Science to Inform Policy:

Science Data, Analytical Tools, and Valuation

U.S. Department of the Interior
U.S. Geological Survey

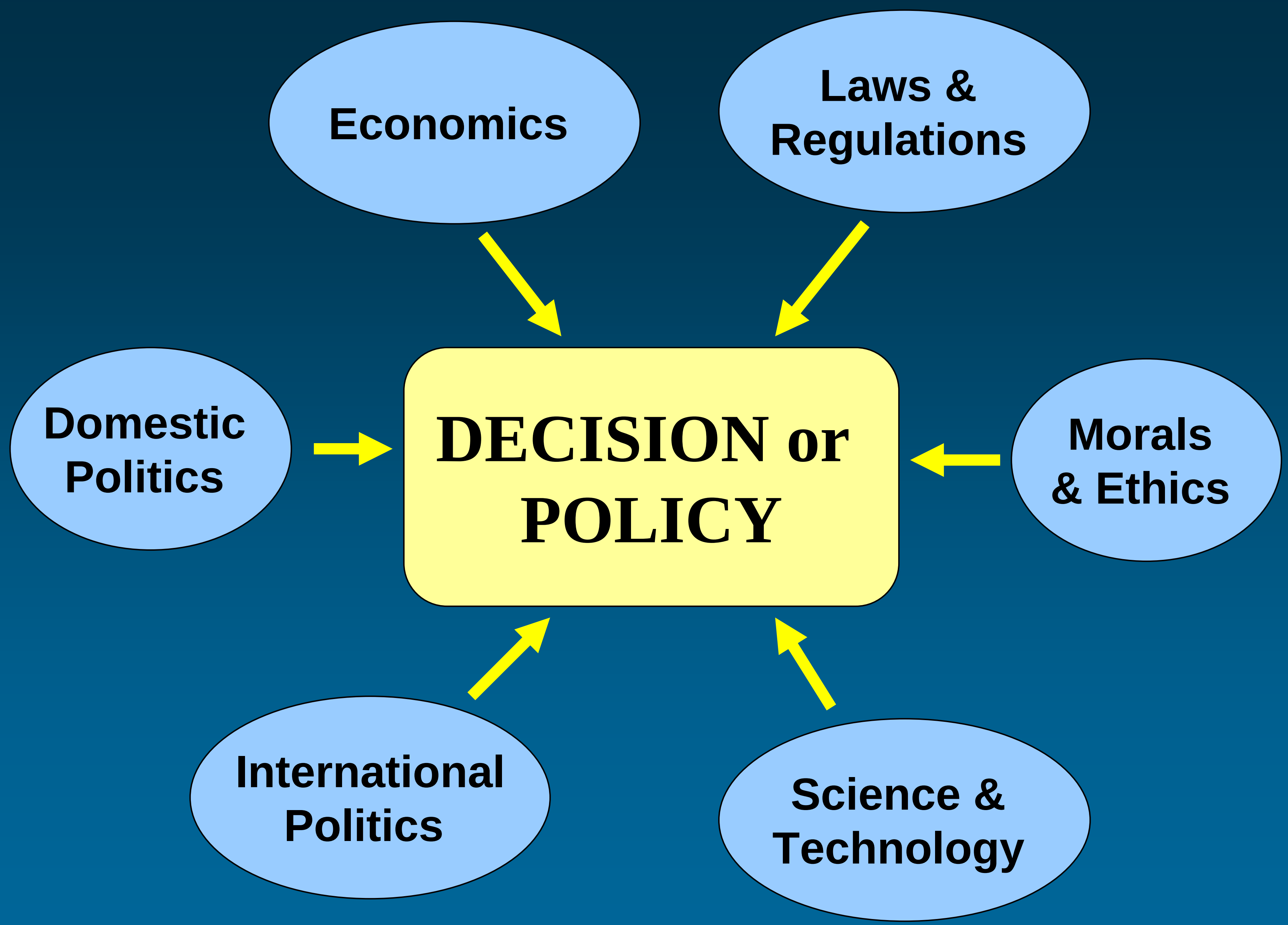
Richard Bernknopf
September 14, 2004

USGS - Geographic Science Discipline

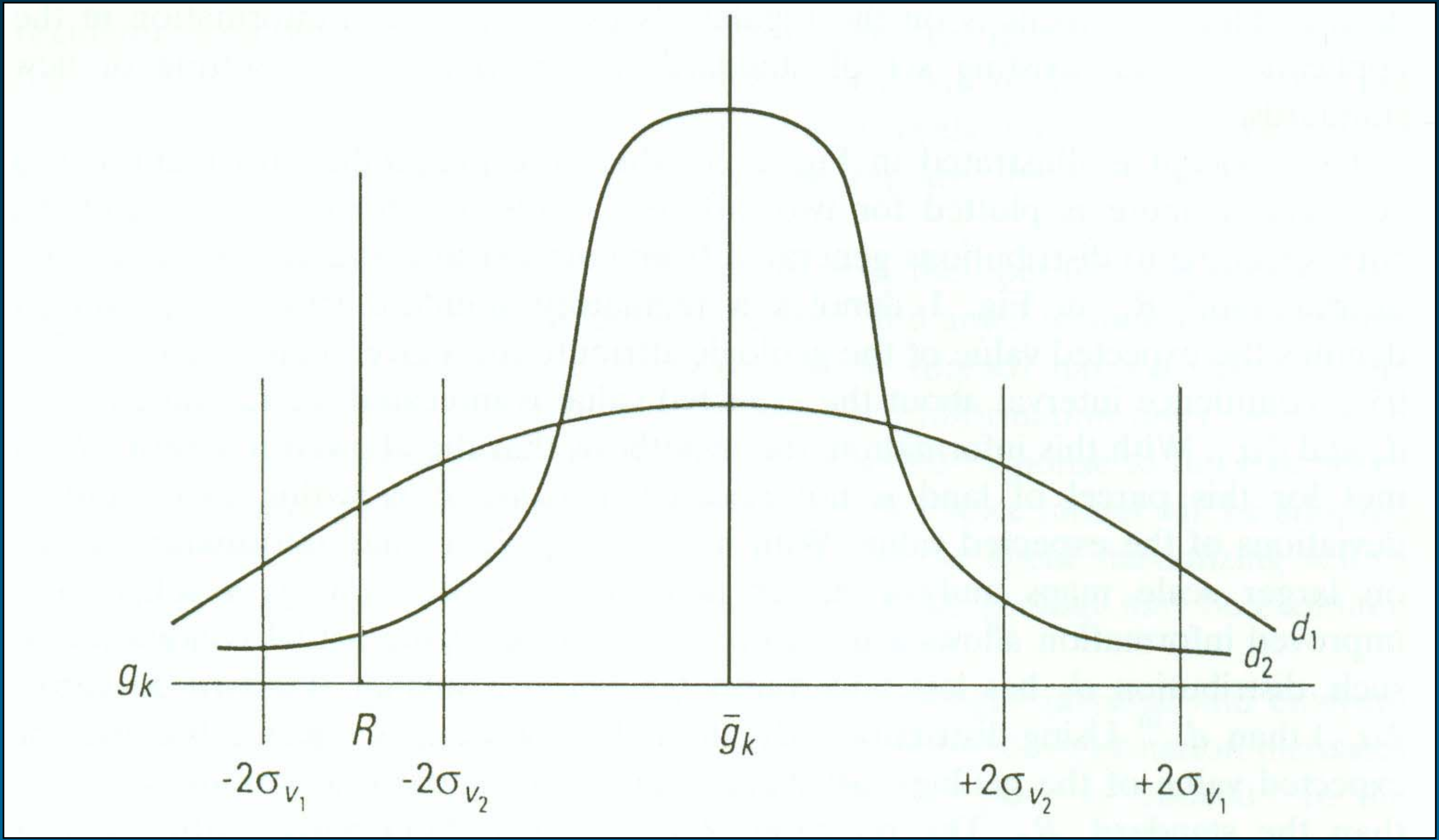
Geographic Analysis & Monitoring

Land Remote Sensing

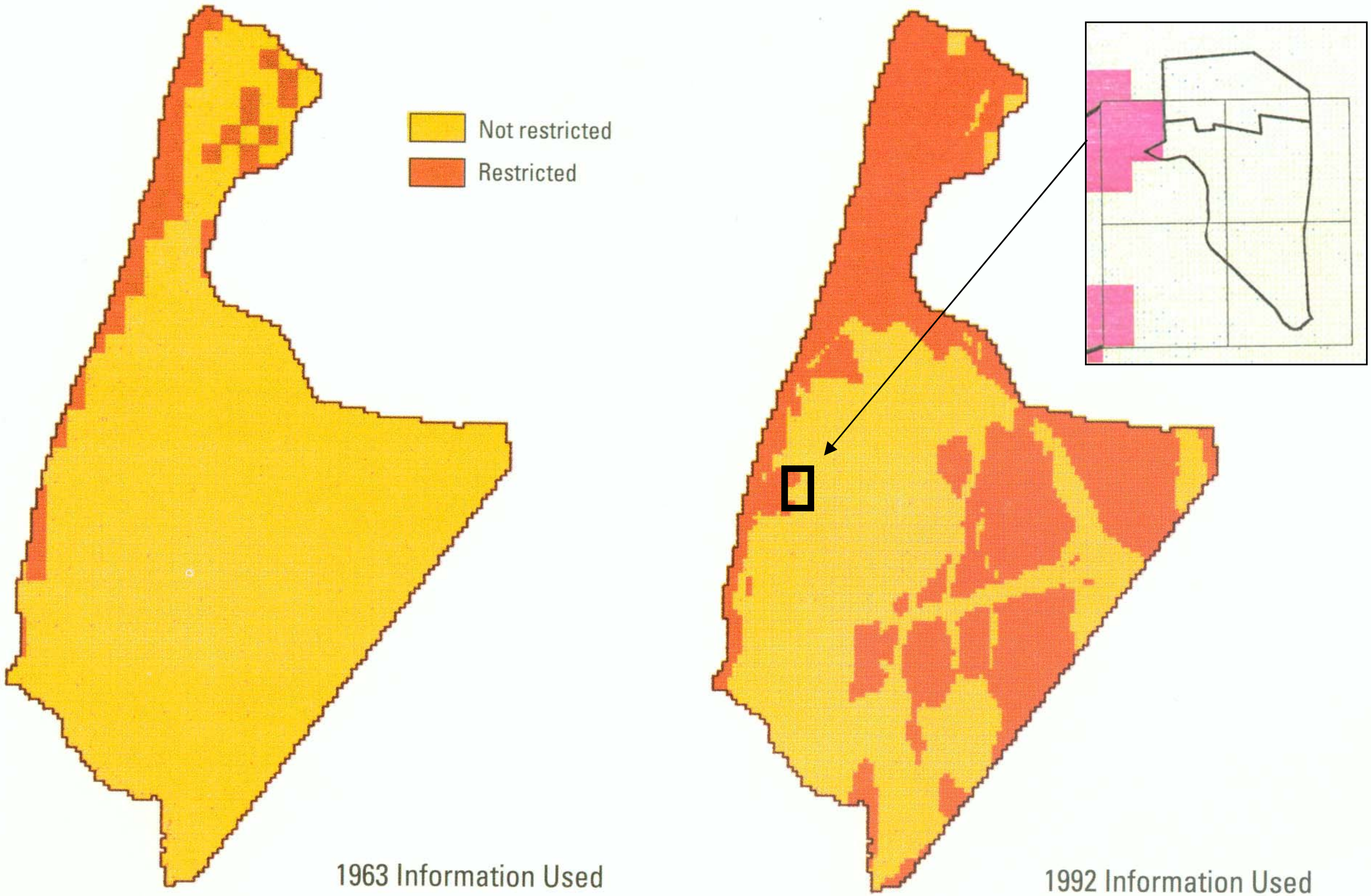
Science Impact


Economics
Laws & Regulations
Domestic Politics
DECISION or POLICY
Morals & Ethics
International Politics
Science & Technology

Value of Scientific Information



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

Framework for Decision Making: A Geospatial Decision Support System (GDSS)

What is it?

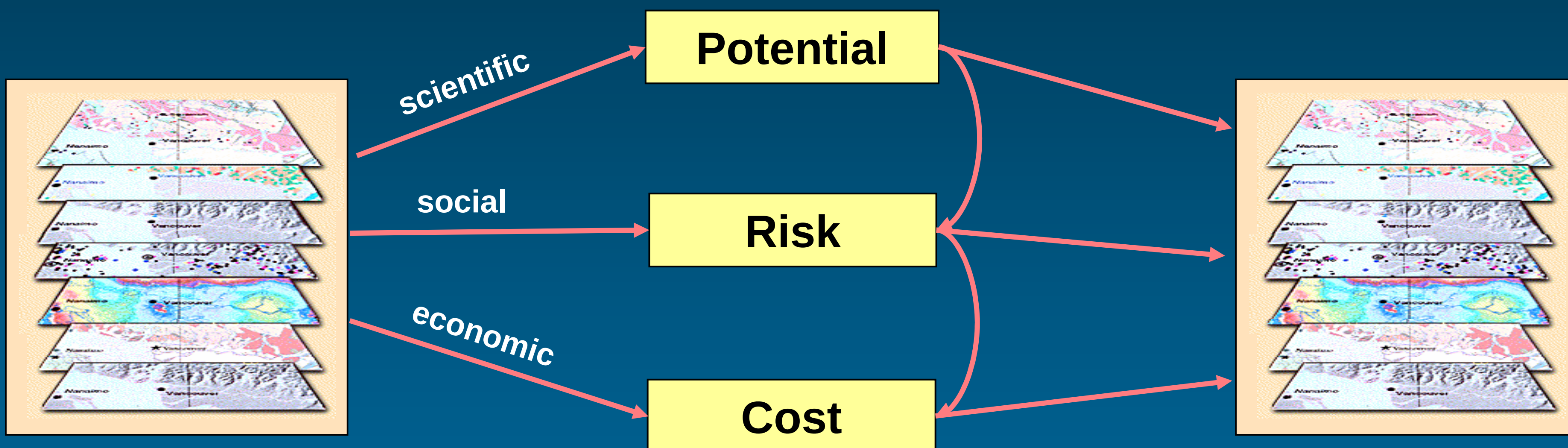
A map-based descriptive model founded on the principles of economics and decision theory

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



Scientific Modeling

Integrated Assessment Modeling

Geospatial Decision Support System

Estimate a physically based stochastic model

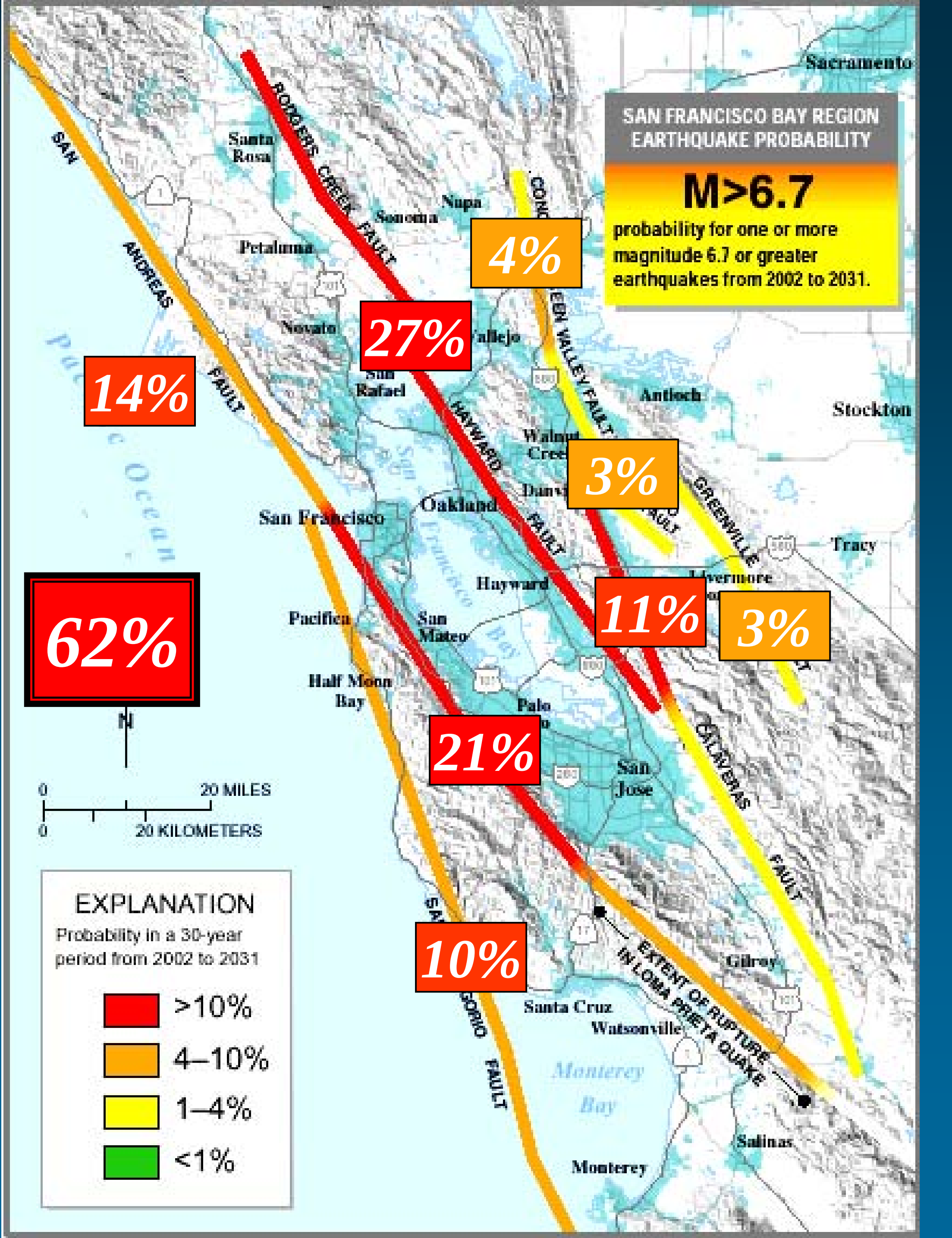
The probability of environmental change is the probability of the occurrence of an event that is estimated with scientific variables

$$p = p(s \mid t) \times p(t)$$

conditional spatial probability of an environmental change

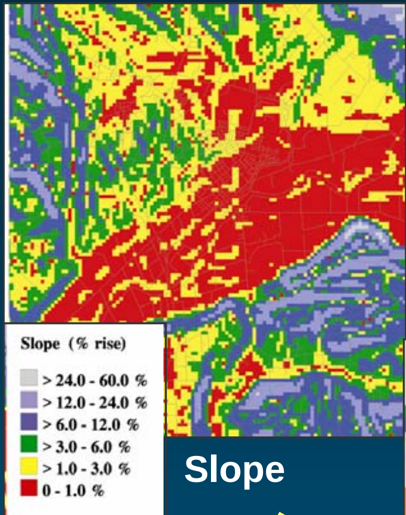
probability of recurrence of an environmental change

Hazard Identification

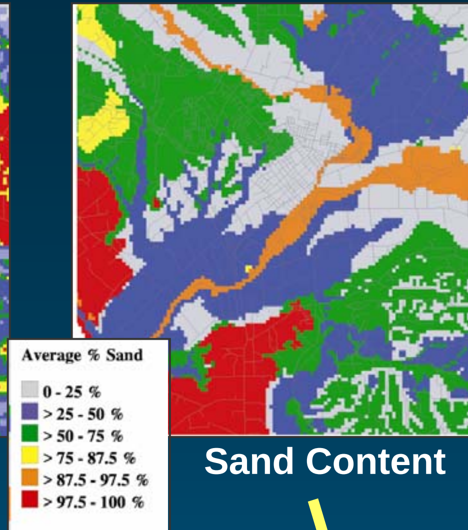


San Francisco Bay Region Earthquake Probability

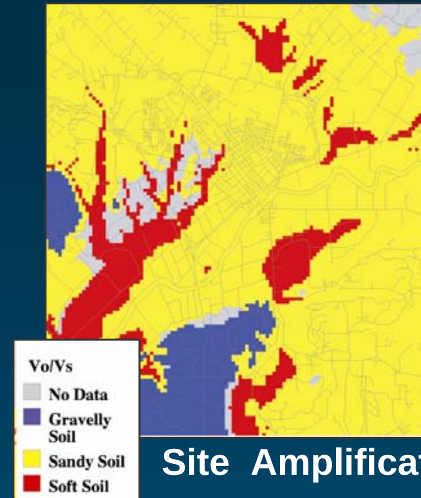
Probability for one or more M6.7 or greater earthquakes from 2002 to 2031: p(t)



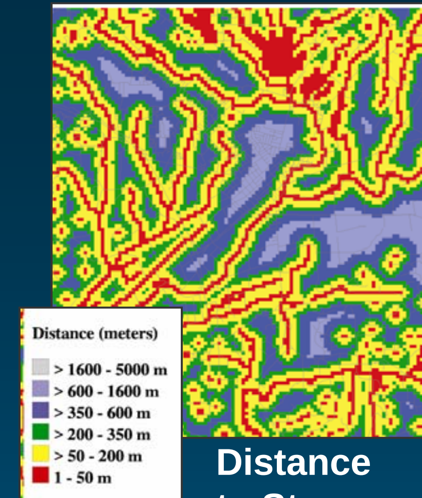
Slope



Sand Content

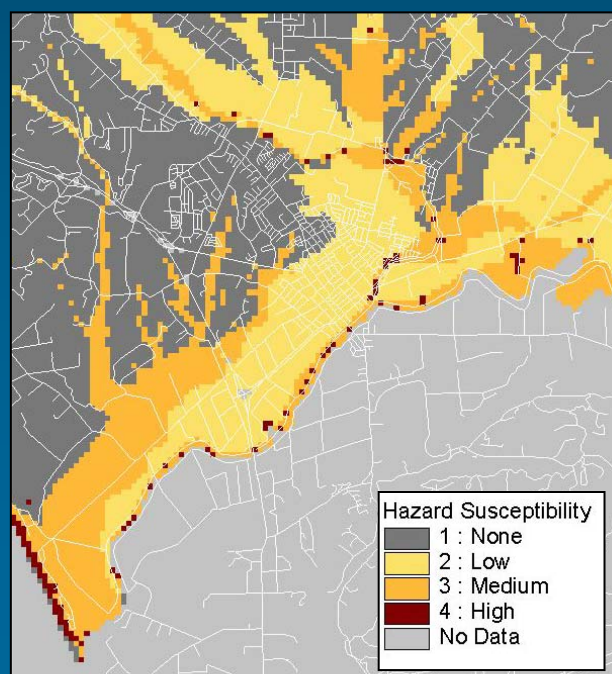


Site Amplification



Distance to Stream

Ordered Probit Statistical Regression for Predicted Hazard Susceptibility Classes and Associated Probabilities



Joint Probabilities of Experiencing Lateral-Spread

ZONE	DECIMAL	FRACTION
1	0.0	None
2	0.0018	1/555
3	0.0047	1/212
4	0.0219	1/46

Geospatial Decision Support System

Apply a model for decision making under uncertainty

The mean - variance choice model for expected utility:

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

μ : expected value of an outcome or payoff

σ : uncertainty or standard deviation of outcome

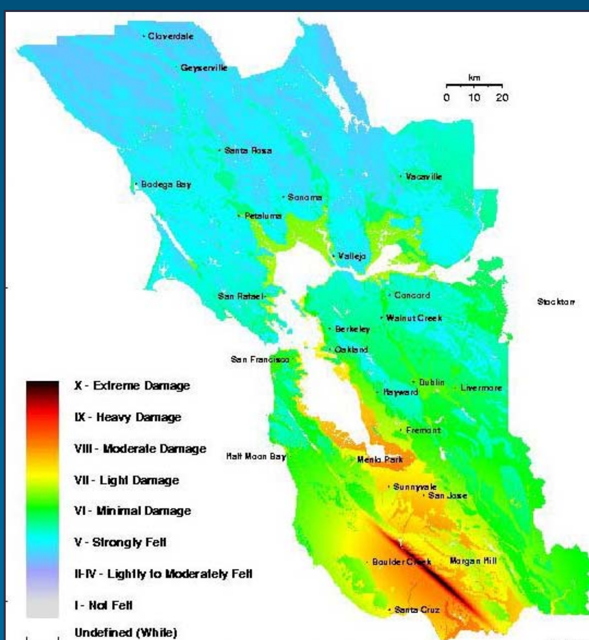
Risk Analysis

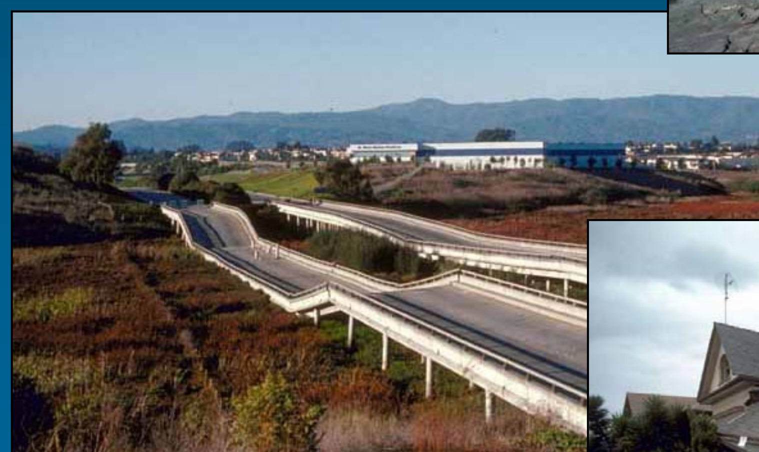
Issue: What are the regional impacts of earthquake hazard mitigation policies?

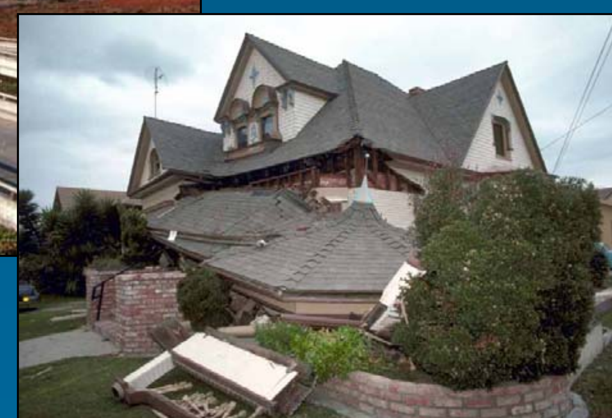
- Study Area: earthquake induced lateral-spread ground failure susceptibility in a coastal California community
- Risk Assessment –
  - Conduct a policy comparison using the GDSS
  - Test sensitivity of that assessment to changes in hazard descriptions and mitigation policies.
- Risk Management - compare 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



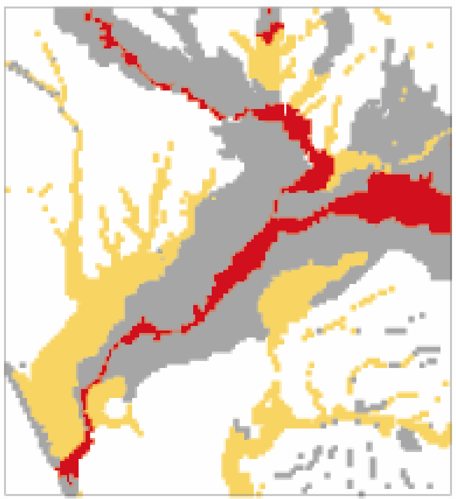




What impacts do different hazard models have on mitigation?

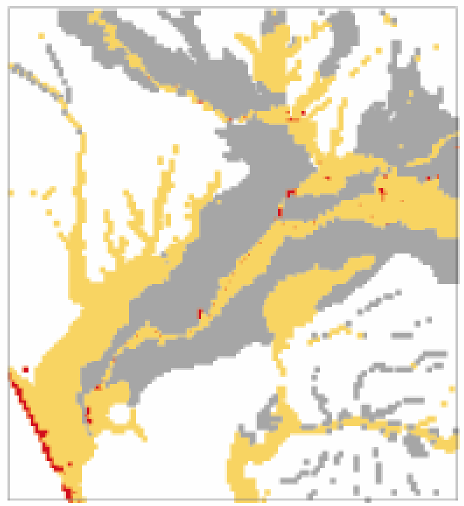
Lateral-Spread Ground Failure Zone Classification Comparison: $[p(s \mid t)]$

A. Expert Determined



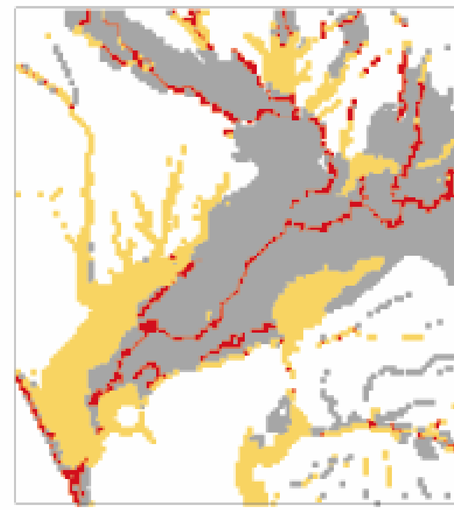
Zone	Locations	Probability
N/A	N/A	0.00
0	3,622	0.008
1	2,061	0.003
2	949	0.074

B. Ordered Probit



Zone	Locations	Probability
N/A	N/A	0.00
0	3,664	0.006
1	2,841	0.016
2	127	0.073

C. Probabilistic Neural Network

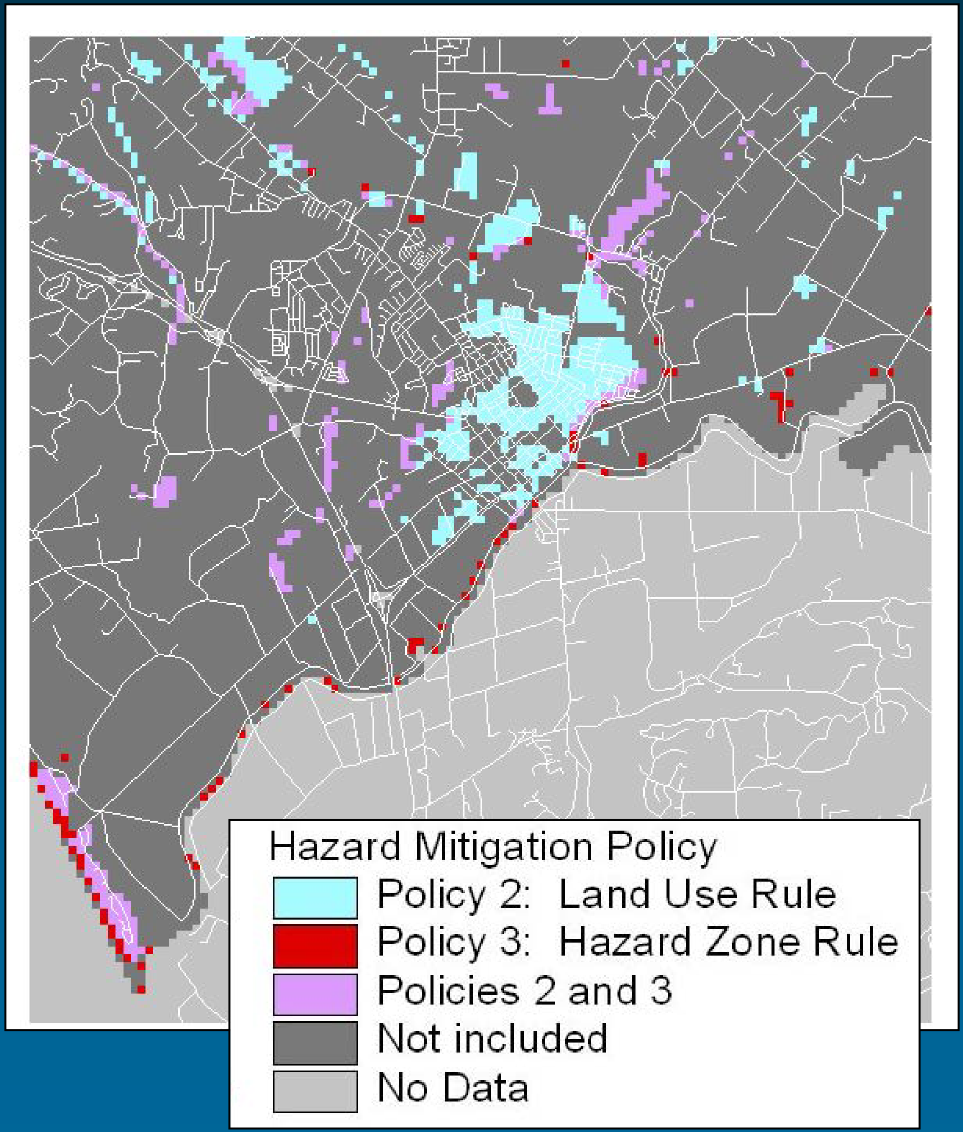


Zone	Locations	Probability
N/A	N/A	0.00
0	3,964	0.013
1	2,005	0.006
2	663	0.060

What impacts do different hazard-reduction strategies have on mitigation?

Mitigation Policies

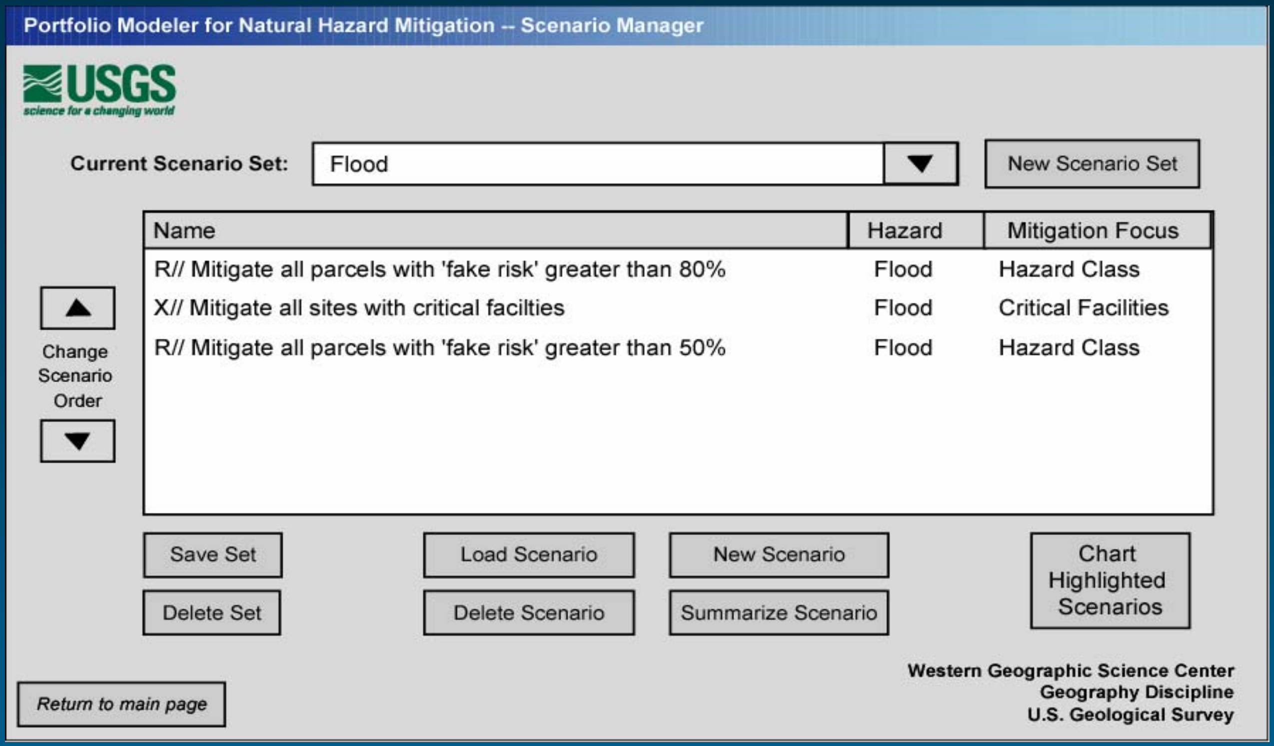
- No Mitigation Regulation
- Prioritize by Land Use
- Prioritize by Hazard Zone

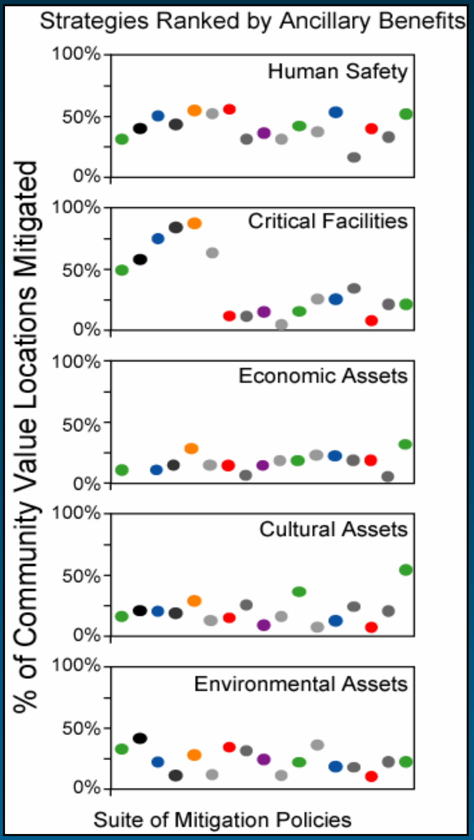


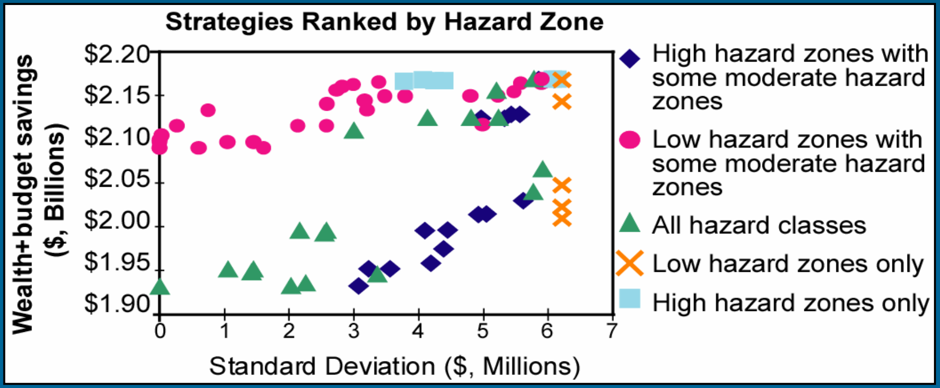
	Policy 1: Status Quo			Policy 2: Highest Hazard Zone			Policy 3: Residential Land Use		
	Expert	Probit	PNN	Expert	Probit	PNN	Expert	Probit	PNN
Mitigation Budget (millions)	0	0	0	$ 8.65	$ 3.12	$8.69	$ 55.54	$ 55.54	$ 55.54
Locations Mitigated	0	0	0	562	99	431	722	722	722
Expected Wealth ($, millions)	$977.30	$977.30	$976.00	$979.04	$978.81	$977.78	$979.30	$979.60	$978.78
Wealth Std. Dev. ($, millions)	$5.84	$5.86	$7.88	$3.23	$3.53	$5.16	$2.71	$2.28	$3.57
Total Expected Loss ($, millions)	$3.66	$3.65	$4.98	$1.93	$2.17	$3.20	$1.68	$1.38	$2.19
Mean Expected Loss Per Location	$950	$948	$1,293	$588	$577	$935	$535	$442	$701
Standard Deviation of Loss Per Location	$2,572	$3,318	$2,877	$934	$763	$1,532	$1,537	$1,256	$1,928
Percent of Expected Loss Eliminated	0	0	0	47%	40%	35%	54%	62%	55%
Dollars Spent Per Percent of Loss Eliminated (mil)	0	0	0	$ 0.18	$ 0.08	$ 0.25	$ 1.03	$ 0.90	$ 1.01

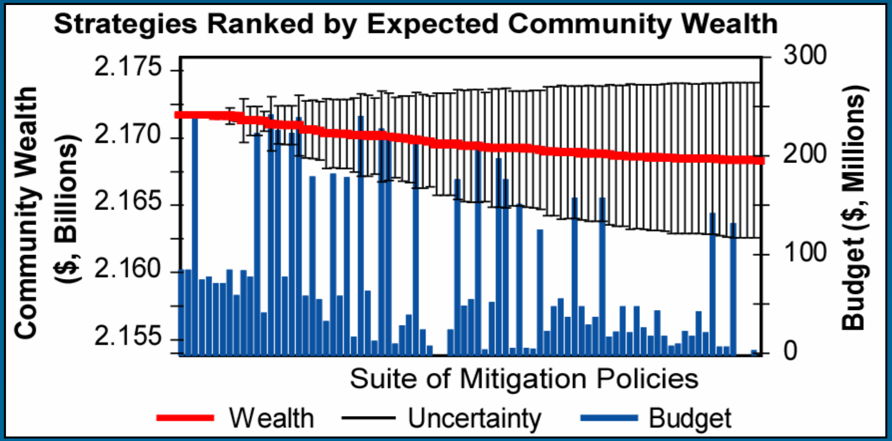
Outcome statistics for three policies and three interpretations of scientific information for a regional mitigation portfolio

The Portfolio Modeler: Comparing Scenarios









Issues related to ecosystem valuation

Uncertainty

Scale

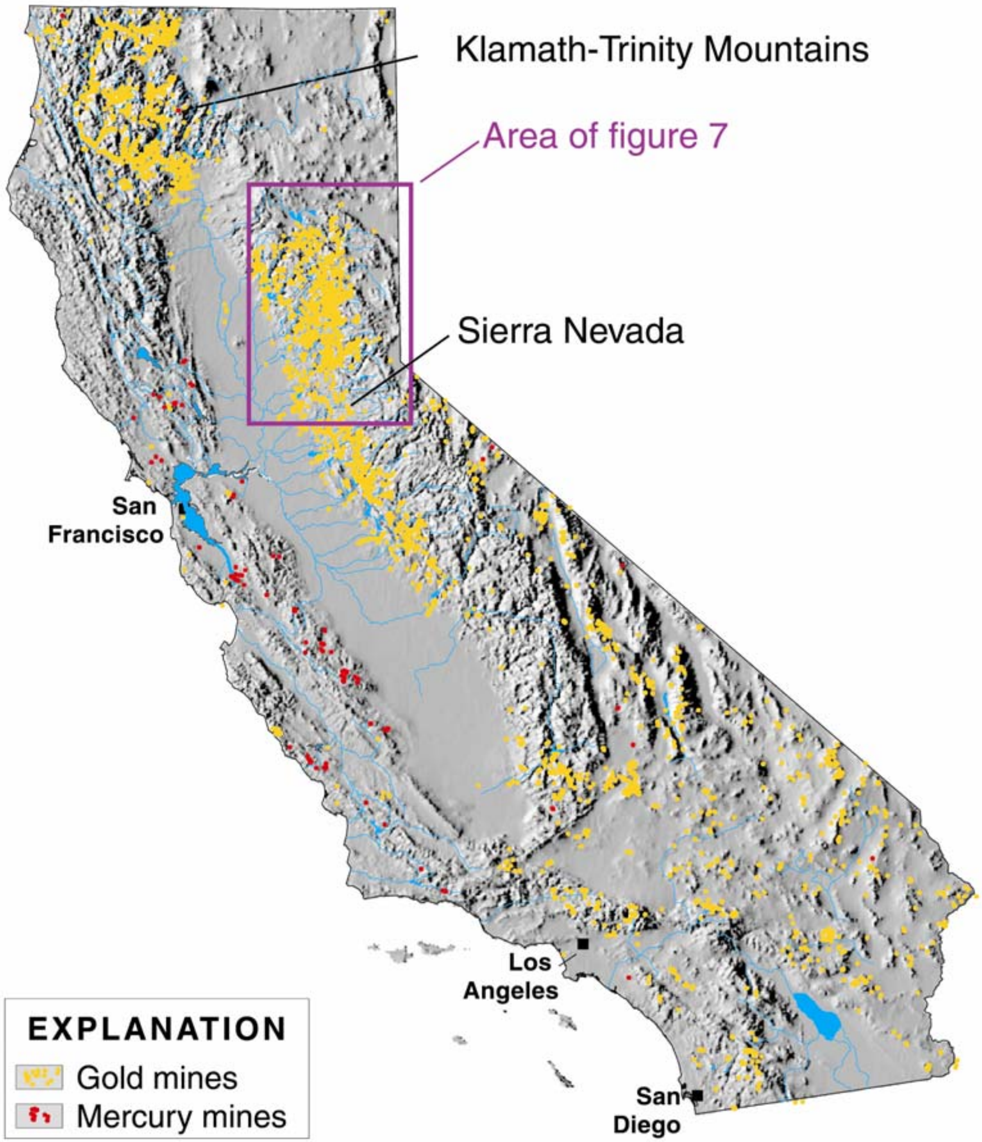
Regulator Risk

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



USGS

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

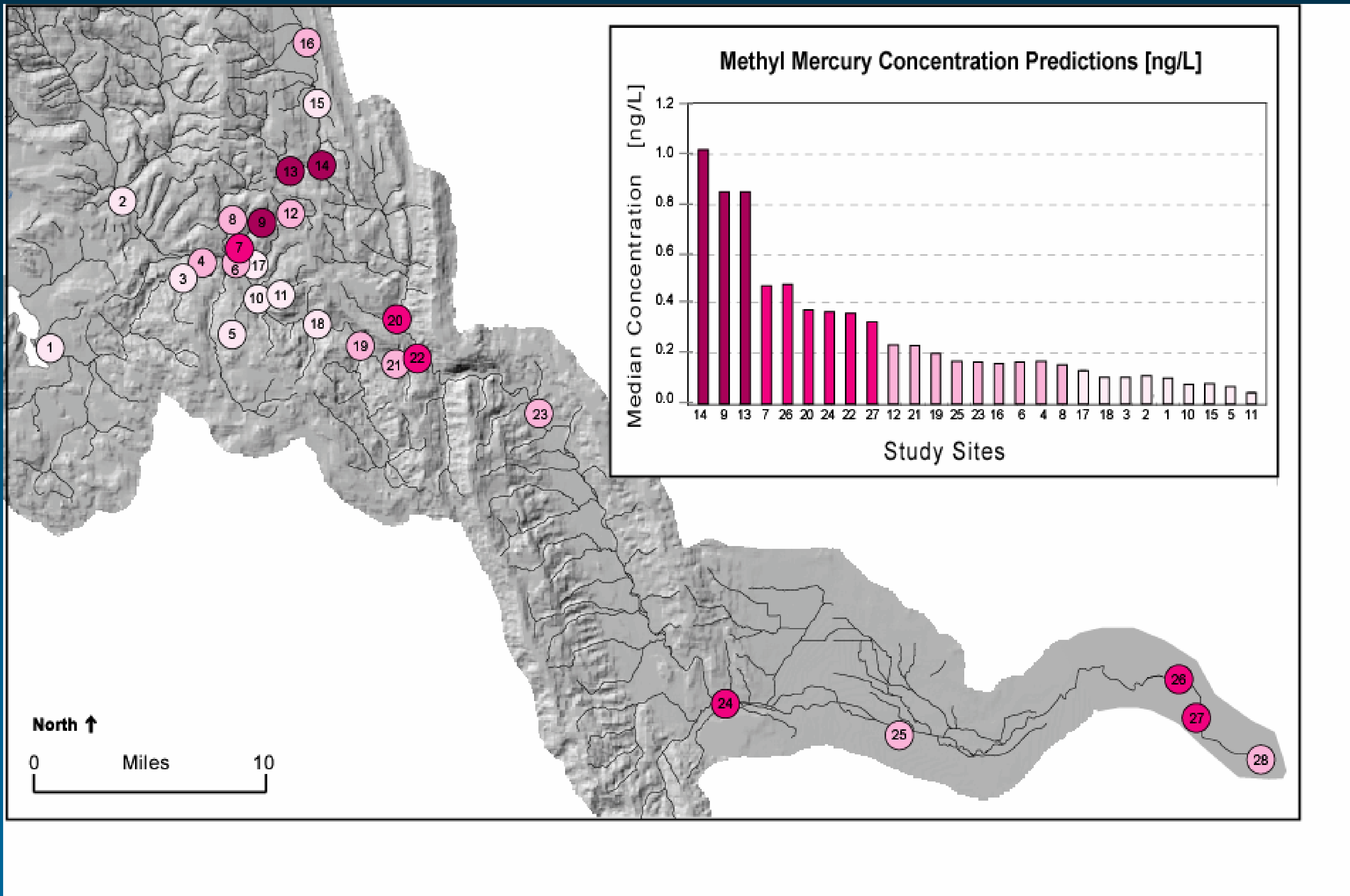
Building Blocks for Probabilistic Framework: MeHg Model

- 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

L10TMeHg = – 0.816 + 0.450*DRY + 0.429*L10HgT – 0.072*L10FLow – 0.189*L10Elevation

(R^2 = 0.63; 127 samples)

MeHg Concentration Predictions (Cache Creek Watershed)



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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)

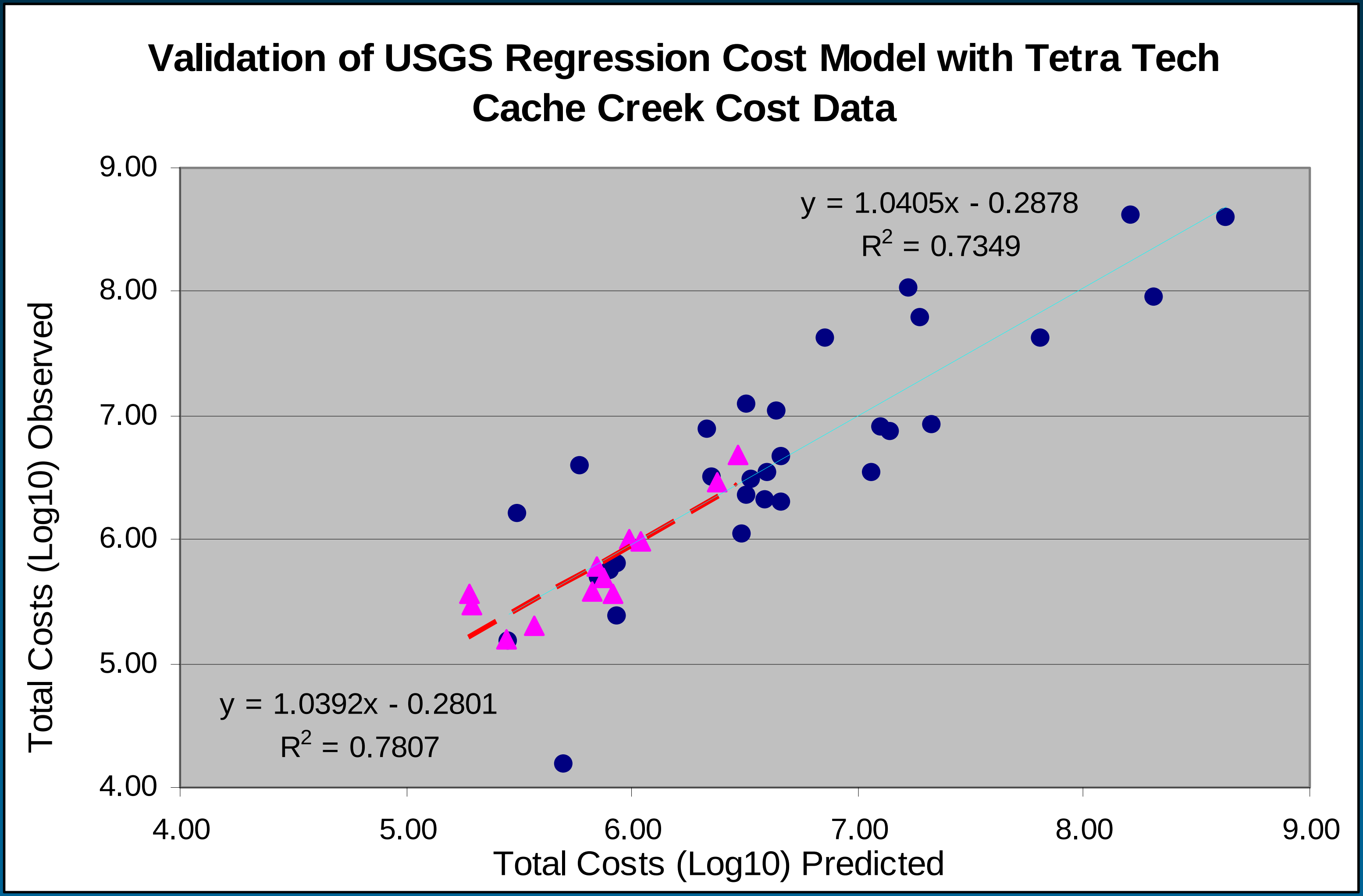
- Predicting the total offset remediation costs

$$L10TC = 5.05 + 0.77PoCu - 0.62CA + 0.39Log10VolCY$$

(R^2 = 0. 76; 29 samples)

USGS

USGS Cost Model Testing Output



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

USGS

Communicating the Hazard Risk at Regional Scale

Finding Targets of Opportunity and Vulnerability

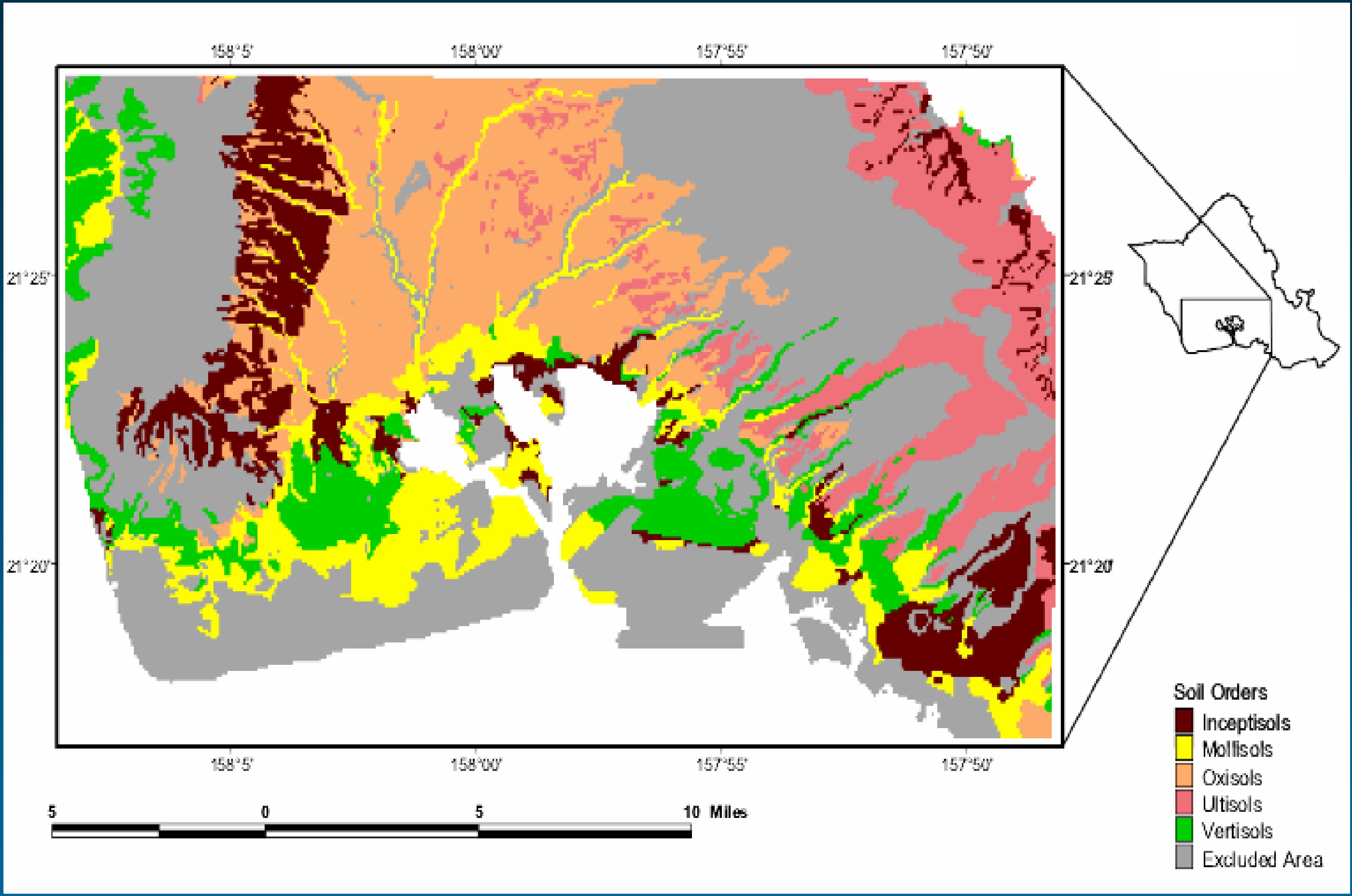
Pesticides used in Hawaii for sugarcane and pineapple (after Kleveno et al., 1992)

Common names	Use in Hawaii
Ametryn	Herbicide, 1964-present
Atrazine	Herbicide, 1958-present
Bromacil	Herbicide, 1963-present
DBCP	Soil fumigant, 1955-1984
Diuron	Herbicide, 1954-present
EDB	Insecticidal fumigant, 1946-1983
Fenamiphos	Nematicide, 1969-present
Hexazinone	Herbicide, 1976-present
Oxamyl	Insecticide/nematicide, 1969-present
Simazine	Herbicide, 1956-present

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

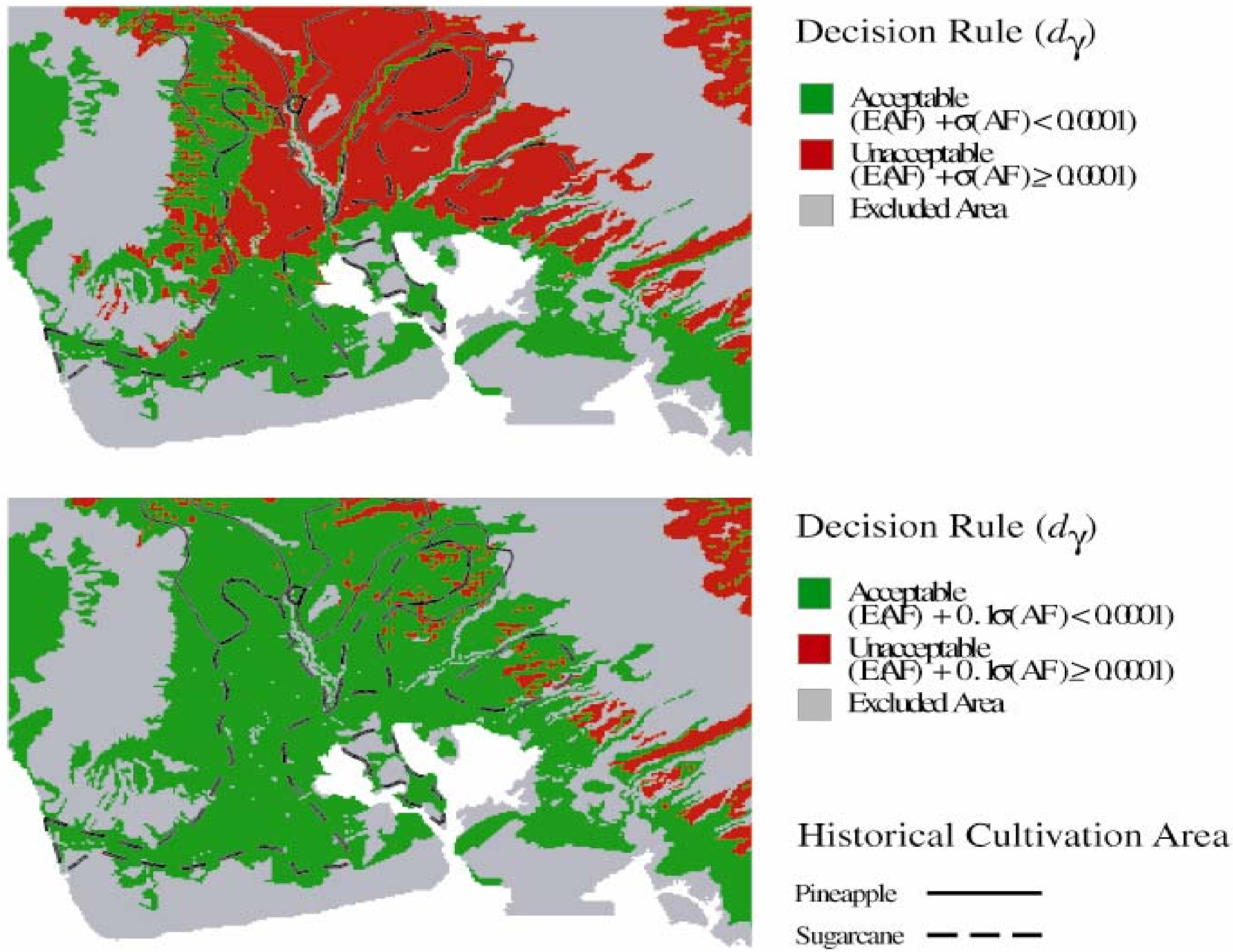


Soil Orders for the Pearl Harbor Basin, Island of Oahu, Hawaii

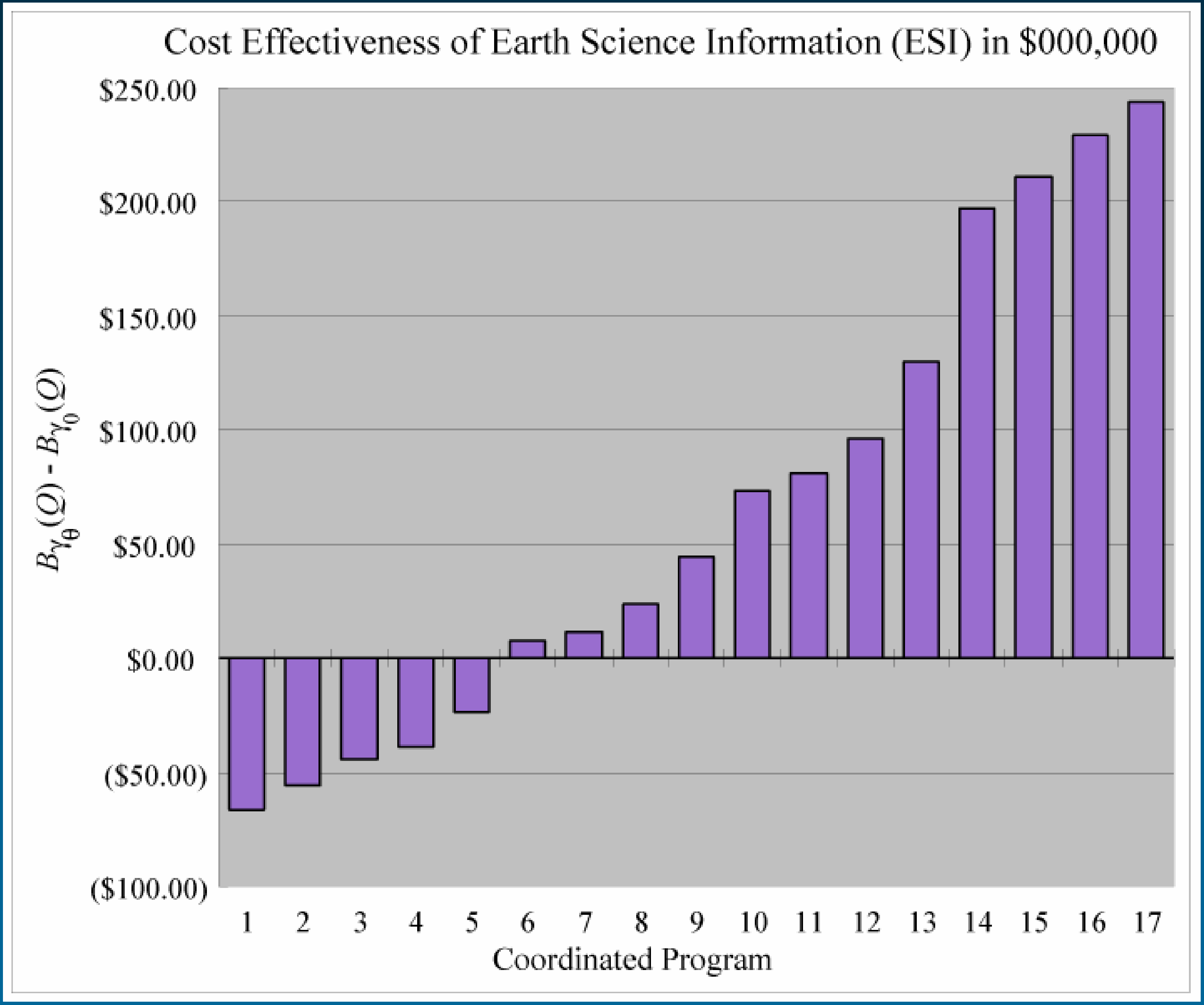
Earth science information Indices of pesticide mobility

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

Attenuation Factor (AF)	**Classification**
0.0 and < 0.0001	very unlikely
0.0001 and < 0.01	unlikely
0.01 and < 0.1	moderately likely
0.1 and < 0.25	likely
0.25 and 1.0	very likely
Retardation Factor (RF)	**Classification**
= 1	very mobile
> 1.0 and < 2.0	mobile
> 2.0 and < 3.0	moderately mobile
> 3.0 and < 10.0	moderately immobile
= 10	very immobile



Groundwater vulnerability maps for the Pearl Harbor Basin, Island of Oahu, Hawaii, for the Oxamyl/ Bromocil combination based upon the *AF*. Decisions (d_γ) to accept or reject the application of a pesticide without wellhead treatment are based on the rule: $E(\gamma_\theta) \pm F(P) \cdot \sigma(\gamma_\theta) <$ or $> R_0$. 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)
$B_{\gamma_\theta}(Q) - B_{\gamma_0}(Q)$
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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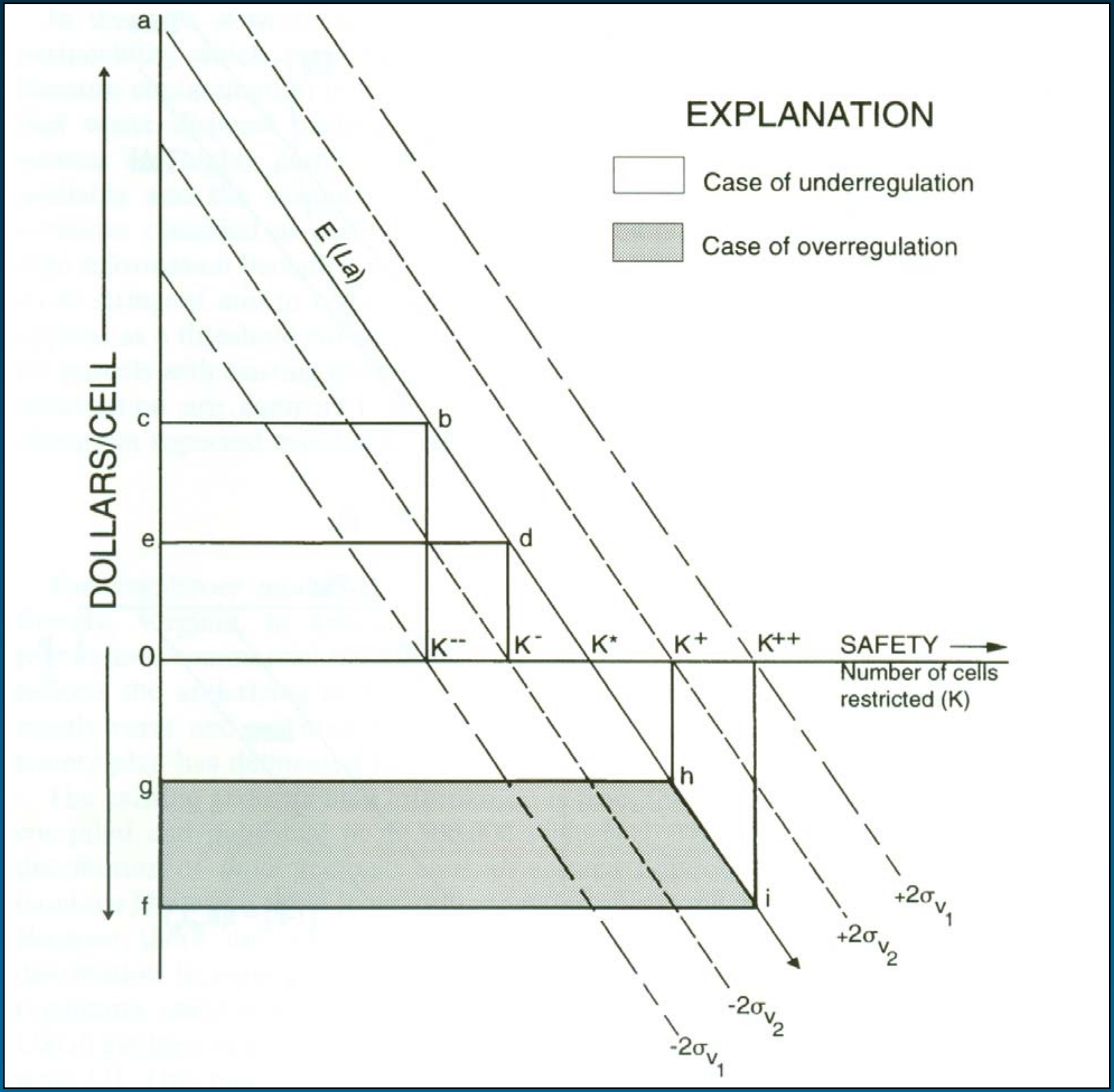
16
17
Coordinated Program

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

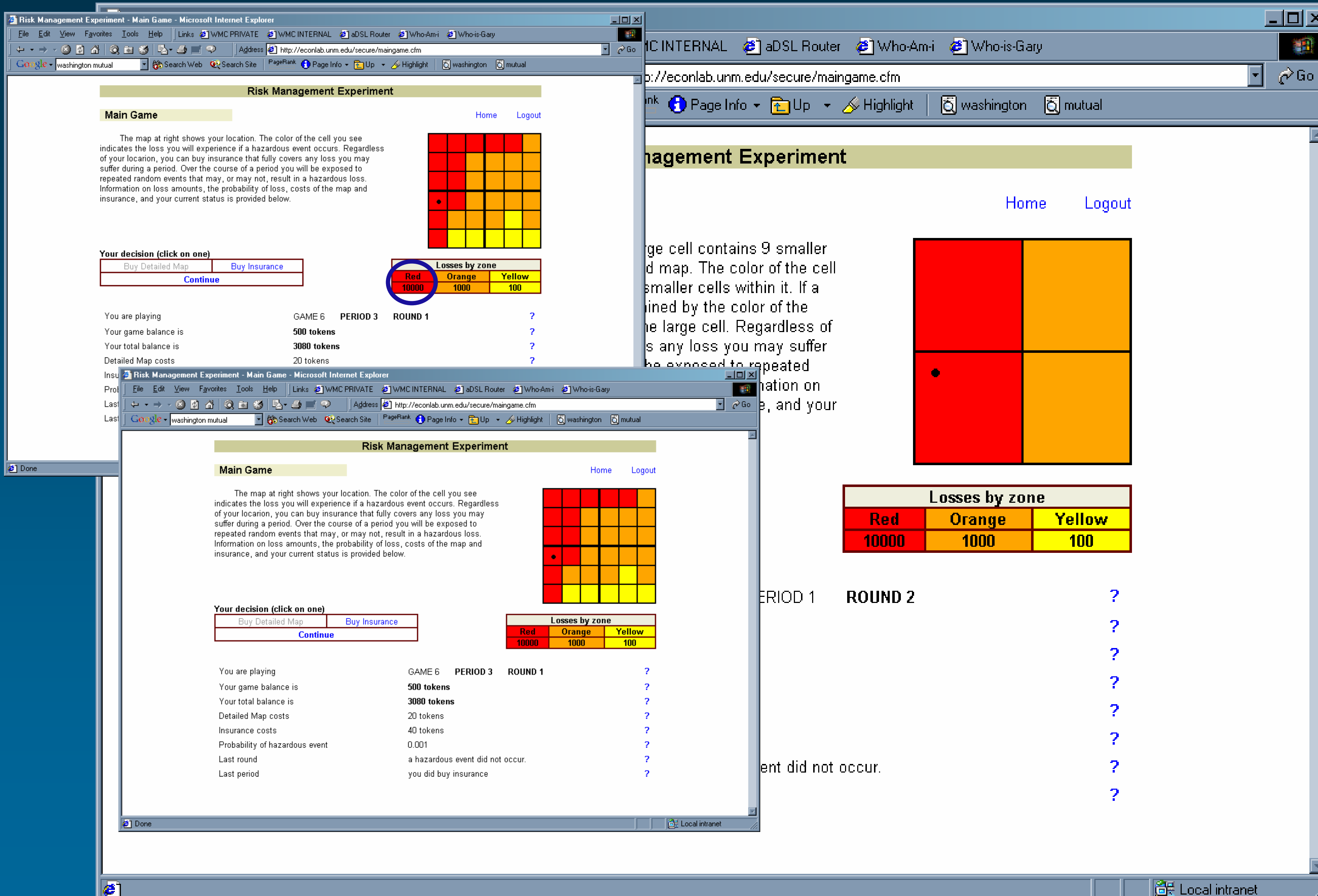
Stated Preference

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



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 geo-science 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

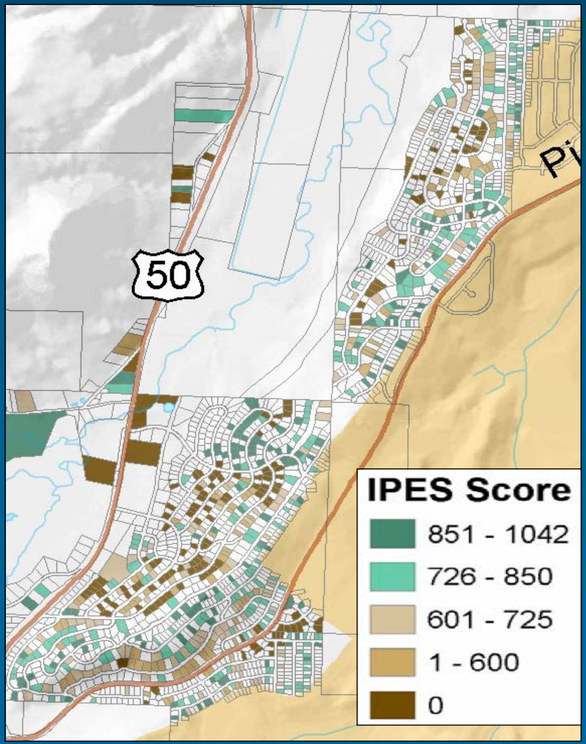
Supports long-term planning in the Basin, by considering plans' environmental, social, and/or economic effects in the Lake Tahoe Basin

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?



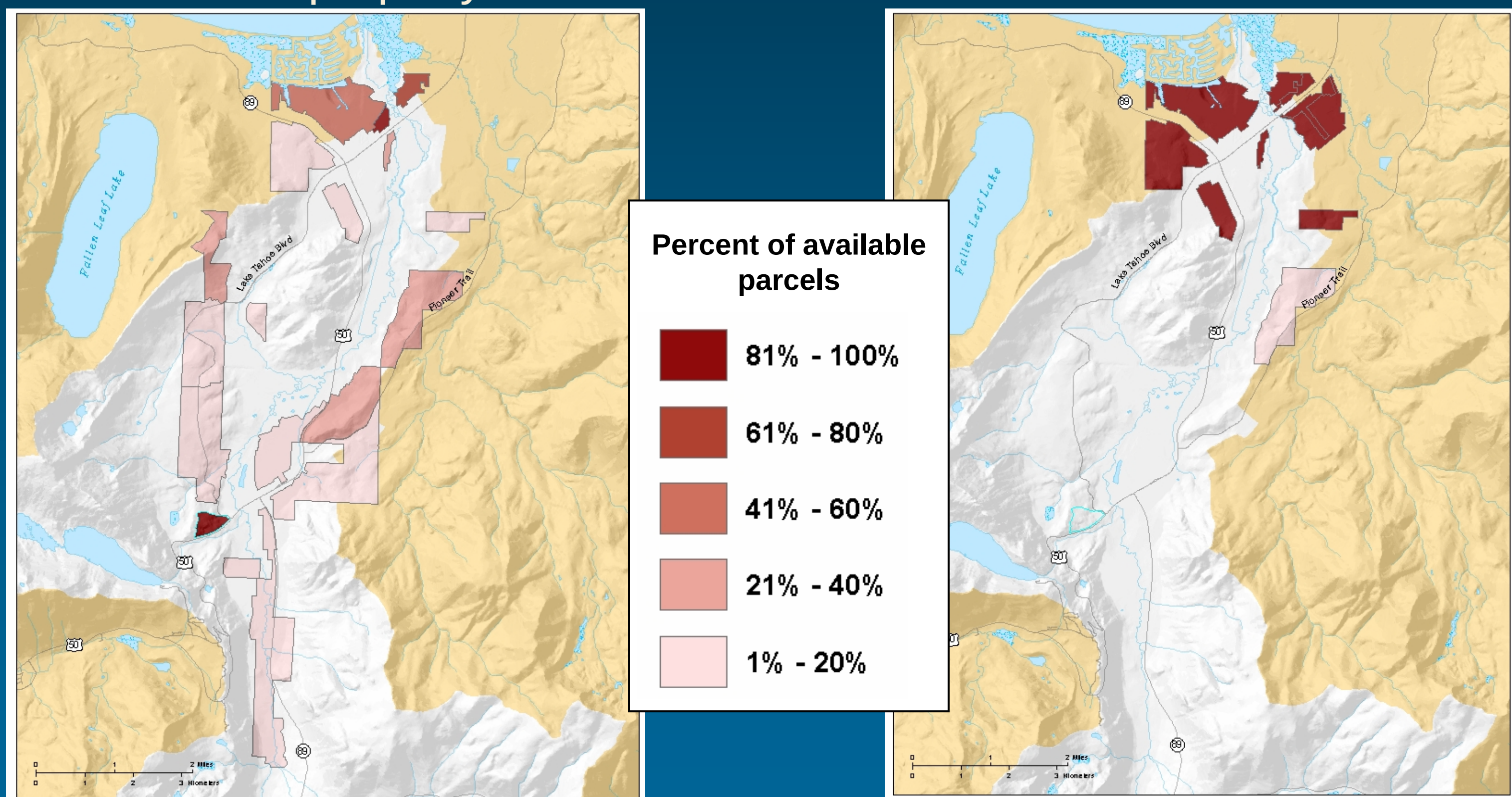
TCOM Methods

- 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

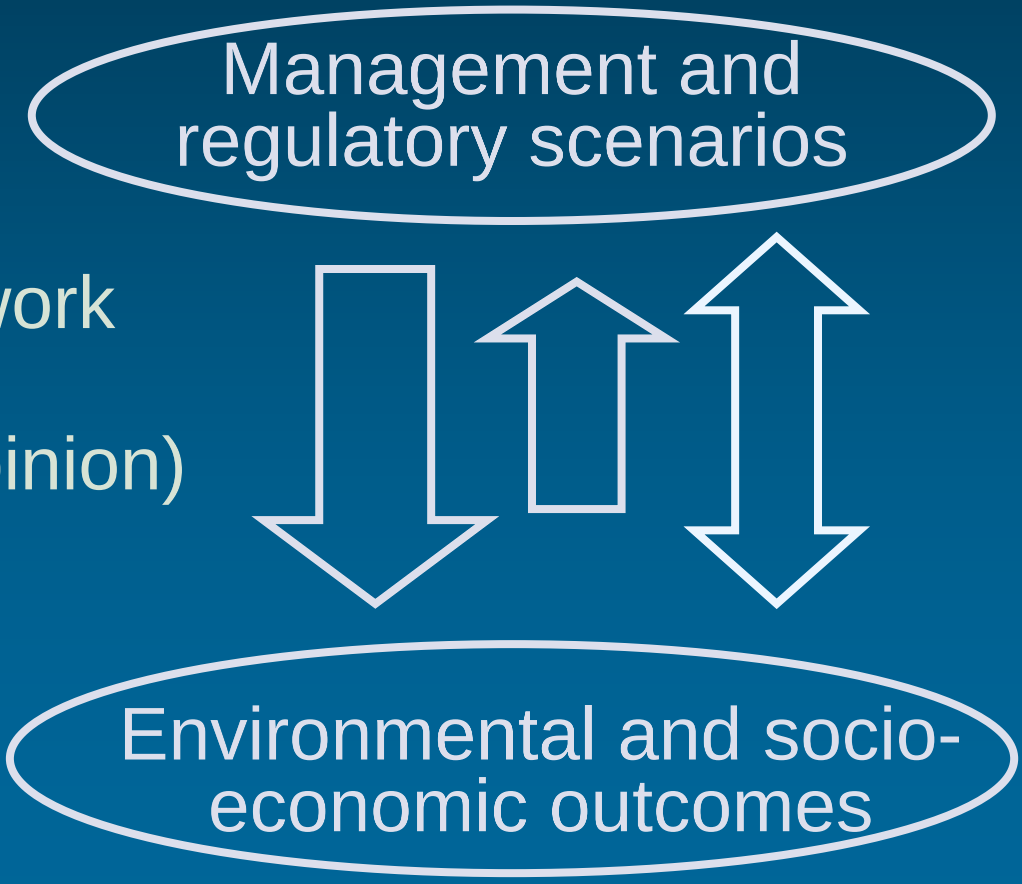


The maps highlight critical (sometimes problematic) model assumptions and conclusions.

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,

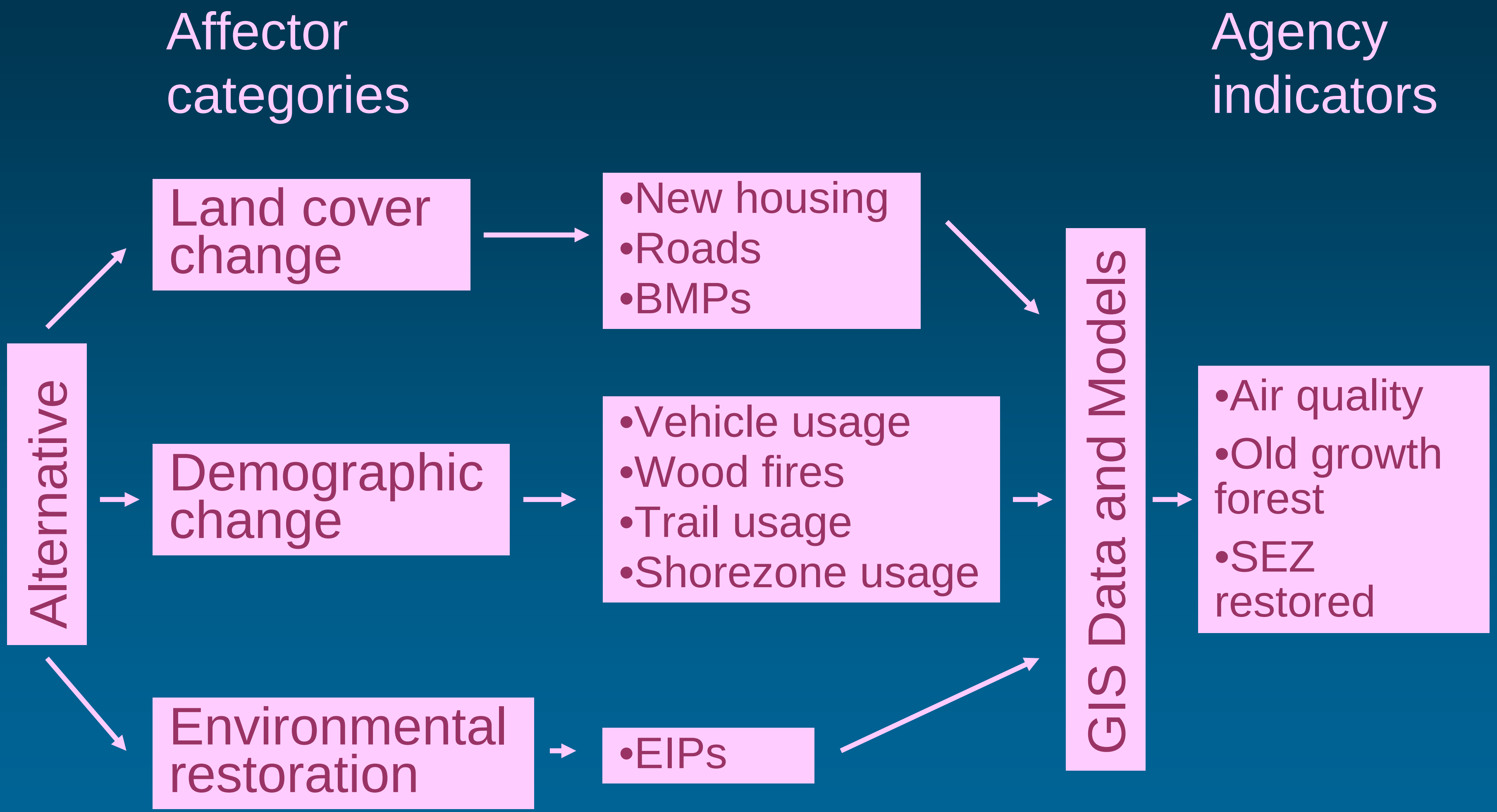
demography,

and management and regulatory decisions including

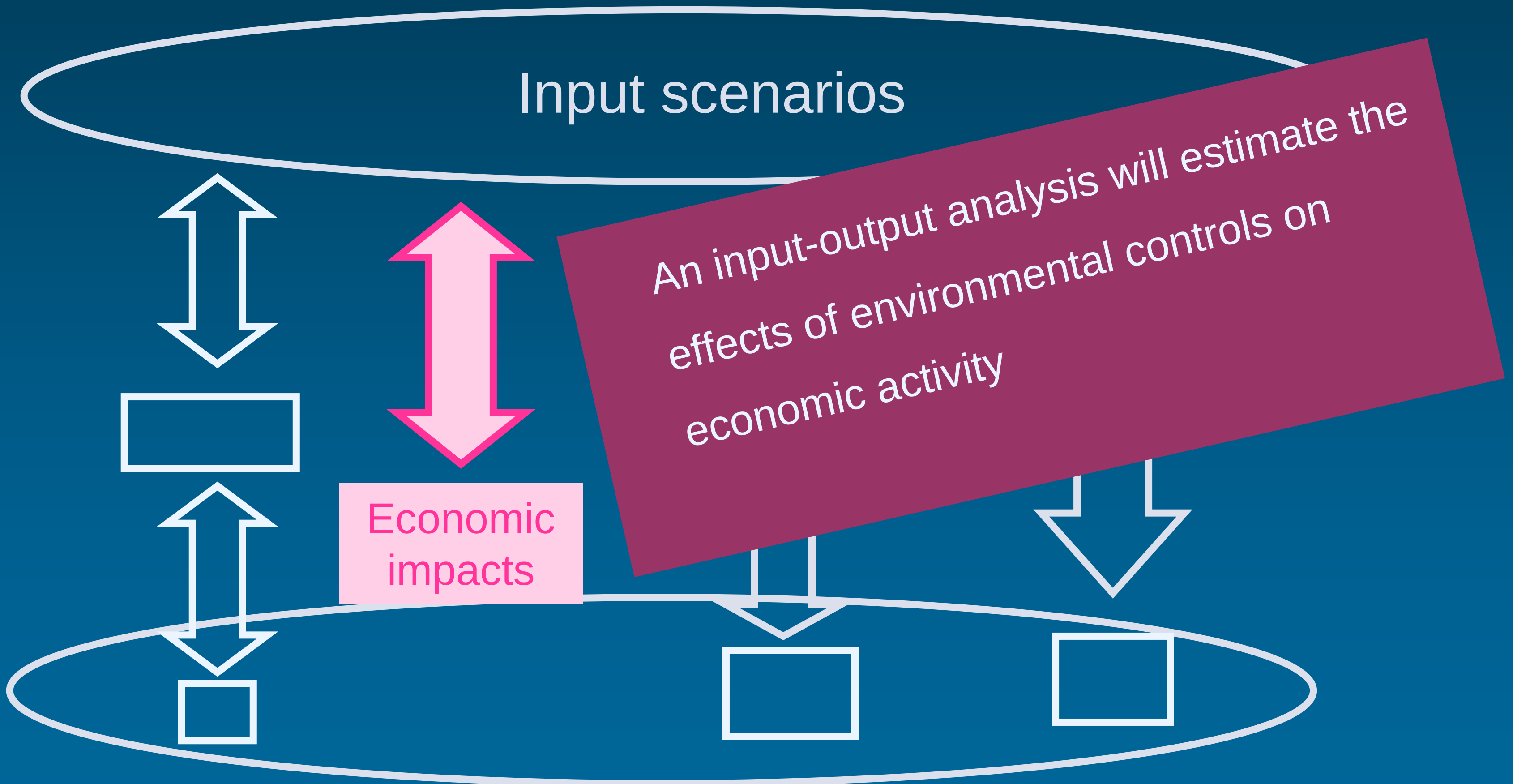
regulation of land use and zoning,

EIP projects

fuel treatments.

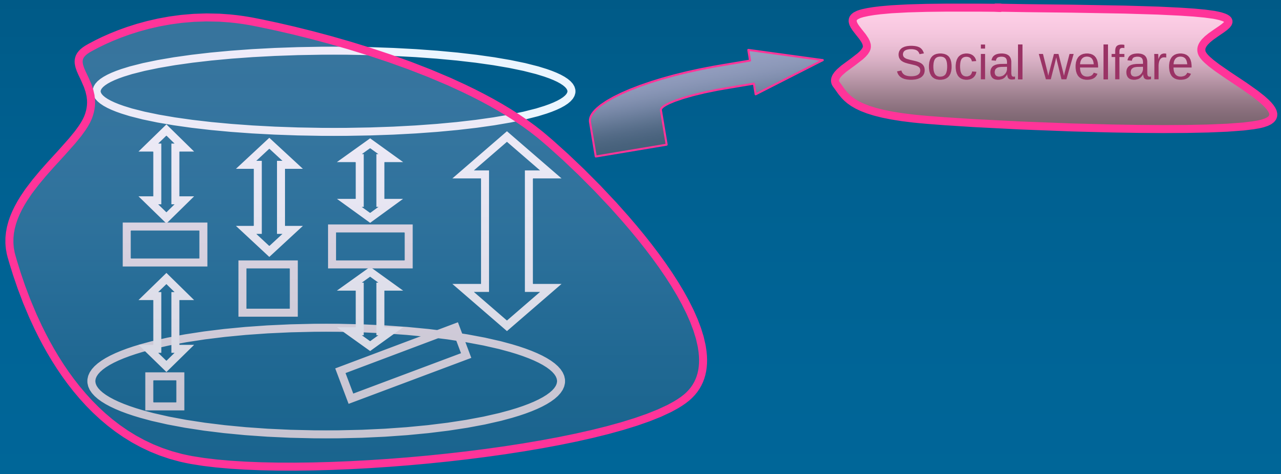

Affector categories
Agency indicators
Alternative
Land cover change
Demographic change
Environmental restoration
•New housing
•Roads
•BMPs
•Vehicle usage
•Wood fires
•Trail usage
•Shorezone usage
•EIPs
GIS Data and Models
•Air quality
•Old growth forest
•SEZ restored

Component modules



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:

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