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Cognitive Barriers in Floods Risk Perception and Management: A Mental Modeling Framework and Illustrative Example

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***Abstract*— Recent severe storm experiences in the U.S. Gulf Coast illustrate the importance of an integrated approach to natural disaster preparedness planning, one that harmonizes stakeholder and implementing agency efforts. Risk management decisions that are informed by and address decision maker and stakeholder risk perceptions and behavior are essential for effective risk management policy. Formal (versus ad hoc) analyses of risk manager and stakeholder cognition represent an important first step. Mental modeling has been successfully used to reveal, characterize and map stakeholder beliefs about risks in order to develop more effective cross-stakeholder communication strategies. This paper summarizes diagram-based representation of mental models, and presents an example specific to U.S. Army Corps of Engineers (USACE) flood preparedness and response program needs. Understanding flood risk mental models will enable USACE to bridge differences across and within stakeholder groups, cultures and disciplines internally and externally involved in natural disaster response in order to develop approaches for handling floods and other emerging challenges.**

***Keywords*—mental modeling, floods, homeland security**

I. INTRODUCTION

In the fall of 2005, hurricanes Katrina and Rita revealed inadequacies in severe storm and flood protection plans for the U.S. Gulf Coast. Initial criticism centered around engineering design and management issues (e.g., impact and loss projections, flood protection infrastructure) and degradation over time of the region's wetland defenses by various industries (e.g. energy, transportation) [5,12]. More recent critiques stress the importance of human factors in disaster prevention planning. For example, Gheytanchi et al. [10] states:

> *An interdisciplinary approach to the field of disaster management that views psychology as a central element… will lead to stronger, more resilient communities, [and] result in better decisions on the part of government*

Even before hurricane Katrina, similar recommendations were made in the United Kingdom by the Institution of Civil Engineers panel as part of their assessment of flood management practices in response to 1998 and 2000's severe flooding episodes. Two key recommendations of their report were to "learn to live with rivers" by accommodating waterway expansion from rainfall, and provide greater weight to human and social factors when assessing flood risk. For example, anticipated victim distress should be considered when designing flood mitigation strategies [8, 9]. Also, all stakeholders should be involved in a cooperative dialogue, thinking together about flood management issues in an interdisciplinary way [22].

The U.S. Army Corps of Engineers (USACE) and others are working to increase interagency coordination and stakeholder inclusion in coastal restoration planning for Louisiana and Mississippi. The proposed, unified approach includes multi-objective management tailored to the needs of specific communities and the region in general. A recent report by USACE [19] considers the use of formal decision-analytic processes for recovery planning in the Gulf Coast. USACE initiated the "Action for Change" initiative to update disaster management strategies within USACE and address its organizational culture in ways that can provide and facilitate systemic approaches to risk management to better accommodate stakeholder concerns. This adaptive management approach reinforces efforts of the Working Group for Post-Hurricane Planning for the Louisiana Coast [23]. As the de facto leader of U.S. flood risk management efforts, USACE hopes to evolve from a historic engineering emphasis to address flood risks to well-informed strategic planning in coordination with state and local authorities. State and local managers typically regulate their floodplains in ways that often do not consider effects on adjacent communities [11, 16].

Further complicating matters, most citizens do not take personal responsibility for flood planning, and instead often expect government agencies to manage all zoning, insurance, and emergency response issues, irrespective of agency ability to provide these services. USACE architectural designs to reduce flooding probability, along with government levee certification and National Flood Insurance Program requirements, help to perpetuate personal irresponsibility for flood planning [11]. The National Flood Risk Management Program established by USACE has helped address some personal responsibility issues by requiring at-risk individuals to insure their property against flooding [11, 16]. However, approaches which incorporate stakeholder perspectives and encourage them to take an active role in disaster planning are

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critical to future sustainable disaster management in the Gulf Coast.

The importance of accommodating social and human dimensions in disaster preparedness is clear, but specific tools for integrating stakeholder knowledge and values with that of USACE groups are still underdeveloped. The mental models approach is a useful framework for better understanding and addressing deeply held beliefs, and can enhance stakeholder involvement in strategic planning and decision making. Some past work with this method has investigated laypersons' perceptions of floods, e.g. [13, 14, 21], though these studies did not use diagrams as part of their approach to informing the formulation of emergency plan alternatives. Also, although some work has compared layperson and expert perceptions of flood risk, e.g. [18], how differences between these groups can be addressed remains unknown... The result of a diagram-based technique for representing mental models is presented here, in an attempt to inform emergency manager decision-making while accounting for the values of stakeholder groups. Conclusions based on this work and next steps are also discussed.

II. MENTAL MODELING APPROACH

Our previous work [24] reviews four methods for diagram-based representation and recommends an influence diagram approach, historically used for developing risk communication literature, as the most suited method for synthesizing flood risk management views. This technique has been described as:

> *…the premier method to integrate multi-stakeholder decision-making models (systems models) with technical risk assessment models (risk models), and allow for direct comparison with empirical research into multiple stakeholders' values and perceptions regarding the system and/or the risk* [6]

This section summarizes the general method. Specifics on its application follow.

A. Method

Risk Communication Influence Diagrams (RCIDs) were developed as a way to detect differences between layperson and expert knowledge of a domain for later use in environmental risk communications to the public [4,15]. Fischhoff [7] describes risk communication as fulfilling an implicit social agreement between those that create risk (e.g. government planners, industry) and those that bear risk (e.g. laypersons, plan implementers). This method has been used to create brochures for laypersons to learn more about risks associated with radon exposure [1, 2], climate change [3, 17], and other hazards [15]. Some have even used this method in the development of business research and development plans [20].

Bostrom et al. [4] describes RCID creation as a four-step process. First an expert model is created (see Fig. 1). Experts participate in semi-structured interviews intended to elicit what the expert knows about the domain of interest to identify important concepts and how they may be causally related to each other. Next, layperson beliefs are elicited through similar one-on-one interviews that typically begin with general questions to identify what individuals know about the topic, and then move systematically to increasingly focused questions to identify what laypersons know about specific expert concepts. Layperson beliefs elicited in this way are then mapped onto the expert diagram or expert model. Finally, alignments and misconceptions held by laypersons, as well as gaps between expert and lay knowledge are described using dissociations identified in the previous step. The severity of misconceptions can be measured by administering questionnaires to new lay participants where interviewee responses are given on a Likert scale ranging from "definitely false" to "definitely true."

B. Metrics

Several quantitative metrics can be used to compare between-group mental model structure [4, 20]. Completeness is a measure of the layperson model identifying how much of the expert reference model is covered by a layperson's mental model. It is computed as a ratio of the number of expert concepts identified by a layperson divided by the total number of expert concepts. Specificity assesses the level of detail in a layperson model. A ratio of the number of specific concepts to general concepts is calculated for both layperson and expert models. The layperson ratio is then divided by the expert ratio. As with completeness, specificity is only calculated using concepts that were included in the expert model.

C. Strengths

The RCID method typically compares an aggregated mental model diagram from laypersons to an aggregated expert model. The expert model can represent an estimate of the 'true' state of the world from those who are best able to report its structure and content. The strength of this method comes from the comparisons that can be made between laypersons, who presumably have little knowledge of a technical domain, and experts who possess all important knowledge about the domain. Comparisons against the expert consensus model can illustrate areas where informing laypersons may be helpful. RCID can also serve to identify points of emphasis between experts across specialties (e.g. meteorologists, hydrologists) or between one specialty and all experts in general. Quantitative measures for comparisons across diagrams are intuitive and easy to understand with limited technical knowledge.

D. Challenges

One of the primary challenges of expert models is the universality in representing divergent perceptions. Expert and layperson mental models may differ significantly in their structure (how concepts are connected), content (what concepts are included), and complexity (how well concepts are elaborated). For example, a weather expert may know that low atmospheric pressure and high humidity together result in rain. Laypersons may have a different model structure, believing that changes in atmospheric pressure cause changes in humidity which in turn cause rain. The weather expert model may also have a variety of complex categories for the conditions that lead to rain, whereas the lay model may only contain one or two simple categories for these preceding events. These differences may limit the effectiveness of an expert model used to design communications and policies intended for lay audiences.

Similarly, subgroups may exist who differ in their perceptions of the structure, content, and complexity of a domain. These subgroups, even if they are a minority of the overall population, may contribute significantly to implications for risk communication and policy. Even experts of similar competence in a domain may have different mental models of that domain, particularly if the topic area is broad and incorporates many disciplines. Each discipline might have its own terminology and perceptions of influence structure.

Those creating and using expert models should take great care in developing models independently from various stakeholder groups and significant subgroups, without assuming that one group's model (e.g. experts) can be used as a scaffold for another group's model (e.g. laypersons). The mental models approach addresses issues of model independence by first asking broad questions about general topics early in the interview. Only after participants talk at length about a topic are more focused questions asked to elicit knowledge about specific concepts that were not volunteered from general questioning. In this way, participants are less likely to frame what they know within a predefined framework.

Another challenge for RCID concerns the consistency of mental model representations. As a product of the social sciences, influence diagrams have been used mostly to depict qualitative relationships. Though more quantitative relationships seen in the physical sciences can be represented via influence diagrams, the emphasis is typically on illustrating differences of kind, and not of degree. Influence diagrams' qualitative nature can make it difficult to compare models in a way that lends itself to quantitative analyses typically used to determine measurement consistency. However, since mental models are often employed in making policy judgments and other decisions that are more interested in qualitative descriptions of phenomena, the desire for quantitative precision in assessment is more relaxed than in other fields (e.g. medicine, engineering).

A related issue concerns the aggregation of differing opinions presented in interview data when developing an expert model. The subjective nature of the model building process can make weighing or prioritizing perspectives difficult. One way to address this issue is to elicit expert opinions in a group setting where differences can be discussed openly to achieve the highest possible degree of consensus on contentious topics. If necessary, alternative models can be developed to represent alternate perceptions. This process is usually iterative and allows for validation and adjustment of the model, ensuring appropriate interpretations from available data.

III. APPLICATION TO USACE FLOOD RISK MANAGEMNET

To develop the expert models of *Influences on USACE Flood Risk Management*, a small number of USACE experts were interviewed to draft a simple expert model. This simple expert model was shared with 11 USACE experts in a workshop conducted on September 10, 2008. Workshop participants represented a variety of disciplines within USACE, including researchers, planners and senior leaders. Due to extenuating circumstances, USACE engineers were unable to attend the workshop. To gather their input, the project team conducted in-depth, one-on-one phone interviews with five engineers in October 2008. Workshop and interview data was used to refine the model and develop more detailed submodels. These models were reviewed with workshop and interview participants via conference call in January 2009 and further refined.

The expert model of *Influences on USACE Flood Risk Management* is presented below (see Fig. 1). This model is in the form of an influence diagram; a directed graph in which arrows (influences) link related variables in the system (nodes). An arrow between two nodes indicates that the node at the tail of the arrow influences the node at the arrow's head. Note that nodes in the model represent variables that can be measured, enumerated, weighted or otherwise evaluated. The following is a narrative description of the expert model.

A. Drivers

The model starts with the nodes in the upper left-hand corner that depict *Political*, *Societal* and internal *USACE Drivers*, those factors that establish the environment that drives USACE activities.

1) Political Drivers: Political drivers are influences that come from other government entities that can influence or directly control *USACE Flood Risk Management* activities. *Political Drivers* include *Congressional Directives* that fund and mandate specific flood risk management activities; *Federal Policy* that mandates *USACE Flood Risk Management* priorities such as economic development, cost sharing, etc.; and the *National Flood Insurance Program* which mandates flood insurance for unprotected areas that face certain levels of flood risk. This mandate drives much of the building of flood control structures to reduce flood risk levels and thus removing them from areas mandated to purchase flood insurance.

2) Societal Drivers: Societal drivers are influences that come from society at large, including *Economic Development* priorities that encourage or protect national and regional economic development and protect against economic damage (e.g. dams or levees that reduce flood risk for an area and encourage/protect development); *Public Health & Safety* priorities to protect the health, safety and welfare of citizens; *Social & Community Impact* priorities to protect community social networks and organizations that reflect the collective impact to individuals and the direct impact on social structures and organizations; *Public Expectations* regarding publicly acceptable flood risks levels and flood control structure effectiveness; and *Environmental Protection & Climate Change* priorities regarding the protection of the environmentally sensitive areas such as wetlands and the response to the changes in climate, which may influence flood risks.

3) USACE Drivers: USACE Drivers are factors internal to the Army Corps that influence *Flood Risk Management* activities, including *Funding* and cost sharing requirements, which limit the number of projects with positive benefit-to-cost ratios that can be enacted; *Mission & Mandate*, covering areas such as public protection, war fighting, protecting water resources, protecting the environment, maintaining waterway infrastructure, and homeland security; *Principles & Values*, focusing on relevance, readiness, responsibility, and reliability; *Technology*, and technical innovation such as software to model floods for risk assessment and risk planning purposes, software to encourage and enable knowledge sharing and retention, and technology such as construction methods and materials to improve flood control structure reliability and performance; *Prioritization* of *Flood Risk Management* activities based on economic development and public health and safety criteria; and *Planning Assumptions*, particularly the appropriate or acceptable level of flood risk.

4) Historic Flooding Events: The *Drivers* are particularly influenced by *Historic Flooding Events* including events like Hurricane Katrina and the historic flooding of the Mississippi River Valley. Experts believe the impact of these events has had a significant influence on public perceptions and public expectations, which in turn strongly influence *Societal*, *Political*, and Internal *USACE Drivers*.

B. USACE Flood Risk Management

The nodes grouped together in the middle of the model depict *USACE Flood Risk Management* activities, the actual tasks performed by Corps personnel, including:

1) Quality of Flood Risk Issue Identification: This node represents the process of identifying potential flood risks to be investigated further through USACE *Flood Risk Assessment* activities.

2) Quality of Flood Risk Assessment: This node represents the study and quantification of specific flood risks to establish risk-based priorities for USACE *Flood Risk Management Planning* activities.

3) Quality of Flood Risk Management Planning: This node represents the planning activities in preparation for USACE *Flood Risk Management Implementation* activities.

4) Quality of Flood Risk Management Implementation: This node represents activities which include *Flood Control Construction*, activities such as building dams and levees; *Assessment Management*, activites such as the operation and maintenance of dams and levees; *Non-Structural Activities*, activities other than the construction of strutures such as dams and levees including influencing changes in zoning and development that reduce risk by removing potentially affected structures and people from flood prone areas; *Flood Preparedness*, activities in preparation of flood events such as flood warning systems and evacuation planning; and *Flood Response*, activities undertaken by USACE in response to floods such as emergency repair of levees and other flood control structures.

These *Flood Risk Management* activities, in turn, influence the node found in the lower left portion of the model depicting *Influences on Flood Risks.*

C. Influences on Flood Risks

The node in the lower left corner of the model represents *Influences on Flood Risks.* These include naturally occurring variables like weather, geography and demography as well as human influences such as flood control structures, policies and individual decision making, as well as the following influences: *Weather & Climate,* such as hurricanes and other extreme weather events and the impact of climate change on the frequency, magnitude and distribution of such events; *Geography, Topography & Demography,* such as the lay of the land and course of waterways and coastal areas potentially impacted by flooding events, combined with population levels that result in flood risk exposure; *Development and Land Use,* the concentration of residential development and other land uses that affect the magnitude of risk exposure and potential for impact; *Flood Control Structures,* such as dams and levees that protect against damage from flooding events; *Non-Structural Measures,* such as activities that reduce flood risk exposure by limiting development in areas prone to flooding or improving warning and evacuation procedures to protect public health and safety; and *Flood Response & Mitigation,* activities in response to floods such as emergency repair of levees and other flood control structures, drainage of flooded areas, evacuation of people.

D. Collaboration, Coordination, and Communication

The nodes in the upper right section of the model depict influences on Corps activities related to *Workforce Capacity* and *USACE Collaboration, Coordination, and Communications*, internally and externally as well as the *Quality of USACE Public Engagement*.

1) Workforce Capacity: Workforce capacity is the effectiveness of the USACE workforce based on alignment of workforce resources with workload requirements. This is due, in part, to the number of resources, but also factors such as *Capability & Expertise*, the particular specialties and depth of expertise and experience in areas like planning, engineering, operations, and maintenance; *Communities of Practice*, networks of specialty disciplines designed to support and retain capabilities across the USACE; *Retirement & Replacement*, the ability to address workforce needs from retirement trends that deplete the workforce of experienced personnel; *Workforce Distribution & Mobilization*, the distribution of expertise and experience among Divisions, Districts, Branches and Teams; *Workload Sharing & Balancing*, the distribution of workload among Divisions, Districts, Branches and Teams to avoid capacity constraints; *Knowledge Retention*, policies and activities designed to retain knowledge and expertise independent of the workforce itself, such as record keeping, training manuals, etc.; and *Workforce Morale*, factors that may affect workforce productivity and quality of work and may be influenced by recognition and reward structures.

2) Quality of Internal USACE Collaboration, Coordination, & Communication: This node represents the effectiveness of internal procedures, policies, and activities that affect the quality and effectiveness of working relationships within the USACE, including *Horizontal & Vertical Coordination*, the ability of different disciplines to work together effectively within and across disciplines and organizational structures; *Organizational Structure*, the structure of Divisions, Districts, Branches and Teams designed to respond to the Corps' responsibilities; *Leadership & Culture*, policies and behaviors that promote the appropriate level of cooperation, risk taking, and other qualities desirable in an effective workforce; and *Collaboration Technologies*, technologies that enable collaboration and information sharing within and among Corps groups.

3) Quality of Collaboration, Coordination, & Communication with Government Partners: This node represents the effectiveness of internal procedures, policies and activities that affect the quality of working relationships with other Federal, State and Local agencies and entities, such as *Bureau of Land Reclamation*, *FEMA*, *EPA*, *USGS*, *HUD*, *Park Service*, and *State & Local Cost-Sharing Partners*.

4) Quality of Collaboration, Coordination, & Communication with Other Stakeholders: This node represents the effectiveness of procedures, policies, and activities that affect the quality of working relationships with other stakeholders, such as *Environmental Groups*, *Waterway Navigation Groups*, *Recreation Groups*, *Agriculture Groups*, *Utilities & Hydropower Groups*, *Aquaculture Groups*, *Residential & Commercial Development Groups*, *Resource Industries* (e.g. mining), and *Advisory Groups* (statutorily mandated & technical/scientific peer advisory groups).

5) Quality of Public Engagement: This node represents the USACE activities directed at the public with respect to their *Flood Risk Management* activities, including risk and information communications, educational programs, and other outreach activities.

E. Individuals' Mental Models of Flood Preparedness and Response

This node represents the perceptions held by individuals that determine their assessment of flood risks, and the effectiveness of flood risk controls and *USACE Flood Risk Management* activities. These Mental Models are significant in their influence on public decision making and behaviour, which can in turn influence the level of their individual flood risk as well as *Societal Drivers* expressed via public expectations regarding flood risk, and flood risk management. This node is influenced by the *Quality of Public Engagement*.

F. Desired Outcomes

The end point of the model is the *Desired Outcomes* node in the lower right hand corner. *Desired Outcomes,* the degree to which *USACE Flood Risk Management* activities can achieve desired goals and objectives, such as: *Optimal USACE Flood Risk Management*; *Effective Public Engagement*; *Optimal Public Preparedness & Response*; and *Positive Perceptions of USACE Trustworthiness & Competence*. These outcomes are influenced by the Quality of *USACE Flood Risk Management* activities and by the node directly above, *Individuals' Mental Models of Flood Preparedness and Response*.

IV. CONCLUSION

Although much is known about flood risk, laypersons and expert groups have beliefs about the causes and consequences of flooding that can notably differ. This may only be the tip of the iceberg. Hurricane Katrina taught USACE how differences in beliefs can lead to poor coordination of flood mitigation and recovery efforts with other government management groups. A review of available literature [24] demonstrates there is a great need for methods that integrate the knowledge and viewpoints of participating groups to encourage coordinated involvement.

The expert model research process reported in this paper has resulted in detailed models of influences on USACE flood risk management. These models can be used to establish a common understanding of the relationships, issues and opportunities facing the USACE and can be used as a framework for future research activities. Suggested next steps include in-depth mental models interviews with Corps personnel to evaluate issues and priorities among these influences and the quality of USACE activities and potential areas of improvement

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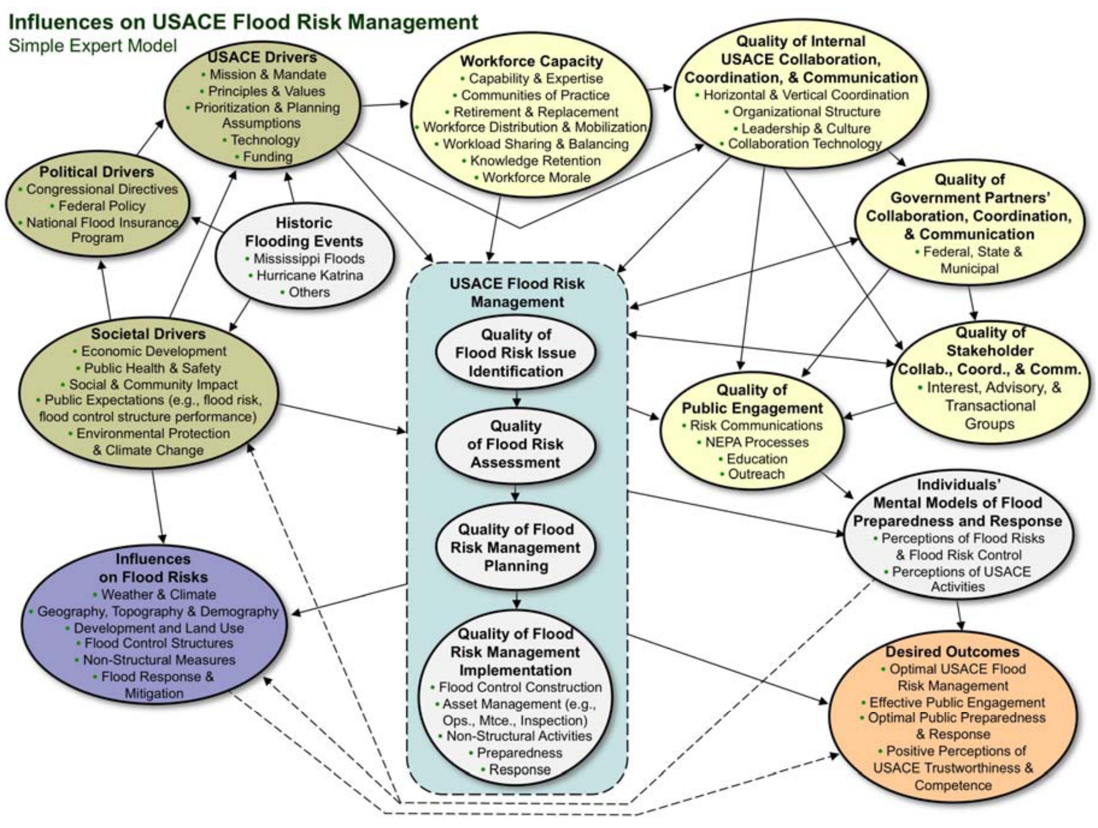

Figure 1. Simple Expert Model of Influences on USACE Flood Risk Management