

# The Vulnerability of Science and the Science of Vulnerability

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The events of September 11th shocked the nation and painfully illustrated our vulnerability to international terrorist attacks. Despite some of the most sophisticated models, monitoring systems, and science in the world, officials were unable to anticipate and predict these cascading events. The collective scientific ability to geographically represent environmental threats, map exposures, and map consequences is relatively straightforward when the threats are recognized. But what happens when we cannot recognize threats or some of their unintended consequences? This article examines the twin issues of the inadequacies in our current modes of understanding (the vulnerability of science) and the need for more integrative approaches in understanding and responding to environmental hazards (vulnerability science). *Key Words: geographical understanding, hazards, September 11th, vulnerability.*

The organized complexity of modern existence is a new phenomenon in [hu]man's experience. Considering what has happened in the United States during the last century, one is tempted to ask whether we are living in a moment of great progress or of great aberration in the human adventure.  
—Thomas 1956 (xxxv–xxxvi)

Watching the tragedy of September 11th unfold on television highlighted the instantaneous globalization of an essentially local hazard event (albeit with national and international repercussions), an event similar to other rapid-onset hazards, such as major earthquakes. The terrorist hijackings, the collapse of the World Trade Centers, and the attack on the Pentagon resulted in the most costly disaster in the nation's history, yet the immediate disaster response employed the same procedures and activated the same emergency response plans that were already in place at the local, state, and federal levels for natural disasters.

Immediately following the initial rescue and relief phases of the emergency (after the first month or so) the questions began. Why did we not foresee this type of attack as a real threat? Why was the nation not more prepared for these types of terrorist attacks? When and where will this type of action occur again? How should the nation prepare for and respond to potential threats such as those manifested by the September 11th events? What constraints are there on such responses, both domestically and internationally?

The events of September 11th illustrate some of the shortcomings in our knowledge about the world we live in. Despite some of the most sophisticated models, monitoring systems, and science in the world, we were unable to effectively anticipate and predict the series of cascading impacts rendered by the attacks, nor were we able to completely understand and articulate the root causes of such actions. This article examines the twin issues of the inadequacies in our current modes of understanding (the vulnerability of science) and the need for more integrative approaches in understanding and responding to environmental hazards (vulnerability science).

## Why Is Science Vulnerable?

According to *Webster's Dictionary*, one of the definitions of vulnerable is "open to or easily hurt by criticism or attack." There are many ways in which science is vulnerable. I will only focus on a few that are most relevant to understanding environmental threats: assumptions of rationality and objectivity; expert versus lay judgments; inability to capture surprise; and the social construction of scientific practice.

## Objectivity and Rationality

The U.S. public readily turns to science for inputs relevant to hazards such as hurricane tracking or tornado

monitoring. One of the primary values of science is its power of explanation, which is then tested by prediction. The problem, from a hazards or risk perspective, is one of bounding. How can one calculate *all* the probabilities and contingencies associated with dangers and dangerous activities? This is impossible, for people are constrained both by the sheer volume of available information and by human cognitive abilities to process all of it. Therefore, the evaluation of risks (and dangers) is based on a narrower set of information and becomes a subjective process based on value judgments (Shrader-Frechette 1991) and other simplifying criteria. Decisions on what risks are acceptable (and to whom) often lead to the contested nature of risk assessment (as a formal process and practice) and the politicization of public policies to reduce or manage them (Cutter 1993). How do individuals and societies choose what risks to ignore and which ones to manage?

The rational-actor paradigm that is so prevalent in modern science is a Western worldview, one that presumes that humans are rational beings motivated by self-interest who consciously evaluate alternative courses of action to maximize individual reward (Jaeger et al. 2001, 23). As a theoretical starting point, this paradigm alone appears insufficient to explain the seemingly nonrational (at least from a Western perspective) behavior of suicide bombers and terrorists in the Middle East and elsewhere. On the other hand, if rational choice is construed in relative terms, then the context or framing perspective becomes important (Smelser 1998) and helps to explain the “irrational” outcome. For example, the same risky behavior (e.g., suicide bomber) would seem like a perfectly rational choice in one setting (disenfranchisement of Palestinian youth), but appear as totally irrational in another (American mass media). How does science explain this seeming contradiction?

### **Expert vs. Lay Judgments: How Safe Is Safe Enough?**

Another aspect of science’s vulnerability is the notion that scientific judgments about threats are always correct, while public perceptions of threats are misguided because they are fostered by the mass media and therefore are largely emotional. The result is conflict between what is termed actual or “real” risk based on some type of quantitative metric (normally measured by expected fatalities from the activity or technology in question) and “perceived” risk based on more qualitative assessments using a set of more expansive factors than just expected fatalities (Freudenburg 1988). The former often are called “expert views,” the latter “lay judgments.”

Historically, risk assessments and judgments were left up to experts, the so-called risk professionals (Starr 1969; Dietz and Rycroft 1987). The communication of such risks to the public was hierarchical (from the top down), with the risk assessors telling the public what technology or activity was risky, not the other way around (National Research Council 1989).

With advancements in risk-perception research spearheaded by the psychology community (Slovic 1987, 2001) a new understanding emerged. First, both expert and lay judgments are subject to cognitive biases based on human inability to process all the required information needed for a decision. Instead, decision-making relies on a series of heuristics (or decision tools) that enable people to simplify the information and cognitively process it more effectively. The availability heuristic, for example, suggests that when hazard or risk incidents are easily recalled from memory (such as media coverage of tornado damage or airplane crashes), people develop biased probability estimates and tend to overestimate the actual frequency of tornadoes or airplane crashes. Another example is the affect heuristic (Slovic et al. 2002). This simplifying rule states that activities or technologies that are disliked or feared (an emotional response) influence both the perception of the risk (high) and the perceptions of the benefits of that technology or activity (low).

Second, risk-perception research found that public understanding of risk was not flawed or wrong; rather, risks were more broadly defined by the public, who took into account some of the societal implications of accepting the risks in their acceptability/unacceptability judgments (National Research Council 1996). In other words, societal selection of what risks or hazards to emphasize and which ones to ignore often reflected moral, political, and economic choices that were themselves value-laden and socially constructed (Douglas and Wildavsky 1982). Increasingly, the technical or scientific view of risk is being supplanted by issues of feelings, trust, social equity, values, and ambiguities in determining what risks are acceptable by the public and which ones are not. Who is more correct? Which view should be the basis for public policies? Clearly, the politicization of risk and the necessity for public debates on the social tolerance of risk are important. Equally important, however, is to consider how societal processes amplify or attenuate public risk judgments.

In their pioneering study, Kasperson and colleagues (1988) posit that risks interact with social, cultural, economic, psychological, and institutional processes in ways that either amplify or dampen public responses. Using the analogy of throwing different-sized stones into a pond and watching the ripples emerge, some products,

activities, or technologies have relatively minor risks (as defined by technical experts), yet they produce massive public reactions. The anthrax episode following the September 11th terrorist attack is a classic example of the social amplification of risk. Anthrax (*Bacillus anthracis*) is not a new hazard. Anthrax spores have been around for centuries, and human cases of inhalation exposure were most often associated with people who had close contact with animals or animal products, such as those in the tanning and textile industries (Jernigan et al. 2001). The first instance of a large-scale public exposure to weaponized anthrax occurred in 1979 in Sverdlovsk, Russia, when an explosion at a military research facility accidentally released dried spores into the atmosphere, resulting in more than 1,000 immediate fatalities (Oberger 1988; Meselson et al. 1994; Alibek 1999; Guillemin 1999; Miller, Engelberg, and Broad 2001).

As the social amplification of model hypothesizes, large volumes of information about the risk or an event from the media, disputes over factual information (arguments among technical or scientific experts challenging data, assumptions, findings), and the visual dramatization of the event all lead to the amplification of the risk (or risk event) along with its attendant impacts and management challenges (Kasperson and Kasperson 1996). So, did the public fear anthrax because it was inherently dangerous, or were they responding to the sensational media coverage that exaggerated the individual threat potential at the time, which in turn affected the overresponse of management institutions and decisionmakers?

### **Capturing Surprise and Unintended Consequences**

The increasing interconnectedness of human, natural, and engineered systems necessitates greater understanding of all the likely causes and consequences of failures in technological systems. The technological complexity and interdependence of many of our transportation, power, utility, and economic systems means that a failure in one cascades to disruptions and failures in others. For example, the delays (often weeks to months) in factory shipments to consumers (especially computers) from the grounding of commercial aviation in the wake of September 11th was an unanticipated consequence of the collapse of the World Trade Center and Pentagon attacks. As Perrow argued in 1984, the increasing complexity of these tightly coupled and interdependent systems could result in catastrophic failures, as multiple subsystems (and their back-ups) fail (Perrow [1984] 1999). Invariably, a seemingly insignificant problem such as a malfunctioning instrument gauge,

coupled with human error, escalates into a full-blown systems failure, such as the nuclear power plant accident at Three Mile Island (Perrow 1999).

Many examples exist of science's inability to capture "imaginable" surprise (Schneider, Turner, and Morehouse Garriga 1998) and anticipate unintended consequences (Tenner 1996).<sup>1</sup> Not only did the overuse of DDT starting in the 1950s affect bird populations (especially the bald eagle) and ecosystems, as noted by Carson (1962), but environmental persistence and pest resistance to these chlorinated pesticides ushered in a new generation of synthetic pesticides and other industrial chemicals (organochlorines) that are now bioaccumulating in the environment and affecting human health (Wargo 1996; Thornton 2000). Some of these synthetic compounds mimic natural hormones and disrupt developmental and reproductive processes, which in turn lead to increases in birth defects, hormonal disorders, and reproductive failures in many species (amphibians and mammals, including humans) (Colborn, Dumanoski, and Myers 1996; Schettler et al. 1999). The environmental endocrine hypothesis, as it is known, was initially greeted with skepticism by the scientific community, but it has now become a central focus of environmental health research and policy agendas (Krimsky 2000).

There are historical analogs as well. The most obvious example was the implementation of the "Atoms for Peace" program in the Eisenhower administration, policies that promoted the peaceful use of atomic power, especially for electrical power generation. The nation embarked on a commercial nuclear power program without fully realizing the necessity for or the technological specifications of managing the long-term disposal of high-level nuclear wastes. The consequence is the lack of a permanent national repository and the ongoing controversy over the selection of Yucca Mountain as the site for high-level radioactive waste disposal (Jacob 1990, Shrader-Frechette 1993).

What emergent risks are awaiting us and how might they manifest themselves (Erikson 1994)? The widespread use of antibiotics during the past decades for bacterial infections (an effective treatment) and viruses such as common colds, flu, or sore throats (an ineffective treatment) has resulted in antibiotic-resistant bacteria (CDC 2002). Infectious diseases and bacterial infections that were once easily treatable (such as children's ear infections) are now more difficult and costly to care for, and the reemergence of drug-resistant forms of tuberculosis and bacterial pneumonias foreshadows one of the most pressing health problems for the nation and the world (Smith 2001). The increasing role of genetically modified organisms (GMOs) will have

unintended consequences, many that are only imaginable in the fertile minds of science-fiction authors (Clement 2001; Sherbaniuk 2001). Who really knows when, where, and under what conditions these risks might emerge?

The world is not static, and we discover new threats daily. A case in point is the recent analysis of the nation's water quality, which provided a detailed assessment of the occurrence of organic wastewater contaminants (pharmaceuticals, medications, personal care products) excreted by livestock and humans (Revkin 2002). The researchers found that 80 percent of the streams sampled had organic wastewater contaminants. The most frequently detected substances included steroids, insect repellants, nonprescription drugs, and disinfectants (Kolpin et al. 2002). This research illustrates another potential source of hormonally active chemicals into the environment, many of them with unknown effects on humans and aquatic ecosystems. As Kates (1985, 47) so eloquently stated nearly two decades ago, "The shift from better-understood hazards to less-understood hazards has placed an enormous burden on science to identify hazards and assess their risks." He (1985, 56–57) reminds us further that "New products will bring new hazards problems. Old products and processes in new locales will bring new hazard problems. . . . Finally, there will be surprises—surprises that in turn will generate new concerns and activities." The question becomes: is science up to the job?

### **Social Construction of Science and Scientific Practice**

Attempts to explain the intrinsic order of nature often fall into polarizing extremes. In the nineteenth century, for example, it was science versus religion. In the latter half of the twentieth century, C. P. Snow (1993) labeled the dichotomy the "two cultures" in 1959, highlighting the growing schism in modes of language and explanation between science on the one hand and the humanities on the other. More recently, the new "science wars" pit realists against relativists (Gould 2000). Realists uphold the objective nature of science and its empirical adequacy, while relativists argue that science is but one set of beliefs where universality or scientific truth is socially conditioned, not absolute.

The contending visions of science are rarely complementary, but more often than not, they are mutually exclusive (see Turner 2002). For some, science is a lens through which we view the world. It is not the only way of viewing it, of course, but science has been the dominant perspective in the twentieth century and beyond. Another

view of science is that it is a process for understanding and making sense of the world, largely reflected in its methods. Finally, there is a pragmatic vision of science, which is to support public policy, to offer "objectivity" in a sea of political waves. These competing visions of science by various stakeholders result in a less than satisfying understanding of the causes and consequences of and responses to environmental threats, including terrorism.

One critique of science, from the perspective of standpoint theory, argues that the acquisition of knowledge is partially determined by adopting different views about the natural world. These perspectives are influenced by gender, race, social, and cultural differences (Haraway 1988; Harvey 1996; Schiebinger 1999), and translate into privileged or unprivileged positions within society (Pulido 2000). Inasmuch as the belief of science and the acquisition of knowledge are socially influenced, the practice of science also is socially constructed (Harding 1991). The social construction of science helps to explain why some scientific results are not always replicable—different labs working on the same "problem," using the same protocols, and coming up with different results, the discrepancy attributed to the social organization within the lab itself. Scientific problems and hypotheses themselves can be defined and structured differently depending one's perspective and agenda.

The underrepresentation of women and people of color in science is a perennial problem, one that affects the nature of scientific inquiry and the practice of science. Workforce diversity leads to new scientific discoveries by challenging existing norms and research paradigms (Rosser 2000). The underrepresentation of women, children, and people of color in clinical trials—a peculiar omission given the age, race, and gender-specific pattern of major debilitating diseases such as asthma, breast cancer, osteoporosis, or hypertension—also highlights the social construction of scientific practice. Formal federal recognition of the latter occurred in 1991 when the National Institutes of Health established its fifteen-year, multi-million-dollar Women's Health Initiative. Designed to identify gaps in biomedical research on the common causes of mortality, disease, and impaired quality of life in postmenopausal women, clinical trials involving more than 167,000 women began. Similarly, more environmental-health science research is now focused on the differential susceptibility of children to environmental toxicants through a comparable Children's Health Initiative. Pediatric environmental disease (lead poisoning, asthma, cancer, neurobehavioral disorders) averages around 3 percent of the U.S. total health care costs (Landrigan et al. 2002), an unacceptable level for many health professionals.

## The Role of September 11th

Science-conditioned expectations defined pre-September 11th dangers, especially from a national security perspective. American national-defense policy was oriented towards advanced technology and exotic missile defense systems. The likely source of the threat, based on prevailing Cold War ideologies, was strategic nuclear warheads. In many ways, the low-technology simple weapons (the use of a fully-loaded jet airliner) were not part of the collective perception of national security concerns. The events of September 11th highlighted the vulnerability in the nation's information-gathering—an overreliance on technologically sophisticated surveillance assets at the expense of additional, on-the-ground human intelligence—and contributed to our surprise and general lack of understanding about some of the root causes (precursors) of international terrorism. The American public was left without sufficient explanations about why this group (al Qaeda), why now, and why the World Trade Center and Pentagon as targets.

With the collapse of the World Trade Center towers, there was and continues to be an underestimation of the impacts of this failure at all spatial scales. There is inadequate prediction and understanding of the cascading impacts of the September 11th events on local, regional, national, and global economies—impacts that we still are discovering nearly a year and a half after the event. Finally, the events of September 11th illustrated in very private ways the interconnectedness of modern society, and painfully and publicly exposed the extent of our societal vulnerabilities. As noted in the National Research Council's (2002, ES-1) *Making the Nation Safer* report:

The vulnerability of societies to terrorist attacks results in part from the proliferation of chemical, biological, and nuclear weapons of mass destruction, but it also is a consequence of the highly efficient and interconnected systems that we rely on for key services such as transportation, information, energy, and health care. The efficient functioning of these systems reflects great technological achievements of the past century, but interconnectedness within and across systems also means that infrastructures are vulnerable to local disruptions, which could lead to wide-spread or catastrophic failures.

## The Need for a Geographical Response: Personal Reflections

My formative intellectual years were in the San Francisco Bay Area during the mid- to late 1960s, where

my social and environmental activism was nurtured first in high school and later as an undergraduate at California State University, Hayward. My first research experience was as an undergraduate, examining defoliant spraying in Vietnam (Agent Orange) and its effects on human settlement patterns in the region (Thomas 1975). Initially trained in qualitative approaches (the Berkeley School) with a strong emphasis on fieldwork, my graduate studies at the University of Chicago were just the opposite (spatial analysis and quantitative methods). By the time I reached Chicago, Gilbert White had already left for the University of Colorado, but the rich human environmental tradition remained. I maintained my interest in environmental issues and was fortunate enough to work on one of Brian Berry's funded research projects at the time (Berry 1977). This comparative metropolitan assessment of the social burdens of pollution was one of the first environmental-justice research projects and fostered my ongoing concern about the relationship between race, class, and environmental quality in urban areas. My dissertation (directed by Berry) examined community attitudes towards pollution in Chicago (Caris 1978) and added additional methodological skills in survey research to my toolkit. In hindsight, I am convinced that my interests in environmental activism, social justice, methodological pluralism, nature-society interactions, and—yes—tacky landscapes (especially the ubiquitous plastic pink flamingo) all had their origins in my experiences as a formal student.

As I embarked on my professional career, first as a visiting assistant professor in geography and environmental studies at the University of Washington, and then in a tenure-track appointment at Rutgers (surprisingly enough, not in geography, at first), I was able to foster my intellectual curiosity in all aspects of environmental science and policy by working in these multidisciplinary contexts. It was clear to me that geography, instead of being at the core of environmental studies (where it rightfully belonged), was instead on the periphery. With such a rich tradition in nature-society themes, how could this have happened?

As I watched the September 11th events unfold on television, it was obvious that the discipline could assist in the disaster response and recovery efforts, but more importantly, that it *should* take a lead role in guiding public policy in understanding what made people and places vulnerable to these and other environmental threats. I did not want the discipline to be a tertiary player in guiding public-policy response, as it was in the formative stages of the early environmental movement (harkening back to my frustrations as a student). The combination of geography's technical sophistication, regional expertise,

understanding of the relationships between physical systems and social systems, methodological diversity, and history of well-received pragmatic research gave us an advantage over other social science and natural science disciplines. My activist response was to spearhead a collaborative research and action agenda on the geographical dimensions of terrorism on behalf of the AAG (Cutter, Richardson, and Wilbanks 2002).<sup>2</sup> It is too soon to gauge the effectiveness of this effort, but the discipline has been recognized by federal policy, mission, and funding agencies for the thoughtfulness and rapidity of its response.

## Vulnerability Science

Society expects science to help reduce uncertainty, yet for many environmental controversies and some environmental threats, science has actually increased ambiguity. While uncertainty is a part of reality, especially when describing environmental threats such as climate change (National Research Council 1999a), oftentimes the only socially responsible thing for science to do is to highlight it and talk about the consequences of doing something or doing nothing about the threat. Within the hazards arena, the precautionary principle (e.g., evacuations from hurricanes, vaccinations for communicable diseases) is one way that uncertainty is handled.

One of the great challenges for the environmental sciences is to live up to their policy potential and address questions that are of interest to policy-makers, instead of narrowly focused research questions that appeal only to environmental scientists (National Research Council 2001). Vulnerability science is one such approach. Vulnerability science helps us understand those circumstances that put people and places at risk and those conditions that reduce the ability of people and places to respond to environmental threats. Vulnerability science provides a basis for risk, hazard, and disaster reduction policies. It integrates the constructs of risk (exposure), hazard, resilience, differential susceptibility, and recovery/mitigation. It parallels sustainability science (National Research Council 1999b; Kates et al. 2001) and employs many of the same concepts (susceptibility, resistance, resilience, and adaptation), but applies them more locally in trying to understand environmental risks and hazards and their adverse impacts. The current research trends in hazard vulnerability, however, are too focused on local social dynamics or identification of physical exposures (FEMA 1997), too broad in their applications (models of physical processes and their attendant regional to global human impacts) (Downing

1991; Blaikie et al. 1994; Clark et al. 2000), or examine only individual risks, not multihazard or multiple risks (Cutter 1996).

Vulnerability science requires an integrative approach to explain the complex interactions among social, natural, and engineered systems. It requires a new way of viewing the world, one that integrates perspectives from the sciences, social sciences, and humanities. Since vulnerability can refer to individuals (person, housing structure), groups, systems, or places, scalar differences and the ability to articulate between geographic scales are important components. Vulnerability manifests itself geographically in the form of hazardous places (floodplains, remnant waste sites); thus, spatial solutions are required, especially when comparing the relative levels of vulnerability between places or between different groups of people who live or work in those places. Lastly, methodological diversity in the examination and explanation of those circumstances that give rise to vulnerability and those factors that influence resistance and resilience to harm are essential.

Vulnerability science builds on the integrated and multidisciplinary tradition of hazards research (Mileti 1999; Cutter, Mitchell, and Scott 2000; Cutter 2001a; Montz, Cross, and Cutter forthcoming). It uses qualitative and quantitative approaches, employs historic to future time perspectives, and incorporates pragmatic problem-selection and problem-solving. In addition to the obvious and considerable contributions from the nature-society interaction perspectives within the discipline (which gave rise to hazards research in the first place), geography has added a technological sophistication to hazards research that is unrivaled among the social sciences. The discipline is rapidly becoming the driving force behind vulnerability science, in much the same way that it was the driving force behind human dimensions of global change science (Turner et al. 1990) and, more recently, sustainability science.

Imbedded throughout the discussion on the science of vulnerability is the requirement to anticipate surprise, capture uncertainty, and accept change in our science and understanding. But how to do that poses one of the greatest challenges to the discipline. In advocating this new approach, the science of vulnerability, one must be mindful of how vulnerability science is affected by some of the vulnerabilities of science itself—rationality, expert versus lay judgments, uncertainty.

A research agenda for vulnerability science has been suggested elsewhere (Cutter 2001b), but it bears re-examination in light of the events of September 11th. A number of the most significant themes for the discipline of geography are described below briefly.

### **Driving Forces that Amplify or Attenuate Vulnerability**

We need to identify, delineate, and understand those driving forces that increase or decrease vulnerability at all scales. There was some initial work on this topic at the global scale (Blaikie et al. 1994; Kasperson, Kasperson, and Turner 1995; Mitchell 1999; Clark et al. 2000; Kasperson and Kasperson 2001) and regionally (Heinz Center 2002), but much more research is required to answer the important questions. What makes megacities such as Caracas or Tokyo increasingly vulnerable to natural hazards or economic disruptions? How do the processes and patterns of urbanization affect developing countries' susceptibility to disease and increased mortality among their youth? How do the patterns of resource exploitation (or crop conversion) lead to environmental degradation, which in turn produces environmental refugees, which in turn increases ethnic tensions, ultimately creating more civil strife and armed conflict? What are some of the root causes of terrorism and terrorist acts, and what is the geographical linkage between the sources of financing and potential targets?

### **Risk Relocation**

What is the role of our current practices and public policies in fostering the relocation of risk (Etkin 1999)? In what ways do our current policies transfer the risk burden from one individual to another or from one place to another? A case in point is the increase in car insurance rates in some areas among current policy-holders to compensate for the large pool of motorists without insurance, or the reduction in the choice of insurance companies for purchasing homeowners insurance in post-Hurricane Andrew, Florida. How do federal policies, initially aimed at risk and hazard reduction, inadvertently put more people and places at risk? Despite some successes in relocating structures out of riverine floodplains, the National Flood Insurance Program is not particularly adept overall at reducing development in flood-prone barrier-island locations, ultimately encouraging coastal development rather than deterring it (Platt 1999; Heinz Center 2000). Many of our public policies transfer the risk to future generations through a "use now, pay for the impacts later" mentality. The most obvious examples are the lack of a secure repository for high-level nuclear waste and controls on greenhouse gas emissions. How can we prevent this in the future? Vulnerability science can help guide us to answers on the temporal and spatial transference of risk.

### **Forecasting Losses and Their Impact**

As a nation, we lack the most elemental data on what hazard events cost this nation on an annual basis. It may come as a surprise to many, but there is inconsistent and incomplete data on hazards events and losses (Mileti 1999; Thomas 2001) for the U.S. Oftentimes, events that are recorded (many are not) have incomplete information (cover only a certain time period), include only a few selected hazards (earthquakes, or meteorological events), and define and measure losses in so many different and inconsistent ways that the development of a standardized national baseline of hazard events and losses is problematic at best. In addition to data, we lack the predictive capability to forecast future losses based on these historical analogs. Furthermore, the lack of data hampers any type of analysis of the effectiveness of risk and hazard reduction programs, since we do not really know what the temporal and spatial patterning of losses were before the program or policy was implemented and certainly do not know them twenty years later. We have failed as a nation in developing audits of hazard and risk reduction programs, preferring instead to continue with disaster business as usual. At a minimum, loss estimation needs to be more scientifically based and less politically driven if we are to advance our understanding of vulnerability, especially at the subnational level.

### **Better Integrative Models**

One of the areas in vulnerability science that requires significant development is the modeling community. We need dynamic—not static—models that integrate risk exposures with place-based biophysical and social indicators. While there are very sophisticated and advanced risk models in the natural, engineering, and health sciences, most of these are hazard-specific, and they rarely incorporate a spatial dimension (Hill and Cutter 2001). There is an enormous potential for the discipline to be in the forefront in the development of spatially integrated all-hazards assessment models, an opportunity that should not be squandered. Contributions from the geographical information science field, among others, are required.

### **Comparative Indicators**

From the perspective of the policy community, there is a real need to develop a set of metrics to measure and compare the relative vulnerability of one place to another. Indices such as the UN Human Development Index (UNDP 2000) or the disaster risk index (Cardona,

Davidson, and Villacis 1999), while imperfect, do enable this type of comparative assessment of environmental and social conditions. The renewed interest in ecological and sustainability indicators (National Research Council 2000; World Economic Forum 2000; World Bank 2001) and social vulnerability indicators (Heinz Center 2002; Cutter, Boruff, and Shirley forthcoming) are recent examples. In many instances, the tools and techniques are available if adapted properly, but we lack the conceptual development on the most appropriate metrics and scale, as well as the minimum subset of indicators that will provide the foundation for comparisons.

### Visualization and Representation

Geography is a visual discipline and should be the leading intellectual force in developing visual representations of dynamic phenomena such as vulnerability. The use of GIS in hazards mapping and emergency response has increased during the past decade (Monmonier 1997; Radke et al. 2000; Hodgson and Cutter 2001). GIS certainly became a focal point for the September 11th rescue and relief operations (Cahan and Ball 2002; Thomas et al. 2002). Better representations in three and four dimensions are required for real time response, yet we need to be cognizant of how emergency managers (and the public for that matter) respond to, process, and use such visualizations. The goal should be to develop an accurate and easily understandable visualization of risks, hazards, and vulnerability. This will require enhanced linkages between the research community in GIScience (visualization and modeling) and the practitioner community in emergency preparedness and response and is absolutely essential if we are to advance vulnerability science.

### Decision-Making in Response to Threats

How individuals estimate risk, the role of uncertainty in risk judgments, and how risk cognition translates into overt action is another potential research area for our community. Within geography, natural-hazard perception research originated through collaborations with psychologists in trying to understand individual and collective decision-making in response to extreme threats (Sims and Baumann 1972; White 1974; Burton, Kates, and White 1993). There is considerable work within the discipline on evacuation behavior (Baker 1991; Cutter 1991; Cova and Church 1997; Dow and Cutter 1998, 2000, 2002) and the adoption of hazard mitigation options (e.g., insurance) in response to risk perceptions (Palm and Hodgson 1992; Palm 1994). Behavioral geographers have not focused as

much attention on hazards as they could, preferring instead to focus on urban spatial behavior (travel, transportation) and cognitive processes in understanding maps and spatial information (Golledge and Stimson 1997; Golledge 2002). One of the most perplexing questions presently confronting the social-science community is, why do people place themselves at risk and increase their vulnerability to environmental threats? More importantly, what contextual factors (e.g., institutions, market forces, social status) decrease individual responsibility for the consequences of stupid locational decisions?

### Geography's Science and Practice

It is clear that vulnerability science has contributed to some of the increased vulnerabilities in science during the past few decades. As it evolves into a more robust field, however, vulnerability science is in a position to help reduce some of the inherent vulnerability of science and scientific explanations. But it will require transdisciplinary linkages, methodological pluralism, place-based knowledge, and a continued practical focus on policy relevancy.

The science of vulnerability seeks to understand the range of possible effects of unlikely but possible events, their unintended consequences (on people and places and in scientific and technological research and development).<sup>3</sup> Further, vulnerability science is reflexive (Beck 1999), learning from experience and anticipating how future vulnerability will change. In many ways, vulnerability science is the most intrinsically anticipatory branch of science and the one to turn to in times of crisis and response. Ultimately concerned with the pragmatic, vulnerability science has the response knowledge, supporting data, and tools and techniques for contingency analysis and is certainly ready to help understand unlikely and unanticipated eventualities. Vulnerability science links geography's research and application communities, providing a common and important ground for interaction. But it does more than that: it provides a critical linkage between geography and other social, natural, engineering, and health sciences.

One challenge we face is to produce the next generation of researchers who will further advance the development of new conceptual models, tools, and techniques for understanding vulnerability. It is imperative that we move beyond the hazard du jour approach in our current scholarship and seek funding and reward mechanisms that enable an all-hazards approach to vulnerability science.

The discipline of geography is at the core of vulnerability science, and we should not be bashful about this claim. As Harlan Barrows (1923, 1) stated more than a

century ago, “[G]eography . . . properly can claim the title of Mother of the Sciences.” Let us use this to our advantage. The importance and relevance of geography to public policy is also vital and has been a consistent theme echoed by past presidents as well, including White (1962, 279), who wrote: “The contributions which geographic thought can make to the advancement of society are . . . so powerful that failure to recognize them jeopardizes the ability of citizens to deal intelligently with a rapidly changing and increasingly complex world.” This statement is applicable now more than ever, as we seek information about terrorism and terrorist threats, root causes, and our collective vulnerabilities to them. However, we cannot be mired by philosophical debates and ruminations about cause and effects, nor can we be so eager to blissfully apply all of the geographical techniques to these pressing problems without questioning the repercussions of their use on privacy and personal freedoms. We must find the balance between theoretical and the applied perspectives to more fully engage the pragmatic and public policy dimensions of vulnerability. This is not a new admonition either, as many past presidents have made similar remarks. For example, Brian Berry (1980, 454) wrote,

Many of the concepts employed by practitioners do have their origin in scholarly work, but even larger numbers of such concepts have been applied and found wanting, misguided, or irrelevant. Such practical assessments should be the source of change in academia, for a scholarly agenda developed in isolation can quickly become scholastic, misdirected, or just plain wrong.

We need to take the road still beckoning (Kates 1987) and provide the theory and practical understanding of human environmental science and to make it more spatially informed. Vulnerability science is one path that leads to understanding what makes people, places, and societies vulnerable to a range of environmental threats. With geography as the intellectual and integrative driving force behind vulnerability science, the goal—and thus grand challenge—is to improve our public policies to lessen the vulnerability of our own children and the world’s children, all of whom deserve and demand the right to a healthy environment and a peaceful future. If our science and practice can achieve this, then we will have truly made a difference.

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