Decision Making under Uncertainty:

Introduction to Structured Decision Analysis for Performance Assessments

Paul Black, Ph.D.
and lots of others at Neptune

NEPTUNE AND COMPANY

Improving the quality of environmental decision making.

This is our Perspective

- We like to be objective
- Currently, radioactive waste disposal is an obstacle to the nuclear industry
- A paradigm shift is needed for better decision making
- We think this is important if we want to make better (optimal) use of our limited resources
- We think this is important if we want to defensibly support the nuclear industry
- We think this is important if we want to help future generations

Overview

- Why a decision analysis approach might be helpful:
  - Brief historical PA context – what and why
  - Possible paradigm shift – what and why
  - Decision analysis overview
  - A decision analysis framework tool
  - Some applications
  - Research needs
  - Summary

Why Do PAs Need Improvement?

- Traditionally, PAs have supported the *status quo*
  - Focused on demonstrating compliance rather than on optimal decision making

    (for disposal, closure, long-term management)
  - Mis-applied conservatism leading to
    - poor (sub-optimal) decision making
    - unnecessarily increased costs
    - opacity to stakeholders (and to reviewers)
  - Difficult to communicate and defend

Past Approach to PA

- Fate and transport modeling
  - Process-level modeling
  - "East coast" mentality – groundwater focused
  - Insufficient coupling of processes
- Deterministic for low-level waste
- "Conservative"
- Default receptor scenarios
- Aimed at compliance

Initiated about 30 years ago without the technology available today

Improved Approach to PA

- Fate and transport modeling
  - Systems-level modeling (supported as necessary)
  - Consider all pathways & coupling of processes
- Move towards probabilistic (not fully there yet)
- Still too conservative (but better)
- Some consideration of site-specific scenarios
- Some consideration of site management
  - But not optimization yet

We learned in the past 30 years – we applied some of what we have learned, ***and there is further to go***

- Revisions to 10 CFR 61 and 435.1 don't get us there

Focus Order of Current Approach to PA

1. Science (fate and transport modeling focus)
   - Hydrology, hydrogeology, geochemistry, soil science, plants, animals, etc.
2. Risk/dose assessment
   - Human health – risk or dose
   - Ecological risk
3. Statistics and Decision Analysis
   - Bayesian for decision modeling
4. Stakeholder engagement/communication

Re-thinking – Change Focus

- Holistic approach to solving decision problems
- Decision focused – top down – a paradigm shift
  1. Stakeholder engagement/communication
  2. Statistics and Decision Analysis
     - Bayesian for decision modeling
  3. Risk assessment
     - Human health and ecological risk
  4. Science
     - Hydrology, hydrogeology, geochemistry, soil science, plants, animals, etc.

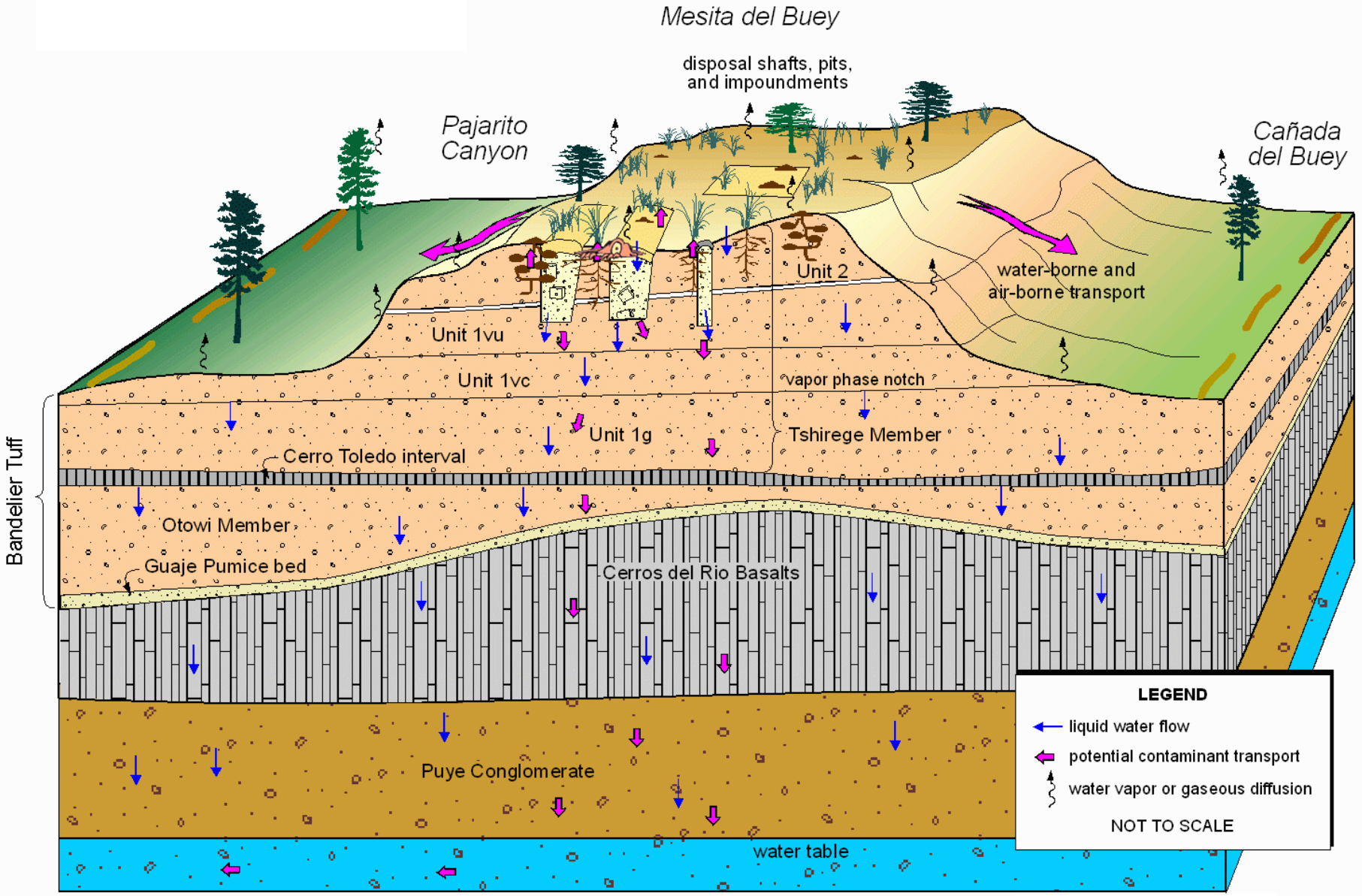
All aspects are important, but the ordering has shifted

Decision Risk

Potentially Unacceptable Health Risk

Radioactive Waste Disposal Example

More complicated risk problem?



Decision Analysis for PA
(and other complex environmental decisions)

- Decision Analysis can provide a different approach to the way in which Radioactive Waste Disposal is considered/evaluated
  - A **"Paradigm Shift"**
  - A "Revolution"? – really an "Evolution"
- Some environmental programs are moving forwards in this regard (e.g., EPA sustainability, watershed management and land use programs)
- Food safety is moving in this direction (FDA)
  - Although both NRC and DOE have previously performed cost-benefit analysis (using population risk)

Why Does PA Need a Makeover?

If we want nuclear industries, then we need to:

- Make the best use of our existing disposal facilities
- Move beyond compliance determinations
- Optimize use of ever more scarce funding
- Remove conservatism
  - over-engineering, creating problems that do not exist
  - use “reasonable realism” – will improve communication

So, stop wasting money

nuclear industries (which really means the current generation of tax payers) foots the unnecessary bill

and maximize benefits to all stakeholders

Decision Analysis – Basic Principles

- Decisions are made by evaluating decision risk
- Human health and environmental risk are components of decision risk for some types of problems (environmental, food)
- Some decisions should be made with respect to populations rather than individuals
- Decision risk decreases with time (social discounting) – need "insurance" to address possible future concerns
- Modeling is performed in the context of decision risk

Thoughts?

- "All models are wrong, but some are (hopefully) useful" (George Box, 1979)
- "Models should be as simple as possible and no simpler" (Morgan & Henrion, 1990)
  - Smarter tools, not bigger ones
  - 10 commandments of policy/risk analysis
- Remove "*conservatism on top of conservatism on top of conservatism*…." – otherwise GIGO
- Radioactive waste management tail is wagging the nuclear industry dog
  - and we still have legacy waste to deal with

Perspectives

- Environmental problems are diverse, however…
- …the basic **process** for finding solutions should be the same
  - Past efforts, such as DQOs, tried to address this
- Regulations and guidance essentially developed 30+ years ago
  - I.e., we can benefit from 30 years of changes in technology, improved methods, and lessons learned
- Obstacles?
  - Difficult to change regulations/guidance
  - Old dogs; new tricks

Lessons Learned

- There are some difficult environmental risk-based problems
  - Thoughtful solutions are needed for good decisions
    - This requires effort
  - Conservatism often leads to poor decisions
  - Deterministic models do not allow uncertainties to be evaluated properly
  - Decision objectives should drive modeling needs
  - Solutions should be site-specific
    - “Cookie cutter” solutions don’t work
  - Stakeholders should be involved throughout
    - Stakeholder values should be included

Site-specific Decision Making

Site-Specific Exposure Scenarios
can make a difference in
distinguishing site performance.

Problems of Conservatism

There is conservatism in

- regulations and guidance
- performance objectives
- deterministic modeling (and modeling tools)

Conservatism on top of conservatism on top of conservatism…

The resulting dose and risk calculations

- might not actually be conservative because of competing influences, and
- cannot be meaningfully interpreted probabilistically or for decision making

It is fine to make conservative decisions, but not to make difficult decisions based on "conservative" models

ALARA opens the door

10 CFR 20.1101(b) requires that:

> "The licensee shall use, to the extent practicable, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (**ALARA**)."

ALARA implies objectives, implies values, and **implies *decision analysis***

Decision Analysis for PA

- PAs should be decision tools
- Decision-focused, addressing
  - stakeholder values, costs and benefits
  - uncertainty (with probabilistic modeling)
- Sustainable – 3 pillars of sustainability
  - economics, environment (ecology), society
- Transparent
- Defensible
- Adaptive depending on meeting objectives
  - consideration given to compliance

What is Decision Analysis?

- "Formalized common sense"
- A set of tools for structuring and analyzing complex decision problems
- An approach for making logical, reproducible, and defensible decisions in the face of:
  - Technical complexity
  - Uncertainty
  - Costs and value judgments
  - Multiple, competing objectives

Stakeholder driven Decision Analysis

- Actively involve stakeholders, customers or users at *all stages* of the decision analysis process (instead of only at later stages, which is more typical)
- Identify objectives, decision options, and events that define the decision analysis
- Clearly communicate judgments about costs and values, uncertainty (probabilities), and risks

Decision Analysis Cycle

- Identify objectives and decision options
- Build a model with available information
  - Probabilistic model (uncertainty)
  - Costs and value judgments
- Evaluate model – uncertainty analysis
- Perform sensitivity analysis and value of information analysis
- Can decision be made or should more information be collected? (gets at confidence in the decision)
- **Iterate**

Open, transparent, defensible…

Fully operationalizes the Scientific Method

“Bayesian DQOs”

Bayesian Paradigm Shift

- Decision analysis is based on representing and revising beliefs for choosing actions in situations of uncertainty
- Bayes' theorem provides the crank for revising beliefs in light of new evidence
- Bayesian approach leads to maximizing expected utility (minimizing expected loss)

Decision Analysis Results

- In the long run, it is best to choose the alternative (decision option) that provides the best expected outcome, given what you know or believe about future events.
- This is the basis of *cost-benefit analysis.*
- Evaluate **sustainability**: economics, environmental and social pillars
- Aim to ***Maximize expected societal welfare***

Also – Risk management, Economic analysis….

Roots of Decision Analysis

- Bayesian probability theory (Bayes, 1765)
- Utility theory (von Neumann & Morgenstern, 1947)
- Bayesian Statistical Decision Theory (de Finetti, 1930s, Savage, 1954, DeGroot, 1970)
- Behavioral Science (von Winterfeldt and Edwards, 1986)
- Risk and Policy Analysis (Morgan and Henrion, 1990)
- Structured Decision Making (Gregory et al., 2012)

Roots of Decision Analysis

- Decision Analysis established as an applied discipline and a field of research in the late 1960's
- Howard Raiffa (Harvard)
  - emphasis on decision analysis as a method with real world applications
  - Initial elicitation methods
- Ron Howard (Stanford)
  - emphasis on influence diagrams and economic analyses in the face of uncertainty

Benefits of a Decision Analysis approach

- Easier to understand
- Easier to communicate and explain
  - Because it represents what we think we know and our uncertainties about that
    - I.e., it's honest
  - Rather than what we know to be wrong, inaccurate, or mis-applied
- Consequently, more difficult to disagree
  - Helps avoid redo, or another stone

Common Application Areas

- Oil and gas industry
- Risk analysis (business decision risk)
- Pharmaceutical and biotechnology industries
- Public sector applications
  - Department of Defense
- Environment – moving in this direction
  - White House circular in 2001

Environmental Evolution

- Strong evidence of an evolutionary change:
  - OMB – policy analysis
  - DOE
    - Enterprise Risk Management effort (2004)
    - Risk-informed decision making
  - EPA CREM
  - NRC NUREG – risk-informed guidance
  - NAS documents – perform risk assessment
  - Professional societies – SRA, INFORMS
  - Impact of changes in education system

EPA Examples

- SMARTe – Sustainable Management Approaches and Revitalization Tools
  - *Brownfields revitalization*
- Re-imagining Cleveland
  - *Regional land use planning*
- DASEES – Decision Analysis for a Sustainable Environment, Economy, and Society –
  - *Land re-use*
  - *Watershed management*
  - *Coral reef management*
  - *Social network tool for stakeholder involvement*
- Asbestos remediation
- Vapor intrusion characterization

Other Agencies

- DoD – cleanup chemical warfare agents
- MMRP – characterize and remediate UXO
- FDA – prioritizing resources for mitigating foodborne illnesses
- Climatology – fire prediction, ecological observatory design
- Risk management, environmental liability issues for commercial industry

The evolution is happening!

Tight budgets – need to focus on better solutions, need some optimization

Radiation Projects

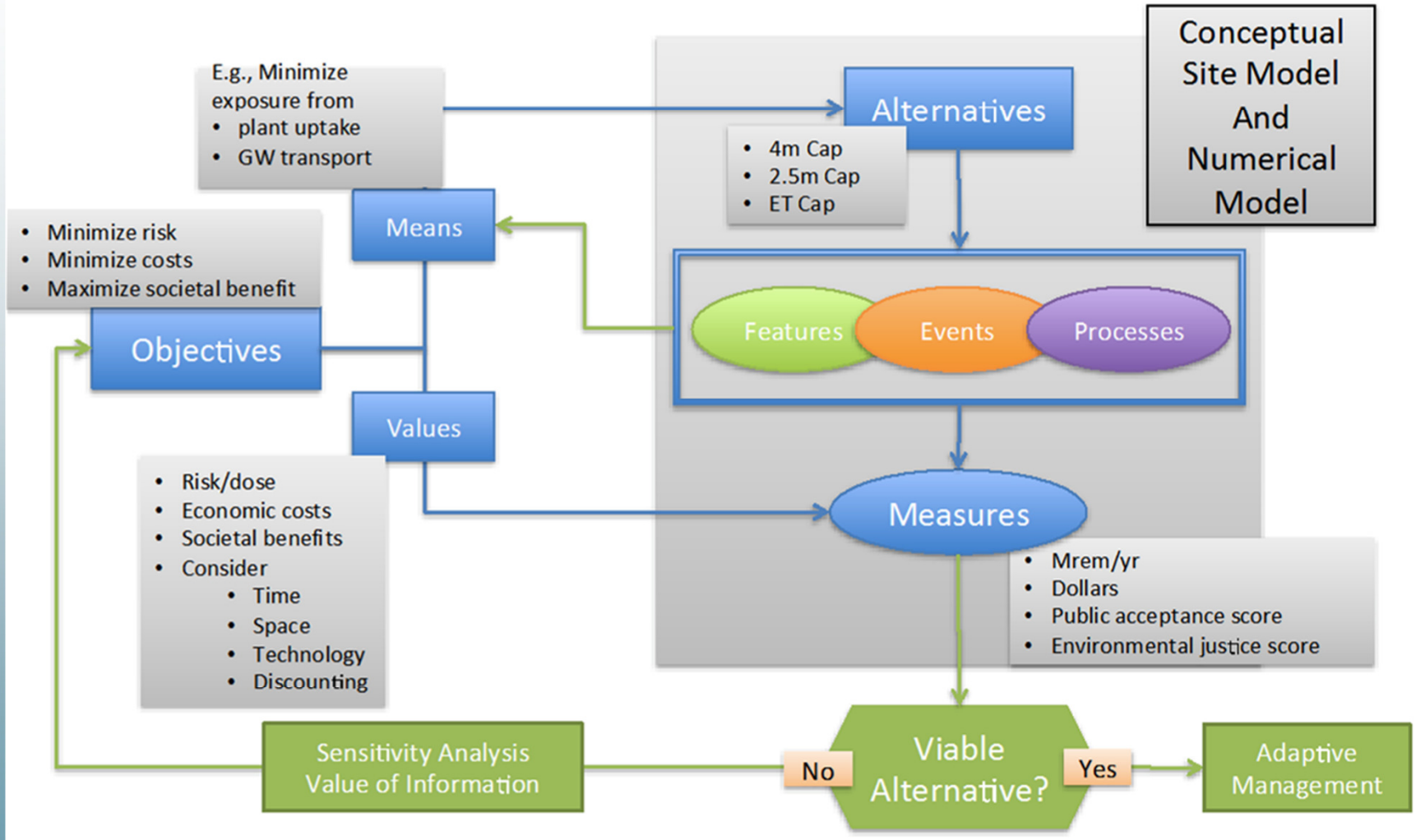
- NTS (NNSS) Areas 3 and 5 Radioactive Waste Management Sites – optimized disposal and closure
- Energy*Solutions*, Clive, Utah – optimizing disposal and closure
- Waste Control Specialists, West Texas – optimizing disposal
- LANL – options analysis for RH TRU
- NTS (NNSS) – options analysis for Smoky Site
  - Saved $200M, still protective, defensible, transparent

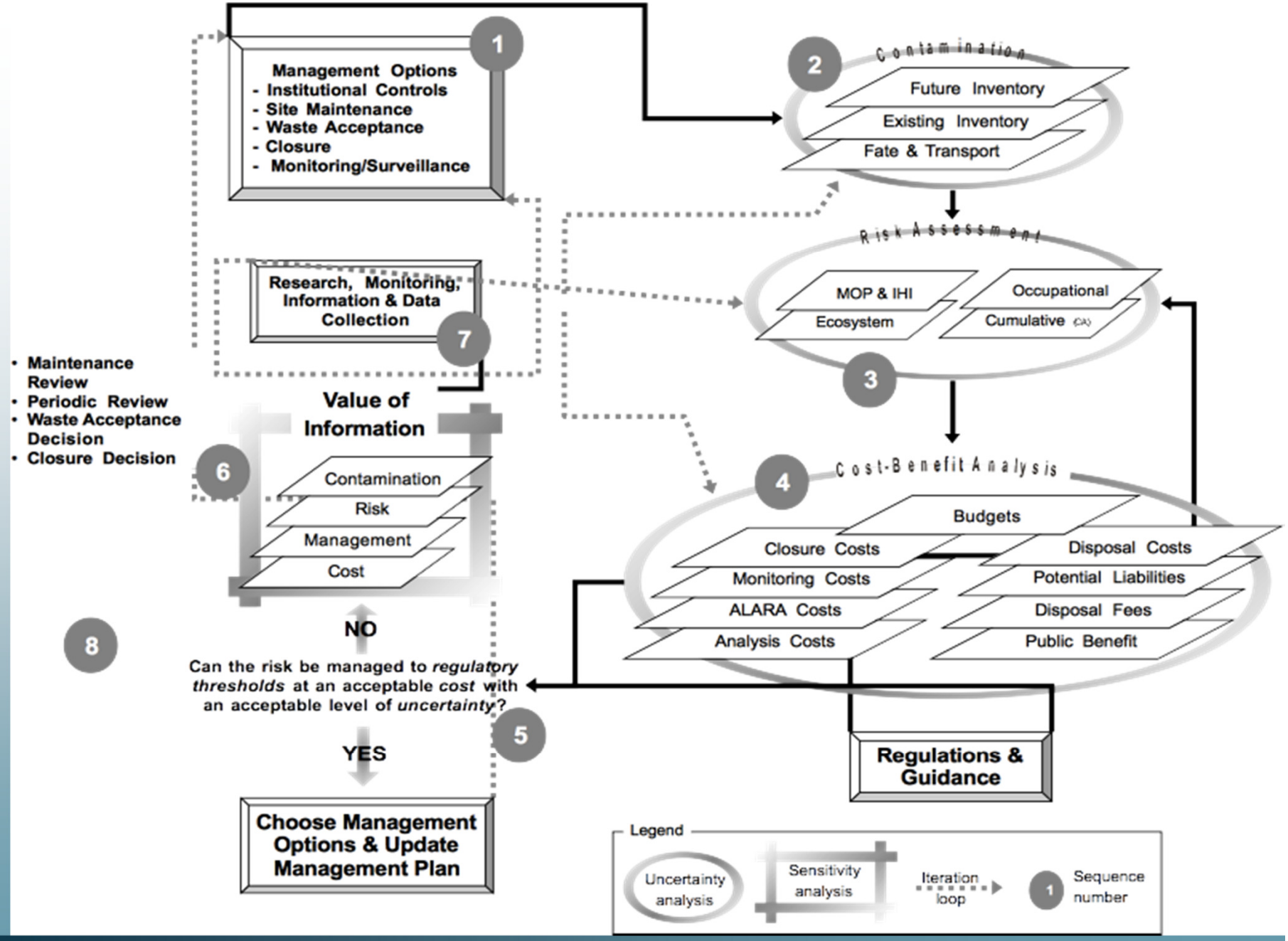
ALARA/DA precedents?

- Application of population risk using cost measures
- Initially $1,000 per person rem with no discounting (NUREG/BR 0058, Rev 2, 1995)
- "Upgraded" to a distribution from $1,000 - $6,000 per person rem per year with a 7% discount rate (NUREG 1757, 2003)
- Updated to $2,000 per person rem with discounting (NUREG/BR-0058, Rev 4, 2004)

Implies need for Population Risk Assessment

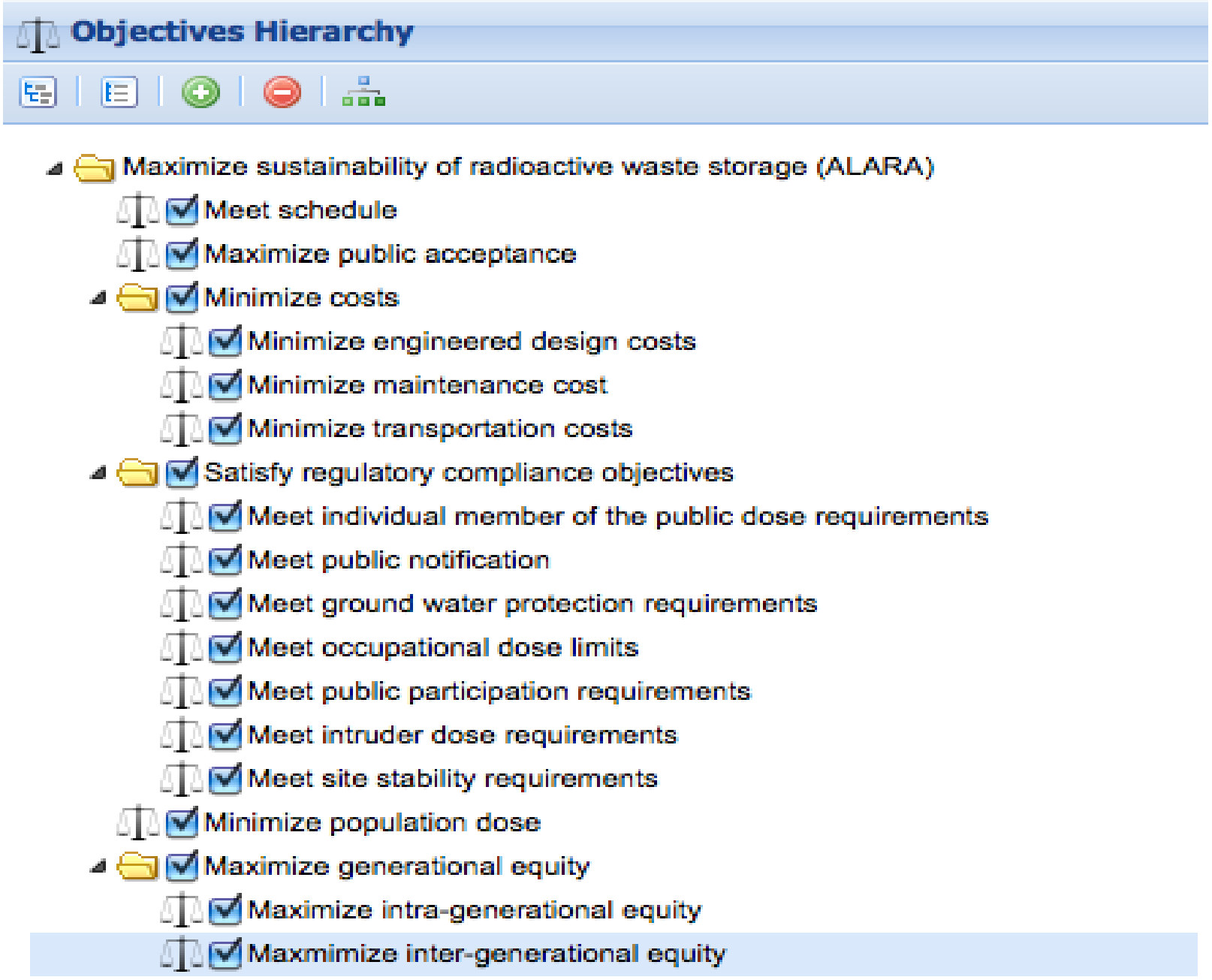
PA as a Structured Decision Analysis Process



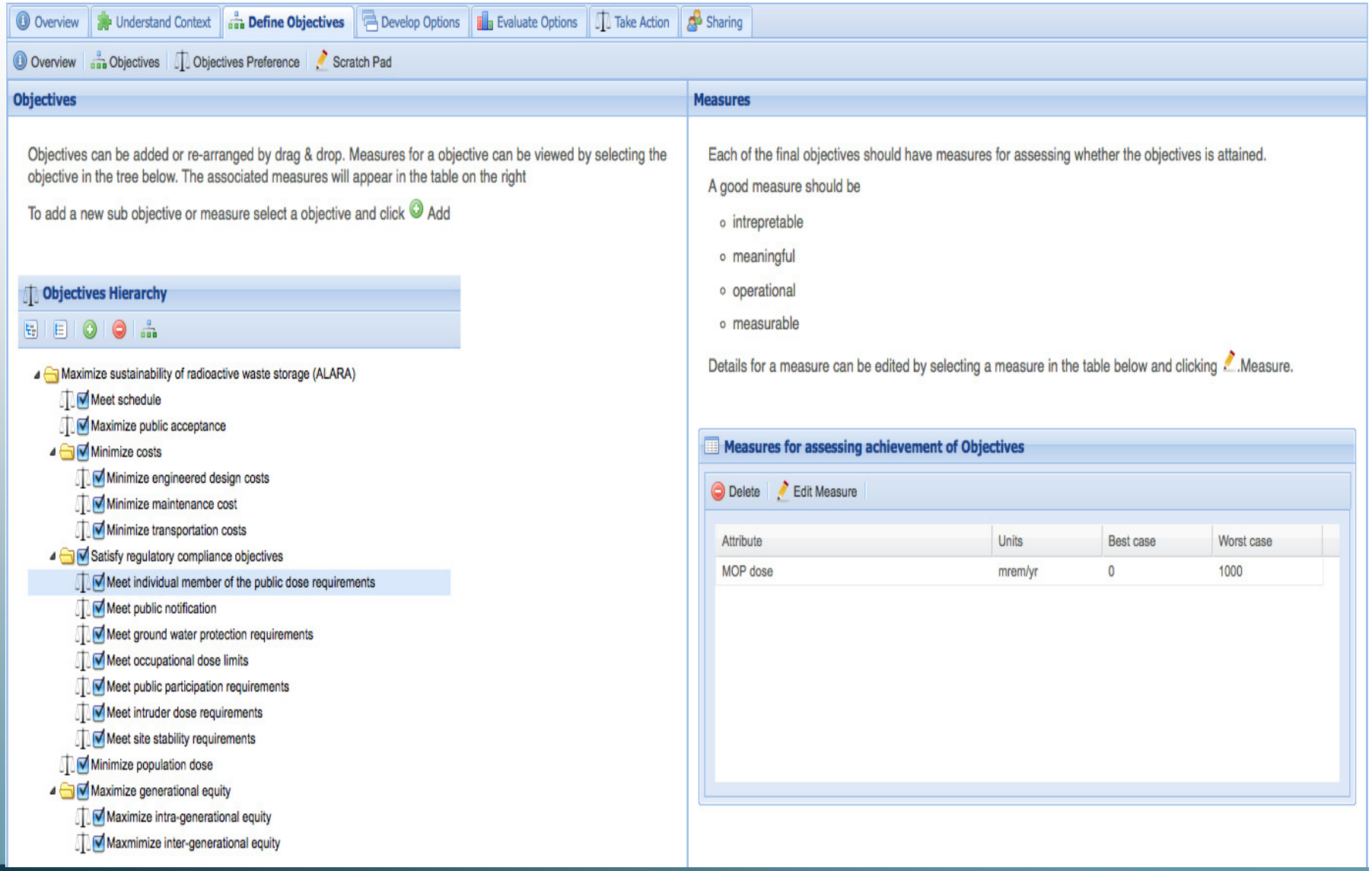

1
Management Options
- Institutional Controls
- Site Maintenance
- Waste Acceptance
- Closure
- Monitoring/Surveillance
2
Contamination
Future Inventory
Existing Inventory
Fate & Transport
Risk Assessment
MOP & IHI
Ecosystem
Occupational
Cumulative (CA)
3
4
Cost-Benefit Analysis
Budgets
Closure Costs
Monitoring Costs
ALARA Costs
Analysis Costs
Disposal Costs
Potential Liabilities
Disposal Fees
Public Benefit
Regulations & Guidance
5
Can the risk be managed to regulatory thresholds at an acceptable cost with an acceptable level of uncertainty?
NO
YES
6
Value of Information
Contamination
Risk
Management
Cost
7
Research, Monitoring, Information & Data Collection
8
• Maintenance Review
• Periodic Review
• Waste Acceptance Decision
• Closure Decision
Choose Management Options & Update Management Plan
Legend
Uncertainty analysis
Sensitivity analysis
Iteration loop
1
Sequence number

Economic or Cost-Benefit Issues

- Market and non-market costs and benefits
  - Market – Engineering costs
  - Non-market – Risk reduction
- Decision management options
  - Engineering options
  - Storage and retrievability
  - Trust funds – e.g., for generational re-evaluation (changes in society/technology), facility maintenance
  - Insurance – disasters, problems
- Additional considerations
  - Discounting
  - Generational equity issues
  - Population risk/dose


Objectives Hierarchy
Maximize sustainability of radioactive waste storage (ALARA)
Meet schedule
Maximize public acceptance
Minimize costs
Minimize engineered design costs
Minimize maintenance cost
Minimize transportation costs
Satisfy regulatory compliance objectives
Meet individual member of the public dose requirements
Meet public notification
Meet ground water protection requirements
Meet occupational dose limits
Meet public participation requirements
Meet intruder dose requirements
Meet site stability requirements
Minimize population dose
Maximize generational equity
Maximize intra-generational equity
Maxmimize inter-generational equity

Measures


Overview
Understand Context
Define Objectives
Develop Options
Evaluate Options
Take Action
Sharing
Overview
Objectives
Objectives Preference
Scratch Pad
Objectives
Objectives can be added or re-arranged by drag & drop. Measures for a objective can be viewed by selecting the objective in the tree below. The associated measures will appear in the table on the right
To add a new sub objective or measure select a objective and click Add
Objectives Hierarchy
Maximize sustainability of radioactive waste storage (ALARA)
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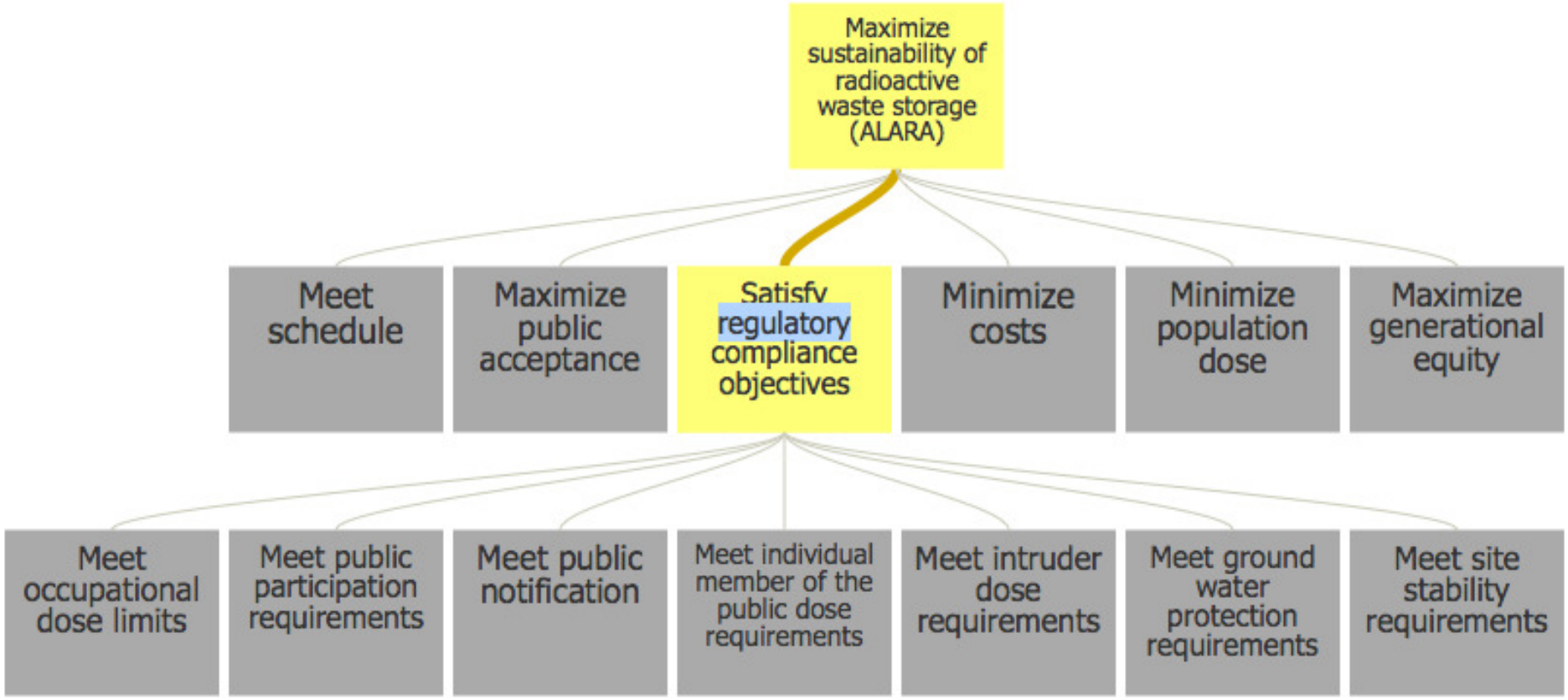
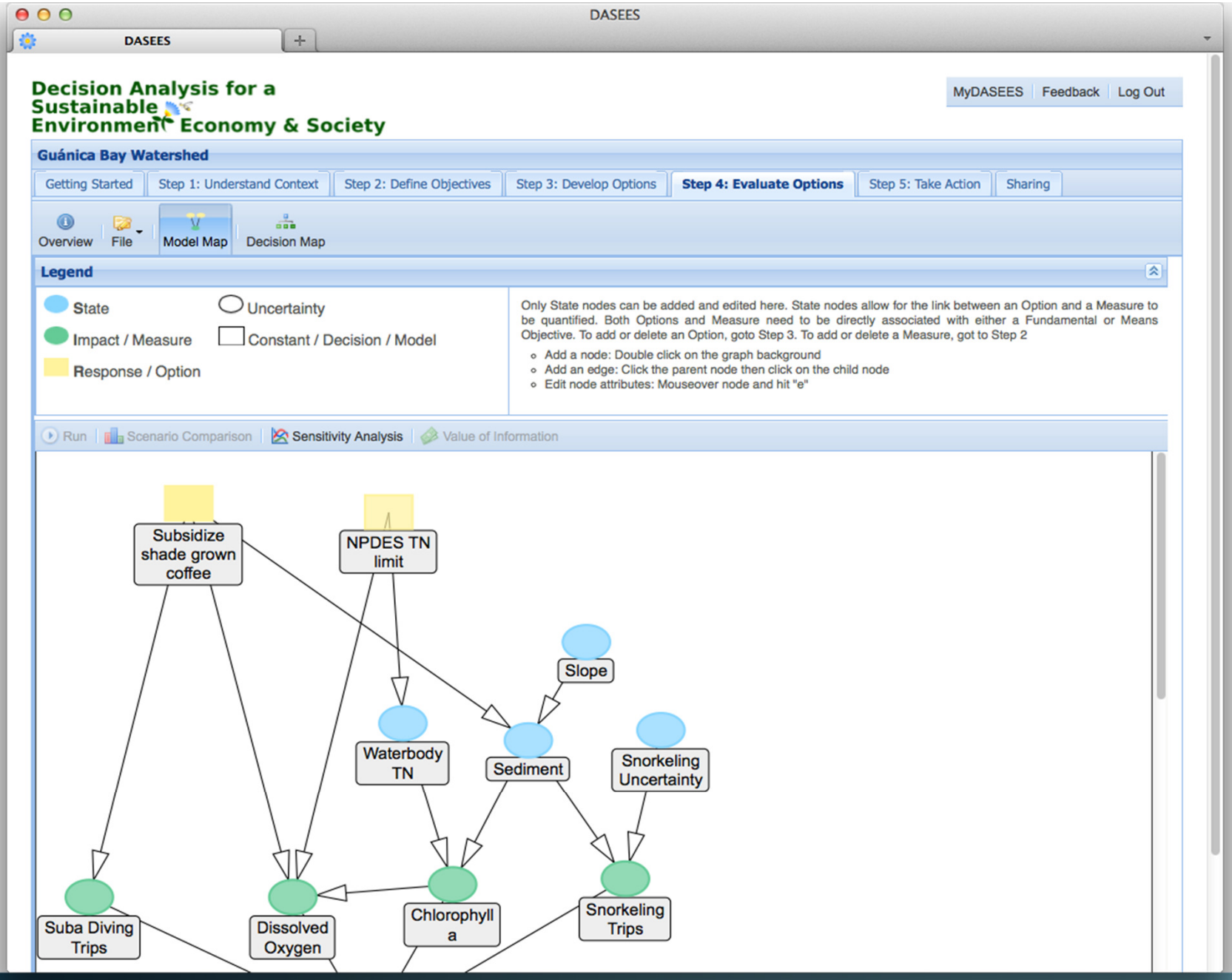
Meet site stability requirements
Minimize population dose
Maximize generational equity
Maximize intra-generational equity
Maxmimize inter-generational equity
Measures
Each of the final objectives should have measures for assessing whether the objectives is attained.
A good measure should be
intrepretable
meaningful
operational
measurable
Details for a measure can be edited by selecting a measure in the table below and clicking Measure.
Measures for assessing achievement of Objectives
Delete
Edit Measure
Attribute
Units
Best case
Worst case
MOP dose
mrem/yr
0
1000

PA "Objectives Hierarchy"




DASEES
DASEES
Decision Analysis for a Sustainable Environment Economy & Society
MyDASEES | Feedback | Log Out
Guánica Bay Watershed
Getting Started
Step 1: Understand Context
Step 2: Define Objectives
Step 3: Develop Options
Step 4: Evaluate Options
Step 5: Take Action
Sharing
Overview
File
Model Map
Decision Map
Legend
State
Uncertainty
Impact / Measure
Constant / Decision / Model
Response / Option
Only State nodes can be added and edited here. State nodes allow for the link between an Option and a Measure to be quantified. Both Options and Measure need to be directly associated with either a Fundamental or Means Objective. To add or delete an Option, goto Step 3. To add or delete a Measure, got to Step 2
Add a node: Double click on the graph background
Add an edge: Click the parent node then click on the child node
Edit node attributes: Mouseover node and hit "e"
Run
Scenario Comparison
Sensitivity Analysis
Value of Information
Subsidize shade grown coffee
NPDES TN limit
Slope
Waterbody TN
Sediment
Snorkeling Uncertainty
Suba Diving Trips
Dissolved Oxygen
Chlorophyll a
Snorkeling Trips

Other considerations for PA DA

- Discounting
  - Temporal
  - Social
  - Spatial
  - Technological
- Value of Future Generations
- Compliance Period implies no discount rate for the duration, and then a value of 0 thereafter
  - This is a discount function, rather than a simple rate
  - Current generation bears the full cost (pay now to protect future generations)
  - This approach can have unintended consequences for near-term generations.

Decision Analysis Framework

Structure:

- Understand Context
- Define Objectives
- Define Options
- Evaluate Options
  - Modeling, sensitivity analysis
- Take Action (or iterate)

Sensitivity Analysis - briefly

- Modern methods allow global sensitivity analysis on probabilistic non-linear non-monotonic models
- We use gradient boosting, but have tested various other methods
- We are working on a method using discretized Bayes nets
- See presentation at WM2015

Some research needs

- Effective probabilistic modeling
  - Input distributions – scaling – correlation (otherwise GIGO)
  - Effect of simulation time steps
  - Bayesian spatio-temporal modeling
  - Bayesian updating for model calibration
- Effect of computer tools on elicitation bias
- Using global sensitivity analysis directly in a value of information analysis (hence Bayes nets)
- Applying sensitivity analysis across the time frame of a dynamic model (hence Bayes nets)

Some research needs

- Model abstraction – inputs to "systems-level" models sometimes come from "process-level" models
- Merging decision analysis tools with traditional fate and transport modeling and HH and eco risk assessment tools
- Visualization of sensitivity analysis and other aspects of PA modeling

We don't need a bigger sledgehammer, we need smarter tools

DA for PA – Summary

Decision Analysis provides the appropriate paradigm for evaluating cost-benefit of alternative options

This approach is achievable with current technology for PA-related decisions, and has been implemented for other complex environmental decision problems

It can (should) be stakeholder driven

Decision models should be based on "reasonable realism" coupled with uncertainty

It is fine to make conservative decisions, but not to make important decisions based on conservative models

We need this approach to help optimize decision making for the nuclear industry

WM2015

- The intent today was to introduce decision analysis concepts
- We have examples as indicated, and will present some at WM2015 (turn abstract into concrete)
- We will also conduct an interactive panel session on Thursday afternoon at WM2015 as an initial (simplified) demonstration of how this decision analysis process works
- Watch for us at WM2015

Technical needs

- Complex projects such as PA require multi-disciplinary approaches to problem solving
- Typically PA involves modelers, scientists, engineers
- PA following a decision analysis path also needs:
  - statisticians, decision analysts, economists,
  - computer scientists,
  - elicitation experts,
  - stakeholder involvement experts
- All with a common vision!

In Summary...

Performance Assessment

can serve

Structured Decision Making

in the presence of

Values and Uncertainty.