furthermore, it is synergistic with property-stakeholder Ri$k ownership, due diligence, and SOP improvement, and it complements/focuses/improves mitigation and assistance programs. See ***Flood Insurance in Communities at Risk of Flooding*** and ***Flood Risk and the US Mortgage Market***.

### 6.2 Participation reflects and enhances Su$tainability.

A **Su$tainable** property or whole community is one which holds its economic value. Uninsured properties and communities with large amounts of uninsured property have low Re$ilience. Properties and communities with low Re$ilience are less **Su$tainable**. Hence, poorly insured communities tend to become less Su$tainable.

Community Su$tainability is also tied to other Ri$ks, as well as general demographic and economic vitality—employment, income, tax base for services, and bond rating.

Communities that are reasonably Su$tainable can improve participation and Su$tainability with a flood insurance mandate for all collateralized property and all public facilities; plus a property tax surcharge on non-participants to cover EAC for abandonment.

But communities with Su$tainability challenges face a downward spiral: rising insurance cost erodes economic value and hinders insurance participation, which worsens Su$tainability. These communities increasingly seek assistance (see Lesson 10). See the recent 7-part series about insurance and Su$tainability in Louisiana: ***Breaking Point: Louisiana homeowners reckon with skyrocketing insurance rates*** and ***Differential flood insurance participation and housing market trajectories under future coastal flooding in the United States***.

### 6.3 Like banking, insurance requires government oversight.

A sound approach to insurance involves

- Support for a private, competitive market where/when viable—i.e., where/when aggregate long-term Ri$k uncertainty is manageable.
- Transparency and stability of entities for their own aggregate Ri$k liability.
- A range of corporate structures, such as cooperatives and mutual companies.
- Consistency between property-specific actuarial cost and SOP Ri$k EAC—no under/over-pricing of anyone's insurance.
- High standards of service for disaster response.

See ***Climate Change, Disaster Risk, and Homeowner's Insurance***, Congressional Budget Office, August 27, 2024 and ***How will the US flood insurance market evolve amidst rising risks and modeling advancements***, Moody's, July 2024.

# Lesson 7: **Ri$k Mitigation**

Post-Katrina upgrades to the New Orleans perimeter storm surge system cost $15 Billion and are still not complete. With intensifying flood Ri$k concern, pressure for public mitigation investments is mounting across the country. Three critical mitigation principles must be kept in mind.

### 7.1 Mitigation is largely an investment to reduce future insurance cost.

SOP cost-effectiveness compares **Reduction in Ri$k Present Value versus Present Value of Life-Cycle Cost** using SOP data, modeling, and analysis: e.g., based on Full-ʃpectrum hazard encompassing all exposures and future change (limited scenarios are only for initial screening). Properties/community should be otherwise Su$tainable. **The bottom line: it is hard to justify mitigating Ri$k that is cheaper to insure.** For example: In 2006 Congress only authorized the Corps of Engineers to rebuild/upgrade the perimeter system as needed for National Flood Insurance Program certification, thus assuming evacuation as well as insurance of residual Ri$k. Other benefits can sometimes tip the scales: safety/health, ecosystem enhancement, recreation, reducing unpriced risk, and reducing the cost of assistance.

### 7.2 Mitigation planning requires a System Approach.

The System Approach addresses the long-term performance of all relevant measures and components working together to reduce the aggregate flood Ri$k in a given hydrologic area (catchment, watershed, basin, polder, etc.). All alternatives—structural and non-structural measures and components—must be on the table. The goal is overall optimization—getting the **Most Bang-for-Buck**. Evaluation of alternatives also needs to account for adverse flood, environmental, economic, social, and cultural impacts. See ***A Systems Engineering Based Assessment of The Greater New Orleans Hurricane Surge Defense System Using the Multiple Lines- of-Defense Framework***.

### 7.3 Mitigation systems benefit from a single authority.

The system's long-term performance benefits when the authority is accountable to the area's property-stakeholders and possesses relevant capabilities for management, engineering, operations, and maintenance, including periodic upgrades. The authority should direct the planning and implementation of all measures and components and oversee other agencies involved in aspects of the system.

# Lesson 8: **Limitations of Ri$k Mitigation**

Major failures of the New Orleans perimeter system during Hurricane Katrina allowed more than 300,000 acre-feet of water to inundate three urban polders (bowls) (see Figure 9 and Table 3)—causing most of the previously noted deaths and destruction. **These failures are a dire warning against ignoring the limitations of any flood mitigation measure—and highlight three principles**.

### 8.1 Mitigation is NOT "protection."

"Protection" systems have an explicit goal to safeguard lives and must be reliable for at least the 0.01% AEP flood (1-in-10,000). **Mitigation is only a partial solution**. Mitigation authorities and community leaders must establish evacuation/sheltering contingency plans for Residual Life and Safety Risk. (Sadly events such as the ***Nursing home company which evacuated residents to an ill-equipped warehouse during Hurricane Ida in 2021*** continue to occur.)

They must also address insurance for residual Ri$k.

Example: the Corps of Engineers renamed the upgraded New Orleans perimeter system from the "Hurricane *Protection* System" to the "Hurricane and Storm *Damage Risk Reduction* System" (HSDRRS).

### 8.2 Mitigation always has residual Ri$k.

**Property-specific estimates of with-mitigation Full-ʃpectrum hazard curves and Ri$k metrics are essential,** addressing:

- The performance limits of all measures/components and identification of system weak links. Note that modest added performance for a component is not a "Factor of Safety" (e.g., pump capacity, erosion resistance).
- All failure scenarios (e.g., floodwall/levee overtopping and breach thresholds, pump station failures,) and life-cycle impediments (e.g., gate operations, conveyance system maintenance).

### 8.3 Mitigation authorities must directly address residual Ri$k.

Elected and appointed officials and program managers for public flood mitigation programs must commit to:

- **Explicit communication—transparency and clarity—about ALL of 8.1 and 8.2.**
- Professional independence.
- Improving SOP Median estimates as required by S&T advances.
- Confronting coordination and oversight issues.

Community leaders, property-stakeholder organizations, and the media must insist on these commitments.

Example 1: Roughly 66% of the Orleans Metro Polder flood volume came from three floodwall collapse breaches (no overtopping) under-designed for soil conditions. Roughly 88% of the St. Bernard Polder flood volume came from eroded levees under-designed for the selected fill material. Under-design was fostered by leaders who avoided dealing explicitly with system limitations.

Example 2: Table 4 shows the post-Katrina 1%AEP HSDRRS design (using an UCL for wave overtopping) resulted in significant differences in SWL freeboard around the East-Bank perimeter and thus residual hazard.

Example 3: Figure 10 gives a sense of New Orleans east-bank HSDRRS residual inundation hazard for multi-decadal multiple independent exposures to 1% AEP wave overtopping.

Example 4: As recently reported in The Advocate (December 17, 2024), five companies that helped design and install a concrete barrier along Interstate 12 median—which worsened inundation upstream during the August 2016 Flood—agreed to settle a lawsuit for $21 million. Cross conveyance openings were sufficient for typical "design storms" but not for the extreme >500-year event.

Example 6: Levees.org emphasizes the role of professional negligence in the New Orleans perimeter system failures during Katrina. However, more attention should be paid to the role of elected and appointed officials, and senior agency managers, in avoiding explicit treatment of system limitations, as well as the fragmentation of responsibilities among federal, state, and various local agencies.

**Table 3. 16 Major Perimeter System Failures During Hurricane Katrina**
(see Figure 9 for failure locations)
*Managing Hurricane Surge in the Supercomputing Era, Parts II*

| Polder/Location | Type | Inflow Volume | |
|---|---|---|---|
| | | Acre-Ft | Percent |
| **Metro Polder (27,268 acres)** | | **95,072** | **100** |
| 1. 17th St Outfall Canal I-wall | Collapse Breach | 32,399 | 34.1 |
| 2. Orleans Ave Outfall Canal I-wall | Opening | 89 | 0.1 |
| 3. London Ave Outfall Canal I-wall, North | Collapse Breach | 23,555 | 24.8 |
| 4. London Ave Outfall Canal I-wall, South | Collapse Breach | 6,484 | 6.8 |
| 5. IHNC West, North of Florida Ave | Overtopping & Breaches | 25,022 | 26.3 |
| 6. IHNC West, South of Florida Ave | Overtopping | 7,524 | 7.9 |
| **NO East Polder (14,792 acres)** | | **53,578** | **100** |
| 7. IHNC East I-wall | Collapse Breach | 757 | 1.4 |
| 8. IHNC East | Overtopping | 12,494 | 23.3 |
| 9. Citrus Back Levee (IHNC to Paris Rd) | Overtopping | 33,289 | 62.1 |
| 10. Citrus Back Levee (East of Paris Rd) | Overtopping & Breaches | 7,037 | 13.1 |
| **St. Bernard Polder (20,015 acres)** | | **154,885** | **100** |
| 11. IHNC East I-wall, South of Florida Ave | Collapse Breach | 2,166 | 1.4 |
| 12. IHNC East I-wall, North of Claiborne Ave | Overtopping & Breach | 13,107 | 8.5 |
| 13. IHNC East Floodwall | Overtopping | 3,400 | 2.2 |
| 14. MRGO and 40 Arpent Levees (IHNC to Paris Rd) | Overtopping & Breaches | 32,260 | 20.8 |
| 15. MRGO and 40 Arpent Levees (Paris Rd to Violet Canal) | Overtopping & Breaches | 43,276 | 27.9 |
| 16. MRGO and 40 Arpent Levees (Violet Canal to Reggio) | Overtopping & Breaches | 60,677 | 39.2 |


**Figure 9. Location of 16 Major Perimeter System Failures During Hurricane Katrina**

**Table 4. Post-Katrina HSDRRS Still Water Level Freeboard (see Figure 7 for locations)**

Freeboard is shown for both the 1% and 0.2% AEP, and at the median and 80% UCL

*NO East-Bank Hurricane Surge Residual Risk Reduction Report*

| Location | Design Crest (ft NAVD88) | 1% AEP Freeboard (ft) | | 0.2% AEP Freeboard (ft) | |
|---|---|---|---|---|---|
| | | Median | UCL | Median | UCL |
| SC02-A | 15.5 | 3.40 | -0.47 | -0.10 | -6.09 |
| ***SC02-B*** | ***14.0*** | ***2.40*** | ***-1.31*** | ***-1.10*** | ***-6.90*** |
| JL01 | 16.5 | 6.80 | 3.70 | 4.30 | -0.38 |
| NO01 | 16.0 | 6.40 | 3.33 | 3.80 | -0.88 |
| NO10 | 15.0 | 5.20 | 2.06 | 2.70 | -2.02 |
| NE01 | 13.0 | 3.60 | 0.59 | 1.30 | -3.19 |
| NE02 | 15.5 | 6.10 | 3.09 | 3.80 | -0.69 |
| NE10 | 17.0 | 5.80 | 2.22 | 2.80 | -2.65 |
| NE11A | 22.0 | 7.30 | 2.60 | 3.80 | -3.19 |
| NE11B | 25.0 | 8.80 | 3.62 | 5.10 | -2.54 |
| NE12A | 28.0 | 10.80 | 5.30 | 6.90 | -1.20 |
| NE12B | 29.0 | 10.80 | 4.98 | 6.70 | -1.86 |
| NE30 | 14.5 | 5.20 | 2.22 | 2.90 | -1.55 |
| NE31 | 16.5 | 7.00 | 3.96 | 4.50 | -0.11 |
| SB11 | 29.0 | 10.20 | 4.18 | 5.90 | -2.97 |
| SB12 | 27.5 | 9.90 | 4.27 | 5.80 | -2.53 |
| SB13 | 26.5 | 8.90 | 3.27 | 4.80 | -3.53 |
| ***SB15*** | ***26.5*** | ***11.60*** | ***6.83*** | ***8.30*** | ***1.31*** |
| SB16 | 26.5 | 9.20 | 3.66 | 5.30 | -2.84 |
| SB17 | 26.5 | 8.30 | 2.48 | 3.90 | -4.78 |

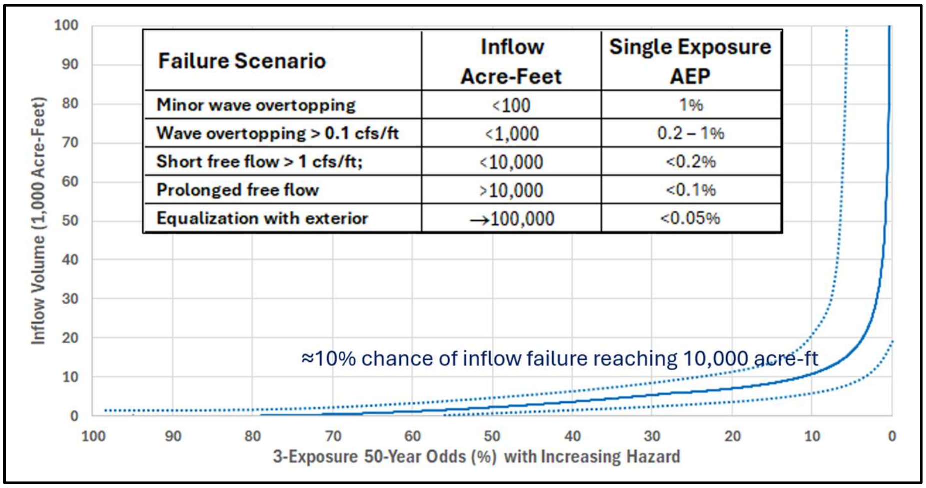


**Figure 10. Simplified East-Bank Residual Hurricane Surge Inundation Hazard**
Due to its size and configuration, the East-Bank HSDRRS has multiple independent exposures.
The table shows simplified single exposure AEP for inflow failure; the curve illustrates 3-Exposure 50-yr odds with increasing hazard; the actual failure odds at each reach vary due to varying freeboard.
***NO East-Bank Hurricane Surge Residual Risk Reduction Report***

## Lesson 9: **Nature-Based Mitigation**

Since Katrina, interest has accelerated in enhancing natural features to mitigate some relevant flood scenarios, as well as to provide other benefits. Two prominent examples are the ***Multiple Lines of Defense Strategy*** for coastal landscapes (see Figure 11) and the ***Living with Water Approach*** developed for urban areas like New Orleans. Nature-based flood mitigation entails multiple—often competing—goals, thus demanding careful attention to two principles.

### 9.1 The same mitigation lessons (8 and 9) apply.

Like other mitigation measures, nature-based measures offer only a partial solution—requiring SOPs for quantifying reduction in Ri$k Present Value (e.g., limited scenarios are only for initial screening) and explicit communication regarding the property-specific residual hazard and Ri$k EAC and Present Value.

### 9.1 The System Approach extends to other benefits.

In addition, nature-based measures require SOPs for granular quantification of long-term ecosystem, recreation, and aesthetic, benefits; Bang-for-Buck evaluations in meeting these other goals; and, moreover, **transparency and clarity for trade-offs between competing goal benefits**.

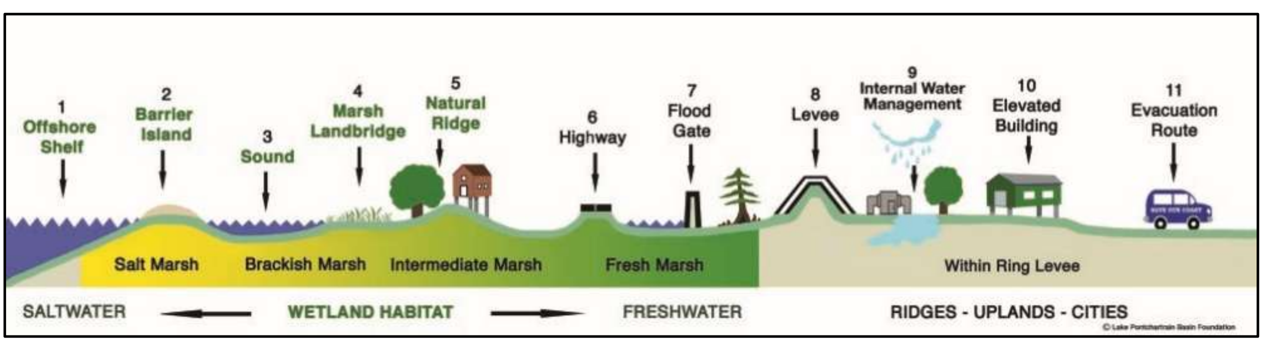


**Figure 11. Multiple Lines of Defense Strategy**
***Multiple Lines of Defense Strategy***

# Lesson 10: **Assistance**

Escalating flood hazard and intensifying flood Ri$k concern are increasing pressure for government assistance. **Re$ilience assistance faces two priorities.**

### 10.1 Our top priority is minimizing distortion of property-specific flood Ri$k.

Rising insurance cost exacerbates frustrations about Ri$k information accuracy and precipitates agitation over unfairness. See ***Louisiana is the most overcharged state for flood insurance***. Before turning to issues of fairness, government must prioritize information accuracy, and expediting progress from crude algorithms (e.g., Risk Rating 2.0) toward insurance pricing for every property consistent with SOP Median estimates for EAC. Transparency and clarity also needed to discourage exploitation of ignorance.

### 10.2 Our second priority is establishing durable solutions to political issues.

These include:

- Who is deserving? On what basis—equity, affordability?
- Which assistance option is appropriate?
  1. Insurance and/or property value subsidy.
  2. Recovery grants/loans.
  3. Ri$k mitigation subsidy.
  4. Property buyout subsidy (convert to green space)—often the preferred option for properties that are not Su$tainable.

  Nos. 1 and 2 can distort Ri$k, while Nos. 3 and 4 can reduce costs for Nos. 1 and 2.
- How much?
- How to fund? externally—e.g., federal/state support for local watershed; internally—some property-stakeholders supporting others.
- How to administer? e.g., address bureaucracy and coordination issues.

See ***Inequitable patterns of US flood risk in the Anthropocene*** and ***Coalition for Sustainable Flood Insurance***.

# Conclusion

Flood Re$ilience in the face of escalating disasters demands the direct, prompt, and complete adoption of these ten fundamental lessons and associated principles. As noted in the Introduction, there are long-established precedents when it comes to taking similar sensible approaches to other hazards. It may even be of interest to recall the 2,000-year-old Proverb of the Wise and Foolish Builders:

> *A wise man built his house on the rock—the rain came down, the streams rose, and the winds blew and beat against that house; yet it did not fall, because it had its foundation on the rock.*
>
> *A foolish man built his house on sand—the rain came down, the streams rose, and the winds blew and beat against that house; and it fell with a great crash.*
>
> (Jesus of Nazareth, from the Sermon on the Mount, Matthew 7)

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**Bob Jacobsen PE**

Bob grew up in New Orleans and earned advanced degrees in both environmental policy and environmental engineering from LSU. Over his four-decade career he has worked with a range of both private and public sector entities—from the largest to the smallest. Beginning in the early 1980s with projects on groundwater contamination he developed a passion for innovative risk-based approaches to complex hydrologic challenges. While serving as the lead consulting hydrologist to the New Orleans east-bank and Baton Rouge regional flood agencies he authored advanced evaluations for the nation's first (2005) and fourth (2016) most expensive floods. (In the mid-2000s Bob directed the first 2D high-resolution simulation of shallow wetland circulation using a high-performance, multi-core computer—for assessing a Mississippi River diversion.) He is a Past-President of the Louisiana Section of the American Society of Civil Engineers and has given dozens of environmental, coastal, and flood hydrology presentations to a wide range of professional, business, government, academic, and citizen audiences.