Scenario-Based Risk Analysis within an Analytic-Deliberative Framework for Regional Risk Reduction Planning

Wein, A.M. [1], M. Journeay [2] and R.L. Bernknopf [1]

[1] Western Geographic Science Center, United States Geological Survey, Menlo Park, California
[2] NRCan/Earth Sciences Sector/Geological Survey of Canada-Pacific Division, Vancouver, BC
Email: awein@usgs.gov

Keywords: *analytic-deliberative, regional risk, natural hazards, risk reduction planning, scenarios*

EXTENDED ABSTRACT

The potential benefits of tighter coupling between risk reduction and comprehensive land use planning have been well-documented (Burby 1998). However, community planning that promotes safety and growth is not fully practiced in the United States and Canada (e.g., IBHS, 2007). To improve the integration, the Geological Survey of Canada, with contributions from the United States Geological Survey, is designing "Pathways," an analytic-deliberative framework for regional risk reduction planning. A case study partnership with the municipality of Squamish, British Columbia is enabling ongoing refinement of the framework (Journeay et al. 2007).

An analytic-deliberative approach to decision–making is a collaborative process, promoted by the US National Research Council that is decision-driven and accesses scientific information to inform public discourse (Stern and Fineberg, 1996). Deliberators include scientists, public officials and affected parties. Stages of the analytic-deliberative approach for the Pathways risk framework are: 1. Problem formulation, 2. Risk assessment (risk characterization), and 3. Alternate risk reduction strategies, and 4. Policy recommendations (risk reduction planning). The Pathways analytic-deliberative approach includes a suite of analytic tools and deliberative processes. The Pathways risk framework utilizes natural hazard scenarios (defined by hazard type, magnitude and location, settlement pattern, and risk reduction strategy) to communicate economic, social and ecologic elements at risk.

Within the framework, we propose a scenario-based risk analysis to accommodate stakeholder risk metrics and decision criteria. Although expected loss is a commonly used risk metric, other measures of risk derived from the distribution of potential outcomes (a "risk curve") may be more appropriate to prioritize and compare mitigation alternatives. Methods to calculate occurrence probabilities of representative scenarios within and across hazard types are needed to construct the risk curves.

1. INTRODUCTION

The Institute for Business & Home Safety (IBHS) surveyed certified community planners in the USA and found that local comprehensive or general plans in most communities fail to recognize the potential impact of natural disasters, making communities more vulnerable to damages when extreme events occur. The study reports that a typical community plan has fewer than 40 percent of the features that are important for safe growth (e.g., a plan, natural hazard data and maps, community support, hazard policies, and implementation). Nearly a quarter of community plans assessed did not include hazards at all (IBHS 2007).

Various factors contribute to decoupled comprehensive community and risk planning: lack of state, regional and local laws, lack of public demand and funding, currently accepted practices for planners to defer safety issues to emergency-management departments, conflicting objectives including quality of life, economic growth, preservation of environmentally sensitive areas, and inaccessible, insufficient, misguided and overly rigid scientific and technical information and models that create disconnects between science and policy (Stern and Fineberg (1996), IHBS (2002), pers. comm., Planning department, Palm Springs, CA). We hypothesize that another factor is the potential investment payoff; investments that will provide benefits for certain (e.g., cutting a recreational trail) are easier to justify than uncertain benefits (e.g., hazard mitigation that may or may not be needed for a planning period).

The National Research Council study (Stern and Fineberg, 1996) outlined the elements of an analytic-deliberative framework to facilitate risk characterization, and risk-based planning. The analytic-deliberative approach is a decision-driven activity directed towards solving problems framed by stakeholders and informed by scientists and technical expertise. This view is echoed in the International Strategy for Disaster Reduction Risk framework (ISDR; 2002). While there is a need to continue refining our understanding of natural hazard processes (fundamental research), more work is needed to deepen our understanding of the analytic-deliberative process.

An analytic-deliberative process is a non-traditional perspective for organizations that historically supply scientific information about natural hazards such as the Geological Survey of Canada (GSC) and the United States Geological Survey (USGS). Recently, these federal agencies, with scientific and technical research agendas, have initiated interdisciplinary projects, with the objective of informing decisions to reduce natural hazard losses and risk while collaborating with and providing information to stakeholders (Wein and Bernknopf, 2007). One such project is the GSC-USGS collaborative project: "Pathways; an Analytic-Deliberative Framework for Risk Characterization and Risk Reduction Planning in Canada". In this paper, we describe the Pathways analytic-deliberative framework and explore the implications for conducting a risk analysis. The framework assumes that multiple natural hazard scenarios are used to communicate and evaluate community risks. The proposed scenario-based risk analysis assembles scenario results along risk curves to evaluate community defined risk metrics and acceptable risk, and to compare risk reduction strategies.

Figure 1. (Modified) analytic-Deliberative framework propos
council study (Stern and Fineberg, 1996)

base … the … a co… debris flows. We note that methods to calculate occurrence probabilities of representative scenarios within and across hazard types are needed to construct the risk curves.

2. ANALYTIC-DELIBERATIVE FRAMEWORK

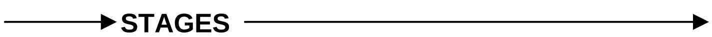
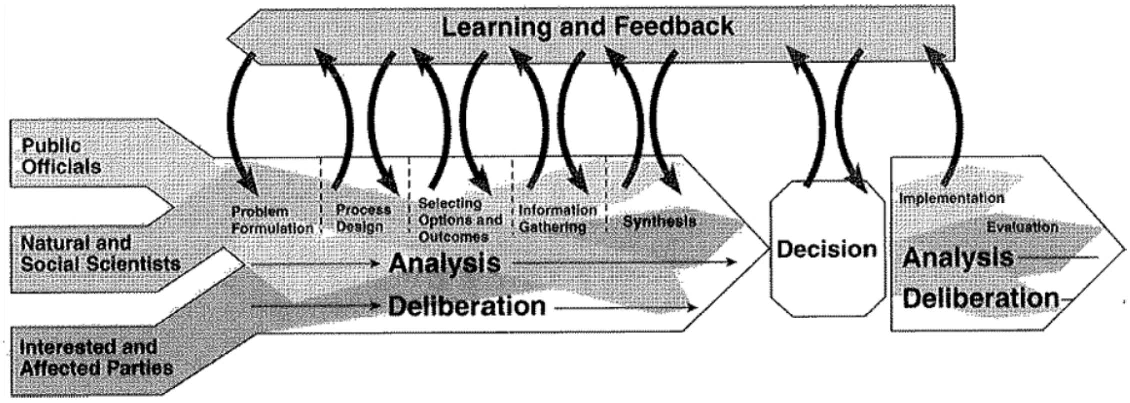


Figure 2. (Modified) Analytic-Deliberative framework proposed by U.S. National Research Council study (Stern and Fineberg, 1996)



A synoptic view of the National Research Council analytic-deliberative framework is illustrated in Figure 1. The key components are: 1. Stages of analysis and deliberation ranging from problem formulation to implementation, and 2. Deliberators including scientists, public officials and affected parties who interact, learn and provide feedback throughout the stages of deliberation. The Pathways version of the framework is described below. It is endowed with analytic tools and deliberative processes.

2.1. Analytic-Deliberative Stages

The analytic-deliberative stages of the Pathways risk framework are: 1. Problem formulation,
2. Risk assessment (risk characterization),
3. Analysis of alternate risk reduction strategies,
4. Implementation of risk-reduction priorities (risk reduction planning).

The problem formulation stage establishes the overall dimensions of risk for a community or region, and articulates the context and focus for the decision making process. Deliberative dialogue is used to:

- explore and profile known hazards in the region;
- document community risk guidelines and policies,
- document elements that are vulnerable and/or perceived to be at risk (physical and socio-economic assets);
- delineate the geographic extent and planning horizons for the risk assessment process;
- define risk objectives;
- determine key risk decisions and performance measures (risk indicators and acceptable risk targets) that will be used to evaluate risk reduction strategies and policy alternatives;
- evaluate (residential and commercial) growth potential over time.

The risk assessment stage provides an estimate of community economic, social and ecologic losses for natural hazard scenarios defined by the natural hazard (event type, location, magnitude and extent), the settlement pattern (existing and anticipated future conditions), and the risk reduction strategy.

The risk analysis and evaluation of alternatives stage assembles the risk assessments to compare hazard risks, and generate and evaluate strategies for reducing risks associated with existing and/or future settlement patterns through structural mitigation (dams, levees, deflection berms, building codes, etc), and/or adaptive land use management (zoning, design guidelines, best management practices, etc.). The risk reduction strategies are evaluated and compared using the performance measures identified during problem formulation. Multi-criteria decision analysis and cost-benefit analysis are used to explore trade-offs between competing societal priorities such as economic vitality, environmental integrity and socio-cultural fabric, and public safety.

The implementation phase of the process translates risk reduction strategies into policies to help guide shorter-term emergency preparedness and/or longer-term growth management and development activities. The policies are submitted to local and/or regional governments for review, approval and implementation within the overarching context of provincial and national risk reduction mandates and policies. The conventional mode of implementation is inherently rigid and not easily modified as new information and/or knowledge about the dimensions of risk become evident in a community or region. For these reasons, the implementation phase is viewed as an iterative process of adaptive risk management -- a planning paradigm that acknowledges the uncertainties inherent in risk characterization and reduction planning, and that seeks to increase the resilience and disaster response capacity of communities through uptake and adoption of evolving information, knowledge and expertise.

The specific trajectory of the analytic-deliberative process will depend on the scope of risk decisions that are relevant to each community or region, the range of hazards, vulnerability and risk analysis required to evaluate risk reduction alternatives, the information, knowledge and expertise available to the research team to engage in a full evaluation and analysis of these alternatives, and the political will of the decision makers to leverage the participatory planning process to develop and implement binding public policy and actions on the ground to reduce risks associated with continued growth and development in hazardous terrains.

2.2. Deliberators

The success of the analytic-deliberative process is influenced by the strength of the interdisciplinary collaboration and by the coherence of ongoing interactions between scientists, engineers, planners, policy analysts, and decision makers, as well as the various public and private sector interests they represent. These collaborations and partnerships are essential to gaining a shared understanding of key risk decisions, and articulating viable hazard mitigation and risk reduction strategies that balance community values against a negotiated set of indicators and performance measures.

The participatory process begins with, and is contingent on, jurisdictional approval for the risk reduction planning process by local and/or regional governments, including formal partnerships and resource allocations to assemble the necessary team, and a commitment to support the process in the development of strategies and draft policies for risk reduction. Decision-makers and stakeholders frame the problem and domain experts inform the problem. The scientific community creates models and tools to both describe and evaluate complex and coupled human-environmental system behaviour (and uncertainties), and to make this knowledge and expertise accessible and relevant to the needs of the decision making process. The planning/policy development community establishes guidelines for current and future land uses. Elected officials of a local and/or regional jurisdiction have the authority granted by their constituents to evaluate trade-offs between choices and consequences, and to make the difficult decisions on which policies to adopt and to enable through State, Provincial and/or Federal legislation. This is the arena where the potential is greatest to promote risk reduction and disaster resilience as part of an ongoing comprehensive planning process.

The Municipal Council for the District of Squamish have agreed to participate in the Pathways process. The implementation of the framework is in the first stage.

2.3. Pathways Analytic Tools and Deliberative Processes

The Pathways team have assembled a suite of analytic tools to support "what if" scenario building, risk assessment and analysis, and multi-criteria decision making. Commercially available software applications (e.g., CommunityViz) have been utilized to enhance the uptake and use by planning and GIS professionals. Multi-criteria decision tools are poised to evaluate the trade-offs between risk reduction and community growth principles.

The Pathways team is leveraging expertise in community participation by collaborating with the "smart-growth on the ground" (scog) team to design surveys and structure workshops to elicit decision-directed input from deliberators and to maintain their involvement throughout the analytic-deliberative stages..

3. RISK ASSESSMENT IN AN ANALYTIC-DELIBERATIVE FRAMEWORK

An analytic-deliberative framework requires experts to anticipate and respond to the requests for scientific and technical information without dictating the formulation of the problem and the decision criteria; science-based decision support tools house scientifically sound methods that are flexible and able to accommodate feedback from stakeholders' deliberations. We acknowledge that defining risk metrics and acceptable risk is part of the process and not predetermined.

3.1. Defining risk

In regional natural hazard risk analyses, risk metrics tend to be assumed or proposed and evaluated, without consulting the decision-maker (e.g., Chang et al. 2000). Often natural hazard risk is defined as expected loss (the product of hazard event occurrence probabilities and associated losses). Expected loss has been referred to as the engineering definition of risk to differentiate it from the financial definition of risk (that measures the variability of the predicted outcome). In financial applications, such as portfolio theory, risk is measured by the standard deviation of the return on investment such that a financial portfolio may have a higher expected return, but be more risky.

Risk aversion to larger and extreme natural hazard events, suggests that those affected will be more concerned about the hazard events in the tail of the loss distribution (the events that are less likely, but incur larger losses and more severe consequences). Measures that accommodate assessment of the tail of a distribution are asymmetric risk measures that include: the semi-variance, the 90th percentile, the probability of exceeding a threshold value, and/or expected weighted loss (a larger weight is applied to larger losses). Preserving the distribution of predicted losses for a hazard type, maintains the flexibility to calculate expected loss and asymmetric risk metrics.

3.2. Defining acceptable risk

Selected risk metrics need to be consistent with the community's concept of accepted or tolerable risk. Some perspectives on acceptable risk are discussed in Hunter and Fewtrell, 2001:

- Currently tolerated: risk that is no worse than the current risk is acceptable.
- Improvement of current: any decrease in the risk is acceptable.
- Intolerable probabilistic threshold: the probability (of a specified loss) below a threshold probability is acceptable.
- Benefit-cost: risk is deemed acceptable relative to the cost of reducing the risk.
- Public acceptance and political resolution: deliberative approaches determine acceptable risk (beyond what may be quantifiable).

More than one of these perspectives may be in effect. For example, there may be a hierarchy of acceptable risk; a probabilistic risk tolerance threshold may be enforced, (for example, a community cannot be built in the zone of 1:10,000 annual probability of landslide occurrence (B.C. Supreme court, 1973)), but decision-makers may use a cost-benefit analysis to justify further investments in risk reduction.

3.3. Risk-assessment methods

Regional risk assessments can be performed using probabilistic hazard maps or probabilistic hazard scenarios. For earthquakes, probabilistic seismic hazard maps of ground motions incorporate all possible damaging earthquakes to arrive at a level of shaking that has a given probability (e.g, Tianquin et al 2003). The maps are suitable for *independent* site specific damage risk analysis and mitigation decisions (such as building codes). A set of representative probabilistic hazard scenarios, their likelihoods, and regional loss estimates provide the basis for a scenario-based risk assessment. A scenario-based risk assessment captures correlated and interdependent effects of individual site damages (i.e., the consequences of the damage at one site is not only contained to that site, such as lifeline damages) and/or regional mitigation solutions (i.e., the mitigation decision is not contained to a single site, such as levee construction). Loss estimation tools, HAZUS-MH and EmerGeo, provide an expanding capability to estimate a suite of direct and indirect losses for a specified hazard event scenario for various mitigation options, but we are unaware of a community planning tool that can accommodate user-defined planning horizons, risk metrics and acceptable risk, and integrate loss estimates for multiple hazard scenarios into a risk analysis.

4. SCENARIO-BASED RISK ANALYSIS

To compare risk reduction strategies, the USGS Land Use Portfolio Model (Bernknopf et al. 2006) is being enhanced to combine the scenario loss estimate results into a scenario-based risk assessment and analysis. Estimated losses for natural hazard scenarios graphed against their likelihoods communicates the range of potential losses for a hazard type and the relative likelihood, losses and risks of multiple natural hazards. For example, four hazard scenarios for the municipality of Squamish are plotted in Figure 2. The GSC compiled scientific information about natural hazards from private geotechnical studies and the Earth Sciences Sector of Natural Resources Canada. EmerGeo was utilized to calculate building damages for a selection of natural hazard event scenarios. Inspection of Figure 2 shows flooding is the dominant natural hazard risk concern regarding estimated damages to the current building stock.

.

Hazard probabilities are often reported as exceedance probabilities (the probability of exceeding a magnitude or level of severity), which is compatible with plotting scenarios along a risk curve (Kaplan and Garrick, 1981). For example, Chang et al. (2000) used 47 earthquake scenarios and "hazard-consistent probabilities" to derive a risk curve of probabilistic earthquake scenarios to evaluate bridge damages and highway system performance. Figure 3 illustrates an application of the risk curve to community planning derived from an extrapolation of the two Squamish flood scenario results and hypothetical effects of two flood mitigation options: an expensive community-wide construction project (e.g., dykes) and a less expensive site specific project (e.g., flood-proofing buildings).

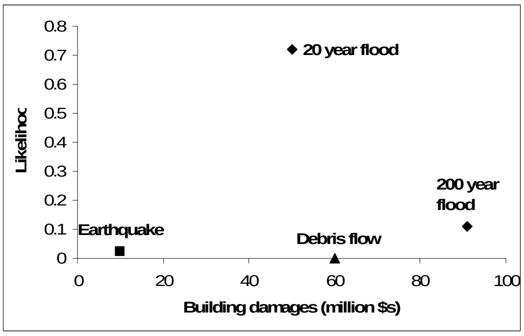


Figure 2. Likelihood (probability of at least 1 hazard scenario over 25 years) and severity (building replacement costs) of multiple natural hazard scenarios in Squamish

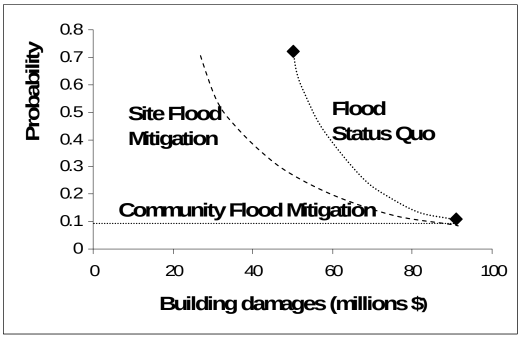


Figure 3. Flood risk curve of the status quo and 2 hypothetical mitigation alternatives: Community mitigation is a large expensive project (e.g., levee) that can fully protect the community up to a design flood; site mitigation is less expensive and protects selected structures (e.g., building flood-proofing)

The areas under the risk curves represent expected losses for the unmitigated and mitigated flood hazard. Risk curves closer to the origin (e.g., the mitigation options in Figure 3) indicate lower expected losses. The tail of the risk curve can be inspected for intolerable losses and acceptable risk. Asymmetric risk metrics, derived from the tail of the risk curve, ensure that while smaller events have been protected against, larger events have not been made worse. For example, mitigation that encourages more people to settle in a region increases the devastation to the area when the mitigation fails (the paradox of safe development (Burby, 2006)). This would be the case in Figure 3 if the community mitigation option were coupled with denser development in the Squamish floodplain.

4.1. Risk-return analysis

Risk curves (with and without mitigation) and mitigation costs are the necessary ingredients to conduct benefit-cost and/or return on investment risk analyses of quantifiable benefits (including reduced replacement cost, loss of life, business interruption, and/or productivity loss). The return on the investment for a hazard event (the loss avoided divided by the cost of the investment) is affected by the magnitude of the hazard scenario event. Greater hazard magnitudes typically occur with decreasing likelihood such that return on mitigation investment is affected by the hazard magnitude, and is probabilistic. Figure 4 demonstrates that the expensive community mitigation alternative has the biggest returns for the larger less likely events (i.e., more losses are avoided), but the probability of receiving larger returns decreases with the probability of larger events. The cheaper site specific mitigation alternative is more efficient for smaller more likely events; the probability of a larger return on investment is linked to the greater likelihood of smaller events.

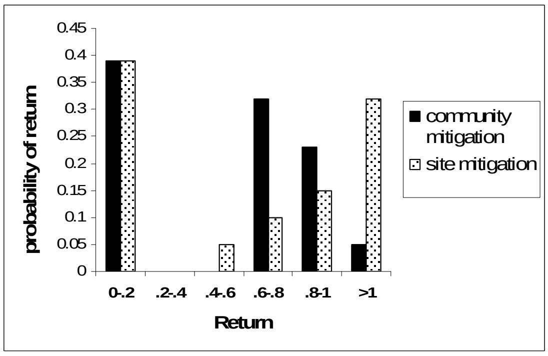


Figure 4. Distribution of return on investment for hypothetical expensive community and cheaper site mitigation alternatives

The expected return on a mitigation investment can be calculated from the distribution of returns. The financial risk (e.g., 0 return) involves both ends of the risk curve because the investment risk resides in the possibilities of no or insignificant hazard events and failed mitigation investments due to an extreme event exceeding the mitigation design criteria.

4.2. Issues

In this section, we highlight implementation and methodology issues regarding the number and type of representative scenarios to evaluate and the calculation of the representative hazard events probabilities within and across hazard types.

The number of representative hazard scenarios: A large number of scenarios can be evaluated when information about the hazard events is available and programmable models are available to transform the hazard information into damages and losses; a scenario-based risk analysis is limited by the availability of hazard event data and/or the capability to generate damage and performance outcomes. Initially, the municipality of Squamish has spatial information for two floods. In this case, the 20 year and 200 year floods are representative of an anticipatable event and a disaster. During problem formulation, deliberators need to identify the set of representative scenarios (i.e. how many and which hazard event scenarios cover the range of possibilities that are of regional interest and concern).

Estimation of hazard scenario occurrence probabilities within and across hazard types: Methods are needed to calculate hazard-consistent probabilities of occurrence for the set of representative scenarios (e.g., Chang et al. 2000). In addition, to perform a multiple hazard risk assessment and analysis, we should calculate consistent probabilities of hazard events across hazard types. Because natural hazards are typically studied independently of one another, there are some discrepancies between the reporting of hazard occurrence probabilities by the different science disciplines. Flood magnitudes are reported as return periods, meaning that a flood of a least a given size occurs on average every return period (e.g., a 20 year flood). An earthquake of a particular magnitude may be reported as an X% chance in Y years. We have found that spatial data on landslide occurrence probabilities can be scant.

5. DISCUSSION

The Pathways analytic-deliberative framework for risk characterization and risk reduction planning is designed to be decision-directed, responsive to stakeholder feedback and informed by scientific input and results from a suite of analytical tools. Natural hazard scenarios provide a tangible means to explore and communicate the consequences of multiple natural hazard events, and to scope out emergency response exercises (Wein and Bernknopf, 2007). We propose a comprehensive approach to combine scenario results into a scenario-based risk analysis that does not predetermine the community risk metrics and acceptable risk perspective. The risk curve preserves the distribution of losses across the range of potential hazard outcomes and can be used to derive risk metrics, communicate risk reduction priorities, compare risk-reduction alternatives, and conduct benefit-cost and return-on-investment analyses.

The interactive case study partnership allows for ongoing refinement of the framework based on a more informed understanding of stakeholder concerns and decision needs, and provides a basis for natural hazard scientists to be more informed about the decision contexts in which their scientific knowledge is used. The success of a community experiment will be evident in the uptake and use of the science-based model results in the formation of new policies, and/or adoption of the methodology, tools, indicators, and criteria by community planners.

Acknowledgement

Nathan Wood and Richard Champion provided comments that helped us improve the clarity and appearance of this presentation.

6. REFERENCES

Bernknopf, R., S. Rabinovici, L. Dinitz, and N. Wood (2006), The Influence of Hazard Models on GIS-Based Regional Risk Assessments and Mitigation Policies, International, *Journal of Risk Assessment and Management*, 6(4/5/6), 369-387.

Burby, R. J., Ed. (1998), Cooperating with Nature; Confronting Natural Hazards with Land-Use Planning and Sustainable Communities, *Natural Hazards and Disasters*, Washington, DC, Joseph Henry Press.

Burby, R.J. (2006), Hurricane Katrina and the Paradoxes of Government Disaster Policy; Bringing about Wise Governmental Decisions for Hazardous Areas, *Annals of the American Academy of Political and Social Science*, 604(1),171-191.

Chang, S.E., M. Shinozuka, and J. E Moore (2000), Probabilistic Earthquake Scenarios: Extending Risk Analysis Methodologies to Spatially Distributed Systems, *Earthquake Spectra*, 16(3), 557-572.

CommunityViz, http://www.communityviz.com

EmerGeo, http://www.emergeo.com

HAZUS-MH, http://www.fema.gov/plan/prevent-/hazus/ index.shtm

Hunter, P.R. and L Fewtrell, D.J. (2001), Acceptable Risk, Ch. 10 in Water Quality: Guidelines, Standards and Health, eds. L Fewtrell and J. Bartram, IWA Publishing, UK, 207-227

ISDR (2002), United Nations Inter-Agency Secretariat, Living with Risk; A Global Review of Disaster Reduction Initiatives, I.S.D.R. (ISDR), Editor. UN Publications, Geneva: Geneva, Switzerland, 387p.

IBHS (2002), Are We Planning Safer Communities? Results of a National Survey of Community Planners and Natural Disasters Institute for Business & Home Safety, http://www.ibhs.org/publications/downloads/289/pdf

Journeay, M., S. Talwar, B. Brodarick, and C-J Chung (2007), Pathways; an Analytic-Deliberative Framework for Risk Characterization and Risk Reduction Planning in Canada, Interim (draft) report, Natural Resources Canada, 114p.

Kaplan, S. and B.J. Garrick, H, (1981), On the quantitative definition of risk, *Risk Analysis*, 1, 11-27.

SCOG, http://www.sgog.bc.ca/

Stern, P.C., and H.V. Fineberg, Eds. (1996), *Understanding Risk: Informing Decisions in a Democratic Society*, National Research Council, National Academies Press: Washington, D.C. 264p.

Tianqing C., W. A. Bryant, B. Rowshandel, D. Branum, and C. J. Wills (2003), Revised 2002 California Probablistic seismic hazard maps, http://www.conservation.ca.-gov/CGS/rghm/psha/fault_parameters/pdf/2002_CA_Hazard_Maps.pdf

Wein, A.M. and R.L. Bernknopf (2007), Inter-disciplinary approaches to regional risk-reduction decision-making, *MODSIM* proceedings.