Research & Development Strategy for Flood Risk Management

US Army Corps of Engineers ®

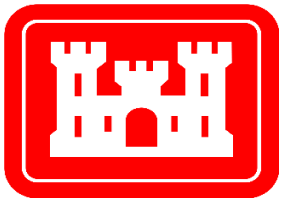
FLOOD RISK MANAGEMENT RESEARCH & DEVELOPMENT
PREPARATION
RESPONSE
RECOVERY
MITIGATION
Tools for Driving Down Risk

December 2015

Research and Development Strategy for Flood Risk Management

Fiscal Years (2017 – 2021)

December 2015



A report prepared for the
US Army Engineer Research and Development Center

ERDC
Engineer Research and Development Center

Research & Development Strategy for Flood Risk Management

Fiscal Years 2017 – 2021

(December 2015)

USACE Mission in Flood and Coastal Risk Management

The US Army Corps of Engineers has the following nine distinct Civil Works business areas:

1. Navigation
2. Flood risk management (FRM)
3. Ecosystem restoration
4. Water supply
5. Recreation
6. Hydropower
7. Regulation
8. Emergency response
9. Support for others

Navigation, FRM, and ecosystem restoration are the largest business areas that drive the structure of the USACE Civil Works Research and Development (R&D) plan. The FRM Business Area is supported by a requirements-driven portfolio of R&D programs executed by the Engineer Research and Development Center (ERDC), including the Flood and Coastal Systems, Coastal Field Data Collection Program, Coastal and Ocean Data Systems, and National Shoreline Erosion Control Development and Demonstration Program. This portfolio of programs balances applied and basic research, development of technology, and the transition of R&D outcomes to communities of practice. These programs leverage resources in other USACE research areas and programs, other Federal and non-Federal agencies, academia and industry to address the most challenging problems as they relate to the Corps' role in mitigating flood and coastal storm risk. This Strategy was developed in consideration and context of the USACE Campaign Plan, FY15-19 (USACE 2015d), Sustainable Solutions to America's Water Resource Needs: Civil Works Strategic Plan 2014-2018 (USACE 2015c), USACE Resilience Strategy[1], and USACE Civil Works R&D Strategy, (USACE 2013c). Further, the Strategy considered many external influencers and enabling documents (see Figure 1).

Aligned with the Civil Works R&D Strategy (USACE 2013c), the R&D Strategy for FRM will strive to:

1. Result in field-ready, environmentally sustainable products
2. Improve the quality of Corps planning, design, construction and operations and maintenance
3. Foster collaboration with partners and stakeholders
4. Harvest innovation and state-of-the-art methodologies and technologies from partners and collaborators
5. Develop and deliver new and emerging technologies and tools
6. Transfer knowledge and capabilities to practitioners and decision-makers

[1] As per discussions with Sheri Moore, Program Manager USACE Resilience Strategy

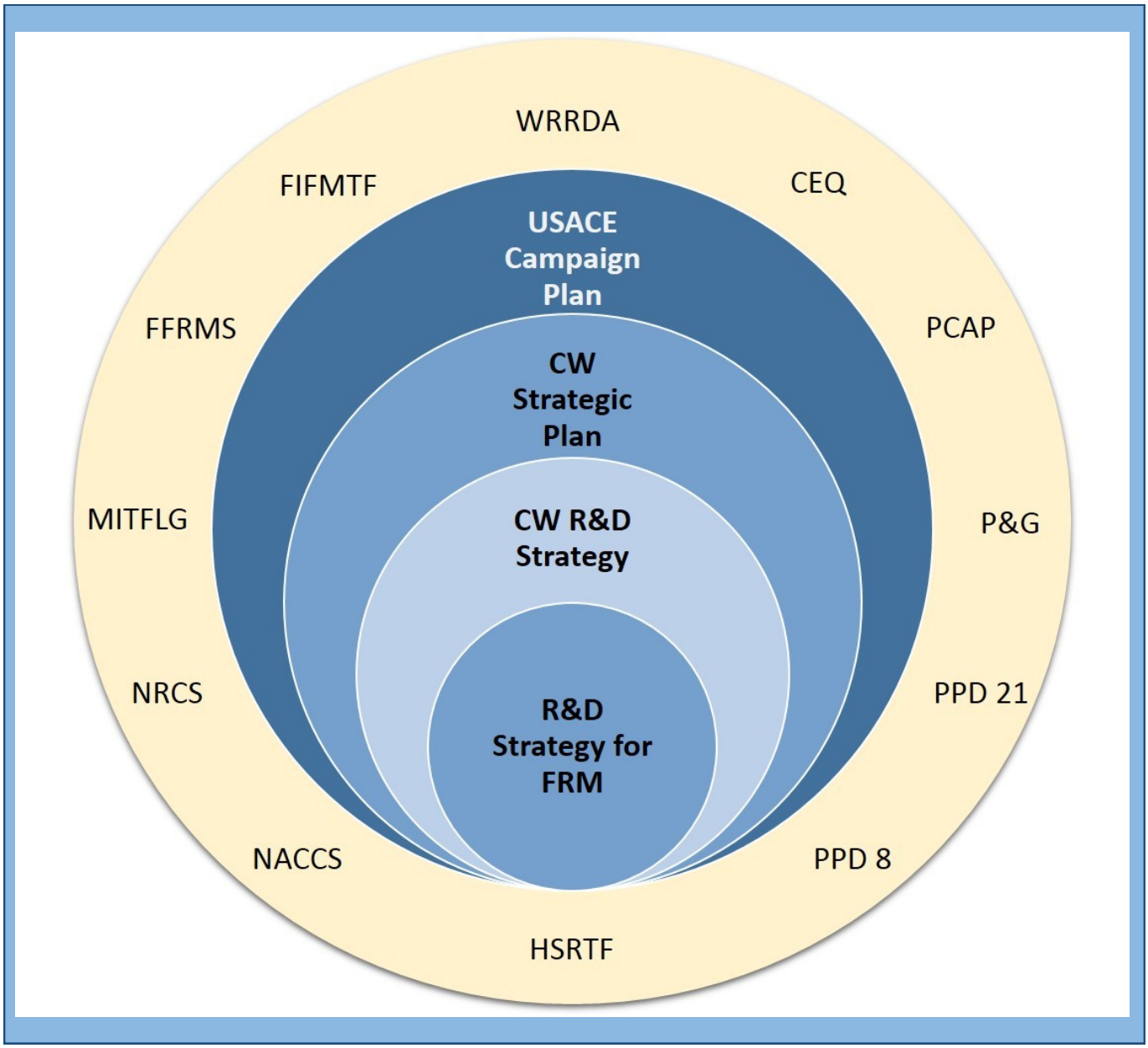


Figure 1. Hierarchy of USACE strategic plans and other enabling documents and external influencers that informed this R&D Strategy for FRM (center of circle). External influencers: WRRDA (Water Resources Reform and Development Act of 2014), CEQ (White House Council on Environmental Quality), PCAP (President's Climate Action Plan), P&G (Principles, Requirements, and Guidelines), PPD 21 (Presidential Policy Directive 21: Critical Infrastructure Security and Resilience), PPD 8 (Presidential Policy Directive 8: National Preparedness), HSRTF (Hurricane Sandy Rebuilding Task Force), NACCS (North Atlantic Coastal Comprehensive Study), NRCS (National Research Council Studies), MITFLG (Mitigation Framework Leadership Group), FFRMS (Federal FRM Standard), FIFMTF (Federal Interagency Floodplain Management Task Force), Internal influencers: USACE Campaign Plan, USACE Civil Works Strategic Plan, USACE Civil Works R&D Strategy. *(See references*.)

Drivers for R&D in FRM

Flood and coastal storm risk is escalating due to changes in population demographics, climate change, and aging and inadequate infrastructure. Compounding the Corps' challenges in addressing the Nation's flood risk and improving its resilience is the need for a balanced water management strategy that addresses the often competing needs for water availability, energy, and ecosystem sustainability. With a growing need for maintenance and recapitalization of water resources infrastructure, combined with fiscal austerity within both Federal and non-Federal levels of government, an integrated water resource management strategy is needed.

With a core mission area in FRM, the USACE continues to play a unique role in addressing the Nation's flooding challenges. A critical objective of the USACE Civil Works program is to reduce the Nation's flood risk and increase resilience to disasters.

Long-range drivers contributing to rising flood risk and impacting a R&D Strategy for FRM include (adapted from USACE CW Strategic Plan (2015c)):

- Aging and Inadequate Infrastructure (failing infrastructure, back log on maintenance and recapitalization, design exceedance, increasing requirements, changing needs, etc.)
- Climate Change (sea level rise, precipitation frequency and intensity, storm patterns, rising temperature, ocean acidification, etc.) (USACE 2013a)
- Population Demographics (shifts in population centers, growth along coasts, impacts to vulnerable populations, etc.) (NOAA 2013)
- Water Security and Competing Demands (water availability, flood and drought, declining water quality, rising energy demand, decentralized water governance/ mission across agencies, increasing water consumption)
- Declining Ecosystems (lost habitat due to erosion, development and sea level rise, declining biodiversity, pollution and hypoxia, changes to salinity, impacts to Threatened and Endangered Species)
- Resource Availability (limited and declining federal budgets and resources, rising need for recapitalization, competing priorities)

Purpose

The **purpose** of the plan is to:

Develop an FRM five-year R&D strategy that includes high-level R&D goals and opportunities. The strategy is informed by pending and future challenges and is designed to address future technology requirements.

The strategy will guide development of an FRM R&D implementation plan and will inform annual research priorities and investment decisions.

Vision

The **vision** seeks to establish:

An R&D roadmap that provides transformational and evolutionary scientific and engineering solutions to support the Nation's toughest FRM challenges.

Mission

The **mission** of the Plan is to:

Conduct R&D at the forefront of science and technology in collaboration with others to reduce the Nation's risk from flood and coastal storm disasters while energizing the economy, sustaining environmental resources, and promoting community resilience.

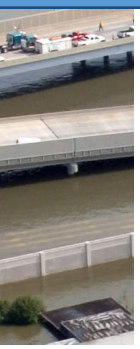
Preparing an R&D Strategy for FRM

The R&D Strategy for FRM has been developed to identify the gaps and advance the science and technologies that will be necessary to meet the challenges of the USACE in their FRM mission as impacted by the drivers (page 3). Further, the strategy is intended to foster conversations both within the agency and externally with USACE stakeholders, partners, and other agencies that lead to innovations that drive down the Nation's flood risk.

Using the most relevant literature and reports, an extensive set of interviews and consultations and an iterative review process, five key challenge themes emerged. R&D goals were established around these themes, supporting both technical capabilities and cross-cutting strategies (see Figure 2). Three of the strategic goals support development of scientific and technical capabilities that help USACE reduce disaster risk, increase resilience and support sustainable water resource infrastructure. The remaining two goals address cross-cutting strategies that encompass all the goals and the inter-related challenges of taking a systems approach and embracing collaboration and partnering. The strategy seeks to identify the most critical challenges and identify the highest level opportunities for R&D that impact the USACE FRM business line.

Figure 2. FRM R&D goals

Goal 1. Risk Reduction: Challenges



The Nation's risk from floods and coastal storms continues to rise. The rising cost of disasters, growing impacts from climate change, and increased flood exposure due to population dynamics and changing land use; coupled with an aging and stressed infrastructure is creating profound challenges for water resource and emergency management decision-makers and practitioners. Climate change, alone, generates a need to better assess watershed and coastal hazards, including changes to precipitation frequency and intensity, heat, drought, and water quality, coastal storm frequency and intensity, and sea level rise.

In line with the growing risk and costs to the Nation from flooding, the White House released the new Federal FRM Standard in Executive Order 13690 (Obama 2015). The new standard raises the bar on protecting federal investments in flood-prone areas.

USACE Campaign Plan

Goal 3: Reduce Disaster Risks. Deliver support that responds to, recovers from, and mitigates disaster impacts to the Nation while ensuring sustainable operations.

A critical aspect of applying the standard is understanding and quantifying the hazard, especially as it pertains to the evolving scientific understanding of climate change. It is also essential to both understand and quantify the impacts, risks and uncertainties, and interdependencies between the natural, social and built environments affected by this hazard.

Challenge Areas

- Predictive capabilities for pre-event planning and post-event response
- Science and engineering to support immediate and long-term recovery
- Hazard identification and risk assessment
- National flood risk assessment and strategy

Flood risk and emergency managers are tasked with preparing for, responding to, recovering from and mitigating against all flood and coastal hazards. Better technologies are needed for hazard identification and risk assessment and to clearly communicate risk to the public, community leaders, and responsible authorities. Improved capabilities are needed for real-time forecasting to enhance rapid response.

Planning and construction methodologies should support quick recovery, but embrace a long-term vision for a sustainable, resilient future. Innovative design options for risk reduction projects should consider both structural and non-structural alternatives including natural and nature-based features (NNBF) that ensure a strong recovery and mitigate against future disasters.

Finally, many of the reports (ASCE 2014, NRC 2014, USACE 2015b) and participants in the development of this strategy communicated the need for a common framework to assess, prepare for and mitigate the Nation's flood risk. R&D data, tools and technologies can be used to support the challenge to conduct a national flood risk assessment.

Five-Year R&D Goal

Develop R&D tools and technology to streamline and improve disaster preparedness, response, recovery and mitigation.

Goal 1. Risk Reduction: R&D Opportunities

Science & Engineering

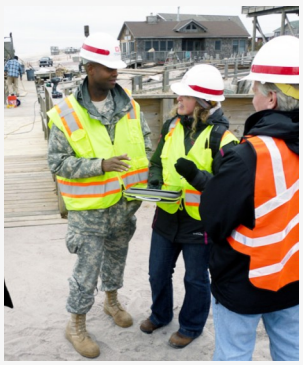
- Understand and improve quantification of the impacts of inland and coastal flooding and flood frequency due to potential non-stationarity and variability in storm meteorology
- Improve quantitative numerical prediction of hydrology, hydrodynamics and sediment transport related to episodic flooding, major events, and future extreme events
- Provide interdisciplinary approach to understanding the natural physical, chemical and biological recovery processes that occur post-event, such as storm beach recovery, riverine scouring and shoaling, salinity intrusion, ecosystem adaptation, etc., to inform reconstruction and restoration alternatives
- Improve risk assessment methods and modeling to identify areas of highest consequences, including direct and indirect or cascading impacts to vulnerable populations, socio-cultural assets, regional and local economies, critical infrastructure and ecosystem assets

Product & Technology Solutions

- Integrate flood and coastal storm modeling and predictive tools into products that inform emergency response, including dynamic and real-time modeling and mapping
- Provide shared and ready access to consistent and up-to-date hydrologic, hydrodynamic and underlying data sets such as lidar, model outputs, GIS and gage information to emergency managers
- Provide technologies and processes to support the FRM life cycle, including planning, response, recovery and mitigation
- Provide innovative and cost-effective monitoring and measuring technologies and equipment to collect data for pre- and post-storm assessments of natural and built infrastructure for both inland and coastal storms to inform recovery
- Transform post-disaster project repair, restoration and/or replacement with innovative, technically sound, cost-effective methodologies that meet or exceed flood risk standards, consider community recovery needs and incorporate innovative structural and non-structural solutions
- Develop tools and methodologies to support a national assessment, to include metrics and strategy for improved national understanding and coordination of flood risk management

R&D Success

Hurricane Sandy was the largest deployment of handheld emergency operations inspection tools — MICA (Mobile Information Collection Architecture) — developed by ERDC. MICA was also used during the flood fights of 2011 and 2013 on the Mississippi River.



Goal 2. Increase Resilience: Challenges

To prepare for the escalating uncertainties associated with episodic disturbances, long-term climate change, population dynamics, and aging infrastructure, the USACE has established the USACE Resilience Program to better ensure that the organization improves its support to community resilience through changes in its business practices, decision-making, and designs. The USACE Resilience Program principles (Prepare, Absorb, Recover, and Adapt) are important to consider in the face of adverse events and changing conditions (see Figure 3).

Challenge Areas

- Resilience guidance, policy, and regulation in day-to-day practice
- Performance and resilience of projects, recovery processes and monitoring
- Quantification and valuation of non-traditional alternatives to reduce flood risk and increase resilience
- Integrated approaches to promoting resilience that consider the socio-economic, natural and built environment
- Preparing for and adapting to an uncertain future with resilient approaches

The USACE's renewed focus on resilience is founded on its risk-informed decision-making principles. The Resilience Program will draft and revise its related policy, guidance, and regulations in order to improve day-to-day resilience-building practices. These practices will require supporting R&D efforts to reach the intended outcomes. For example, in the near-term, an inventory and assessment tool(s) will be needed to establish a baseline for screening the relative resilience of USACE's infrastructure and project portfolio.

From the President's Executive Order 13653 (Obama 2013b), *Preparing the US for the Impacts of Climate Change*

Definition:

"… **resilience** means the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."

Further, quantitative approaches will be necessary to validate the existing and predict the future performance of NNBF, traditional projects, non-structural approaches and other combined projects and systems for their ability to withstand and recover from future conditions. Monitoring will be essential to adapt strategies as uncertainties shift and more is understood about the threats and hazards impacting communities, ecosystems and critical infrastructure (USACE 2015b, HSRTF 2013).

Figure 3. Cycle of Resilience

Five-Year R&D Goal

Support improved resilience practices by generating concepts and methodologies, advancing theories, and validating peer-reviewed science to build and maintain resilient infrastructure, increase community resilience and enhance effective use of natural and modified systems.

Goal 2. Increase Resilience: R&D Opportunities

Science & Engineering

- Establish metrics and standards to quantify the storm and flood benefits of resilience-related measures over the project life cycle (see Figure 4)
- Assess the impacts of both near-term flood threats and long-term flood risk projections (climate change, development, aging infrastructure) on the lifecycle functionality of existing inland and coastal projects
- Assess and quantify the engineering performance and fragility, lifecycle benefits, and resilience of NNBF and other non-structural methods (such as low-impact development, green infrastructure, buffer zones, building codes, land use, flood-proofing)
- Identify triggering events (improbable, sequenced, cascading) that lead to catastrophic failure of critical infrastructure (built and natural)

Product & Technology Solutions

- Develop a resilience framework for data and technology sharing, tracking performance and best practices to aid in decision-making and encourage community action
- Develop efficient and expedient methodologies to quantify resilience of flood and storm risk management systems for planning, engineering and O&M
- Develop design guidance and operational solutions to prevent or minimize catastrophic failure, incorporate life safety measures, maintain critical services and/or some level of functional performance during catastrophic events
- Develop a comparative framework and trade-off assessment that considers the lifecycle costs and a full stream of benefits and services
- Incorporate climate change scenarios in resilience assessments, design of resilience measures, and decision-support tools
- Develop monitoring technologies to evaluate changing environmental and climatic conditions and infrastructure performance to help identify critical thresholds and management actions to enhance resilience

R&D Success

ERDC applied new tools in a pilot study to evaluate community resilience within Jamaica Bay, NY

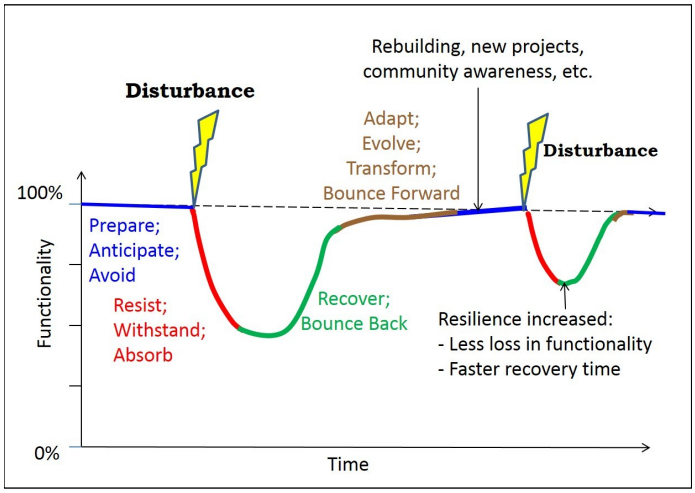


Figure 4. Resilience Timeline (Rosati 2015)

Goal 3. Sustainable Infrastructure: Challenges

The USACE owns, operates and maintains a vast water resources infrastructure portfolio with a replacement value of over $250 billion, much of which has surpassed its design life. USACE is facing a daunting challenge of maintaining and operating its portfolio to provide an expected level of service (USACE 2012, USACE 2015c). The cost of maintaining and operating this aging portfolio is increasing while the budget is more constrained and demands on the system are escalating.

USACE Infrastructure Assets:

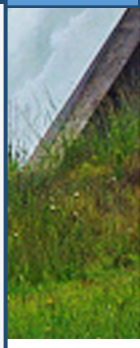
- Over 700 dams
- 270 locks
- 14,500 miles of levees
- 400 miles of coastal protection

Challenges associated with changing demographics, land use, increasing population, and climate change are increasing demands and performance expectations, as well as the potential for failure and damage consequences. Major rehabilitations, replacements, repairs, and decommissioning scenarios have to be prioritized within a limited budget.

Further, the USACE system is only part of the Nation's extensive network of flood and coastal storm damage reduction features that include levees, dikes, dunes, seawalls, and beaches that are built and/or maintained by others to unknown specifications or inconsistent levels of protection and functionality.

Challenge Areas

- Risk management tools and technologies
- Design and operational flexibility to adapt to changing demands and needs
- Evaluating and improving infrastructure integrity
- Lifecycle asset management, including O&M



To meet these challenges, R&D investments are needed to develop new and improved engineering tools, risk-management methodologies, and monitoring/inspection capabilities. These techniques should lead to improved risk management procedures and reliability metrics.

R&D is also needed to develop innovative and sound engineering procedures for the adaptation and modification of existing infrastructure to meet future challenges and to assess the structural and functional integrity of infrastructure. The Corps will be challenged to explore innovative and non-traditional structural and non-structural means to mitigate flood risk while still providing expected services. Finally, decision-support tools are needed that can assist in enacting lifecycle portfolio management and in prioritizing infrastructure investments.

Five-Year R&D Goal

Develop new and improved engineering tools, risk management methodologies, and modeling, simulation and monitoring capabilities that support the Corps' aging water resources infrastructure portfolio.

Goal 3. Sustainable Infrastructure: R&D Opportunities

Science & Engineering

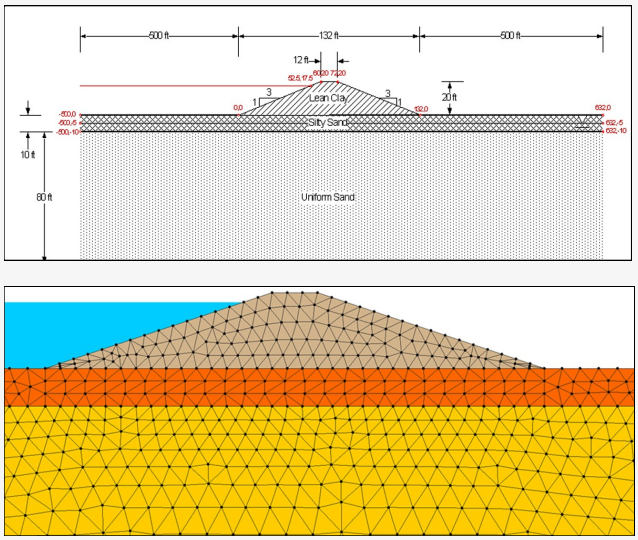
- Improve physics-based analysis of internal erosion, seepage, underground defects, overtopping, breaching and other failure mechanisms of earthen structures (levees, dams, compacted earthen structures)
- Improve physics-based analysis of littoral sediment transport processes and coastal landscape evolution
- Analyze and quantify risks and probabilities associated with defects and failure mechanisms that could lead to catastrophic failure
- Identify critical components and their functional interrelationship for improved lifecycle performance and asset management
- Apply interdisciplinary approaches to modeling soil-water behavior for purposes of design loading and failure prediction of earthen structures
- Apply interdisciplinary approach to design and evaluate lifecycle performance of NNBF considering associated risks and unique O&M requirements

Product & Technology Solutions

- Develop and/or adapt materials, technologies and techniques for resilient and innovative repair, replacement and/or rehabilitation of critical components
- Develop risk forecasting tools to optimize lifecycle infrastructure performance
- Develop and evaluate innovative engineering and construction solutions to improve design, reliability and lifecycle performance of inland and coastal structures
- Develop modeling and assessment tools to evaluate the impacts and options associated with adapting, retrofitting, decommissioning and/or operating existing water infrastructure to meet changing demands and new requirements
- Develop technologies for inspection, measuring and monitoring coastal and inland infrastructure and systems (meeting requirements such as minimally invasive, real-time, near-field and far-field assessments)

R&D Success

Cross-section diagram and finite element mesh of a typical levee cross-section from southeast United States. The finite element transient seepage analysis is used by ERDC to improve levee engineering practice.



Goal 4. Systems Approach: Challenges

The natural, built, and socio-cultural systems all comingle to impact the vitality of a region. Regional and/or system flood risk is likewise influenced by all three of these systems, providing both a challenge and an opportunity for planning, design, and operations of FRM projects. Adapting and developing tools that support and use system approaches to managing the Nation's flood risk challenge can develop better and more beneficial projects.

The influence and interdependencies a project, its operation, and/or modifications have on system-scale impacts needs to be assessed. A system approach has the added advantage of providing integrated opportunities across multiple missions and benefit categories (environmental, socio-cultural, economic). Additionally, collaboration at all levels (local to federal) and resource sharing (i.e., data, models, communication frameworks) are essential to facilitate better outcomes and reduce redundant expenditures. Capitalizing on a systems perspective can provide advantages to broad geographic areas such as watersheds, coastal regions, and/or complex urban areas, while still maintaining the perspective of the local stakeholder (see Figure 5).

"We must continue to advocate for long-term, strategic, systems thinking that will lead us to decisions that make the Nation more sustainable and resilient." (USACE 2015a)

Steve Stockton, Director of Civil Works, USACE

Challenge Areas

- Engineering resilient and sustainable systems
- Systems analyses across hydrologic, geomorphic, political boundaries
- Understanding the interrelationships of system components
- Engaging multidisciplinary teams to balance needs of natural, social and built systems
- Integrated water resources management: Integrating projects and systems (functions, interactions, budgets, authorization)

R&D investments are needed that promote the interrelationship between system resiliency and sustainability. Requirements include assessing baselines and monitoring resilience in the context of all the projects and components within the system; tools to allow system analysis across hydrologic, geomorphic, and political boundaries; and methods for analyzing the processes, responses and interdependencies of watersheds, coastal littoral regions, urban areas, and sediment transport networks. Further, R&D should support the ability to analyze and understand a system-of-systems.

Figure 5. Path to a comprehensive systems approach. (Stockton 2013)

Five-Year R&D Goal

Understand, adapt and develop the science and engineering tools that support system approaches to managing the Nations' flood risk challenge.

Goal 4. Systems Approach: R&D Opportunities

Science & Engineering

- Define and classify attributes of systems as they relate to FRM needs
- Understand the interrelationship of hydrologic, hydrodynamic, water quality, and sediment processes (i.e., waves, currents, surge, salinity, water levels, stream flow) within large-scale systems (rivers, coasts, estuaries, urban areas)
- Understand the response of adjacent or connected systems to episodic, seasonal, multiple, and/or large-scale (magnitude, duration and spatial) events
- Predict system evolution over time in response to natural and anthropogenic drivers

System Scale Analysis & Modeling

- Develop and incorporate network analysis into system-scale evaluations to identify and quantify critical component relationships, interdependencies and cascading impacts resulting from disruptive events
- Couple or integrate modeling to include interrelationship of processes for large regional scales or systems (see Figure 6)

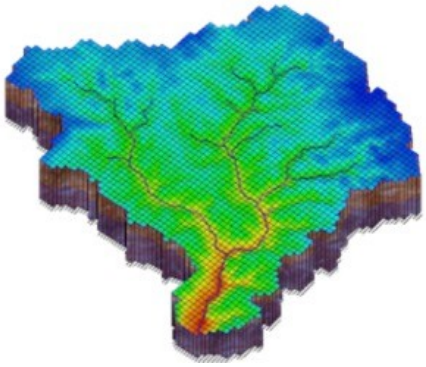


Figure 6. Next-Generation Hydrologic System Model

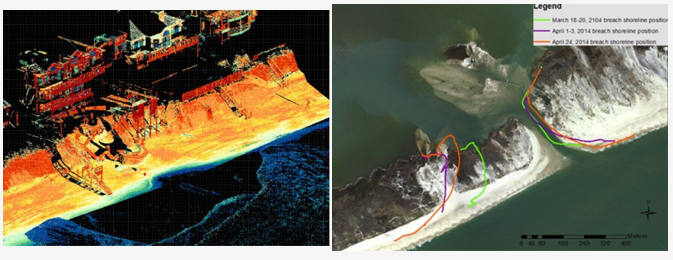
- Establish multidisciplinary teams to better model system dynamics, assess existing and future positive and adverse impacts, and balance the needs of natural, socio-economic, and built systems across multi-mission and functional areas

Product & Technology Solutions

- Develop modeling tools (decision-support) and procedures to rapidly or more easily conduct robust analyses of multiple planning alternatives and/or operational scenarios for flood reduction systems in support of *Objective 1.1 Modernize the Civil Works project planning program* (USACE 2015c)
- Develop tools to comprehensively evaluate and track system changes to include physical processes, life cycle vulnerabilities, and long-term benefits over appropriate temporal and spatial scales

R&D Success

The evolution of coastal systems is evaluated through lidar data and historical maps. These data, supplemented by process models, are used to investigate dune recovery, inlet migration, and beach trends.



Goal 5. Collaboration & Partnering: Challenges

Beyond the purely technological challenges of FRM, there are two additional factors that are critical to meeting the future requirements for effective flood and coastal risk reduction: (1) people understand, accept, and share FRM (see Figure 7); and (2) effective and efficient transition of innovative R&D to promote science and technology-fueled actions. Agency and subject matter leaders, stakeholders and partners all speak to the challenge and importance of communicating flood and coastal risk (NRC 2014).

Community leaders, other decision-makers, and individuals are often caught up with a myriad of challenges that require them to focus on today's most pressing risks. When the memory of flooding has faded, future flood risk situations often receive little attention or resources. Yet the best way to reduce risk from flooding is to prepare in advance of the threat. The best and most innovative science and engineering solutions will go unheeded and unused if risk is not communicated to those who need to take action, and the technology is not available and accessible to those who are in a position to implement. This means that developing an effective flood FRM strategy requires both a strong risk communication plan and an effective transition of research to applications.

Challenge Areas

- Risk communication and decision-support tools that integrate engineering, socio-economic and environmentally sustainable management strategies
- User-friendly and accessible data and products that help transition the best science and technology to end-users
- Collaborative R&D activities among agencies, academic partners and communities, incorporating both civil and military knowledge
- Innovative partnering and financing to develop and transition R&D technologies to government and market-driven opportunities

> "Build a crosscutting culture of Critical Infrastructure Security and Resilience R&D collaborations."
>
> Priority Area, National Critical Infrastructure Security and Resilience R&D Plan (DHS 2015)

Scientists and engineers engaged in flood and coastal risk management R&D have a unique opportunity as thought leaders in their fields of expertise to deliver credible solutions to the Nation's flood risk challenges. By providing products and data that are not only accurate and informative, but easy to access and understand, flood risk can be communicated to a broader audience. Risk reduction actions that also promote resilience can be implemented by decision-makers.

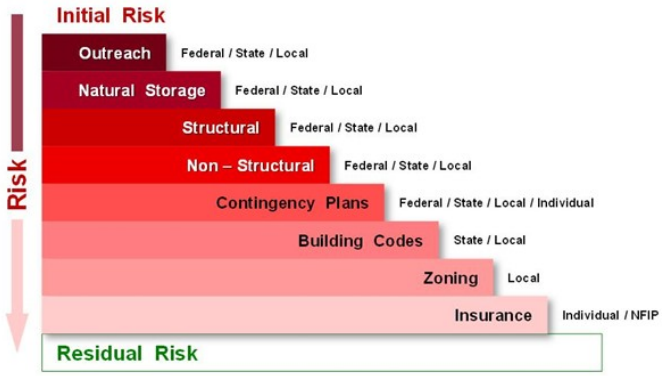


Figure 7. Shared Disaster Risk Management

Five-Year R&D Goal

Using collaboration and communication, promote and apply the best science and technology for improving the Nation's ability to manage flood risk.

Goal 5. Collaboration & Partnering: R&D Opportunities

Risk Communication & Decision-Support

- Develop science-informed and robust cross-disciplinary visualization products and decision-support tools that can be used by and improve communication between planners, economists, environmentalists, engineers and policy-makers
- Take an inter-disciplinary approach, including social science, to develop common risk communication messaging and products that are both understandable and accessible to emergency managers, the community, the public, other stakeholders and partners
- Support the conduct of a national assessment and develop a risk management strategy for improved national understanding and coordination of flood risk (See Goal 1)

Transition of R&D to Applications & Operations

- Identify needs and opportunities to coordinate and promote transition of science and technology through existing outreach activities, such as Silver Jackets or event-focused opportunities in engaging communities about flood risk
- Develop interagency online tools, interactive data, and training for the workforce to learn community engagement and outreach skills
- Improve technology transfer by using a combination of traditional, innovative, and information technology (IT)-based methods
- Adapt existing and develop future data and models in an open-source and/or shared environment that promotes inter- and intra-agency use, encourages commercial partner-ships and drives market development
- Develop strategies to provide multidisciplinary technical assistance and applications guidance for practitioners to improve understanding risk and the development of structural and non-structural mitigation measures

Collaboration & Innovative Partnering

- Create a collaborative environment to foster and reward innovation
- Collaboratively develop user-focused technology products that communicate risk and address shared responsibility of FRM
- Promote innovative partnering to advance technologies, using existing R&D partnering instruments such as Cooperative R&D Agreements, Broad Agency Announcements, and Testing Services Agreements
- Provide coordinated approach (inter- and intra-agency) via collaborative agreements and advance planning for pre- and post-storm assessments with a deployable cadre of subject matter experts
- Actively seek federal agency collaboration and coordination in developing modeling and decision support capabilities and tools
- Establish national FRM strategy for R&D goals and collaborative studies with other agencies, academia, industry, and NGOs
- Conduct technical exchanges with international organizations to address best management practices for FRM

R&D Success

The Corps Wave Information System (WIS) is a national resource of multi-decadal hindcast wave fields covering all coasts (including the Great Lakes). A multi-agency network of measurement buoys supports WIS accuracy. WIS products are used in collaboration with academia, industry, agencies, and internationally.

Key References

American Society of Civil Engineers (ASCE) (2014). *Task Committee on Flood Safety Policy and National Strategy*. ASCE publications.

Department of Homeland Security (DHS) (2015). *National Critical Infrastructure Security and Resilience Research and Development Plan*. November 2015. Available at https://www.dhs.gov/publication/national-critical-infrastructure-security-and-resilience-research-and-development-plan. Accessed December 1, 2015.

Federal Emergency Management Agency (FEMA) (2014). *National Mitigation Framework*. Available at http://www.fema.gov/media-library-data/20130726-1914-25045-9956/final_national_mitigation_framework_20130501.pdf. Accessed October 29, 2015.

Federal Interagency Floodplain Management Task Force (FIFMTF) (2013). *Federal Interagency Floodplain Management Task Work Plan*. Available at http://www.fema.gov/media-library-data/20130726-1759-25045-4816/fifm_tf_work_plan_updated24jan2013.pdf. Accessed October 29, 2015.

Hurricane Sandy Rebuilding Task Force (HSRTF) (2013) *Hurricane Sandy Rebuilding Strategy – Stronger Communities, A Resilient Region*. Available at http://portal.hud.gov/hudportal/documents/huddoc?id=hsrebuildingstrategy.pdf. Accessed October 29, 2015.

National Oceanic and Atmospheric Administration (NOAA) (2013). *National Coastal Population Report: Population Trends from 1970 to 2020*. Available at http://stateofthecoast.noaa.gov/features/coastal-population-report.pdf. Accessed November 3, 2015.

National Research Council (NRC) (2014). *Reducing Coastal Risk on the East and Gulf Coasts*. Washington, DC. The National Academy Press.

Obama, Barack (2011). *Presidential Policy Directive 8: National Preparedness*. Available at http://www.dhs.gov/presidential-policy-directive-8-national-preparedness. Accessed October 29, 2015.

Obama, Barack (2013a). *The President's Climate Action Plan*. Washington, DC. Available at http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf. Accessed October 29, 2015.

Obama, Barack (2013b). *Executive Order 13653: Preparing the United States for the Impacts of Climate Change*. Available at https://www.whitehouse.gov/the-press-office/2013/11/01/executive-order-preparing-united-states-impacts-climate-change. Accessed October 29, 2015.

Obama, Barack (2013c) *Presidential Policy Directive 21: Critical Infrastructure Security and Resilience*. Available at https://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil. Accessed October 29, 2015.

Obama, Barack (2015). *Executive Order 13690 – Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input*. Available at https://www.whitehouse.gov/the-press-office/2015/01/30/executive-order-establishing-federal-flood-risk-management-standard-and- . Accessed October 29, 2015.

Rosati, J.D., Touzinsky, K.F., Lillycrop, W.J. (May 2015). *Quantifying coastal system resilience for the US Army Corps of Engineers*, Environmental Systems Decisions, DOI 10.1007.s10669-015-9548-3. Springer Science+Business media, New York.

Key References, continued

Stockton, Steve (2013). "Water Resources Management and Challenges and Opportunities." Presentation to the National Association of Flood and Stormwater Management Agencies, December 9, 2013.

United States Army Corps of Engineers (USACE) (2012). *Modernizing the USACE Water Resources Infrastructure Portfolio*. Available at http://www.usace.army.mil/Portals/2/docs/civilworks/cw_tran/CWTran_SP_infrastructure.pdf Accessed November 2, 2015.

USACE (2013a). *Incorporating Sea level Change in Civil Works Programs*. Engineer Regulation 1100-2-8162. USACE. Print.

USACE (2013b). *USACE Campaign Plan FY13-18*. Available at http://www.usace.army.mil/Portals/2/docs/USACE%20Campaign%20Plan%20FY13-18_FINAL_PAO.pdf. Accessed October 29, 2015.

USACE (2013c). *USACE Civil Works Research and Development Strategy*. Engineer Research and Development Center. Print.

USACE (2015a). *Flood Risk Management Newsletter*, Vol 8, No 5, Oct 2015. Available at http://operations.usace.army.mil/flood/pdfs/FRM-1510.pdf. Accessed November 2, 2015.

USACE (2015b). *North Atlantic Coast Comprehensive Study: Resilient Adaption to Increasing Risk*. Available at http://www.nad.usace.army.mil/CompStudy. Accessed October 29, 2015.

USACE (2015c). *Sustainable Solutions to America's Water Resource Needs: Civil Works Strategic Plan 2014-2018*. Available at http://www.usace.army.mil/Portals/2/docs/civilworks/news/2014-18_cw_stratplan.pdf. Accessed October 29, 2015.

USACE (2015d). *USACE Campaign Plan, Executive Summary (Priority Actions).* Available at http://www.usace.army.mil/Portals/2/docs/150520_USACECampaignplanFY15-19_UCP_01MAY2015%20.pdf. Accessed October 29, 2015.

Water Resources Reform and Development Act (WRRDA) (2014). H.R. 3080-113th Congress: water resources reform and development act of 2014, 12 Nov 2014. Available at https://www.govtrack.us/congress/bills/113/hr3080/text. Accessed October 29, 2015.

The White House Council on Environmental Quality (CEQ) (2013). *Principles and Requirements for Federal Investments in Water Resources*. Washington, DC.

The White House Council on Environmental Quality (CEQ) (2013). *Updated Principles and Guidelines for Water and Land Related Resources Implementation Studies*. Available at https://www.whitehouse.gov/administration/eop/ceq/initiatives/PandG. Accessed October 29, 2015.