Decision Analysis and Ecosystem Restoration: Framework and Applications

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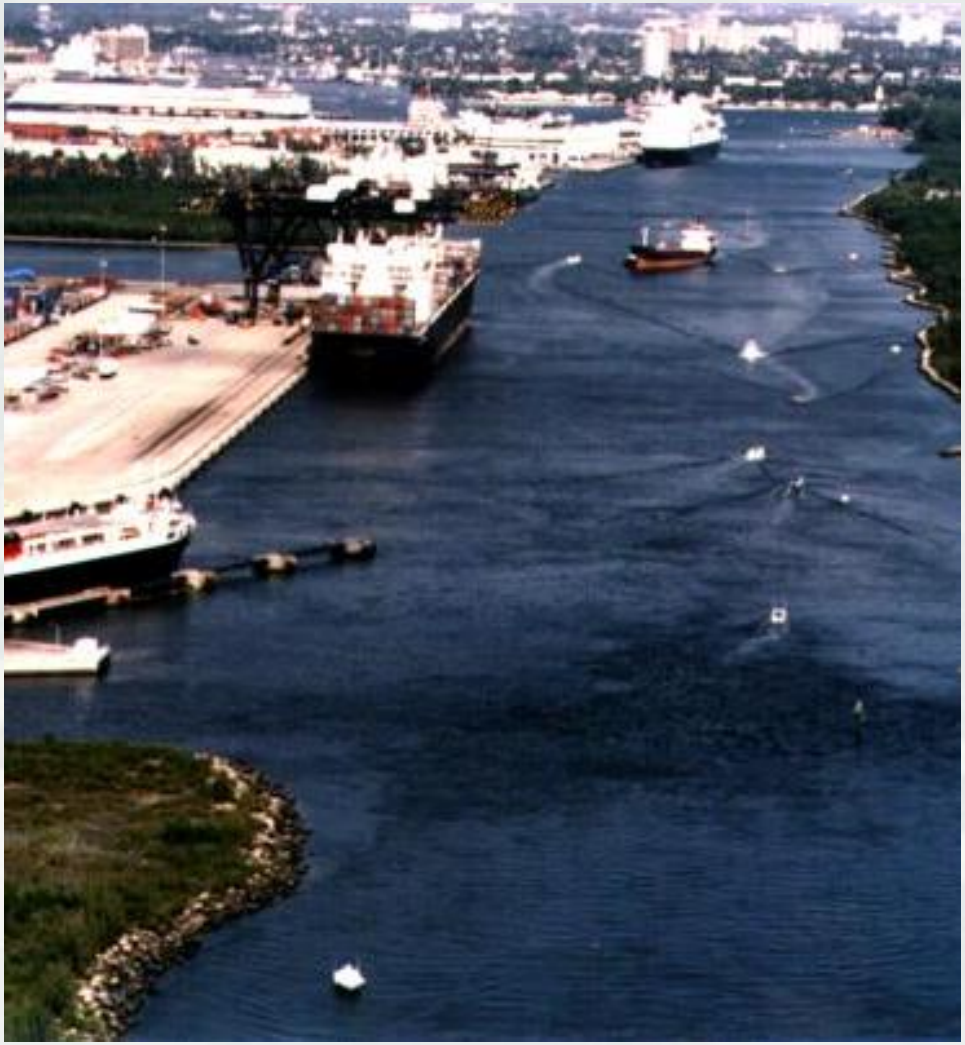
Restoration and Adaptive Management: Needs

Resource Management Context

- Uncertainty
- Rapid Change
- Complexity

Restoration Challenges



- Alternative management plans can produce changes at many scales across many landscapes
- Alternative plans present uncertain benefits and potentially unintended consequences

21st Century Challenges

- Significant ecological complexities & uncertainties
  - ► e.g. , climate, energy demand, water availability
- Multiple potential effects of environmental systems and built environments
  - ► e.g., human population growth, demand for transportation infrastructure, habitat migration
- Dynamic ecological, economic, & social context
  - ► e.g., public interest, regulatory environment, policy mandates, international relations

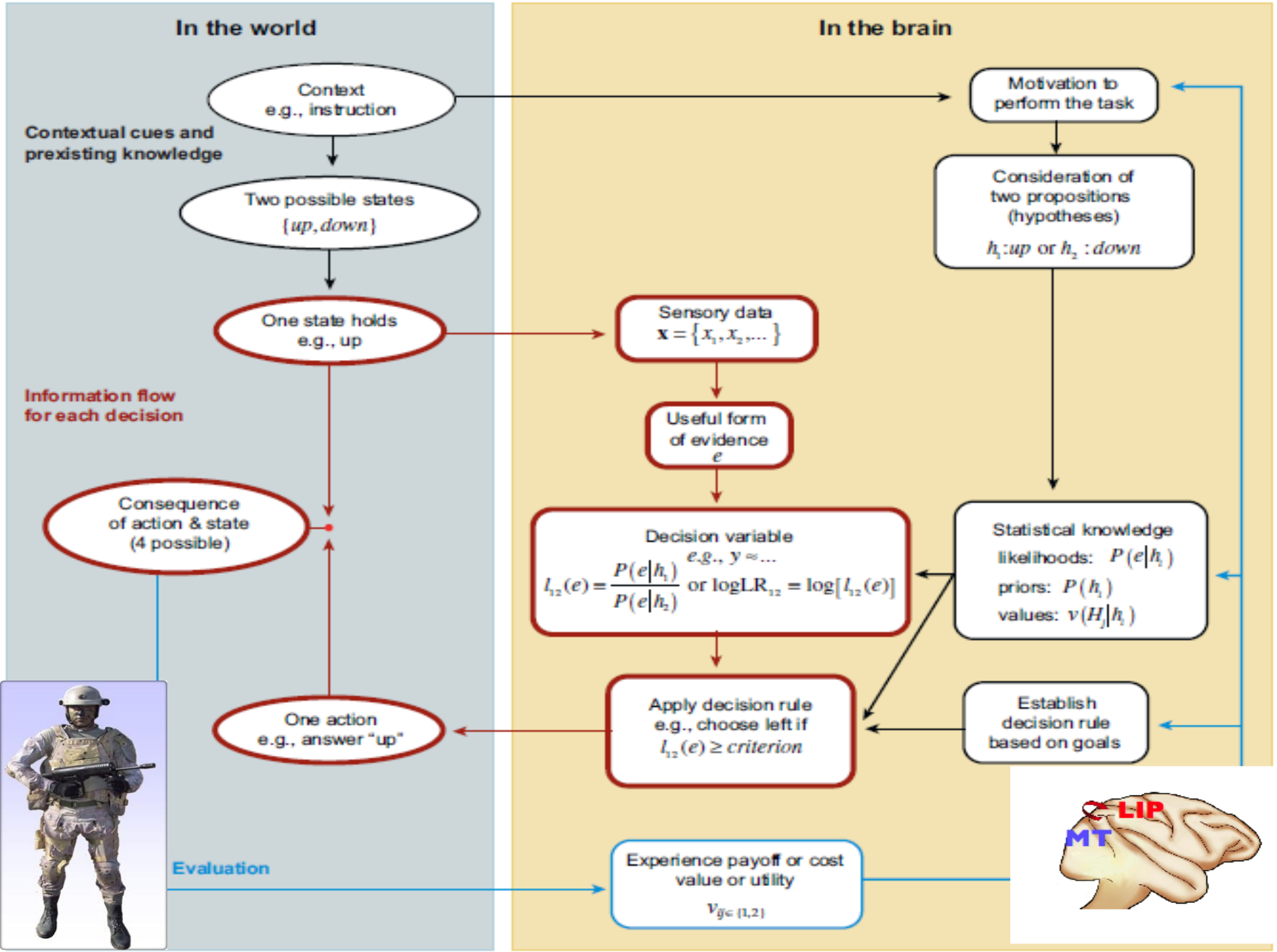
Hurricane Katrina image from NASA Vision website

What Can be Done?

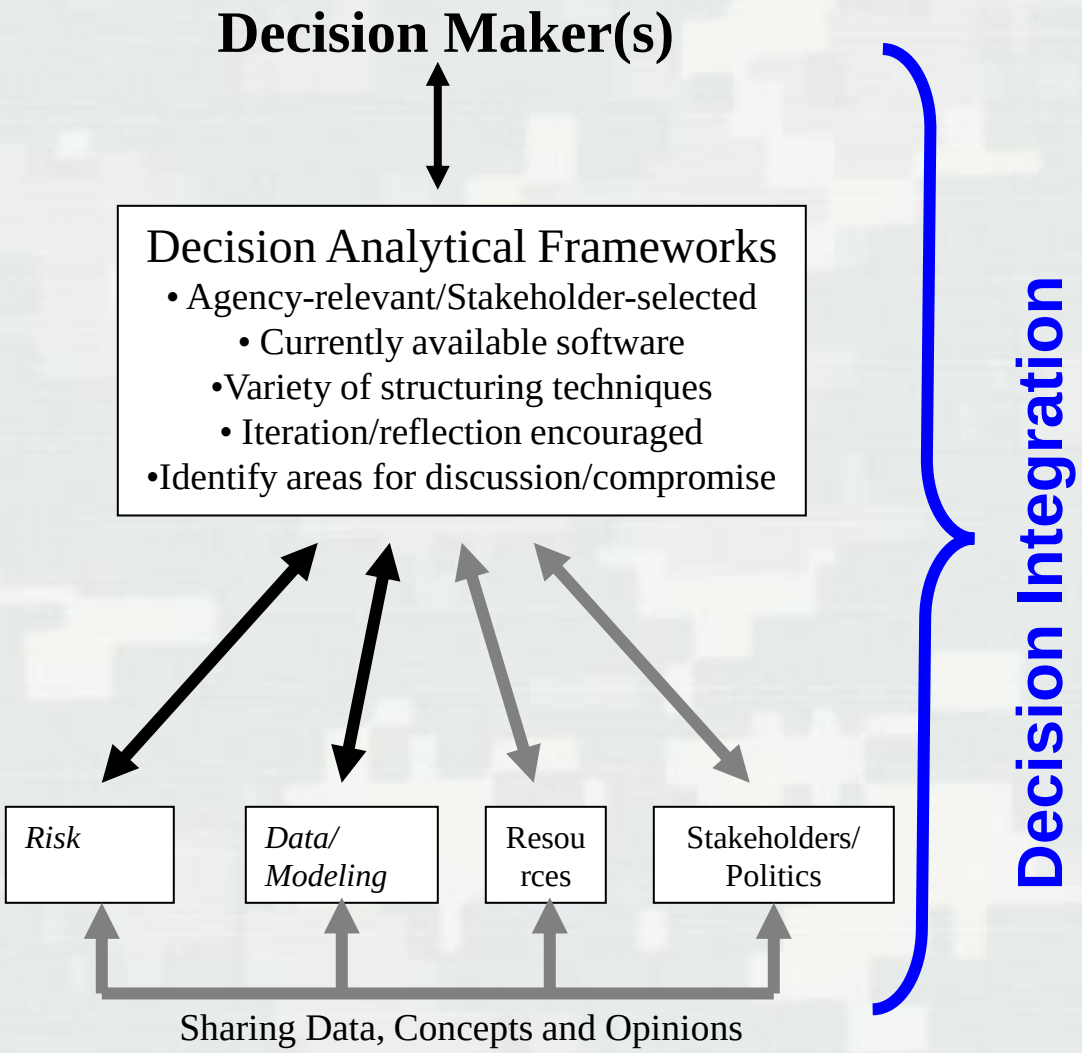
In press

Using Our Brains to Develop Better Policies

Journal:	*Risk Analysis*
Manuscript ID:	RA-00086-2011.R2
Wiley - Manuscript type:	Perspective
Key Words:	environmental policy, neuroeconomics, risk analysis

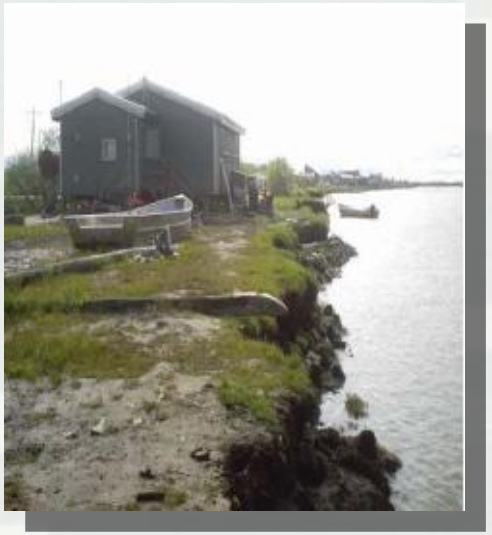

In the world
In the brain
Context
e.g., instruction
Contextual cues and prexisting knowledge
Two possible states
{up, down}
One state holds
e.g., up
Information flow for each decision
Consequence of action & state (4 possible)
One action
e.g., answer "up"
Motivation to perform the task
Consideration of two propositions (hypotheses)
h1: up or h2 : down
Sensory data
x = {x1, x2, ... }
Useful form of evidence
e
Decision variable
e.g., y ≈ ...
l12(e) = P(e|h1) / P(e|h2) or logLR12 = log[l12(e)]
Statistical knowledge
likelihoods: P(e|hi)
priors: P(hi)
values: v(Hj|hi)
Apply decision rule
e.g., choose left if
l12(e) ≥ criterion
Establish decision rule based on goals
Evaluation
Experience payoff or cost value or utility
vgj∈{1,2}
LIP
MT

Decision Analytical Framework



What Can Decision Analysis Do?

- Tradeoffs between alternatives
- Integration of multiple criteria
- High uncertainty, emerging future scenarios
  - ► Traditional optimization techniques are inadequate
- View from a system-wide perspective
- Entire system life cycle
- Building communities based on stakeholder views



Contents lists available at ScienceDirect

Science of the Total Environment

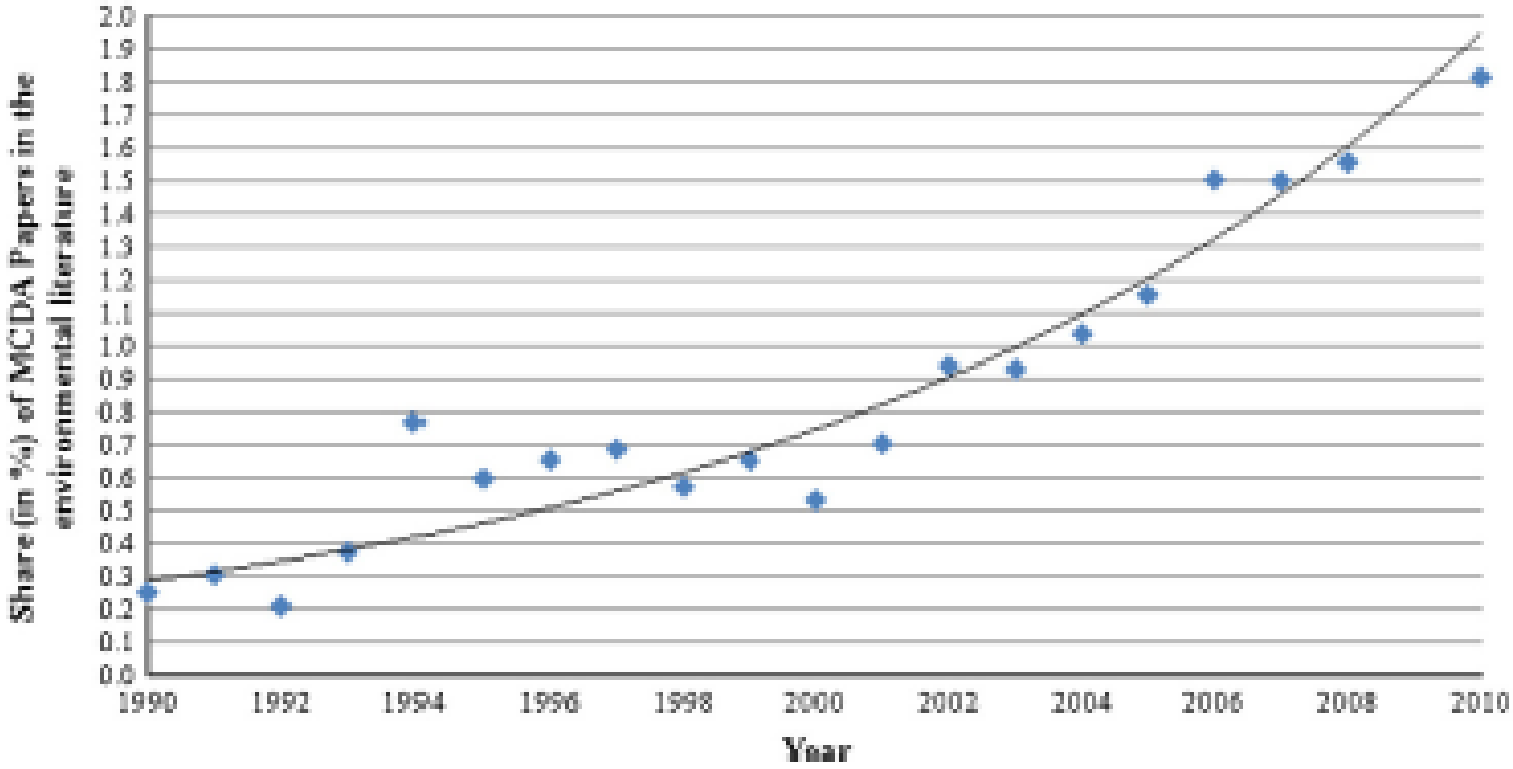
journal homepage: www.elsevier.com/locate/scitotenv

Review

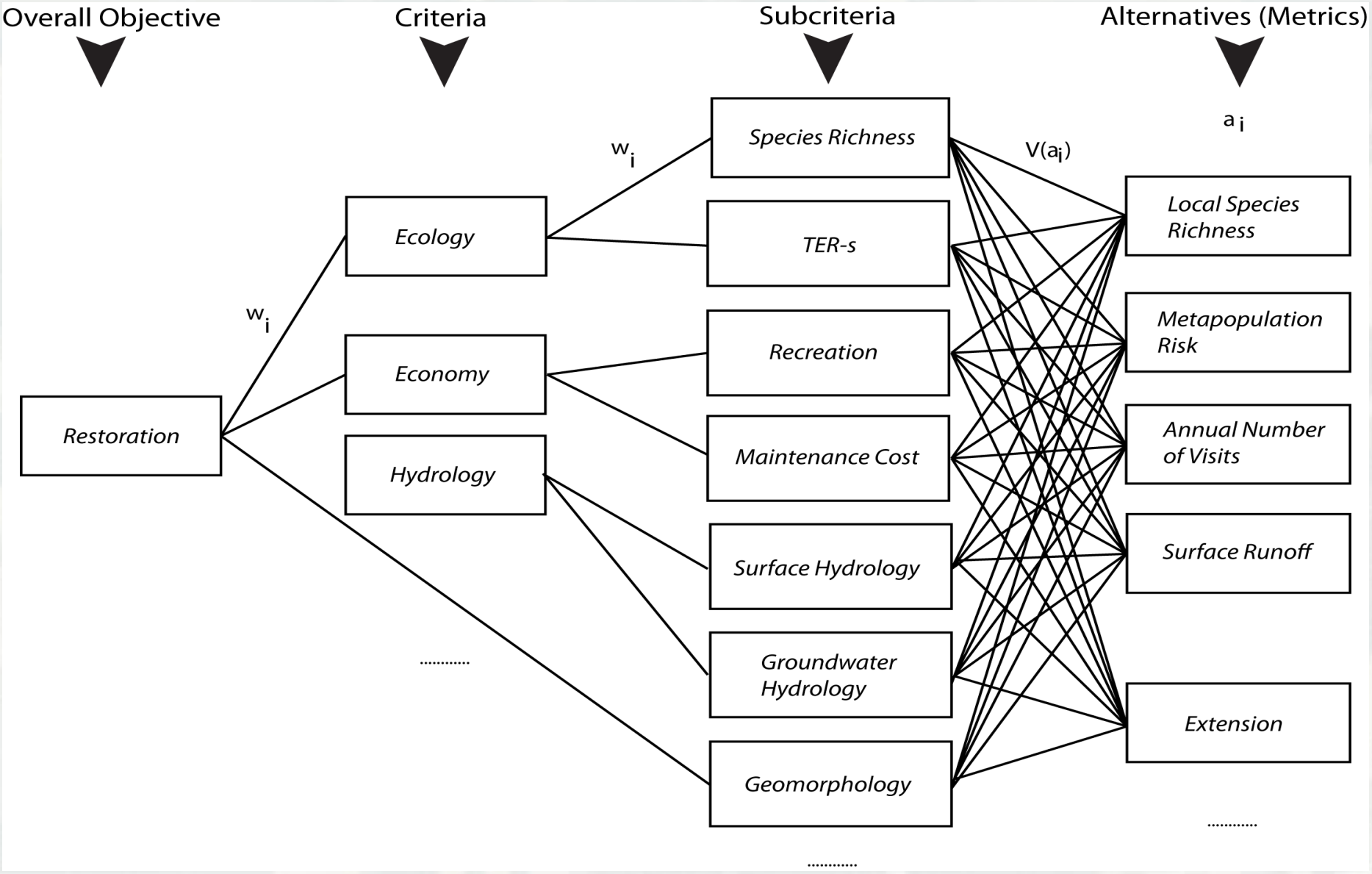
Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends

Ivy B. Huang [a], Jeffrey Keisler [b], Igor Linkov [c,*]

2011, published on-line



Restoration Metrics Selection: MCDA for riparian restoration (USACE/ERDC)



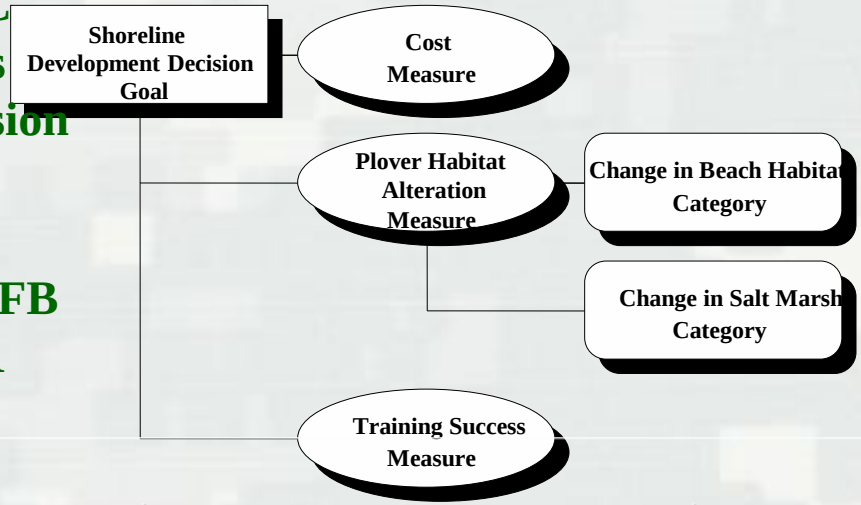
Climate Change and Operations Risks at FL Military Installations (SERDP)

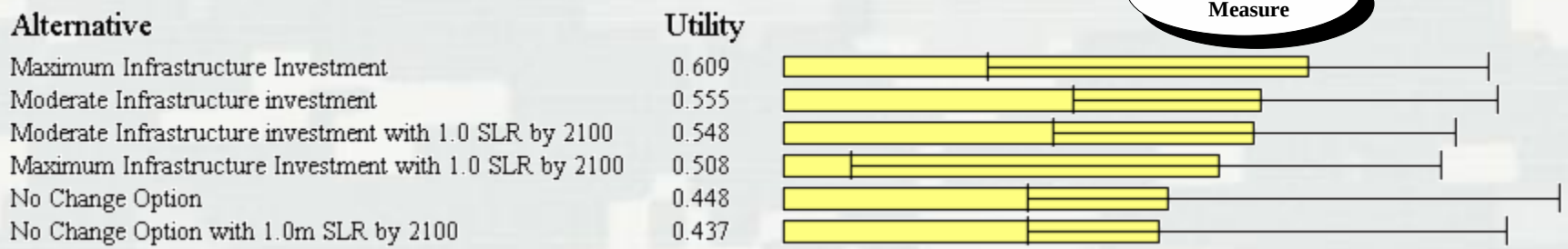
Purpose/Objective

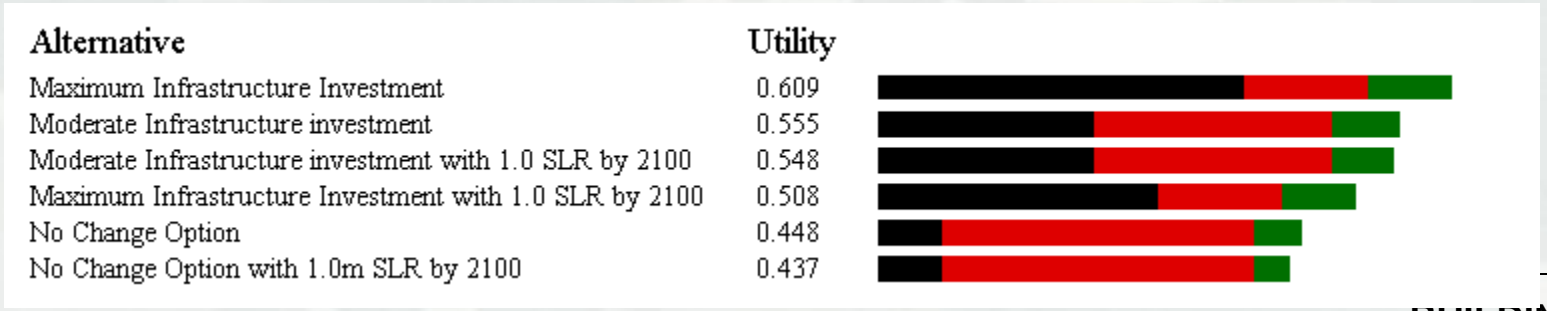
- Assess vulnerability for Eglin AFB to CC
- Develop habitat models for coastal birds
-Integrate results into a risk-informed, decision model for management options

Example MCDA framework

• Objectives under development with Elgin AFB
• Rankings with uncertainty + Future SLR
• Criteria contribution to decision







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Impact of Management Alternatives on Birds

Habitat Suitability

0
30
60
80
100

Available Areas (with uncertainty)

Low confidence

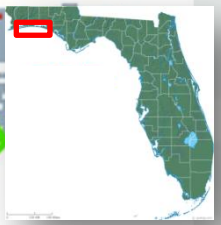
High confidence

X = No Training

SP critical areas P(SP=1, r=120 m)

Eglin AFB

Spatial resolution: 30x30 m
Temporal resolution: month



Higher confidence

Spatial areas available for training

Lower confidence

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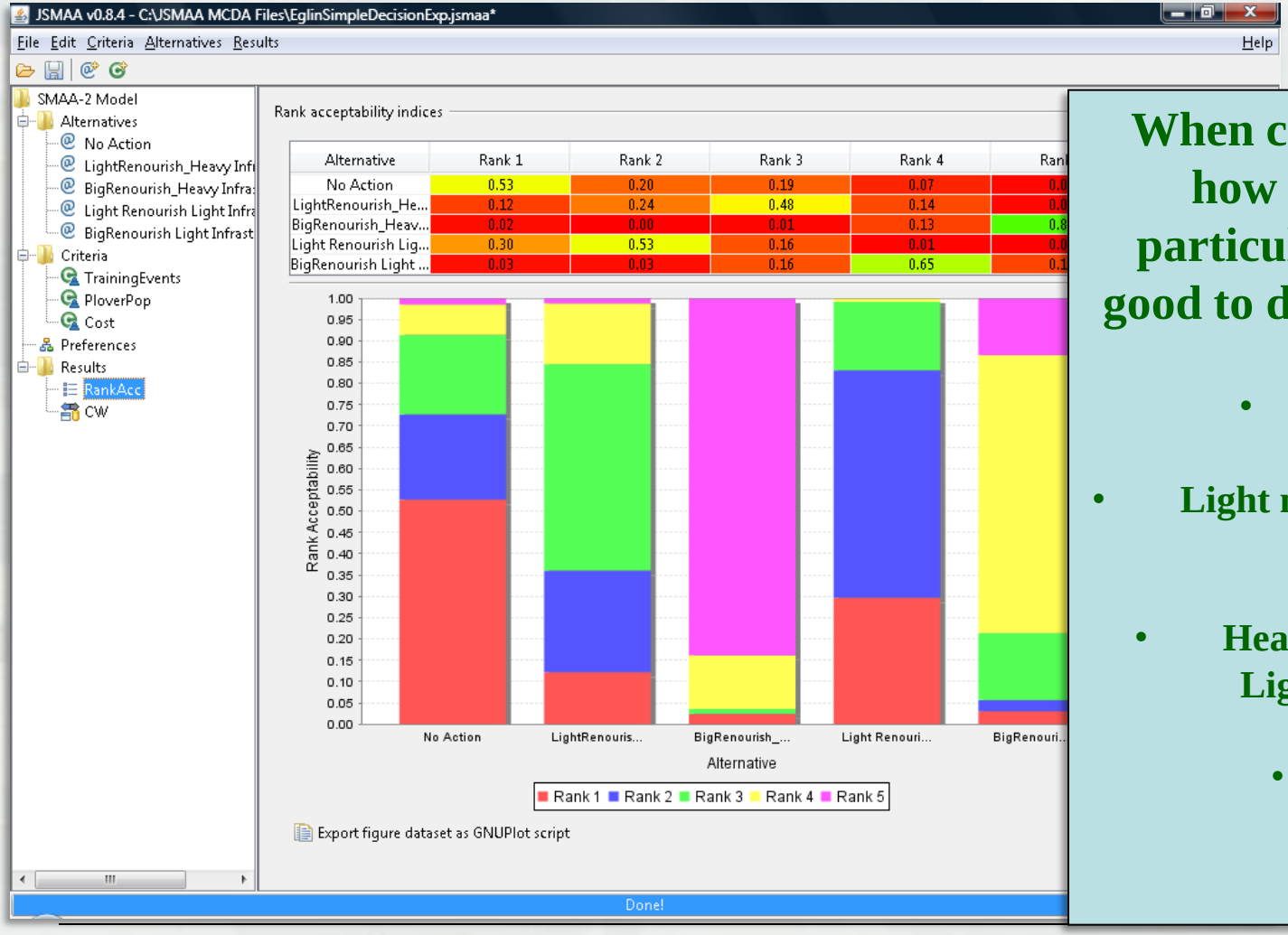
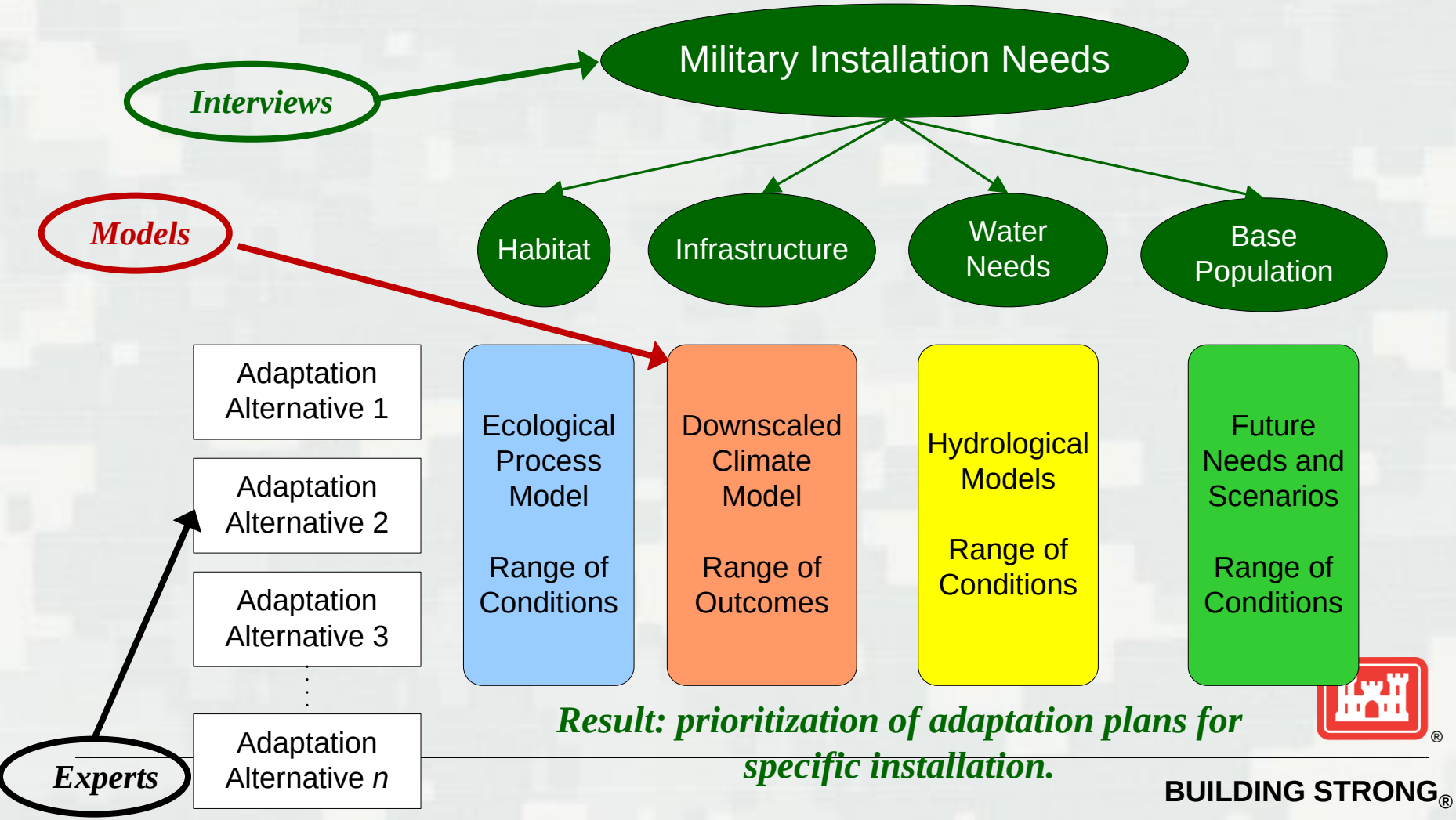
Infrastructure and Coastal Decisions with Varying Criteria Weights and Future States: (Beach Nourishment and Infrastructure)



When conditions vary, how often does a particular option look good to decision makers?

- **No action**
- **Light nourishment & Light infrastructure**
- **Heavy nourishment & Light infrastructure**
- **Etc…**

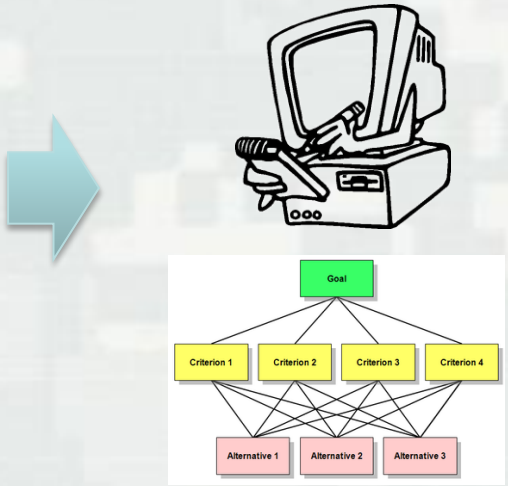
Integrated Modeling and Risk Analysis for the Environmental Consequences of Climate Change (USACE/ERDC)

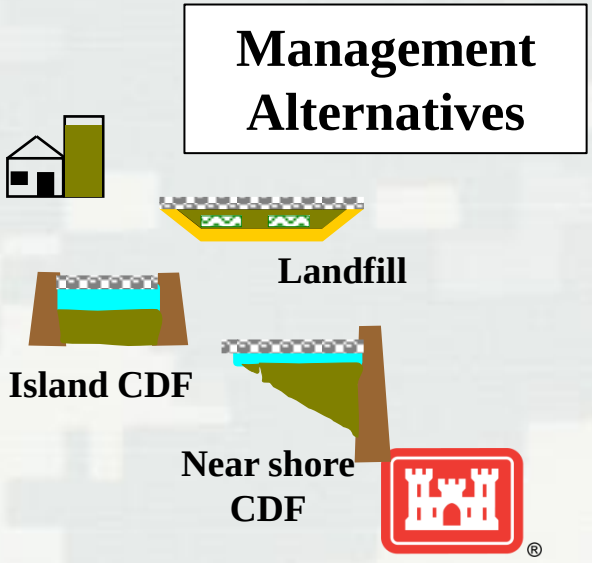


Result: prioritization of adaptation plans for specific installation.

Long Island Sound Dredged Materials Management (USACE)

A decision-aiding method incorporating **multicriteria decision analysis** to address stakeholder **contention** during early phases of the systems lifecycle and to support **innovation** and discussion of requirements and alternatives.





Restoration and Adaptive Management Current Use and Misuse

Restoration of a Marsh

Plan based on existing conditions:

- currently successful species
- current sea level, storm severity patterns

"Adaptive Management" approach: Revise plan if it fails

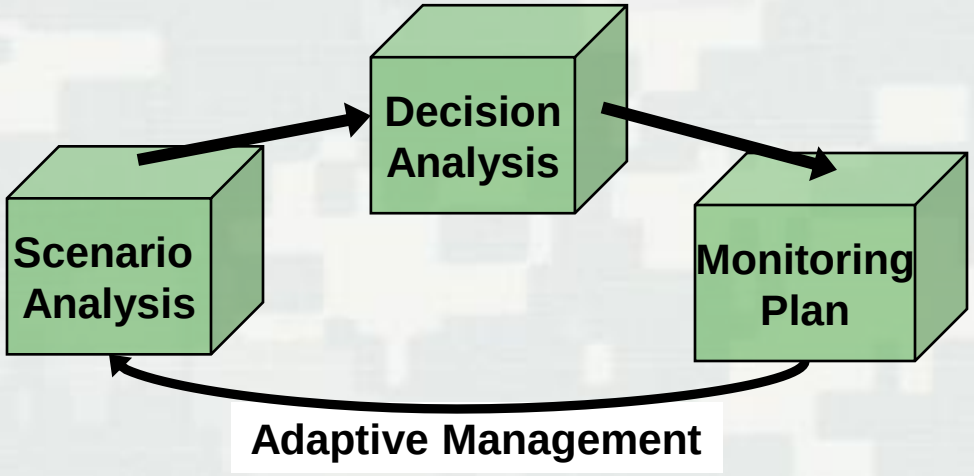
- detected through monitoring
  (often simply engineering specifications)

Restoration and Adaptive Management in Practice: Critiques and Challenges

- Overall approach exhibits lack of:
  - clear nexus between adaptive management plans and resource management needs
  - process for scientific feedback to affect management decisions
  - prioritization of monitoring needs
  - framework for integrated learning
- AM plans
  - assume static overall context
    - i.e., sea levels will remain constant, storm frequencies will follow historic patterns
  - lack a decision framework to identify ahead of time the feasible scope of options for revising management actions

Enhanced Adaptive Management Key Requirements

- ***Decision analysis*** to prioritize management strategies given objectives and uncertainties in the future states
- ***Scenario analysis*** to define potential range of future states
- ***Monitoring plan*** to collect data that informs management decisions about key conditions



Management Using Decision Analysis (DA)

Define alternatives (i.e., courses of action) and metrics for success
- species breeding conditions (size, vegetation, etc.)
- vegetation settlement/growth conditions
- stabilization, erosion control

Conditions for successful marsh drive the design/management
- optimal alternative depends on these conditions
- validate design through “performance” monitoring

Note: measurement of species abundance, etc. under these conditions is not “adaptive management” as it does not inform future actions.

What is Adaptive Management Meant to Do?

- Adaptive management is a framework to support actions (decisions) in the face of uncertainty by:
  - ► collecting information relevant to management goals during action implementation;
  - ► modifying the course of action to enhance results based on collected information and analysis.

Adapted from
"Adaptive Management for Water Resources Project Planning,"
National Research Council, 2004

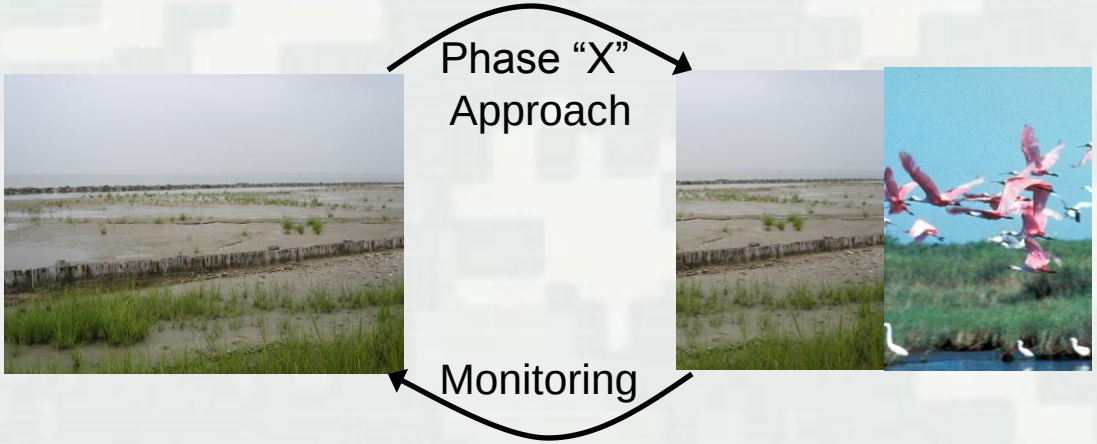
Adaptive Management using DA

Model conditions for "successful" marsh

- relationship (with error) between condition and breeding population
- vegetation growth dependence on abiotic conditions
- grade vs. rate of erosion, dependence on precipitation

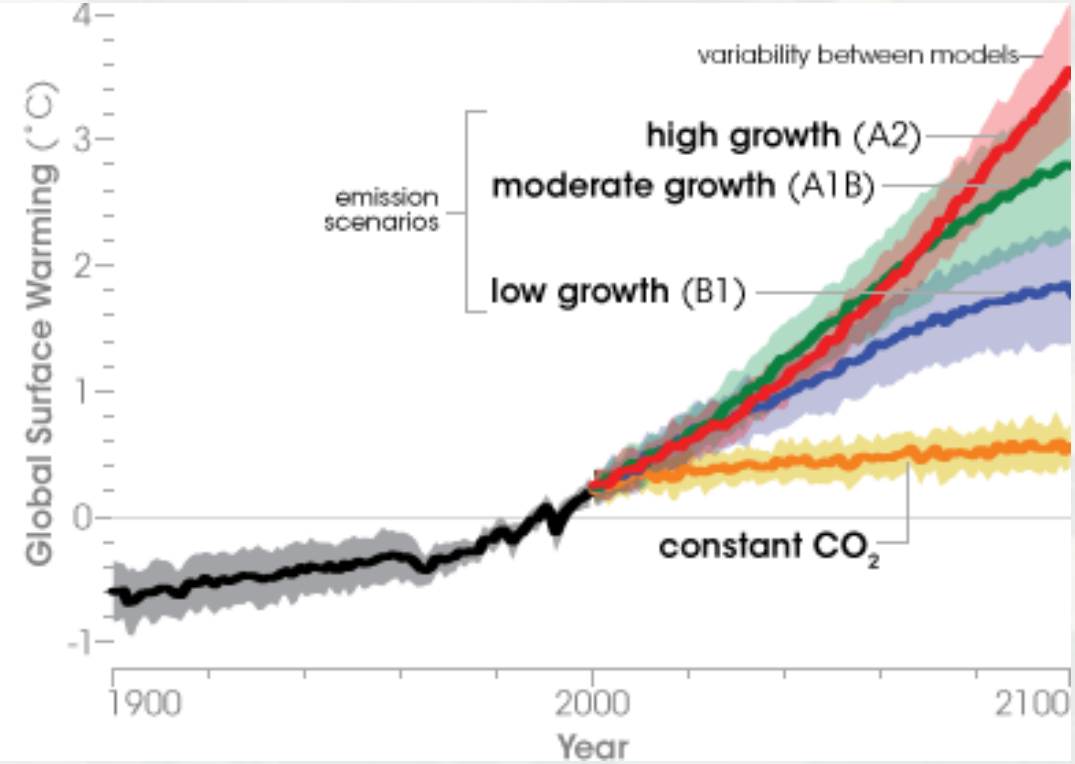
"Successful" conditions and "model uncertainty" determine actions

- incorporate optimal conditions from model
- monitor conditions, populations, growth, erosion, precipitation
- update the relationships, certainty of models based on monitoring
- alter marsh management for new "optimal" conditions from models



Enhanced Adaptive Management: Benefits of Scenario Analysis

- Identification of critical future conditions that require a change in the management approach



IPCC Global Temperature Change Scenarios (www.epa.gov)

- Ranges and limits for the needs of the management approach
- The relationship between uncertainty and operational objectives

Adaptive Management using DA and Scenario Analysis

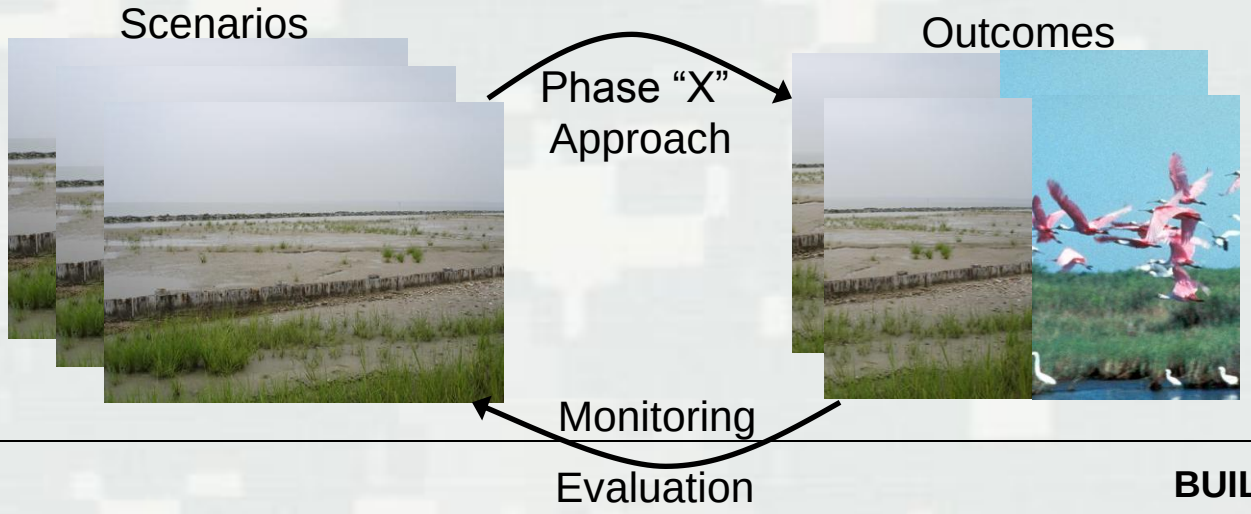
Model conditions for “successful” marsh

Develop future “scenarios” to evaluate design/management plans

- range of future temperatures, precipitation, habitats
- range of future sea levels, storm severity, inundation
- range of potential land use constraints, population growth

Choose most robust, probable “successful” conditions for Phase 1 approach

- monitor conditions, populations, growth, erosion, precipitation
- alter marsh management conditions according to updated models



What are the Benefits?

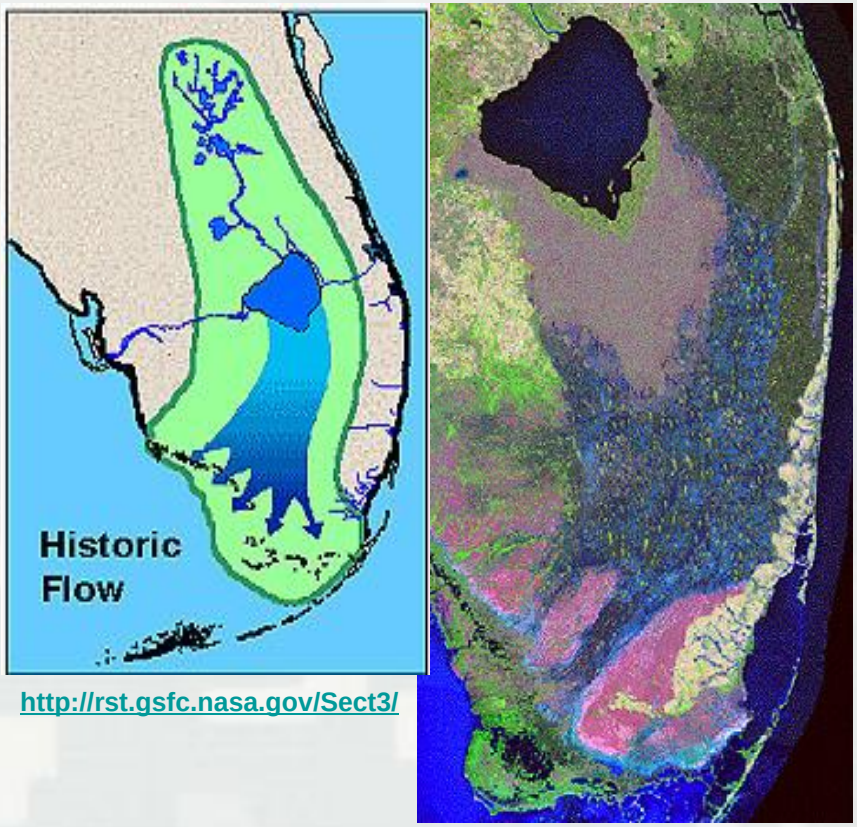
- Promotes flexible decision making in the face of uncertainty
  - ► i.e., use of weather forecast to determine if an umbrella is necessary
- Provides opportunity for iterative learning through careful monitoring of the effects of management options
  - ► i.e., necessity of consulting a forecast or having umbrella available under certain conditions
- Advances understanding of ecological, biological, or social processes in light of specific operations or policies
  - ► i.e., determine the accuracy/utility of weather forecasting

Hypothetical Enhanced AM Example: Everglades Adaptive Management

- Sophisticated hydrologic and ecological models but not well used to inform management actions

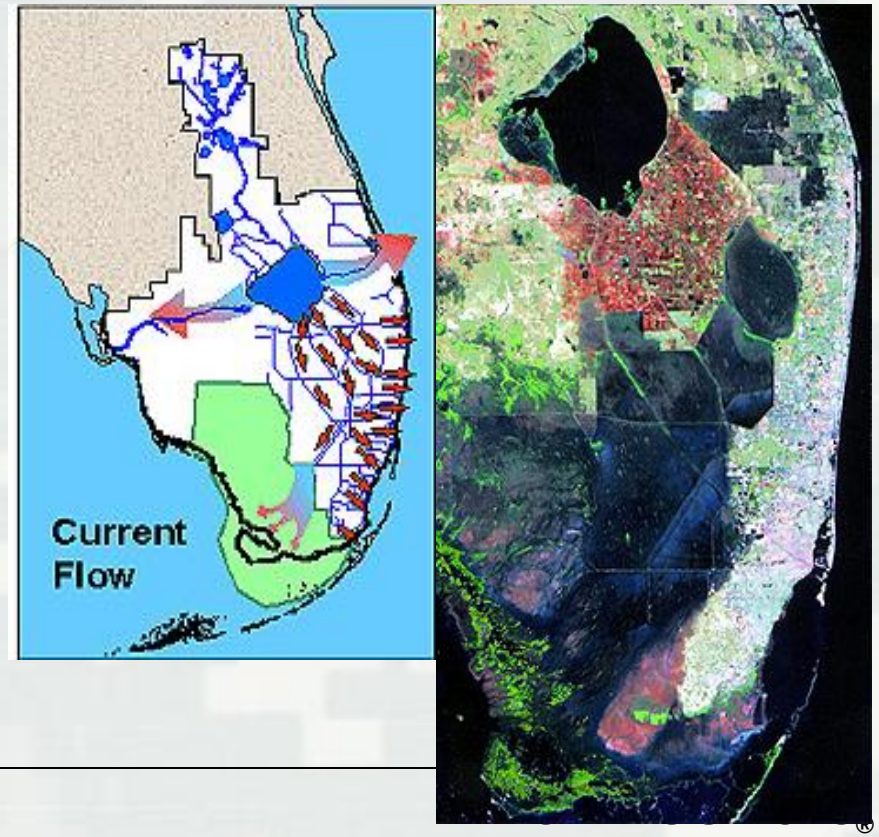
- Criticized for limited opportunity to “learn from” actions

Adaptive Management Needs



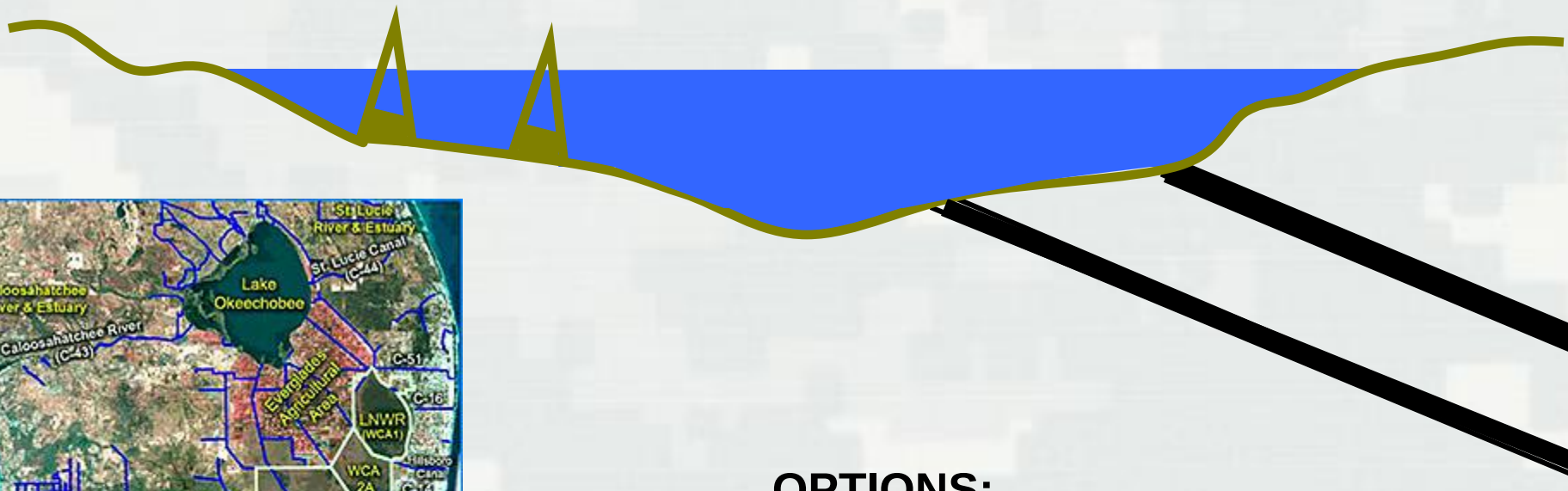
http://rst.gsfc.nasa.gov/Sect3/

Levee and canal flood protection cut water flow, resulting in ecological damage.



Management Alternatives

Alternative actions that could be taken to control water level include degradation of levees and backfilling canals.



http://rst.gsfc.nasa.gov/Sect3/

OPTIONS:
Minor canal fill
Major canal fill
Minor levee degradation
Major levee degradation

Everglades Enhanced Adaptive Management Decision Model Parameters

-Decision objectives: restore ecosystem, maintain flood protection, minimize monetary costs

-Management Timeframe: two periods

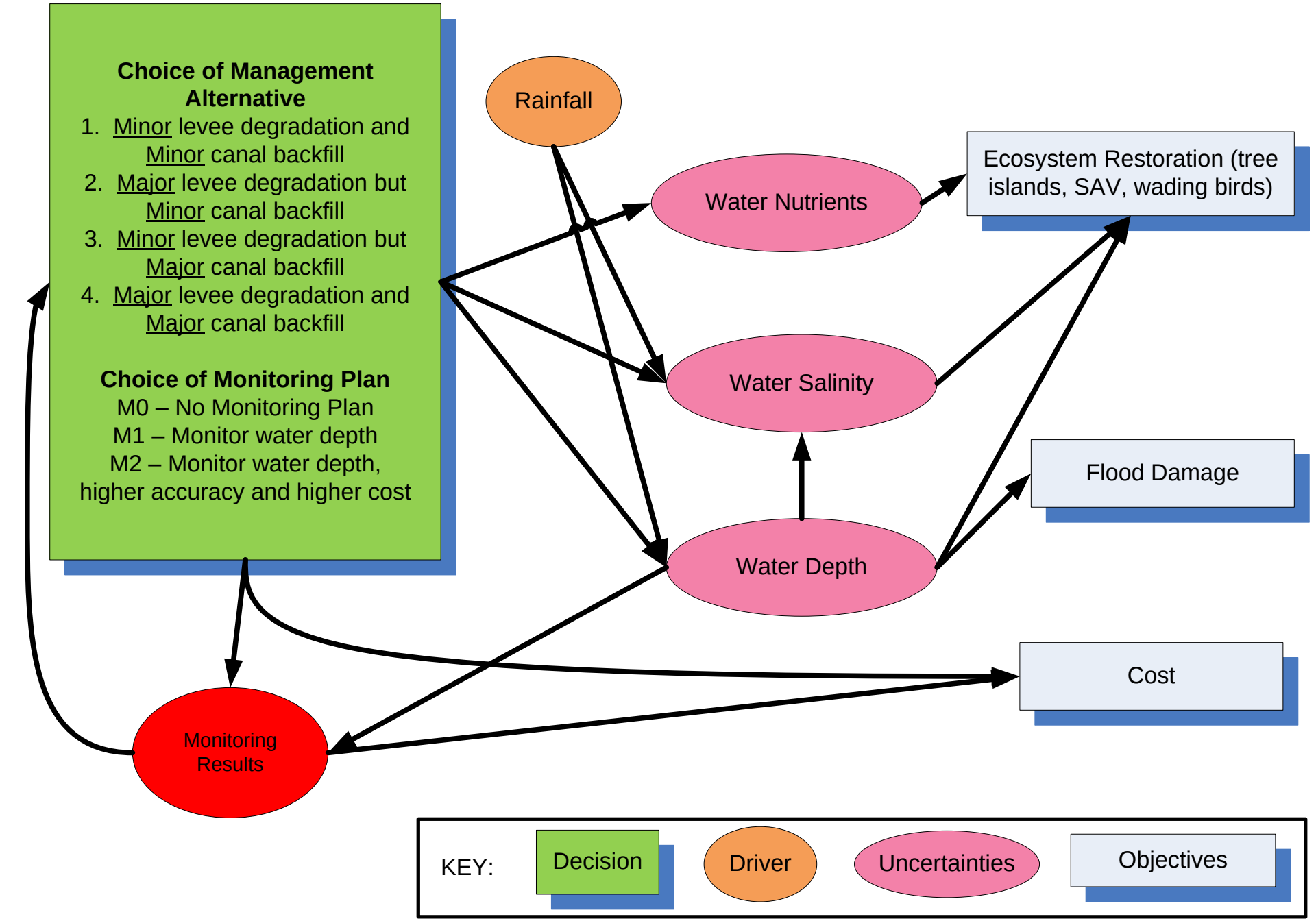
-Decision alternatives:

- Different degrees of degradation for levees and backfilling for canals (minor, major) for each of the 2 periods
-monitoring plan during period 1

Alternative	Levee Degrad'n	Canal backfilling
1	*Minor*	*Minor*
2	*Major*	*Minor*
3	*Minor*	*Major*
4	*Major*	*Major*

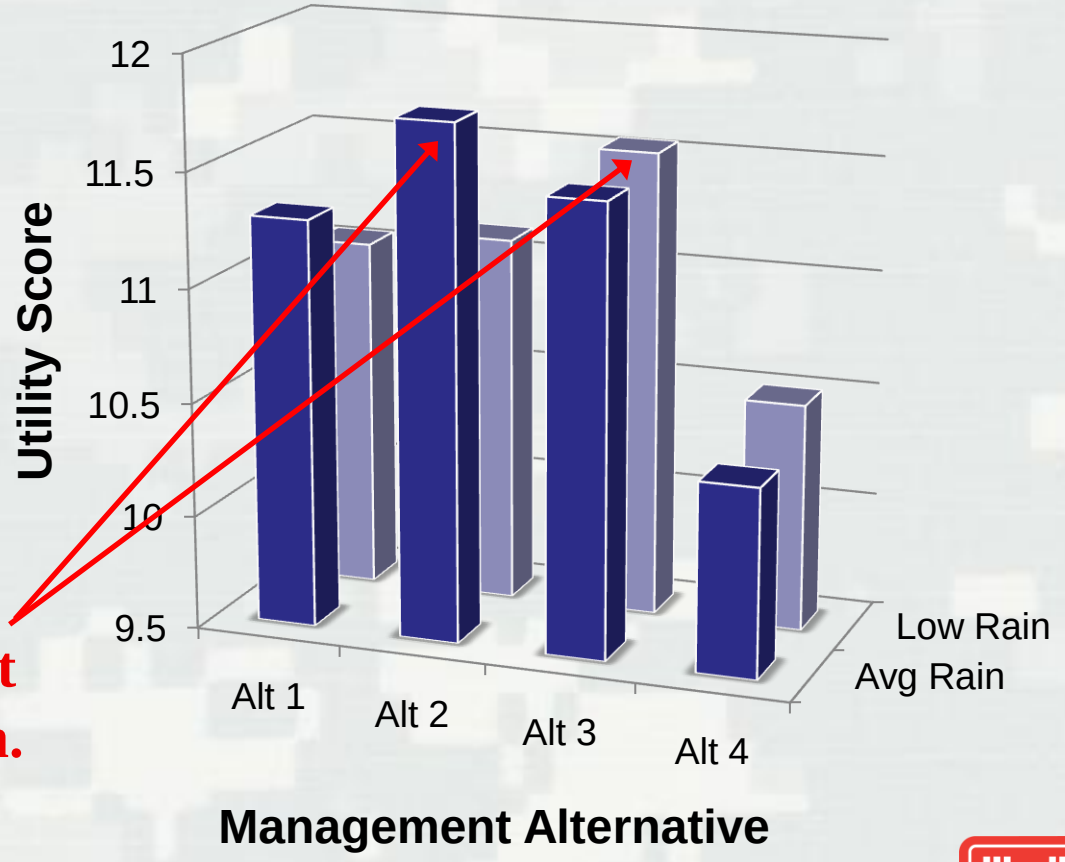
- Uncertainties:
  - Water nutrients (Too low, Normal, Too High)
  - Water salinity (Too low, Normal, Too High)
  - Water depth (Too low, Normal, Too High)

- Driver/Scenario: rain


Choice of Management Alternative
1. Minor levee degradation and Minor canal backfill
2. Major levee degradation but Minor canal backfill
3. Minor levee degradation but Major canal backfill
4. Major levee degradation and Major canal backfill
Choice of Monitoring Plan
M0 – No Monitoring Plan
M1 – Monitor water depth
M2 – Monitor water depth, higher accuracy and higher cost
Rainfall
Water Nutrients
Ecosystem Restoration (tree islands, SAV, wading birds)
Water Salinity
Flood Damage
Water Depth
Cost
Monitoring Results
KEY:
Decision
Driver
Uncertainties
Objectives

Sensitivity to Assumptions

What if there is a decrease in the anticipated rain level over the next few years?



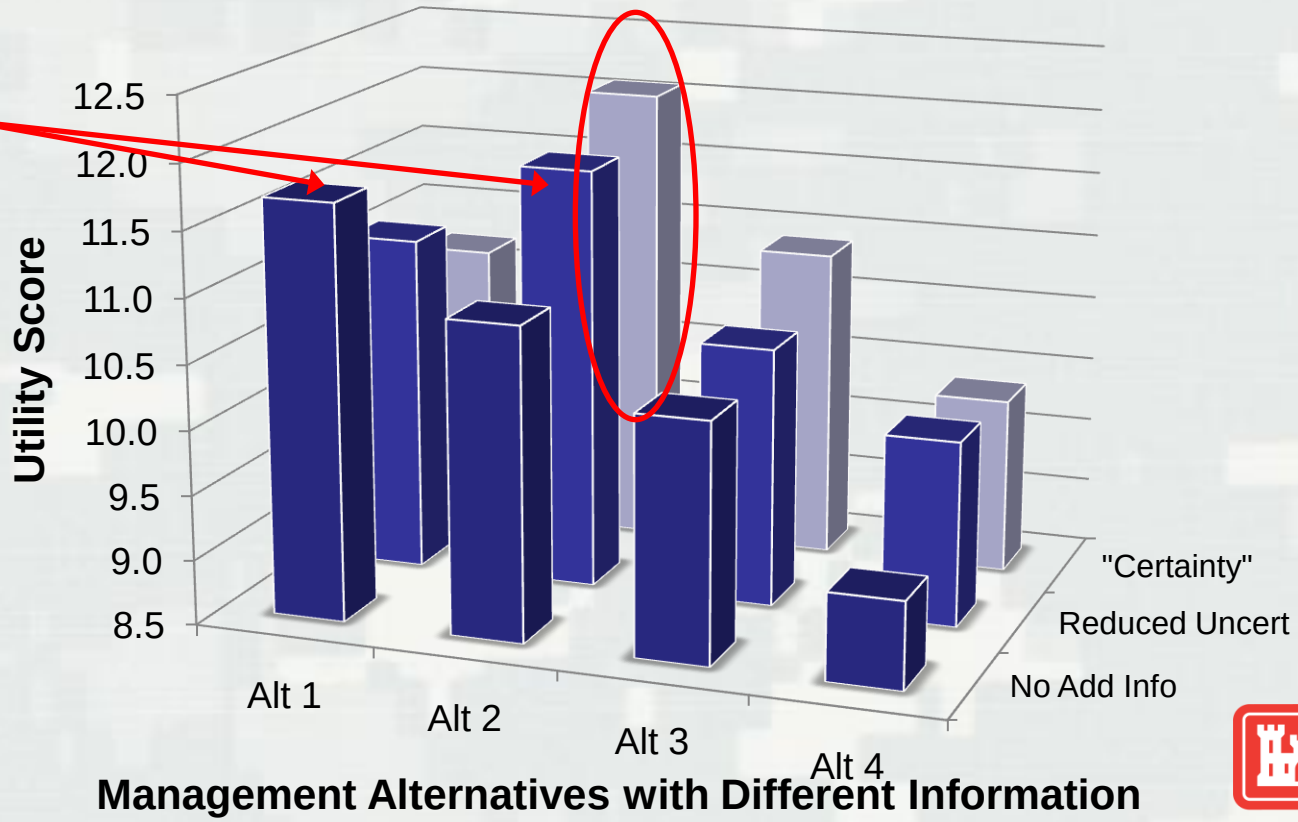
More aggressive management action is favored under different assumptions about rain.

Effect of Reducing Uncertainty

What is the utility value of a reduction in uncertainty of the effects of a particular management alternative? In other words, if you know the implications of your actions with more certainty, what is the relative value.

Change in choice with reduced uncertainty.

Quantified value of perfect information (certainty).



Current "Adaptive Management" vs Enhanced Adaptive Management

Currently:

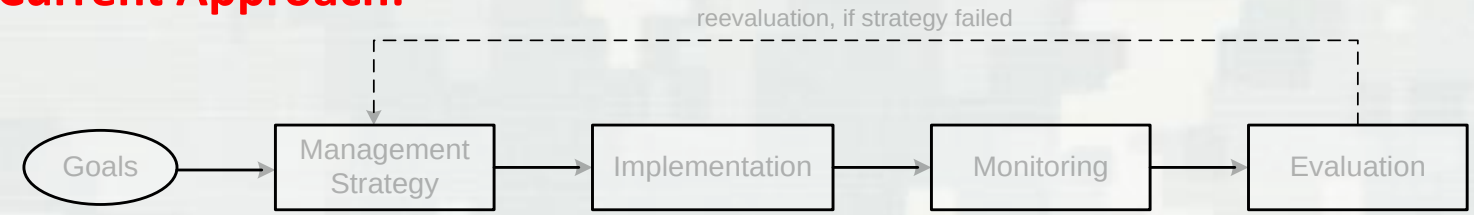
- monitoring plan may not link to management needs
- management plan selection dependents only on current conditions
- AM plan may not situate within a clear framework of action options

Enhanced:

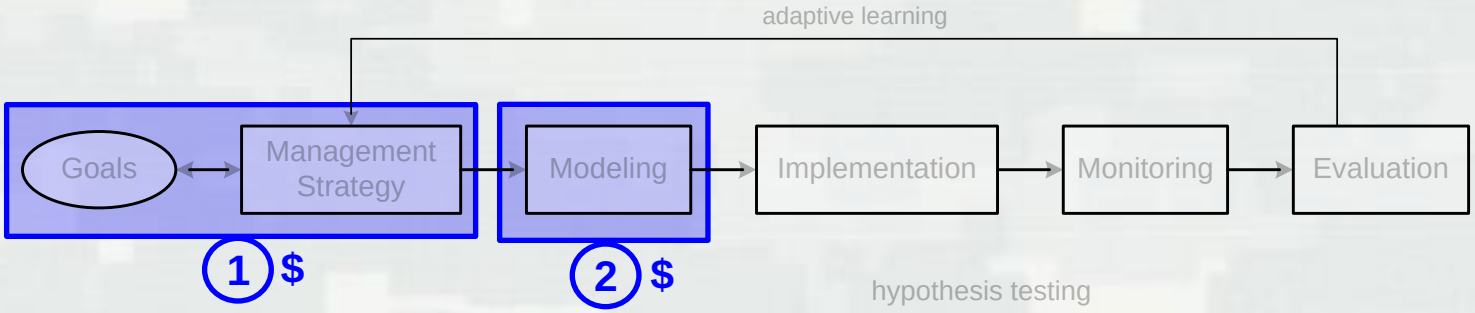
- dynamically adjust course of action
- utilize predictive value of models
- robust under uncertainty and changing conditions

Necessary Commitment of Resources and Time

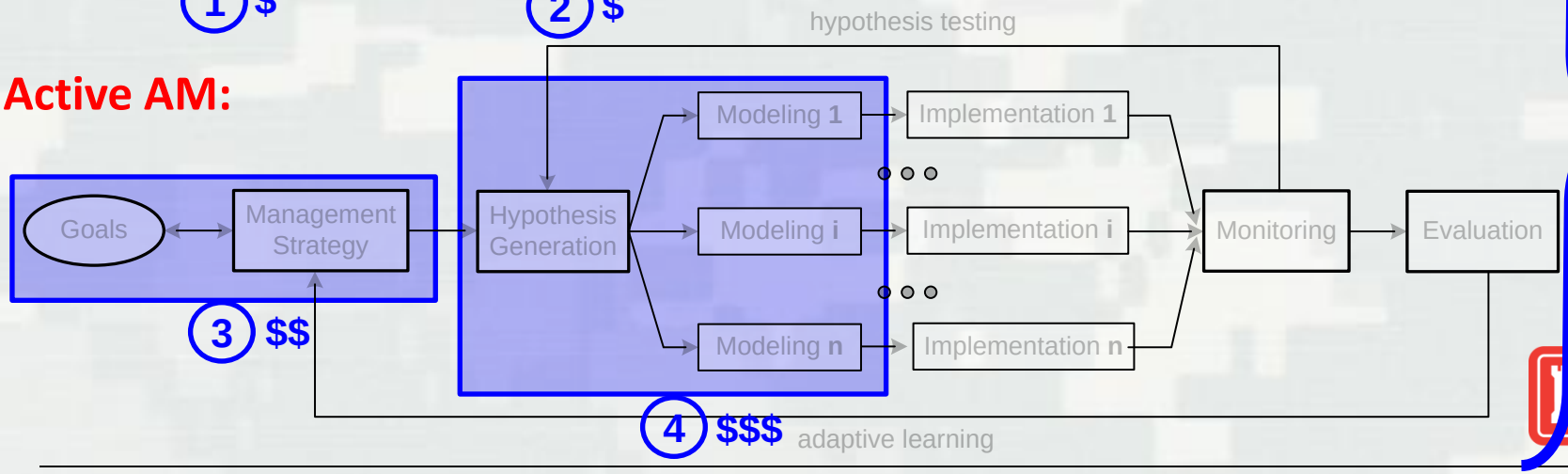
Current Approach:



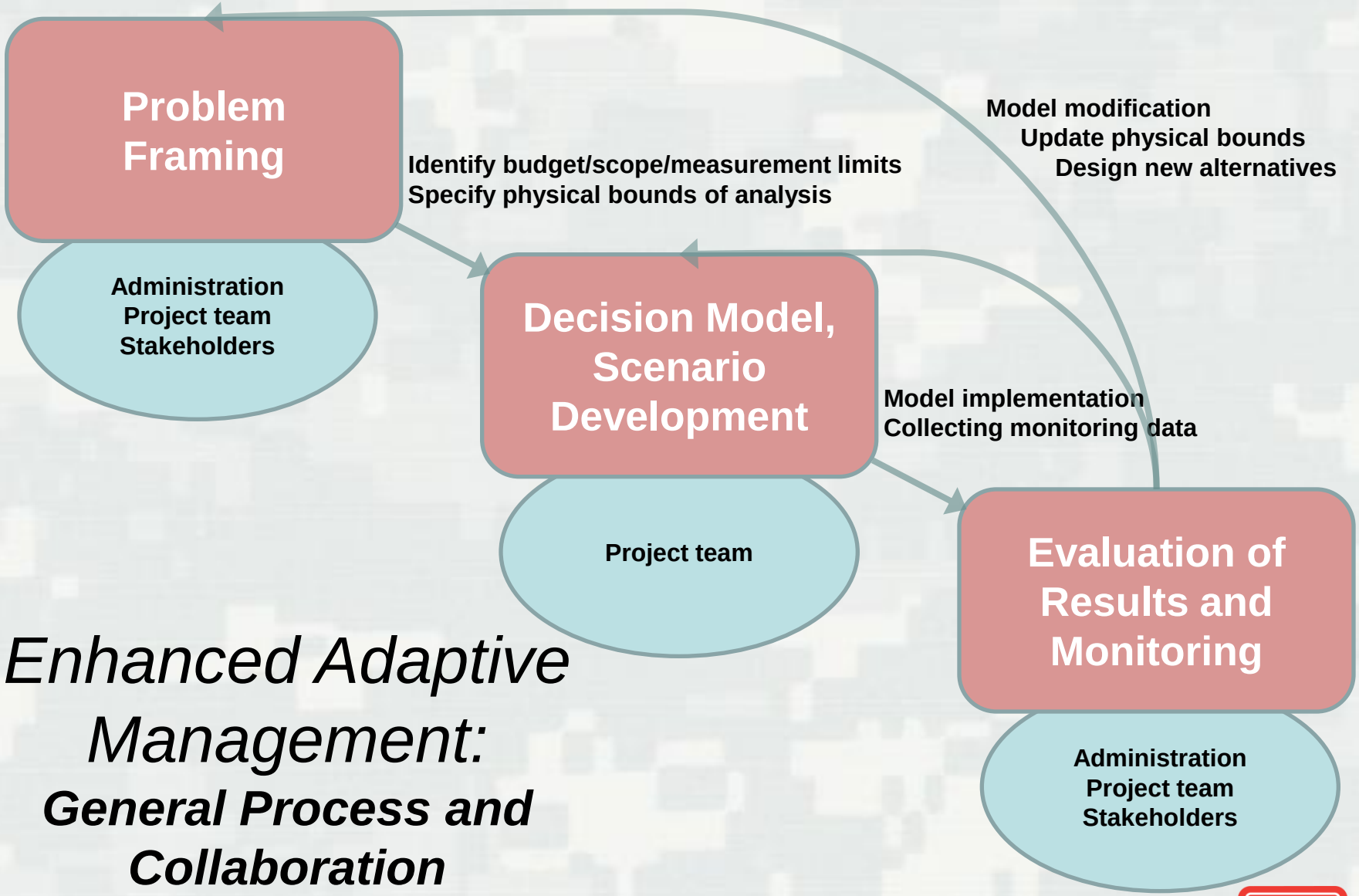
Passive AM:



Active AM:



Enhanced Adaptive Management®



Enhanced Adaptive Management:

General Process and Collaboration

People, Process and Tools

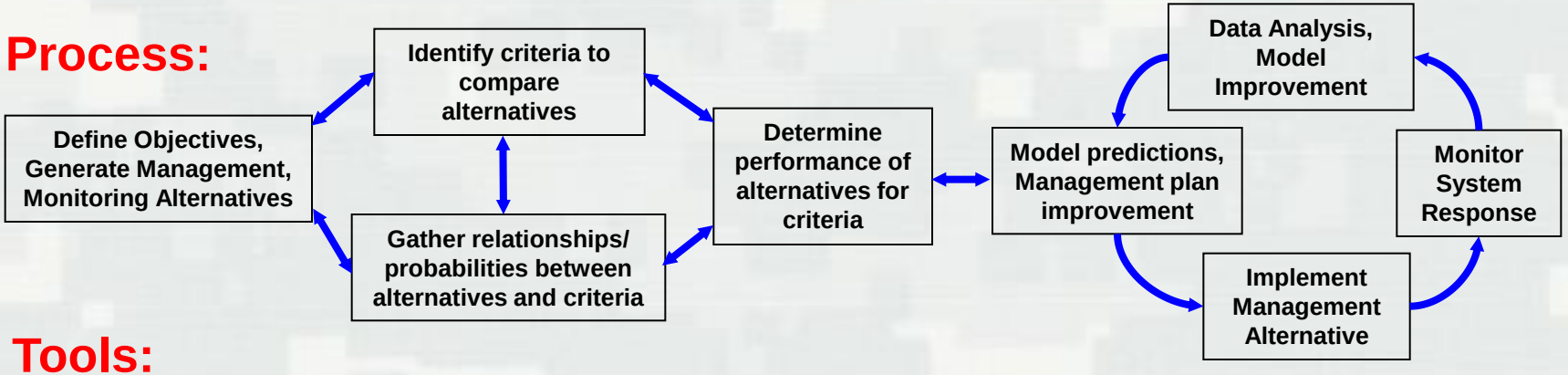
People:

Policy Decision Maker(s)

Scientists and Engineers, Decision Analysts

Stakeholders (Public, Business, Interest groups)

Process:



Tools:

Environmental Assessment/Modeling (Risk/Ecological/Environmental/Simulation)

Decision Analysis/Scenario Analysis/Optimization of Monitoring

Timeline*:

6 – 12 months

1 project management cycle

***Duration/cost depends on complexity of application**

Enhanced Adaptive Management
Next Steps

- Develop Applications: provide a roadmap for complete adaptive management approach implementing decision analysis and scenario analysis

- Implement and Document: determine aspects of the process that are the most complex, time consuming, difficult to apply or critical for the outcome(s)

- Benefits: Analysis of cases allows demonstration of benefits and best practices of enhanced adaptive management

Recommended Actions

- Integrate decision analysis and scenario analysis into adaptive management plans
- Promote the “next steps” in demonstrating the utility and increasing the capacity for this approach: case studies, development of expertise, expanded range of application

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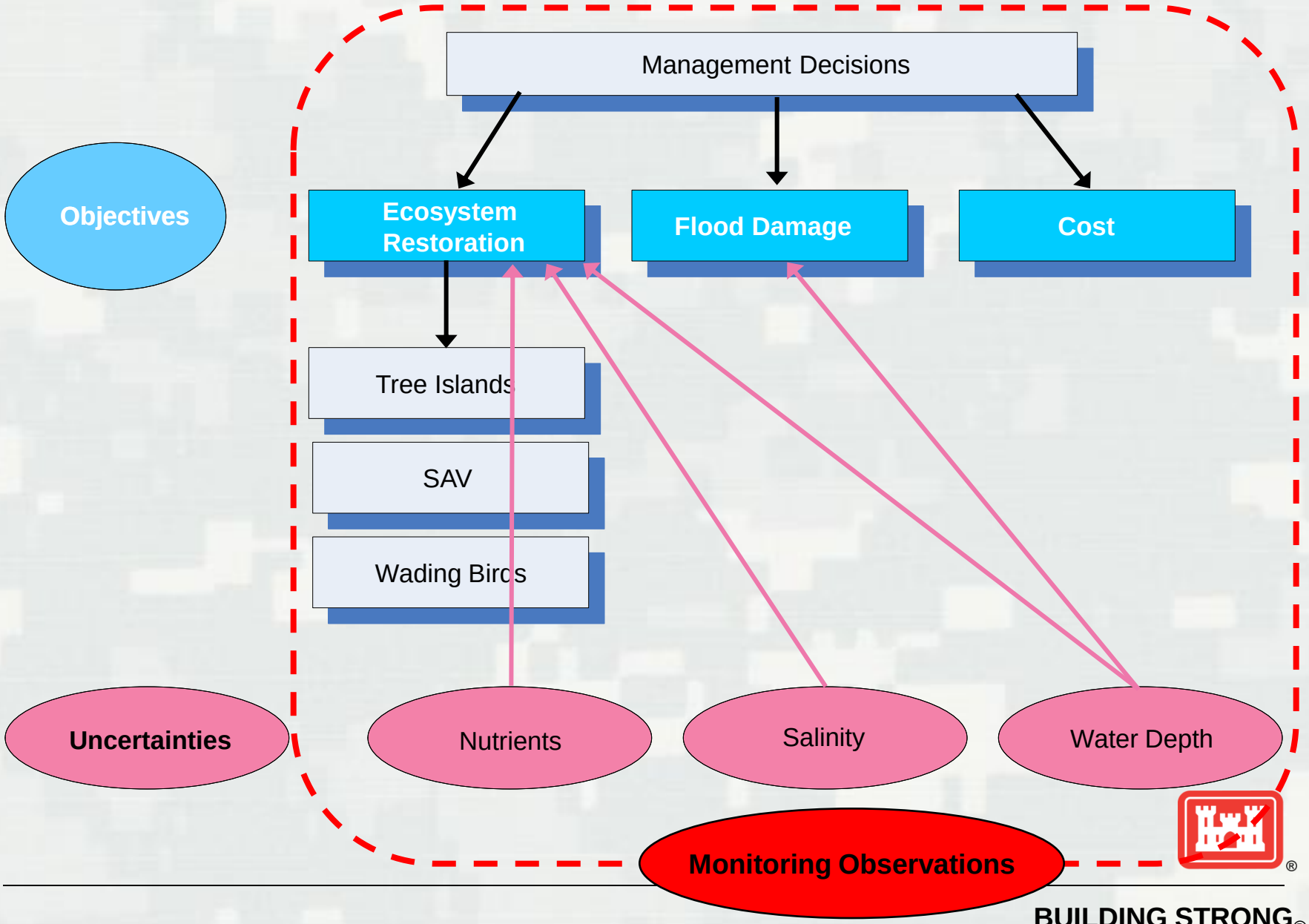
Everglades Management Decision Context



OUTLINE

- Restoration and Adaptive management
  - Purpose
  - Current implementation
  - Critiques and challenges
- Enhanced Adaptive Management
  - Decision model
  - Monitoring plans
  - Scenario analysis
- Comparison of approaches
- Enhanced Adaptive Management:
  - Hypothetical example
  - Requirements for implementation
  - Process, resources and collaborations
- Recommended next steps

Management Scenarios

- Different drivers are used as scenarios that impact the management decisions.
- Events directly and indirectly (through uncertainties) impact objectives.
- The simplest scenarios would be combinations of high, medium and low levels for each driver.

Model Results

Without monitoring: Model determines the value of each alternative management option given specific assumptions (probability, costs, relationships).

Conclusion: Minimal action (Alt 1) is the best choice.

With the monitoring plan: Model determines value of each alternative management option given assumptions and cost of monitoring. Also calculated are which monitoring results would change the best choice of management strategy.

Conclusion: Major levee degradation and minor canal filling (Alt 2) is the best choice. If water depth is too high, switch to minimal action (Alt 1).