Risk Assessment Methodologies for US Army Corps of Engineers Civil Works Infrastructure

Presentation to the Pipeline Risk Model Work Group

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US Army Corps of Engineers
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TOPICS

- Background on USACE
- Risk Assessment Methodologies
  - Major Rehabilitation Program
  - Dam Safety Program
  - Levee Safety Program
  - Asset Management Program
- Conclusions

USACE Mission Areas

Source: MG Jackson – OPM

Civil Works Value to the Nation





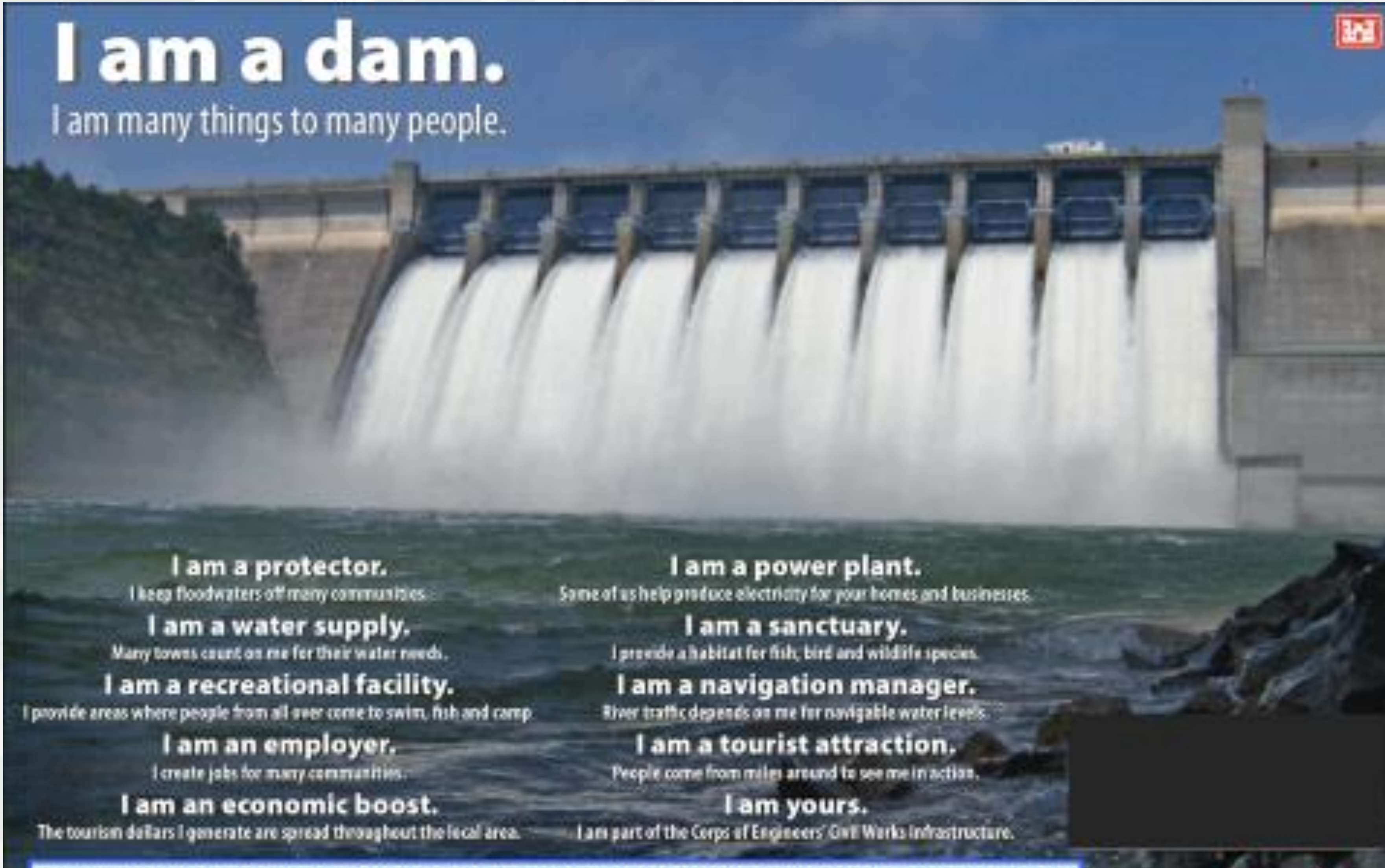



- Every $1 spent on Flood Risk Management prevented nearly $8 in flood damages (Both adjusted for inflation)
- 709 dams; 14,700 miles of levees; 400 miles of shoreline protection
- 183 major ports (250K+ tons of commerce), 884 smaller harbors
- 12,000 miles of commercial inland waterways
- Marine transportation supports $1 trillion in commerce and 13,000,000 jobs annually
- Environmental restoration
- Response to 17 Presidentially declared disasters (2015)
- Largest US outdoor recreation program – 370 million visits a year
- Stewardship of 11.7 million acres of public lands
- 75 hydropower plants produce 3% of US electric energy
- Water supply: 6.9 billion gallons per day
- Nearly $4.9 B in contracts to private business


"The Nation's security depends on its economic strength, and its economic strength depends on its infrastructure"

10

Source: MG Jackson – OPM



MULTIPLE Corps "Business Lines," and more, provide Value and benefits and influenced by investments in a single asset!

"Knowing the assets contribution to value"

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Major Rehabilitation

- Major Rehabilitation (MR) Program
  - MR process started in USACE in early 1990’s
    - Joint effort between engineering, planning and operations
  - MR still in usage today by many USACE Districts
    - Widely applied to number of USACE projects over the past 25 years
    - Future increase in number of projects performing MR in FY15.

Major Rehab Authorization

- WATER RESOURCES DEVELOPMENT ACT OF 1992
  - Section 205 - DEFINITION OF REHABILITATION FOR INLAND WATERWAY PROJECTS.
    - Pub. L. 102–580, title II, § 205, Oct. 31, 1992,
    - 106 Stat. 4827
    - 33 USC 2327
      - Title 33 - NAVIGATION AND NAVIGABLE WATERS
      - CHAPTER 36 - WATER RESOURCES DEVELOPMENT
      - SUBCHAPTER V - GENERAL PROVISIONS
      - Sec. 2327 - Definition of rehabilitation for inland waterway projects

Major Rehabilitation for USACE Projects

- Engineering Pamphlet (EP) 1130-2-500
  - Dated - 27 Dec 1996
  - CECW-O - Operations policy document
    - Rehabilitation Evaluation and Report preparation will be funded under the Operation and Maintenance, General, appropriation
    - Major Rehabilitation Construction, funded out of Construction, General appropriation
    - 3 year budget cycle submission for CG funds

Major Rehabilitation for USACE Projects

- Engineering Pamphlet (EP) 1130-2-500
  - Chapter 3 – Major Rehabilitation Program
    - Purpose, Background and Guidance
  - Appendix B – Rehabilitation Evaluation Report
  - Appendix C – Conceptual Approach for Analyzing Rehabilitation
  - Appendix D – Introduction to Assessment of Structural Reliability
  - Appendix E – Benefit Evaluation Procedures
  - Appendix F – Example of Combining Risks and Consequences

EC 1110-2-6062

US Army Corps of Engineers®

ENGINEERING AND DESIGN

EC 1110-2-6062
1 February 2011

Risk and Reliability Engineering for Major Rehabilitation Studies

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-CE

EC 1110-2-6062

Circular
No. 1110-2-6062

1 February 2011

EXPIRES 31 JANUARY 2013
Engineering and Design
RISK AND RELIABILITY ENGINEERING
FOR MAJOR REHABILITATION STUDIES

1. Purpose. This Engineer Circular (EC) presents comprehensive guidance for engineering risk and reliability for Major Rehabilitation studies. This EC includes the methods for developing engineering reliability applications. It covers applications for multiple engineering disciplines. Although there is discussion of economic consequences from unreliable performance, the focus of this EC is on predicting engineering performance, not on the economics of investment decisions. A fuller treatment of risk assessment to inform the major rehabilitation investment decisions will be developed while this EC is used as interim guidance.

2. Applicability. This circular is applicable to all USACE commands having responsibility for the major rehabilitation studies.

3. Distribution Statement. Approved for public release; distribution is unlimited.

4. References. References are at Appendix A.

5. Discussion. The use of probabilistic analytical methods, including the development of hazard functions, is a relatively new concept within USACE. In the last 15 years, the use of probabilistic and risk-based methods has become an acceptable and required analysis technique for USACE studies. Most of the historical use of engineering reliability analysis within USACE has included the development and utilization of hazard functions for major rehabilitation studies, systems studies, and evaluation of the need for new navigation projects when the existing structure is in a deteriorated condition.

FOR THE COMMANDER:

JAME C. DALTON, P.E., SES
Chief, Engineering and Construction Division
Directorate of Civil Works

4 Appendices
Appendix A – References
Appendix B – Navigation Reliability
Appendix C – Flood Control Reliability
Appendix D – Hydropower Reliability

Major Rehab Process

- Assemble PDT – PM, Engineering, Environmental, Economist, Cost, etc…
- Document Project History
  - ▸ Current and historical
    - Condition
    - Poor performance
    - Maintenance – annual and emergency
    - Cost of repairs
    - Etc….

Major Rehab Process

- Failure Modes Effects and Criticality Analysis (FMECA)
- Establish Base Condition
  - ► "Fix as Fails"
  - ► Used as measuring stick against all alternatives
- Perform Reliability Analysis
  - ► Estimate PUP or hazard rate (time-dependent) using reliability models

Reliability Methods

- Two ways to estimate reliability for Major Rehabilitation Studies:
  - ▶ Non-Probabilistic
  - ▶ Probabilistic

- <u>Non-Probabilistic Reliability Methods</u>
  - Historical Frequency of Occurrence
  - Survivorship Curves (hydropower equipment)
  - Expert Opinion Elicitation

Historical Frequencies

- Use of known historical information for records at site to estimate the failure rates of various components

- For example, if you had 5 hydraulic pumps in standby mode and each ran for 2000 hours in standby and 3 failed during standby. The failure rate during standby mode is:

Total standby hours = 5(2000 hours) = 10,000 hours

Failure rate in standby mode = 3 / 10,000

= 0.0003 failures per hour

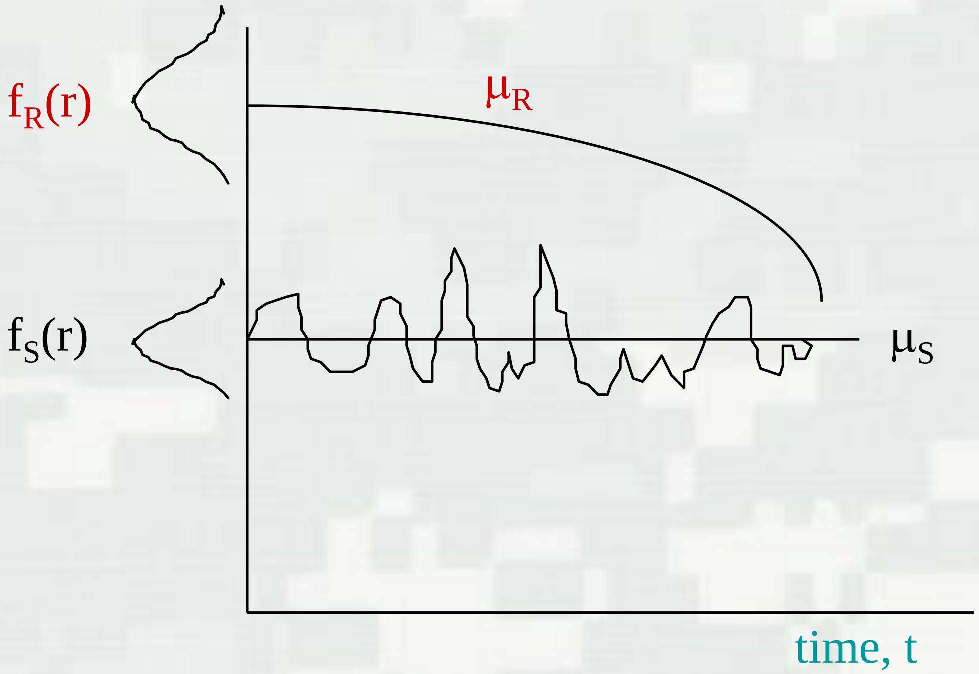
- <u>Manufacturers' survivorship/mortality curves</u>

  - ► Curves are available from manufacturers' for different motors, pumps, electrical components, etc...
  - ► Curves are developed from field data and "failed" components
    - Caution is to be exercised on mode of failure
    - Failure data may have to be censored
  - ► However, usually this data id not readily available for equipment at Corps projects except mainly hydropower facilities
  - ► Report available at IWR on hydropower survivorship curve as well as many textbooks on the subject

- <u>Expert Opinion Elicitation (EOE)</u>
  - ► Solicitation of “experts” to assist in determining probabilities of unsatisfactory performance or rates of occurrence.
  - ► Need proper guidance and assistance to solicit and train the experts properly to remove all bias and dominance.
  - ► Should be documented well for ATR/IEPR
  - ► Used frequently when limit states are not easily defined and data is poor
  - ► Used commonly in Dam and Levee Safety Risk Assessments

- Probabilistic Reliability Methods
  - Reliability Index (β) Methods
    - ▷First Order Second Moment (Taylor Series)
    - ▷Advanced Second Moment (Hasofer-Lind)
    - ▷Point Estimate Method
  - Monte Carlo Simulation
  - Time-Dependent (Hazard Functions)
  - Response Surface Modeling

- Hazard Functions
  - Degradation of Structures
    - Relationship of strength (R) (capacity) vs. load (S) (demand)



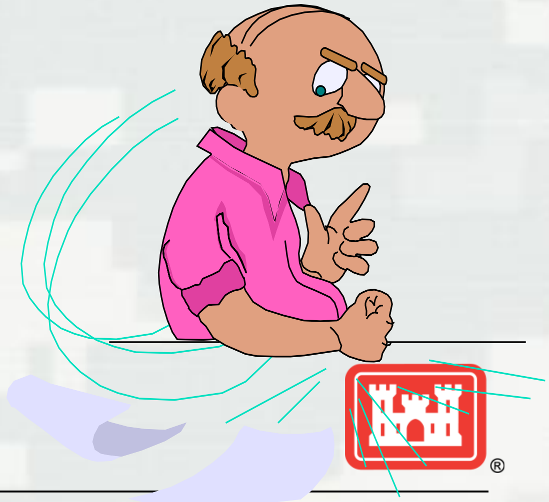
- <u>Hazard Function (conditional failure rate)</u>

  - ► Developed for the ORMSSS economists/planners to assist in performing their economic simulation analysis for ORMSSS investment decisions

  - ► h(t) = P[fail in (t,t+dt)| survived (0,t)]

  - ► h(t) = f (t) / L(t)

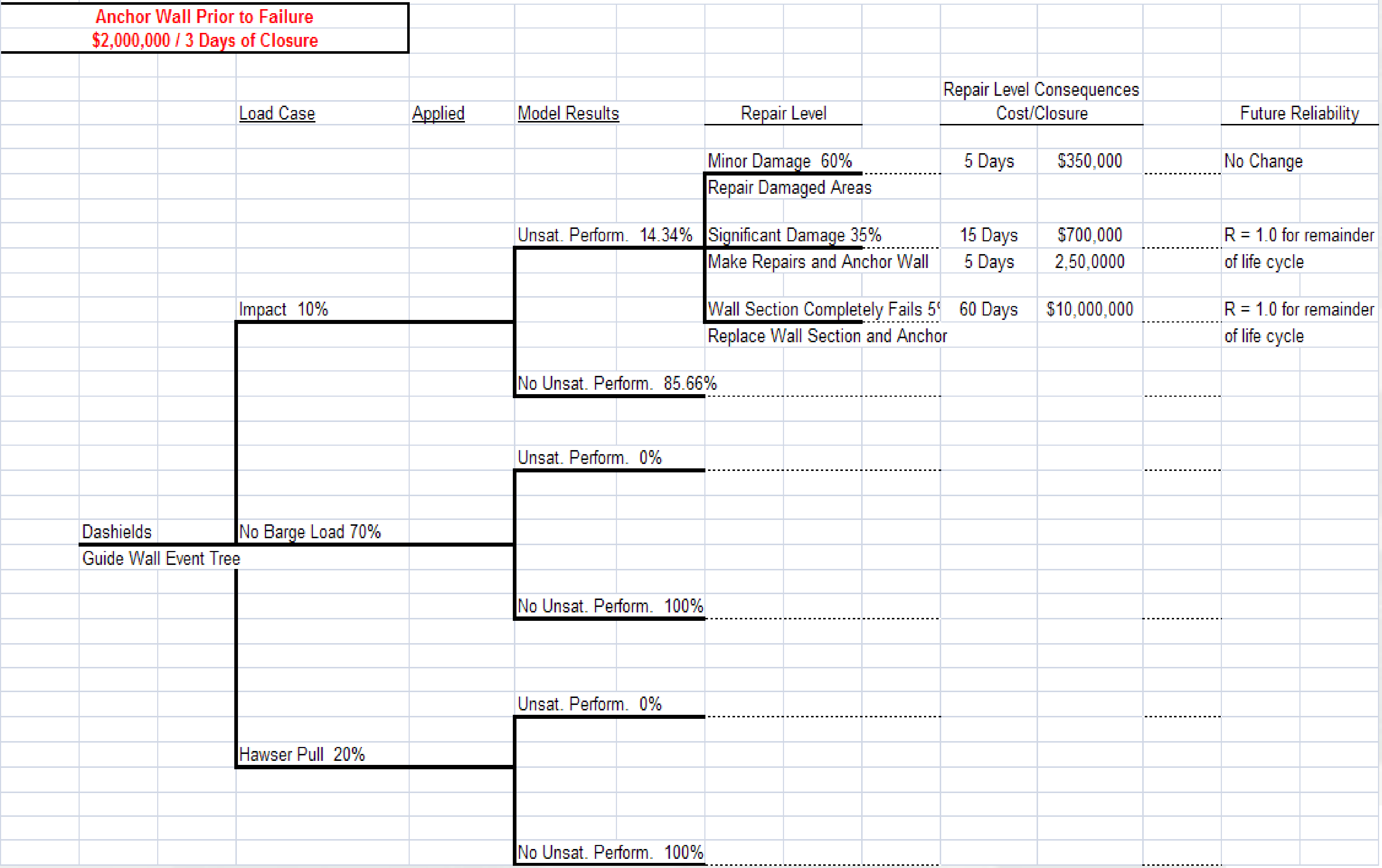
$$= \frac{\text{No. of failures in t}}{\text{No. of survivors up to t}}$$



Event Trees

- Used in many engineering applications for risk assessments
  - Risk
    - Probability of Failure
    - Consequences
  - Probability of events
  - Developed by engineers with input from economists

Dashields Guard Wall Event Tree



Major Rehab Process

- Economic simulations
  - Determine BCR and NED
    - Base Condition
      - Uses PUP from Engineering
    - With Rehabilitation
      - Alternatives
      - Advanced maintenance or scheduled repair or maintenance strategies.


GO TO HUMAN RESOURCES FOR A PSYCHOLOGICAL EVALUATION.
E-mail: SCOTTADAMS@AOL.COM
WHY???
HAVE I SAID ANYTHING THAT IS ABNORMAL?
YOU'RE AN ENGINEER. EVERYTHING YOU SAY IS ABNORMAL.

Dam Safety Program

- ER 1110-2-1156 – Safety of Dams (2014)

DEPARTMENT OF THE ARMY — ER 1110-2-1156
US Army Corps of Engineers
CECW-CE — Washington, DC 20314-1000

Regulation
No. 1110-2-1156 — 31 March 2014

Engineering and Design
SAFETY OF DAMS – POLICY AND PROCEDURES

TABLE OF CONTENTS

Dam Safety Program

- Dam Safety Assurance Program (~1996)
  - ► Follow on to Major Rehab Program
  - ► Probabilistic Risk Assessments
    - Loading – Flood or seismic
    - Fragility - utilize similar reliability methods from Major Rehab program
    - Consequences – damage to property or life loss
  - ► Flood Risk Management projects put into Major Rehab cue for funding

Dam Safety Program

- Screening Portfolio Risk Assessment (2003-2007)
  - Examined USACE portfolio of ~620 flood control and navigation dams
  - Relative risk method
    - Loading ranges established for flood and seismic loads
    - Used base rate adjustment for critical failure modes
      - Base rates adjusted by four descriptors (A, PA, PI, I)
    - Consequences for load events

Engineering Rating Summary

Feature Navigation High Head Dam	Normal Water Level	50% Exceedence Duration Water Level with OBE	50% Exceedence Duration Water Level with MDE	Unusual (100yr)	Extreme (PMF)
Concrete Structures – Rock Foundation					
External Stability	I	PA	PI	I	I
Internal Stability	I	PA	PI	I	I
Foundation Stability – under dam	PA	A	A	PA	PA
Scour Protection	PA	A	A	PA	PA
Foundation -Seepage & Piping	PA	A	A	PA	PA
Abutment Foundation Stability	A	A	A	A	A
Concrete Structures – Pile Foundation					
Foundation Seepage & Piping (Incl. upstream cu	NA	NA	NA	NA	NA
Foundation Liquifaction	NA	NA	NA	NA	NA
External Stability1	NA	NA	NA	NA	NA
Foundation Stability (Incl. pile capacity) 1	NA	NA	NA	NA	NA
Internal Stability	NA	NA	NA	NA	NA
Scour Protection	NA	NA	NA	NA	NA
....................Void....................	NA	NA	NA	NA	NA
Abutment Foundation Stability1	NA	NA	NA	NA	NA
Gates & Gate Structure					
Spillway gate(s) failure 2	I	PA	PA	I	I
Spillway gate piers – structural capacity	PA	A	PA	PA	PA
Gates – Electrical/Mechanical	A	A	PA	A	PA
Lock gates (struct/elect/mech)	I	PA	PI	I	I
....................Void..............	NA	NA	NA	NA	NA
Embankment & Closure Dikes					
Embankment Seepage & Piping	PA	A	A	PA	PA
Embankment Stability and/or Liquefaction	A	A	PA	A	A
Erosion: Toe, Surface & Crest	A	A	A	A	PA
Abutments Seepage & Piping	A	A	A	A	A
Abutments Stability and/or Liquefaction	A	A	A	A	A
Foundation Seepage & Piping	A	A	A	A	A
Foundation Stability and/or Liquefaction	A	A	A	A	A
Emergency Closure Systems					
Service bridge,	A	A	PA	A	A
Crane & Power	A	A	PA	A	A
Bulkheads	PI	A	A	A	A
....................Void....................	NA	NA	NA	NA	NA
Other Features					
Feature 1	A	A	PA	A	PA
Feature 2	NA	NA	NA	NA	NA
Feature 3	NA	NA	NA	NA	NA
Feature 4	NA	NA	NA	NA	NA

Definition of Engineering Ratings

A	Adequate = 1	confidence backed up by data, studies, or obvious project characteristics and judged to meet current engineering standards and criteria.
PA	Probably Adequate = 10	and may not specifically meet criteria. Requires additional investigation or studies to confirm adequacy.
PI	Probably Inadequate = 100	confidence and requires additional studies and investigations to confirm. Judged to not meet current criteria.
I	Inadequate = 1000	confidence. Physical signs of distress are present. Analysis indicates factor of safety near limit state.
NA	Not Applicable = 0	Feature does not exist

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Dam Safety Program

- ER 1156 Risk Assessment Methodology
  - Potential Failure Mode Analysis (PFMA)
    - Evaluate and Describe Potential Failure Modes
  - Construct Event Trees to Analytically Describe the Potential Path to Failure
  - Use Expert Elicitation with an Experienced Facilitator to Evaluate Relative Likelihoods of Each Event Tree Branch
  - Use the Analysis to Develop a Rational Case to Support a Decision
  - Examine tolerable risk curves (Farmer's Curves)

Risk Assessment Framework

P(Load) * P(Failure | Load) * Consequences = RISK

P(Load)

- Likelihood of a Loading Event
- Flood Loading or Seismic Loading

P(Failure | Load)

- Given the Event Occurs, What is the Likelihood of Adverse Structural Response of the System?
- Event Tree Construction

Consequences

- For Each Specific Adverse Response, What are the Life Safety and Economic Consequences?

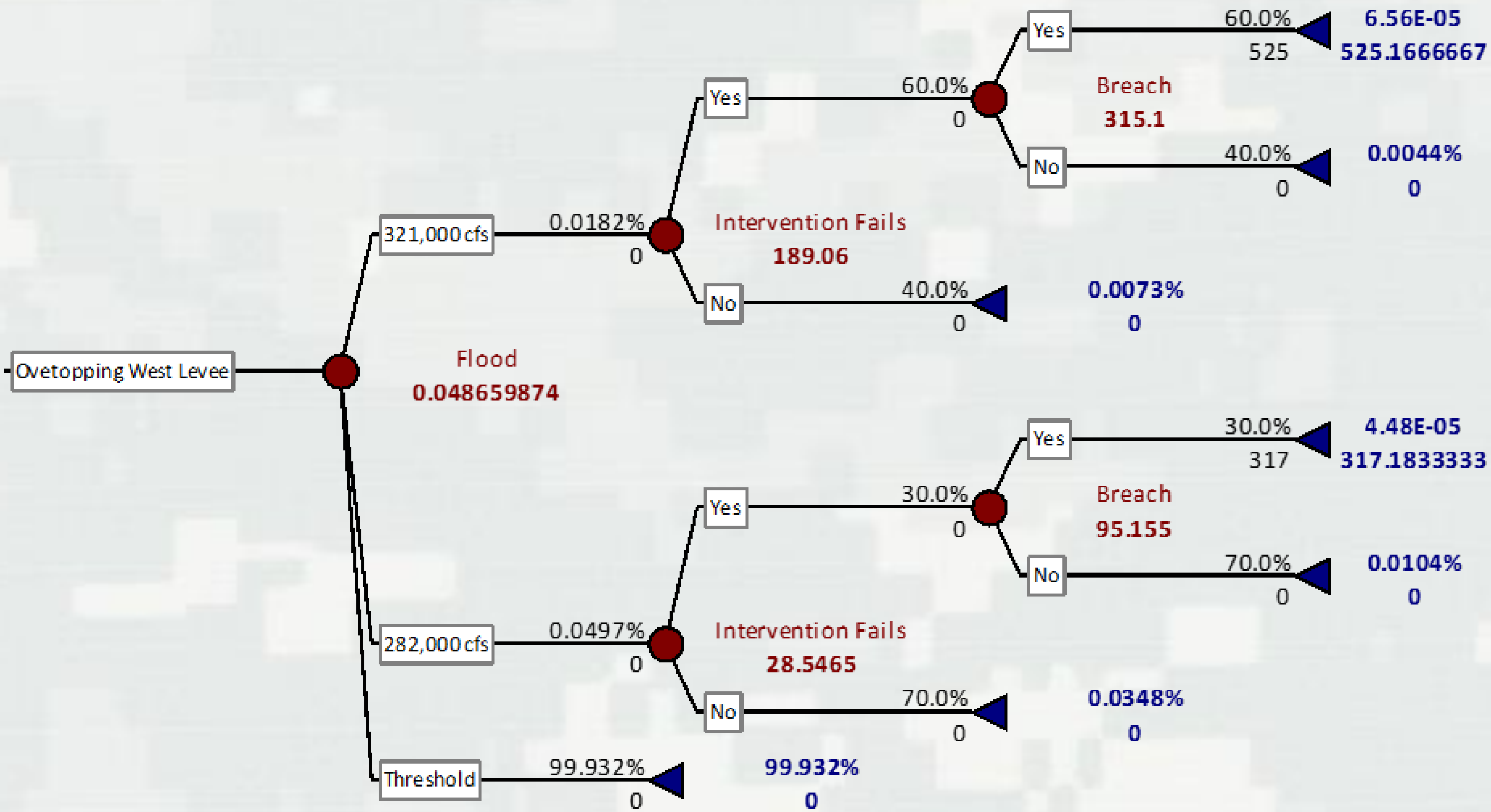
Event Information	
Loading Condition:	Hydrologic
Failure Mode:	Overtopping Erosion of the Levee
Location:	Low Areas based on Survey Results
Event and Initiator:	Very Large Flood with Possible Debris Blockage at Bridges

Influence Factors	
More Likely (Adverse)	Less Likely (Favorable)
Expect there to be more debris at large flood flows than has been seen in the past	Needs close to SPF to trigger (overtop) without debris blockage
Trestle bridge has closely spaced supports which are more likely to catch debris	Except for trestle bridge, bridge piers are typically widely spaced
Bridge decks may catch debris at high flow since they are typically close to the levee crest	Backwater at bridges due to debris would be of limited extent upstream
Some areas of the levee would overtop at SPF without debris blockage by up to 1 to 2 feet	Small area near DART line most susceptible (lowest crest), could be sand bagged (1,000 to 2,000 feet)
Largest peak storm is a flashy local thunderstorm occurring between the upstream reservoirs and the levee – may not have much time to react	Could attempt to deal with debris at bridges using backhoes or other equipment
Local inundation of the exit roadways may hinder evacuation	Fairly confident in hydraulic model and predicted water surface profile, so should have relatively good idea when overtopping will occur (with no debris)
Vulnerable population (hospitals, nursing homes, etc.) may need assistance to evacuate	Short distance to safety – the inundated areas will be relatively close to the river, evacuation to upper floors of buildings possible
	EAP would likely be initiated for event like this which would lead to early evacuations
	Short duration of overtopping may not breach levee – hydrographs indicate peak flows may not be long duration

Likelihood Category: Low to Moderate **Confidence**: Moderate

Rationale: Although it is likely the levee embankments would overtop during a flood equal to the Standard Project Flood (SPF) or greater, the compacted clay soils of the embankments will likely survive some level of overtopping without breach. The main uncertainty had to do with the possible duration of overtopping at large floods similar to the SPF that would overtop the dam.

Event Trees



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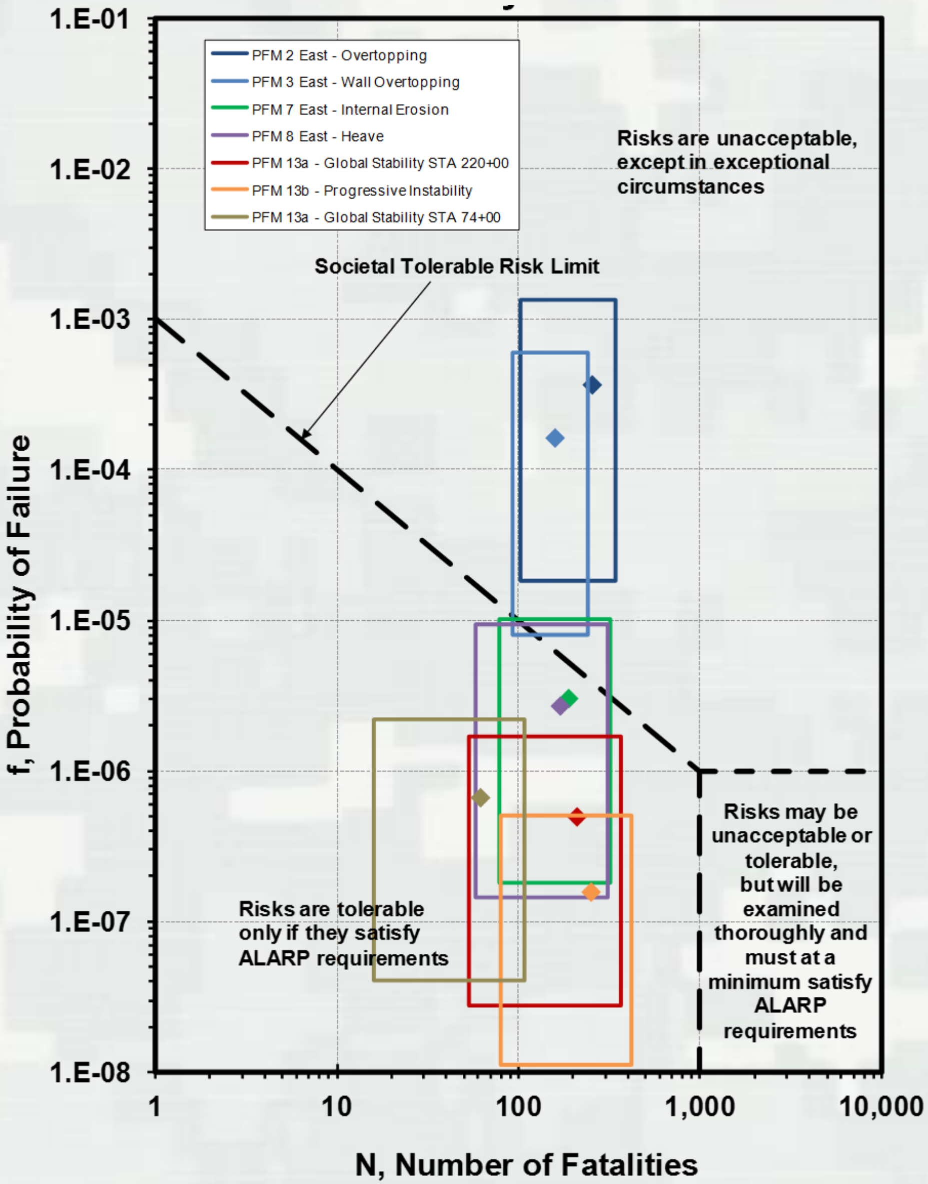
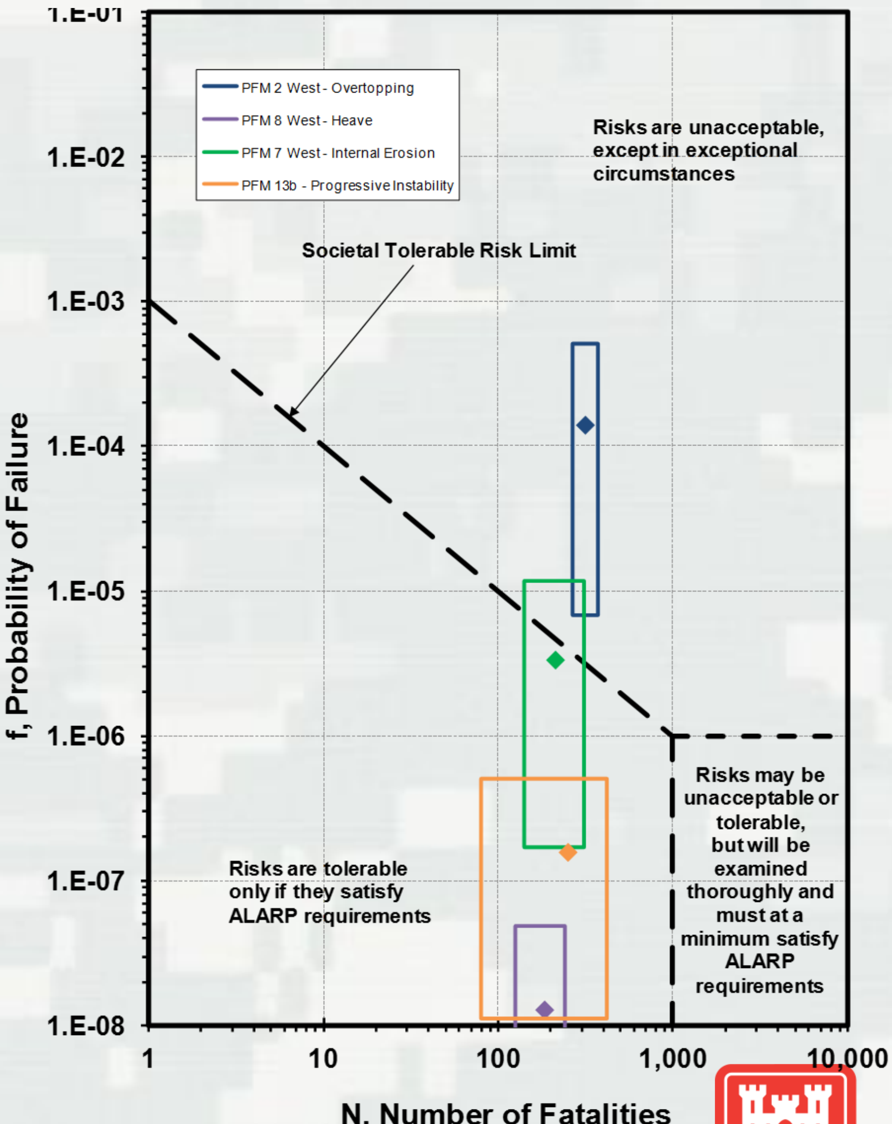


PFM 2 East - Overtopping
PFM 3 East - Wall Overtopping
PFM 7 East - Internal Erosion
PFM 8 East - Heave
PFM 13a - Global Stability STA 220+00
PFM 13b - Progressive Instability
PFM 13a - Global Stability STA 74+00
Risks are unacceptable, except in exceptional circumstances
Societal Tolerable Risk Limit
Risks may be unacceptable or tolerable, but will be examined thoroughly and must at a minimum satisfy ALARP requirements
Risks are tolerable only if they satisfy ALARP requirements
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1
10
100
1,000
10,000
f, Probability of Failure
N, Number of Fatalities



PFM 2 West - Overtopping
PFM 8 West - Heave
PFM 7 West - Internal Erosion
PFM 13b - Progressive Instability
Risks are unacceptable, except in exceptional circumstances
Societal Tolerable Risk Limit
Risks may be unacceptable or tolerable, but will be examined thoroughly and must at a minimum satisfy ALARP requirements
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1.E-01
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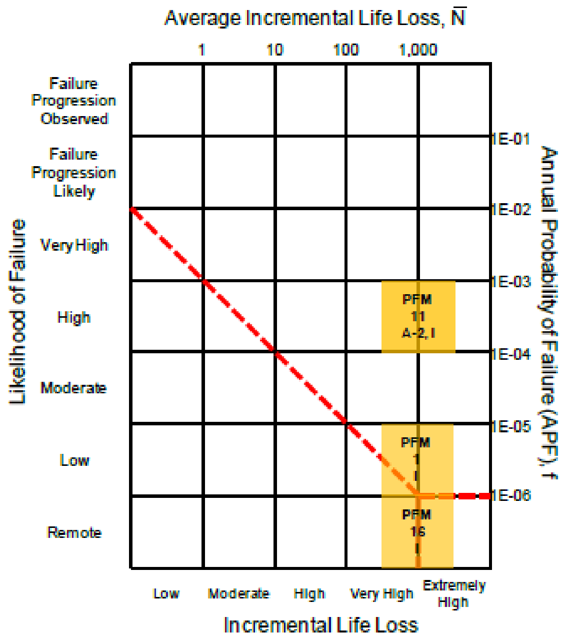
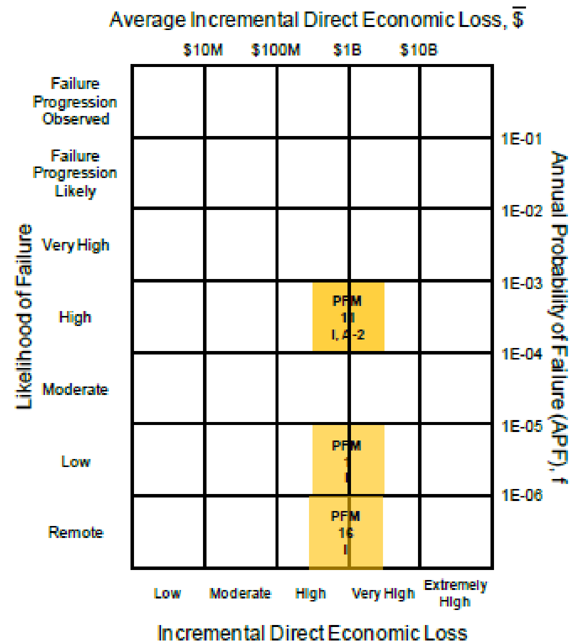
1.E-05
1.E-06
1.E-07
1.E-08
1
10
100
1,000
10,000
f, Probability of Failure
N, Number of Fatalities

Dam Safety Program

- Semi-Quantitative Risk Assessment (SQRA)
  - ► Screening level approach but more rigor than SPRA
  - ► Risk matrix approach to examining probability of failures and consequences
  - ► Uses PFMA to estimate probability of failure
  - ► Uses rough estimates for consequences (loss of life and direct economic loss)

SQRA





Unit/ Reach	PFM	Failure Likelihood	Confidence	Incremental Loss of Life	Confidence	Economic Loss	Confidence
Unit 2 A-2/I	PFM 11 – Backwards erosion piping in foundation	High	Low	Very High to Extremely High	Moderate	High to Very High	Moderate
Unit 2 I	PFM 1 – Overtopping with breach	Low	Low	Very High to Extremely High	Moderate	High to Very High	Moderate
Unit 2 I	PFM 16 – Concentrated leak erosion along pipe penetrations	Remote	Moderate	Very High to Extremely High	Moderate	High to Very High	Moderate

Dam Safety Program

- Event driven process – flood or seismic
- PFMA does not look at consequences or criticality directly
- Relies on Expert Opinion Elicitation for ET nodes
  - ► Kent Tables for descriptors and probabilities
  - ► No probabilistic methods
- Does not include time dependency
- Does not include uncertainty
- Does not include operational risks


WE'LL NEED A RISK ANALYSIS ON THIS PROJECT BEFORE I CAN APPROVE IT.
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S. Adams
RISK 1: INDECISIVENESS
RISK 2: OVERANALYSIS
RISK 3: CLUELESSNESS
RISK 4: MICROMANAGE-MENT...
CLICK
CLICK
CLICK
© 1997 United Feature Syndicate, Inc.
I DON'T UNDERSTAND THESE RISKS.
THAT'S NUMBER THIRTY-SIX.

Levee Safety Program

- ER 1120-2-XXXX Safety of Levees (guidance still under development)
- Reliability of levees were was first developed under the Major Rehabilitation Program in 1990’s
  - ► Developed reliability models for levees and floodwalls (Taylor Series Finite Difference)
  - ► Examined consequences (property damage but not life loss) of levee failures

Hurricane Katrina – Aug 2005

Overtopping along Gulf Intracoastal Waterways

Hurricane Katrina – Aug 2005

17th Street Canal Breach

Hurricane Katrina – Aug 2005

London Avenue Canal North Near the Robert E. Lee Bridge

Interagency Performance Evaluation Task (IPET) Force

…"to provide credible and objective scientific and engineering answers…."

Chief of Engineers

- **System**
- **Storm**
- **Performance**
- **Consequences**

Repair/Rebuild

Report - Draft JUN06
Report - Final MAR07

- **Risk**

Higher Protection

Maps JUN/JUL 07
Maps AUG 07
Maps MAR 08
Report – Draft NOV 07
Report – Final MAY 08

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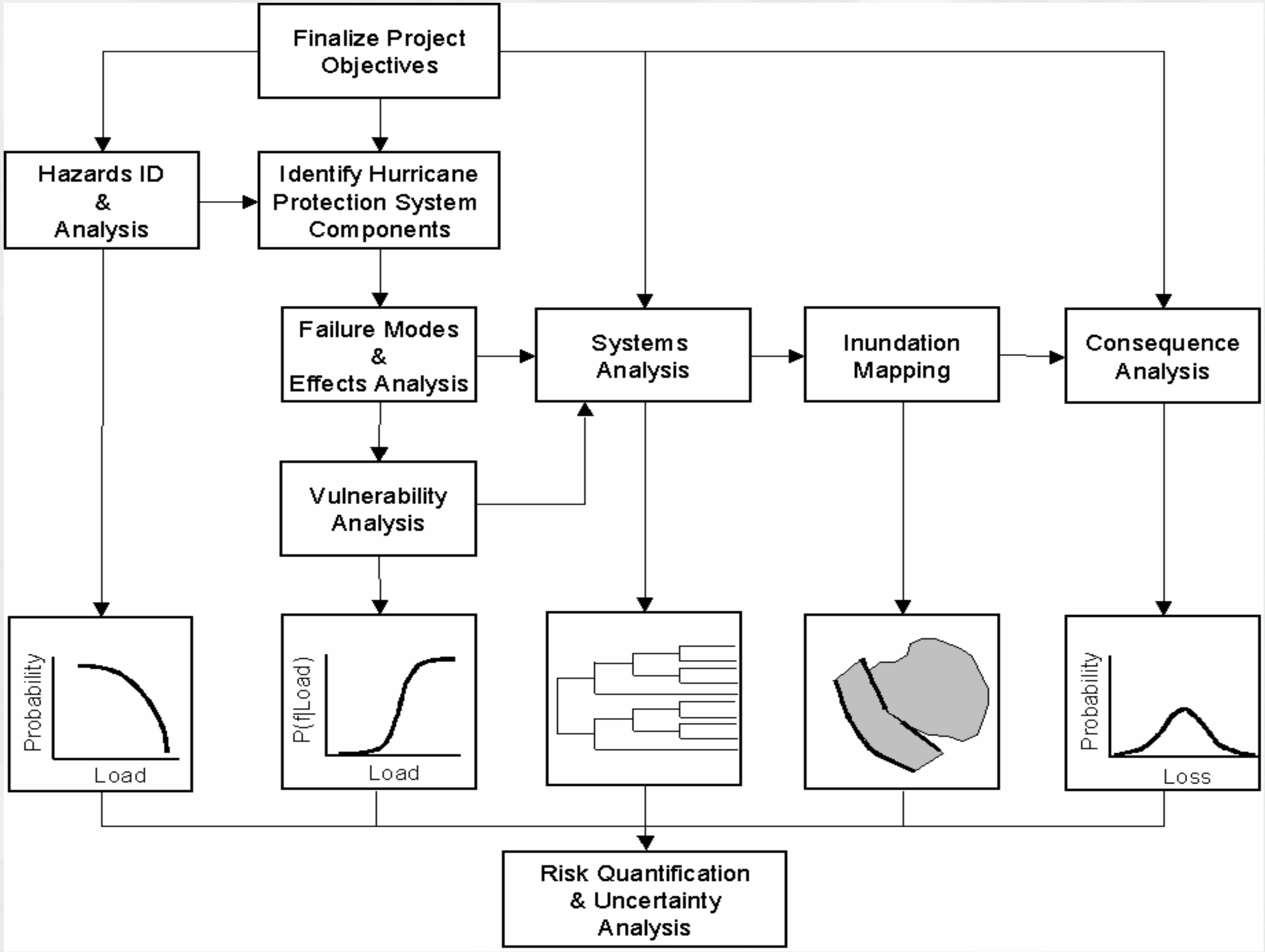
https://ipet.wes.army.mil

NOLArisk.usace.army.mil

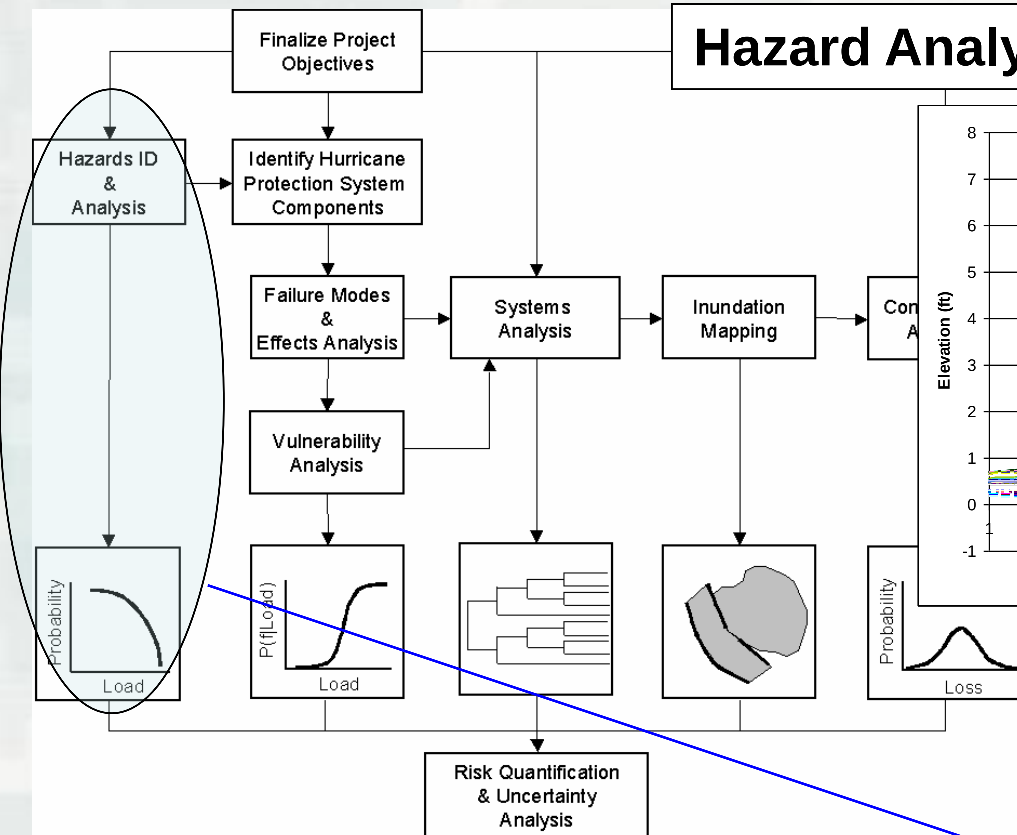
IPET Risk Assessment

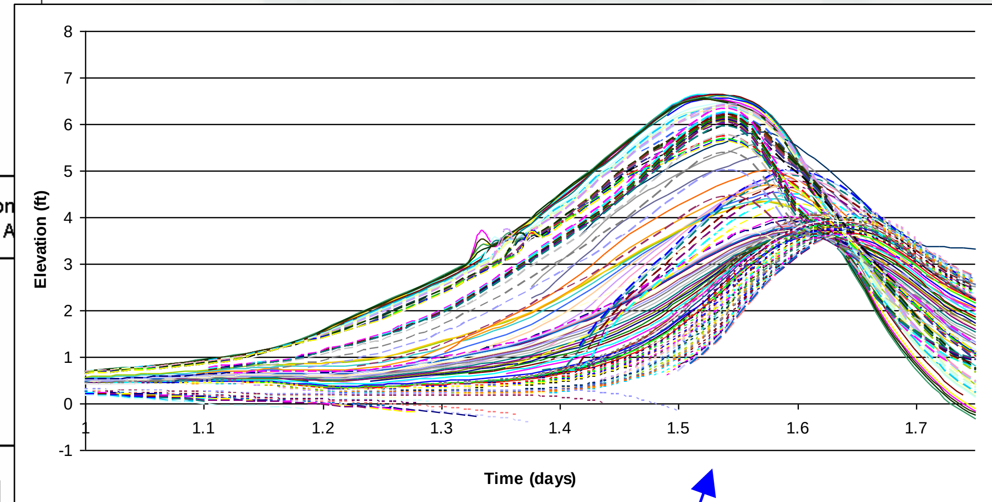
- IPET Background
- Risk Assessment Model
- Hazard
- System Identification
- Reliability Modeling
- Risk Analysis
- Uncertainty
- Validation
- Lesson Learned

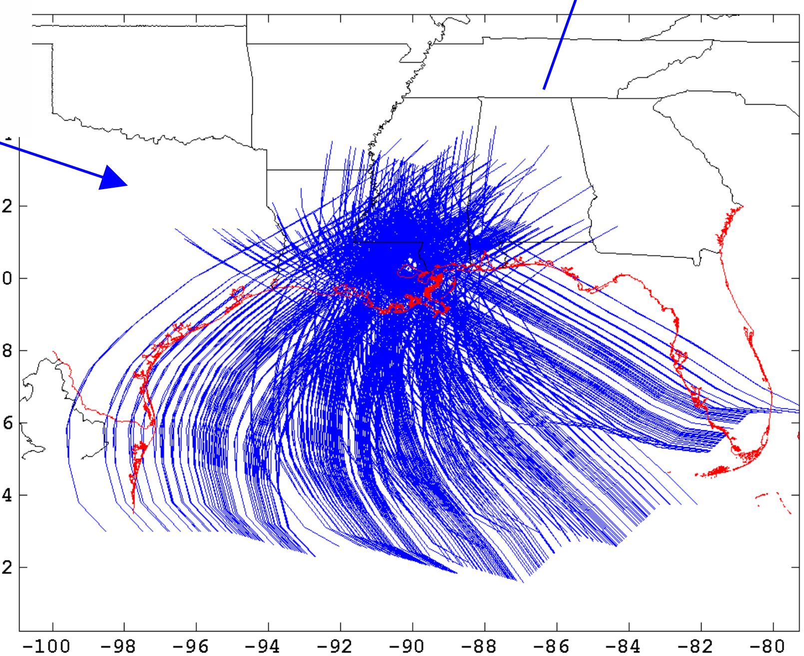
Risk Assessment



Hazard Analysis







Storm Modeling

•ADCIRC

•Historic storms in parameter set

•100+ Low Res Runs

•1800+ Med Res Runs

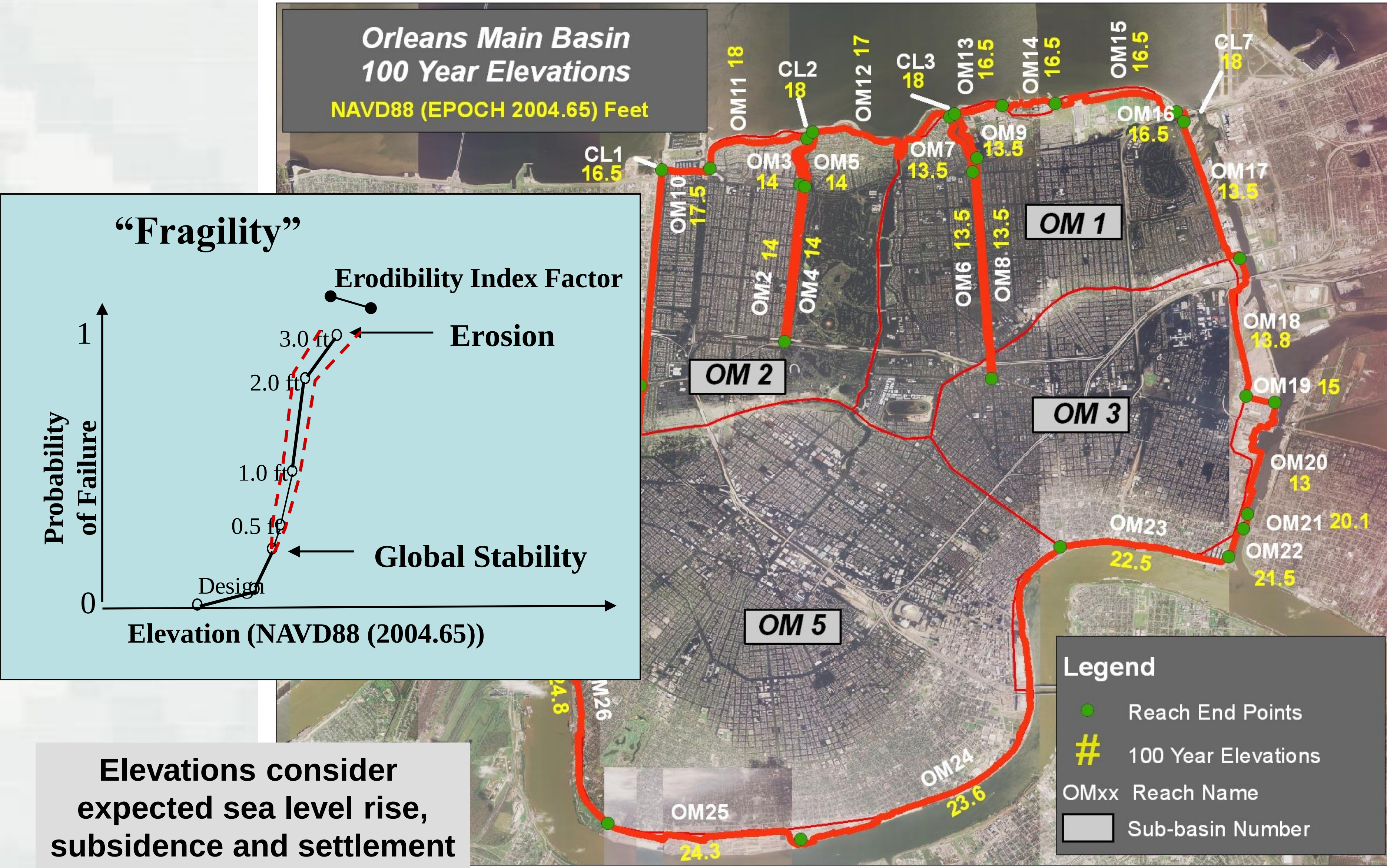
•60+ High Res Runs

•Frequency Analysis

•~~Calibrate (HWM & Storm Team Results)~~

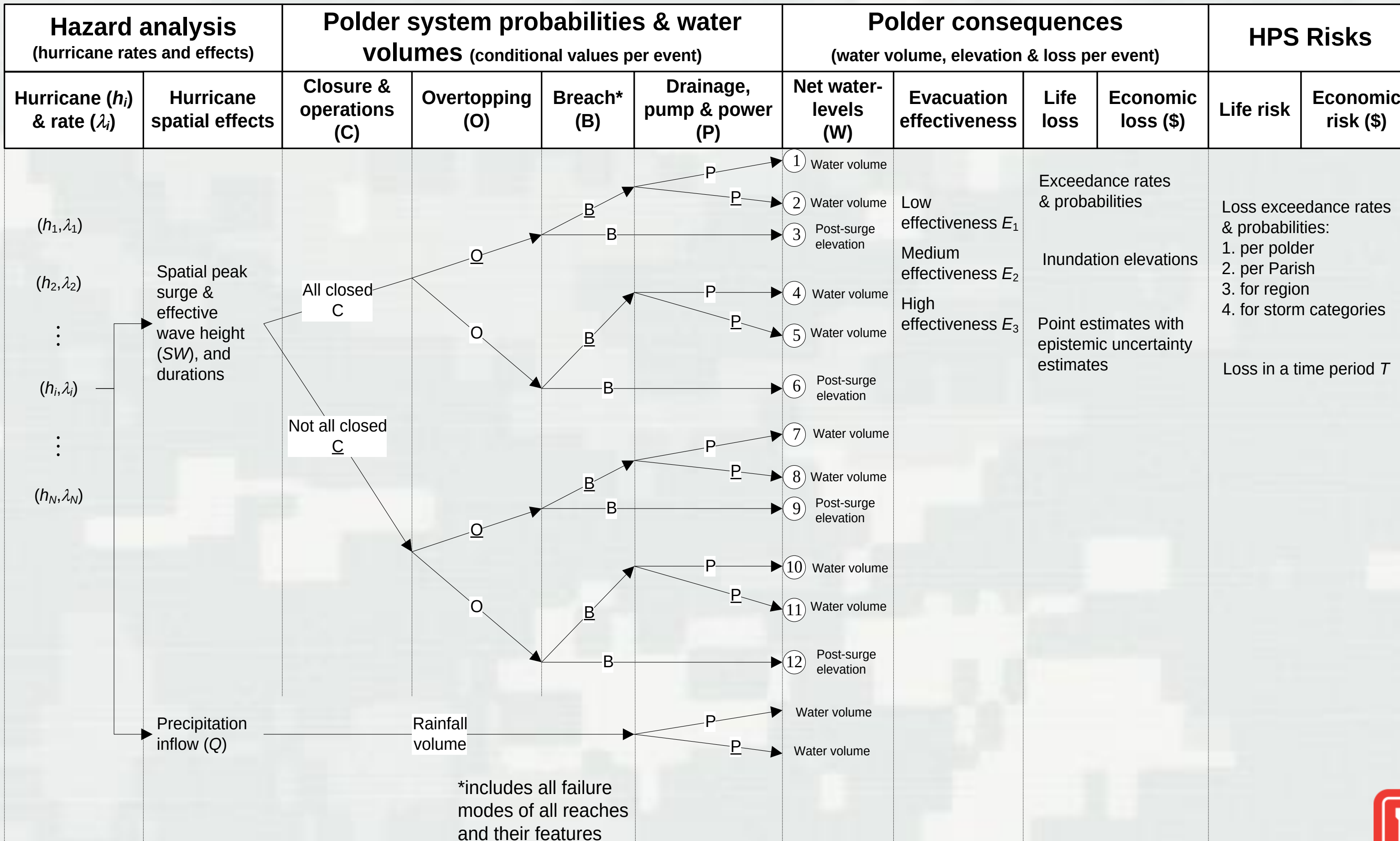
•Add Waves

System Performance

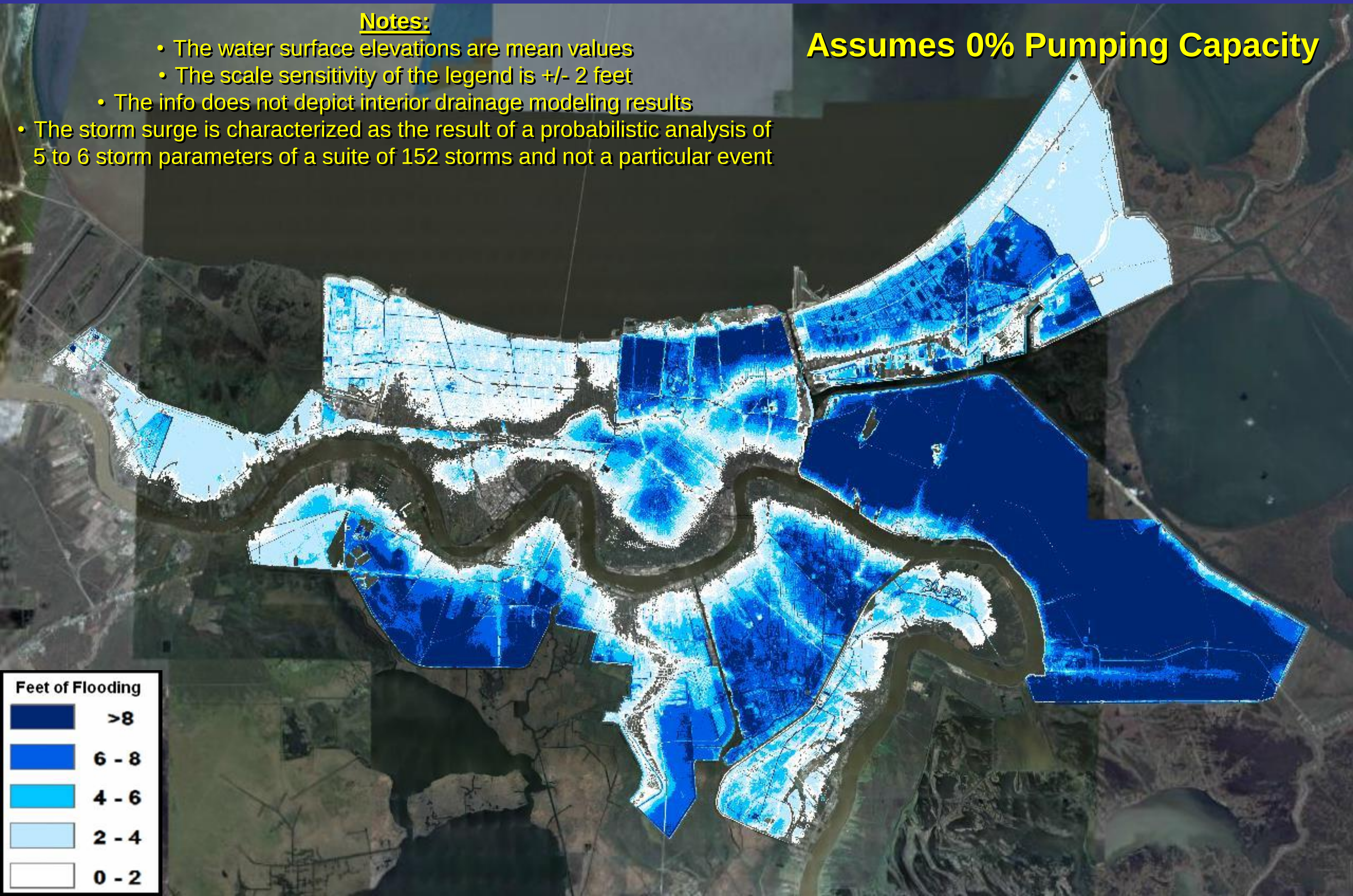


Elevations consider expected sea level rise, subsidence and settlement

Event Tree

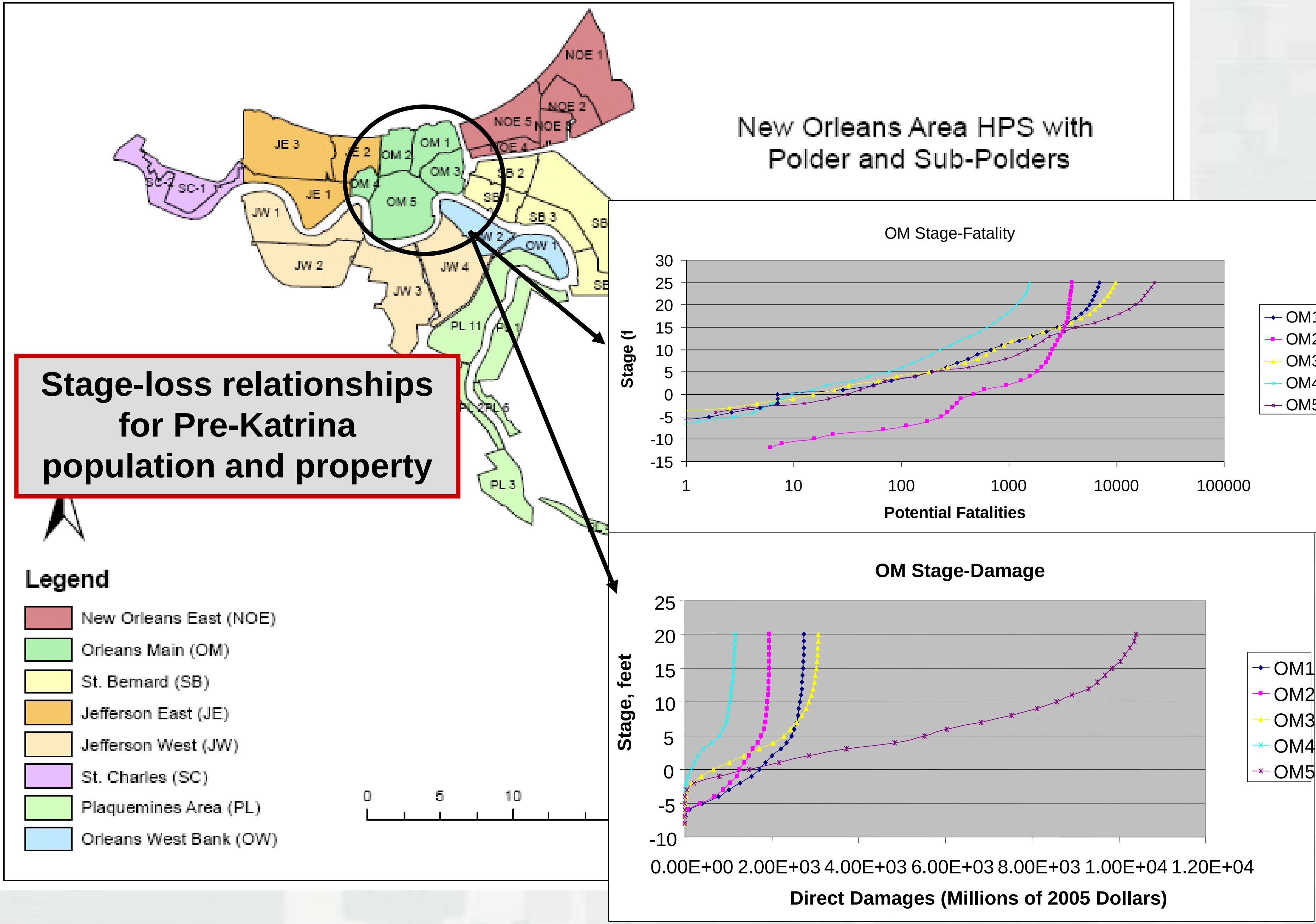

Hazard analysis
(hurricane rates and effects)
Polder system probabilities & water volumes (conditional values per event)
Polder consequences
(water volume, elevation & loss per event)
HPS Risks
Hurricane (h_i) & rate (λ_i)
Hurricane spatial effects
Closure & operations (C)
Overtopping (O)
Breach* (B)
Drainage, pump & power (P)
Net water-levels (W)
Evacuation effectiveness
Life loss
Economic loss ($)
Life risk
Economic risk ($)
(h_1,λ_1)
(h_2,λ_2)
⋮
(h_i,λ_i)
⋮
(h_N,λ_N)
Spatial peak surge & effective wave height (*SW*), and durations
Precipitation inflow (*Q*)
All closed
C
Not all closed
C
Rainfall volume
O
O
O
O
B
B
B
B
B
B
B
B
P
P
P
P
P
P
P
P
P
P
1 Water volume
2 Water volume
3 Post-surge elevation
4 Water volume
5 Water volume
6 Post-surge elevation
7 Water volume
8 Water volume
9 Post-surge elevation
10 Water volume
11 Water volume
12 Post-surge elevation
Water volume
Water volume
Low effectiveness E_1
Medium effectiveness E_2
High effectiveness E_3
Exceedance rates & probabilities
Inundation elevations
Point estimates with epistemic uncertainty estimates
Loss exceedance rates & probabilities:
1. per polder
2. per Parish
3. for region
4. for storm categories
Loss in a time period *T*
*includes all failure modes of all reaches and their features

Before Katrina, you had a 1% chance every year of flooding this deep from Hurricanes



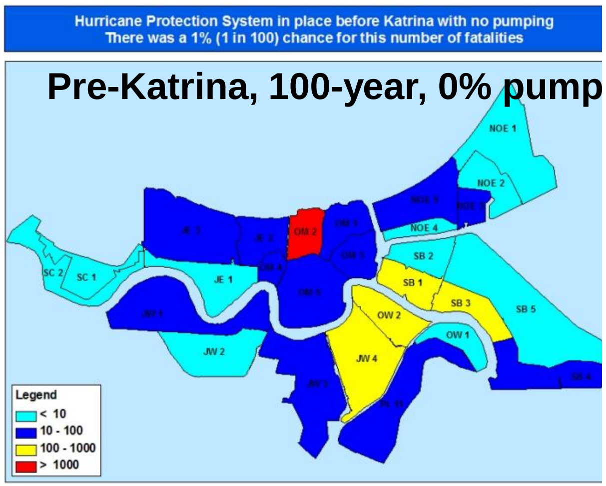
Consequences

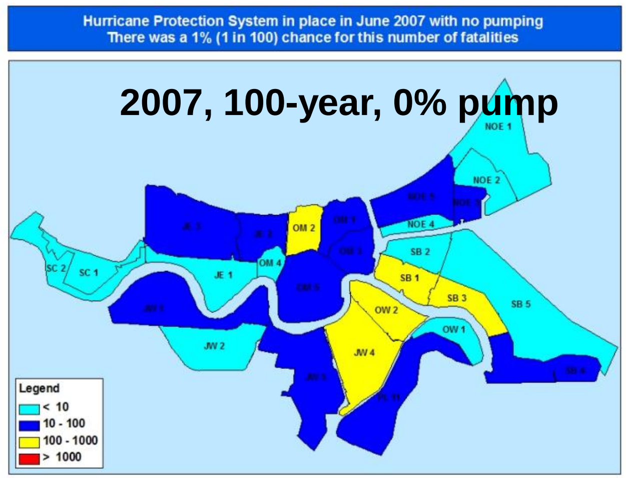
Stage-loss relationships for Pre-Katrina population and property

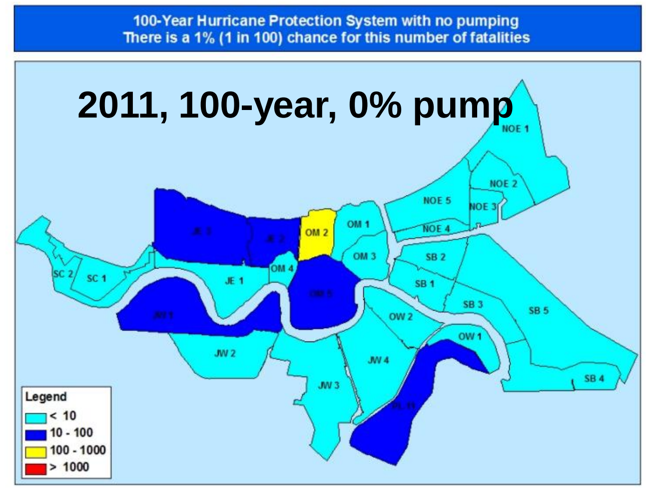


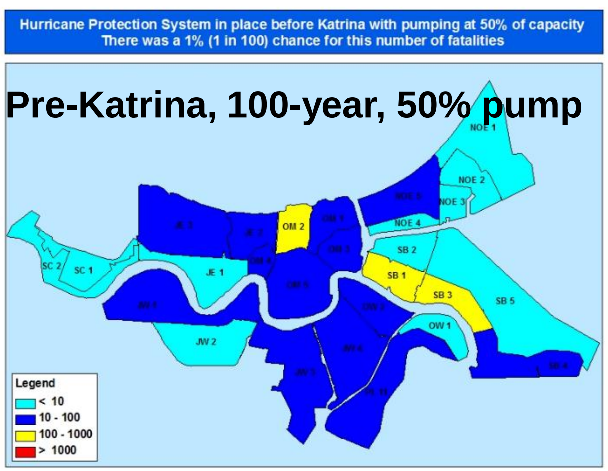
Loss of Life Risk Maps

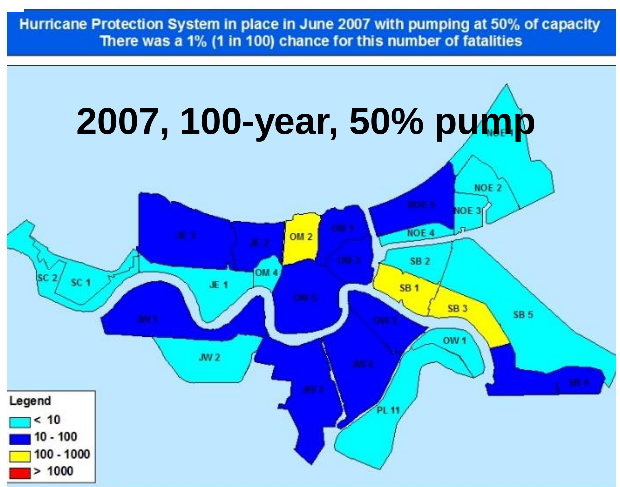
(Pre-K Population and Property)

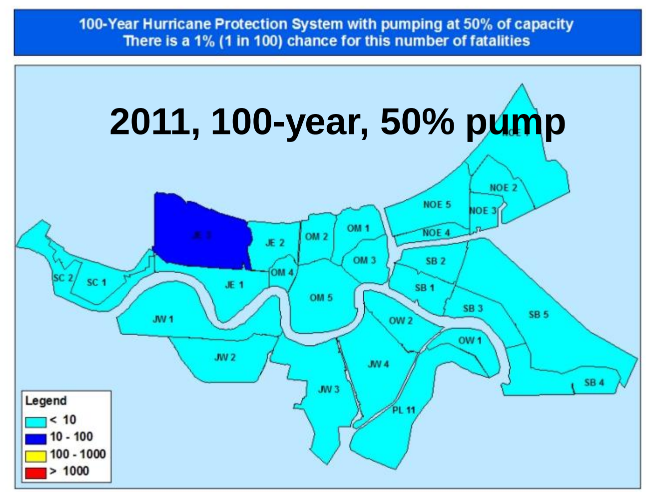




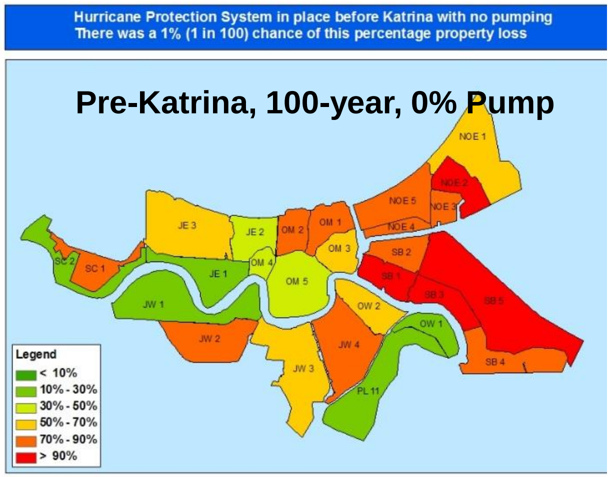


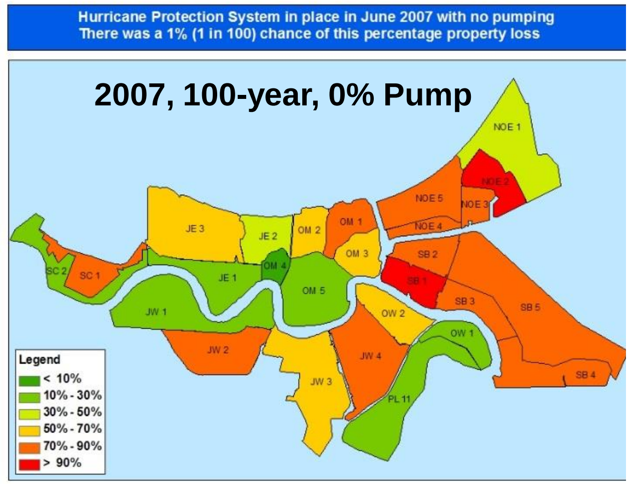


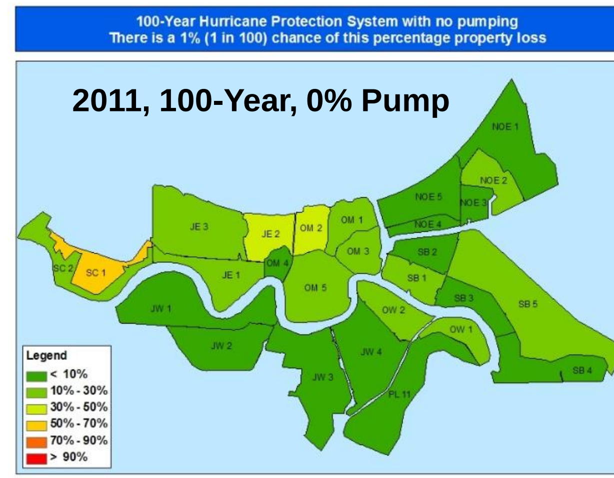


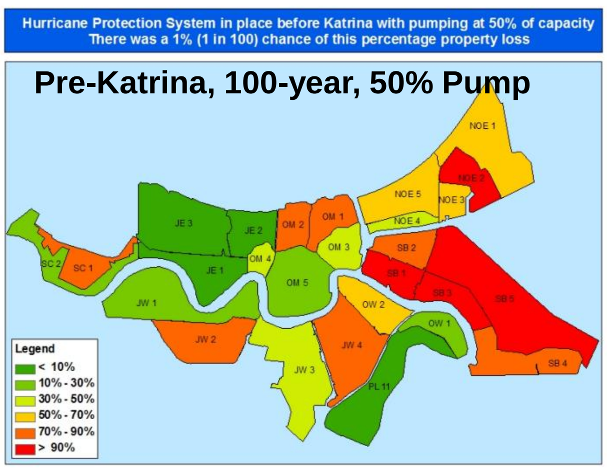


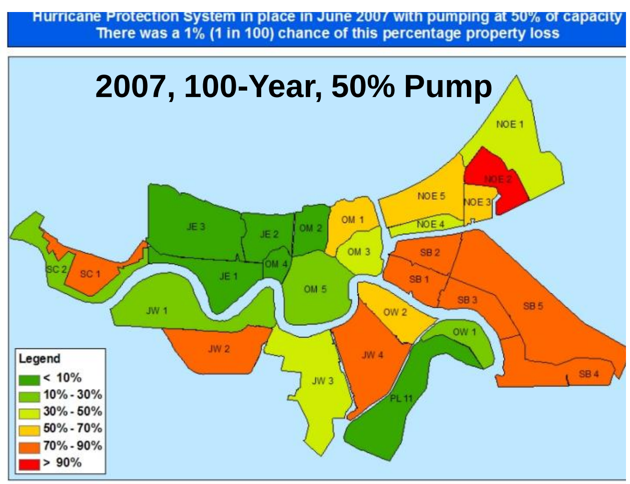
Economic 1% Risk Maps
(Pre-K Population and Property)

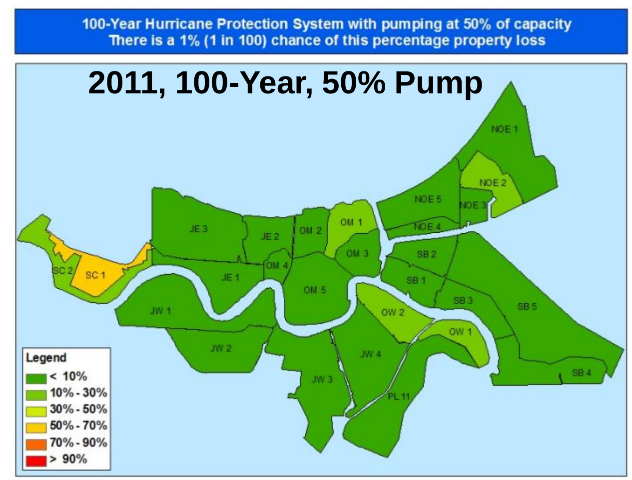












PAST **PRESENT** **FUTURE**

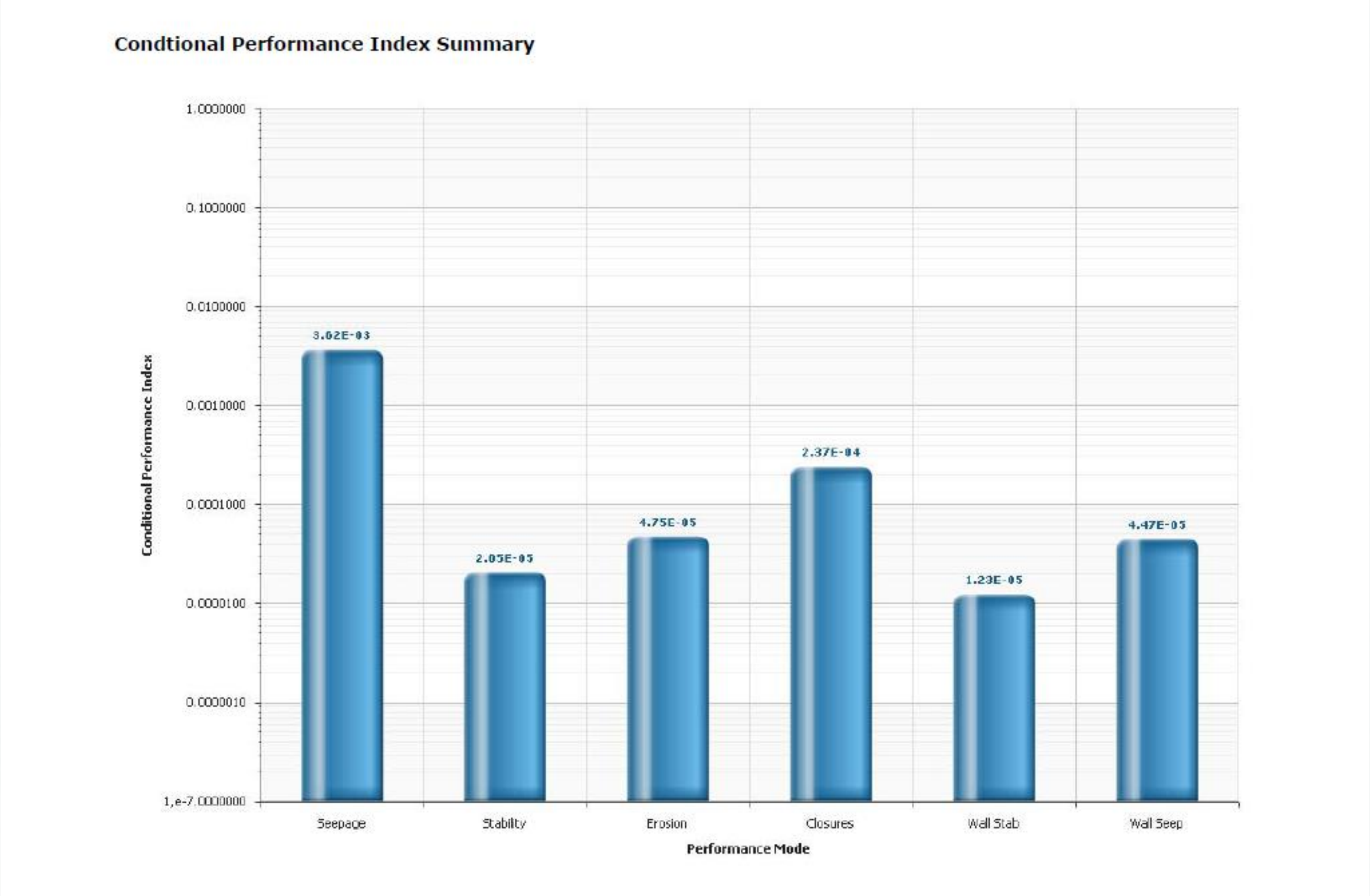
Levee Screening Tool (2009)

- Used to rank levees in terms of Levee Safety Action Classification (LSAC) ratings and prioritization for future risk assessments
- Base failure rate for critical performance modes for levees and floodwalls
- Base rate adjustment made using Bayesian techniques and three likelihood modifiers (A, M, U)

Table 2.1 Performance Modes and Related Inspection Items

Performance Mode	Inspection Item Category	Inspection Item Number	Inspection Item Name
Embankment and Foundation Seepage and Piping	Levees	1	Unwanted Vegetation Growth
	Levees	3	Encroachments
	Levees	7	Settlement
	Levees	9	Cracking
	Levees	10	Animal Control
	Levees	11	Culverts / Discharge Pipes
	Levees	14	Under Seepage Relief Wells / Toe Drainage Systems
	Levees	15	Seepage
Embankment Stability	Levees	3	Encroachments
	Levees	5	Slope Stability
	Levees	7	Settlement
	Levees	8	Depressions / Rutting
	Levees	9	Cracking
	Levees	14	Underseepage Relief Wells / Toe Drainage Systems
Embankment Erosion	Levees	2	Sod Cover
	Levees	6	Erosion / Bank Caving
	Levees	12	Riprap Revetments and Bank Protection
	Levees	13	Revetments other than Riprap
Closure Systems	Levees / Floodwalls	4 / 3	Closure Systems
Floodwall Stability	Floodwalls	1	Unwanted Vegetation Growth
	Floodwalls	2	Encroachments
	Floodwalls	4	Concrete Surfaces
	Floodwalls	5	Tilting, Sliding, or Settlement of Concrete Structures
	Floodwalls	6	Foundation of Concrete Structures
	Floodwalls	8	Underseepage Relief Wells / Toe Drainage Systems
Floodwall Underseepage and Piping	Floodwalls	1	Unwanted Vegetation Growth
	Floodwalls	2	Encroachments
	Floodwalls	8	Underseepage Relief Wells / Toe Drainage Systems
	Floodwalls	9	Seepage
	n / a	n / a	Culverts / Discharge Pipes

Levee Screening Tool



Levee Safety Program

- Current Risk Assessment Methodology
  - ▸ Potential Failure Mode Analysis (PFMA)
    - Evaluate and Describe Potential Failure Modes
  - ▸ Construct Event Trees to Analytically Describe the Potential Path to Failure
  - ▸ Use Expert Elicitation with an Experienced Facilitator to Evaluate Relative Likelihoods of Each Event Tree Branch
  - ▸ Use the Analysis to Develop a Rational Case to Support a Decision
  - ▸ Use tolerable risk guidelines (Farmer's curves)

Levee Safety Program

- Semi-Quantitative Risk Assessment (SQRA)
  - ► Screening level approach but more rigor than SPRA
  - ► Risk matrix approach to examining probability of failures and consequences
  - ► Uses PFMA to estimate probability of failure
  - ► Uses rough estimates for consequences (loss of life and direct economic loss)

Levee Safety Program

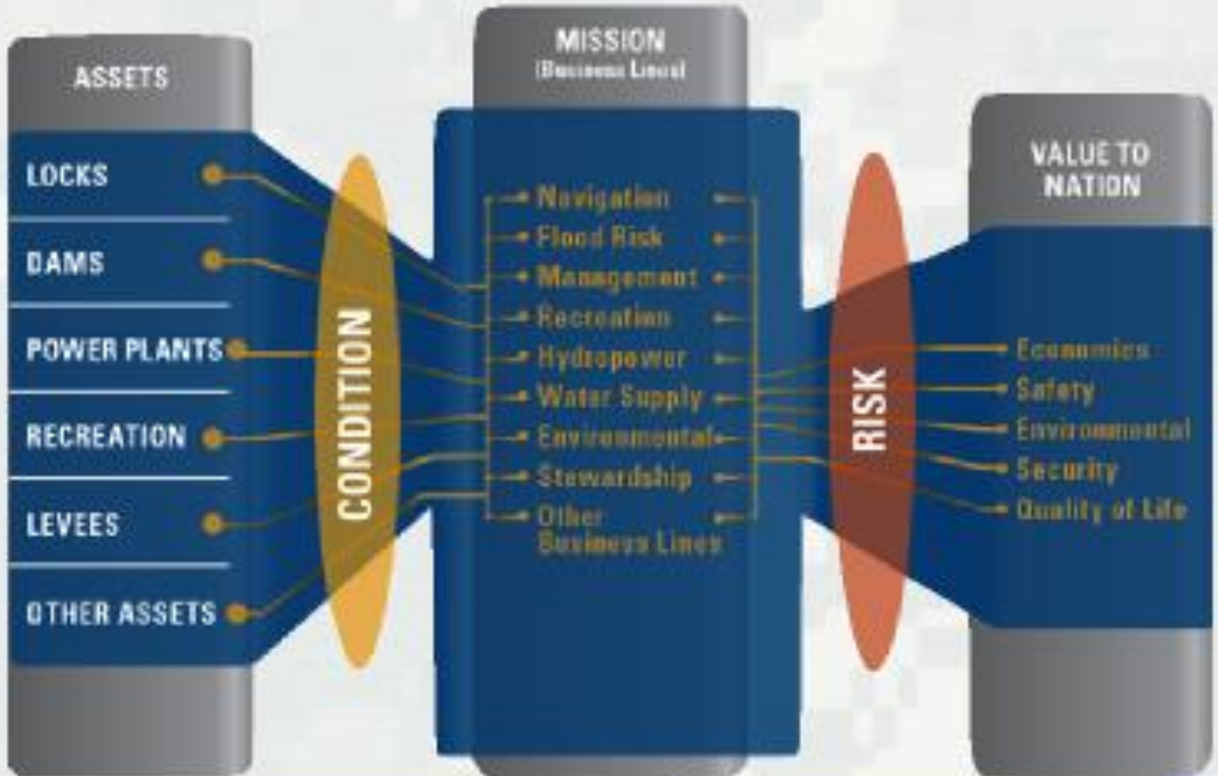
- Event driven process – flood or seismic
- PFMA does not look at consequences or criticality directly
- Relies on Expert Opinion Elicitation for ET nodes
  - Kent Tables of descriptors and probabilities
  - No probabilistic methods
- Does not include time dependency
- Does not include uncertainty


AS YOU CAN CLEARLY SEE IN SLIDE 397...
www.dilbert.com
GAAAAH!
Z
Z
"POWERPOINT" POISONING.

Asset Management

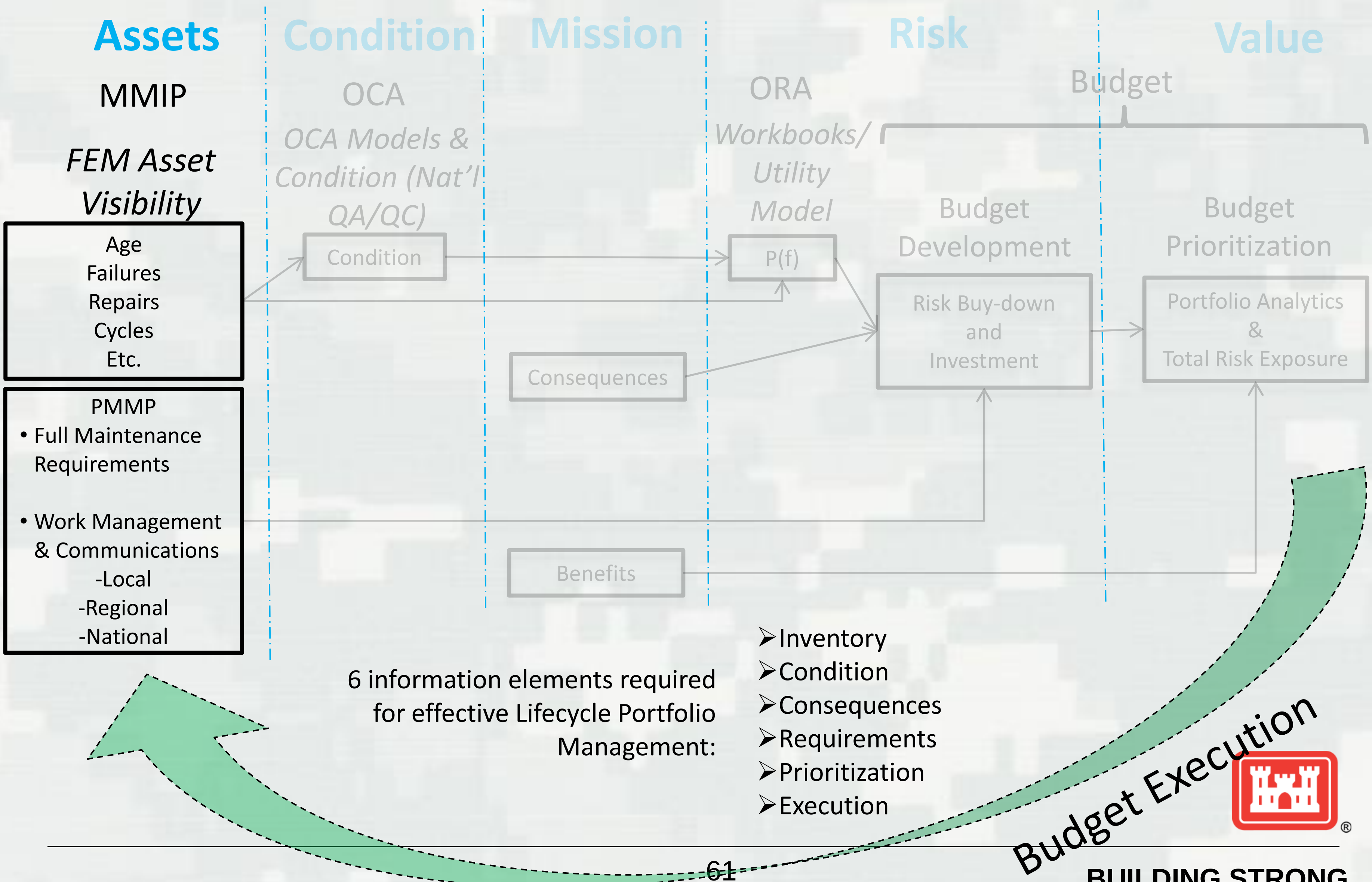
- USACE AM program started in 2006
- Program is developed to support risk-informed decision making and prioritization of USACE Operations and Maintenance budget work packages (~14,000 work packages a year, ~$2B)
- AM looks at and across all USACE business lines
- AM focuses on value and utility of each work package

USACE Asset Management



What, where and when do I invest? Providing "Line of Sight" to enable the assets greatest Value to the Nation!

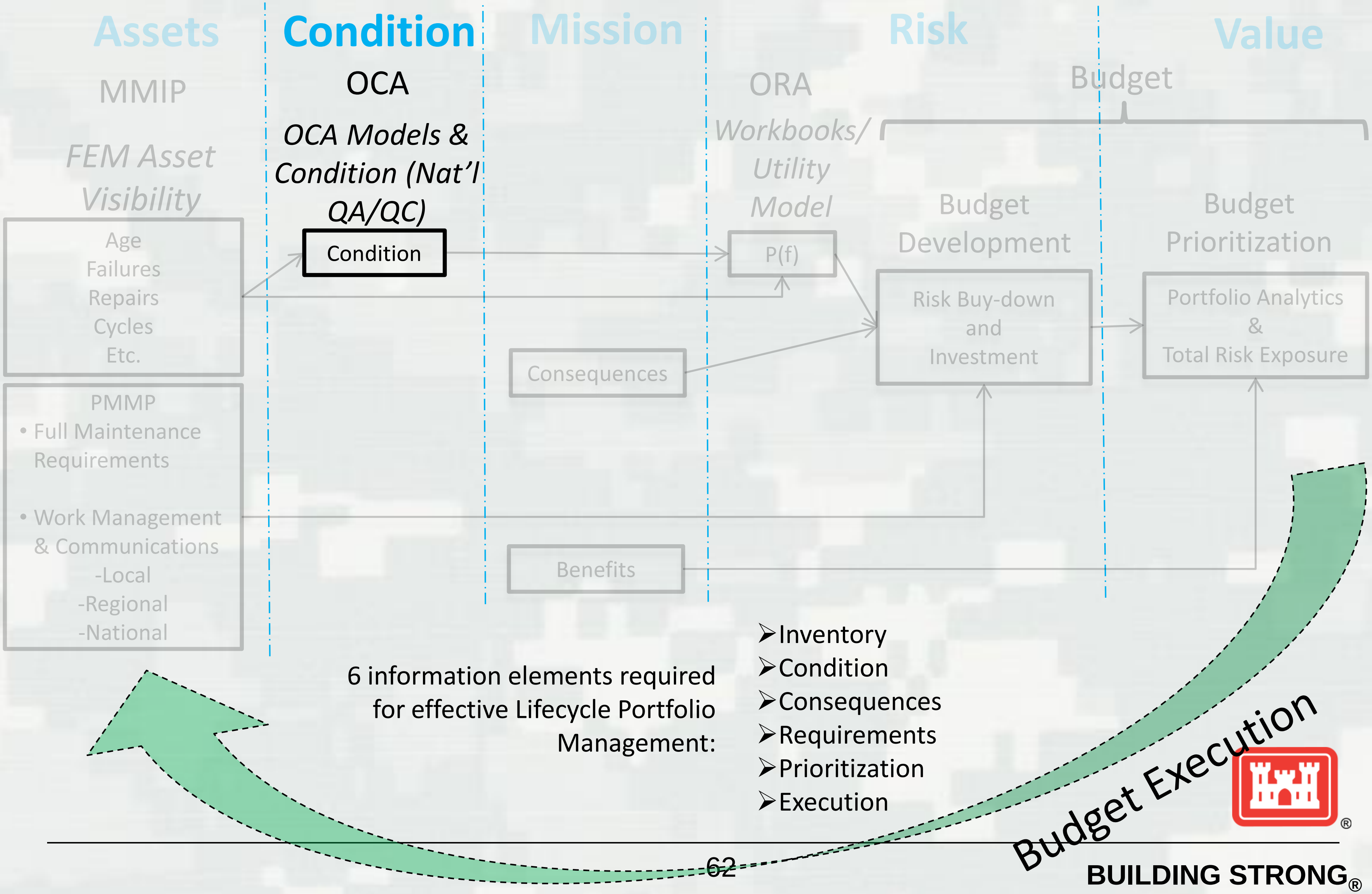
Lifecycle Portfolio Management Process



6 information elements required for effective Lifecycle Portfolio Management:

- Inventory
- Condition
- Consequences
- Requirements
- Prioritization
- Execution

Lifecycle Portfolio Management Process



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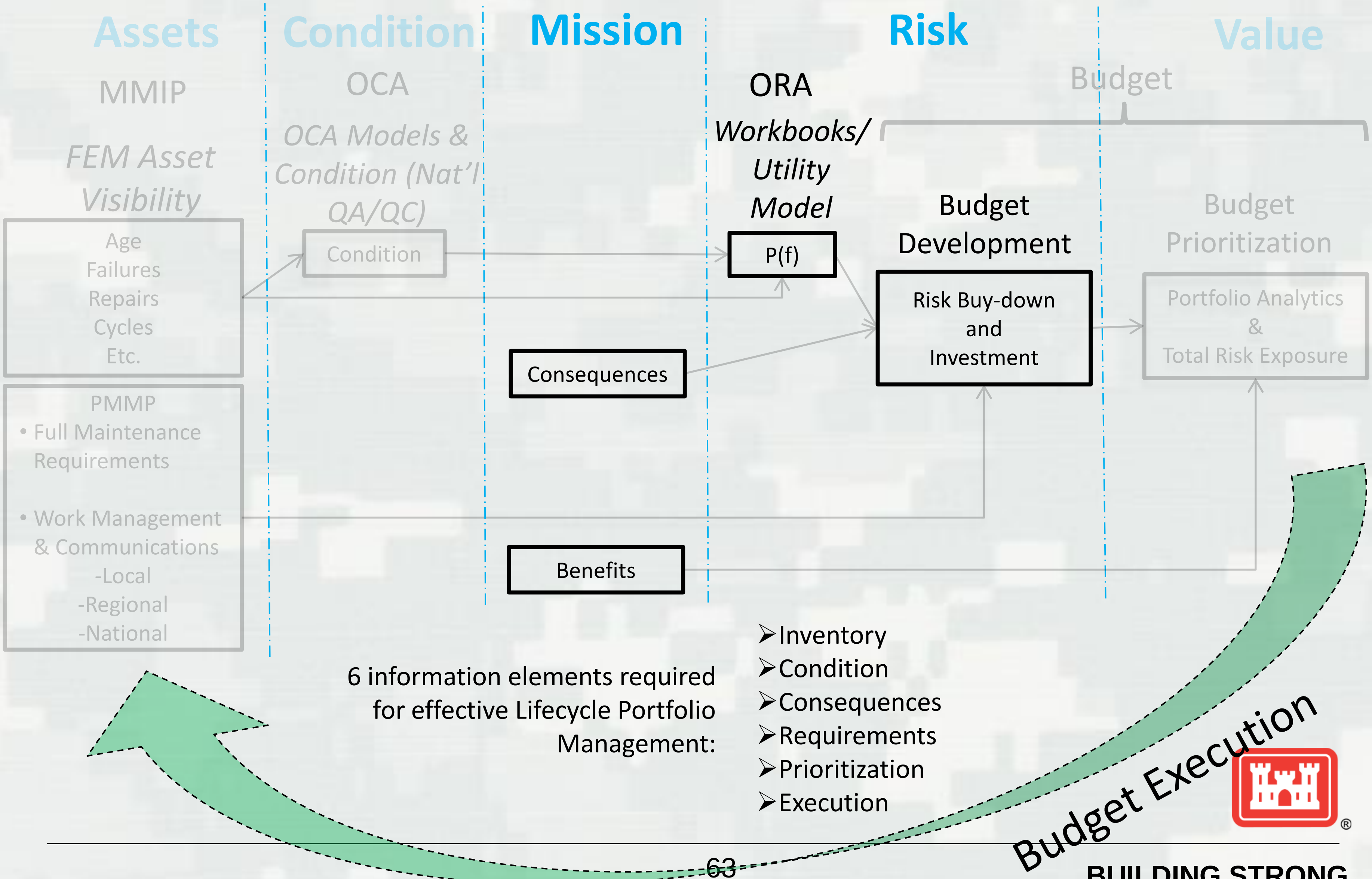
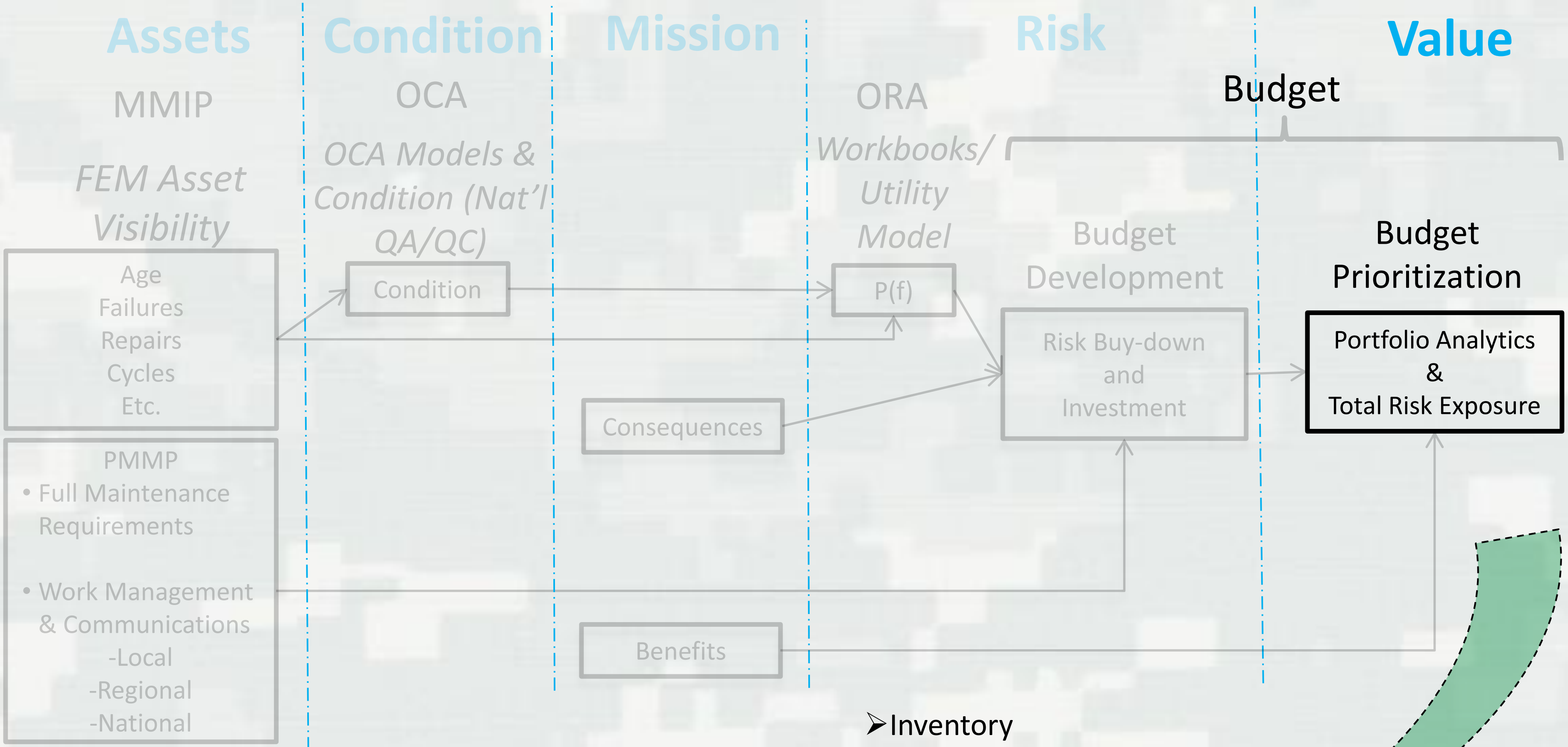
Lifecycle Portfolio Management Process



6 information elements required for effective Lifecycle Portfolio Management:

- ➢Inventory
- ➢Condition
- ➢Consequences
- ➢Requirements
- ➢Prioritization
- ➢Execution

Lifecycle Portfolio Management Process

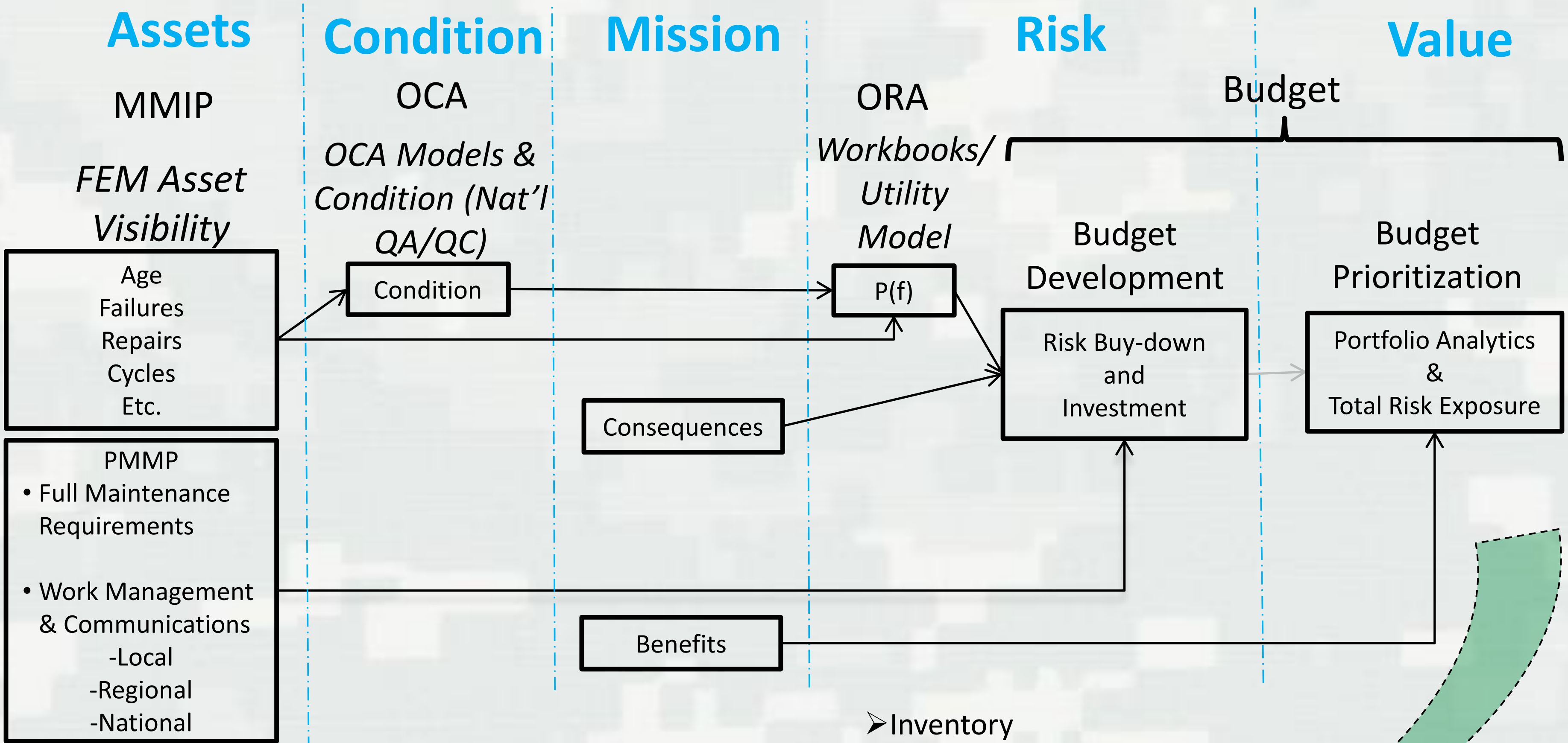


6 information elements required for effective Lifecycle Portfolio Management:

- Inventory
- Condition
- Consequences
- Requirements
- Prioritization
- Execution

Budget Execution

Lifecycle Portfolio Management Process



6 information elements required for effective Lifecycle Portfolio Management:

- ➢Inventory
- ➢Condition
- ➢Consequences
- ➢Requirements
- ➢Prioritization
- ➢Execution

Budget Execution

Operational Risk Assessment

Risk = Probability of Failure X Consequences

- 5x5 Relative Risk Matrices
  - Currently available in Budget EC
  - Known limitations – based on one consequence
- Prototype ORA Workbook tool for Nav Locks & Dams
  - OCA data, probability of failure for components, economic impacts
  - Started with FY13 budget development
- Hydropower Modernization Initiative (HMI)
  - Used to help plan non-BPA capital investments
- Other BL's – No Risk Assessment tool

5x5 Risk Matrix

TABLE D-5 Relative Risk Value Matrix (1-25 Matrix)

			Relative Risk Value Matrix (1-25 Matrix)				
			FRM Project Condition Tool (Illustration D.1)				
Consequence Category		Condition / Consequence	F (1) Failed	D (2) Inadequate	C (3) Probably Inadequate	B (4) Probably Adequate	A (5) Adequate
Consequence Category	1	High	1	2	6	10	15
	2	Medium High	3	5	9	14	19
	3	Medium	4	8	13	18	22
	4	Low	7	12	17	21	24
	5	Minimal	11	16	20	23	25

- High Relative Risk
- Med-High Relative Risk
- Medium Relative Risk
- Low Relative Risk
- Minimal Relative Risk

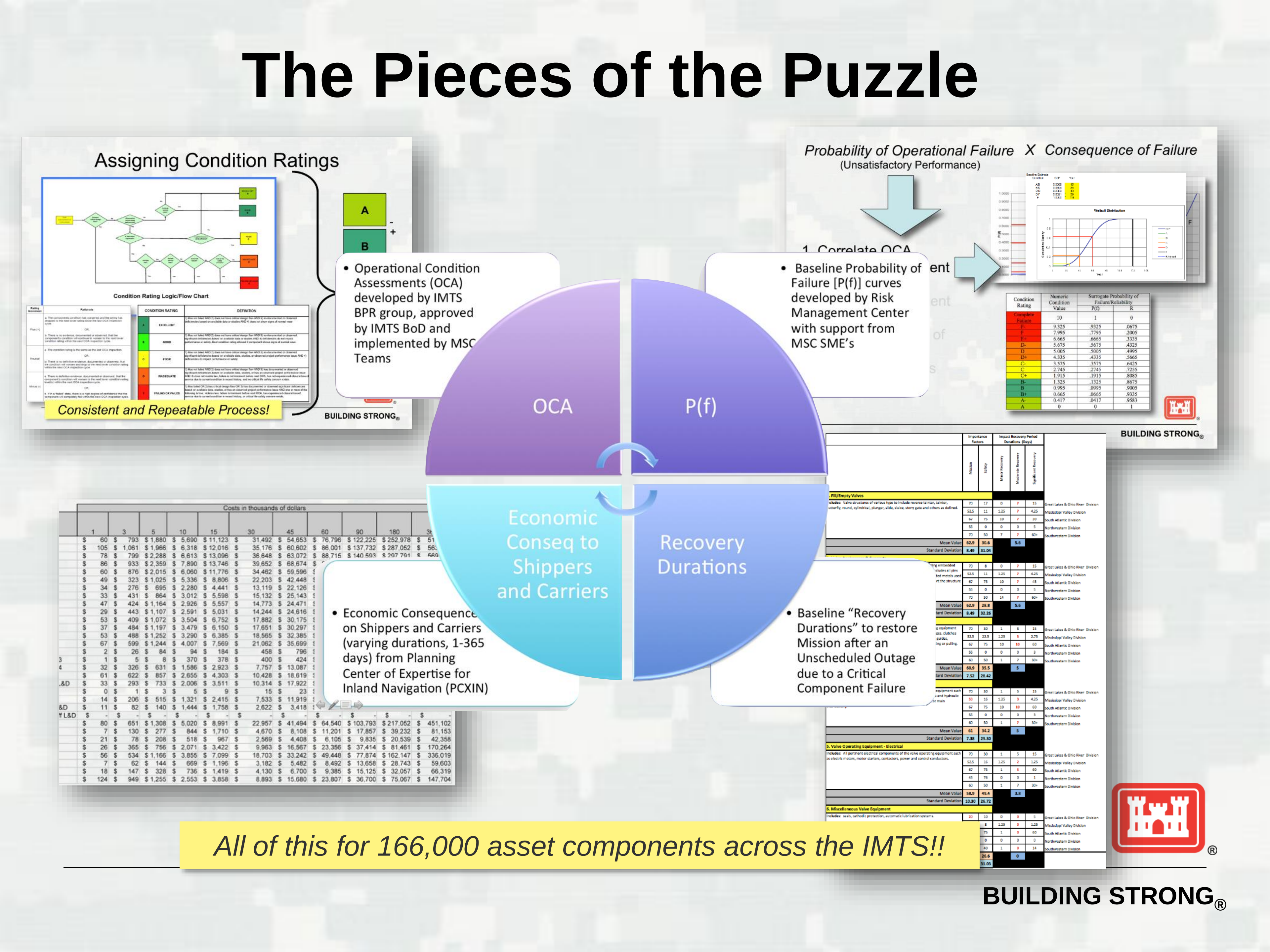
5x5 Risk Matrix - OCA & Consequences

TABLE D-3. Condition Assessment Standards for Sub-Features

Condition Classification	Definitions
A Adequate	1) Component is fully functional, 2) No documented critical design flaw in terms of structural/operational capacity or functionality, 3) No documented or observed deficiencies by definition, 4) No indication of wear.
Condition Classification	**Definitions**
B Probably Adequate	1) Component is fully functional, 2) No documented critical design flaw in terms of structural/operational capacity or functionality, 3) Documentation, testimonies and/or observations concluded that a deficiency by definition exists, 4) A clear mode of failure cannot be confirmed, 5) The components performance is not affected by the deficiency, 6) The feature mission requirement(s) (i.e. flood control, water quality, water supply, etc.) are not affected by the deficiency, 7) Normal operating procedures and routine maintenance requirements are not affected by the deficiency, 8) Safety of personnel and end users are not affected by the deficiency, 8) There are indications of normal wear as documented, reported or observed.
Condition Classification	**Definitions**
C Probably Inadequate	1) Component is fully functional, 2) A critical design flaw potentially exist in terms of structural/operational capacity or functionality, but must be further substantiated by owning District, 3) Documentation, testimonies and/or observations conclude that a deficiency by definition exists, 4) Documentation, testimonies, and/or observation can confirm a progressing degradation of the components condition, 5) A clear mode of failure cannot be confirmed, 6) The components performance is not presently affected by the deficiency, but is likely due to the substantiated progress in degradation, 7) The feature mission requirement(s) (i.e. flood control, water quality, water supply, etc.) are not presently affected by the deficiency, but likely due to the substantiated progress in degradation, 8) Normal operating procedures and routine maintenance requirement are not presently affected by the deficiency, but likely due to the substantiated progress in degradation, 9) Safety of personnel and end users not presently affected by the deficiency.
Condition Classification	**Definitions**
D Inadequate	1) Component is functional, 2) Documentation, testimonies and/or observations conclude that a deficiency by definition exists, 3) Documentation, testimonies, and/or observation can confirm that the deficiency is significant by any of the following criteria: a. A clear mode of failure exists, b. The components performance is presently affected, c. Feature mission requirement(s) (i.e. flood control, water quality, water supply, etc.) are presently affected, d. Normal operating procedures are presently affected, e. Routine maintenance requirements are presently affected, 4) A recent unsatisfactory performance or failure of service due to the deficiency cannot be confirmed by documentation or testimonies, 5) It is not likely that an imminent failure of the component will occur, 6) A critical life safety concern to personnel or end users does not exist.
Condition Classification	**Definitions**
F Failling or Failed	Failing: 1) Component is functional, 2) Documentation, testimonies and/or observations conclude that a deficiency by definition exists, 3)Documentation, testimonies, and/or observation can confirm that the deficiency is significant by any of the following criteria: a. A clear mode of failure exists, b. The components performance is presently affected, c. Feature mission requirement(s) (i.e. flood control, water quality, water supply, etc.) are presently affected, d. Normal operating procedures are presently affected, e. Routine maintenance requirements are presently affected, 4) In addition to the affect the deficiency has on performance and operation, a recent unsatisfactory performance or failure of service due to the deficiency can be confirmed by documentation or testimonies, 5) In addition to the affect the deficiency has on performance and operation, it is likely that an imminent failure of the component will occur, 6) In addition to the affect the deficiency has on performance and operation, a critical life safety concern to personnel or end users exists. Failed: Component is presently out of service or not functional

“Or” logic – can only use 1 consequence

Consequence Category 1 Rating Criteria		Category Rating
PAR:	PAR ≥ 100,000	1
	50,000 ≤ PAR < 100,000	2
	25,000 ≤ PAR < 50,000	3
	10,000 ≤ PAR < 25,000	4
	PAR < 10,000	5
Consequence Category 2 Rating Criteria		**Category Rating**
Economic Impact:	Damages to residential and nonresidential structures, their contents and vehicles greater than $10B	1
	Damages to residential and nonresidential structures, their contents, and vehicles ranging from $1B to $10B	2
	Damages to residential and nonresidential structures, their contents, and vehicles ranging from $100M to $1B	3
	Damages to residential and nonresidential structures, their contents, and vehicles ranging from $10M to $100M	4
	Damages to residential and nonresidential structures, their contents, and vehicles less than $10M	5
Consequence Category 3 Rating Criteria		**Category Rating**
Environmental:	Permanent loss of nationally scarce habitat	1
	Permanent impacts to Federal listed threatened or endangered species and their designated critical habitat	2
	Permanent loss of regionally scarce, or declining aquatic and/or associated habitats	3
	Temporary adverse impacts to all designated special status species and habitat	4
	Insignificant loss of scarce habitat; no effect on special status species	5
Consequence Category 4 Rating Criteria		**Category Rating**
Critical Infrastructure:	Ratio of Essential Structures Damaged ≥ 30%	1
	25% ≤ Ratio of Essential Structures Damaged < 30%	2
	20% ≤ Ratio of Essential Structures Damaged < 25%	3
	10% ≤ Ratio of Essential Structures Damaged < 20%	4
	Ratio of Essential Structures Damaged < 10%	5
Consequence Category 5 Rating Criteria		**Category Rating**
Legal Mandate (Federal):	Federal Law dictates closure or suspension of the project operations	1
	Financial penalties or criminal liabilities imposed but do not impact the operations of the project.	2
	Legal Mandates issues are based solely on State or Local statutes	3
	No Legal Mandate exists	4
	No Legal Mandate exists	5
Consequence Category 6 Rating Criteria		**Category Rating**
Social Vulnerability:	Population over 65 ≥ 30%	1
	25% ≤ Population over 65 < 30%	2
	20% ≤ Population over 65 < 25%	3
	10% ≤ Population over 65 < 20%	4
	Population over 65 < 10%	5
Consequence Category 7 Rating Criteria		**Category Rating**
Historic:	Massive losses to historic or culturally significant sites (> $1B)	1
	Major losses to historic or culturally significant sites ($10M-$1B)	2
	Moderate losses to historic or culturally significant sites ($1M-$10M)	3
	Minor losses to historic or culturally significant sites (<$1M)	4
	No historical or culturally significant properties impacted	5
Consequence Category 8 Rating Criteria		**Category Rating**
Coastal Projects:	Highest economic impact > $100M	1
	High economic impact $10M - $100M	2
	Moderate economic impact $1M - $10M	3
	Low economic impact <$1M	4
	No economic impact	5


The Pieces of the Puzzle
Assigning Condition Ratings
Condition Rating Logic/Flow Chart
Consistent and Repeatable Process!
BUILDING STRONG®
• Operational Condition Assessments (OCA) developed by IMTS BPR group, approved by IMTS BoD and implemented by MSC Teams
Probability of Operational Failure X Consequence of Failure
(Unsatisfactory Performance)
• Baseline Probability of Failure [P(f)] curves developed by Risk Management Center with support from MSC SME's
BUILDING STRONG®
OCA
P(f)
Economic Conseq to Shippers and Carriers
Recovery Durations
Costs in thousands of dollars
• Economic Consequences on Shippers and Carriers (varying durations, 1-365 days) from Planning Center of Expertise for Inland Navigation (PCXIN)
• Baseline "Recovery Durations" to restore Mission after an Unscheduled Outage due to a Critical Component Failure
All of this for 166,000 asset components across the IMTS!!
BUILDING STRONG®

OCA and ORA

- AM needed methodology to estimate the probability of failure for Operational Risk Assessment (ORA) processes
- AM required the development of a relationship between both Operational Condition Assessment (OCA) data and the estimate of the probability of failure
  - Utilize state-of-practice and state-of-the-art models and methods to map OCA to Pf

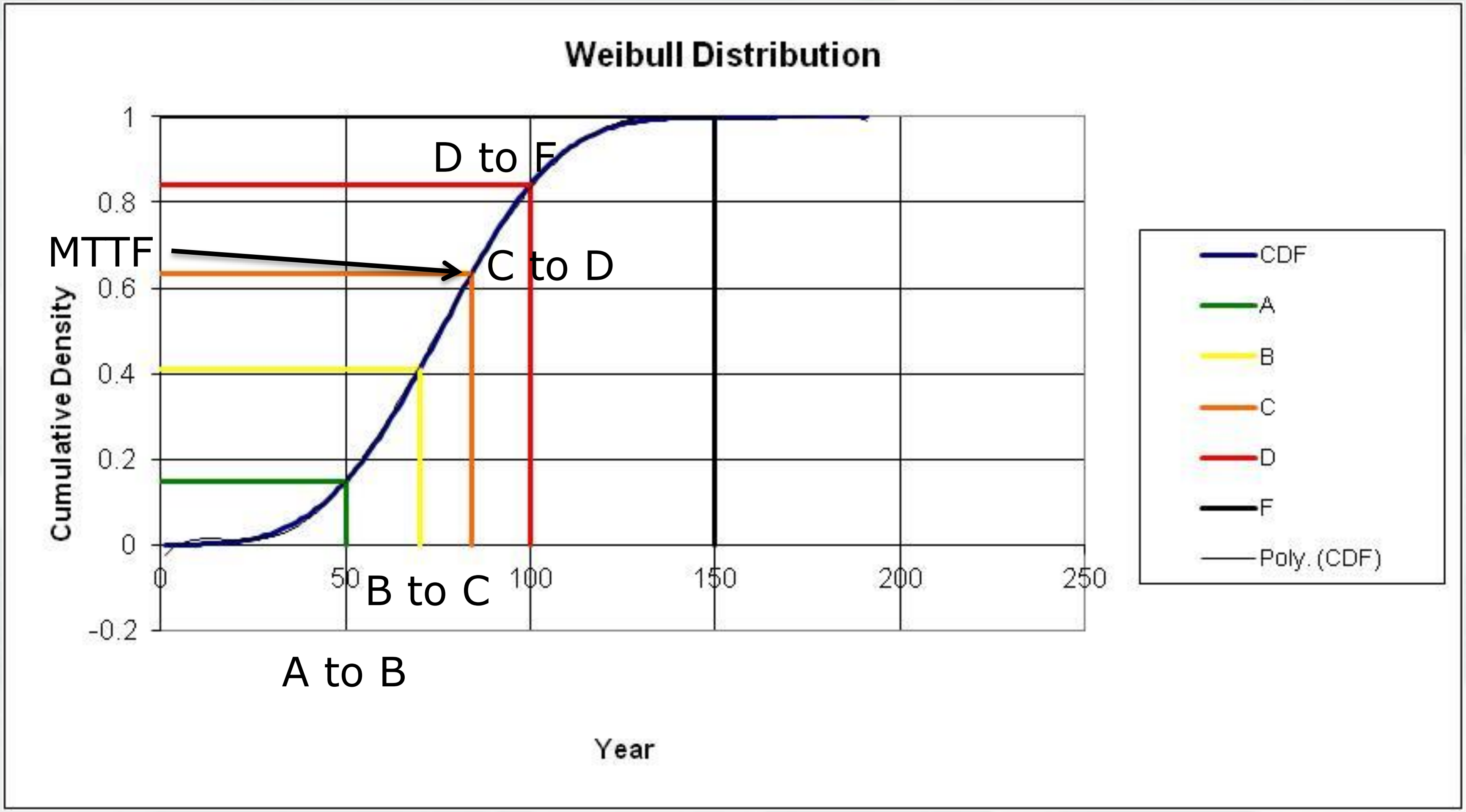
Development of Baseline Weibull Curves

- Initial estimate of OCA to probability of failure translation for predefined set of components by major categories
- Estimated probabilities of failure using Expert-Opinion Elicitation
  - ►Navigation SME/RTS from USACE Districts nationwide
  - ►Real-time processing data to Weibull curves for experts input and review

Development of Baseline Weibull Curves

- Estimate OCA and Pf transitions based on statistical estimation of the Maximum Likelihood Estimator (MLE) properties of Weibull Distributions
  - Translations can be adjusted as age and condition are defined by OCA resulting in updated Pf
- As additional OCA and failure data are collected Bayesian updating process can be utilized to modify and adjust baseline Weibull parameters
  - Permits more accurate estimation of Pf as additional data is collected and processed

Expert-Opinion Elicitation



Calculating Operational Risk (ORA)

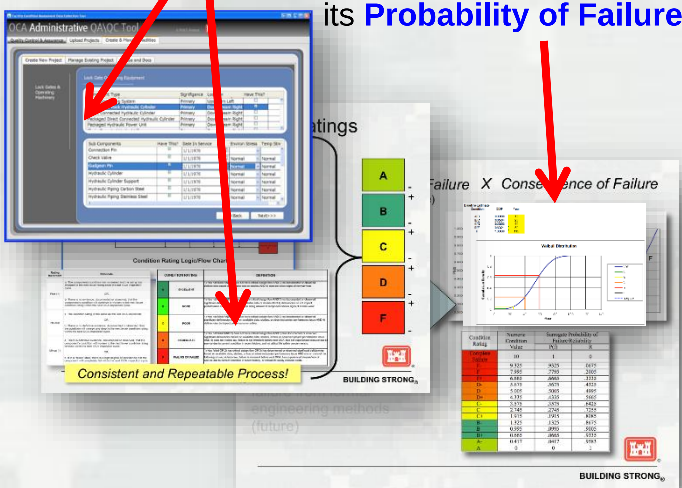
Probability of Operational Failure X *Consequence of Failure*

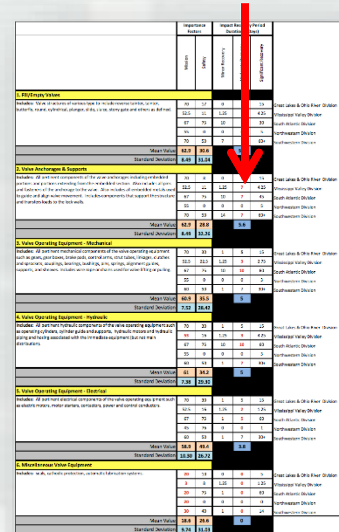
(Unsatisfactory Performance)

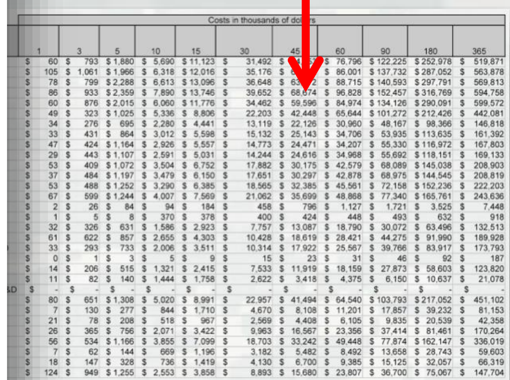
What is the **Condition** of Components in your site specific Inventory? and based on the condition of THAT Component what is its **Probability of Failure**?

What is the average "Impact **Recovery Duration**" (in DAYS) to **restore Mission** capability for that component from a failure that caused an Unscheduled Outage?

What **Economic impact on Shippers-Carriers** is there based on the Duration of that Unscheduled Outage?







Notional Example:

Component "X" in Condition "D"
Has P(f) = 0.488996058

Component "X" has an IRD = 20 days

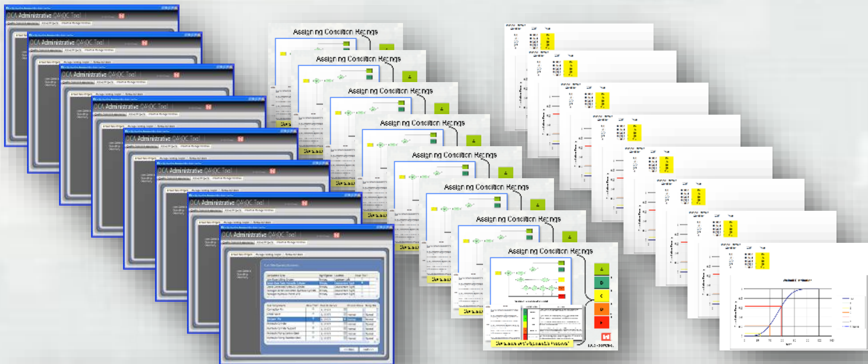
At L&D Site Y" the Econ Impact on Shippers-Carriers for an Unscheduled Outage of 20 days = $2,663K

P(f)	x	Consequence =		Risk
0.488996058	X	$2,663,000	=	$1,302,197

USACE AM Total Risk Exposure (TRE)

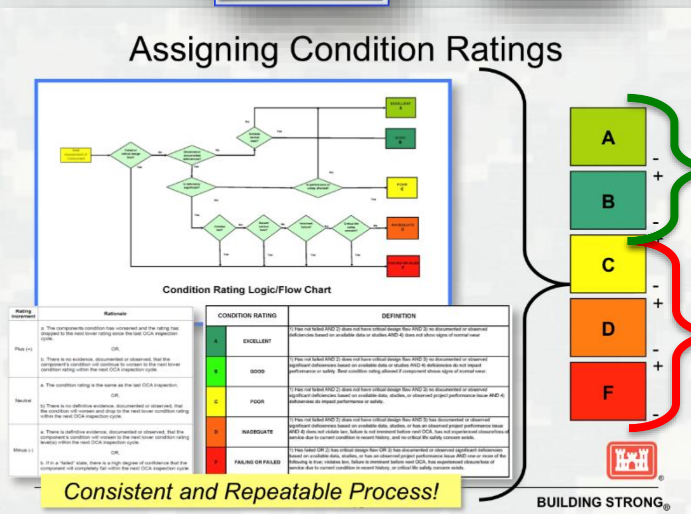
For EACH IMTS Site (to Component level)**:**

Inventory Condition P(f) **X** Econ Impact on Shippers and Carriers **=** Risk (@ Component level)



X

∑ = TRE



Total Risk Exposure is composed of:

"Residual Risk" – Components in "A" & "B" condition that *currently* do NOT show impacts on mission performance (including components that have been Repaired/Replaced)

"Operational Risk" – Components in "C" thru "F" condition that *currently* show impacts on mission performance

Each IMTS Site will have varying degrees of Operational and Residual Risk which can inform Investment Strategies

Operational Risk Exposure – Feature | System

(Condition/Risk of Critical Components across entire IMTS)

Feature | System

Feature | System	Operational Risk Exposure ($K)	Residual Risk AFTER Repair ($K)
Dam	$1,004,913	$165,124
Dam Gates & Operating Machinery	$538,761	$79,510
Dam Structures	$466,152	$85,614
Lock	$2,208,032	$304,897
Lock Filling and Emptying Systems	$64,109	$8,181
Lock Gates & Operating Machinery	$600,950	$77,625
Lock Structure	$1,542,973	$219,091
Miscellaneous Support Structures & Systems	$12,321	$1,533
Emergency Maintenance & Closure System	$9,095	$878
Lock & Dam Bridges	$3,226	$655
Utilities/Power/Controls	$19,276	$3,633
Controls, Indicators, Interlocks & PLC's	$5,856	$1,255
Primary Utilities Distribution & Controls	$13,386	$2,374
Secondary Utilities Distribution & Controls	$35	$5
Grand Total	$3,244,542	$475,188

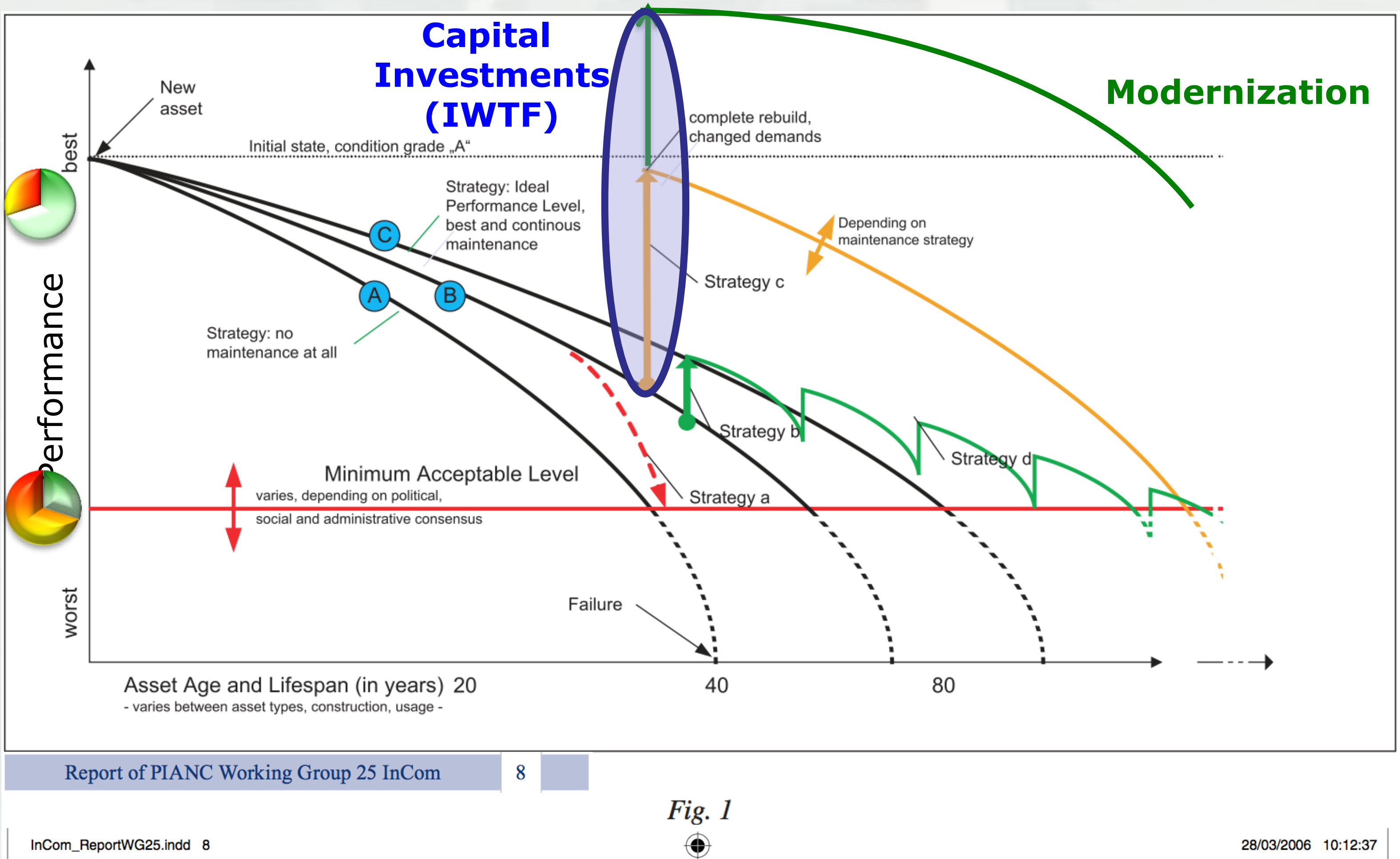
Notional Working Draft Pre-decisional Example

Feature | System | Sub-System | Component

Lock	$2,208,032	$304,897
Lock Filling and Emptying Systems	$64,109	$8,181
Lock Gates & Operating Machinery	$600,950	$77,625
Lock Gate Anchorages & Support Features	$185,598	$21,384
Lift Gate Anchorage	$11,591	$1,742
Miter Gate Anchorge	$147,027	$15,995
Sector Gate Anchorage	$26,134	$3,571
Tainter Gate Anchorage	$847	$76
Lock Gate Operating Equipment	$46,220	$7,256
Chain Hoist Mechanism (Electric)	$649	$187
Direct Acting Hydraulic Cylinder	$1,931	$344
Electrical Operating Equipment (Lock Gates)	$5,345	$1,360
Ohio River Type Assembly (Electric)	$1,765	$333
Ohio River Type Assembly (Hydraulic)	$27,453	$3,725
Packaged Direct Connected Hydraulic Cylinder Assembly	$117	$21
Panama Type Assembly (Electric)	$4,857	$860
Rope Hoist Mechanism (Electric)	$1,269	$217
Rope Hoist Mechanism (Hydraulic)	$2,779	$207
Wire Rope Cable (Horizontal Pull) Assembly	$53	$3
Lock Gate Structures	$189,876	$29,112
Miter Type Gate	$133,404	$19,814
Sector Type Gate	$19,016	$4,814
Tainter Type Gate	$2,146	$352
Vertical Lift Type Gate	$35,310	$4,131
Misc Lock Gate Features	$179,256	$19,873
Miter Guide	$1	$0
Pintles	$60,238	$8,496
Quoin Blocks & Other Load Blocks	$119,016	$11,377

Maintain and Repair the Most Critical Components that have the Potential to Cause Highest Mission Impacts

Life Cycle Investment Strategies



Risk Exposure assists in informing Life Cycle Investment Decisions

Budget Prioritization

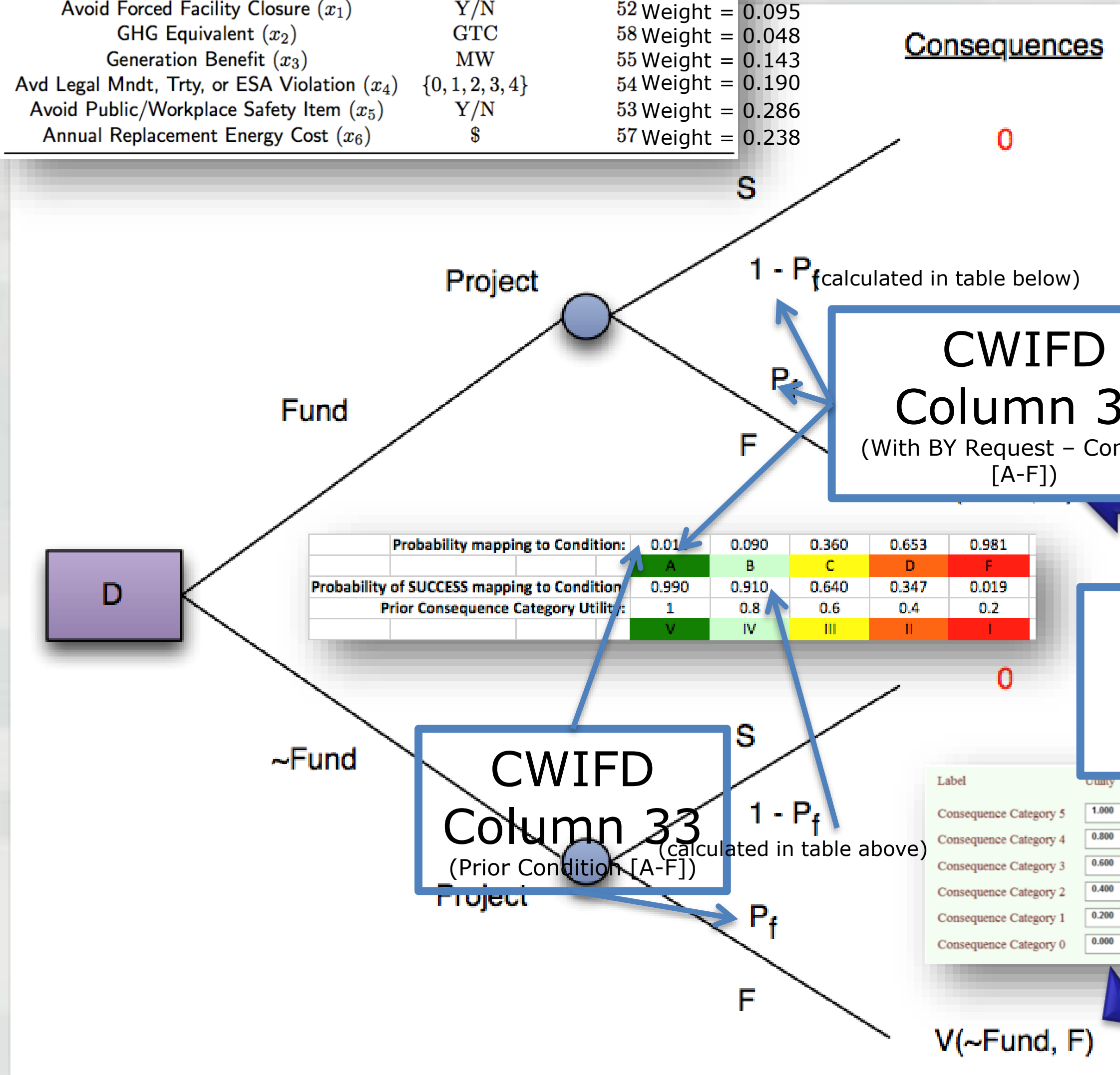
- AMPA tool - FRM, NAV, and HYD
  - AMPA Technical Documentation (2015) - Details regarding specific business line data, value model design and process
  - Very important to enter accurate data in CWIFD and complete all the fields
  - Available on the AMPA SharePoint site, folder called AMPA Budget Tools-AMPA-FY18 Budget Development folder:

https://cops.usace.army.mil/sites/AM/PA/AMPA%20Budget%20Tools/Forms/AllItems.aspx

  - Or at the AM Tools site under the "AMPA Workbook Tools and Download (NAV, FRM, HYD)" link at: https://assetmanagement.usace.army.mil/tools/
- AMPA tool - Demonstration

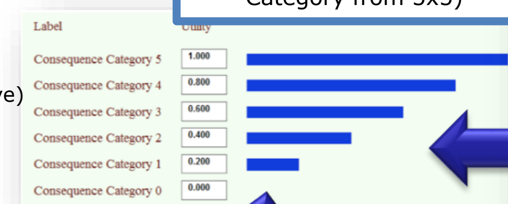
Value Model Attribute	Units	CWIFD Column
Avoid Forced Facility Closure (x_1)	Y/N	52 Weight = 0.095
GHG Equivalent (x_2)	GTC	58 Weight = 0.048
Generation Benefit (x_3)	MW	55 Weight = 0.143
Avd Legal Mndt, Trty, or ESA Violation (x_4)	$\{0,1,2,3,4\}$	54 Weight = 0.190
Avoid Public/Workplace Safety Item (x_5)	Y/N	53 Weight = 0.286
Annual Replacement Energy Cost (x_6)	\$	57 Weight = 0.238

Decision Model Variable	Data Source
$V(\text{Fund}, \text{F})$	$V_{\text{hyd}}(\mathbf{x})$
$V(\sim\text{Fund}, \text{F})$	CWIFD Column 34
$\Pr(\text{Fund}, \text{F})$	CWIFD Column 37
$\Pr(\sim\text{Fund}, \text{F})$	CWIFD Column 33



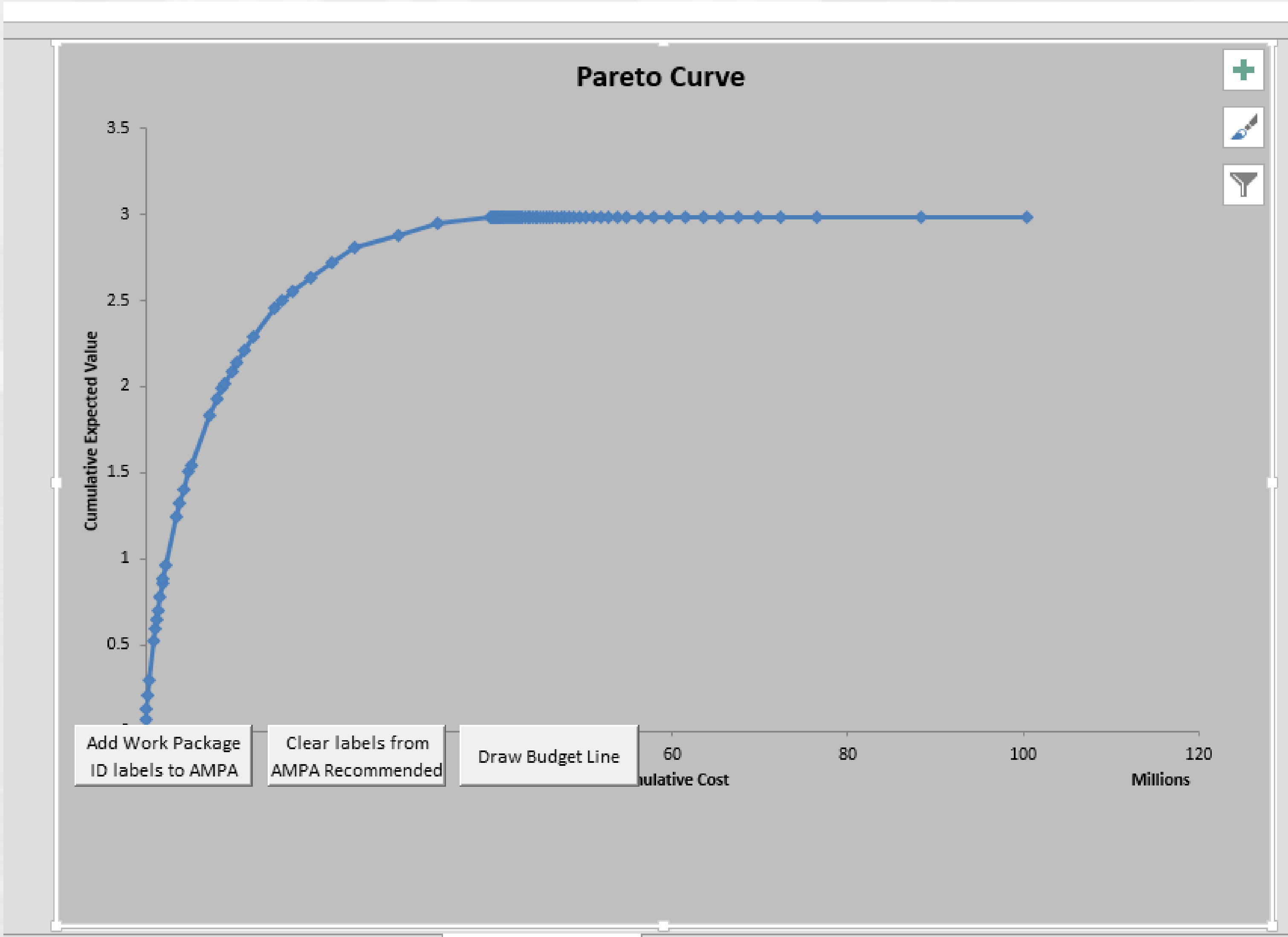
Probability mapping to Condition:	0.01	0.090	0.360	0.653	0.981
	A	B	C	D	F
Probability of SUCCESS mapping to Condition	0.990	0.910	0.640	0.347	0.019
Prior Consequence Category Utility:	1	0.8	0.6	0.4	0.2
	V	IV	III	II	I

$$(x_1, \ldots, x_6) = \sum_{i}^{6} w_i v_i(x_i), \qquad (1)$$



Consequence Category	Consequence Rating Criteria
I	**High:** - Public or Life Safety Impact and/or - Violation of Legal Requirement(s) and/or - Forced Outage /Closure resulting in Highest Economic Loss and/or - Greatest Decrease in Performance (e.g., efficiency, capacity, reliability) and/or - Greatest Increase in Life Cycle Costs and/or - Greatest Increase in Critical Maintenance Backlog
II	**Medium-High:** - Forced Outage / Closure resulting in High Economic Loss and/or - Great Decrease in Performance (e. g., efficiency, capacity, reliability) and/or - Great Increase in Life Cycle Costs and/or - Great Increase in Critical Maintenance Backlog
III	**Medium:** - Forced Outage/Closure resulting in Moderate Economic Loss and/or - Moderate Decrease in Performance (e.g., efficiency, capacity, reliability) and/or - Moderate Increase in Life Cycle Costs and/or - Moderate Increase in Critical Maintenance Backlog
IV	**Low:** - Forced Outage/Closure resulting in Minor Economic Loss and/or - Minor Decrease in Performance (e.g., efficiency, capacity, reliability) and/or - Minor Increase in Life Cycle Costs and/or - Minor Increase in Critical Maintenance Backlog
V	**Minimal:** - Forced Outage/Closure resulting in Minimal Economic Loss and/or - Minimal Decrease in Performance (e.g., efficiency, capacity, reliability) and/or - Minimal Increase in Life Cycle Costs and/or - Minimal Increase in Critical Maintenance Backlog

Work Package ID	Value Differenc	Cost	Cumulative Cost	Cumulative Value	Value Rati	Work Package Title	District Ran	MSC Ra	AMPA Rar	Increment	Program Name
9365	0.063888889	40000	40000	0.063888889	1.59722E-06	Erosion Repair on Dam Embankme	200	-	1	4.5	SAM RAYBURN DAM AND RESERVO
110434	0.063888889	80000	120000	0.127777778	7.98611E-07	Replace Wire Ropes on Flood Gate	241	-	2	4.5	SAM RAYBURN DAM AND RESERVO
24220	0.083333333	125000	245000	0.211111111	6.66667E-07	Repair Training Wall	1230	-	3	4.5	GREERS FERRY LAKE, AR
43275	0.083333333	153000	398000	0.294444444	5.44662E-07	Replace Roadway Median Hatch Co	1070	-	4	3.5	NORFORK LAKE, AR
21571	0.225	500000	898000	0.519444444	0.00000045	FY18 NRWP Repair Crack in Spillwa	17	-	5	3.5	KAW LAKE, OK
92554	0.073611111	165000	1063000	0.593055556	4.46128E-07	Replace Dam Main Power Switchge	1130	-	6	4.5	NIMROD LAKE, AR
48258	0.052777778	150000	1213000	0.645833333	3.51852E-07	Rehabilitate Surface Drainage	177	-	7	4.5	WRIGHT PATMAN DAM AND LAKE,
9531	0.05	150000	1363000	0.695833333	3.33333E-07	Pave west abutment access road	287	-	8	5.5	TOWN BLUFF DAM, B A STEINHAGE
90954	0.083333333	250000	1613000	0.779166667	3.33333E-07	Repair Right Training Wall	1170	-	9	4.5	BEAVER LAKE, AR
9008	0.077777778	250000	1863000	0.856944444	3.11111E-07	Hardwire Low Flow Controllers	237	-	10	4.5	GRAPEVINE LAKE, TX
57294	0.030555556	100000	1963000	0.8875	3.05556E-07	2015 Flood Event Class II: Upstrear	209	-	11	4.5	LAVON LAKE, TX
103774	0.070833333	235000	2198000	0.958333333	3.01418E-07	Replace Wet Well Balancing Valves	181	-	12	4.5	BELTON LAKE, TX
25928	0.288888889	1250000	3448000	1.247222222	2.31111E-07	DSPMT SWD# 3.036 SWG#3.001 Rep	35	-	13	3.5	BUFFALO BAYOU AND TRIBUTARIES
103734	0.070833333	350000	3798000	1.318055556	2.02381E-07	Replace Overhead Crane Hoist Cab	175	-	14	4.5	BELTON LAKE, TX
99654	0.083333333	500000	4298000	1.401388889	1.66667E-07	Clear Vegetation from Toe of Dam,	1260	-	15	4.5	GREERS FERRY LAKE, AR
43335	0.104166667	625000	4923000	1.505555556	1.66667E-07	Replace Sluice Gate Wiring, Sump I	1050	-	16	3.5	TABLE ROCK LAKE, MO & AR
48397	0.036111111	245000	5168000	1.541666667	1.47392E-07	Replace Riprap	182	-	17	4.5	NAVARRO MILLS LAKE, TX
25925	0.288888889	2170000	7338000	1.830555556	1.33129E-07	Rehabilitation Clodine Ditch Phase	48	-	18	4.5	BUFFALO BAYOU AND TRIBUTARIES
23372	0.094444444	798000	8136000	1.925	1.18351E-07	Dewater and Repair Stilling Basin	1280	-	19	4.5	CLEARWATER LAKE, MO
9540	0.063888889	582000	8718000	1.988888889	1.09775E-07	Repair Shoreline Erosion	126	-	20	3.5	SAM RAYBURN DAM AND RESERVO
23036	0.030555556	300000	9018000	2.019444444	1.01852E-07	Rebuild Tainter Gate Break	180	-	21	4.5	LAVON LAKE, TX
110754	0.070833333	750000	9768000	2.090277778	9.44444E-08	Repair Cracked Service Gate	125	-	22	3.5	BELTON LAKE, TX
9320	0.045833333	539000	10307000	2.136111111	8.5034E-08	Replace Hydraulic Pump Unit on Sl	187	-	23	4.5	WHITNEY LAKE, TX
112375	0.076388889	950000	11257000	2.2125	8.04094E-08	DSPMT SWD# 3.098 SWG# 3.006 Re	41	-	24	4.5	WALLISVILLE LAKE, TX
23090	0.077777778	1000000	12257000	2.290277778	7.77778E-08	Replace Four Emergency Slide Gate	163	-	25	3.5	GRAPEVINE LAKE, TX
9299	0.163888889	2500000	14757000	2.454166667	6.55556E-08	Phase 3 Repair Tainter Gates	198	-	26	4.5	WACO LAKE, TX


Pareto Curve
3.5
3
2.5
2
1.5
1
0.5
Cumulative Expected Value
Add Work Package ID labels to AMPA
Clear labels from AMPA Recommended
Draw Budget Line
60
80
100
120
ulative Cost
Millions

Conclusions

- Over the past 25 years, USACE has invoked many different risk assessment methodologies for use in their risk-informed decision making processes.
- Each risk assessment methodology has their particular benefits and drawbacks
- Risk assessment methodologies are not static but dynamic and change with the next generations

and THIS, ladies and gentlemen, is how a Twinkie is made. Any questions?