The Science of Science Policy:
Integrating Geoscience and Socioeconomic Information Reduces Uncertainty in Societal Decision Making

Carl Shapiro and Rich Bernknopf, USGS
7th Annual Geohazards Forum
Cost Benefits of Geoscience Information
Asheville, NC
August 1, 2007

U.S. Department of the Interior
U.S. Geological Survey
How much should a nation spend on science? What kind of science? How much from private versus public sectors? Does demand for funding by potential science performers imply a shortage of funding or a surfeit of performers? These and related science policy questions tend to be asked and answered today in a highly visible advocacy context that makes assumptions that are deserving of closer scrutiny.

A new “science of science policy” is emerging, and it may offer more compelling guidance for policy decisions and for more credible advocacy.

Working Definition of the Science of Science Policy

The science of science policy is an emerging, interdisciplinary research area, creating and applying knowledge to help government, and society in general, make better research and development investment decisions.

It includes the study of science (including technology and innovation) and its interconnections, the impact of science on society, and policies affecting science directions.

Examples of research in the science of science policy include models to understand the production of science, qualitative and quantitative methods to estimate the impact of science, and processes for choosing from alternative science portfolios.
Interagency Task Group on the Science of Science Policy

Create a roadmap for federal efforts.

Assess and inventory the current status and identify gaps.

Identify data and tools for modeling and analysis that can contribute to improved indicators and metrics.

Identify and coordinate Federal funding opportunities to develop tools, theories, and methods.

Report to Subcommittee on Social, Behavioral, and Economic Sciences (SBE), Committee on Science and Committee on Homeland and National Security, National Science and Technology Council
Science policy discussions are dominated by advocates for particular scientific fields or missions.

Decisions are frequently based on past practice or data trends that may have limited relevance to the current situation.

Need capacity to predict how best to make and manage future investments.

Charter, Interagency Task Group on Science of Science Policy
Rationale

I do not fear so much that our current [science and technology] budgets are too small… But I worry constantly that our tools for making wise decisions…are not yet sharp enough…

…the field of science policy is…to a great extent a branch of economics, and its effective practice requires the kind of quantitative tools economic policy makers have available… Much of the available literature on science policy is being produced piecemeal by scientists who are experts in their fields, but not necessarily in the methods and literature of the relevant social science disciplines… It is a chronic affliction of social science that it is undervalued by those who could benefit most from its methodologies and its insights.

I think the science of science policy is undervalued and underfunded despite its potential for providing a basis for understanding the enormously complex dynamic of today’s global, technology-based society.

John Marburger, Director OSTP, Oct. 31, 2005, Washington, DC.
Aims to foster the development of the knowledge, theories, data, tools, and human capital needed to cultivate a new Science of Science and Innovation Policy (SciSIP).

Understand the contexts, structures and processes of Science & Engineering research.

Evaluate the tangible and intangible returns from investments in research and development (R&D)

Predict the likely returns from future R&D investments within tolerable margins of error and with attention to the full spectrum of potential consequences.
Key Issues

Complexity in linking science with societal issues

Decision making with uncertainty

Private versus public benefits

Retrospective versus prospective
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.
Benefits and Costs: What is Counted?

PC=Private Benefits, SB=Societal Benefits, PC=Private Cost, SC=Societal Cost, P=Price, Q=Quantity
(R. Bernknopf, L. Dinitz, S. Rabinovici, N. Wood, R. Taketa, and A. Evans)

Risk analysis using hazard zonation maps for land use and mitigation

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<tr>
<th>Zone</th>
<th>Locations</th>
<th>Probability</th>
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<tr>
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<td>0.003</td>
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<tr>
<td>2</td>
<td>949</td>
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**INPUTS**
- Hazard event probability: 30% in 30 years
- Conditional probability of structural failure from frequencies
- All or none structural failure
- Asset value from assessor

**OUTPUTS**
- Total investment cost
- Number of locations mitigated
- Mean and standard deviation of post event community wealth
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

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<thead>
<tr>
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<tbody>
<tr>
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<td>0.016</td>
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<tr>
<td>2</td>
<td>127</td>
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<td>0.006</td>
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<tr>
<td>2</td>
<td>663</td>
<td>0.060</td>
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</table>
Comparison of Mitigation Policies and Hazard Classification Methods

![Graph showing expected community wealth vs. standard deviation for different policies and methods.

<table>
<thead>
<tr>
<th></th>
<th>Policy 1: Status Quo</th>
<th>Policy 2: Highest Hazard Zone</th>
<th>Policy 3: Residential Land Use</th>
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<tbody>
<tr>
<td></td>
<td>Expert</td>
<td>Probit</td>
<td>PNN</td>
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<tr>
<td>Percent of Expected Loss Eliminated</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Dollars Spent Per Percent of Loss Eliminated (mil)</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</table>
Seismic Events and Probabilities (in 50 years)
- Repeat of 1811-1812 (magnitude 7.7): 10%
- Magnitude about 6.0 or greater: 25%
- Liquefaction Zone: Probability greater than 60%

Consider strengthening building codes for new commercial and industrial development to mitigate the consequences of a seismic event similar to the 1811 New Madrid earthquake.

Seismic Risk Mitigation in Memphis, TN
(P. Hearn, R. Bernknopf, D. Strong, E. Schweig, and J. Gomberg)
GIS Used to Apply Hazard Data and to Select Specific Parcels at Risk

Parcels selected as having 60% or greater risk of major liquefaction
Hazard and Mitigation Scenario 1

- Inputs
  - Total value: $9.6 billion
  - Vulnerability: $2.5 billion
  - No mitigation
  - M7.7 earthquake NW of Memphis
  - Earthquake happens today
  - Modeled building values for vacant commercial parcels (11976 parcels)

- Outputs
  - Expected loss: $2.5 billion
  - Return on investment: N/A
  - Wealth retained: $7.1 billion (74%)
Hazard and Mitigation Scenario 5

- **Inputs**
  - M7.7 earthquake NW of Memphis
  - Annual probability of event: 0.002
  - 20 year planning horizon
  - Properties mitigated in zones of >60% liquefaction potential
  - Mitigation Cost: (10%) $141 million
  - (30%) $424 million

- **Outputs**
  - Expected loss: $32.9 million
  - Wealth retained: $9.49 billion (99%)
  - Return on investment (10%) 48%
  - (30%) 16%

Parcels located in areas with 60% or greater potential for major liquefaction
Liquefaction risk assessment:
$M_0 = 7.7$; asset value =$9.6B; $n=11,976$ parcels

<table>
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<tr>
<th>Scenario</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>Exposure ($B$)</td>
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<td>2.5</td>
<td>2.5</td>
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<td>EQ prob</td>
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<td>1.0</td>
<td>0.002/yr</td>
<td>1.0</td>
<td>0.002/yr</td>
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<td><strong>Time horizon</strong></td>
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<td>1</td>
<td>20</td>
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<td>20</td>
<td>50</td>
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<td>% mit</td>
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<td>100.0</td>
<td>100.0</td>
<td>&gt;60% sites</td>
<td>&gt;60% sites</td>
<td>&gt;60% sites</td>
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<tr>
<td>Mit cost ($B)</td>
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<td>0.14</td>
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<td>(10%)</td>
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<td><strong>Outputs</strong></td>
<td></td>
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<tr>
<td>Wealth retained ($B)</td>
<td>7.1</td>
<td>9.6</td>
<td>9.6</td>
<td>8.7</td>
<td>9.5</td>
<td>9.4</td>
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<tr>
<td>(74%)</td>
<td>(100%)</td>
<td>(100%)</td>
<td>(91%)</td>
<td>(99%)</td>
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<tr>
<td><strong>Results</strong></td>
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<tr>
<td>ROI</td>
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<td>0.13</td>
<td>11.7</td>
<td>0.5</td>
<td>1.2</td>
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<tr>
<td>(10%)</td>
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<tr>
<td>Acceptable risk ($B)</td>
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<td>0.8</td>
<td>0.3</td>
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Parcels located in areas with 60% or greater potential for major liquefaction.
Squamish, British Columbia has had, in historic memory, instances of severe flooding and land slides, and is subject to earthquake hazards.
THE TRANSBOUNDARY PROJECT

The Transboundary Project is a cooperative effort between Natural Resources Canada and the US Geological Survey to provide a scientific basis for natural hazards management and mitigation along the Pacific Coast boundary between the two nations.

This phase of the project concerns flood hazard, land use planning, mitigation, and emergency management in the Municipality Squamish.
The Municipality of Squamish is vulnerable to multiple hazards

The population is expected to double (from 15,000) in the near term

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Prob 25 years</th>
<th>Loss Million CAN$</th>
<th>Odds Ratio</th>
<th>Loss Ratio</th>
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<tbody>
<tr>
<td>Debris Flow</td>
<td>0.08%</td>
<td>12</td>
<td>1</td>
<td>1.0</td>
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<tr>
<td>Earthquake</td>
<td>2.25%</td>
<td>40</td>
<td>28</td>
<td>3.3</td>
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<tr>
<td>Flood</td>
<td>11.00%</td>
<td>91</td>
<td>138</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Downtown Squamish: 1921

The Municipality will accommodate the expanded population by allowing building in the flood plain and by mitigation.

What are the socioeconomic consequences of this decision?
Hazard and Mitigation Scenario 1

- Inputs
  - Current land use plan
  - 20 year flood
  - No mitigation
  - 25 year planning horizon
  - Structural value (2004)

Outputs
- Vulnerability: $41 million
- Expected loss: $29 million

Caveats
- Accounted for damage from at most 1 flood
- Flood damage is for a 20 year flood
Hazard and Mitigation Scenario 17

**Inputs**
- Future land use plan
- 20 year flood
- 25 year planning horizon
- No mitigation

**Outputs**
- Vulnerability: $43 million
- Expected loss: $31 million

**Caveats**
- Accounted for damage from at most 1 20 year flood
Hazard and Mitigation Scenario 29

Inputs
- Future land use plan
- 200 year flood
- 50 year planning horizon
- Mitigation cost: $100 million

Outputs
- Prob. At least 1 flood: .25
- Vulnerability: $268 million
- Expected avoided loss: $67 million
- Return on investment: 268%, 67%

Caveats
- Smaller floods unaccounted for
- Damage from a 200 year flood
- No unmitigated loss
ANALYSIS OF IMPROVED GOVERNMENT GEOLOGICAL MAP INFORMATION FOR MINERAL EXPLORATION

**GSC**
Marc St-Onge
Geologist

Stephen Lucas
Geologist (now at Health Canada)

**USGS**
Richard Bernknopf
Economist

Anne Wein
Operations Research Analyst

April 2006
Approach

Quality and quantity of Earth Science information
Provided as a public good

Vintage and resolution of geological bedrock maps

Mineral exploration decisions consider the productivity, efficiency, effectiveness, risk, and budget of locating targets

Behavioral model

Value of updated and more detailed information to society

Effect of better information on initial exploration investment → society
## Case Studies

<table>
<thead>
<tr>
<th>Exploration Status</th>
<th><strong>Flin Flon Belt</strong></th>
<th><strong>South Baffin Island</strong></th>
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</thead>
<tbody>
<tr>
<td>Hindsight</td>
<td>Mature</td>
<td>Frontier</td>
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</table>

| Reference area     | Itself            | Geologically analogous area: Cape Smith Belt (St-Onge et al. 1999, 2001, 2002) |

<table>
<thead>
<tr>
<th>Exploration campaign results</th>
<th>Productivity &amp; efficiency</th>
<th>Productivity &amp; efficiency</th>
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<tr>
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<td>Effectiveness</td>
<td>Effectiveness</td>
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<tr>
<td></td>
<td>Risk</td>
<td>Risk</td>
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<td></td>
<td>Value of information</td>
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<table>
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<tr>
<th>Map comparisons</th>
<th>Old coarser resolution</th>
<th>Updated coarser resolution</th>
<th>Old coarser resolution</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Updated finer resolution</td>
<td>Updated finer resolution</td>
<td></td>
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</tbody>
</table>
Case Study Locations

FFB: Flin Flon Belt
CSB: Cape Smith Belt
SBI: South Baffin Island
Flin Flon Mineralization Favorability Maps

Bailes 1971
1:253,440
Old coarser resolution

NATMAP 1998
1:325,000
Updated coarser resolution

NATMAP 1998
1:100,000
Updated finer resolution

Legend
- VMS targets in map favorability 3 domain
- VMS targets in map favorability 2 domain
- VMS targets in map favorability 1 domain
- VMS targets in map favorability 0 domain
- Old map extent
- Map favorability 3 domain
- Map favorability 2 domain
- Map favorability 1 domain
- Map favorability 0 domain

VMS targets in map favorability 3 domain
VMS targets in map favorability 2 domain
VMS targets in map favorability 1 domain
VMS targets in map favorability 0 domain
Old map extent
Map favorability 3 domain
Map favorability 2 domain
Map favorability 1 domain
Map favorability 0 domain
South Baffin Island
Mineralization Favorability Maps

Old coarser resolution

Updated finer resolution

Old vs. Updated

Legend
- Old map favorability 1 and 3 domains
- Map favorability 3 domain
- Map favorability 2 domain
- Map favorability 1 domain
- Map favorability 0 domain

Blackadar 1967, 1:506,000

St-Onge et al. 1999, 1:100,000
Map comparisons of expected exploration efficiency, productivity and effectiveness

Optimal expected number of search units examined

Optimal expected number of exploration targets

New map locates more targets when all favorability domains are searched (more effective)

New map uses less search unit examinations to locate any number of expected targets (more efficient)

New map locates more targets for any number of search unit examinations (more productive)
Results: Flin Flon map comparisons of expected campaign efficiency and productivity

Continuums of expected exploration outcomes

Optimal expected number of exploration targets

Optimal expected number of search units examined, highest to lowest favorability

- Old coarser resolution map, exploration campaign OC1 searches favorability 1
- Updated coarser resolution map, exploration campaign UC1 searches favorability 1
- Updated finer resolution map, UF32 searches favorability 2 and 3 etc.
Results: Updated map campaigns compared with old map campaigns

**Updated Flin Flon Belt maps:**
- (coarser resolution) locates 60% more expected targets and is 44% more efficient
- (finer resolution) enables an additional 17% reduction in search effort across all favorable domains and a 55% reduction in search effort in the most favorable domain

**Updated finer resolution South Baffin island map:**
- locates at least 40% more expected targets
- is at least 27% more efficient

**Finer resolution maps**
- define more favorability classes, offering more exploration options
**Decision Model**

- **Target density**
  - Maximize efficiency/productivity
  - Minimize risk
  - Minimize budget
  - Maximize effectiveness

- **Campaign number of search unit examinations**
  - Updated map campaign
  - Old map campaign

- **Campaign target density**
  - Budget
  - Effectiveness
Decision Model Results for South Baffin Island

Expected Campaign Target Density

Number of Campaign Search Unit Examinations

- Risk criterion (.95 probability of finding at least 10 targets)
- Target density (.02)
- Exploration budget
- Iso-benefit curve (55 expected targets)
- Iso-benefit curve (78 expected targets)
Investment Advantage of Updated Information for South Baffin Island

Exploration investment = search unit examination costs + target exploration costs for the optimal exploration campaign

$1.86 million cost of producing the updated finer resolution maps

Exploration campaign outcome

- UF3
- UF32
- UF321

Differential exploration investment millions $CAN
Summary

• Derived a flexible method for considering the societal value of information from a public good that depends on the use of the information as determined by critical decision making elements.

• Demonstrated that updated information improves efficiency, productivity, effectiveness and likelihood of success of exploration campaigns, and finer resolution information provides for dramatic initial improvements if the search is prioritized by favorability.

• Justified the cost of producing the information for south Baffin with even the most conservative of exploration campaign outcomes if exploration investment translates into at least equivalent benefits to society.

• Joint publication: GSC Bulletin 593 - USGS Professional Paper 1721, due 9/06.

• Revealed further work that could:
  • elaborate on uncertainties and inaccuracies in the estimates
  • accommodate 2-D and 3-D models to favorability class assignment
  • incorporate additional environmental benefits from improved efficiency.
Emerging U.S. Mega-regions
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