Our Systems

• **Navigation system:**
  – locks, dams, channels

• **Reservoir system:**
  – structures and operating procedures

• **Flood risk reduction system:**
  – Structural, nonstructural, ecosystem features

• **The components of a sediment remedy and the encompassing watershed and its uses**
We need help to resolve our decision problem

• The complexity of the system
  – Intuition is an unreliable guide

• Sediment clean-up projects are “wicked problems” (Rittel and Webber, 1973)
  – no definitive formulation of the problem
  – no right or wrong solutions, only better or worse solutions
  – a broad diversity of values and opinions that are germane to defining solutions
  – no ultimate test of a solution to the problem
How to Manage the Risks

• Navigation vs. Cleanup
  – Do the sediments have to go?

• *In situ* alternatives
  – Monitored Natural Recovery (MNR)
  – Capping
  – Treatment

• *Ex situ* alternatives
  – Dredging
    • Containment
    • Treatment

• What combination of technologies is optimal?
  – Satisfy your objectives hierarchy
What are the objectives and decision criteria?

• 9 NCP criteria
  - Threshold Criteria
    • Overall protection of HH and E
    • Compliance with ARARs
  - Balancing Criteria
    • Long-term effectiveness/permanence
    • Reduction of TMV thru treatment
    • Short-term effectiveness
    • Implementability
    • Cost
  - Modifying Criteria
    • State (or support agency) acceptance
    • Community acceptance

• Other/Imbedded Criteria
  - Consistency with current uses of the waterbody
    • Recreation, navigation
  - Consistency with objectives for the waterbody
    • Restoration
  - Compatibility with other ongoing remediation or restoration activities
  - Compatibility with other activities in the watershed
  - Etc.
Optimization

- History: Operations research arose during WW II to support logistics and training schedules. Later applications within industry.
- OR aims to improve the quality of decisions about the management of limited resources:
  - How to allocate limited resources efficiently
  - Applicable to capital investments, quality of life/environment, etc.

Optimization

Operations Research, Management Science

Decision Analysis, Decision Science

- Linear/Non-Linear/Integer Programming
- Project Management (e.g., Critical Path)
- Risk Analysis
- MCDA
Simple Optimization Problem

- Inspect at least 250 points per day
- Two grades of inspectors, A and B
- 7 grade A and 15 grade B inspectors are available
- Inspector A can check 25 points and B can check 18 points per day
- Wage of Grade A is $80 and $60 for Grade B per day
- What is optimal assignment of inspectors?
Transporting Dredged Material to a Landfill

- You want to determine how much sediment to go from each dredging site to each landfill in order to minimize the total cost
  - Cost can include not only $, but also other non-monetary impacts
- Can consider multi-period planning
OR Success Stories

• FAA Ground-Delay Program
  – To reduce congestion and improve flow of air traffic into airports
    • Determine which aircraft/ how long to delay departures
    • Between 1998 and 2000, 90,000 hours of schedule delays were avoided at a cost savings of more than $150 million

• NYC
  – To improve the deployment of street cleaner, garbage trucks, and inspectors
    • Productivity increased 17%

• GM
  – To identify the optimal way to ship 300 types of components to 30 assembly plants.
    • Cut cost by 26%, saving $2.9 million a year
Multi-Objective Optimization

• Problem: Allocating remedial approaches across a spatially diverse site
  – Site divided into three areas
  – 3 remedial technologies available
  – What is the optimal allocation?

• Objectives:
  – Minimize Cost
  – Minimize incidental harm/risks
  – Minimize time to achieve acceptable risk reduction

• Constraint
  – Each area can use only one of the 3 options
  – Only remedial option 1 or 2 are applicable to Area 1
  – Only remedial option 2 or 3 are applicable to Area 3
  – The total suspended concentration from two adjacent areas must be less than 8
# Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Option 1</td>
<td>Option 2</td>
<td>Option 3</td>
</tr>
<tr>
<td>Cost per cubic yard</td>
<td>10</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Risk reduction time (mos.)</td>
<td>60</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>Incidental harm/risk</td>
<td>13</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Suspended conc.</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
## Results

<table>
<thead>
<tr>
<th>Optimal Decision &amp; Performance</th>
<th>Objective</th>
<th>When minimize</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cost</td>
</tr>
<tr>
<td>Optimal technique</td>
<td></td>
<td>Area 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Area 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Area 3</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk Reduction Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incidental Harm/Risk</td>
</tr>
</tbody>
</table>
• Optimal solution depends on the relative importance of each objective
  – E.g., Two extreme points are \((W_{\text{cost}}, W_{\text{risk}})=(1,0)\) or \((W_{\text{cost}}, W_{\text{risk}})=(0,1)\)
  – With multiple objectives, can use \(Z = W_i * f(i) + W_j * f(j) + \ldots + W_t * f(t)\)
    where \(f(i)\) is a function of various objectives
Multi-Criteria Decision Analysis

• An approach for structuring and analyzing decision problems

• Emphasis given to:
  – Defining the problem
  – Establishing explicit objectives
  – Defining metrics for evaluating alternative solutions/plans
  – Incorporating human values and risk attitudes
    • Through weighting and utility functions
  – Ranking plans based on quantitative scores derived from metrics
    • Using multi-attribute utility theory
## Data Matrix

<table>
<thead>
<tr>
<th>Metric (Weight)</th>
<th>Units</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
<th>Option 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (25)</td>
<td>Dollars</td>
<td>27,000</td>
<td>45,000</td>
<td>30,000</td>
<td>35,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Resale Value After Three Years (5)</td>
<td>% of Original Value</td>
<td>44</td>
<td>56</td>
<td>57</td>
<td>49</td>
<td>33</td>
</tr>
<tr>
<td>Repair/Maintenance Cost Per Year (5)</td>
<td>Dollars</td>
<td>100</td>
<td>500</td>
<td>1,000</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>Fuel Efficiency (15)</td>
<td>MPG</td>
<td>30</td>
<td>25</td>
<td>45</td>
<td>27</td>
<td>32</td>
</tr>
<tr>
<td>Passenger Compartment Space (15)</td>
<td>ft³</td>
<td>150</td>
<td>170</td>
<td>165</td>
<td>160</td>
<td>145</td>
</tr>
<tr>
<td>Style and Comfort (5)</td>
<td>Qualitative</td>
<td>Finest</td>
<td>Finest</td>
<td>Average</td>
<td>Average</td>
<td>Poor</td>
</tr>
<tr>
<td>Safety Rating (30)</td>
<td>NHTSA Safety Rating</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>
Ranking and Contributions by Metric
Ranking Sensitivity to Weight Allocation

Cost: 25 to 30  Safety: 30 to 25

Option 3
Option 4
Option 5
Option 2
Option 1

Fuel Efficiency  Cost  Passenger Compartment Space  Safety Rating  Resale Value After Three Years  Style and Comfort  Repair/Maintenance Cost Per Yr
LaCPR Objectives and Metrics

**Planning Objectives**
- Reduce risk to public safety from catastrophic storm inundation
- Reduce damages from catastrophic storm inundation
- Promote a sustainable ecosystem
- Restore and sustain diverse fish and wildlife habitats, and
- Sustain the unique heritage of coastal Louisiana by protecting historic sites and supporting traditional cultures

**Risk Metrics**
- National Economic Development
  - Residual damages
  - Life-cycle costs (Implementation, O&M)
  - Construction time
- Regional Economic Development
  - Regional Economic Development (jobs, income, regional output)
- Environmental Quality
  - Spatial integrity
  - Wetlands restored and/or protected
  - Direct impacts
  - Indirect impacts
  - Historical properties protected
  - Archeological properties protected
- Other Social Effects
  - Residual population impacted
  - Historical districts protected
LaCPR Weightings Results

Weight allocation for gov’t agencies (a) and all stakeholders (b)

(a) (b)

Environmental Objectives
National Economic Objectives
Regional Economic Objectives

Outliers
Example Plan Rankings

---

**Scenario 1**

Metric: GA-A

---

**Scenario 2**

Metric: GA-A

---

**Scenario 3**

Metric: GA-A

---

**Scenario 4**

Metric: GA-A
A Sediment Example

KEY:
- **Green**: Dredged Material
- **Blue**: Effluent
- **Yellow**: Manufactured Liner
- **Brown**: Dike Wall
- **Gray**: Cap
- **Light Green**: Standard Landfill Waste

# Criteria Levels for Each NY DM Alternative

| DM Alternatives | Cost ($/CY) | Public Acceptability | Ecological Risk | Human Health Risk | Estimated Fish COC / Risk Level |
|-----------------|-------------|-----------------------|----------------|------------------|---------------------------------
| CAD             | 5-29        | 4400                  | 23             | 680              | 18                              |
| Island CDF      | 25-35       | 980                   | 38             | 2100             | 24                              |
| Near-shore CDF  | 15-25       | 6500                  | 38             | 900              | 24                              |
| Upland CDF      | 20-25       | 6500                  | 38             | 900              | 24                              |
| Landfill        | 29-70       | 0                     | 0              | 0                | 21                              |
| No Action       | 0-5         | 0                     | 41             | 5200             | 12                              |
| Cement-Lock     | 54-75       | 0                     | 14             | 0.00002           | 25                              |
| Manufactured Soil | 54-60      | 750                   | 18             | 8.7              | 22                              |

Blue Text: Most Acceptable Value  
Red Text: Least Acceptable Value
Criteria Contributions to Decision Score

**USACE weighting**
- Cost
- Maximum Cancer Probability (Non-Barge Worker)
- Ecological Hazard Quotient
- Est. COC Conc in Fish / Risk-based Conc
- Complete Human Health Exposure Pathways
- Complete Ecological Exposure Pathways
- Ratio of Impacted Area to Facility Capacity

**EPA weighting**
- Cost
- Maximum Cancer Probability (Non-Barge Worker)
- Ecological Hazard Quotient
- Est. COC Conc in Fish / Risk-based Conc
- Complete Human Health Exposure Pathways
- Complete Ecological Exposure Pathways
- Ratio of Impacted Area to Facility Capacity
Adaptive Planning and Engineering

- Uncertainty is inherent to planning, design, construction, and O&M
- Adaptive management requires a framework for collecting and using information that results from:
  - Implementing a plan
  - Monitoring the performance of the plan
  - Learning
- The OR and MCDA provide suitable approaches
Risk Reduction Trajectories

- Risk
- Time

New information incorporated

Risk reduction goal
The Path Forward

• 3 principles relevant to transforming practice
  – Sediment remedial projects should be addressed as decision problems
  – Deliberation is essential to the successful resolution of risk-decision problems
  – Transforming practice requires commitment to change, experimentation, and learning