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

Wanted: Better Benchmarks

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.

John Marburger III, Director of the Office of Science and Technology Policy. Science, May 20, 2005, p. 1087.

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

Need for Science of Science Policy

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.

NSF Solicitation

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.

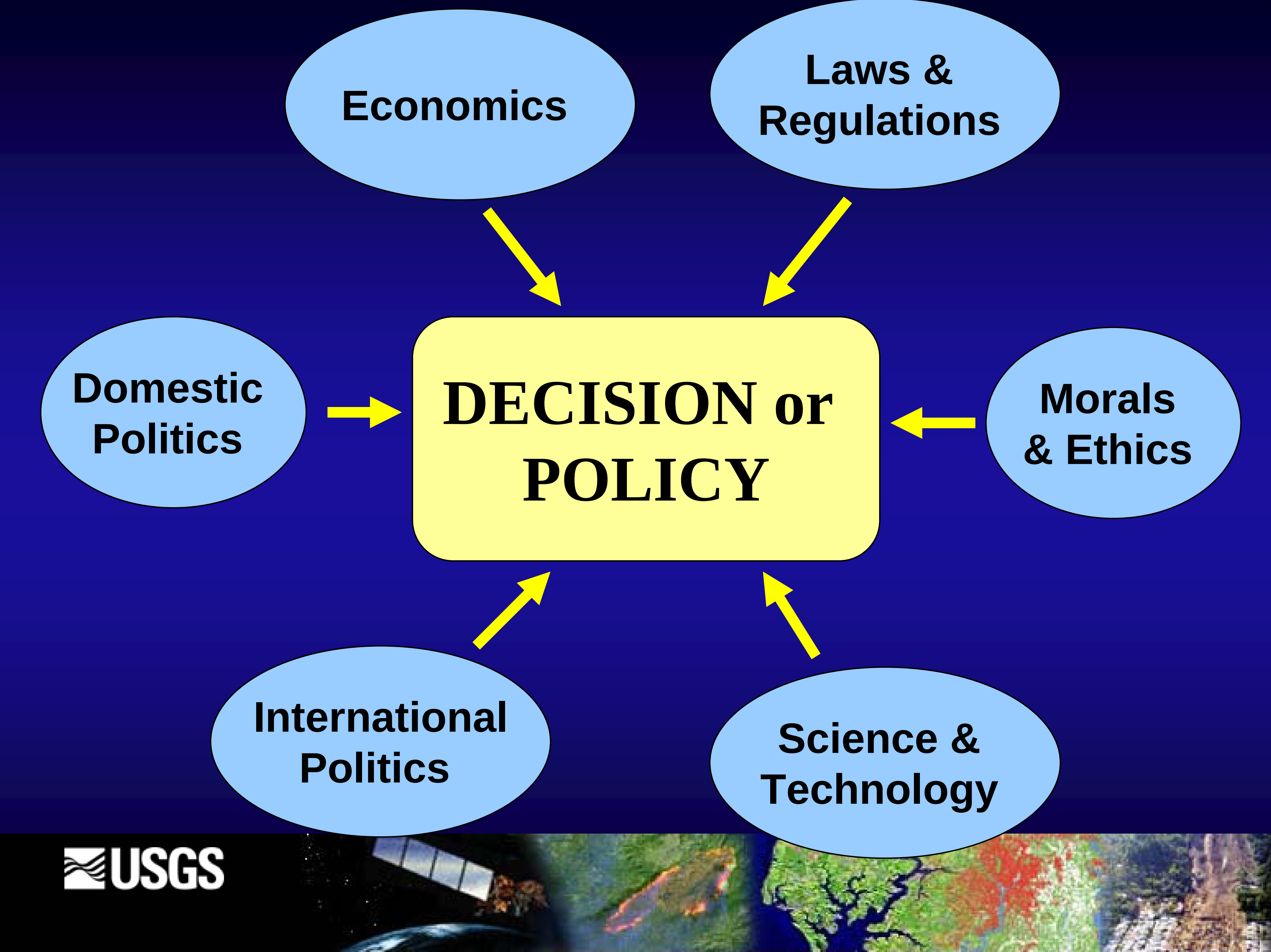
Key Issues

Complexity in linking science with societal issues

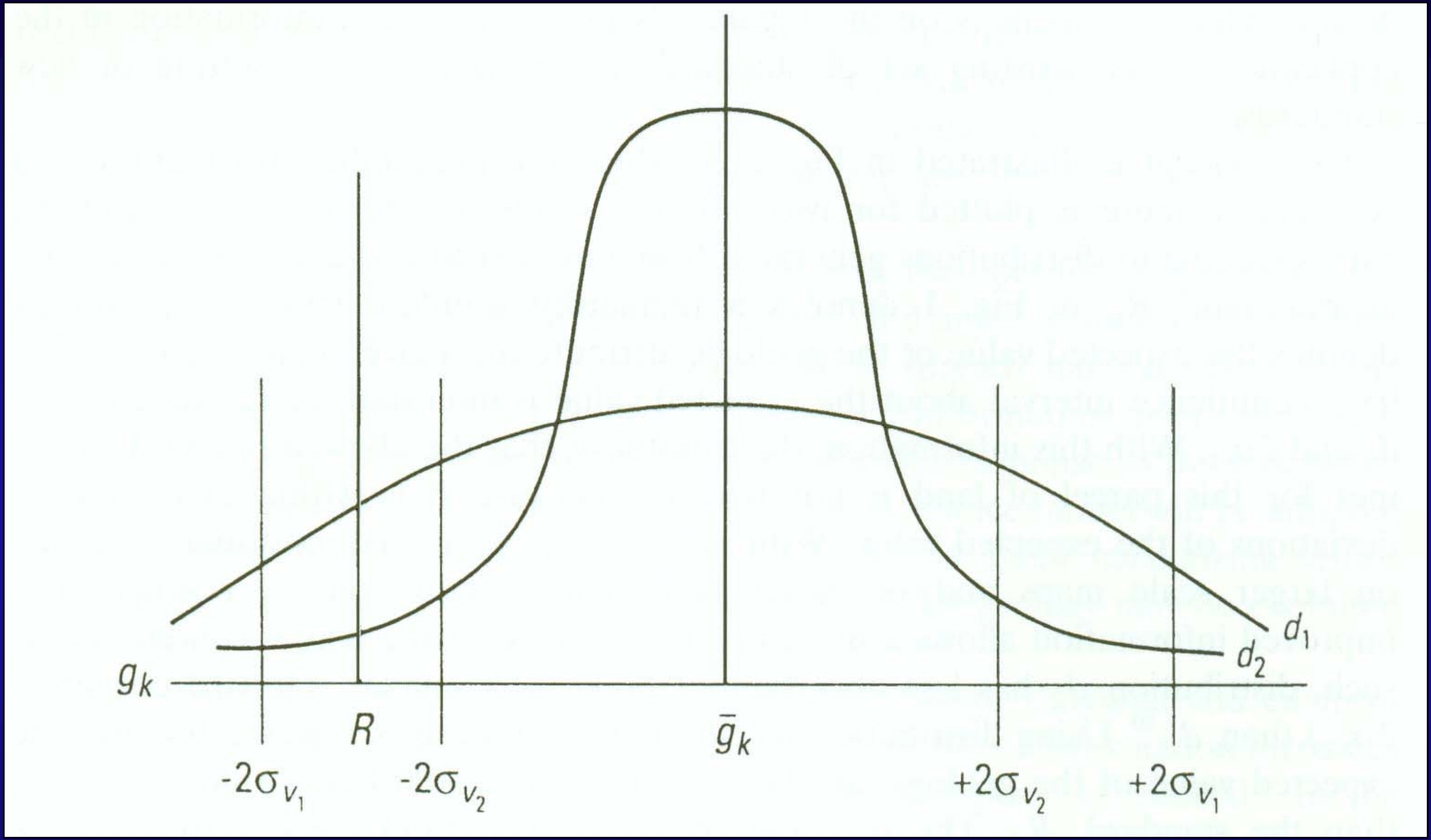
Decision making with uncertainty

Private versus public benefits

Retrospective versus prospective

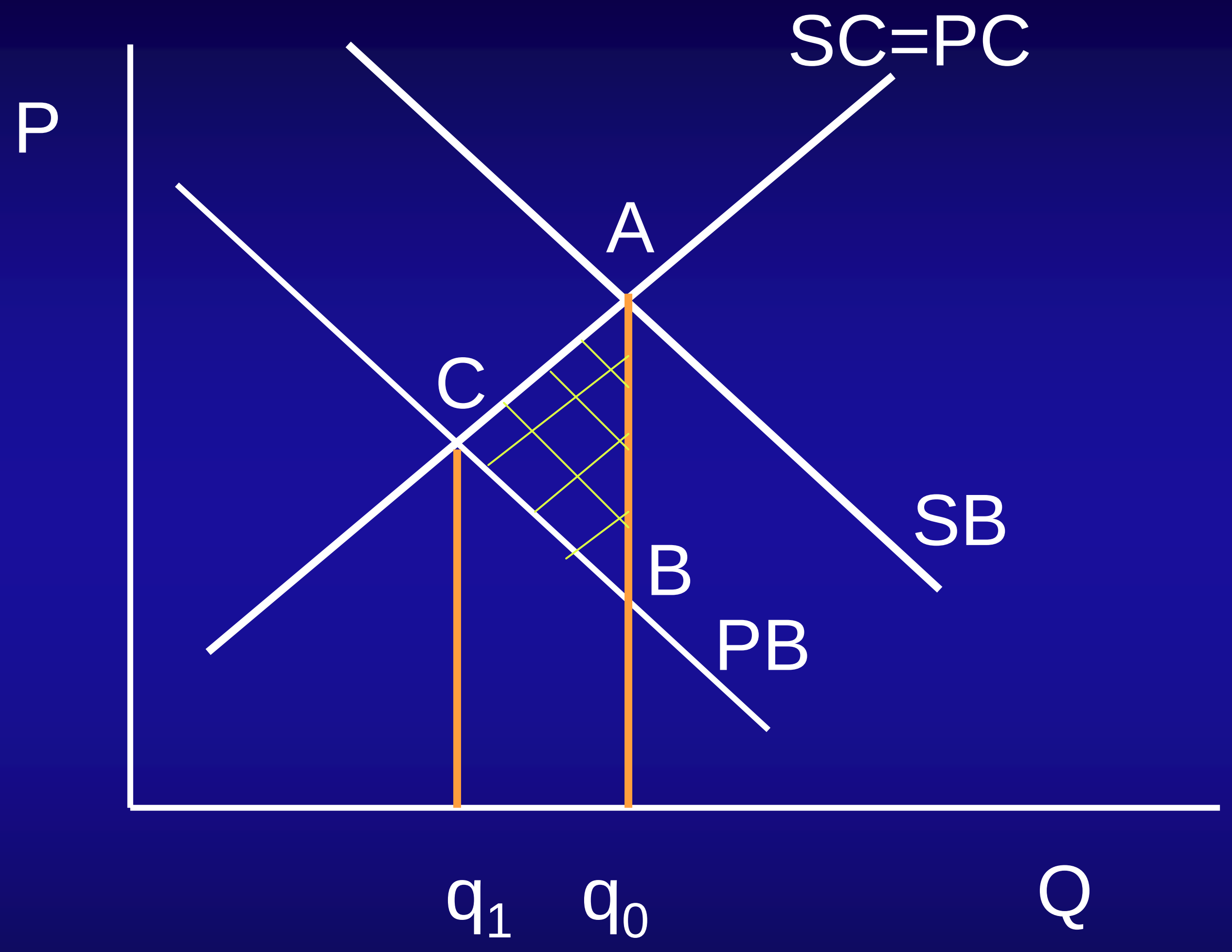

Economics
Laws & Regulations
Domestic Politics
DECISION or POLICY
Morals & Ethics
International Politics
Science & Technology
USGS

Geoscience 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.

Benefits and Costs: What is Counted?



PC=Private Benefits, SB=Societal Benefits, PC=Private Cost, SC=Societal Cost, P=Price, Q=Quantity

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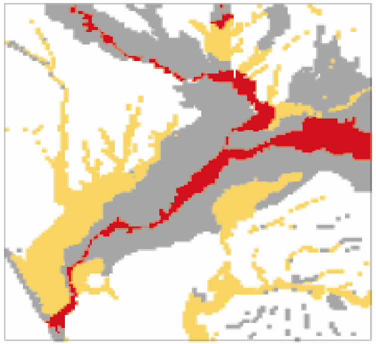
Seismic Risk Analysis, Alternative Mitigation Policies, and the Impact of Hazard Zonation Methods: Watsonville, CA

(R. Bernknopf, L. Dinitz, S. Rabinovici, N. Wood, R. Taketa, and A. Evans)

Risk analysis using hazard zonation maps for land use and mitigation

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

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

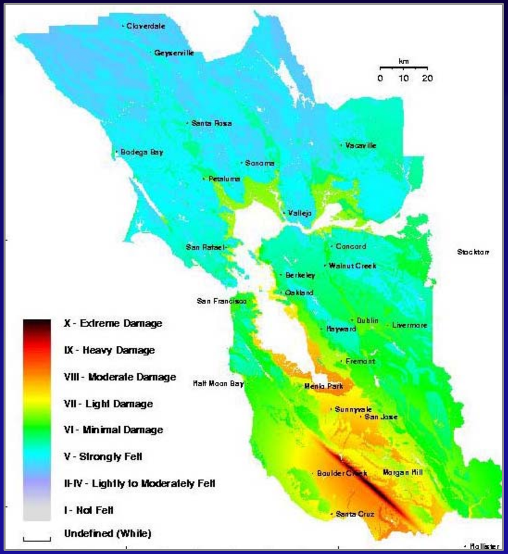
Number of locations mitigated

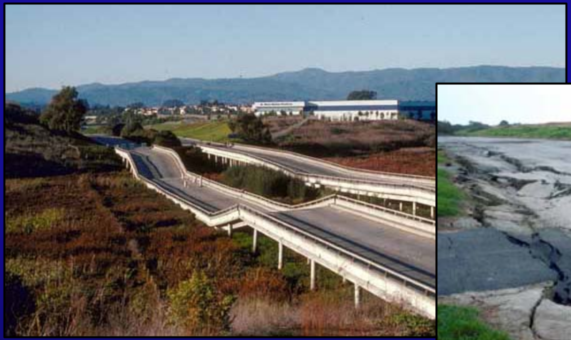
Mean and standard deviation of post event community wealth

USGS

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

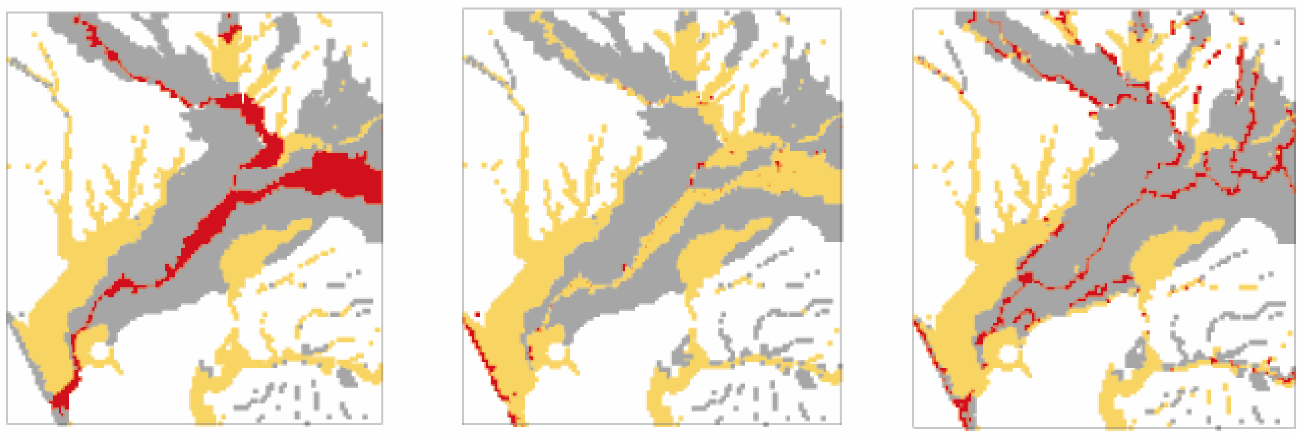




What impacts do different hazard models have on mitigation?

Lateral-Spread Ground Failure Zone Classification Comparison

A. Expert Determined | B. Ordered Probit | C. Probabilistic Neural Network



A. Expert Determined

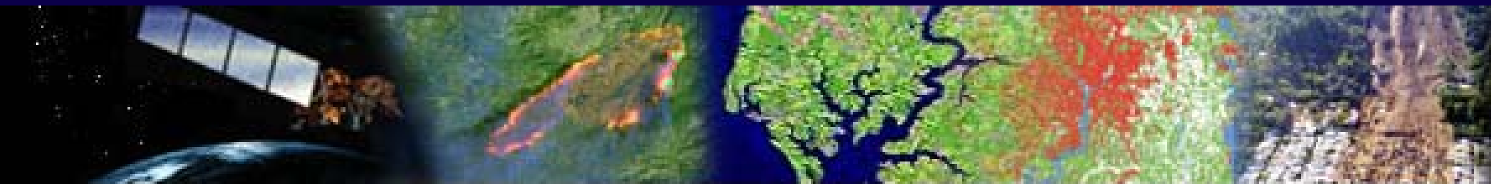
Zone	Locations	Probability
N/A	N/A	0.00
0	3,622	0.008
1	2,061	0.003
2	949	0.074

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



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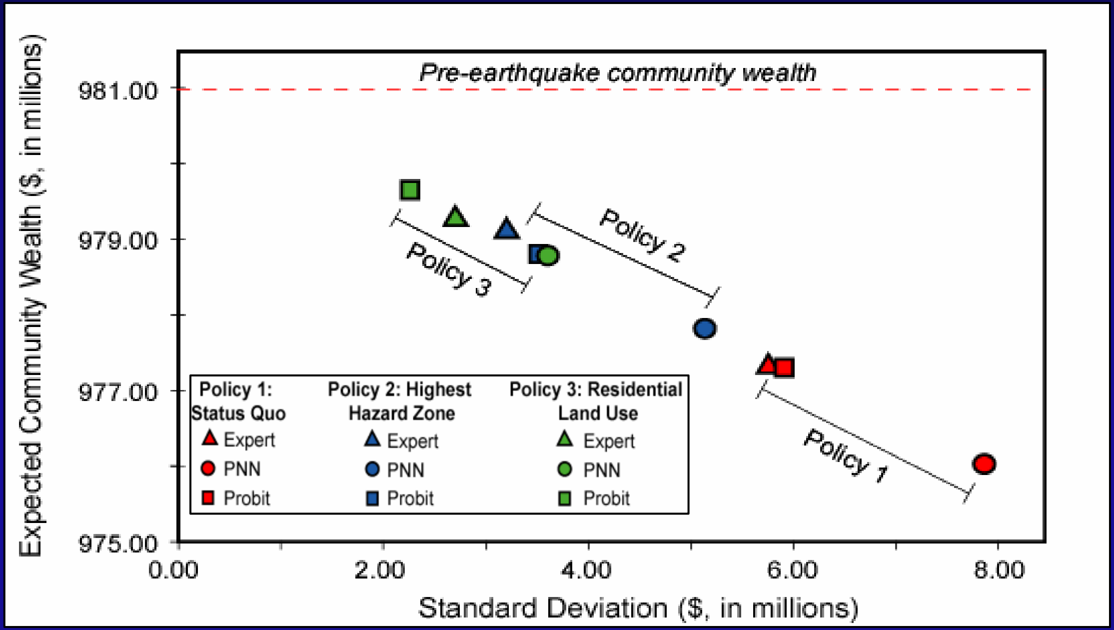
Comparison of Mitigation Policies and Hazard Classification Methods

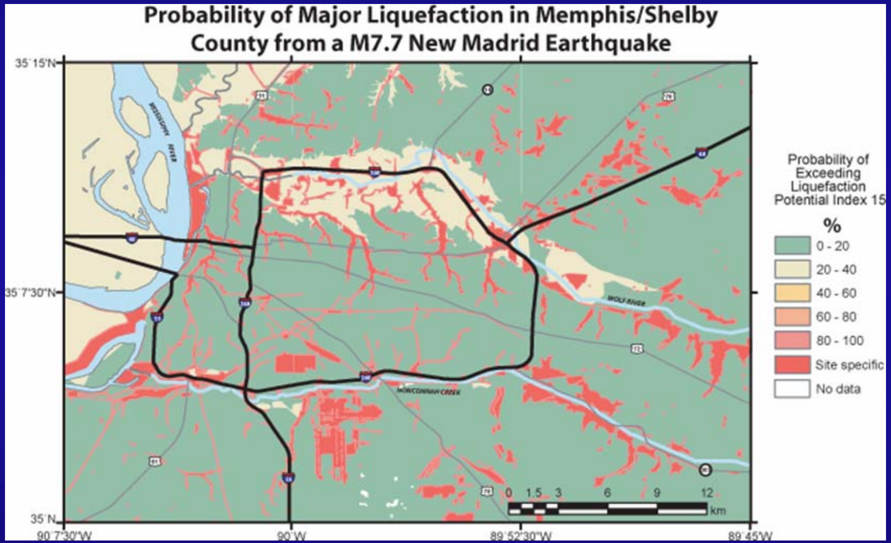


	Policy 1: Status Quo			Policy 2: Highest Hazard Zone			Policy 3: Residential Land Use		
	Expert	Probit	PNN	Expert	Probit	PNN	Expert	Probit	PNN
Percent of Expected Loss Eliminated	0	0	0	47%	40%	35%	54%	62%	55%
Dollars Spent Per Percent of Loss Eliminated (mil)	0	0	0	$ 0.18	$ 0.08	$ 0.25	$ 1.03	$ 0.90	$ 1.01

Seismic Risk Mitigation in Memphis, TN

(P. Hearn, R. Bernknopf, D. Strong, E. Schweig, and J. Gomberg)

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 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%

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GIS Used to Apply Hazard Data and to Select Specific Parcels at Risk

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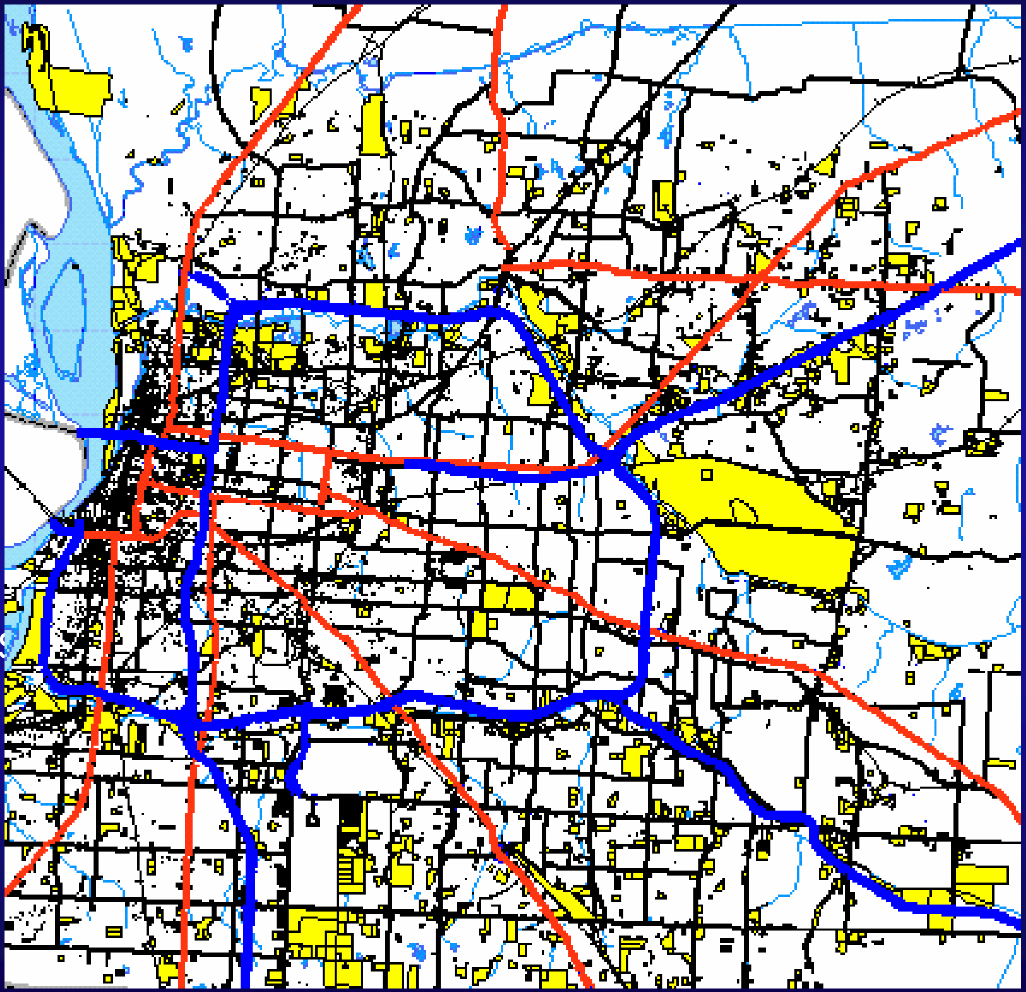
Hazard and Mitigation Scenario 1

- 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%)



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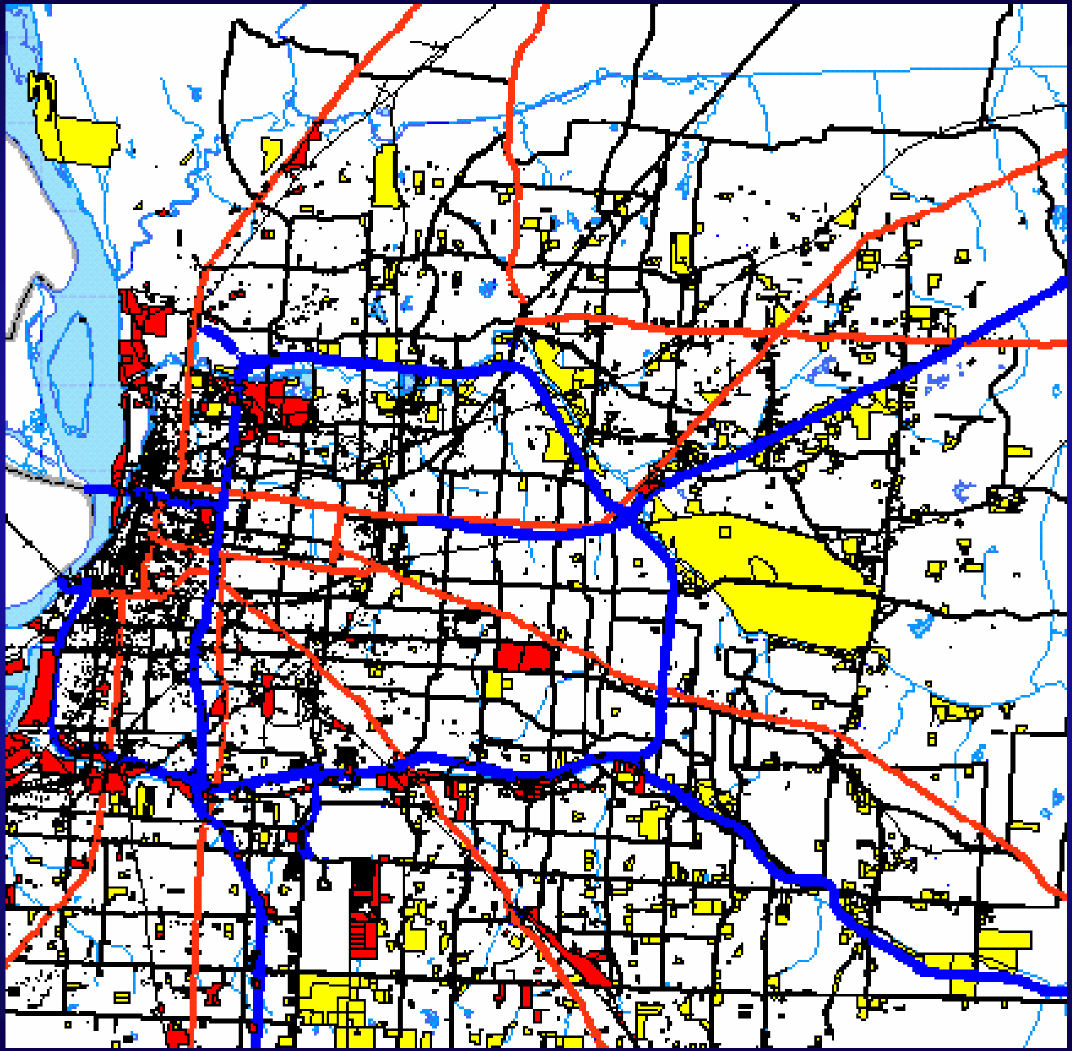
Hazard and Mitigation Scenario 5

- 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

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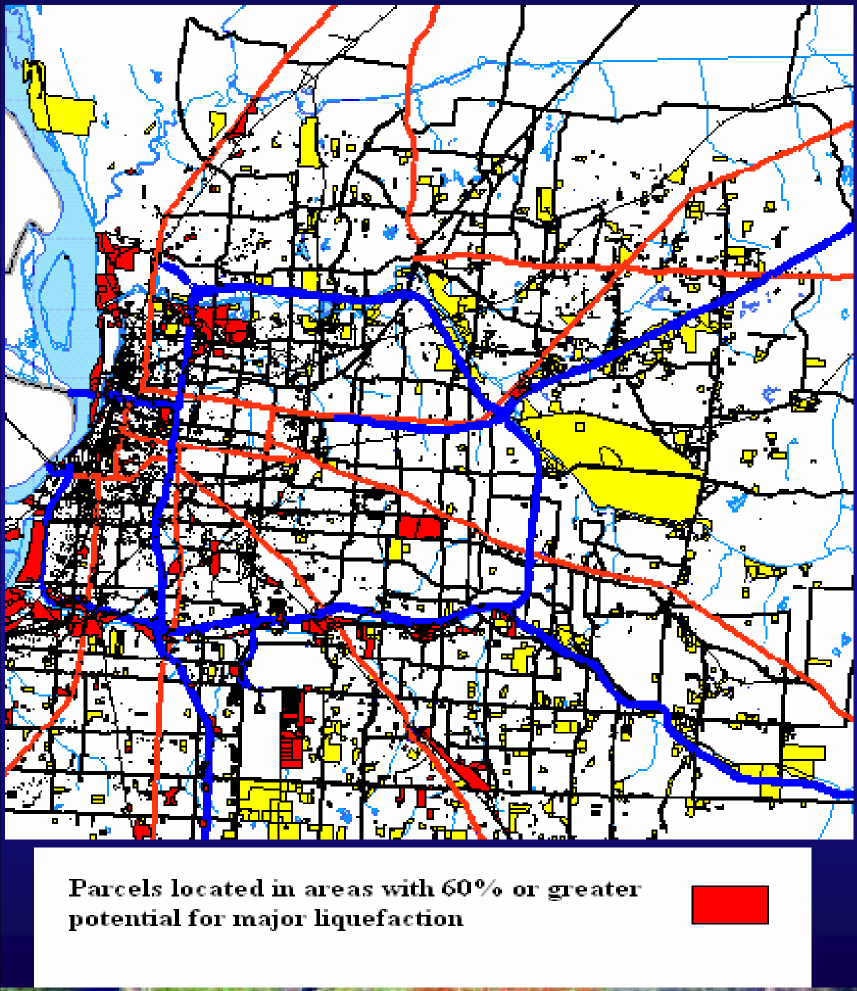
Liquefaction risk assessment:

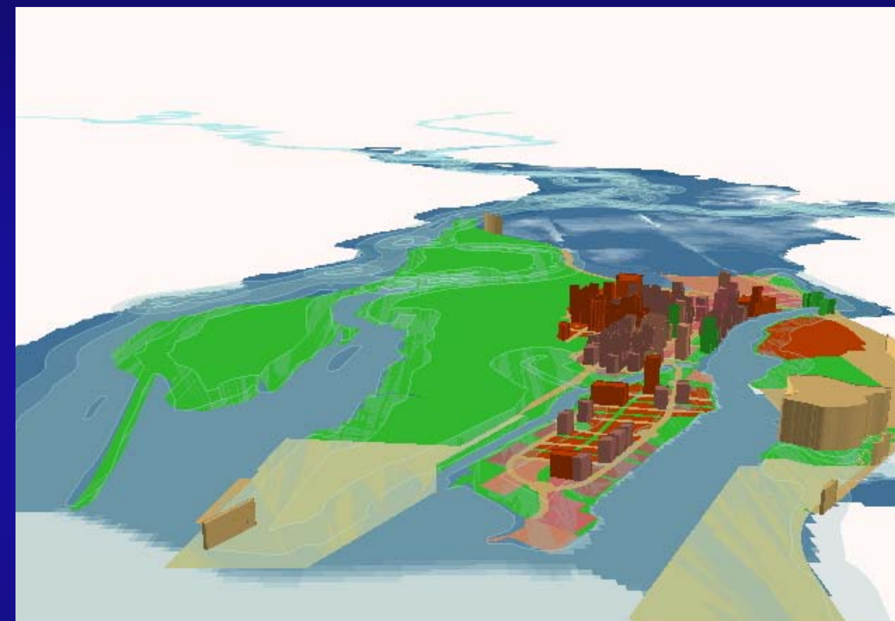
M_0 =7.7; asset value =$9.6B; n=11,976 parcels

Scenario	1	2	3	4	5	6
Inputs Exposure ($B)	2.5	2.5	2.5	2.5	2.5	2.5
EQ prob	1.0	1.0	0.002/yr	1.0	0.002/yr	0.002/yr
Time horizon	1	1	20	1	20	50
% mit	0.0	100.0	100.0	>60% sites	>60% sites	>60% sites
Mit cost ($B)	0.0	0.75 (10%) 2.25 (30%)	0.75 (10%) 2.25 (30%)	0.14 (10%) 0.42 (30%)	0.14 (10%) 0.42 (30%)	0.14 (10%) 0.42 (30%)
Outputs Wealth retained ($B)	7.1 (74%)	9.6 (100%)	9.6 (100%)	8.7 (91%)	9.5 (99%)	9.4 (99%)
ROI	n/a	3.27 (10%) 1.09 (30%)	0.13 (10%) 0.05 (30%)	11.7 (10%) 3.9 (30%)	0.5 (10%) 0.2 (30%)	1.2 (10%) 0.4 (30%)
Acceptable risk ($B)	2.5	0.0	0.0	0.8	0.3	0.1



Counting the Cost: The Economic Consequences of Development in the Squamish Flood Plain

(R. Bernknopf, R. Champion, J. Jones, P. Ng, A. Wein, M. Jouneay, C. Chung, and S. Talwar)



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.

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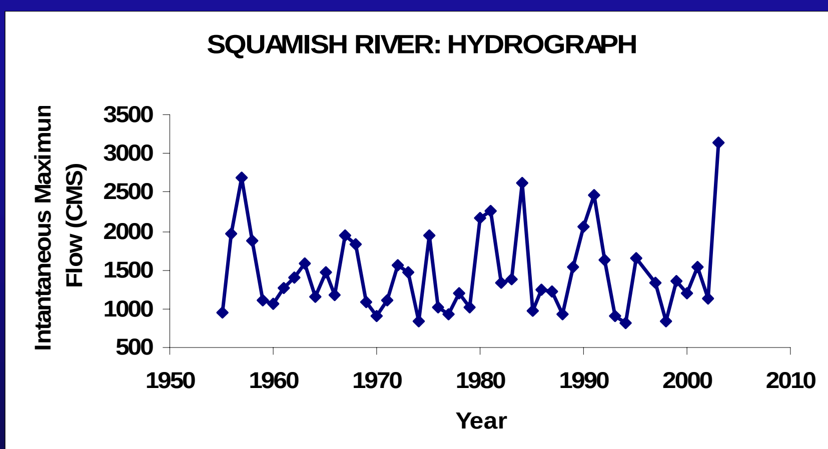
The Municipality of Squamish is vulnerable to multiple hazards

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

Hazard	Prob 25 years	Loss Million CAN$s	Odds Ratio	Loss Ratio
Debris Flow	0.08%	12	1	1.0
Earthquake	2.25%	40	28	3.3
Flood	11.00%	91	138	7.6



Downtown Squamish: 1921

Major flood events: 1921, 1940, 1955, 1968, 1975, 1980-1984, 1989-1991, and 2003

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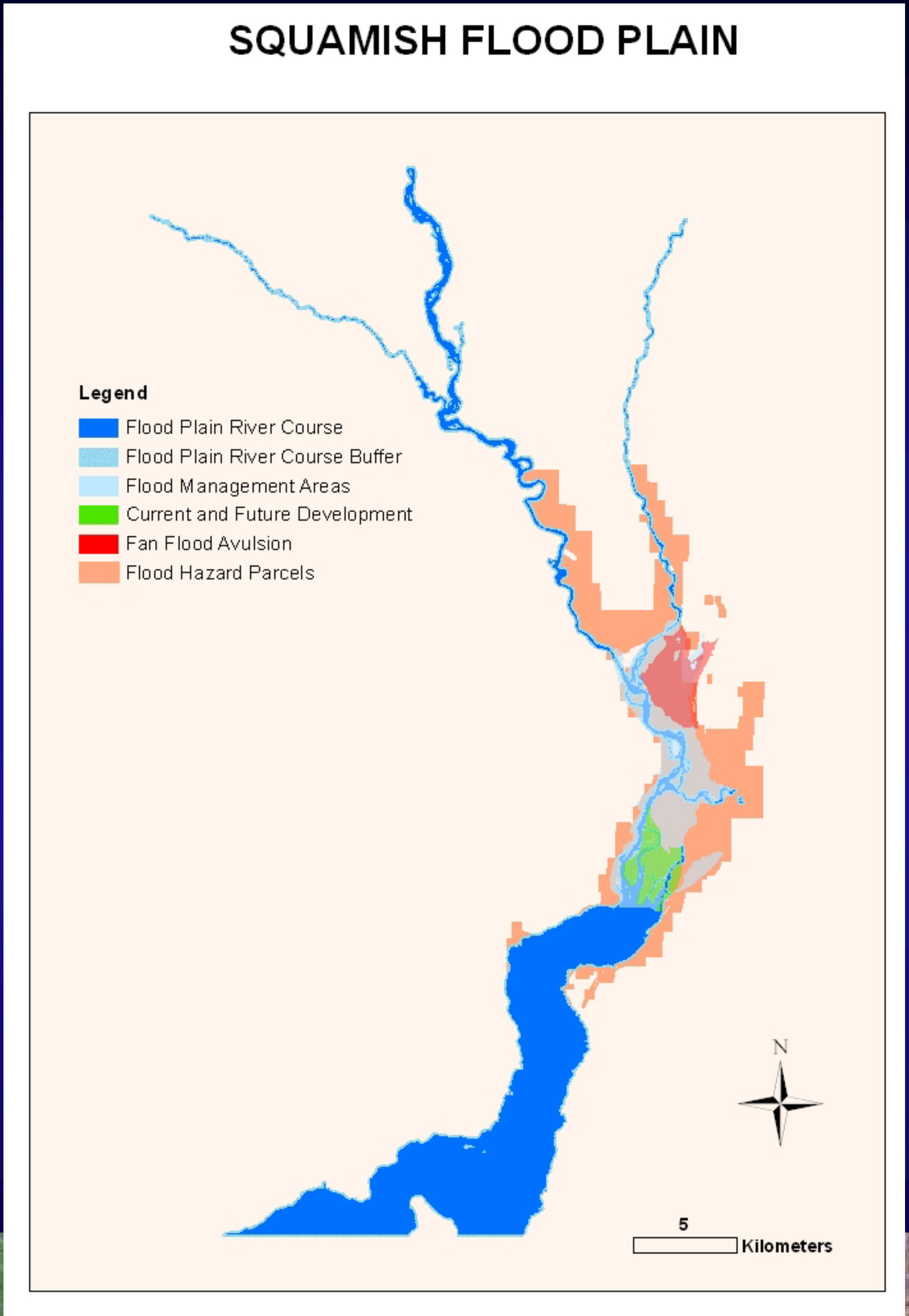
The Municipality will accommodate the expanded population by allowing building in the flood plain and by mitigation.

What are the socioeconomic consequences of this decision?



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Hazard and Mitigation Scenario 1

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

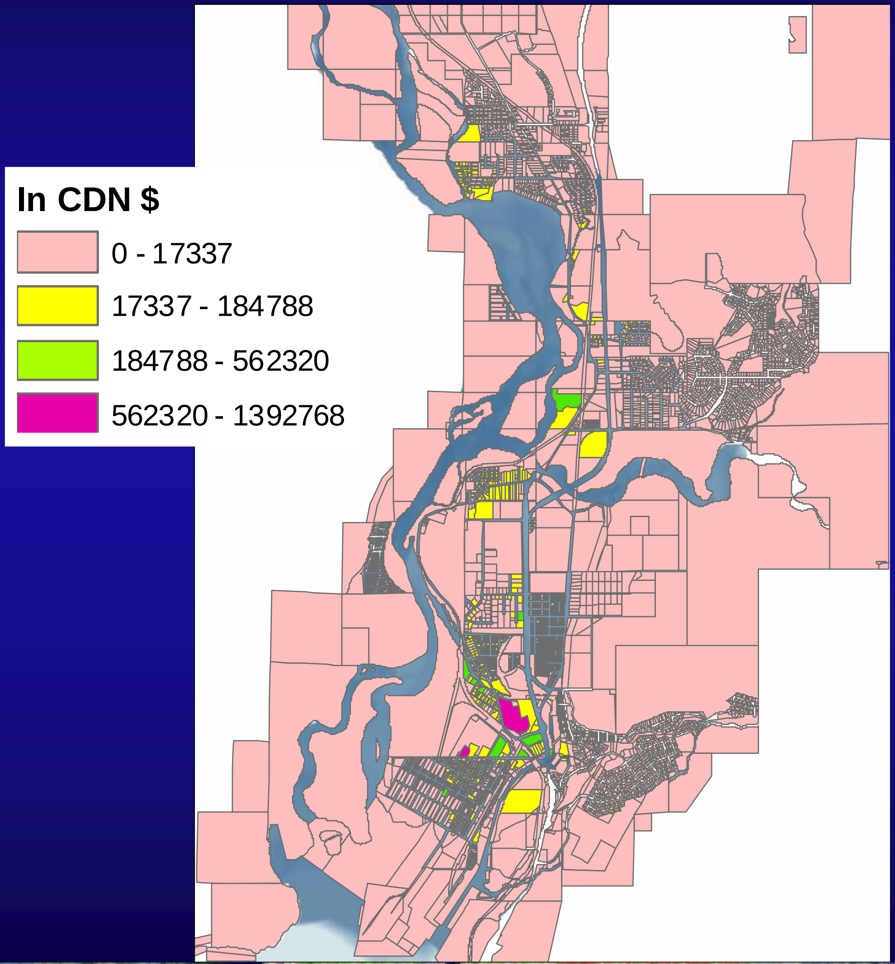
Outputs

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

Caveats

- Accounted for damage from at most 1 flood
- Flood damage is for a 20 year flood

Expected Losses



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Hazard and Mitigation Scenario 17

- Inputs
- Future land use plan
- 20 year flood
- 25 year planning horizon
- No mitigation
- Structural value (2004) + average assessed improved value (2005)

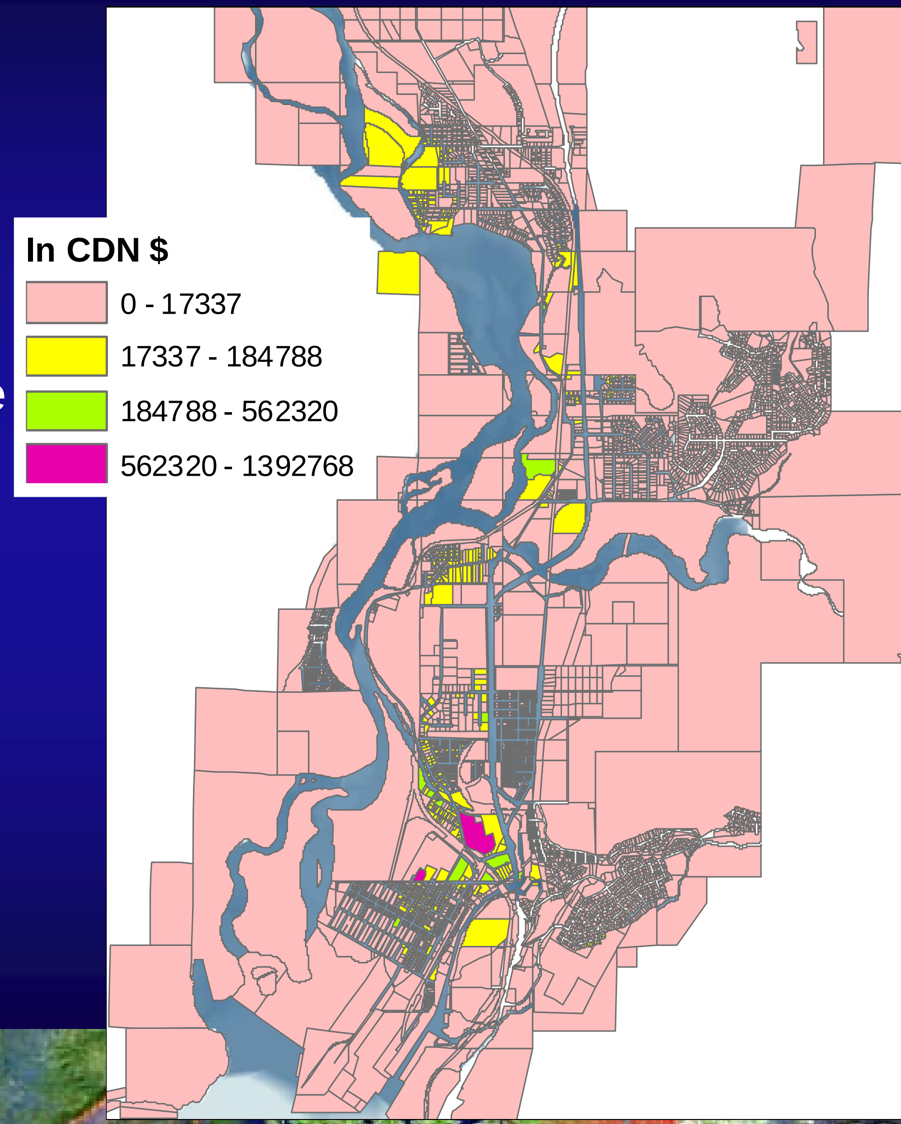
Outputs

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

Caveats

- Accounted for damage from at most
  1 20 year flood

Expected Losses



Hazard and Mitigation Scenario 29

- Inputs
- Future land use plan
- 200 year flood
- 50 year planning horizon
- Total value (2004) + average assessed total value (2005)
- Mitigation cost: $100 million

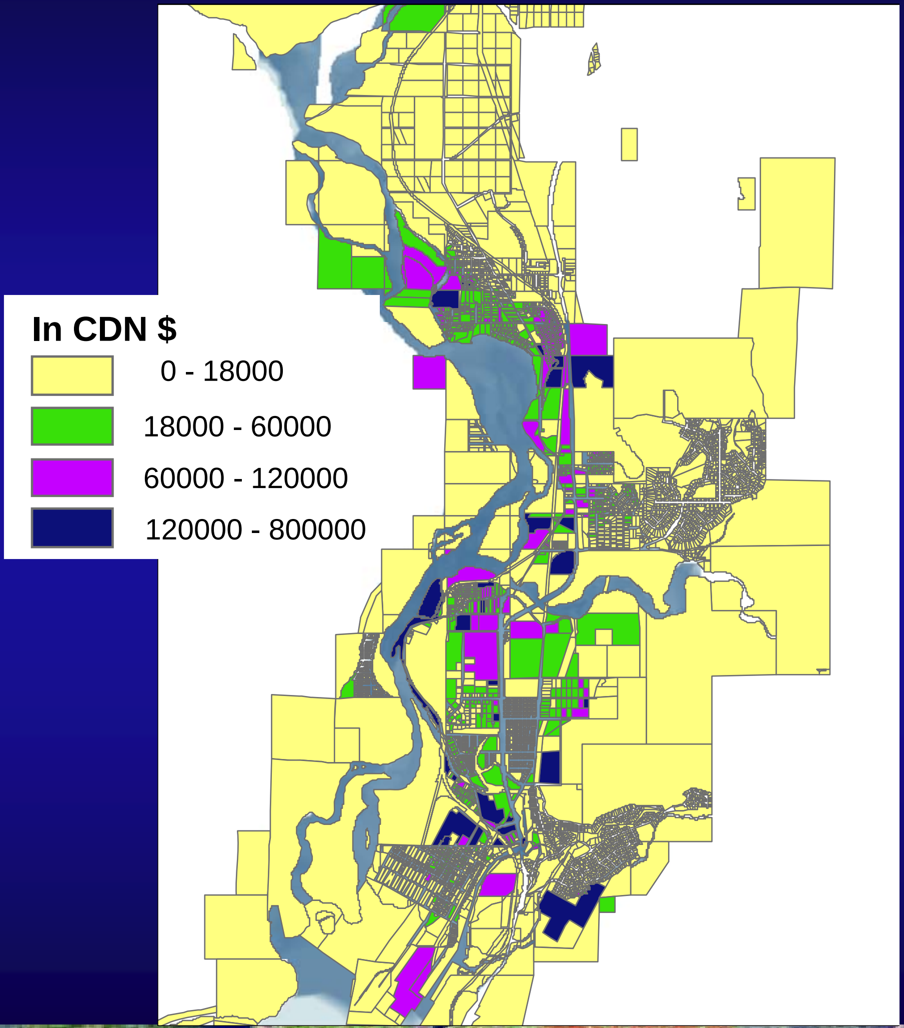
Outputs

- 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

Expected Avoided Losses



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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

USGS

April 2006

Approach

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

Behavioral model

Value of updated and more detailed information to society

Vintage and resolution of geological bedrock maps

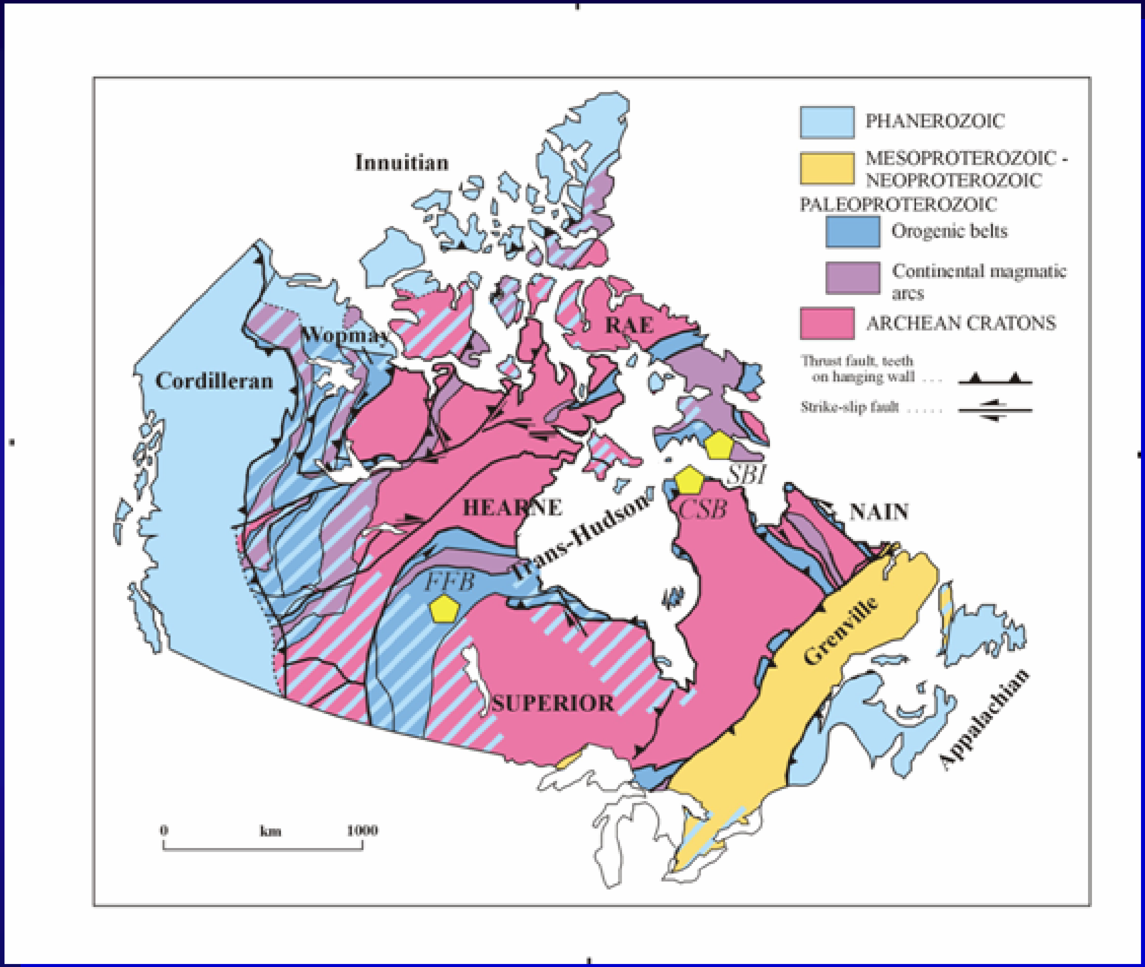
Mineral exploration decisions consider the productivity, efficiency, effectiveness, risk, and budget of locating targets

Effect of better information on initial exploration investment
- - - - -▸ society

Case Studies

	Flin Flon Belt	*South Baffin Island*
Exploration Status	Mature	Frontier
Perspective	Hindsight	Predictive
Reference area	Itself	Geologically analogous area: Cape Smith Belt (St-Onge et al. 1999, 2001, 2002)
Exploration campaign results	Productivity & efficiency Effectiveness Risk	Productivity & efficiency Effectiveness Risk Value of information
Map comparisons	Old coarser resolution Updated coarser resolution Updated finer resolution	Old coarser resolution Updated finer resolution

Case Study Locations



FFB: Flin Flon Belt

CSB: Cape Smith Belt

SBI: South Baffin Island

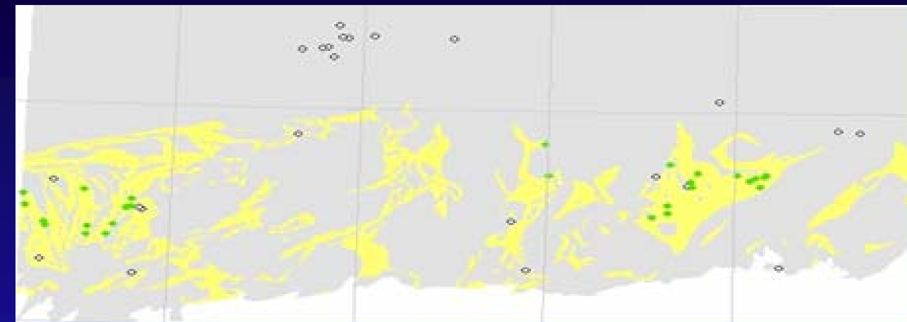
Flin Flon Mineralization Favorability Maps

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

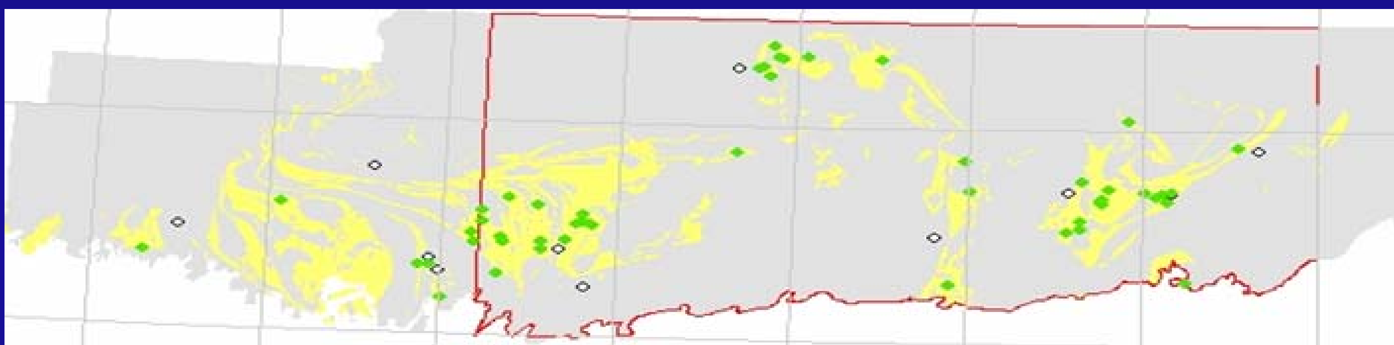
Bailes 1971
1:253,440

Old coarser resolution



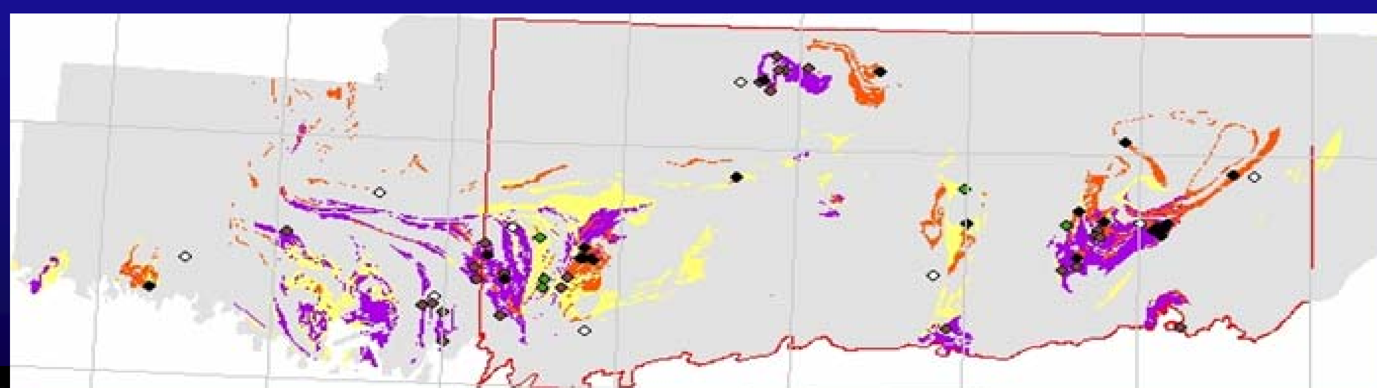
NATMAP 1998
1:325,000

Updated coarser resolution



NATMAP 1998
1:100,000

Updated finer resolution

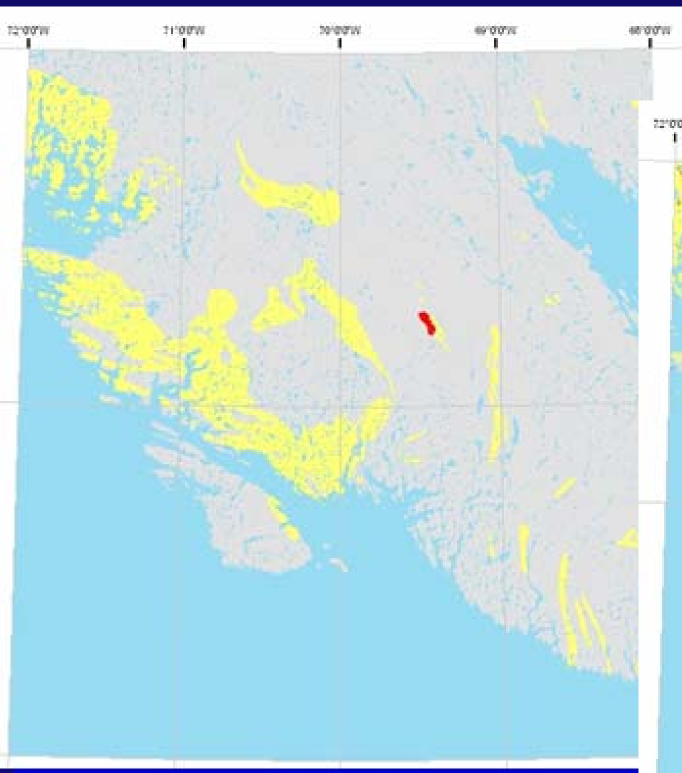


South Baffin Island Mineralization Favorability Maps

Legend

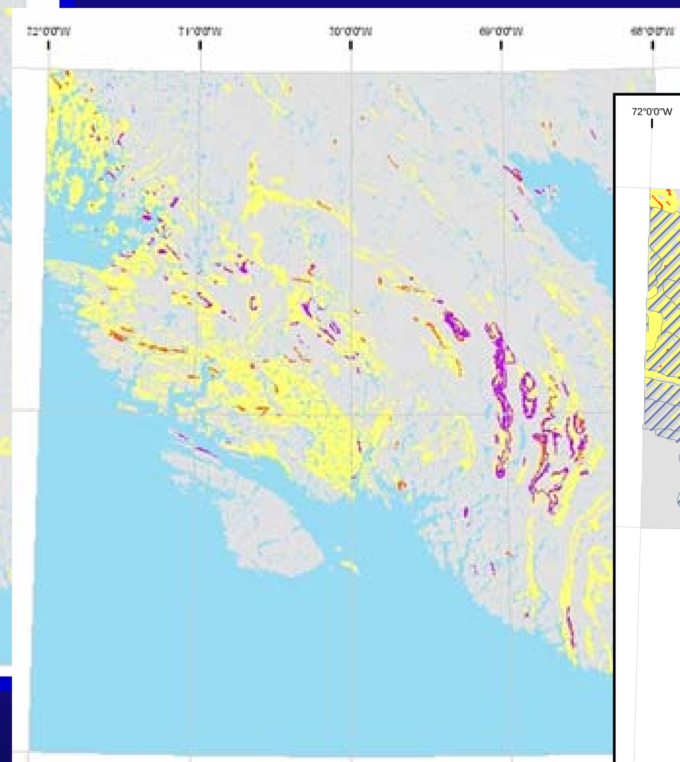
- Old map favorability 1 and 3 domains
- Map favorability 3 domain
- Map favorability 2 domain
- Map favorability 1 domain
- Map favorability 0 domain

Old coarser resolution



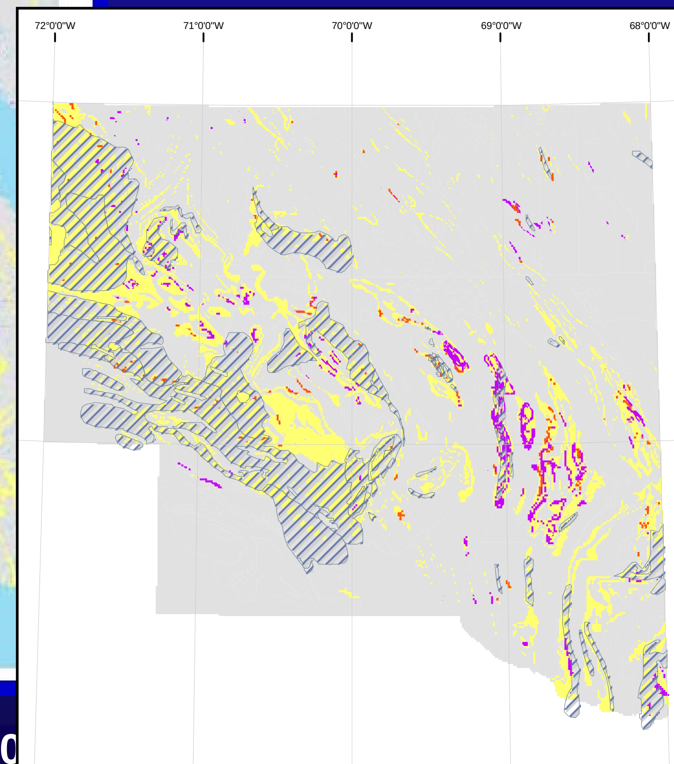
Blackadar 1967, 1:506,000

Updated finer resolution



St-Onge et al.1999, 1:100,000

Old vs. Updated



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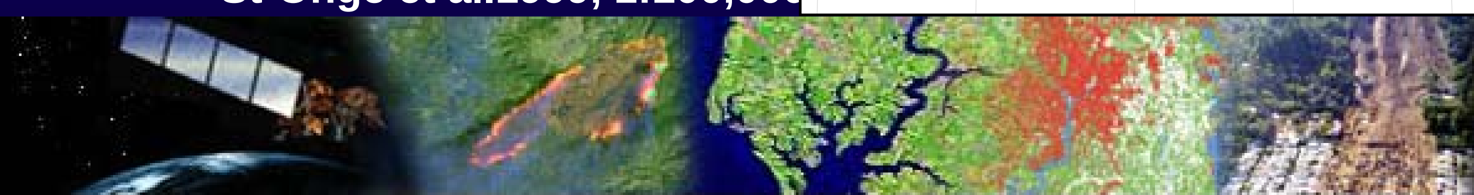
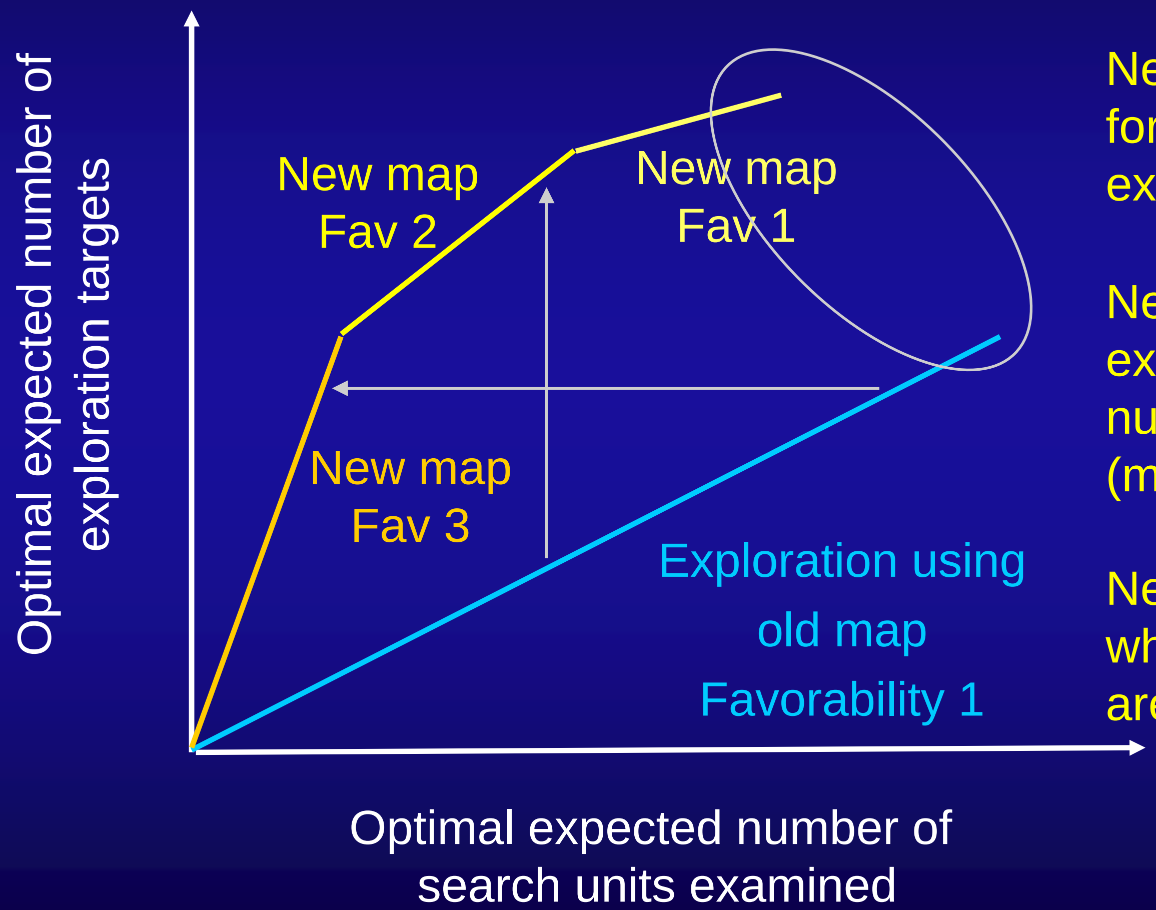


Map comparisons of expected exploration efficiency, productivity and effectiveness



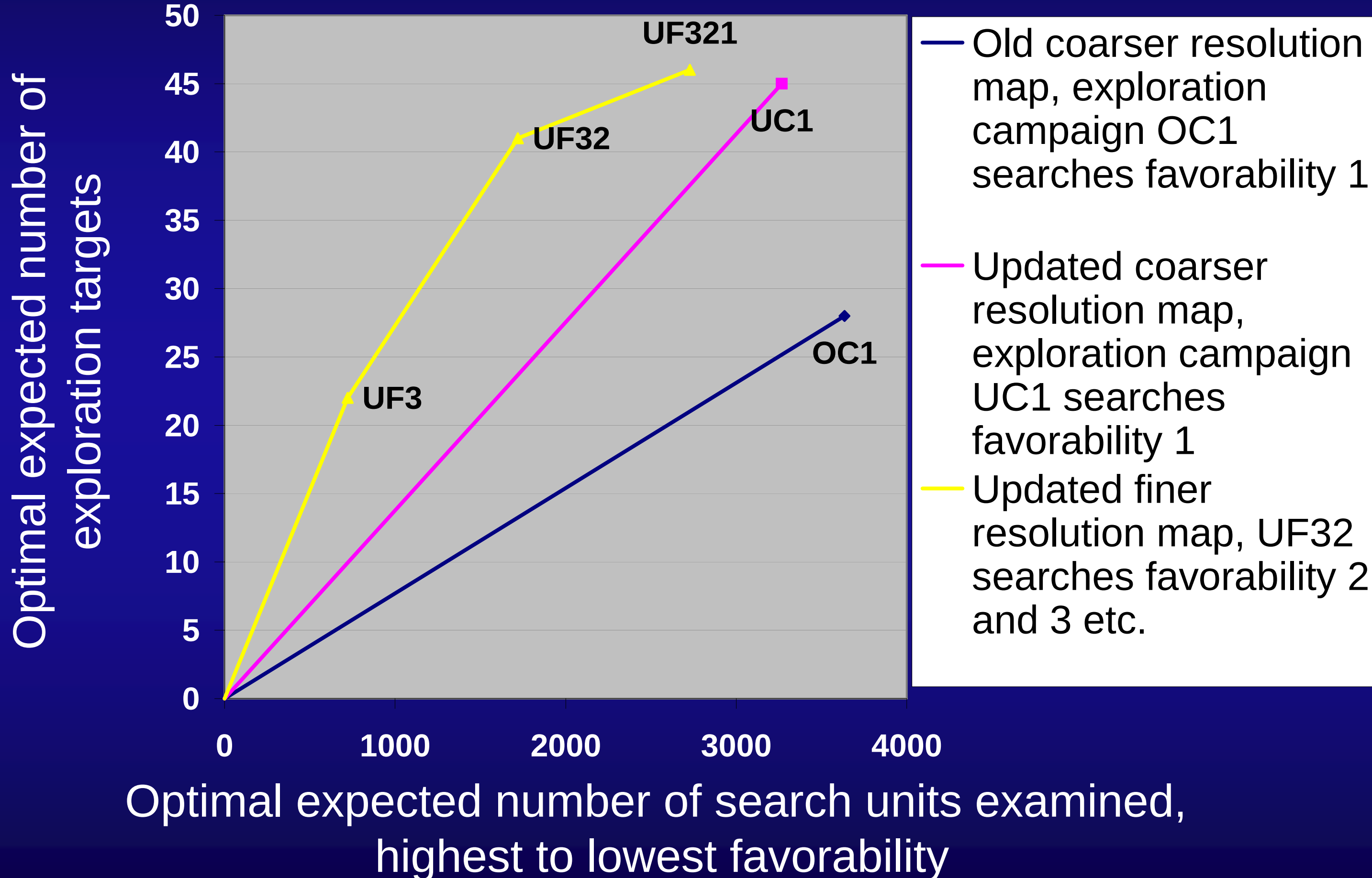
New map locates more targets for any number of search unit examinations (more productive)

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

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

Results: Flin Flon map comparisons of expected campaign efficiency and productivity

Continuums of expected exploration outcomes



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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

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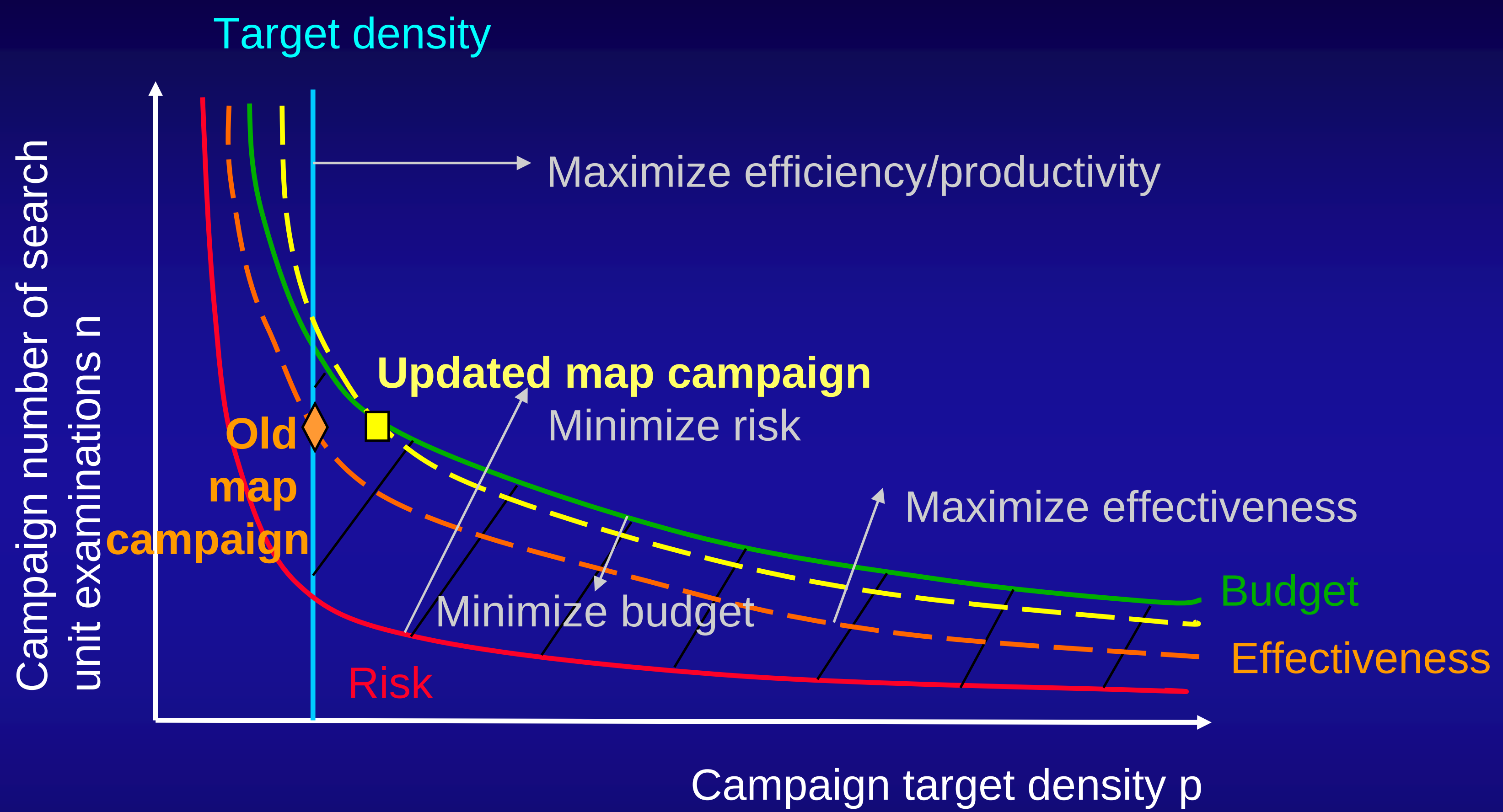
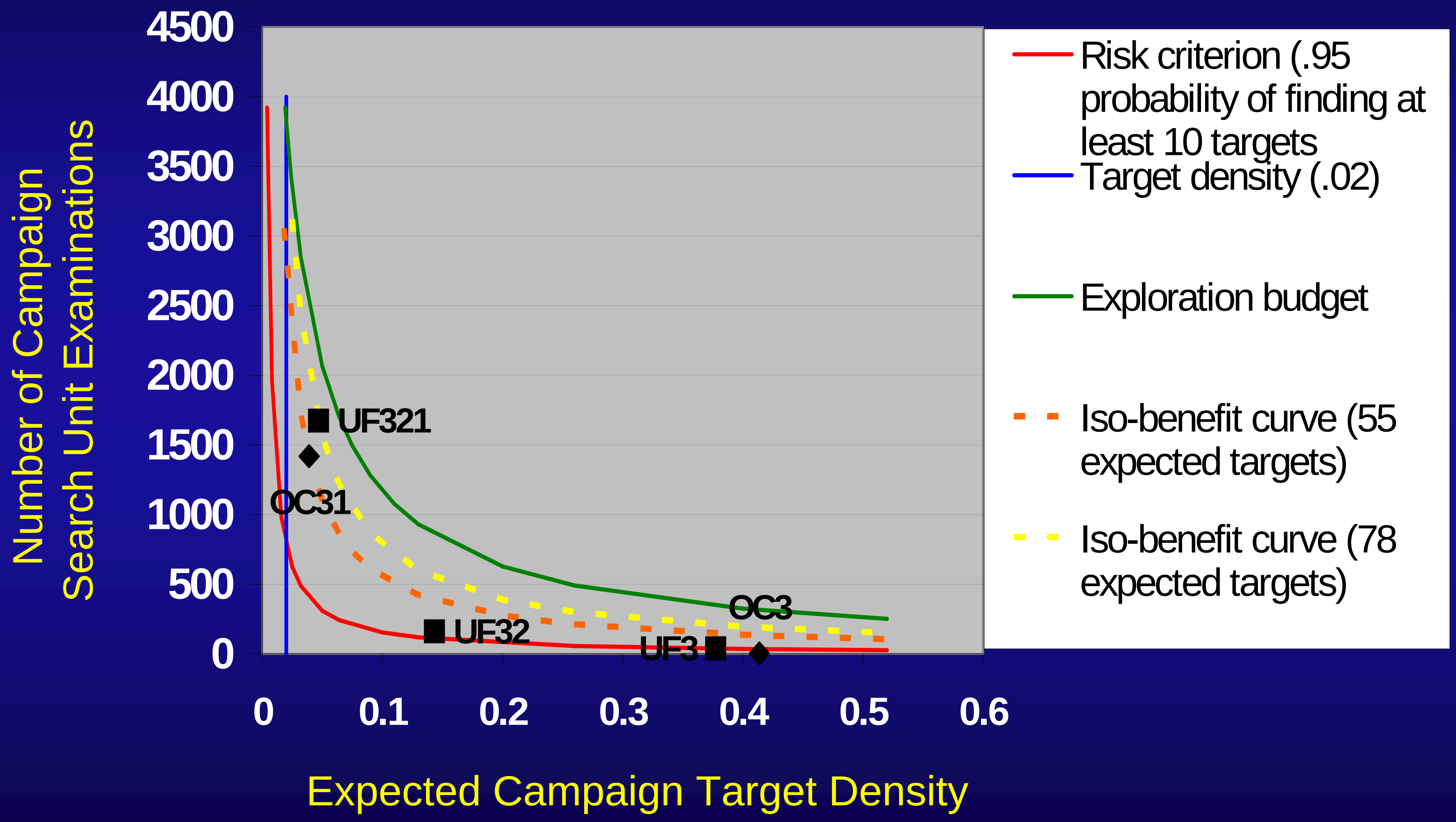
Decision Model



Decision Model Results for South Baffin Island



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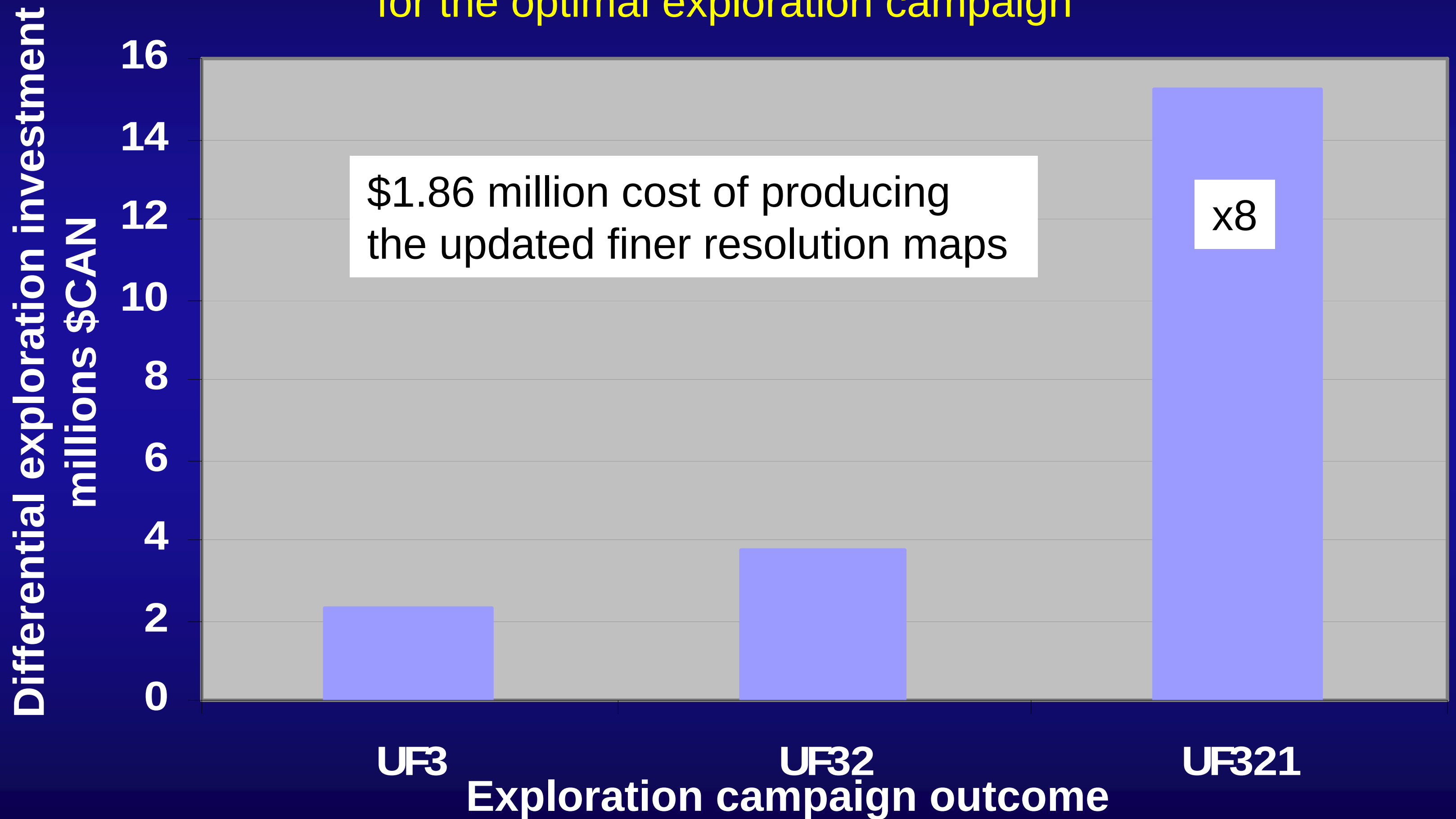
Investment Advantage of Updated Information for South Baffin Island

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



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

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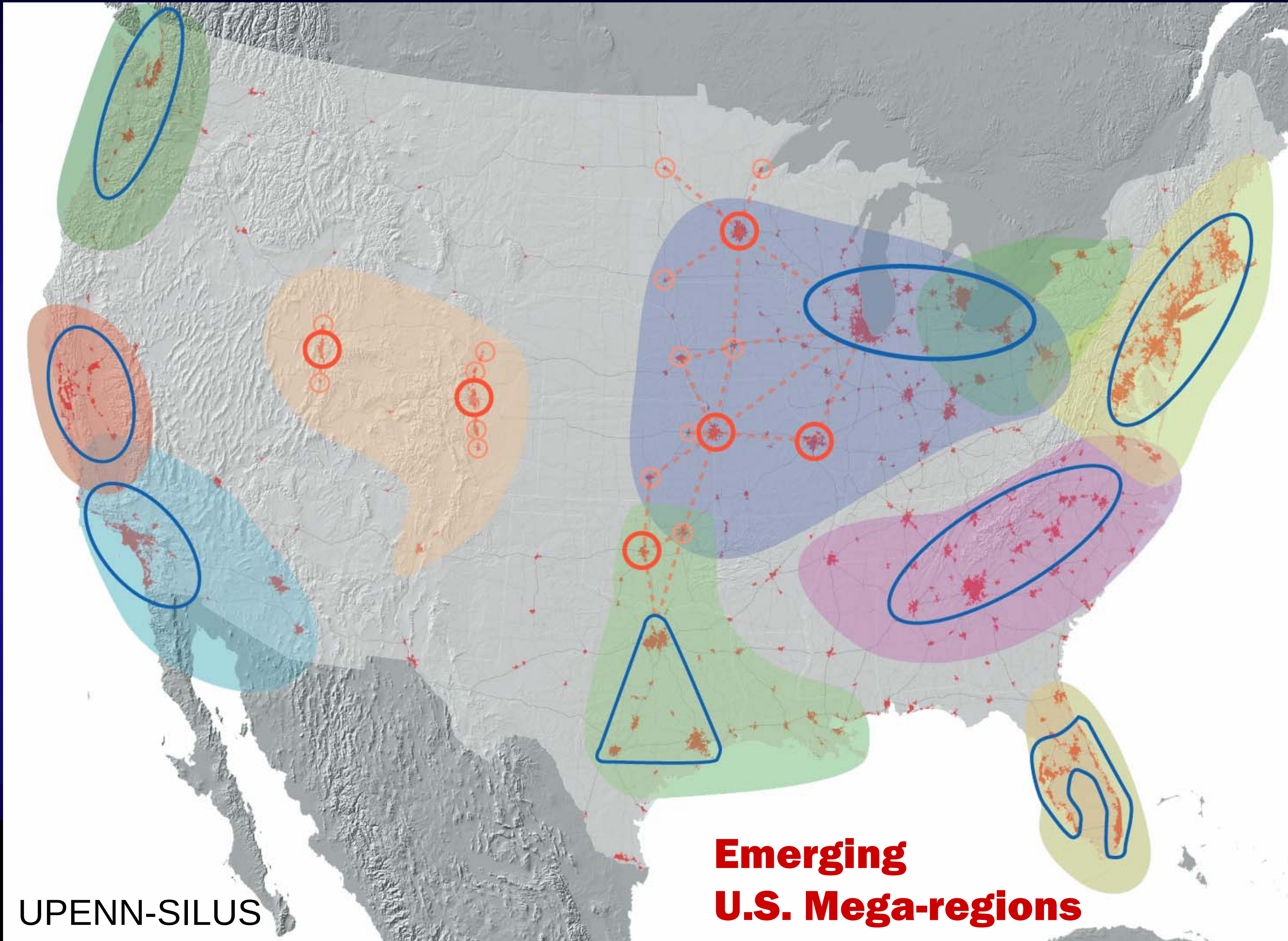
Metropolitan Growth 2002-2025

UPENN -SILUS


UPENN-SILUS
Emerging
U.S. Mega-regions

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