Science to Inform Policy:
Science Data, Analytical Tools, and Valuation

Richard Bernknopf
September 14, 2004

U.S. Department of the Interior
U.S. Geological Survey
USGS - Geographic Science Discipline

Geographic Analysis & Monitoring

Land Remote Sensing

Science Impact
The probability distributions, $d_1$ and $d_2$, of a geologic characteristic, $g_k$, for two geologic maps of different vintages and scales, $v_1$ and $v_2$, for the same area.
Problem: Where should the county locate the next landfill? Spatial distribution of cells in eastern Loudon County, VA, restricted from further consideration as a possible landfill site on the basis of existing (1963) and improved (1992) geologic map information.

What is it?
A map-based descriptive model founded on the principles of economics and decision theory

Why do we create them?
• Ability to classify spatial gradations of risk is critical to predicting the effects of and prioritizing remediation/mitigation efforts
• Enhances our ability to overcome risk communication obstacles
  • Environmental and human system complexity
  • Spatial and temporal variability
  • Conflicting definitions, priorities, and interests
Geospatial Decision Support System

Information

Assessment

Scenario

Potential

Risk

Cost

Scientific Modeling

Integrated Assessment Modeling

scientific

social

economic
The probability of environmental change is the probability of the occurrence of an event that is estimated with scientific variables.

\[ p = p(s \mid t) \times p(t) \]

- Conditional spatial probability of an environmental change
- Probability of recurrence of an environmental change
San Francisco Bay Region Earthquake Probability

Probability for one or more M6.7 or greater earthquakes from 2002 to 2031: $p(t)$
Ordered Probit Statistical Regression for Predicted Hazard Susceptibility Classes and Associated Probabilities
Geospatial Decision Support System
Apply a model for decision making under uncertainty

The mean - variance choice model for expected utility:

$$\max U = U (\mu, \sigma)$$

- $\mu$: expected value of an outcome or payoff
- $\sigma$: uncertainty or standard deviation of outcome
**Issue:** What are the regional impacts of earthquake hazard mitigation policies?

- **Study Area:** earthquake induced lateral-spread ground failure susceptibility in a coastal California community

- **Risk Assessment –**
  - Conduct a policy comparison using the GDSS
  - Test sensitivity of that assessment to changes in hazard descriptions and mitigation policies.

- **Risk Management** - compare cost effectiveness of loss avoidance alternatives
THE OCTOBER 17, 1989 LOMA PRIETA EARTHQUAKE

- Damage and business interruption estimates reached as high as $10 billion, with direct damage estimated at $6.8 billion
- Over 62 people died
- At least 3,700 people were reported injured
- Over 12,000 were displaced
- Over 18,000 homes were damaged and 963 were destroyed
What impacts do different hazard models have on mitigation?

Lateral-Spread Ground Failure Zone Classification Comparison: $[p(s \mid t)]$
What impacts do different hazard-reduction strategies have on mitigation?

Mitigation Policies

- No Mitigation Regulation
- Prioritize by Land Use
- Prioritize by Hazard Zone
<table>
<thead>
<tr>
<th>Outcome Statistics</th>
<th>Policy 1: Status Quo</th>
<th></th>
<th>Policy 2: Highest Hazard Zone</th>
<th></th>
<th>Policy 3: Residential Land Use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expert</td>
<td>Probit</td>
<td>PNN</td>
<td>Expert</td>
<td>Probit</td>
<td>PNN</td>
</tr>
<tr>
<td>Mitigation Budget (millions)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$8.65</td>
<td>$3.12</td>
<td>$8.69</td>
</tr>
<tr>
<td>Locations Mitigated</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>562</td>
<td>99</td>
<td>431</td>
</tr>
<tr>
<td>Expected Wealth ($, millions)</td>
<td>$977.30</td>
<td>$977.30</td>
<td>$976.00</td>
<td>$979.04</td>
<td>$978.81</td>
<td>$977.78</td>
</tr>
<tr>
<td>Wealth Std. Dev. ($, millions)</td>
<td>$5.84</td>
<td>$5.86</td>
<td>$7.88</td>
<td>$3.23</td>
<td>$3.53</td>
<td>$5.16</td>
</tr>
<tr>
<td>Total Expected Loss ($, millions)</td>
<td>$3.66</td>
<td>$3.65</td>
<td>$4.98</td>
<td>$1.93</td>
<td>$2.17</td>
<td>$3.20</td>
</tr>
<tr>
<td>Mean Expected Loss Per Location</td>
<td>$950</td>
<td>$948</td>
<td>$1,293</td>
<td>$588</td>
<td>$577</td>
<td>$935</td>
</tr>
<tr>
<td>Standard Deviation of Loss Per Location</td>
<td>$2,572</td>
<td>$3,318</td>
<td>$2,877</td>
<td>$934</td>
<td>$763</td>
<td>$1,532</td>
</tr>
<tr>
<td>Percent of Expected Loss Eliminated</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>47%</td>
<td>40%</td>
<td>35%</td>
</tr>
<tr>
<td>Dollars Spent Per Percent of Loss Eliminated (mil)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$0.18</td>
<td>$0.08</td>
<td>$0.25</td>
</tr>
</tbody>
</table>

Outcome statistics for three policies and three interpretations of scientific information for a regional mitigation portfolio.
The Portfolio Modeler: Comparing Scenarios

Current Scenario Set: Flood

<table>
<thead>
<tr>
<th>Name</th>
<th>Hazard</th>
<th>Mitigation Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/I Mitigate all parcels with 'fake risk' greater than 80%</td>
<td>Flood</td>
<td>Hazard Class</td>
</tr>
<tr>
<td>X/I Mitigate all sites with critical facilities</td>
<td>Flood</td>
<td>Critical Facilities</td>
</tr>
<tr>
<td>R/I Mitigate all parcels with 'fake risk' greater than 50%</td>
<td>Flood</td>
<td>Hazard Class</td>
</tr>
</tbody>
</table>

Strategies Ranked by Ancillary Benefits

% of Community Value Locations Mitigated

Strategies Ranked by Hazard Zone

Strategies Ranked by Expected Community Wealth

Budget ($, Millions)

Community Wealth ($, Billions)

Suite of Mitigation Policies

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Issues related to ecosystem valuation

Uncertainty

Scale

Regulator Risk

Consumer Preferences
Uncertainty in Mercury Offset Decisions

- Sources of Mercury (Hg) and Methyl Mercury (MeHg)
- Baseline Total Hg Loadings
- Bioavailability: transformation to MeHg
- Remediation/Mitigation Costs
- Liabilities (Transaction Costs)
- Remediation impacts on Hg loading downstream
- Others
Sources of Mercury

Mining sources
Current and historic wastes from 239 known mines, most in Coast Range (inorganic Hg & MeHg) (Alpers & Hunerlach 2000)

Riverine inputs
Contaminated waterways in Coastal and Sierra ranges continue to export inorganic Hg and MeHg to the Bay-Delta

Data Sources for Hg Modeling
--Central Valley RWQCB
--CALFED reports
Modeling Framework

Generalized Decision Objectives for Offset Participant

- **Environmental**: Meet permit loading reduction requirements and other requirements *at an acceptable level of certainty*
- **Economic**: Find “lowest cost strategy” while meeting environmental objective
- Other Criteria Important to Stakeholders

Framework

- Utilizes probabilistic, rather than deterministic, expressions to describe the relationships among variables
- Provides a conceptual framework for explicitly incorporating our uncertainties about our information in the decision-making process
- Integrates all forms of knowledge, whether expressed as a process-based description, a data-based relationship, or quantification of expert judgment
Building Blocks for Probabilistic Framework: MeHg Model

- The complexity of scientific processes in various aquatic environments has precluded defining general controls on MeHg formation in all types of ecosystems.

- Case Study: Cache Creek Watershed

- Predicting MeHg concentrations in water

\[
\text{L10TMeHg} = -0.816 + 0.450\times\text{DRY} + 0.429\times\text{L10HgT} - 0.072\times\text{L10Flow} - 0.189\times\text{L10Elevation}
\]

\[
(R^2 = 0.63; 127 \text{ samples})
\]
Building Blocks for Probabilistic Framework: Cost Model

• The USGS approach uses regression modeling as a mechanism for predicting remediation/mitigation costs to help NPDES permittees choose cost-effective offsets

• National Database (cost data on a national scale)

• Predicting the total offset remediation costs

\[ L10TC = 5.05 + 0.77\text{PoCu} - 0.62\text{CA} + 0.39\log_{10}\text{VolCY} \]

\( (R^2 = 0.76; 29 \text{ samples}) \)
USGS Cost Model Testing Output

Validation of USGS Regression Cost Model with Tetra Tech Cache Creek Cost Data

Circles: “training set” data samples used in USGS Cost Model
Triangles: “validation set” data samples from Tetra Tech Report

\[ y = 1.0392x - 0.2801 \]
\[ R^2 = 0.7807 \]

\[ y = 1.0405x - 0.2878 \]
\[ R^2 = 0.7349 \]
Communicating the Hazard Risk at Regional Scale

Finding Targets of Opportunity and Vulnerability
### Pesticides used in Hawaii for sugarcane and pineapple (after Kleveno et al., 1992)

<table>
<thead>
<tr>
<th>Common names</th>
<th>Use in Hawaii</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ametryn</td>
<td>Herbicide, 1964-present</td>
</tr>
<tr>
<td>Atrazine</td>
<td>Herbicide, 1958-present</td>
</tr>
<tr>
<td>Bromacil</td>
<td>Herbicide, 1963-present</td>
</tr>
<tr>
<td>DBCP</td>
<td>Soil fumigant, 1955-1984</td>
</tr>
<tr>
<td>Diuron</td>
<td>Herbicide, 1954-present</td>
</tr>
<tr>
<td>EDB</td>
<td>Insecticidal fumigant, 1946-1983</td>
</tr>
<tr>
<td>Fenamiphos</td>
<td>Nematicide, 1969-present</td>
</tr>
<tr>
<td>Hexazinone</td>
<td>Herbicide, 1976-present</td>
</tr>
<tr>
<td>Oxamyl</td>
<td>Insecticide/nematicide, 1969-present</td>
</tr>
<tr>
<td>Simazine</td>
<td>Herbicide, 1956-present</td>
</tr>
</tbody>
</table>
A Risk Assessment of Regional-Scale Nonpoint Source Groundwater Vulnerability

- Issue: Can it be cost-effective to concurrently support agricultural production and protect groundwater resources in the Pearl Harbor basin?
- Problem: Are there ways to reduce the economic burden on agricultural producers who use pesticides on crops which could contaminate groundwater?

- Alternative policies for groundwater protection
  - Alternative A
    - Conduct a region-wide wellhead treatment program over the productive lifetime of the resource to remove all pesticides from the groundwater before consumption
  - Alternative B
    - Target areas of vulnerability by increasing the amount of scientific information collected and decreasing the uncertainty of the components of AF and RF; areas that meet the regulatory standard do not require wellhead treatment, whereas the remaining vulnerable areas do
Soil Orders for the Pearl Harbor Basin, Island of Oahu, Hawaii
Earth science information Indices of pesticide mobility

- Retardation factor (RF) is a linear measure of mobility
- Attenuation factor (AF) is an exponential measure of pesticide leaching relative to a compliance depth

<table>
<thead>
<tr>
<th>Attenuation Factor (AF)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 and &lt; 0.0001</td>
<td>very unlikely</td>
</tr>
<tr>
<td>0.0001 and &lt; 0.01</td>
<td>unlikely</td>
</tr>
<tr>
<td>0.01 and &lt; 0.1</td>
<td>moderately likely</td>
</tr>
<tr>
<td>0.1 and &lt; 0.25</td>
<td>likely</td>
</tr>
<tr>
<td>0.25 and 1.0</td>
<td>very likely</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Retardation Factor (RF)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 1</td>
<td>very mobile</td>
</tr>
<tr>
<td>&gt; 1.0 and &lt; 2.0</td>
<td>mobile</td>
</tr>
<tr>
<td>&gt; 2.0 and &lt; 3.0</td>
<td>moderately mobile</td>
</tr>
<tr>
<td>&gt; 3.0 and &lt; 10.0</td>
<td>moderately immobile</td>
</tr>
<tr>
<td>= 10</td>
<td>very immobile</td>
</tr>
</tbody>
</table>
Groundwater vulnerability maps for the Pearl Harbor Basin, Island of Oahu, Hawaii, for the Oxamyl/ Bromocil combination based upon the AF. Decisions \( (d_f) \) to accept or reject the application of a pesticide without wellhead treatment are based on the rule: \( E(\gamma_0) \pm F(P) \cdot \sigma(\gamma_0) < \text{or} \geq R_0 \). Outlined areas are representative of active pineapple and sugar production in 1980 (Armstrong, 1983).
Cost Effectiveness of Earth Science Information (ESI) in $000,000

$250.00
$200.00
$150.00
$100.00
$50.00
$0.00
($50.00)
($100.00)

$B_{\gamma}(Q) - B_{\gamma_0}(Q)$

Coordinated Program

1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17
Demand for Environmental Safety

Economic impact of a regulation based on geospatial information. $E(L_a)$ is the marginal expected loss avoided; $K^*$ is the optimal level of safety.
Direct and Indirect Valuation Methods

Direct Methods:

Assessed Property Value and Hedonic Property Estimation
Discounted Cash Flow
Econometric Investment Equation

Indirect Methods:

Contingent Valuation
Stated Preference
The Role of Geo-Science in Natural Hazard Risk Management: Evidence from Web-based Experiments

Goals of project

• Use website as the experiment interface
• Use internet for spatial and temporal expansion of subject pool
• Use interactive web-pages to write and read databases in real time
• Use graphical interface to present detailed and complex information
Buying Better Risk Information

The map at right shows your location. The color of the cell you are in indicates the loss you will experience if a hazardous event occurs. Regardless of your location, you can buy insurance that fully covers any loss you may suffer during a period. Over the course of a period, you will be exposed to repeated random events that may, or may not, result in a hazardous loss. Information on loss amounts, the probability of loss, costs of the map and insurance, and your current status is provided below.

Your decision (Click on one)
- Buy Main Map
- Buy Insurance

Insurance costs: 50 tokens
Costs: 10 tokens

Period: Period 1
Round: Round 1

Losses by zone
- Red: 10,000
- Orange: 1,000
- Yellow: 100

You are playing
- GAME 6
- PERIOD 3
- ROUND 1

Your game balance is 500 tokens
Your total balance is 3,000 tokens

Detailed Map costs: 20 tokens
Insurance costs: 40 tokens
Probability of hazard: 1/20
Last round: a hazardous event did not occur

Last round you did not buy insurance

The large cell contains 9 smaller cells within it. If a hazard occurs in the large cell, regardless of your location, hazard will be transmitted to any smaller cell within it. If a hazard occurs in any of the smaller cells, it will be transmitted to the large cell. Regardless of your location, the same hazard may occur in any smaller cell.
Results

- Behavior is consistent with the expected utility theory.
- Information and insurance are purchased less with higher costs and both are insensitive to the other.
- The relationship between the two decisions is strong and positive.
- Subjects are aware of the benefits that arise from the more detailed geoscience information. As earnings accumulate, subjects are less likely to purchase a detailed map, but more likely to purchase insurance.
- Subjects who hold insurance outside the experiment are more likely to buy insurance.
- Risk-related information is relevant to the decision to insure against natural hazard risks.
Tahoe Decision Support System

An Analytical Tool for Land Use Planning and Public-Private Collaborative Decision Making

Supports long-term planning in the Basin, by considering plans’ environmental, social, and/or economic effects in the Lake Tahoe Basin
Tahoe Constrained Optimization Model

Focused on TRPA’s **Individual Parcel Evaluation System** (IPES) for managing new residential development in the Upper Truckee Watershed.

Asked:

- Do existing data reveal IPES’ economic and sediment effects?
- How do IPES-based policies affect sediment loading?
- What development patterns might result from different management goals?
- Does IPES affect real estate values?
TCOM Methods

• **Access database and Visual Basic application**
  - manage and reconcile the disparate data
• **Hedonic property valuation**
  - measures IPES’s impacts on property values
• **USLE-based sediment model (DRI)**
  - estimates parcels’ sediment contributions under different development statuses
• **Linear programming**
  - trades off different management priorities
• **GIS**
  - provides spatial data and maps inputs and outputs
TCOM findings: GIS

Develop 200 additional parcels to maximize property value

Develop 200 additional parcels to minimize soil loss

The maps highlight critical (sometimes problematic) model assumptions and conclusions.

Percent of available parcels:
- 81% - 100%
- 61% - 80%
- 41% - 60%
- 21% - 40%
- 1% - 20%
TDSS MGT GOAL: Tie agency decisions to environmental and economic impacts

Objectives:
- a transparent framework incorporating existing models (and expert opinion)
- easy manipulation of inputs and assumptions
... and will be built from

assumptions about climate, growth, demography, and management and regulatory decisions including regulation of land use and zoning, EIP projects fuel treatments.
Component modules

An input-output analysis will estimate the effects of environmental controls on economic activity.
Non-market valuation

This analysis of regulations’ impacts could be supplemented by an estimate of the (aesthetic and environmental) benefits those scenarios create or protect.
Why Do We Need Nonmarket Values?

*Fundamental management problem is to get the mix of environmental service flows and resource service flows that represents all types of preferences across all types of good.*

- World of scarcity
- Make choices in balancing the built environment and the natural environment
- More of one thing means less of another; tradeoffs are inevitable
- Establish what is a service flow and how they are linked to markets
- Others are not linked, markets will not account for them
- How do they differ from preferences for market goods—can’t observe them, but similar in that they vary
Contributors:
University of New Mexico, University of Pennsylvania, Stanford University, Desert Research Institute, Tahoe Regional Planning Agency, Sacramento Valley Sanitation District, California Regional Water Quality Control Board, US EPA, USFS, and numerous USGS scientists

Richard Bernknopf, email: rbern@usgs.gov, phone: 650-329-4951