ERDC/EL TN-11-1
March 2011

Flood Risk Management: Insights from an Expert Modeling Process

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PURPOSE: Recent severe storm experiences in the U.S. Gulf Coast illustrate the importance of an integrated approach to natural disaster preparedness planning that harmonizes efforts of implementing agencies and stakeholders. Risk management decisions that are informed by and address risk perceptions and behavior of decision makers and stakeholders are essential for effective risk management policy. Formal (versus ad hoc) analyses of risk manager and stakeholder cognition represent an important first step. The mental models approach (e.g. Morgan et al. 2002) is one methodology for revealing, characterizing, and mapping stakeholder beliefs about risk that has demonstrated success in developing more effective cross-stakeholder communication strategies and informing policy decisions. This technical note summarizes the diagram-based, expert mental models representation of influences on U.S. Army Corps of Engineers (USACE) flood risk management activities. Understanding these expert mental models of processes central to USACE functions, including those of flood risk, preparedness and response will enable the Corps to bridge differences across and within stakeholder groups, cultures, and disciplines, internally and externally. The mental modeling approach can be used by USACE to synthesize values and objectives of Corps organizational units to provide a unified framework for managing natural disasters, as well as other emerging challenges related to USACE's mission and vision.

BACKGROUND: 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; Cigler 2007; Johnson 2005). In recent analyses, the importance of human factors in disaster prevention planning is a more prominent theme. For example, Gheytanchi et al. (2007) state:

> *An interdisciplinary approach to the field of disaster management that views psychology as a central element—rather than second to engineering or information science—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 by the Institution of Civil Engineers panel in the United Kingdom as part of their assessment of the state of flood management and their proposed improvements in response to severe flooding there in 1998 and 2000. Two key recommendations of their report were to "learn to live with rivers" by accommodating waterway expansion from rainfall and to provide greater weight to human and social factors when assessing flood risk (Fleming 2002a, 2002b). Work by Welp and colleagues (Welp et al.

2006) advocates decision-making approaches that involve stakeholders (including laypersons) in a cooperative dialogue that emphasizes thinking together about issues in an interdisciplinary way.

The U.S. Army Corps of Engineers (USACE) and other agencies are currently working on increased interagency coordination and stakeholder inclusion in restoration planning for coastal Louisiana and Mississippi. The proposed more unified approach includes multi-objective management tailored to the needs of specific communities and the region in general. USACE has initiated the "Action for Change" program intended to update disaster management strategies within USACE and address its organizational culture in ways that can provide and facilitate systemic approaches to risk management that better accommodate stakeholder concerns. This adaptive management approach reinforces efforts of the Working Group for Post-Hurricane Planning for the Louisiana Coast (2006). In addition, a recent report by the U.S. Army Engineer District, New Orleans (2008) considers the use of formal decision-analytic approaches for recovery planning in the Gulf Coast.

As the de facto leader of U.S. flood risk management efforts, USACE efforts are evolving from the historic emphasis on engineering to address risks of flooding to well-informed strategic planning in coordination with state and local management authorities. State and local authorities typically manage floodplains at a micro-level in ways that often do not consider the effects of mitigation plans on upstream or downstream communities (Hecker et al. 2008; Rabbon et al. 2008). Further complicating matters, most citizens do not take personal responsibility for flood planning. Instead they tend to expect government agencies to handle planning related to zoning, insurance requirements, and emergency response issues, irrespective of agency ability to adequately provide these services (Hecker et al. 2008). USACE design of architecture to reduce flooding probability, along with government certification of levees and National Flood Insurance Program requirements, help to perpetuate the phenomenon of personal lack of responsibility for flood planning. The National Flood Risk Management Program established by USACE has helped address some personal responsibility issues by requiring some individuals to insure their property against flooding to reduce their risk of loss (Hecker et al. 2008; Rabbon et al. 2008). However, approaches that incorporate stakeholder perspectives and encourage them to take an active role in disaster planning are 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 what stakeholders[1] know and value with the knowledge, values, and interests of USACE groups are still underdeveloped. The mental models approach has been recognized as a useful framework for better understanding and addressing deeply held risk and value beliefs that can enhance stakeholder involvement in strategic planning and decision making. Some past work with this method has investigated laypeople's perceptions of floods (e.g. Kolkman et al. 2007; Lave and Lave 1991; Wagner 2007), though these studies did not use diagrams as part of their approach to formulating emergency plan alternatives. Also, although some work has compared layperson and expert perceptions of flood risk (e.g. Siegrist and Gutscher 2006), much work remains to understand how differences between these groups

[1] A stakeholder for the purpose of this report is defined as an individual or organization with direct or indirect interest (e.g. economic, social, psychological) in flood preparedness or response.

might be addressed. This technical note presents the results of a diagram-based technique for representing mental models in the service of informing emergency manager decision-making in ways that can account for the values of stakeholder groups. Conclusions based on this work and next steps are also discussed.

RISK COMMUNICATION INFLUENCE DIAGRAM FRAMEWORK: A previous paper (Wood et al., 2010) reviews four methods for diagram-based representation and recommends an influence diagram approach as the most suitable method for flood risk management and communication. Used early in its history for the development of risk communication literature, 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 allows for direct comparison with empirical research into multiple stakeholders' values and perceptions regarding the system and/or the risk (mental models; Decision Partners, LLC 2009)." This section summarizes the general method, and then specifics on its application to expert groups in USACE.

Risk Communication Influence Diagrams (RCIDs)[1] were developed as a means to detect differences between layperson and expert knowledge of a domain for use in communication of environmental risks to the public (Bostrom et al. 1992; Morgan et al. 2002). Fischhoff (1995) describes risk communication as fulfilling an implicit social agreement between those that create risk (e.g. government planners, industry, natural resource managers) and those that bear risk (e.g. laypersons, plan implementers). This method has been used as the basis for creating brochures for laypersons to learn more about risks associated with radon exposure (Atman et al. 1994; Bostrom et al. 1994a), climate change (Bostrom et al. 1994b; Read et al. 1994), and other hazards (Morgan et al. 2002). Some have even used this method in the development of business research and development plans (e.g., Vislosky and Fischbeck 2000).

Bostrom et al. (1992) describe RCID creation as a four-step process. First an expert model is created based on interviews with individuals who have a particularly high level of knowledge on the topic being assessed. The interview utilizes a semi-structured, written protocol intended to elicit what these expert individuals know, identifying important concepts for the domain of interest, and how these concepts may be related to each other. Next, layperson beliefs are elicited, often through one-on-one interviews, using similarly structured interview protocols that typically begin with general questions allowing individuals to highlight what is important to them on the topic endogenously, and then move systematically to increasingly focused questions to cue what laypersons know about specific concepts highlighted by the experts. Layperson beliefs are then compared to the experts' knowledge illustrated by the expert model. Finally, alignments and gaps between expert and layperson knowledge can be depicted in an adapted version of the expert model. The prevalence and magnitude of gaps and alignments can be measured through questionnaires with a larger population of lay participants, asking them to indicate their beliefs about the plausibility of specific concepts using a Likert scale ranging from "definitely false" to "definitely true."

[1] Professionals in the risk communication field often refer to their representations of mental models as risk diagrams. The label risk communication influence diagram is used here to emphasize the roots of this method and the causal attributions between concepts that are its defining feature.

Several quantitative metrics can be used to compare between-group mental model structure (Bostrom et al. 1992; Vislosky and Fischbeck 2000). *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* is another metric that 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.

Strengths. The RCID method typically compares an aggregated mental model diagram from laypersons to an aggregated expert model. The expert model represents an approximation of the 'true' state of the world from those individuals who are best able to report its structure and content. A primary strength of this method for use in flood risk management comes from the comparisons that can be made between laypersons, who presumably have little knowledge of a technical domain, and experts, who possess significant knowledge about the domain. Comparisons against the consensus expert model can illustrate areas where informing laypersons may be helpful. RCID can also serve to identify points of emphasis between experts of different specialties (e.g. meteorologists and hydrologists). Finally, quantitative measures for comparisons across diagrams are intuitive and easy to understand with limited technical knowledge.

Challenges. One of the primary challenges of expert models is their universality in representing differing 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 concepts that were not volunteered in the response to general questions. In this way, participants are not led into framing their knowledge of an area within some predefined structure.

Another challenge for RCID concerns the consistency of mental model representations. As a product of the social sciences, influence diagrams have been used most often to depict qualitative relationships. Though most quantitative relationships seen in engineering and the physical sciences can be represented via influence diagrams, the emphasis is typically on illustrating differences of kind, and not of degree. The qualitative nature of influence diagrams can make it difficult to compare models in a way that lends itself to quantitative analyses that are 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 as high a degree of consensus as possible on contentious topics and when necessary, alternative models can be developed to represent alternate perceptions. This process can be an iterative one that allows for validation and adjustment of the model, ensuring appropriate interpretations from available data.

RCID FRAMEWORK APPLIED TO USACE FLOOD RISK MANAGEMENT: The RCID framework was used to develop a more complete understanding of the factors influencing USACE flood risk management with an interest in improving management and response procedures, as well as stakeholder perceptions thereof. To develop the expert models of *Influences on USACE Flood Risk Management*, two USACE research scientists were interviewed to draft a simple expert model. This simple expert model was then shared with nine additional 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. As engineering was an underrepresented discipline in the September workshop, follow-up one-on-one phone interviews were conducted with five engineers in October 2008 to gather their input. Information from the workshop and subsequent interviews was used to refine the simple model and to develop more detailed sub-models. These models were then reviewed with workshop and interview participants via conference call in January 2009 and further refined.

The simple expert model of *Influences on USACE Flood Risk Management* is presented below (see Figure 1). This model is in the form of an influence diagram; that is, a directed graph in which arrows, or “influences” link related “nodes” – the variables in the system. An arrow between two nodes indicates that the node at the tail of the arrow exerts a certain “influence” on the node at the arrow’s head. Note that nodes in these models can be considered variables, meaning that they can be measurable, enumerable, weighted, or otherwise evaluated. The following is a narrative description of the simple expert model.

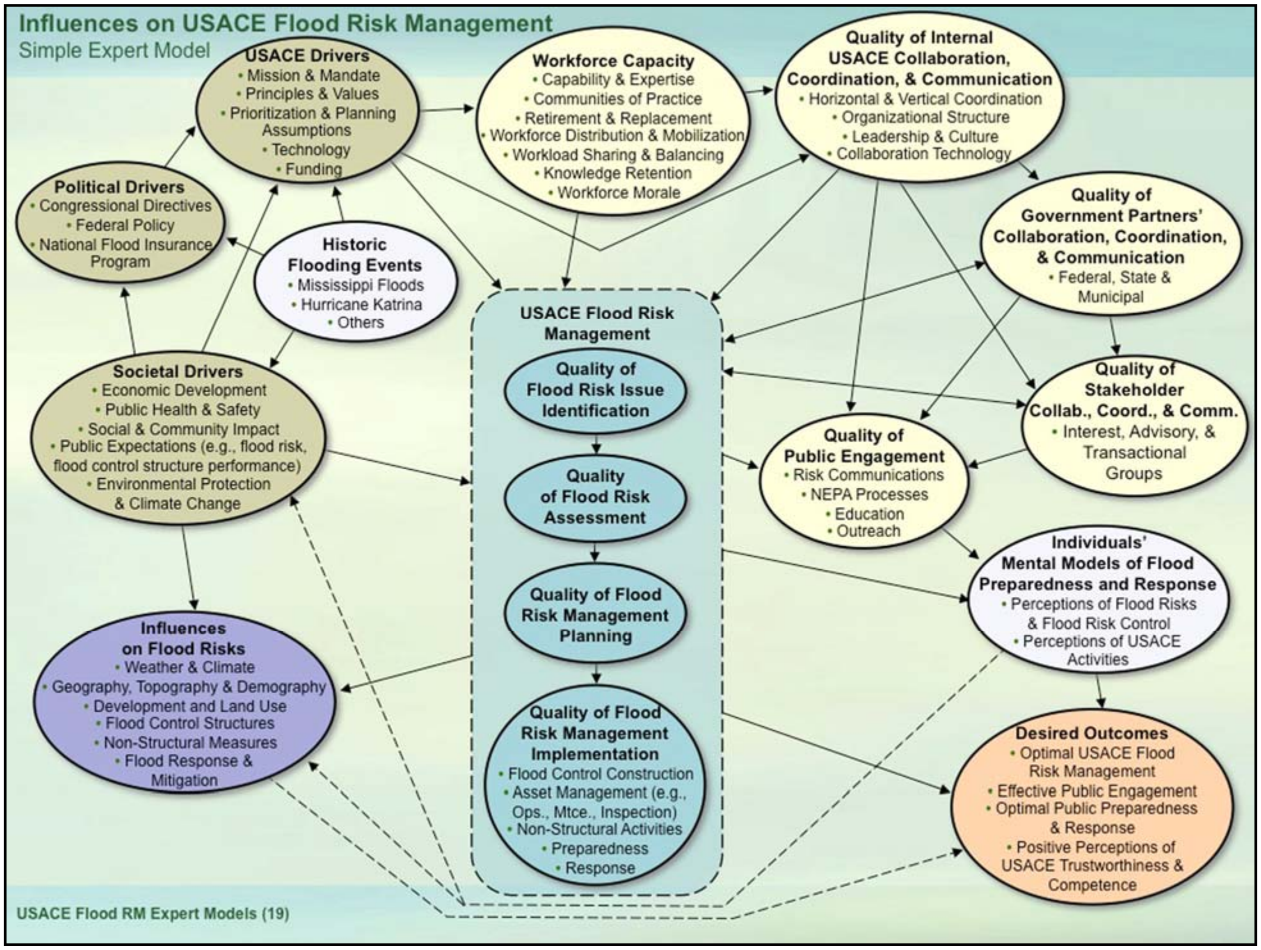

Figure 1. Simple expert model of influences on USACE flood risk management.

Drivers. The model starts with the nodes in the upper left-hand corner that depict political, societal, and USACE internal drivers, those factors that establish the environment or the fundamental conditions that drive USACE activities.

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.
- 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 the level of flood risk, thus removing them from areas mandated to purchase flood insurance.

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 (e.g., flood control structures that reduce flood risks for an area enabling and encouraging economic development) and protect against economic damage.
- *Public health & safety* priorities to protect the health, safety, and welfare of citizens.
- *Social and 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 level of flood risks and effectiveness of flood control structures.
- *Environmental protection and 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.

USACE Drivers. USACE drivers are factors internal to the U.S. Army Corps of Engineers 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 and mandate,* covering areas such as public protection, war fighting, protecting water resources, protecting the environment, maintaining waterway infrastructure, and homeland security.
- *Principles and 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.
- *Planning assumptions,* particularly the appropriate or acceptable level of flood risk.

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 the following.

Historic Flooding Events. The drivers are particularly influenced by *historical flooding events* including events such as 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*.

Quality of Flood Risk Issue Identification. The process of identifying potential flood risks to be investigated further through USACE Flood Risk Assessment activities.

Quality of Flood Risk Assessment. The study and quantification of specific flood risks to establish risk-based priorities for USACE Flood Risk Management Planning activities.

Quality of Flood Risk Management Planning. The planning activities in preparation for *USACE Flood Risk Management Implementation* activities.

Quality of Flood Risk Management Implementation. Activities related to the execution of flood risk management plans. These activities include:

- *Flood Control Construction,* activities such as building dams and levees.
- *Asset Management,* activities such as the operations and maintenance of dams and levees.
- *Non-Structural Activities,* activities other than the construction of structures such as dams and levees include 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 flooding events such as flood warning systems and evacuation planning.
- *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 simple model depicting *Influences on Flood Risks.*

Influences on Flood Risks. The node in the lower left corner of the simple model represents influences on flood risks. These include naturally occurring variables such as weather, geography and demography as well as human influences such as flood control structures, policies and individual decision making, and includes the influences below.

Weather and Climate. Includes hurricanes and other extreme weather events and the impact of climate change on the frequency, magnitude, and distribution of such events.

Geography, Topography, and Demography. The lay of the land, the 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. The dams, levees, and other built defenses that protect against damage from flooding events.

Non-Structural Measures. 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.

Flood Response and Mitigation. Activities in response to floods such as emergency repair of levees and other flood control structures, drainage of flooded areas, and evacuation of people.

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

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 and Expertise,* the particular specialties and depth of expertise and experience in areas such as planning, engineering disciplines, operations and maintenance.
- *Communities of Practice,* networks of specialty disciplines designed to support and retain capabilities and expertise across the USACE.
- *Retirement and Replacement,* the ability to address workforce needs in light of retirement trends that deplete the workforce of experienced personnel.
- *Workforce Distribution and Mobilization,* the distribution of expertise and experience among Divisions, Districts, Branches and Teams.
- *Workload Sharing and 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.
- *Workforce Morale,* factors that may affect workforce productivity and quality of work and may be influenced by recognition and reward structures.

Quality of Internal USACE Collaboration, Coordination, and Communication. This node represents the effectiveness of internal procedures, policies and activities that affect the quality and effectiveness of working relationships within the USACE:

- *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 Army Corps' responsibilities.
- *Leadership and Culture,* policies, actions and behavior that promote the appropriate level of cooperation, risk-taking, and other qualities desirable in an effective workforce.
- *Collaboration Technologies,* technologies that enable collaboration and information sharing within and among groups within the Corps.

Quality of Collaboration, Coordination, and 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 and local cost-sharing partners.*

Quality of Collaboration, Coordination, and 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 and Commercial Development Groups, Resource Industries* (e.g., mining) and *Advisory Groups* (both statutorily mandated and technical/scientific peer advisory groups).

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 informational communications, educational programs, and other outreach activities.

Individuals' Mental Models of Flood Preparedness and Response. This node represents the perceptions held by individuals that determine their assessment of flood risks of the effectiveness of flood risk controls and of *USACE Flood Risk Management* activities. These mental models are significant in their influence on public decision making and behavior, 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.*

Desired Outcomes. The end point of the model is the *Desired Outcomes* node in the lower right-hand corner. *Desired Outcomes* are 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*.

CONCLUSIONS: Although the RCID method presents some limitations, the potential benefits from using this method are great. The RCID approach, if done effectively, is able to accomplish the following:

- Elicit individuals' knowledge, beliefs, and values.
- Integrate this information in multiple ways.
- Develop a common understanding among relevant stakeholder groups.
- Produce quantitative outputs to inform current USACE decision-making paradigms.

These points, particularly the last, are valuable to USACE in identifying key organizational goals and drivers. This method can also be used to foster collaboration between USACE teams, with other government agencies (federal, state, and local), and other stakeholders affected by USACE activities.

There are a few limitations to this study. Concerning the RCID method itself, mental model diagrams can have differences in scope and structure across stakeholder groups (e.g. engineers, planners, laypersons). The simple expert model diagram reported here (see Figure 1) is only one way expert knowledge about USACE Flood Risk Management could have been represented with this framework. Care has been taken to ensure that models of all affected stakeholder groups have been elicited and weighted appropriately. Though other possibilities exist, this work represents a consensus of more than 15 subject matter experts from USACE utilizing an iterative process, and therefore should provide a reasonable depiction of concepts related to flood risk management and how they influence each other. Care should be taken when these models are used to inform policy decisions. Confirmatory research is under way to validate and expand on the model presented here.

The RCID framework was used successfully here to study flood risk management knowledge, values, and beliefs among USACE experts. These experts were able to establish a common understanding of influences on the flood risk management process, and identified several desired outcomes using the mental model diagramming process. Desired outcomes included optimization of internal flood risk management activities, improvement of public preparedness and response, more effective public engagement, and an improvement in the public's perception of USACE trustworthiness and competence. USACE experts also expressed a belief that the most direct way to achieve desired outcomes is through changing the organization's current flood risk management activities. Those activities related to the engagement of the public in management activities and the public's perceptions were especially important. In the model, these are illustrated by pathways linking current flood risk management practices to desired outcomes through nodes related to public perception and engagement.

Current work builds on these conclusions and uses the RCID framework to identify ways to better engage stakeholders and improve perceptions of USACE flood risk management activities. In particular, more robust models of influences on stakeholder attitudes and engagement are under development.

Future work should identify effective methods for identifying and improving stakeholder perceptions and engagement of the USACE flood risk management process, and prioritize them in terms of their utility to maximize the likelihood of success given effort. Future work should also expand use of this methodology to other functions related to USACE's mission. The method can be coupled with statistical techniques (e.g. structural equation modeling) or machine learning algorithms to provide more refined information about the degree of influence between nodes in the model. More specific knowledge about how concepts relate to each other in mental model influence diagrams will help to inform future actions of USACE research teams, managers, and policymakers alike.

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> Wood, M. D., I. Linkov, T. Bridges, D. Kovacs, S. Thorne, and G. Butte. 2011. Flood risk management: Insights from an expert modeling process. ERDC/EL TN-11-. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://el.erdc.usace.army.mil/*.

AUTHOR NOTE: The authors would like to thank Drs. Jack Davis and Edmond Russo of the U.S. Army Engineer Research and Development Center for advice and discussions. Thanks also to Ann Bostrom and Alexander Tkachuk for help in manuscript preparation and review. Funding was provided by the Civil Works Basic Research Program. Permission was granted by the USACE Chief of Engineers to publish this material.

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