RETHINKING FLOOD ANALYTICS

PROCEEDINGS FROM THE 2017 FLOOD ANALYTICS COLLOQUIUM

COASTAL RESILIENCE CENTER
A U.S. Department of Homeland Security Center of Excellence

RENCI

THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

Aerial of a flooded neighborhood in New Orleans with cars floating and homes damaged by Hurricane Katrina (2005). Thousands of people were forced to seek shelter on their roofs and in their attics.

Photo by Jocelyn Augustino/FEMA

FOREWORD

This report documents outcomes from the Rethinking Flood Analytics Colloquium held at the Renaissance Computing Institute (RENCI) in Chapel Hill, N.C., Nov. 7-9, 2017. The Colloquium agenda and speakers may be found in Appendix A and list of participants in Appendix B.

The Colloquium was sponsored jointly by the Coastal Resilience Center of Excellence (CRC), RENCI and the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T).

The purpose of the Colloquium was to support the DHS S&T Flood Apex Program by convening a multi-disciplinary group of technical specialists and end users from a variety of sectors and disciplines to reimagine flood analytics and help shape a coordinated research agenda. The DHS S&T Flood Apex Program applies new and emerging technologies to improve community resilience from flood disasters. Its goals are to reduce fatalities and property losses from future flood events, increase community resilience to flooding and develop better investment strategies to prepare for, respond to, recover from and mitigate flood hazards. Although planning for the Colloquium began well before the 2017 hurricane season, its timing proved prescient in light of the year's major flood-producing events, including three major hurricanes, Harvey, Irma and Maria.

The intent of this report is to present the lively and wide-ranging interactions of Colloquium participants in a manner that encourages further exchange between flood analytics professionals and those affected by flood events. The Colloquium identified paths forward for this exchange and ways that emerging technologies could facilitate flood analytics that have a broader reach and increased impact. It did not produce simple solutions or final answers, but it did avoid the pitfall of "admiring the problem" that a keynote speaker warned against during his opening remarks.

The Colloquium provided a powerful forum for free and open discussion between experts. The hope of the Colloquium's sponsors is that this sharing will continue through the personal relationships established in Chapel Hill and that the flood analytics community will embrace new methods at the same time it welcomes new members.

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EXECUTIVE SUMMARY

FLOODS ARE THE MOST COMMON, FREQUENT AND COSTLY TYPE OF DISASTER IN THE UNITED STATES.

This should be no surprise. As a nation that began on the coast and moved inland along a rich and complex system of bays, estuaries, rivers and tributaries, the connections between population centers and surface waters are historic and enduring.

The many benefits of these connections always have come with the cost of flood risk. In recent years, it appears that exposure to flooding is changing due to factors such as altered weather patterns, land subsidence and sea-level rise. However, the most dramatic changes have been in the consequences of such flooding, as expansion and development often have paid little or no regard to flooding exposure. The most recent example is Houston, Texas, where unprecedented rainfall from Hurricane Harvey combined with minimally regulated land development produced a disaster of unimaginable scope and severity.

At the same time, the method for quantifying flood risk is changing and the potential for doing a much better job of addressing that risk through analytics has increased dramatically. Some techniques, such as numerical modeling, have been part of flood risk analysis for years. While important, evolutionary changes in the existing tools typically result in only incremental improvement. The most dramatic advances tend to come from techniques not previously considered in connection with flood risk analysis or used only sparingly. Examples include big data, artificial intelligence, remote sensing, social media and the internet of things. Merging the rapidly growing capabilities of analytics and innovative technologies with continuous improvement of existing tools, and incorporating non-technical disciplines, such as social science and demographics, offers the possibility of revolutionary improvements in flood risk analysis. This possibility was the inspiration for the Rethinking Flood Analytics Colloquium.

The Colloquium convened a multi-disciplinary group of technical specialists and end users from a variety of sectors and disciplines to reimagine flood analytics. The participants engaged in free and open discussions in a collaborative format for two and a half days while facilitators and note takers helped guide and capture their discussions. The Colloquium set a framework for advancing flood analytics by identifying the attributes that should drive how research is conducted and the topics that need advancement.

The foundational discussions to reframe analytics began with creating a vision for a flood-resilient nation and its associated challenges. In striving to reach that vision through improved flood analytics, the discussions went from exploring the current state of analytics to describing a "blue sky" set of guiding principles for future flood analytics. Along the way, participants identified opportunities to bridge the gaps between where flood analytics currently stands and where it could be by identifying key research and development needs and opportunities. Finally, the Colloquium served to initiate a more collaborative and transdisciplinary approach in which coproduction of research with end users will help move research to action.

The summary of concepts below encapsulates the essence of the discussions and lays a foundation for further engagement.

A flood resilient nation:

- Avoids risk by protecting its most important assets from flooding and by considering where its citizens live and where development takes place.
- Invests in mitigation by understanding the real costs of flood disasters, valuing the real benefits of flood mitigation and investing in actions to achieve those benefits.
- Transfers and accepts risk by such actions as purchasing flood insurance and implementing mechanisms to cope with residual risk.
- Understands that timing is everything by providing the right information to the right people in an efficient and effective manner.
- Embraces resilience as part of its culture by embedding the principles of resilience in how it thinks and acts and by encouraging all of its citizens to participate in building resilience.

Improved flood analytics – guiding principles for the "dream state":

- Transdisciplinary: analytics link current flood-centric data and models with socio-economic and ecosystem models. Analytics are integrated across disciplines, scales and hazards.

- Made for and with the end user: outputs, products and services are developed jointly with the end user to meet their needs and delivery requirements.
- Clear communication: information is translated and transmitted in ways that are understandable by the intended audience and that lead to action.
- State-of-the-art analytics: standards and interoperability are used together with advances in machine learning, artificial intelligence, network analysis, etc., to improve speed and efficiency and reduce uncertainty.
- Tech-savvy solutions: analytics are improved by leveraging technology advances, such as sensors, the internet of things, social media and hardware platforms, from smartphones to high-performance computers.

Areas for improvement – bridging the gap to the "dream state":

- Advancing model and data analytics
- Technology-driven analytics
- Model and data integration*[1]
- Networks and systems analytics*
- Risk and damage assessment analytics*
- Insurance analytics**[2]
- Mitigation investment analytics**
- Neighborhood-scale analytics**
- Communicating analytics with graphics and visualization
- Institutionalizing analytics

What's next – beyond the Colloquium:

- Build a community of practice and a platform for analytic advancement.
- Forge relationships that connect practitioners with end users.
- Establish transdisciplinary approaches that include new expertise; e.g., social sciences.
- Include underserved communities, especially at the neighborhood level.
- Continue holding such meetings.

The Colloquium's sponsors hope that the flood analytics community will take on the challenges and ideas presented in this report and use the framework and concepts developed here to initiate action. The problem of flooding and its impact on the nation are too important to ignore, and it will take the whole community to get to the finish line.

NOTES

[1] * High potential for integration and near-term success

[2] ** High potential to fill voids in current flood analytics methods

Clearing roadways of sand and debris is a priority in Loiza District east of San Juan, Puerto Rico, after Hurricane Irma (2017) hit the island.

Photo by K.C.Wilsey/FEMA

INTRODUCTION

THE URGENCY AND OPPORTUNITY OF DISASTER

FLOODS ARE AMONG THE MOST COSTLY NATURAL DISASTERS IN TERMS OF ECONOMIC DAMAGE AND DEATHS.

Every state suffers from at least one form of flooding, and the numbers are rising as more people and more development move into flood-risk areas. In the United States, flood damages average approximately $8 billion annually and more than nine million people live in flood hazard areas.

Weather and climate-related disasters in the United States caused $306 billion in damages during 2017, the costliest year on record, according to the National Oceanic and Atmospheric Administration (NOAA)[3]. Three major hurricanes – Harvey, Irma and Maria – accounted for a staggering $265 billion of those losses. They ranked 2nd-, 5th- and 3rd-most costly, respectively, in the 38 years NOAA has recorded billion-dollar disasters (Hurricane Katrina in 2005 was the costliest). What is the relationship of climate to flooding disasters? Hurricanes generate wind, surge and waves, but often, as we saw with Harvey, Irma and Maria, result in extreme precipitation events.

Other types of climate and weather events can also trigger floods. Widespread fires following a severe drought in California during 2017 resulted in deadly mudslides in January 2018, when heavy rains fell on the scorched landscape. Tropical storm Joaquin in October 2015 generated a meteorological collision of atmospheric fronts that inundated South Carolina, testing the bounds of an aging infrastructure and resulting in the failure of 49 state-regulated, one federal and numerous private dams[4]. Hurricane Matthew in October 2016 killed 31 people and displaced thousands, reminding North Carolina of the importance of rebuilding with resilience in mind. The midwest flood of April-May 2017 demonstrated the collective power an already-wet spring, coupled with heavy rain, could exert on the capacity of large river systems, swamping parts of five states.

Then there are surprises. A rogue meteorological rain cell in July 2016 sparked a flash flood that wiped out the historic town center of Ellicott City, Maryland. The following month, 31 inches of rain fell in Baton Rouge, Louisiana, causing flooding the Red Cross characterized as “the worst natural disaster to strike the U.S. since Hurricane Sandy.”[5] Climate may also be contributing to making these events worse, increasing their variability and extremes[6].

The Department of Homeland Security (DHS), Science and Technology Directorate (S&T) Flood Apex Program, created in 2014, offers a platform for coping with the nation’s top natural disaster by examining how new technologies and new thinking can reduce flood fatalities, lower economic losses and increase community resilience[7].

Challenges and Opportunities of Analytics

Ever-increasing data and computational power are facts of modern life, with no real slowdown in sight. Whether gathered from social media, new weather satellites, economic transactions, fitness trackers, distributed sensors, autonomous vehicles or simulations run on supercomputers, rich data is widely available, and the amount of data is increasing exponentially. Technological advances have made data storage cheap, and the miniaturization of components has enabled the development of powerful computer chips that can be used almost anywhere.

Two data trends hold special significance for analytics. The first is the increase in data generated purposely, e.g., weather data. The second is the recognition of new sources of data, e.g., social media, collected but not originally thought of as data, which are now considered rich sources of potential new insights. One estimate suggests that by 2020 “about 1.7 megabytes of new information will be created every second for every human being on the planet.”[8] In a particularly relevant example, the latest GOES[9] series of NOAA weather satellites coming online are estimated to produce approximately one terabyte of data per satellite every day. Driving the growth of GOES data is an increase in satellite resolution of “three times more spectral information, four times greater spatial resolution, and more than five times temporal coverage.”[10] This richer stream of satellite data will have a positive impact on weather prediction and weather response capabilities.

On the computational side, there is a saying that today’s supercomputer is the desktop of five or ten years in the future. Smartphones are said to have more computing capability than the computers used to land man on the Moon. Expansive compute capabilities are ubiquitous, from desktops to supercomputers. Perhaps more important than the absolute increase in computing power is the diffusion of that power and the data it generates across a significant portion of the human experience.

The combination of these two trends, more data and greater computing power, has enabled the development and application of new techniques that exploit these trends to seek new insights. Collectively, these new techniques may be termed "analytics." Analytics includes approaches ranging from data mining and neural networks (forms of artificial intelligence) to new forms of modeling and visualization. Analytics typically features either data-intensive or computationally intensive techniques, or some combination of the two. Leveraging these new approaches has the potential to increase our understanding of the world around us, from the behavior of water to human behavior.

Advanced analyses of large, complex datasets ("big data") are providing new insights into many areas, such as human behavior, market dynamics, logistics, medicine and preventative maintenance. Models representing natural phenomena from weather to water utilize increasing amounts of data to improve their forecasts. These applications suggest the exciting potential to use these new types of analytics approaches in the context of floods. Analytics has the potential to improve understanding of flood dynamics, impacts of resilience planning, disaster response, risk communication and more.

These new approaches, however, bring challenges with the opportunities. First among many are difficulties related to management and curation of large amounts of data. Another is taking these new approaches out of the research domain and operationalizing them for on-the-ground decision-makers, such as planners, first responders and engineers. Related to both is the challenge of managing the pace of technological change encompassed by new data and new approaches.

About the Colloquium

The Rethinking Flood Analytics Colloquium could not have been timelier. The damages caused by weather and climate-intensified disasters in 2017 reminded participants of the importance associated with collecting, analyzing and providing timely and meaningful flood analytics to inform individuals, communities, and local, state and federal decision-makers. Could new ideas contribute to improvements in the way the nation responds to, prepares for, recovers from and mitigates flood disasters?

The Colloquium was designed as a two-and-a-half-day gathering of the best and brightest to challenge the status quo of current flood analytics by identifying and capturing

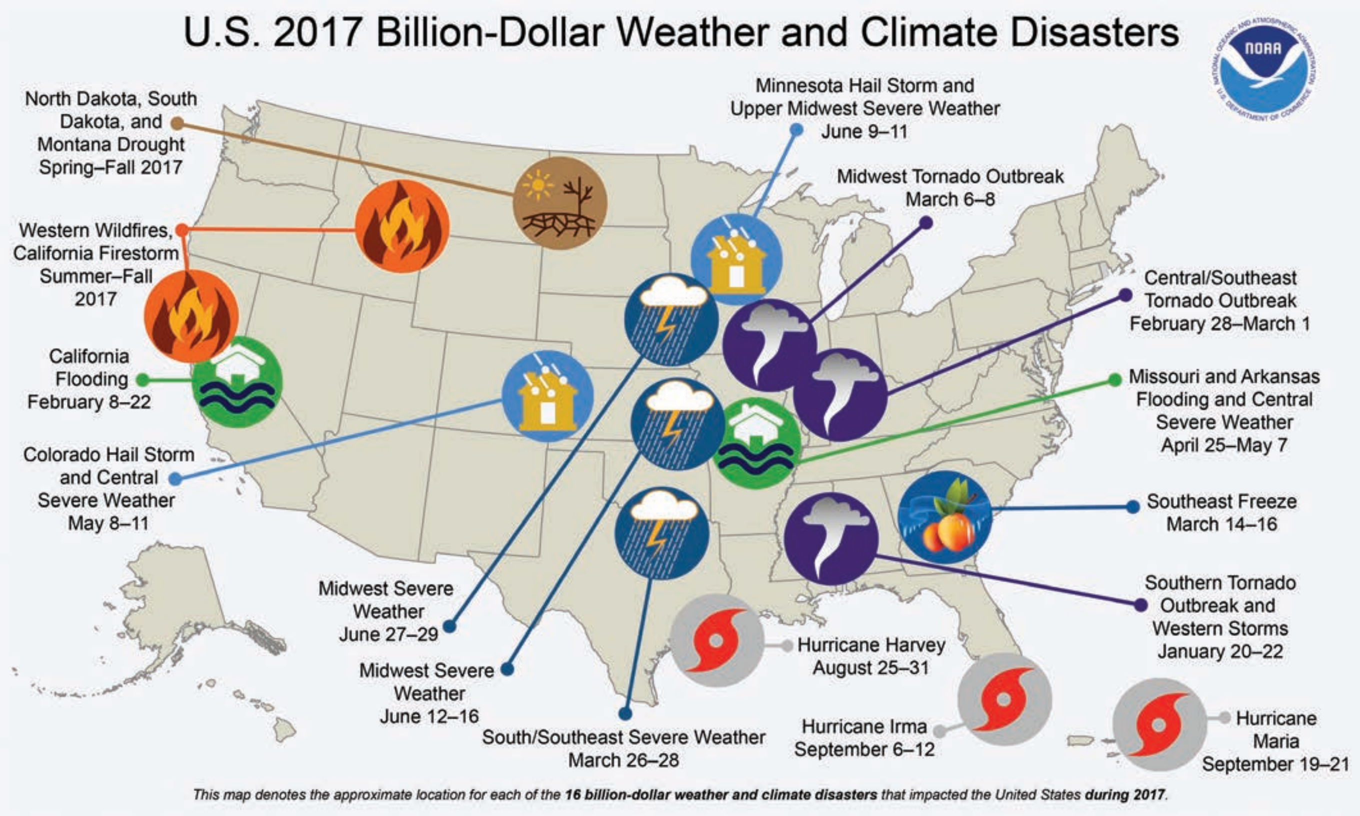

Figure 1. The United States experienced 16 separate billion-dollar weather and climate disasters during 2017. Source: National Oceanic and Atmospheric Administration, National Center for Environmental Information.[11]

disruptive technologies and transformational ideas. The multi-disciplinary group of scientists, sociologists, economists, engineers, technologists, graphics editors, emergency managers and policy specialists represented a cross-section of sectors – government (local, state and federal), academia, private industry and media. The Colloquium planning team sought to bring in experts whose careers had been dedicated to the science, engineering, analytics and/or disaster management of floods ("inside the bubble") and those who could add aspects of social science, environmental justice and analytics beyond the usual flood community of practice ("outside the bubble").

A broad interpretation of flood analytics was used to encourage a far-reaching scope of ideas and conversation. Analytics was used at times as a label to encompass an array of forward-looking technologies as part of the rethinking process. Leading-edge and experimental technologies, such as drones, sensor webs, arrays of micro-satellites and crowdsourced information, were included in the conversation. While these technologies are not, strictly speaking, analytics, they are relevant to developing a future vision and identifying potential technology gaps. Further, many of these technologies will produce significant data outputs that will feed into a consideration of flood analytics.

The Colloquium featured two keynote challenge speakers, two plenary panels and breakout sessions designed to explore the future of data use, models and information before, during and after disasters. Concepts in four breakout exercises were applied in "2025" renditions of hurricanes Harvey and Irma and to the Midwest and Ellicott City floods. Participants shared their own research and study findings during short "open mic" sessions and an informal show-and-tell social. The agenda and speakers may be found in Appendix A and participants in Appendix B.

About This Report

This report draws from the vision of a flood-resilient nation and its associated challenges to address the current state of analytics and a "blue sky" set of principles that guides where analytics may lead. It then seeks to bridge the gaps between where flood analytics stands and the finish line by identifying key research and development needs and opportunities. Finally, it discusses opportunities within the Flood Apex Program and among other academic and agency efforts for inclusion and collaboration to rethink flood analytics.

NOTES

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FLOOD-RESILIENT NATION

WHAT DOES A FLOOD-RESILIENT NATION LOOK LIKE?

It reduces or eliminates fatalities, minimizes disruptions and reduces economic losses to flooding. Describing this vision may be an easy task[12]. Achieving it is hard. Some successes achieved through improved early warning systems and preparedness have helped reduce fatalities, but they have not eliminated them. In some cases, such as Puerto Rico's devastation by Hurricane Maria, cascading impacts following a disaster lead to deaths that may not be fully counted as part of the initial response[13], and economic losses will continue to climb.

NOAA[14] statistics from 2017 add to a growing body of evidence that the cost of flooding is rising. While investments in resilience are growing, it appears that the nation's flood resilience may be decreasing.

Risk exposure is increasing with more frequent and more extreme events, rising sea levels, population growth in coastal communities and expanding development in urban areas, but the costs of these events may not be fully recognized. Reported costs focus on direct losses, largely those incurred by government or backed by insurance. The actual costs of these disasters to individuals, communities and the nation due to indirect losses, such as business collapse or slow recovery, health-related impacts, disruptions to education and social cohesion, are often not included in the accounting. For example, the appropriated supplemental funding for Hurricane Katrina was just over $100 billion[15] and was spent on direct damages and insured losses, while some estimates state that economic losses from Katrina were as high as $250 billion[16].

MOONSHOTS AND CRYSTAL BALLS

Inspired by the speakers and participants at the Colloquium, the following forward-thinking concepts – moonshots and crystal balls – both provocative and pragmatic, helped reframe the discussion about floods and the analytics that are needed.

Moonshots

The purpose of the Colloquium was to investigate advancing flood analytics, but keynote speakers, panelists and participants reminded participants of the broader problems and complexity associated with floods and the urgency to take action. Roy Wright, acting associate administrator of the Federal Emergency Management Agency's (FEMA) Federal Insurance and Mitigation Administration (FIMA), stated that the time to "admire the problem" is over and urged participants to "get to the finish line." He discussed how explore-build-finish is a tenet upon which to organize transformation. Exploring, rethinking approaches, and developing ideas are important, but organizations are graded on how they finish. FEMA has set two goals – "moonshots" – as targets for that finish line:

- Quadruple mitigation investments by 2023
- Double flood insurance coverage by 2023

FEMA Moonshots[17]

"Run from Water"

A well-known adage in weather circles advises, "Run from water, hide from wind." A resounding theme at the Colloquium was to consider moving the nation's most important assets – people, infrastructure and housing – out of harm's way to avoid high flood-risk areas. Avoidance is only one aspect of mitigating flood risk, but it is an aspect that has not been embraced effectively. Mitigation, as defined in the National Mitigation Framework[18], is "risk-management action taken to avoid, reduce or transfer natural hazard risks." Historically, mitigation efforts, such as flood insurance (designed to transfer risk), flood-protection works, such as levees, dams and seawalls, flood proofing and home elevations (designed to reduce risk) do not take assets out of the highest-risk flood areas. In fact, many experts contend that the availability of flood insurance and the presence of flood structures actually incentivize development in high-risk areas. Hurricane Harvey's impact on Houston offers a fresh example of how development exacerbates risk. Many flooded homes were located far from FEMA-designated floodplains. The delineation of these floodplains does not account for changing climate scenarios or future real estate development. More and more, the reality of a rising sea has forced thinking about resettling the most exposed coastal communities to higher ground. Slowing down development and retreating from rising seas are not popular options, but it is time to start rethinking them. Resilient measures should be considered that would incentivize such behavior and limit further development in these areas.

Harris County, which surrounds the City of Houston, took this approach in December 2017 when it approved an overhaul of its flood rules[19], expanding them from 100-year floodplains (i.e., 1% chance of flooding in a given year) to 500-year floodplains (i.e., 0.2% chance of flooding). The new rules (which do not apply inside the City of Houston) require developers to elevate any new building up to 8 feet higher than in the past. To implement these new rules, Harris County voters will be asked to approve a flood control bond package worth more than $1 billion.

In a resilient future, we would protect our most important assets by considering where we live and where and how we develop. Understanding there is no zero-risk environment, we would incentivize development to avoid high-risk areas.

"It's the economy, stupid!"[20]

Mitigation works. A new study released by the National Institute of Building Sciences[21] states that a $1 investment in mitigation can save $6 in future disaster costs. Mitigation and resilience measures add value beyond their risk-reduction benefits. Innovative investments in green infrastructure, nature-based solutions, open space and resilient housing can result in multi-beneficial and adaptive solutions. Calculations must go beyond damages avoided to attract investors to fund mitigation and resilience efforts. Quantifying all the benefits helps support a strong return on investment.

The study also showed that investing in hazard-mitigation measures that exceed select requirements of the 2015 International Codes (the model building codes developed by the International Code Council) can save $4 for every $1 spent.

In addition to economic returns on investment, mitigation could prevent an estimated 600 deaths, one million nonfatal injuries and about 4,000 cases of post-traumatic stress disorder long-term. Designing new buildings would result in 87,000 new, long-term jobs and an approximate 1% increase in utilization of domestically produced construction material.

It is about the economy when the nation and taxpayers continue to foot the bill for ever-growing disaster costs. A flood-resilient nation understands the real cost of disaster, values the real benefits of mitigation and invests in action. Imagine the return on investment when FEMA reaches its moonshot, quadrupling investments in mitigation by 2023.

We accept, we cope, we buy insurance

Given there is always residual risk, a resilient future would cover more people with insurance while developing coping mechanisms (preparedness and adaptability) that allow individuals and communities to "live with water." This is about risk acceptance and transfer.

Accepting risk means better understanding what assets are at risk and increasing transparency. For example, acceptance means understanding that, in the future, more frequent and intense flooding could eliminate access to emergency support, utilities or even evacuation routes. It means understanding when to run from water and when to shelter in place. Transparency means homebuyers are aware of previous flood damage and potential future risk so they can make informed decisions about ownership and insurance.

Insurance can transfer some of the risk, but only if assets are insured and/or insurable. FEMA's moonshot to double insurance policies by 2023 seeks to address the first part. But for properties that are too exposed (e.g., repetitive loss properties), owners must decide whether they will leave (avoid) or stay (accept). Incentives/disincentives and coping mechanisms will be required for both.

In the Netherlands, floating houses are considered viable options for mitigating flood impacts. An article in CityLab[22] asserts floating houses are safer, cheaper and more sustainable than houses built on land since they can be more readily adapted to existing needs by changing function or moving to a new location. Such sustainable urban design on water can also combat urban sprawl (i.e., floating houses are constructed more densely) and allow for more efficient energy use. An article in The New Yorker[23] describes the efforts of Dr. Elizabeth English of the University of Waterloo to design and build amphibious structures that are not permanently elevated, but float in rising water. These are examples of how to not only accept risk, but cope with it.

A resilient future means individuals and communities understand and accept their risk and implement coping actions, whether that is preparedness, avoidance, flood proofing and/or insurance.

Timing is everything

Getting the right information in the right format at the right time to flood-risk management decision-makers is critical. Colloquium participants were asked to consider the types of decisions made and the types of data needed before, during and after disasters. In disaster management terms, before considered mitigation actions to minimize or reduce future flood risks, such as buying insurance, flood proofing and building codes, and preparedness measures, such as catastrophic planning and exercises, evacuation plans, warning systems and preparedness kits. Before also considered decision and data needs for long-range planning, such as capital improvements, development siting or home purchases. During, for purposes of the Colloquium, included thinking about disaster response in terms of providing forecasts ahead of the event, locating and deploying resources, preparing communities for evacuation and/or flood proofing in advance, search and rescue of survivors, meeting survivor needs and stabilizing destroyed infrastructure. After dealt with recovery. How could analytics better inform the recovery process in such a way that communities build back stronger and are on their feet faster? Decisions during recovery deal with health impacts, debris removal, individual assistance, issuing insurance claims and rebuilding critical infrastructure.

These time lenses helped frame gaps in information delivery to decision-makers. FEMA leadership, for instance, expressed the desire to quantify damages within 72 hours of the event or, even better, estimate the location and extent of damages in advance. Even when the lead time is days, such as in hurricane forecasting, it can be difficult to run predictive models, integrate data sources or even obtain access to information in a timely manner for decision-making. At the individual level, homeowners need to know their risk before they buy. At the community level, developers and government officials need to know the consequences of what, how and where they build. Understanding the lead time and data needed for different actions before, during and after events will lead to a more prepared nation.

In a flood-resilient future, the right information is provided to the right people in an efficient and timely manner.

Culture of resilience

Colloquium participants discussed how resilience could be imbedded into the culture and thinking of society. In a resilient future, people do not drive through floodwaters or assume their home cannot flood beyond the Special Flood Hazard Area. Families and communities understand flood threats and the actions needed, particularly in the context of other hazards and disruptions to which they may be exposed. Engineers, architects and planners consider disaster-resilient measures as fundamental elements of good design, just as they would structural loading, aesthetics, performance and function, and they have access to the resources and skills needed to build back in a more resilient way after a disaster.

Participants identified a variety of approaches for building and improving this culture, including effective risk communications; coproducing tools, from forecasting to resilient planning; identifying socio-economic and cultural metrics and indicators to robustly measure resilience before, during and after a disaster; seamless integration of products and information from individuals to communities to state and national programs; and infusing federal and private-sector investments.

In a flood-resilient future, everyone participates in building resilience.

CLEARING THE HURDLES TO THE FINISH LINE

Analytics helps inform decisions for responding to disasters, reforming policy and planning for long-range capital investments. However, merely improving the speed, variety and technical accuracy of analytics does not guarantee improvement in their application to practical decision-making. Participants repeatedly emphasized several non-technical issues that interfere with the effective use of analytics before, during and after disasters. Recurring discussions centered around these hurdles to the finish line.

Fast thinking, slow thinking

Ed Link used Daniel Kahneman's paradigm of "fast thinking" versus "slow thinking" as the centerpiece of his presentation. The theme resonated through the remainder of the Colloquium. In his 2011 book[24], Thinking, Fast and Slow, Kahneman described two modes of thought that lie at the heart of behavioral science, engineering and medicine. Fast thinking is automatic, frequent, emotional and largely unconscious. It draws on stereotypes, habit and experience. It is heuristic, interpreting new information against the pattern of familiar information, like a judge who sees a current case only in terms of familiar precedents. Fast thinking forms conclusions quickly and intuitively.

Slow thinking is analytic. It is logical, calculating and conscious. It does not jump to conclusions but attempts to interpret new information on its own merits. It is, therefore, inherently more difficult and time-consuming.

The dichotomy between the two modes of thought has deep relevance to emergency management. Responders, especially incident commanders, are in their positions because they work well with other people and are adept at fast thinking. They operate on interpersonal trust and make decisions quickly. Analysts, on the other hand, are in their positions because they think more slowly, logically and objectively. They weigh facts consciously and try to interpret all data on the merits.

The two systems co-exist awkwardly, at best, under the high pressure of an emergency. Incident commanders may simply dismiss outright any information that conflicts with their instincts or their experiences. Or they may (and typically do) favor analyses based on official national sources over analyses based on local or non-standard sources. Hence analysts' perennial frustration that however great their work, however appropriate, timely and intelligible their results, they can still be ignored, especially if their results are counter-intuitive.

Perfect is the enemy of the good

Different from but entwined with the fast/slow dichotomy is the dilemma of speed versus accuracy. Analysts' instincts are to strive for accuracy and precision, but these take time. Roy Wright crystallized the problem in his opening remarks: "Analysts fear being wrong. Responders fear being late."

There is no simple answer to this dilemma. Sending resources in a timely manner to the wrong place is as useless as sending them to the right place too late. Judgment and experience are needed on both sides – the analyst's and the responder's. Wright advised Colloquium participants not to "admire the problem" too much, not to become so wrapped up in the subtleties and complexities of flood analytics that "good-enough" solutions never emerge. Uncertainty must not paralyze action. The analyst must recognize the value of fast thinking and accept that emergency managers' personalities are the right ones for the job, even when they make mistakes. Effective management requires decisiveness and momentum as much as analytic accuracy.

Listening to the audience

Finding the solution that is good enough, however, is not just an 80/20 calculation (getting an 80 percent accurate result in 20 percent of the time it would take to reach perfection). It also means listening to the audience. What questions does the decision-maker really want to answer? At times the analyst's perfect answer is so complex that the audience can't understand it, or it comes with so many caveats that a clear path forward isn't visible. Simplifying the problem is essential. The analyst must provide the best information available to choose between realistically available options and then move on.

In practice this can be a tall order. The 2017 hurricane season was a case in point. By the end of the summer, Houston had suffered three "500-year floods" in three years. As one participant described it, suggesting the possibility of a flood just half the size of Harvey was disallowed as totally unrealistic some years before, even though the models said it was possible. Preparing the analyst to deal with the changing dynamics of floods in the 21st century requires constant communication between technology, sociology, economics and politics. The analyst often needs wisdom in addition to skill. Wisdom is the ability to know what to do – and what questions to answer – in an unprecedented situation.

NOTES

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These waterfront homes in Texas had their landscaping and roads damaged or destroyed by storm surge and waves from Hurricane Ike (2008).

Photo by Jocelyn Augustino/FEMA

ANALYTICS IN THE COLLOQUIUM CONTEXT

> ANALYTICS IS FORMALLY DEFINED AS “TECHNIQUES USED TO ANALYZE AND ACQUIRE INTELLIGENCE FROM BIG DATA.”[25]

The notion of analytics has risen in popular awareness through movies like Moneyball and The Big Short, through corporate advertising touting the benefits of their particular flavor of analytics and through the popularization of the concept of big data.

From Abstract Concept to Application

Analytics and big data go hand in hand. Corporations are leveraging analytics that are run against large, complex data sets to increase efficiency, safety, uptime and productivity. Analytics drives new capabilities, such as cognitive computing and artificial intelligence. Think IBM Watson. The convergence of data, compute and analytics supports breakout new technologies, reflected in such examples as self-driving vehicles[26] and programs that learn with little input from humans, and better and faster algorithms.[27]

Scientists and researchers in many disciplines use analytics as a research tool, leveraging large data sources and new techniques, with examples in health care, medicine, operations research, economic behavior and geosciences, to name a few. These new data-driven approaches are finding their way into disciplines not usually associated with quantitative approaches, such as history, literature and linguistics. In the flood domain, analytics approaches are being applied to neural networks to predict river flow, mining time series data for flood prediction, spatial data analytics applied to hydrologic data and analytics applied to social media in a disaster-management context.[28]

In spite of the existence of a ‘formal’ definition, there are still many opinions and questions about how to define analytics. Is analytics simply a marketing term applied to statistical techniques run against big data or is the analysis of big data fundamentally different? Is analytics another way to describe data mining and machine learning? What are the important characteristics of analytics that suggest the need for a focused look at the potential of these approaches to improve the state of practice for understanding, predicting, planning and responding to flood events? The workshop presented analytics as having three key elements: a significant data aspect (data fusion, data assimilation or big data), a computational aspect (whether through analytical techniques or complicated models) and leading-edge methodologies (artificial intelligence, deep learning, neural networks or agent-based models). The intent was to illustrate the potential of analytics through examples.

In practice, the idea of analytics functioned during the workshop as a heuristic representing a broader range of new technology, analytical approaches, tools, non-traditional data and new epistemologies raised by participants and discussed as leading-edge or over-the-horizon ideas in the context of preparing for and responding to floods.

Zooming in on Flood Analytics

Flood analysts seek to understand the relative likelihood of coastal, riverine and rain-driven flooding, the impacts of that flooding and the need to communicate that risk to a broad range of users, including emergency managers, mitigation specialists and community planners.

Understanding and communicating flood risk is a core goal of flood analysts. Flood-risk analysis requires first the collection, aggregation and storage of data. Data are then modeled and analyzed, using both traditional methods and, more recently, analytics methods that incorporate a next level of complexity – big data that are often in the aggregate and unstructured, artificial intelligence approaches and network and systems analysis.

While there is always a desire for updated, higher-resolution data and increased accuracy and refinement of the models, the greater challenges in flood analytics today are in aggregating, integrating and applying fundamentally new methods to the existing data and models. Data collected postevent include progressively more unstructured imagery data, including those from satellites, that must now be integrated with the older, traditionally structured datasets. This integration will require new data architectures and cyber infrastructure to support integration and alignment of data across multiple formats and resolutions. High-performance computing (HPC) is already used for many of the flood models, and the increase in data requirements (resolution, quantity and complexity), as well as the repeated requests for increased accuracy, resolution and speed, suggest that HPC must become standard.

Workshop participants provided examples of new approaches and leading-edge ideas that stretch the notions of what is needed and what is possible. They discussed effective ways to quantify flood impacts and the value of implemented mitigation measures. The conversation did not simply offer a traditional cost-benefit analysis but went beyond to change how the costs and benefits are calculated to provide a more accurate assessment of various policy choices in a dynamic environment. The group saw examples of the power of high-resolution spatial data and assimilation of various types of data for rapid damage assessment. Examples of new types of data being leveraged in the context of flood response, such as social media and crowdsourced data, were also described. Other presentations and discussion focused on the complexity of modeling these phenomena and how to communicate the results in a form that is useful for decision-makers. An example of linking machine learning to physical models demonstrated a potential application of advanced analytics.

Flood and Flood Impacts Data

Flood analysis requires data about water and the underlying ground. In the United States, these data are largely collected and made available from federal sources. Riverine flow rates are available through the U.S. Geological Survey as a collection of nearly 10,000 data points, managed and stored in databases, some available on the web or through electronic transfer (e.g., application programming interface, or APIs) and some that must be exported manually. The relative height of riverine waters can be measured by comparing water surface elevation to the underlying ground surface, as defined by digital elevation maps and other sources. Corresponding systems provide data for coastal and estuarine environments. These “steady-state” data provide a baseline for understanding changes during flooding.

Analyzing flood impacts requires understanding the intersection between flood waters and people – both the populations themselves and the infrastructure upon which they rely for shelter, energy and transportation. With rapid expansions and movement of the populations, datasets must be constantly updated to account for rapid and increasing urbanization, changes in and projections of population and demographic structures, social dynamics within those communities and the interactions between the population and their built environment. Differences in urban and rural transportation requirements, resilience and cultural norms must be applied to flood modeling to more deeply understand the impacts of events and effectively plan for successful recovery. These changes are, in many cases, being captured in the data that are collected as a part of demography, sociology and economics programs but have not been as consistently integrated into our understanding of flood impacts and consequence analysis.

The challenge inherent in these data are their quantity and complexity. The data are collected by a large number of organizations and stored in disparate, often poorly aligned systems. The formats, units and data structures are inconsistently conserved across systems and can often require significant manual effort to find, access and extract. The data are complex in that water measurements differ relative to their source (e.g., riverine, oceanic, coastal, estuarine or precipitation) and are meaningful only in context to the underlying earth surface data (e.g., bathymetry, stream or river bed, coastlines and built infrastructure). These challenges are not unique to floods but, given the sheer number of watersheds and total length of coastline (areas at risk of flooding due to proximity, as well as those potentially affected by rain, rapid snow melt or infrastructure failures), the volume of data needed to support flood analysis is a powerful illustration of the need for better ways to manage and access these data.

Flood Modeling and Analysis

Flood modeling and analysis is a robust field that has yielded powerful tools to predict and analyze both the likelihood and impacts of water in riverine and coastal environments. These efforts include new and expanded weather forecast models developed by federal agencies and the private sector that can be applied to improving predictions for the storm events that most often drive severe flooding. These models have been developed primarily by and for the expert community, from coastal models, such as ADCIRC and SLOSH, to the national riverine water model currently being developed and made available through the National Water Center. Efforts are underway to integrate these methods to address estuarine flooding, a gap between riverine and coastal flood-modeling efforts that requires modeling areas where riverine systems physically merge with coastlines, amplifying the complexity and requiring integration both of the underlying data and the corresponding algorithms. Integrated water modeling has been developed and successfully implemented in Iowa and elsewhere, providing a critical proof of principle and demonstrating that such efforts are tractable and worthwhile. However, these efforts must be expanded nationally. In addition to geographic coverage, integrated methods will also need to be applied to complex or hybrid events as expectations increase.

The most widely used flood consequence model remains Hazus, a FEMA model originally designed and still optimized to support actuaries at FIMA. While other models have become available (e.g., the Hydrologic Engineering Center Flood Impact Analysis from the U.S. Army Corps of Engineers), none of the current models are readily available to support response operations nor are they designed to perform nuanced analysis, whether around changing demography, updated urban dynamics or detailed economic assessments for community-specific recovery.

Significant effort has helped make the results from these models more readily accessible through better visualization tools, widely used data formats and collaboration with risk communication experts. However, both the flood event and consequence models require, in most cases, high-performance computing and complex data architectures, and the results require additional translation steps or significant training to be applied to practical decisions.

Communication: Data Visualization and Decision Support
The biggest challenge in the current flood analytics field is effectively communicating the results of the data analysis, modeling and analytics to non-expert users for practical decision-making. The situational awareness dashboards traditionally used are limited in their ability to effectively communicate risk. New visualization efforts are underway and being tested both in the public and private sectors, with companies pushing the envelope of new visualization techniques and federal efforts applying a new focus to the effective communication of results. These efforts can be seen in the integration of aerial and satellite imagery in response dashboards, in 3D visualization of flood waters impacting infrastructure along a coastline and in the focus of the National Water Center and Coastal Resilience Center, among others, on providing viewer-compatible file types and outputs designed to inform both detailed advanced planning and mitigation efforts, as well as response operations.

Despite these efforts, the biggest gaps articulated by local users of flood analysis was in the communication of results. The need for rapid analysis to support immediately practical decision-making is still not being met.

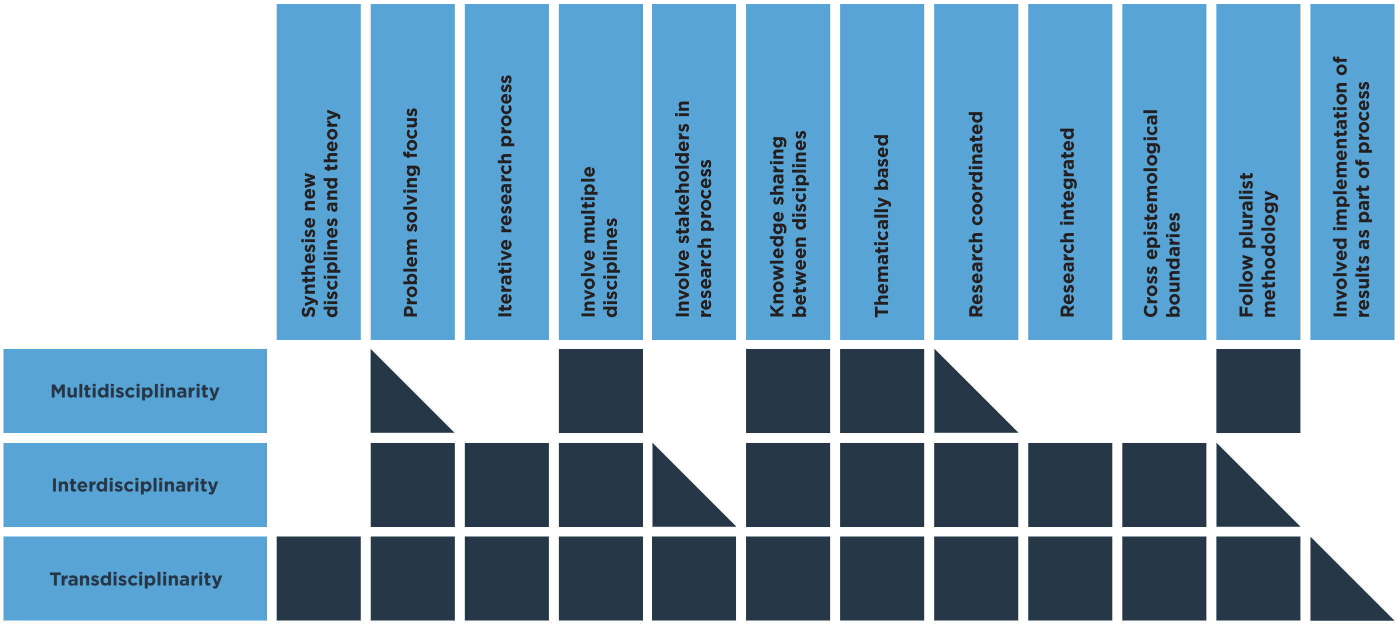
ATTRIBUTES FOR DREAM STATE ANALYTICS

The exact nature of the future state of flood analytics may not be known, but participants agreed that rethinking flood analytics requires encapsulating some higher principles or guidelines. Transformational changes to our current state of practice are contingent upon elements that can improve the way problems are approached. While there have been promising and successful advances, real transformation will require a range of approaches.

Transdisciplinary Approaches
Flood analytics is a team sport. Complex problems should involve the collective, holistic integration of many disciplines.

In the dream state, current flood-centric data/models will link with other physical models and socio-economic and ecosystem analytics, taking a transdisciplinary approach.

Analytics is integrated across disciplines, scale and hazards. It expands upon single, multi-disciplinary and interdisciplinary approaches. A single-disciplinary approach is characterized by the development of a single data/model within a well-defined specialization/expertise. A multi-disciplinary approach combines the efforts of experts from more than one discipline,



	Synthesise new disciplines and theory	Problem solving focus	Iterative research process	Involve multiple disciplines	Involve stakeholders in research process	Knowledge sharing between disciplines	Thematically based	Research coordinated	Research integrated	Cross epistemological boundaries	Follow pluralist methodology	Involved implementation of results as part of process
Multidisciplinarity		◣		■		■	■	◣			■	
Interdisciplinarity		■	■	■	◣	■	■	■	■	■	◣	
Transdisciplinarity	■	■	■	■	■	■	■	■	■	■	■	◣

Figure 2. Defining characteristics of interdisciplinary, multidisciplinary and transdisciplinary approaches as defined by Stock and Burton, 2011.[29]

with each discipline/expert working separately in his or her own way to create different perspectives on the same issue. An inter-disciplinary approach involves diverse experts from multiple disciplines (e.g., social and natural science) jointly developing new data/models. A transdisciplinary approach involves not only diverse disciplines and experts but also policymakers and communities collaborating to create new data/models. In a 2011 article in Sustainability, Paul Stock and Rob Burton expand upon this concept.[30]

Made For and With the User

The best analytics are developed with the user in mind.

It is critical to know who the users are and include them in the development of flood analytics. It is also important to seek out a wide range of users. What might work in one neighborhood may not work well in another. In the dream state, outputs, products and services meet the needs and delivery requirements of the user. A recurring theme of the Colloquium, and perhaps the weakest link in successfully advancing flood analytics, is understanding the user and user requirements.

Flood analytics would embrace coproduction, a process whereby researchers work alongside users and with communities, sharing resources to reduce flood risk. It is an increasingly common way of addressing problems in a more transparent way and is being used in health and environmental research to lead to new knowledge.[31] Coproduction could be used to help bridge the "valley of death" – the chasm between good research and applications.

By working closer with users, analytical products and tools could:

- Respect local capacity and capability.
- Help translate the complex to the meaningful.
- Deliver the right analytics to practitioners and decision-makers who will use them.
- Revolutionize an industry and challenge the status quo.

Communicate Clearly

In a dream state, more attention is given to translation of information in a way that is understandable and leads to action.

As discussed at the Colloquium by Ed Link, a wide gap often exists between "Type 1 and Type 2 thinkers," as described earlier. Targeting our messages and deliverables in a way that helps users understand their meaning and relevance will lead to informed decisions. Communicating clearly means that analytics are believable, presented in understandable formats and effective in translating the results for practical application. Many Colloquium practitioners and researchers noted the challenge of communicating innovative technical ideas and concepts to the real-world user. Working with end users to produce new methods and tools can help, but using plain language, bringing translators to the discussion and incorporating intuitive visualization tools can greatly improve communications.

Photo by Jocelyn Augustino/FEMA

This elevated home illustrates state-of-the-art construction from the early 1990s through the early 2000s. The stilts mitigate water damage, however the roof and shingles are susceptible to wind and water damage.

Use State-of-the-art Analytics
Rethinking analytics requires applying both new and developing concepts, such as artificial intelligence, machine language, deep learning and other advanced methodologies. Researchers and practitioners must move out of comfort zones and engage with experts who have mastered these methods, and they must improve standards and interoperability. As new methodologies are embraced, articulating the uncertainties will help instill confidence in the approach. Rethinking analytics may require what Einstein articulated: “We shall require a substantially new manner of thinking if mankind is to survive.” A dream state for flood analytics embraces new approaches that improve speed and efficiency of information and reduce or quantify the uncertainties.

Embrace Tech-savvy Solutions
An analytics dream state takes advantage of emerging technology.

Analytics are improved by leveraging technology advances, such as sensors, internet of things, social media, crowdsourcing, open source and hardware platforms (from Raspberry PI and cell phones to satellites and HPC). Flood-risk management practice already has embraced many of these transformational technologies, some of which were presented and discussed at the Colloquium. These revolutionary technologies are radically changing how people live – from transportation to ecology, health to education. Staying abreast of and incorporating the latest technology into analytics will improve the nation’s ability to prepare for and respond to floods.

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BRIDGING THE GAPS

MUCH OF THE CHALLENGE OF IMPROVING FLOOD RESILIENCE LIES IN BRIDGING GAPS IN OUR UNDERSTANDING.

Hydrologic and hydraulic engineering models have been in development, with iterative refinements and improvements, by a robust research community for decades. Linking these models with the newer concepts of community resilience, expanding upon the tools with new analytical methods and larger and less-structured datasets, and more effectively communicating these integrated results is the new challenge.

The Colloquium provided a forum for taking a critical first step in identifying research gaps. Participants focused on ideas for new and expanded research that could inform new opportunities. Despite the diversity of expertise and backgrounds represented at the Colloquium, the number of participants was limited as was the time allotted for discussion on each topic. Therefore, expertise gaps likely existed, particularly in advanced analytics, that if represented could have offered additional insights into research gaps and challenges. These should be explored in other circles.

Advancing Model and Data Analytics
The current state of practice in flood analytics largely focuses on physical processes or algorithms and statistical relationship-based observations to characterize the flood and its physical impact. A recent review of models in a report by the Rand Corporation for the Flood Apex Program[32] identified seven broad functional categories for tools that support flood decision processes. These ranged from risk-assessment tools that quantify estimated physical damages or hydrodynamic models that predict flooding to emergency management tools that track hurricanes and map evacuation routes and decision support tools that use maps or simple algorithms to relate the risk of damages to action alternatives.

While these models and data analysis have grown in sophistication and accuracy over the years, they have yet to capitalize on the emerging use of artificial intelligence techniques, such as machine learning, or other big data analytics that could inform a new approach to flood predictive analytics. As is being done in such areas as health and transportation, big data analytics should be used to advance the understanding of physical and social aspects of disasters, help quantify and reduce uncertainties, and give an alternative perspective on characterizing the complexity of flooding, including extreme events.

Current models and methods prevail in flood analytics, and improvements are mostly evolutionary and incremental. Shifting that paradigm toward data-driven analytics will require considerable thought and effort in terms of testing and evaluating new techniques, leveraging new computing environments and capacity-building.

Suggested Research Topics

- How can advanced analytics give better and faster predictions, especially when the window for decision-making is small?
- How can current and future computational platforms increase prediction speed?
- How can models be more easily connected, e.g., across geographies or through time?
- Can analytics facilitate model-data assimilation?
- Are there ways to use data analytics to get from micro-scale, structure-level attributes to macro-scale, near-real-time national flood awareness?
- What analytic methods are needed to deal with extreme events, such as Hurricane Harvey, or chronic situations, such as nuisance flooding?
- How can advanced analytics give us earlier warnings, e.g., for flash flood events?
- Can a data-driven approach better integrate social and physical responses to an event?
- What other types of socio-behavioral modeling can be incorporated in these contexts, e.g., agent-based modeling?
- How can physics-based models be coupled with techniques, such as machine learning, deep learning, data mining, neural networks or other types of artificial intelligence?

Technology-driven Analytics
It is clear that the future of analytics will be shaped by new technologies. Disruptive technologies, from micro-computers and quantum computing to autonomous vehicles, are changing how individuals, communities and nations live and work in a global network.

Technology enablers are currently one of the clearest areas of advancement in flood analytics. Satellite imagery, low-cost sensors, autonomous drones, etc., are important data contributors and also add value to current observing and data platforms, such as stream gages and LIDAR.

For example, the Flood Apex Program is developing innovative alert and warning sensors that can connect to the internet of things and is advancing the use of satellite imagery to identify historical areas of flooding.

How can such technologies be integrated into practice while also staying ahead of the technology curve? What is on the horizon?

Suggested Technologies for Exploration

- Synthetic-aperture radar, both from satellites and aerial platforms
- Unmanned airborne vehicles
- Deployable sensors
- Sensors mounted on infrastructure
- Five-dimensional LIDAR (x, y and z plus time and return intensity)[33]
- Blockchain technology to securely share sensitive data and information
- Citizen science and crowdsourcing via technology, such as smartphones, smartwatches, personal sensors or other devices
- Quantum computing

Model and Data Integration
Flood models and their ability to use data have been improving for several decades. Data-driven numerical flood models are used routinely for forecasting, forensic analysis and long-range planning. Areas that need improvement or lack capability include: 1) near-real-time forecasting, 2) coupled or integrated physical process models, such as hydrology with meteorological models and riverine with coastal models, and especially 3) combining socio-cultural, economic and ecosystem data and models with physical process models.

As data availability and computing power increase, process model improvement has focused on increased resolution and faster computing, but the trade-off is that more resolution, even with higher-performing computers, limits speed. In addition, model improvements have tended to be subject-specific. Independent advances in each area (coastal hydrodynamics, riverine hydraulics, hydrology, ecosystem modeling, social behavior) have not produced coupled or integrated models in an operational solution. Advancing such interactions could have immediate impacts on flood-risk management by providing an overall operating picture to help decision-makers understand the extent of flooding, who is affected and perhaps some of the basic or special needs that should take priority. Integrated tools would add value to all phases of the flood problem: mitigation/planning, response and recovery.

The Colloquium brought together many modelers from many subdisciplines of flood analytics. There appeared to be not only recognition that this was an area for collaboration among the attendees but there was enthusiasm among the participants to do something.

Suggested Research Topics

- Integrating time and various spatial scales (i.e., from community and local to national) to address nuisance flooding
- Developing unique identifiers or standards to connect all data across different spatial scales
- Insuring all models include depth and extent of flooding
- Including the value of ecosystem services and incorporating ecological models
- Linking the models to time scales that can address impacts, such as seasonal or daily population variations, demographics, such as age, special needs, language, etc.
- Integrating outputs to provide the fast turnaround needed by emergency managers or for special purposes
- Risk Rating 2.0: Linking valuations to structure footprints (The Flood Apex Program has major research underway on this subject.)
- Producing more maps in advance of flood events, and anticipating what topics the maps will need to address
- Integrating better economics and other social science data (e.g., demography, social resilience, behavioral psychology) into the models
- Ensuring accessibility, fidelity, quality and integration of data from new sources (e.g., social media)

Collaboration Opportunities
The Flood Apex Program has a clear interest here. Work with the National Alliance for Public Safety GIS Foundation might yield topics for pre-designed products or data sources for on-the-fly responses and help link subject matter experts with GIS practitioners.

Networks and Systems Analytics
Modeling independent networks, such as river systems, utilities or transportation, is improving. What is lacking is the ability to tie these networks together in a way that represents their interdependencies and to include other systems, such as social networks. New network modeling methods are being developed and applied across a wide range of fields, from social network models to networked models of infrastructure systems within communities. These models help define and

quantify communities and flooding events as complex systems and can be used to elucidate interdependencies between nodes in the network, define elements that are most key to stability (e.g., the most central) and prioritize investments based on the relative importance of interactions within the system.

Significant research has been focused on interdependencies between infrastructure networks that can result in cascading impacts. For instance, failures in electric power cause other service outages, e.g., water, waste treatment or air conditioning can affect survivors' health and vitality. Communication network failures can impact the logistics that deliver important supplies in a timely manner to those in need. Social behavior and risk communication are key in ensuring that evacuation planning and implementation reduce risk and do not leave people more vulnerable in large storm events.

These tools and the ability to assess risk and vulnerability – the underpinnings of establishing priorities for resilience – are critical for defining not just the individual elements (people or physical infrastructure) but the interactions and interplay between them. Indeed, as articulated throughout the Colloquium, systems analysis is a critical new addition to understanding risk, whether in the response phase of a flood event, during which emphasis shifts from information management to interaction management[34], or in the mitigation and planning phases, to help assign the appropriate pricing structure for flood insurance.

Suggested Research Topics

- Incorporating operations research methods and analysis tools
- Using Bayesian networks to represent the variables and their conditional dependencies
- Using big data approaches to examine interconnectivities and interdependencies of systems
- Building upon interdisciplinary network modeling approaches to develop new quantitative models of resilience

Collaboration Opportunities

Many academic research activities are being conducted in this type of optimization and network modeling, but applications to flooding and flood events are limited. Current work is underway at the National Institute of Standards and Technology's Resilience Center of Excellence to apply network modeling approaches and complex systems analysis to develop new methods of modeling resilience, which could be readily applied to flooding.

Risk and Damage Assessment Analytics

While risk and damage assessments are widely used in flood analytics, they need to be better adapted to reflect all of the damages and do it in an expedient way that is tied to other decision support analytics. Accelerating assessments could result in quicker response and insurance claim payments. Broader assessments of what is at risk and the potential for damage could inform research in mitigation investment and insurance analytics.

Suggested Research Topics

- Create a flood severity index analogous to the Saffir-Simpson scale for hurricanes or the Enhanced Fujita scale for tornadoes.
- Risk Rating 2.0: Linking valuations to structure footprints. (Also listed under Model and Data Integration). The Flood Apex Program has major research underway on this subject.
- Accelerate claims processing and public assistance with improved and faster damage assessments.
- Generate estimates of the number of structures impacted and costs within 72 hours of a flood event.
- Evaluate likely repetitive damage quickly to better inform the trade-off between buyouts and repairs.
- Integrate new data sources.

Collaboration Opportunities

The Flood Apex Program is involved in many of these issues of concern: structures inventory, modeling damages quickly, remote sensing and the possibility of working directly with FIMA to enhance damage assessment workflows and processes.

Insurance Analytics

The National Flood Insurance Program, which boasts a long programmatic history, continues to work toward better ways to manage its efforts by capitalizing on the extensive data it has collected on premium holders, claims and flood histories. The agency has been focused on modernizing and reforming its systems and processes to deliver a fiscally sound and affordable program that mitigates flood risk. It is now exploring analytics in a number of areas to meet its moonshot of doubling policy holders by 2023, reducing the program's overall financial exposure and increasing responsiveness to policy holders following a disaster.

Suggested Research Topics

- What analytics are needed to increase the participation of private companies?
- What data and information are needed for better underwriting or rate setting?
- How can predictive analytics inform response?
- How can analytics identify highest-risk properties and inform policy decisions and mitigation investments?
- How can structure-level risk assessments be used to inform disaster declarations, response and recovery needs, and accelerate insurance claim payments?
- How can analytics inform developers and home buyers about high risk and repetitive loss structures?

Collaboration Opportunities

As mentioned in the preceding section, Insurance Analytics, the Flood Apex Program is involved in structure-level risk.

In addition, it is conducting an assessment of the private insurance market. Findings may point out opportunities for additional institutional and technical work.

Mitigation Investment Analytics

As discussed earlier, The National Hazard Mitigation Saves: 2017 Interim Report[35] reviewed 23 years of mitigation investments from FEMA grants and determined that the payoff is $6 for every $1 spent and that exceeding 2015 ICC building codes in new buildings can provide a 4:1 return on investment. If mitigation can be such a good investment, why aren't more dollars going toward it?

The Mitigation Framework Leadership Group (MitFLG) released the National Mitigation Investment Strategy (NMIS) in January 2018 for public comment.[36] The NMIS seeks to increase investments in and improve collaboration of hazard mitigation actions. The NMIS identified many of the key areas discussed at the Colloquium: the importance of a common vocabulary and metrics, respecting local expertise, life-cycle quantification of costs and risks, improved coordination across mission areas, shared data, risk communication and innovative solutions to the built environment.

The Rockefeller Foundation offers a related innovative finance initiative, called Zero Gap.[37] This initiative seeks funding sources that can fill the gap between what is available and what is needed to achieve the United Nations' Sustainable Development Goals.

Drawing from these and other strategies could provide ideas for developing more robust mitigation investment analytics. Adding FIMA's moonshot (to quadruple mitigation investments by 2023) to the drivers for this subject, mitigation investment analytics research seeks to quantify the real economic benefits of resilient strategies and the actual costs of flood impacts.

To encourage investment, analytics must go beyond calculating losses avoided and actually quantify return on investment. This means broadening current economic evaluations to go beyond damages to the built infrastructure and include other socio-economic and environmental aspects. Quantifying the benefits of newer alternatives, such as green infrastructure, relocation and alternative construction, such as floating houses, could help drive more investment in mitigation.

Suggested Research Topics

- What data and data sources could be used to establish baselines for return-on-investment calculations?
- What are the full economic impacts of disasters, including cascading effects, business disruption, health costs, environmental degradation, shifting demographics, etc.? How can they be quantified?
- What is the payoff from investments in ecosystem services, quality of life, aesthetics, improved health, etc.?
- What are the cumulative effects of individual investments, such as flood proofing, green roofs, pumps, etc., on flood-risk reduction?
- Can disruptive technologies, such as Blockchain, be used to track these investments in a secure manner?
- Are there mechanisms, such as credit scores, bond ratings, etc., that would establish benchmarks for resilience and entice financial investors? Using both government and non-government data, could those mechanisms include indicators, such as social cohesion, expedient recovery and sustainable solutions?
- Are there more advanced ways of predicting human behavior, such as agent-based modeling, to determine what motivates investment decisions?
- Are there techniques and methodologies to conduct trade-off analyses of the most relevant investment strategies? Can these methodologies also identify where not to invest?

Collaboration Opportunities

To properly address mitigation investment analytics requires collaboration among not only professional disciplines but among the organizations and institutions that use their knowledge and expertise, since both (professional disciplines and organizations) have strong tendencies towards insularity. The following are some examples from each category:

Disciplines: economics, anthropology, flood modeling, data analytics, planning, financial analysis, ecology, demographics, social science

Organizations: insurance and reinsurance companies, impact investors, FIMA, National Oceanic and Atmospheric Administration, U.C. Army Corps of Engineers, state hazard mitigation offices, nonprofits (The Nature Conservancy, Environmental Defense Fund, Rockefeller Foundation, etc.), Earth Economics, RAND Corporation, National Institute of Building Sciences

Neighborhood-scale Physical, Social and Environmental Analytics

Analytics and models often focus on broad geographic domains and represent prominent, landscape-scale features and their impacts. This approach can fail to address neighborhood-level issues, particularly in disadvantaged neighborhoods, which can lead to unequal provision of services. A simple example is the impact of inadequate small-scale storm drainage features, such as lack of curbing, overgrown drainage ditches and obstructions to storm sewers. Not only is there considerable difference in infrastructure and potential resilience at the neighborhood level, much of the variation is likely due to demographics and inequities in investment.

Differential services to different neighborhoods are often not taken into account. Planners are seldom sufficiently aware of where vulnerable populations are, and modelers rarely include small features in their analyses.

On National Day of Service and Remembrance, AmeriCorps members chip away flooring for removal from a house in Baton Rouge, Louisiana, damaged by historic flooding in 2016.

Photo by J.T. Blatty/FEMA.

Suggested Research Topics

- Consider the condition of both gray and green infrastructure when assuming flood risk-reduction benefits. Flood impact modeling assumes that existing infrastructure ("gray" or "green") will work as designed, not in its current condition. Age and neglected maintenance are not taken into account in risk and vulnerability assessments.
- Determine how to analytically represent small-scale infrastructure and give credit to those making those investments.
- Integrate local data with state and national sources.
- Improve resilience quantification across the spectrum, from highly vulnerable to highly resilient.
- Coproduce resilience with locals and local partners.
- Improve access to affordable flood insurance.
- Increase social cohesion of vulnerable populations (e.g., people with disabilities, elderly) during preparedness planning.
- Influence behavior change at the micro-local level, such as families and neighborhoods.

Communicating Analytics with Graphics and Visualization

While much of the flood modeling community has traditionally focused on hazard and risk modeling, there was significant discussion of expanding beyond risk analysis and risk communication to the issue of how to communicate that information effectively to a broad audience and apply it to practical decision-making. The focus of the discussion, driven by examples from news reporting and private-sector efforts to build new risk communications visualization methods, was on how to more effectively communicate the results of complex analyses in ways that are immediately accessible and meaningful to the audience.


Photo by Robert Kaufmann/FEMA

FEMA Public Assistance teams and the city of Punta Gorda, Fla., inspected damages and began repairs from Hurricane Irma.

This new way of thinking about communication requires improved data sharing, improved messaging, reduced information overload (by focusing on the relevant information for specific audiences) and analytics that can be readily understood and are immediately useful to their intended users – issues that touch on and rely upon virtually every other topic area. Relevant to all phases of the management cycle – preparedness, response and recovery – there was general agreement that one of the chief failures of flood analytics is identifying what results are needed, where, and when, and how to effectively communicate that information to specific audiences.

Suggested Issues to Explore

- Analysis delivered to communities that have no ability to use it.
- Many elementary and traditional ways of communicating flood information are wrong or misleading: the 100-year flood is the most notable example, but understanding what is meant by the hurricane forecast cone is another. Flood severity often is poorly communicated, e.g., hurricane category (wind speed) is usually regarded as more important than storm surge or flood depth, but the opposite is typically true.
- Risk and vulnerability information is withheld, misleading, inadequate or unavailable. For example, a home seller may be required by law to inform the buyer only whether the property flooded under their ownership.
- Analysts' fears of being wrong is fundamentally at odds with responders' fears of being late.
- Trust versus truth: the most accurate analysis may not be trusted because of its source or because it conflicts with decision-makers' expectations.
- Effective communication relies on understanding the end user or audience and communicating clearly to meet their specific needs.

The Flood Apex Program is conducting behavior studies in this area and is interested in improved messaging of alerts and warnings to improve compliance. This topic is a complex but paramount issue in flood analytics. The challenge is to identify the most critical dimensions and find ways of expanding the number of people who clearly understand flood risk and can incorporate that information into their decision-making.

Institutionalizing Analytics

The amount of data types, data sources, models and analytical approaches is daunting. How to curate data and validate models needs to be addressed early and often. Yet, these efforts are some of the hardest to implement and are chronically under-resourced.

Developing communities of practice formed to support operationalizing and institutionalizing processes that lead to curated, documented and interoperable data and models is essential. Without the right mix of bottom-up and top-down direction, ownership and incentives, the core elements necessary to track quality, set standards and support reproducibility essential to providing the best analytical services to help decision-makers and build capacity will lag or slow the other efforts.

At present, such communities of practice, governance systems and processes are lacking, as is the awareness of the central role of these elements to address the kinds of challenges represented by the advanced methodological and transdisciplinary approaches described above.

Suggested Research Topics

- How to develop stakeholder alignment and communities of practice around these types of core goals
- Institutions, governance, process
- Life-cycle data curation
- Data standards and interoperability
- Model validation, model interoperability, software sustainability
- Open data, open science, open source, intellectual property
- Data- and/or compute-intensive analytics in distributed environments
- Capacity building at all levels
- How to move new ideas, approaches and technologies to operations more quickly
- Providing flood analytics as a service:
  + Better classification of flood types
  + Reliable and trusted providers
  + Centralized or distributed

Collaboration Opportunities

Communities of practice could be initiated by encouraging joint activities with relevant federal agencies, such as NASA, NOAA and USGS, and by participating in groups, such as the Federation of Earth Science Information Partners (ESIP).

These other relevant federal agencies have a significant track record addressing data curation, data interoperability and data access challenges. ESIP provides a venue to share knowledge and learn leading practices.

NOTES

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THE
WAY FORWARD

THE COLLOQUIUM SET A FRAMEWORK FOR ADVANCING FLOOD ANALYTICS BY IDENTIFYING THE ATTRIBUTES THAT SHOULD DRIVE HOW RESEARCH IS CONDUCTED AND THE TOPICS THAT NEED ADVANCEMENT.

Regardless of the theme, flood analytics research should embrace the use of transdisciplinary teams, engage the user and communicate results in a clear and actionable format while embracing transformative analytics and disruptive technologies.

Recap of Best Concepts for Advancing Flood Analytics

To advance flood analytics, Colloquium participants focused on 10 theme areas that could independently or in multiples inform content for research and development programs, workshops, studies and/or scholarly papers. Two of the themes – Model and Data Analytics and Technology-Driven Analytics – are specific to exploring advanced analytic methodologies and evolving technologies that might enable transformational approaches. The concepts in these themes directly support the attributes described above.

Also identified as evolving fields of both practice and research that have the potential for near-term success were Model and Data Integration, Networks and Systems Analytics, and Risk and Damage Assessments. These offer the opportunity to bring together single disciplinary approaches into a more collaborative and interdisciplinary environment to advance and integrate the best and newest data and models.

Insurance, Mitigation Investment and Neighborhood Analytics represent specific niches that could fill voids in the current flood analytic methodologies, enabling informed decision-making and policy reform. Capitalizing on the emerging use of graphical media, social media and visualization, Communicating Analytics with Graphics and Visualization will improve communications and messaging to explain the complex physical, social and economic issues of flooding and help deliver the right data to the right audience.

Finally, as methodologies advance, Institutionalizing Analytics identifies the need to standardize and curate data, assure interoperability and deal with governance.

Coordinated Research Agenda

The research and development gaps and advancements discussed in this report represent what could be studied. The attributes provide the components for constructing a viable approach or study plan, but how the research actually happens requires a more coordinated research approach that would move beyond sharing results and leveraging resources to embrace the coproduction of products while seeking to build a collaborative community of practice among flood researchers and practitioners. Further, the pace of technology development and the urgency of the problem require a proactive and effective strategy to keep research on a path to transition and stay ahead of the curve.

The term coproduction has been around since the 1970s, but it is a process that more recently has been used in areas of policymaking, health and other sciences. The value of the process lies in its ability to connect users and producers, as well as the actual production of knowledge, that can greatly advance the goods and services it supports.[38] Not only does it bind researchers to seek answers to complex theoretical problems, it grounds the outcome to end users and their needs. As research is prioritized, funded and executed, identifying and engaging the end user from conception to transition is critical, as stated many times in this report.

An aerial image shows infrastructure damaged by Hurricane María (2017) in Puerto Rico. The Río Abajo neighborhood in this central mountain region had been cut off after the only bridge connecting it to the nearby town was destroyed.

Photo by K.C.Wilsey/FEMA

Using this approach to rethink flood analytics could help bridge the gap between fast and slow thinkers, provide a dynamic environment to adapt products, and incorporate the needs and capabilities provided by the end users. This approach gets directly to the best way to deliver products to end users, whether that means real-time warnings for response or planning tools for capital improvements. It can help identify priority products or the appropriate level of solutions. Coproduction of research with the end user is a viable method for addressing these questions.

A very clear and positive outcome of the Colloquium was the collaborative opportunity it provided. Many business cards were exchanged and there was much networking. But what happens next? Collaboration activities that continue to convene practitioners and researchers could help put ideas into actions. Specific suggestions included:

- Build a community of practice and a platform for analytic advancement.
- Forge relationships that connect practitioners with modelers.
- Take a transdisciplinary approach to studies (with special attention to social sciences).
- Work across sectors.
- Reach out and include experts beyond the flood community.
- Include underserved communities, particularly at the local/neighborhood level.
- Continue holding workshops.
- Explore a flood analytics service.

The path to a coordinated flood analytics research agenda has already begun. The Flood Apex Program and the Coastal Resilience Center of Excellence have been instrumental in convening and connecting experts and practitioners. Both were developed to bring new technologies and new thinking to mitigating the impact of floods. However, the need to continue to coordinate research will exist beyond their finite lives. A coordinated research agenda would help insure best investments are made in the most pressing problems, reduce redundancy and overlap, and most importantly, lead to better products and knowledge.

To achieve this common operating platform, agencies, private and nonprofit organizations, and academic institutes should look for a way to galvanize the community of practice, coordinate a research strategy and create opportunities to collaborate and coproduce.

Many agencies, with the support of academic institutes and private industry, are working to solve today's flood problems with innovative solutions. Across the national portfolio, such agencies as the National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency and U.S. Geological Survey already support flood-risk management research as part of their mission. Additionally, many academic programs receive funding for research and studies in flood and coastal sciences from other agencies, including the U.S. Department of Homeland Security Science and Technology Directorate, the Federal Emergency Management Agency, the National Institute of Standards and Technology and the National Science Foundation. These collaborative arrangements bring researchers together from many academic institutions and across many disciplines. They provide a forum for agency experts to work side by side with academic experts and practitioners. A specific example of coproduction and collaboration can be found in the development of the National Water Model at the National Weather Service's Water Center in Tuscaloosa, Alabama.

The Colloquium's sponsors hope that the flood analytics community will take on the challenges and ideas presented in this report and use the framework developed to initiate action. The problem of flooding and its impact on the nation are too important to ignore, and it will take the whole of our community to get to the finish line.

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APPENDICES

APPENDIX A: COLLOQUIUM AGENDA

RETHINKING FLOOD ANALYTICS COLLOQUIUM
Nov. 7-9, 2017
Renaissance Computing Institute, RENCI
100 Europa Drive
Chapel Hill, North Carolina 27517

Colloquium Objectives

- Convene and network with a multi-disciplinary group of technical specialists and end users to reimagine flood analytics.
- Capture the challenges and gaps in a Proceedings to help shape a coordinated research agenda for flood analytics.

Goals

- To challenge the status quo of current flood analytics with disruptive technologies and transformational ideas.
- Identify gaps and advance thinking in current leading-edge analytics.
- Integrate and adapt best ideas from thought leaders both within and external to the "flood" community of practice.

DAY 1 • NOVEMBER 7

8:30 AM – 9:00 AM
Registration and Continental Breakfast

9:00 AM – 9:10 AM
UNC Welcome:
Stan Ahalt, RENCI Director

9:10 AM – 9:15 AM
DHS S&T Welcome:
David Alexander, Flood Apex Program Manager

9:15 AM – 9:30 AM
Opening Remarks:
Roy Wright, Associate Administrator, Insurance and Mitigation, FEMA

9:30 AM – 10:15 AM
Keynote Challenge Speaker:
Ed Link, Senior Research Engineer, University of Maryland

10:15 AM – 10:45 AM
Introductions

10:45 AM – 11:00 AM
Break

11:00 AM – 12:30 PM
Plenary Panel:
The Nexus of Analytics and Floods

Moderator:
Chris Lenhardt, Domain Scientist, RENCI

Exploring the latest methods and analytics, this multidisciplinary panel will discuss how new concepts and leading-edge graphics, models and data analytics could improve our ability to prepare for, respond to, recover from and mitigate flood disasters.

- Elizabeth Asche, Chief, Insurance Analytics and Policy Branch, FEMA-FIMA
- David Batker, President, Earth Economics
- Rick Luettich, Director, Institute of Marine Science, UNC
- Al Shaw, Editor and developer, ProPublica
- Rebecca Tippett, Director Carolina Demography, University of North Carolina

12:30 PM – 1:30 PM
Lunch

1:30 PM – 1:50 PM
Open Mic 1

1:50 PM – 2:00 PM
Set up for Technical Breakouts

2:00 PM – 4:00 PM
Technical Session Breakout 1:
Exploring the Possibilities

Participants will break out into smaller multidisciplinary groups to explore innovative and disruptive technologies and potential applications to flood analytics.

PM Break
Breakout teams can work these into their discussion time

4:00 PM – 4:30 PM
"Hotwash" Day 1

These sessions on Days 1 and 2 will provide participants yet another opportunity to share their big ideas and "aha" moments to the full set of Colloquium participants.

DAY 2 • NOVEMBER 8

8:30 AM – 9:00 AM
Continental Breakfast

9:00 AM – 9:10 AM
Welcome Back and set up for day

9:10 AM – 9:30 AM
Open Mic 2

9:30 AM – 10:30 AM
Technical Session Breakout 2:
Capturing our Best Ideas

Groups reconvene to capture their best ideas, identify research and technology gaps and transitional opportunities.

10:30 AM – 10:45 AM
Break

10:45 AM – 12:15 PM
Plenary Panel:
Learning from Disaster

Moderator:
John Dorman, Director of NC Floodplain Mapping, NC

In light of the extraordinary flooding disasters that have occurred in the past few months and years, this panel gives their first-hand testimonial on what sources of information informed decision-making and what lessons they learned.

- Paul Huang, Deputy Assistant Administrator, Federal Insurance, FEMA-FIMA
- Julie Baker, Vice President Operations, URSA Space Systems Inc.
- David Maidment, Hussein M. Alharthy Centennial Chair, University of Texas
- Sam Brody, Director, Center for Texas Beaches and Shores, Texas A&M Galveston
- Gavin Smith, Director, Coastal Resilience Center, UNC

12:15 PM – 1:15 PM
Lunch

1:15 PM – 1:35 PM
Open Mic 3

1:35 PM – 1:45 PM
Set up for Scenario Breakouts

1:45 PM – 3:45 PM
Scenario Session Breakout:
Applying our Discovery

In facilitated breakouts, participants will use real flood disasters to exercise how the technologies and methodologies discussed over the past day and a half could be integrated and influence the future activities and policies of functional areas associated with a disaster – response, recovery, planning and preparedness, mitigation.

PM Break
Breakout teams can work these into their discussion time

3:45 PM – 4:15 PM
“Hotwash” Day 2

4:30 PM – 6:30 PM
Show and Tell Social: Open networking opportunity for attendees to share more details about their research and experiences in smaller interactive groups.

DAY 3 • NOVEMBER 9

8:00 AM – 8:30 AM
Continental Breakfast

8:30 AM – 9:00 AM
Open Mic 4 (see separate list)

9:00 AM – 9:45 AM
Breakout Reports by Session Moderators (Technical and Scenario)

9:45 AM – 10:00 AM
Break

10:00 AM – 12 PM
Closing Session:
Facilitated capture of Colloquium

Moderator:
Sandra Knight, WaterWonks LLC

This important session will engage the participants to not only articulate the key ideas and actions from the Colloquium, but also offer participants the opportunity to share any new ideas and topics that have not been covered or stated. The session will help frame the proceedings and next steps to Rethinking Flood Analytics.

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39. Open Mic sessions – For these TED-style sessions, attendees can sign up in advance to present a five-minute snapshot of a leading-edge innovation or activity that could advance the way we think about analytics or disaster management.

APPENDIX B: COLLOQUIUM ATTENDEES

David Alexander
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John Cooper
Texas A&M University

Andrew Ditmore
IBM Global Business Services

John Dorman
North Carolina Department of Public Safety

Sandra Fatoric
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Elizabeth Frankenberg
University of North Carolina, Carolina Population Center

Tom Goren-Bar
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Maria Honeycutt
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Paul Huang
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Jerry Johnston
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Nadja Popovich
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Al Shaw
ProPublica, Inc.

David Smith
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Gavin Smith
University of North Carolina, Coastal Resilience Center of Excellence

Peter Stempel
University of Rhode Island

Cary Talbot
Engineer Research and Development Center, Coastal and Hydraulics Laboratory

Rebecca Tippett
University of North Carolina, Carolina Population Center

Lloyd Treinish
IBM, The Weather Company

Larry Weber
University of Iowa

Roy Wright
Federal Emergency Management Agency, Federal Insurance and Mitigation Administration

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Claire Tipton
Marc Webb
Darien Williams

A crumbled section of LA-10 near Clinton, Louisiana, one month after the 2016 historic flooding.

Photo by J.T. Blatty/FEMA