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Prediction as an Impediment to Preparedness: Lessons from the US Hurricane and Earthquake Research Enterprises

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Abstract No matter one's wealth or social position, all are subject to the threats of natural hazards. Be it fire, flood, hurricane, earthquake, tornado, or drought, the reality of hazard risk is universal. In response, governments, non-profits, and the private sector all support research to study hazards. Each has a common end in mind: to increase the resilience of vulnerable communities. While this end goal is shared across hazards, the conception of how to get there can diverge considerably. The earthquake and hurricane research endeavors in the US provide an illustrative contrast. The earthquake community sets out to increase resilience through a research process that simultaneously promotes both high quality and usable – preparedness-focused - science. In order to do so, the logic suggests that research must be collaborative, responsive, and transparent. Hurricane research, by contrast, largely promotes high quality science – predictions - alone, and presumes that usability should flow from there. This process is not collaborative, responsive, or transparent. Experience suggests, however, that the latter model – hurricane research - does not prepare communities or decision makers to use the high quality science it has produced when a storm does hit. The predictions are good, but they are not used effectively. Earthquake research, on the other hand, is developed through a collaborative process that equips decision makers to know and use hazards research knowledge as soon as an earthquake hits. The contrast between the two fields suggests that earthquake research is more likely to meet the end goal of resilience than is hurricane research, and thus that communities might be more resilient to hurricanes were the model by which research is funded and conducted to change. The earthquake research experience can provide lessons for this shift. This paper employs the Public Value Mapping (PVM) framework to explore these two divergent public value logics, their end results, and opportunities for improvement.

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Introduction

While most will not personally experience the severity of disaster on the scale of Hurricane Katrina, the Haiti earthquake, or the floods in Pakistan, few will remain untouched by natural hazards throughout their lives. As greater numbers move to coastlines and other hazard-prone areas, as the built environment grows in density, and as the inequitable concentration of wealth increases, disasters like these become increasingly common. Disaster losses rise and so, too, does our collective vulnerability and need for better resilience (Mileti et al. 1999; NSTC 2008).

The US federal government funds hazards research precisely to address such vulnerability. Hazards research – the study of hurricanes, earthquakes, wildfire, drought, and the like - promises to save lives, mitigate property loss, and improve economic efficiency through a better understanding of the physical, social, and built environment dynamics of disasters (JAG/TCR 2007; NHC 2008). Its goal is more *resilient* communities – communities able to withstand an extreme event without outside assistance (NSTC 2008). These are communities with the social systems, infrastructure, and knowledge in place to sustain life nearly as it was before the hazard occurred.

The abiding question is how best to achieve this, and what research will help. There are many options, for example: 1) pure physical science: research on the structure of the inner core of a tropical cyclone or on continental shelf characteristics and predictive models, 2) engineering research: studies on the strength of the infrastructure of coastal buildings, and 3) social research: studies on the social network within coastal communities – modes of communication or the capacity of institutions to respond when disasters strike. Among these, how does a nation choose which of these areas to fund? What is the right balance between them?

With limited resources for hazards research, these are values decisions – decisions that reflect preferences about which problems to solve, beliefs about which approaches will work, and faith in which scientific questions can have the greatest impact. This paper evaluates the success of these decisions, the extent to which they achieve the research community's stated goals. Legislation, research plans, and public reports justify US hazards research in terms of one common goal: *resilience*. Because this end goal is a public (not entirely economic) value, the paper relies on the Public Value Mapping (PVM) framework for its analysis.

The successes and failures of government investments in research and development are often measured by the market: dollar amount of return on investment (e.g. Grilisches 1995). Yet, this presents a problem in cases like natural hazards research, where the end goal is a public – not a market – value. Where resilience is central, and success is reflected in avoided costs rather than incurred benefits, dollar return on investment is not a comprehensive enough measure. PVM adds to a new element of analysis: it evaluates the extent to which public values - the consensus rights to which all citizens should be entitled (e.g. democracy, well-being, subsistence) – are served (Bozeman 2007).

To do this, PVM analysis first defines the central public values and the process by which those values will be served (the public value logic), as proposed in public documents, speeches, research plans and priorities. It then evaluates the decisions and practices of the field according to that logic, and asks where neither the market nor the public sector provides adequate goods and services to achieve the common good (e.g. Bozeman and Sarewitz 2005). In these cases (public value failures), the PVM analysis makes recommendations for a realignment of priorities and practices. For the case of natural hazards research, this paper evaluates hurricane and earthquake research. These two research communities are well developed and well established with rich – and divergent – histories. They also provide an interesting contrast in the implementation of a common mission: resilience.

Natural Hazards Research Public Value Logic

Resilience, consequently, drives the natural hazards research public value logic (Fig. 1). While much of the vast literature on resilience does not relate to natural hazards, increasingly legislation and plans for hazards research converge on resilience as the central, target public value (e.g. P.L. 95–124, H.R. 327). In a hazards context, resilience is the capacity of a locality – human and ecological- to withstand an extreme event without "without significant outside assistance" (Mileti et al. 1999; see also Holling 1973; Timmerman 1981; Klein et al. 2003; Adger et al. 2005).

The remainder of the hazards public value logic is determined by the interplay between resilience - the end goal, an intrinsic public value – and the related instrumental public values, the means to that end (Bozeman 2007). The instrumental

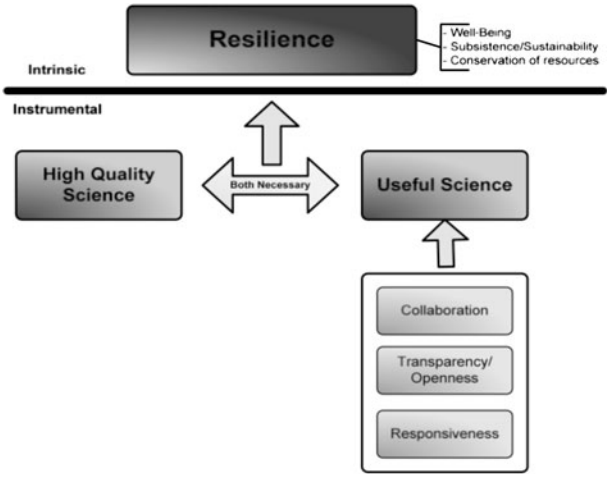

Fig. 1 Public Value Logic

public values in the natural hazards research public value logic are 1) high quality and 2) useful knowledge. Therefore, the natural hazards research community must produce high quality and useful information in order to support resilience. And moving one level beyond that, in order to produce useful knowledge, the research prioritization process should be collaborative, transparent and open, and responsive. This is the natural hazards public value logic, according to its literature and guiding documents (e.g. NSTC 2008; NEHRP 2008; Mileti et al. 1999). The next sections explain these instrumental values in more detail.

High Quality Science

High quality science is that which advances the general state of knowledge, is done according to the scientific method, and is well respected within the scientific community. According to the logic of its guiding public documents (e.g. JAG/TCR 2007; NEHRP 2006, 2008; PL 95-124 (1977)), high quality science is an instrumental value of natural hazards research in two regards: if natural hazards research ultimately intends to make communities more resilient, the higher the quality of its science 1) the more valuable it will be to the communities who will ultimately rely on it, and 2) the more likely it is to be trusted by those charged with decisions about community resilience. In effect, the higher the quality of the science, the more likely it is to be used to enhance resilience.

This logic plays out in both hurricane and earthquake research public documents. Most public documents and plans for US hurricane research argue that if the research community can improve the quality of its hurricane track and intensity forecasts, it will reduce the lives and property lost when hurricanes strike (See Table 1 for specific quotes). A common argument within the scientific research enterprise, this suggests that scientifically "better" information inherently or automatically leads to better decisions. This assumption is not as widespread in the earthquake research community, but even still this community also makes clear the importance of high quality science in building the knowledge base necessary for decisions. In addition to these hazard-specific statements, research on the role of science in decision making suggests that "studies done with high technical proficiency turned out to be more useful" to decision makers because they know they can trust it and rely on it to make decisions (Weiss 1995; see also NSB-06-115 (2007); NSTC 2008; NEHRP 2008).

Useful Science

Useful science is that which is relevant to and able to inform decisions – e.g. decisions about disaster preparation, response, and prevention. In order to be useful, the literature suggests science must be credible, legitimate, and salient to decision makers' needs (Cash et al. 2002; 2003; Cash and Buizer 2005; Guston 2001). It should be grounded in the practical problems that affect decision makers (e.g. Young 2002; Stokes 1997; Winner 1996; Bijker 1993), and it should offer "them direction for tangible action" (Weiss 1995; see also Pielke 2007; Nowtony 2007; Wynne 2007).

Table 1 Statements associated with public values in natural hazards research

Value	Illustrative Quotes	Source
Useful Information	• "Communities must break the cycle of destruction and recovery [from natural hazards] by enhancing their disaster resilience… **High-priority science and technology investments**, coupled with sound decision-making at all levels, **will dramatically enhance community resilience** and thus reduce vulnerability" (NSTC 2008). • "Vast improvements in tropical cyclone prediction are attainable with focused research efforts… The ultimate goal is to prevent loss of life and injuries and to reduce the nation's vulnerability to these potentially devastating storms. This goal can and must be accomplished for the good of the Nation" (JAG/TCR 2007). • NEHRP mission: To develop, disseminate, and promote knowledge, tools, and practices for earthquake risk reduction… that **improve the Nation's earthquake resilience** in public safety, economic strength, and national security.	• National Science and Technology Council Grand Challenges for Disaster Reduction Document. • Interagency Strategic Research Plan for Tropical Cyclones. • National Earthquake Hazards Reduction Program Strategic Plan.
High quality science	• "Studies done with **high technical proficiency** turned out to be more useful" to decision makers (Weiss 1995). • "Tropical cyclones can have catastrophic impacts, which make **accurate predictions** of these events of paramount importance" (JAG/TCR 2007). • With large numbers of people moving to coastlines and losses doubling every 10 years, "the need for substantial improvements… in hurricane track and intensity forecast capabilities has never been greater" (NOAA 2008a). • "**Basic research** in the geosciences, engineering, and social sciences on earthquake phenomena… **is essential to form the knowledge base** from which targeted applied research and mitigation practices and policies can be developed" (NEHRP 2008).	• Weiss 1995. A study of the usefulness of knowledge. • Interagency Strategic Research Plan for Tropical Cyclones. • NOAA's Framework for Addressing Hurricane Research and Forecast Improvement. • NEHRP Strategic Plan.

Table 1 continued

Value	Illustrative Quotes	Source
Collaborative	• "The successful application of new knowledge and breakthrough technologies, which are likely to occur with ever-increasing frequency, will require an entirely new interdisciplinary approach to policy making: one that operates in an agile problem-solving environment and works effectively at the interface where science and technology meet business and public policy" (Lane 2006). • In natural hazards, "policy makers face less a geophysical problem, than an inherently *societal* problem with a geophysical underpinning. Any strategy to attack this problem requires not geophysical research but all-encompassing strategies that would be used to confront any other large-scale social problem" (Meade and Abbott 2003). • "An appropriately **balanced, integrative approach** to hurricane science and engineering… is needed to fully address the many compelling problems that transcend conventional thinking and organizational infrastructures" (NSB-06-115 (2007)). • "Earthquake risk reduction… requires a problem-focused rather than discipline-specfic approach to cut across political, social, and technological boundaries to find lasting solutions" (EERI 2008).	• Former Science Advisor to the President, Neal Lane. • RAND study on natural hazards. • National Science Board review of US Hurricane Research • EERI report on earthquake risk reduction and interdisciplinarity.
Openness, Transparency	• Resilience reflects "the degree to which the system can build capacity for learning and adaptation" (Adger et al. 2005). The resilience literature suggests that the capacity for learning and adaptation can be enhanced by self-awareness and knowledge of that which is produced throughout the research process. • "Earthquake professionals have much to offer NEHRP"; standards are developed through a consensus process as a result."	• Resilience and science policy scholarship • NEHRP Strategic Plan

Table 1 continued

Value	Illustrative Quotes	Source
Responsive, Involvement of end users	• "The old culture of certainty associated with pure science has been replaced with a "culture of research" in which science and society come together to ask questions and search for solutions collectively" (Latour 1998; in Lemos and Morehouse 2005). • "Strategies for research and development are **guided by the broader community and socioeconomic contexts** in which they are applied" (O'Rourke et al. 2008). • Hurricane research "**responds to input from stakeholders**… [and] embraces strong collaboration with non-NOAA partners with objective to **transition research into operations**" (Personal Interview 2008).	• Latour 1998; Lemos and Morehouse 2005. • EERI Contributions of Earthquake Engineering report. • Frank Marks, HFIP director.

Put simply, useful science is necessary to enhance resilience because research that is not used cannot change the state of a community's resilience. For this reason, the science policy literature has long argued that in order to effectively serve policy, science must produce useful information (e.g. Jacobs 2002; Lemos and Morehouse 2005; Weiss 1995; Lindblom and Cohen 1979). Both the earthquake and hurricane research communities make the need for this instrumental value clear (see Table 1).

The literature on useful science suggests that collaboration, openness, and responsiveness are necessary elements to producing useful science. *Collaboration* requires work across disciplines and traditional boundaries of academia. Increasingly, natural hazards researchers recognize the need to address problems from multiple perspectives with multiple sources of input: engineers, social scientists, physical scientists, health professionals, etc. (EERI 2008). In this same spirit, as problem solving becomes a multi-discipline affair, *openness* to voices outside of academia and the world of practice grows in importance, such that any and all have access to the process of both prioritization and research. Public documents suggest useful natural hazards scholarship should be *responsive* to end users such as emergency managers, utility companies, or local government officials. These strategies, public documents suggest, are likely to make hazards research able to create more resilient communities. Table 1 offers specific quotes from these public documents for each of these public values.

An Alternate Public Value Logic

In the practice of natural hazards research prioritization, however, the above logic is not universally held. An alternate public value logic (Fig. 2) posits that high quality

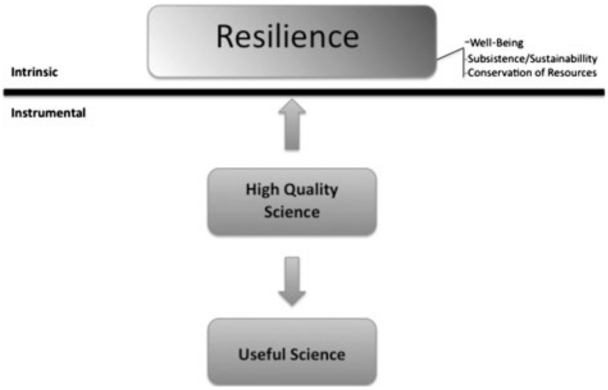

Fig. 2 Public Value Logic #2

science and useful science are not equally necessary criteria for increasing resilience, but instead that high quality science alone is sufficient. According to this logic, high quality science is inherently useful, and therefore should lead directly to increased resilience. Collaboration, openness, and transparency are thus not instrumental values here, and are absent from Fig. 2. While this is a clear break from the public value logic presented for natural hazards research, it is a common mental model in the scientific community – one where the quality of the science is the first priority and the application of that research a second, often more instrumental priority (e.g. Stokes 1997; Byerly and Pielke 1995; Meyer, this issue; Logar, this issue; Bush 1945).

The hurricane and earthquake research endeavors provide a contrast between the two logics. In earthquake research, the guiding natural hazards public value logic (Fig. 1) is predominant, and in hurricane research, the alternate logic (Fig. 2) is predominant. The following sections explore this contrast and the results of these two logics in more detail.

Hurricane Research

At its core, the hurricane research enterprise funds prediction research. It has put the weight and balance of its funds, manpower, and expertise behind the production of high quality science as separate from - and often at the expense of - the production of research with an explicit focus on use. As the following section demonstrates, federal hurricane research funding decisions do not prioritize collaboration, openness, or responsiveness. They are therefore in conflict with the guiding natural hazards public value logic (Fig. 1) and research justifications in this vein, which argue that high quality and usefulness are *each* necessary elements of science that will make communities more resilient.

Several non-research programs within NOAA and elsewhere (e.g. the Storm-Ready communities program) do aim to improve hurricane readiness and response, but the science research programs on balance do not. Put metaphorically by William Hooke and Roger Pielke Jr., focusing only on prediction is akin to having "an orchestra's conductor… focus only on the string section to the exclusion of the horns and percussion" (2000). If the guiding public logic is correct, then one should expect that hurricane research will not successfully achieve the intrinsic value - resilience - that justifies and motivates it. The next sections evaluate trends and results to this end.

Public: Federally Funded Hurricane Research

The story of federal hurricane research plays out within the funding decisions of federal agencies; these decisions determine the extent to which research will reflect instrumental, and thus intrinsic, values. In the US, federal hurricane funding decisions skew heavily in favor of prediction research and the end goal of enhanced predictive capacity. Indeed, a quantitative evaluation of federal research and development for hazards loss reduction (Meade and Abbott 2003) by RAND scholar Charles Meade reported to Congress that the majority of US hurricane research funding supports short-term prediction capabilities, "with less than 2 percent targeted to research on the prevention of loss through improved engineering and design of structures" (NSB-06-115 (2007); Meade 2004). These numbers (see Fig. 4b) – 98% to prediction research, 2% to infrastructure improvement and applied science – suggest a sizable imbalance in the appropriation of funds between high quality science and useful science.

In this same vein, during the 2008 hurricane season, the Bush Administration chose to allocate an additional $13 million to its FY2009 hurricane research budget, in order "to better predict the behavior and development of dangerous storms" (NOAA 2008a). Specifically, these funds support NOAA's Hurricane Forecast Improvement Project (HFIP). HFIP "aims to improve the accuracy and reliability of predicting rapidly intensifying storms and extending the lead time of hurricane prediction with increased certainty" (ibid). This money more than quadrupled NOAA's initial budget request – taking it from $4 million to $17 million. This allocation boldly reinforces the US government's commitment to prediction within hurricane research, particularly because NOAA is the lead hurricane research funding agency in the US. Social science projects, on the other hand, make up only $350,000 of this budget, an amount referred to by a NOAA program manager a "coup" in and of itself (See Fig. 4a). While social science projects can undoubtedly produce knowledge that is neither useful nor collaborative, open, or responsive (Flyvbjerg 2001; Shapiro 2005), interviews suggest that these projects are currently *the sole* avenue for addressing collaborative, open, and transparent – and thus, useful science - public values within hurricane research. By the numbers, therefore, hurricane research embraces prediction in lieu of usefulness. It embraces the alternate public value logic, and assumes that use will follow inevitably from high quality prediction.

The culture of the research agencies that fund and conduct research reflects this same logic. While NOAA documents and research justifications often emphasize the need for more stakeholder involvement and useful services, the practice of what they fund and prioritize does not, at times, match their rhetoric. This situation and NOAA's priorities were aptly summarized by the experience of former NHC director, Max Mayfield, in an interview with the author. Mayfield actively engaged topics regarding understanding of hazards: communications and the media, hurricane preparedness, and better buildings. Yet, for these efforts, he was reprimanded by his former boss, NWS director:

> "My boss at the time, the director of the National Weather Service, called me and told me to stop talking about better buildings and hurricane days in school calendars. He said *'You're a meteorologist, talk about meteorology.'* The weather service is made up of a lot of sharp meteorologists and a few of them feel they've done their job when the forecast is produced (Personal Interview, 2009)."

NOAA is an agency oriented to the production of high quality knowledge in the natural sciences. While its mission and calls for useful products and services suggest a keen interest in the production of useful information as well, its funding process and practice reverts to a model of high quality science that is to be exposed to society's needs after it is produced, rather than as it is being produced (a requirement for useful science by the aforementioned logic, Fig. 1). As a result, the process is neither responsive nor transparent. It is collaborative to the extent that atmospheric scientists work together, but not with engineers or social scientists. Individuals may break from this trend, as was the case with Mayfield:

> "I understood why I was told to stick to meteorology. But the truth is that the Director of the NHC needs to care about the entire Nation's hurricane program and not just the forecast. I continued to talk about other important facets of the hurricane program by referencing people who were knowledgeable and respected in these other areas."

The trends explained above, however, are indicative of the culture and practice of the research community writ large. The above demonstrates the alternate public value logic at play in the practice and priorities of hurricane research, but what of the success of this logic? There is evidence in recent hurricane research to suggest that the alternate public value logic actually jeopardizes the research community's ability to achieve its end goal resilience. Examples, such as Hurricane Katrina, indicate that the failure to embrace and pursue the instrumental values of useful science leads to failure in achieving resilience. When the science is not used, its quality does not matter.

To explain, the National Hurricane Center and National Weather Service passed the test of Hurricane Katrina "with flying colors" (2006), according to the House of Representatives' Select Committee to Investigate the Preparation for and Response to Hurricane Katrina. The National Hurricane Center's storm track projections, released 56 hours before Katrina, were off by only fifteen miles. They predicted Katrina's landfall strength two days before the storm, and "the day before Katrina hit, the NWS office in Slidell, Louisiana issued a warning saying, 'MOST OF THE AREA WILL BE UNINHABITABLE FOR WEEKS…PERHAPS LONGER…HUMAN SUFFERING INCREDIBLE BY MODERN STANDARDS" (US House

2006). Yet, the city of New Orleans, the state of Louisiana, and the US federal government were unprepared for the storm. Hurricane Katrina claimed the lives of over 1,800 people (LA Department of Health and Hospitals 2006), resulted in \$81.2 billion in damage (DoC 2006), and has significantly altered and reduced the population of the city of New Orleans.

The predictions of the hurricane research community were accurate. They achieved their mission of good prediction, and served the public value of high quality science. Yet, they did not achieve their mission of resilience. Good prediction (high quality science alone), in the case of Hurricane Katrina, was not a means to the end of resilience. In presuming that good predictions would inherently lead to more resilience, the research community did little to address societal capacity to use these good predictions.

Hurricane Katrina, research indicates, was not an isolated case. As in Katrina, hurricane forecasts broadly have become more accurate. Hurricane track predictions and lead times have improved. Yet, disaster losses have not decreased, even when normalized for population and economic growth (Pielke Jr. et al. 2008) and forecast use has not improved appreciably (Eosco et al. 2009). In fact, a study conducted by Hooke and Pielke Jr. (2000) suggests that in spite of the increasing precision of hurricane landfall forecasts, evacuation areas have actually widened and disaster management costs have increased. Better hurricane preparation and response plans may in fact be more vital to the reduction of disaster losses than would additional knowledge about landfall. Yet, the voices that might suggest such a change in research priorities – urban planners or engineers or disaster management practitioners - are not part of the prioritization dialogue, because these dialogues are not collaborative, open, or responsive.

Lured by ever-improving predictions and bolstered by institutional and cultural trends that promote better predictions before relationships with emergency managers, city planners, or builders, the US federal hurricane research enterprise is not adequately equipped to work collaboratively and responsively with decision makers as it promises. Budgets for hurricane research are limited, and by emphasizing high quality science as *the* public value of priority, the research enterprise de-emphasizes the other four public values. The preventable losses in Hurricane Katrina and the rising evacuation costs that Hooke and Pielke Jr. (2000) points out reveal problems in the way in which federal hurricane research implements the above public value logic. The following section considers if and how the private sector fills this gap.

Hurricane Research in the Private Sector, Non-profits, and Local Governments

There are successful examples of private sector, non-profit, and local government groups serving the intrinsic public value of increased resilience, as well as the instrumental values proposed in the guiding natural hazards public value logic (Fig. 1). Despite these successes, however, these efforts are not widespread and do not fill the gaps opened by public sector research. Because these groups are not specifically focused on serving public values, much of their research remains private and selective.

One example of a group that tries to fill this gap though, perhaps implicitly, is the Institute for Business and Home Safety (IBHS), a national non-profit insurance trade association, whose mission is "to reduce the social and economic effects of natural disasters and other property losses by conducting research and advocating improved construction, maintenance and preparation practices" (IBHS 2005). Made up of members of the insurance industry, they focus on promoting and implementing tangible solutions that will increase vulnerable communities' resilience to natural hazards. They do so by commissioning engineering studies to develop procedures to assess and improve the disaster resistance of commercial buildings, by identifying effective building techniques and intervening and lobbying to strengthen building codes, and by forming partnerships to promote better residential and small business building safety. They have also created disastersafety.org, an online interface by which to present building safety information to both businesses and individual homeowners (IBHS 2009). According to past President and CEO, Harvey Ryland,

> "[what all major] losses have in common is that many could be reduced, even prevented. Whether it's through building codes, construction methods, maintenance practices or business continuity plans, we do know how to reduce the residential and commercial impact of these incidents. With the support and leadership of our members, we aim to do just that" (IBHS 2005).

Their research is collaborative – it is conducted by and with scholars from across the natural hazards spectrum; responsive – it orients its work specifically to the needs and problems of society; and transparent – its process is open to the scrutiny of several entities such as manufacturers, builders, trade groups, and the insurance groups who fund it. This focus on the production of useful science is perceived to be a success by emergency management practitioners, insurers, as well as operational forecasters. They have effectively intervened through the International Code Council (ICC), an organization that runs a consensus process for setting model codes for the entire US. Apart from resistance from the building community, the code process is perceived to be quite effective (Interviews 2009).

My interviews suggest that while the IBHS and ICC do fill a portion of the useful science gap in the hazards research public value logic, they are unique examples. Predominantly, the private sector serves private not public interests. The insurance industry offers an example of this. In order to set insurance rates for homeowners, insurance companies either conduct their own or contract out research to predict a possible range of losses. Sometimes this research results in knowledge that may reduce the vulnerability of individual homeowners or communities collectively to hurricanes, especially by way of potential credits and recommendations for measures to increase building safety. However, much of the risk research undertaken by the insurance industry serves to buffer insurance and reinsurance companies themselves in the event of a major storm, and thus is not designed to respond to the needs of other decision makers – or to serve a responsive, transparent, or collaborative public value.

In sum, the private sector has more coherently deployed the guiding natural hazards public value logic (Fig. 1) to meet societal need than has the public sector, yet its work is limited to the needs of select groups. With no group specifically focused on the public value of useful science, hurricane research misses opportunities to increase resilience.

Earthquake Research

The US earthquake research enterprise provides a contrast to this hurricane research narrative, because it widely implements the guiding natural hazards public value logic. Public earthquake research, in collaboration with private sector research, places a far higher priority on the production of useful science. It strives to be collaborative, transparent, and responsive. There are weaknesses, certainly, within the earthquake research enterprise, but in terms of the public values it promises to serve, it adheres well to the public value logic laid out earlier in general terms. Earthquake research thus joins useful science with high quality science in its pursuit of better resilience. As Susan Tubbesing, the Executive Director of the Earthquake Engineering Research Institute (EERI) aptly explains, researchers in this field "have always recognized that policy matters, that if you can't change the building codes, you can't solve the earthquake problem" (2009).

Public: Federally Funded Earthquake Research

This trend has been an evolution, however. The US Geological Survey (USGS), one of the main funders of earthquake research, for years, sought methods to determine not just where earthquakes were likely to occur, but also when (Nigg 2000). In the mid-1970s, these efforts seemed on the verge of great success. Based on a series of precursors, and a regional increase in seismicity, Chinese officials evacuated the city of Haicheng just prior to a magnitude 7.3 earthquake. This evacuation was credited with saving around 150,000 lives (USGS 2008a). With this experience bolstering similar predictive efforts and plans already underway, scholars and decision makers at this point embraced a focus primarily on high quality science and not on useful science.

Confidence in the ability of research to predict earthquake timing had begun to ebb by the early 1980s, but the USGS still embarked on a large, long-term prediction project, beginning in 1984: the Parkfield Earthquake Experiment. This was a large-scale earthquake prediction program that set out to understand pre-quake signals and predict major earthquakes (USGS 2008b). Based on "a set of assumptions about fault mechanics and the rate of stress accumulations" (Ludwin 2002), USGS scientists "predicted, with 95 percent certainty, that a moderate earthquake (magnitude 5.0–6.0) would occur along the Parkfield segment of the San Andreas Fault between 1985 and 1993" (Nigg 2000, citing Bakun and Lind 1985). Yet, by 1994, no such earthquake had materialized, and prediction had become a taboo idea within the USGS.

At this same time, the USGS faced an unfriendly political climate. The US electorate swept Democrats out of Congress and replaced them with a Republican majority, led by Newt Gingrich and his "Contract with America," bent on cutting expenditures. The Contract included a plan to abolish the USGS. This threat, the perceived failure of the Parkfield Earthquake Experiment, and a very costly earthquake in Northridge, California, forced the USGS to reassess its activities. Its mission remained the same – to minimize the loss of life and property as a result of natural disasters – but its means of accomplishing that changed. It shifted its research process from the alternate public value logic (Fig. 2) to the guiding natural hazards public value logic (Fig. 1), and began to embrace *both* instrumental values – high quality science and useful science (preparedness). No longer was prediction alone its means to reduce losses. Instead, the USGS set out to build partnerships and to produce a series of tangible, useful products that could clearly be attributed to the USGS (McElroy 2006). This built on trends begun during the Parkfield Earthquake Experiment, when scientists worked with emergency management officials to prepare for the earthquake that would not materialize (Nigg 2000). Thus, the confluence of scientific failure and political threat drove earthquake researchers in new directions that diverge markedly from hurricane research.

Since undertaking this shift, USGS scientists, particularly within its Geologic Hazards Team, have actively developed relationships with the users of their information – e.g. state departments of transportation, building engineers, utilities, and local governments – and have shaped their research agendas based in part on those lasting partnerships. They have, in so doing, become more responsive and transparent – and collaborative as well. The agency's budget also shifted to address decisions these users must make to increase resilience.

For example, in cooperation with lifeline operators (electricity, water, power utilities) and the California Department of Transportation (Caltrans), USGS researchers develop ShakeMaps – assessments of the intensity of ground shaking around an earthquake site. ShakeMaps show the distribution of ground shaking in the region of an earthquake, by the "intensity (local severity of shaking), rather than the magnitude (the total energy released by the earthquake)" (USGS FS-087-03 2003). Intensity information is more salient to decision makers than is magnitude, because magnitude gives only general information about activity at the epicenter, one single point. This may not be the point at which shaking is greatest, and thus provides only moderately useful information about where damage will be most severe, and how to mobilize resources to prevent. This information alone requires extra reconnaissance work on behalf of response organizations. Intensity information, on the other hand, offers knowledge about the distribution of ground shaking, and it does so within minutes of an earthquake (USGS 2003).

USGS researchers at the Geologic Hazards Team worked in concert with Caltrans, lifeline operators such as Pacific Gas and Electric (PG&E), and emergency responders to develop these tools, and to tailor the tools to their needs. As a result, these organizations not only buy into the ShakeMap idea, but also have developed trust and lines of communication with earthquake researchers. Neither the relationships nor the maps have yet been tested by a major earthquake, but they are still widely viewed as successful because of the *process* of developing them. This process of collaboration, responsiveness, and transparency has enabled both researchers and decision makers to evaluate alternative pathways to better resilience; and in so doing, it has made science more useful and responders more prepared. For example, Caltrans has integrated ShakeMaps with their own assessments of the structure of their 25,000 bridges and overpasses, so that when an earthquake hits, they can identify and target the most vulnerable and likely to be damaged bridges and overpasses. Further, in the event of an earthquake, both scholarly and practitioner communities are already in contact, aware of each other's needs and resources, such that they will be able to collaborate immediately to solve immediate problems.

Additionally, a substantial percentage of the USGS Earthquake Hazards Program funding goes toward development of national, regional, and urban seismic hazard assessments that form the basis for building and infrastructure design, as well as the seismic provisions in the model building codes developed by the ICC.

The USGS is only one of four agencies in the National Earthquake Hazards Reduction Program (NEHRP), which coordinates US earthquake research. Two of the other agencies, the National Institute of Standards and Technology and the Federal Emergency Management Agency conduct applied research as well. The fourth agency, the National Science Foundation (NSF), is a basic research agency, yet it, too, has seen a shift toward the production of useful science.

For example, NSF has administered funds for three interdisciplinary Earthquake Engineering Research Centers (EERCs). With the goal of extending "our understanding of the impacts of seismic events on buildings, roads, bridges, energy sources, and other components of our built environment and societal institutions," these centers use a team approach to draw on experts from engineering, geology, geophysics, and the social sciences (NSF 97-059). They set out to increase resilience through a multi-disciplinary, collaborative, and problem-oriented approach to knowledge production. Some have critiqued the centers' researchers' tendencies to continue doing the research they wanted to do, and "producing sexy papers with unusable results. We'd have to spend $1M just to try to figure out what these papers say, how to use them" (Personal Interview 2009). Some of the imbalances in instrumental values remain in earthquake research. Yet, to combat this, the funding for these centers – and the associated research questions within them – has shifted away from NSF and toward private sector groups and their needs. The following section on the private sector will address this shift.

Despite some challenges to the earthquake research enterprise's focus on useful science – especially resistance from academic scientists to applied research questions – the balance of federal research within NEHRP is far more targeted to specific problems and decision contexts and to the use of earthquake knowledge than is the hurricane research enterprise described earlier. Further, as we will see in the shift of funding sources for these engineering research centers, collaboration with the private sector is far more fluid in earthquake research.

Earthquakes and the Market: Research in and Funded by the Private Sector and Local Governments

As in the hurricane research enterprise, the private sector is not assigned the same responsibilities for serving the public interest with its research as is the public sector. Yet, much of its research still sets out to do so. Public utilities, departments of transportation, engineering firms, and state governments all actively engage in the pursuit of resilience to earthquakes. In fact, they have spent several billion dollars over the past thirty years for this purpose. Some of this money has gone to university research, some to contractors, and some to in-house research units. All of it has been directed to solving practical problems of the industries footing the bill.

One example of private funding lies in the second generation of the EERCs described earlier. While these centers began with NSF funding in their first generation, they gradually transitioned to private sources of funding. The Pacific Earthquake Engineering Research (PEER) center, for example, is now funded by Pacific Gas and Electric (PG&E), the main utility company in the state of California, Caltrans, and the State of California itself. To begin this endeavor, decision makers at each of these entities met and laid out what they needed and could use from the earthquake research community. They then found and committed funds to support this research, and found academics through the PEER center to solve specific problems. As a result, this research is directly responsive to decision maker needs as well as inherently transparent to their scrutiny.

Using a similar model, individual companies or government groups – such as PG&E, Caltrans, or the city of Boston (e.g. for the Big Dig) – identify particular problems regarding seismic safety that they need to address, and then they commission research, either from engineering firms, consultants, or academics acting as consultants. Leading academics do a great deal of consulting work of this sort in the private sector. Further, there is often close collaboration between engineering firms and university research, as people tend to move between the two quite regularly. As in the hurricane research arena, building codes are a major area of focus of private researchers, as well in this case as public researchers. Through the International Code Council consensus process, engineering firms and academic researchers make recommendations and help to set codes for seismic safety.

Finally, PG&E has a $2–5M annual budget and a staff of fourteen in-house who conduct seismic safety research to improve the earthquake performance of PG&E's gas and electric infrastructure. Because 70% of the San Andreas Fault runs through PG&E territory, it is in a unique and very pro-active position. The director of its geoscience team, Lloyd Cluff (an earthquake scholar in his own right), has invested $2.5B of PG&E money on hazard risk reduction. The company recognizes the risk, and has opted to invest in research and mitigation to reduce it. The research conducted by PG&E must be aimed at improving its facilities performance during earthquakes. Much of their work goes to upgrading dams, power plants, ad related transmission and distribution facilities in their region. In Cluff's estimation, they are now about 80% as resilient as they could be, starting from about 20% resiliency about 25 years ago.

At PG&E, through the creation of public–private partnerships, independent contractors, and engineering firms, private sector funds join public sector funds to produce knowledge to make buildings and communities more resilient to earthquakes. As in hurricane research, private sector research is oriented exclusively to the needs of a given industry, yet, a) these industries are the providers of essential services to the public at large, and b) there is a more fluid relationship between these private sector groups and the funding priorities of federal research. For these reasons, the private sector, in concert with the public sector, is more oriented to serving each of the public values within the public value logic.

The one widely noted failing of this research community, but for some notable exceptions, lies in the social sciences. While the community is far more integrated and cohesive than is the hurricane research community, it has yet to fully sort out how to integrate social research questions into its research agendas. Strikingly, each interviewee noted with regret how little progress has been made in earthquake research to this end. Figure 3b lays out the failures and successes of the earthquake research enterprise.

Public Values Failures in Natural Hazards

While both their end goal and intrinsic value are the same, these two fields possess divergent conceptions of how to get there (their public value logic). In the hurricane research enterprise, high quality science – prediction – is king, and usefulness should – it presumes – follow automatically from high quality science. The earthquake research enterprise, on the other hand, strives for a collaborative, responsive, and transparent, as well as high quality, research process. This section evaluates the public value failures – areas in which neither federally funded research nor privately funded research increase resilience – within both communities, and thus both public value logics.

The public value failure categories are drawn from Bozeman (2007), and like market failure, identify value categories that are often overlooked in the policy process.

Figures 3a and 3b display this contrast visually. They map public value failures and successes and market failures and successes in each field. In the hurricane research enterprise (Fig. 3a), most programs lie below the x-axis, thus indicating that they are public value failures. By contrast, in the earthquake research enterprise

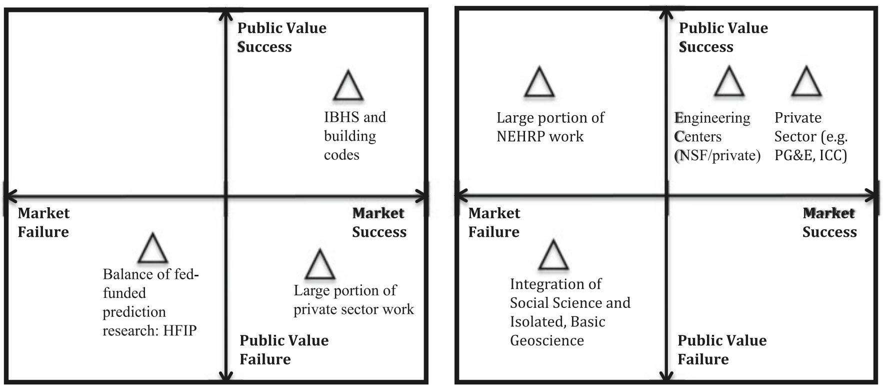

Fig. 3 **a** Public Failure Grid in Hurricane Research. **b** Public Failure Grid in Earthquake Research

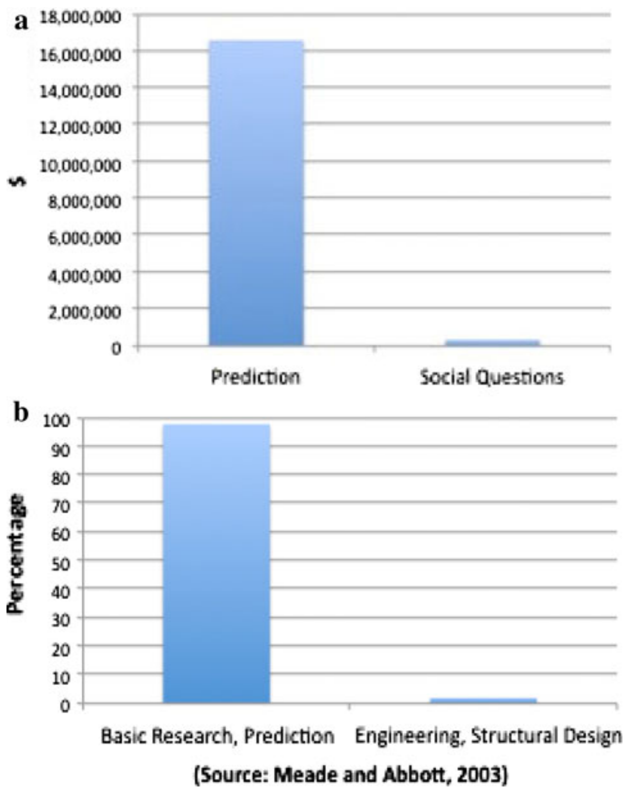

Fig. 4 **a** Relative Funding Levels in NOAA HFIP—Prediction v. Socially Contextual Research. **b** Federal Hazards R&D Budget: Prediction v. Engineering

(Fig. 3b), the majority of programs lie above the x-axis, thus indicating that they are public value successes. Thus, while failures appear in both, they are both more plentiful and more foundational in the hurricane research enterprise. The remainder of this section explains these failures, employing the public failure criteria of Bozeman (2002) and Bozeman and Sarewitz (2005; this issue), and summarized in Table 2, below.

Failure of Values Articulation

Specific values and needs differ from decision maker group to decision maker group. The need for hazards research will be different for a church making an evacuation plan for a low-income population without access to cars than it will be for a power company fortifying its dams. Yet, where the research prioritization process is not responsive or collaborative, there will not be broad mechanisms for the articulation and balance of these disparate values within the research design processes. For example, a social science study of hurricanes demonstrated that in order to heed evacuation warnings, people within vulnerable communities needed to hear the warning from a trusted source - friends or family - within the community

Table 2 Public Failure Criteria

Public Value	Definition	Illustration of Public Value Failure
Mechanisms for values articulation and aggregation	Political processes and social cohesion should be sufficient to ensure effective communication and processing of public values.	There were no mechanisms for articulating the knowledge needs of vulnerable communities, lifeline providers, building engineers, or local decision makers into the research prioritization process leading up to Hurricane Katrina.
Perfect public information	Similar to the market failure criterion, public values may be thwarted when transparency is insufficient to permit citizens to make informed judgments.	With its scant focus on preparedness, US hurricane research does not equip citizens to make informed judgments that may – before, during, and after a hurricane – make them more resilient.
Broad Range of Solutions/ Alternatives	Complex problems with many affected user groups require diverse and multi-faceted solutions and knowledge.	With 98% of research funds going to improved prediction, the range of solutions emerging from US hurricane research is quite limited. While earthquake research is less so, it too struggles with incorporating the input of social science.
Ensure subsistence and human dignity	In accord with the widely legitimated Belmont Code, human beings, especially the vulnerable, should be treated with dignity and, in particular, their subsistence should not be threatened.	The lowest income communities have been the least equipped to respond to the accurate predictions of devastating hurricanes, like Katrina. Without a shift in the process and priorities, hurricane research will do little to ensure subsistence.

rather than a meteorologist or elected official (Tobin and Montz 2004). In this case, trusted knowledge is an instrumental public value for increased resilience. For this community, the broad public value of resilience may be well articulated to decision makers, but the equally important public value of a trusted knowledge source is not well articulated. Few mechanisms exist for articulating *these* public values because the hurricane research prioritization process is not collaborative, responsive, or transparent.

Imperfect Public Information

Similarly because collaboration, responsiveness, and transparency are lacking in hurricane research 1) decision makers are less likely to use knowledge well, and 2) researchers are less able to inform hurricane-related decisions. As in Hurricane Katrina, the predictions were accurate, but their value was limited. Without collaboration and cooperation during the design of forecasts, emergency managers in New Orleans were not ready or equipped to use the forecasts when the hurricane hit. By contrast, having worked collaboratively with the USGS to design the ShakeMaps, Caltrans feels ready to use them minutes after a California earthquake. A healthy process in earthquake research has paved the way for valuable public information. The lack of one has paved the way for imperfect public information in hurricane research. *It is not the outcomes of research, but the process, that fosters better public information.*

Through collaborative discussions about what knowledge to produce and how to produce it, decision makers become more familiar with the range of options available to them, and thus are better able to inform decisions about which options to pursue as part of the hazards research agenda. Citizens and user groups like emergency managers do not necessarily inherently know which science will be most valuable to them. For example, when asked, emergency managers are likely to say that they want better, more accurate predictions (Eosco et al., 2009) without recognizing that research into forecast dissemination processes might help more with disaster response strategies. It is only after a discussion with the producers of knowledge that they become familiar with what is possible.

Limited Range of Solutions or Alternatives

This previous explanation alludes to another public values failure: too limited a range of solutions or alternatives to a stated problem (see Logar, this issue for alternate example of this public value failure criterion). The problem in hazards research is stated and clear: present and growing vulnerability to losses from natural hazards. Yet, particularly within US hurricane research, there is only one predominant response to that problem: prediction. Vulnerability is a complex problem with many causes and implications, and thus the response to it should be similarly complex and multi-faceted. The budget numbers for NOAA's Hurricane Forecast Improvement Project ($350,000 total for social science projects, and the remainder of $17 million for short-term prediction) as well as those provided for general hurricane research budgets by RAND, suggest that a meager 2% of project focus outside of the realm of providing better predictions. No matter how successful that approach, this is not a wide range of options for hurricane emergency managers.

In this area, though, both hurricane research and earthquake research could stand improvement. Because of the problems that earthquake research has had with regard to social science, its research problems are limited to the vantage points of its engineers and utility companies. Scholars who study the dissemination and use of information, who understand population flows during disaster, and the constraints on key decision makers do not have a voice in prioritization. The range of considered alternatives is therefore limited.

Ensure Subsistence and Human Dignity

At its core, hazards research is funded to increase the resilience and thus the long-term sustainability of communities vulnerable to disasters. This intrinsic public value is inextricably linked to the subsistence of communities, and the human dignity of people within them. This is particularly true because where vulnerability to disasters is high, the lowest income portions of the population are most vulnerable and least able to respond. In regard to both hurricanes and earthquakes, vulnerability is greatly and continually increasing, as people move to vulnerable areas and as wealth levels and disparities increase (e.g. Mileti et al. 1999). This trend threatens subsistence and human dignity, and even more so without a shift in capacity for response. Earthquake research shows signs of increasing capacity for response in the US – through its demand for better building codes in all parts of the city, and its integration of engineering with city planning with geosciences research. Hurricane research shows fewer signs in this regard. Better predictions better benefit the wealthy and more mobile populations. This is a public value failure.

Values Chain Analysis

The guiding natural hazards public value logic (Fig. 1) - from public documents within the hazards research field - follows a linear path with a coherent internal logic. Resilience is the intrinsic value of hazards research; it relies on high quality information and useful science, which in turn relies on collaboration, responsiveness, and transparency. After examining the practice of natural hazards research – hurricane and earthquake research specifically, the main lesson is that the field's "primary intrinsic public value" - resilience - is not an end state or a single value outcome. It is instead a healthy process, predicated on the relationships among the instrumental public values collaboration, openness, and responsiveness. Where this process exists in earthquake research, we see relationships formed to foster resilience. The alternate public value logic, by contrast, assumes that the quality of the science alone will ensure resilience. As a result, in hurricane research, we observe high quality technical products, and yet little capacity to use them. High quality as a sole instrumental - or an intrinsic - value is not enough. Failures within the hurricane public value logic reinforce the importance of this healthy process.

In essence, while resilience is presented in most public documents as an end goal defined by quantitative measures—fewer lives lost and less property damage—the public value successes observed most within the earthquake research community suggest that it should not be measured just in quantitative terms, but instead by the relationships that the research process builds. Through open and regular collaboration among scholarly areas, as well as between researchers and practitioners, communities are more able to respond and solve problems collectively when hazards occur in order to prevent the transition to disasters. Again, ShakeMaps are not the measure of earthquake resilience in California. Instead, the readiness of CalTrans and utility companies to employ and perhaps improve these maps, and to regularly work with the USGS researchers developing the maps are more apt measures of resilience.

Recommendations

A primary difference between US hurricane research and US earthquake research is that one is oriented to prediction as the means to preparedness alone, and the other is oriented to a healthy, collaborative research process as a means to preparedness. As such, each of the following recommendations seeks to build a healthier research process in hurricane research – one that restores a balance between high quality prediction and the needs and voices of its user community.

The earthquake research community was not always oriented toward preparedness. It was oriented, not long ago, in a very similar manner to the current hurricane research enterprise. Its primary focus was prediction, and its researchers had yet to establish relationships with emergency managers, lifeline operators, or building code councils. There are lessons, therefore, for hurricane research in the progression of earthquake research. There are three primary lessons that this paper recommends: 1) coordinated research – better partnerships within the different parts of the academic and research community, 2) develop partnerships – as well as sources of funds – from the practitioner community, and 3) enhance the value within hurricane research of preparedness.

The hurricane research community has in fact made strides to achieve the first of these lessons. It has made attempts to establish a National Wind Impact Reduction Program (NWIRP), resembling NEHRP quite closely. The attempt at coordination is a step in the right direction, yet the logistics of the coordination matter a great deal. Because it has culture steeped in prediction rather than collaboration and responsiveness, NOAA is not the appropriate lead agency for such a program. NOAA's de facto coordination has guided its current priorities. NEHRP went a long way to ensuring its success by giving the responsibility for research coordination to an agency that focuses to its core on application and useful science. A NWIRP should do the same.

Further, interested parties in the earthquake private sector have done a great deal to motivate research that increases resilience. They operate, regularly, within the context of those vulnerabilities and know well what problems are most important or would be most helped by new knowledge. Partnerships with similar hurricane research players therefore can reorient a research program toward preparedness. Further, logistically, the funds that private groups brought to earthquake research catalyzed an interest in this type of research. Where there is money, there is interest. Partnerships with hurricane insurance partners or building engineers could bring similar money, as the partnerships develop. The IBHS is a logical starting place for these partnerships.

Through the growth of a collaborative, responsive, and transparent research process, the earthquake research community has embraced a series of related instrumental values to guide research choices and institutional arrangements. As a result, it has evolved toward an increasing capacity to serve intrinsic public values. By beginning these steps in hurricane research, a similar shift will be possible.

The last week in May of 2009 marked National Hurricane Preparedness Week, yet neither the National Hurricane Center nor the National Weather Service website had a link to the robust National Hurricane Preparedness Week website, the weekly NOAA press conference did not address the preparedness week. While preparedness is not now a priority in hurricane research, it is a potential starting point for a different public value logic – and increased resilience.

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