The South Carolina Deluge: Lessons from a Watershed Disaster

A Center for Resilience Studies Assessment

Stephen E. Flynn

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Intriago, Jorge, Tech. Sgt. A breached levee on the Columbia Riverfront Canal. U.S. Department of Agriculture Oct. 5, 2015. Web. 12 Aug. 2016 <https://www.flickr.com/photos/usdagov/21973557910/in/photostream/>; A breached dam in Orangeburg, SC. 15 Oct. 2015. Web. 12 Aug. 2016. <https://www.fema.gov/media-library/assets/images/110737#details>; Intriago, Jorge, Tech. Sgt. 151005-Z-XH297-024. U.S. Department of Agriculture. 5 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/22149047092/in/photostream/>; Johnson, Ryan. Flooded homes in North Charleston. City of North Charleston. 4 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/northcharleston/21352738444/in/photolist-ywSndQ-zcgCxj-zuLh5B-zuLEv8-zcoxfa-yx2daF-zcptik-zcoUdx-zcoHJg-zcpq1Z-ztUNRk-zuM9Fr-zcja1s-ztUbda-zchqqG-zci4rJ-zsPSzq-zcicQh-zsQ1T9-zcgx4y-zsQg6h-zciv33-zci8Is-ywS3bS-zciuYN-y>; Pavelek, Ashleigh, Airman 1st Class. Flooding at the Columbia Canal. U.S. Department of Agriculture. 6 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/21538869944>; Lehmann, Stephen, Petty Officer 1st Class. Aerial view of continued effects of flooding. 7 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/21973557240/in/album-72157659841034125/>; Johnson, Ryan. Submerged cars and flooded roads in North Charleston. City of North Charleston. 4 Oct. 2015. Web. 12 Aug. 2016 <https://www.flickr.com/photos/northcharleston/21787797118>; Lehmann, Stephen, Petty Officer 1st Class. Aerial view of flooded roads. 5 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/21538870634/in/photostream/>; Johnson, Ryan. Flooding in a residential area in North Charleston. City of North Charleston. 4 Oct. 2015. Web. 12 Aug. 2016 <https://www.flickr.com/photos/northcharleston/21787611508/in/photolist-ywSndQ-zcgCxj-zuLh5B-zuLEv8-zcoxfa-yx2daF-zcptik-zcoUdx-zcoHJg-zcpq1Z-ztUNRk-zuM9Fr-zcja1s-ztUbda-zchqqG-zci4rJ-zsPSzq-zcicQh-zsQ1T9-zcgx4y-zsQg6h-zciv33-zci8Is-ywS3bS-zciuYN-y>; Lehmann, Stephen, Petty Officer 1st Class. Aerial view from a Coast Guard helicopter of flooding in the Charleston area. U.S. Department of Agriculture. 5 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/21540578853/in/photostream/>; 151009-D-HQ914-031-2. U.S. Department of Agriculture. N.d. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/22135500006/in/photostream/>; Lehmann, Stephen, Petty Officer 1st Class. Aerial view of flooding in the Charleston area. 5 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/21973558890/in/photostream/>; Johnson, Ryan. Submerged car and residences in North Charleston. City of North Charleston. 4 Oct. 2015. Web. 12 Aug. 2016 <https://www.flickr.com/photos/northcharleston/21787595278/in/photolist-ywSndQ-zcgCxj-zuLh5B-zuLEv8-zcoxfa-yx2daF-zcptik-zcoUdx-zcoHJg-zcpq1Z-ztUNRk-zuM9Fr-zcja1s-ztUbda-zchqqG-zci4rJ-zsPSzq-zcicQh-zsQ1T9-zcgx4y-zsQg6h-zciv33-zci8Is-ywS3bS-zciuYN-y>; Lehmann, Stephen, Petty Officer 1st Class. 151007-G-BD687-515. US Department of Agriculture. 7 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/21538872324/in/album-72157659841034125/>); 151005-G-BD687-493. U.S. Department of Agriculture. 5 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/22149047532/in/photostream/>; 151005-G-BD687-499. U.S. Department of Agriculture. 5 Oct. 2015. Web. 12 Aug. 2016. <https://www.flickr.com/photos/usdagov/22149047292/in/photostream/>; Goddard, Connor. A home damaged during the October flooding. Center for Resilience Studies, Northeastern University. Dec. 2015. Web. 12 Aug. 2016; Johnson, Ryan. A flooded home in North Charleston. City of North Charleston. 4 Oct. 2015. Web. 12 Aug. 2016 <https://www.flickr.com/photos/northcharleston/21352674414/in/photolist-ywSndQ-zcgCxj-zuLh5B-zcoxfa-yx2daF-zcptik-zcoUdx-zcoHJg-zcpq1Z-ztUNRk-zuM9Fr-zcja1s-ztUbda-zchqqG-zci4rJ-zsPSzq-zcicQh-zsQ1T9-zcgx4y-zsQg6h-zciv33-zci8Is-ywS3bS-zciuYN-y>.

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Executive Summary

On October 4, 2015, the Midlands area of South Carolina (centered on metro Columbia and encompassing the counties of Richland, Lexington, and portions of Fairfield) received between 17 and 24 inches of rain in less than a 24-hour period.[1] Other regions of the state received amounts from 6 to 15 inches within the same period. This intense precipitation was preceded by several weeks of above average rainfall. The deluge on October 4 landed on already saturated soils, and riverine systems (i.e., reservoirs, lakes, impoundments, and their watershed networks) that were near or at capacity. The result was overtopping, dam failures, and historic flooding that damaged and disrupted critical infrastructure across the region, inundated 160,000 homes, and led to the loss of 19 lives.[2]

A core mission of the Center for Resilience Studies (CRS) at Northeastern University is to identify lessons that will advance building community and regional resilience by bringing together experts from across a number of academic disciplines in the aftermath of major disasters.

In the fall of 2015, Dr. Stephen Flynn, Director of the Center for Resilience Studies, identified an initial team with expertise in infrastructure resilience, community resilience, and water and transportation infrastructure engineering to study the October 2015 South Carolina historic flooding. In addition, Dr. Flynn reached out to Dr. Susan Cutter, Director of the University of South Carolina Hazards & Vulnerability Research Institute, to assist in analyzing and understanding the event. In a series of field visits to the region, he and his team conducted extensive agency and individual interviews, and developed a set of lessons that are readily transferrable to other jurisdictions that share a similar risk of watershed disasters. These include:

- ***Watersheds operate as a system of systems, but too often this reality is only recognized after a major flooding disaster***. Watersheds include natural and human-constructed waterways, the broader ecosystem, and built infrastructure such as roadways and water treatment facilities, along with impoundments, dams and other flood control measures. The component parts are owned and operated by private individuals, corporations, neighborhood associations and by local (town, city, and county), state, and federal entities. This fractionated ownership, sprawling across multiple jurisdictions, inevitably leads to blurred lines of responsibilities, as well as gaps in oversight that complicate system-wide management. Additionally, years of independent and uncoordinated decisions made in the normal course of civic development and planning often inadvertently end up compromising the integrity of the overall system. Under normal conditions, the system successfully manages the movement of water through the watershed with limited localized human interventions. However, during times of extreme precipitation, the cumulative effect of independent local decisions can lead to flood waters

moving in novel and unanticipated ways, contributing to cascading failures that can impact multiple and interdependent infrastructure sectors over a wide geographic region. Accordingly, assuring the resilience of the infrastructure located in and around a watershed requires a coordinated system of governance of watersheds.

- ***The need for greater public awareness and ongoing oversight of dams and impoundments to keep pace with the growing risk of major flooding events.*** Similarly, more attention needs to be directed at commercial and residential development practices that impact local storm water runoff.

- ***Disaster affected counties and municipalities often have difficulty obtaining a comprehensive understanding of the extent of damage to infrastructure so as to prioritize recovery planning that supports areas of greatest need.*** In some cases, it is only possible to safely access transportation infrastructure[3], agriculture[4], forestry[5] and housing[6] to carry out damage assessments several weeks after a storm. In South Carolina, bridge abutment scouring that required the closing of the associated roadways was only discovered several months after the deluge.[7] Overall damage to agriculture could not be determined until the winter crop harvest and spring planting in 2016. Additionally, when an expedited Major Disaster Declaration is made by the president as it was on October 5, 2015,[8] one unintended consequence is that it can weaken the incentive for states and localities to diligently undertake the preliminary damage assessment that is normally required to obtain such a declaration.

- ***Decision makers and key stakeholders need access to better information and visualization tools that advance an understanding of complex watershed interdependencies and how they can be best managed.*** Overall, disaster recovery planning and operations should be supported by standing and coordinated capabilities at the federal, state and local levels that are put in place *before* disasters strike. A disaster response effort without a complimentary recovery focus inhibits the effective allocation of resources, elevates the risk of misunderstandings, and compromises the ability to take the kinds of decisive actions across multiple levels of government that recovering from a major disaster requires.

- ***Whereas tornados or earthquakes have clearly defined beginnings and endings, climate events such as extreme precipitation or drought can be spread over a region for an extended period of time.*** This reality challenges the ability for states to meet the deadlines set by a number of federal "clocks" that are triggered once the president issues a Major Disaster Declaration. This includes such things as the federal reimbursement rates for debris removal and the timing for disengagement by federal disaster relief personnel to include the Federal Coordinating Officer.[9]

- ***Traditionally, programs that support mitigation, response, and recovery have been managed separately at the federal and state levels, which can create challenges for***

bolstering resilience. For example, FEMA's processes and organization remain primarily focused on responding to the near-term life-safety imperatives associated with a disaster such as providing emergency supplies and temporary shelter to survivors.[10] Meanwhile, the Department of Housing and Urban Development's (HUD) complex processes[11] can take months and even years to navigate before disaster assistance is finally dispersed. In general, federal processes need to be recalibrated to better support the goal of having communities build back smarter and better. Additionally, federal protocols should be adjusted to create more opportunity for state and local officials to provide input on how federal disaster assistance can best be applied towards meeting resilience imperatives.
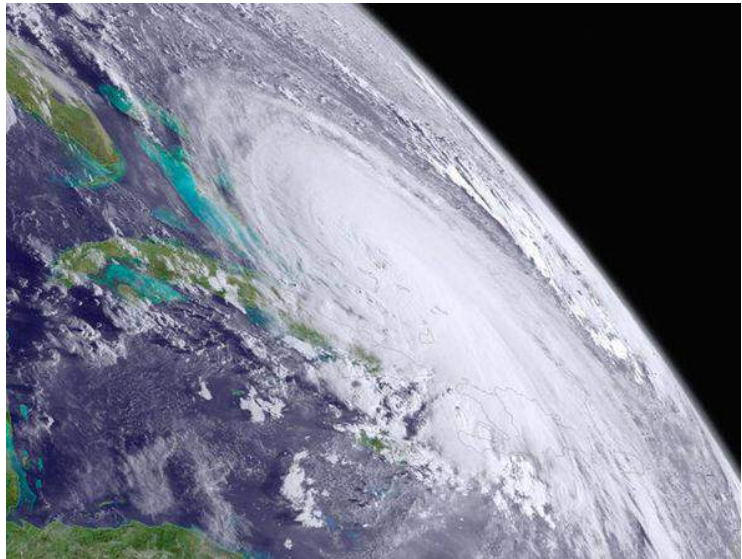
- ***Recovery and resilience planning at city, state, and regional levels would benefit from active dialogue and close cooperation with the academic community.*** As demonstrated by this report, academic institutions such as Northeastern University and the University of South Carolina offer access to research that can helpfully inform the disaster recovery process. In a disaster, local universities are also a part of the impacted community; they provide housing for thousands of students and are deeply embedded into local and regional economies. They thus have a direct interest in partnering with local and state decision makers to support response and recovery efforts. Building relationships between major academic institutions and practitioners ahead of a disaster is crucial to capitalizing on the unique capabilities that students, faculty, researchers, and administrators from academic institutions can provide to their communities.

In the months following the October 2015 floods that devastated the Midlands area of South Carolina and prior to the completion of this report, heavy rains and flash flooding led to loss of lives and substantial damage to property and infrastructure in Northern California; Houston and Harris County, Texas; Biloxi and Gulfport, Mississippi; Southern Oklahoma; West Virginia; Howard County, Maryland; Northern Wisconsin; and southern Louisiana. These events validate the widespread national need for examining the findings and embracing the recommendations for building greater resilience within regional watershed systems that are identified in this report.

Incident Description

The weather on Monday September 28, 2015 in Columbia, South Carolina was unpleasant, but not unusual. It was a muggy, rainy day, described by the Columbia CBS News affiliate Twitter account as "#blah."[12] There was little indication that the cold front making its way over the Northern Plains would eventually stall just off the Carolina coast, or that its associated areas of high and low pressure would form in such a way to draw a long fetch of extreme moisture in from the Atlantic. And it wasn't until 11pm this Monday that the brewing, primary source of this extreme moisture would be given a name: Tropical Storm Joaquin.[13] The collision of these weather systems

A satellite image of Hurricane Joaquin as it passes over the Caribbean islands on its way towards the American East Coast (Source: Fox 31 Denver)

was still days away, as was the deluge that would break Columbia's record precipitation totals and put to the test South Carolina's and the U.S. government's policies, procedures, relationships and authorities for responding to and recovering from a watershed disaster.
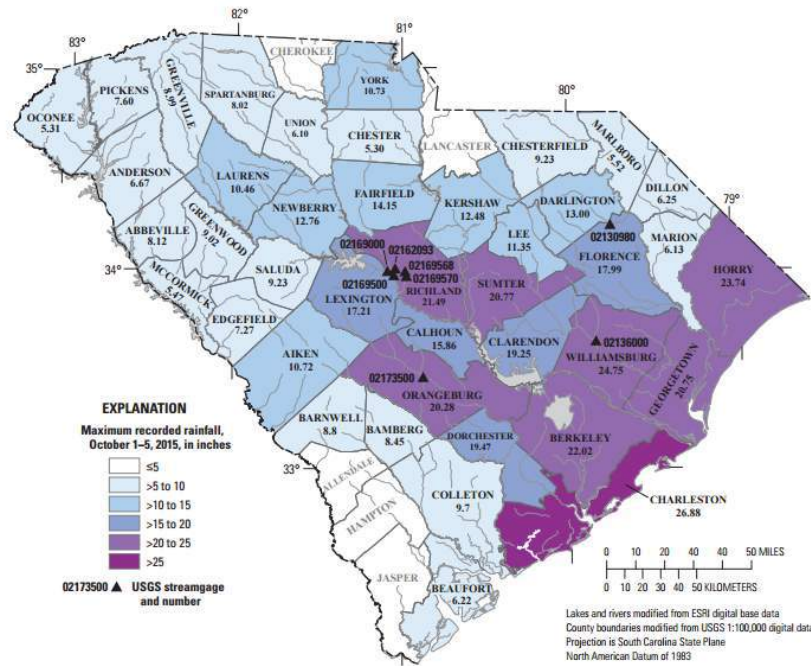
The Low-Pressure System and Hurricane Joaquin

A cold front and low-pressure system moving in from the west that bring rains to South Carolina is a common weather occurrence. South Carolinians also have to be prepared for the periodic risk of hurricanes coming up the Atlantic Coast. But in early October 2015, these two weather events would converge in a unique way. The low pressure system – a region where air and water vapor is drawn up into the atmosphere to condense and often precipitate – slowed down as it passed over South Carolina, and came to a virtual standstill on October 3. It was moving so slowly that not only did it produce persistent heavy precipitation itself, but was also able to siphon moisture from the off-shore Hurricane Joaquin and redirect it toward the coast for a prolonged period of time.[14] [15]

Over the first five days of October, eleven counties would break the five-day state rainfall record of 17.44 inches, set during the Record Flood of 1908.[16] Twenty-one of the state's 46 counties received rainfall totals in the double digits. According to one National Weather Service measurement, Charleston received just shy of 27 inches of rain.[17] The record breaking rainfall totals were described as the equivalent of getting "six months' worth of rain in two days."[18] By October 10, the downpour and

Rainfall totals by county in South Carolina for October 1-5, 2015 (Source: U.S. Geological Survey)

resulting flooding had submerged neighborhoods, businesses, and critical infrastructure and had killed 19 people.[19] Even when the clouds finally parted late on October 5, the "storm" was far from over for South Carolinians as preliminary estimates totaled $1.5 billion in damages across the state.[20]

Timeline of Events: October 1-5, 2015

On October 1, Governor Nikki Haley declared a State of Emergency and on the following day urged South Carolinians to stay home and take time to prepare for the oncoming storm of "historic proportions."[21] By this time, the National Weather Service's Global Forecast System was predicting three-day (October 2 to 5) rainfall totals of 15 to 20 inches in parts of the state, with even the more conservative models showing totals above 13 inches.[22] That same day, South Carolina's Emergency Management Division (SCEMD) raised the state's operational condition to Level 3 (of 5), meaning "a disaster or emergency situation is likely," and said that one flood-related death had already been confirmed in the Upstate, an ominous sign for downstream residents who were nervously waiting in the southeastern part of the state.[23] Over 200 National Guard soldiers and airmen were activated to begin support missions, including the transportation of sandbags and fuel, before the brunt of the storm hit.[24]

On October 4 alone, 17.72 inches of rain poured down on the city of Columbia,[25] making it the wettest day in the city's history.[26] Fifteen inches, enough to break the previous 24-hour state

rainfall record, fell in just ten hours.[27] The Congaree River, which flows through Columbia, rose to 31.8 feet and recorded a peak flow of 185,000 cubic feet of water – the equivalent of two Olympic-sized swimming pools surging by every second.[28] The coast would not be spared from the heaviest rainfall; by the afternoon, Kingstree had recorded 15.7 inches of rain and Charleston had recorded 13 inches.[29]

Throughout the state, almost 30,000 residents lost power.[30] Five people had already been reported dead as a direct result of the storm[31] and rain was still falling. Fifteen counties had raised their operational conditions to the highest Level 1, meaning a "major disaster or emergency situation [was] in effect,"[32] and ten counties and municipalities announced that they were in States of Emergency. Eight had initiated curfews.[33] In just one 12-hour period, 750 motorists requested emergency assistance and 315 collisions occurred.[34] According to Columbia Fire Chief Aubry Jenkins, there were too many water rescues to accurately keep count, but some officials put the number at several hundred by mid-morning alone.[35]

A South Carolina woman walks down a flooded road as heavy rains continue to fall. (Source: Reuters via WSPA News)

That same day, October 4, the deluge prompted the morning failure of the Cary Lake Dam. Downstream the Pine Tree Lake and Semmes Lake Dams were destroyed by the torrent of water, resulting in the inundation of the Gills Creek Watershed,[36] one of the most densely populated areas of Columbia.[37] The Pine Tree Lake Dam alone is estimated to have released 16 million gallons' worth of water.[38] Two more dams in the Gills Creek Watershed failed: the Upper Rockyford Lake and Rockyford Lake Dams.[39] The 125-foot Columbia Canal succumbed as well with a 60-foot portion of its levee collapsing that morning, contributing to a water shortage for the city.[40]

The City of Columbia experienced several water main breaks, leaving many residents without water.[41] When people did have access to water, it was likely not potable due to these breaks and "historically difficult conditions" (it was underwater) at the Canal Water Treatment Plant, which serves nearly 190,000 people.[42] The city issued a city-wide boil water advisory which would not be repealed in full until ten days later, on October 14.[43] Bottled water distribution sites, staffed by the National Guard, were set up alongside potable water stations later that day for the public and continued operation for several days.[44]

A water treatment facility in Columbia, SC is engulfed in floodwater. (Source: Congaree Riverkeeper via WIS-TV)

The Metropolitan Wastewater Treatment Plant, Columbia's only major sewage plant, was also inundated with floodwaters. The plant was also compromised by numerous power outages caused by flooding that reduced the plant's ability to recover and limited its operating capacity.[45] It would not become fully operational again until October 8.[46]

On Monday, October 5, Governor Nikki Haley spoke with President Obama by phone and made the request for an expedited Major Disaster Declaration and for emergency federal support. Having waived the need for a preliminary damage assessment as required by the Robert T. Stafford Act, President Barack Obama issued the declaration the same day.[47] Residents of eight South Carolina counties were then allowed to apply directly for federal resources, and an additional three counties could access funding meant for local governments and private nonprofits.[48] Additionally, over 1,300 members of the National Guard were deployed to assist emergency response personnel.[49]

On the day of her request, Governor Haley reported that 40,000 people were still without drinkable water and that 26,000 homes were still left in the dark by sustained power outages.[50] Most tragically, ten people had died in their cars as the victims of flash floods.[51]

Impacts

In total, the rains and associated flooding led to the closure of over 500 roads and bridges and the failure of 36 dams throughout the state.[52]
Directly following the worst of the storm, 425 state Department of Transportation (SCDOT) workers commenced transit infrastructure repairs. Twenty days later nearly 76 percent of initially-closed bridges and roads had been reopened.[53] By November 25, the total number of closures had dropped to 69.[54] By December, the SCDOT estimated that bridge and road repairs would cost $137 million, $49 million of which the state would bear.[55] But 23 roads in Richland County, effecting 14,000 motorists, remained closed because they once ran over private dams whose owners were unable or reluctant to complete the costly repairs.[56] It is unclear when these roads will be restored since the SCDOT lacks the authority to undertake repairs to private property.[57] Dam owners are usually not eligible for Federal Emergency Management Agency (FEMA) assistance, nor are they covered by private insurance[58] leaving many owners unsure how they can raise the $300,000 to $1 million it costs to reconstruct a

dam to "today's standards."[59] Some dam owners are hoping to obtain federal assistance, arguing their dams provide public services.[60] Meanwhile, businesses, such as local gas stations, which relied on a consistent daily volume of traffic, have suffered from the detours. One gas station owner reported a 90% drop in business because of the Lake Elizabeth Dam failure.[61]

The rain event, and the related dam failures, caused $741 million in damage to nearly 160,000 homes.[62] Of the 101,600 individuals and households that applied for disaster relief funding from FEMA, just over 27,000 of them shared $83.9 million in aid for an average of just under $3,100 per applicant.[63] In December, Governor Haley requested $140 million from the U.S. Department of Housing and Urban Development (HUD) to repair 2,600 flood-damaged properties owned by low- and moderate-income families.[64] HUD responded by allocating $157 million for unmet needs related to housing, economic development, and infrastructure.[65] The grantees — the City of Columbia, Lexington County, Richland County, and the State of South Carolina — have been promised funding for about 76 percent of their unmet needs, or nearly $20 million for Columbia, $16.3 million for Lexington County, $23.5 million for Richland County, and $96.8 million for the state.[66]

Of the dams that failed, thirty-one were state regulated and therefore fell under the oversight of the Department of Health and Environmental Control (DHEC) dam safety program.[67] Years of tight state budgets had left the dam regulation program with limited resources and staff prior to the October deluge. South Carolina devoted approximately $104 annually per regulated dam, or roughly 17 percent of the national average of $610.[68] When the October rains fell, the organization had a total workforce of less than seven full-time employees,[69] each of whom was responsible for approximately 360 of the state's 2,400 regulated dams. In the past, DHEC had assigned some its food inspectors to help complete routine dam inspections.[70] Further, in 2014, only 63 percent of the state's scheduled inspections for its 180 high hazard dams had been completed.[71]

Floodwaters destroyed many roadways by eroding the land underneath (Source: AP/Chuck Burton via Weather.com)

Farmers were also heavily impacted by the October flooding event. Direct flood-related crop damages totaled about $329 million with another $46 million lost when too-wet soil prevented winter plantings.[72] William Hardee, affiliated with Clemson University, commented, "Just about every crop was a failure. Usually one crop will pull you through. This year, a lot of people lost money on everything."[73] Harry Ott, State Farm Bureau President, agreed, estimating that only 20 to 25 percent of the season's crops made it to market.[74] Ott estimates that insurance will only cover one-third of the over $375 million in crop-related losses.[75] To address this, the South Carolina Legislature passed (overriding a veto by the Governor to do so) the Farm Aid Fund that appropriated $40 million from the state's Contingency Reserve Fund to farmers who experienced at least a 40 percent loss in their agricultural commodities due to the flood.[76] The grants can cover 20 percent of a farmer's loss, up to $100,000.[77]

Many fields, like this soybean crop in Sumter county, remained saturated months after the flood (Source: Hannah Mikell via Union Daily Times)

In the aftermath of the October floods, the South Carolina State Legislature appropriated nearly $600,000 to double DHEC's dam safety personnel. However, concerns remain over the adequacy of oversight for a number of unregulated dams throughout South Carolina. Former dam safety director Steve Bradley estimates that over 1,000 additional dams should be regulated by the state, but the associated staffing and resource implications of doing so was deterring the expansion of the inventory of dams that fall under DHEC oversight.[78] One measure that included updates to these regulations, the Dams and Reservoirs Safety Act, was introduced to the South Carolina State Legislature in January 2016 and sparked hours of debate, but ultimately never made it out of committee.[79]

In the end, the historic rainfall that inundated the state of South Carolina in early October 2015, revealed the kind of longstanding shortcomings in watershed management practices that are commonplace throughout much of the United States. The tangled web of ownership and oversight of key assets translated into interdependencies and the associated likelihood of cascading failures being inadequately understood prior to the floods. Public and private underinvestment in flood control measures and oversight elevated the risk. Further, while the floodwaters have now long since receded, much work remains to be done towards making the kinds of changes that will bolster the resilience of the effected communities and infrastructure systems so as to better mitigate the disruption and destruction that future storms will almost certainly bring.

Findings and Recommendations

Finding 1

Assuring the resilience of the infrastructure systems located in and around watersheds requires a coordinated system of watershed governance. Watersheds span multiple jurisdictions and involve privately owned and operated as well as publically owned and operated infrastructure systems. The resultant fractured ownership can translate into uncoordinated oversight which in turn leads to gaps and blurred lines of responsibility that undermines effective management.
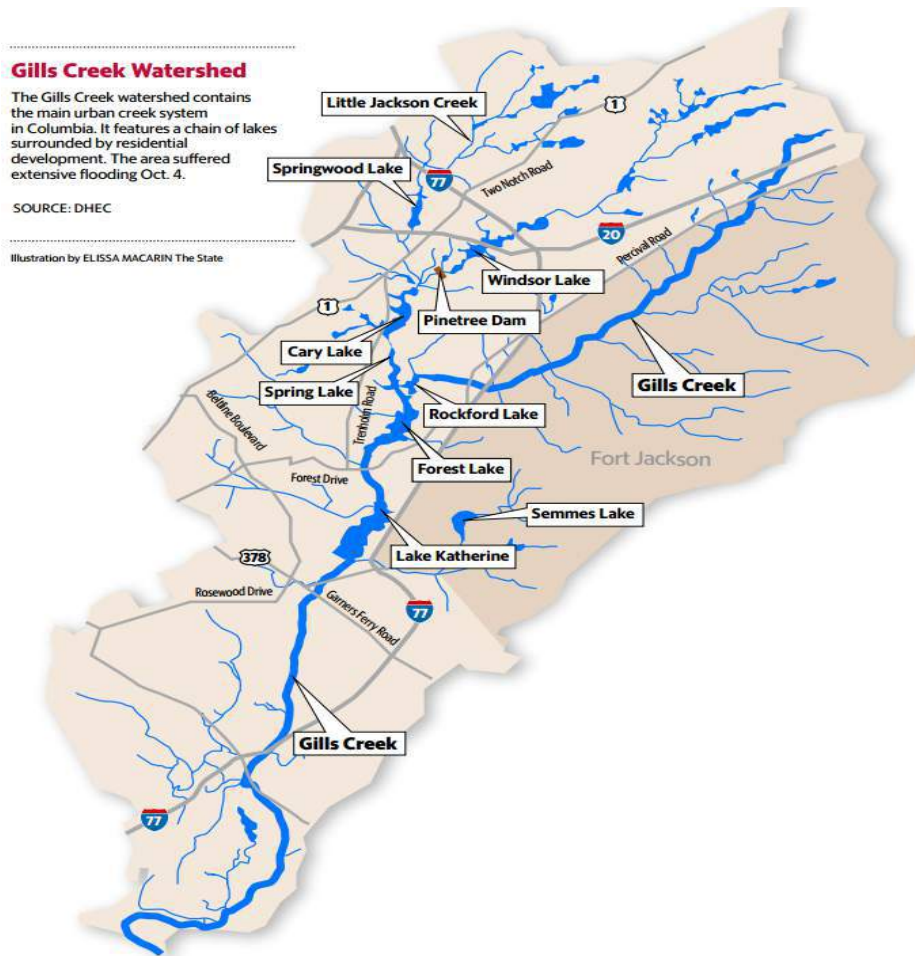
A System of Systems

Watersheds typically include natural- and human-constructed waterways, the broader ecosystem, human-created built infrastructure, and impoundments, dams and other flood control measures. The ownership and operation of the component parts rests with private individuals, corporations, and neighborhood associations as well as with local (town, city, and county), state, and federal entities, spanning multiple jurisdictions. This translates into fractured ownership and oversight which generates gaps and blurred lines of responsibilities that complicate system-wide management. Additionally, years of independent and uncoordinated decisions made in the normal course of civic development and planning inadvertently affect the integrity of the overall watershed infrastructure. In normal times, the system successfully manages the movement of water through the watershed with limited localized human interventions. However, during times of extreme precipitation, the cumulative effect of independent local decisions can end up contributing to cascading failures that can impact multiple and interdependent infrastructure sectors over a wide geographic region. Accordingly, assuring the resilience of the infrastructure located in and around a watershed requires coordinated governance that is capable of managing watersheds as a system of systems.

The Gills Creek Watershed

The Center for Resilience Studies team focused on the Gills Creek Watershed as an example of the kinds of challenges that can be generated by an extreme rain event. In South Carolina, there are 6 to 14 watersheds in any given county.[80] The Gills Creek Watershed in the eastern part of Columbia covers a 75 square-mile area that includes the U.S. Army installation of Fort Jackson.[81] The watershed begins in unincorporated upper Richland County, moves through one, then another incorporated township, receives a tributary from Fort Jackson, flows through the City of Columbia proper, and then back into unincorporated Richland county before if finally discharges into the Congaree River.[82] Along the way it involves over 100 impoundments (e.g., private recreational lakes and agricultural ponds) and associated water management infrastructure systems (e.g., storm water run-off systems)[83] operated by the federal, state, county, and local governments as well as private homeowners and companies.[84] During the October 2015 flooding event, the area experienced the failure of several dams on lakes and

smaller impoundments which exacerbated the flooding from the prolonged rain event and caused severe damage to both public and private infrastructure.

Gills Creek Watershed

The Gills Creek watershed contains the main urban creek system in Columbia. It features a chain of lakes surrounded by residential development. The area suffered extensive flooding Oct. 4.

SOURCE: DHEC

Illustration by ELISSA MACARIN The State

Little Jackson Creek

Springwood Lake

Two Notch Road

Percival Road

Windsor Lake

Pinetree Dam

Cary Lake

Spring Lake

Gills Creek

Rockford Lake

Forest Drive

Forest Lake

Fort Jackson

Semmes Lake

Lake Katherine

Rosewood Drive

Garners Ferry Road

Gills Creek

Gills Creek Watershed (Source: Elissa Macarin, The State)

The watershed contains both highly developed (housing and commercial) and significantly undeveloped (Fort Jackson) land usage. Those parts of the watershed that are developed include significant areas of impermeable surfaces. Before the flooding event, the focus of watershed activity, both public and private, was on water quality (e.g., "green" projects), but comparatively little attention was given to coordinated storm water management and flood control across the watershed system.[85] Most of the water impoundments within the watershed were not originally created as flood control measures, but rather as a means to create artificial lakes around which developers built homes. Continuing economic development and revitalization in the area has been marked in some cases by developers who sought to exploit regulatory and zoning loopholes that minimize their costs of complying with current water management (e.g., storm water run-off) codes. For instance, local officials cited redevelopment of a large shopping center that managed to avoid, through "grandfather provisions," the mandated creation of absorption areas around impermeable surfaces. Several older developments, both of housing and commercial space, were built on highly vulnerable flood plains.[86]

FEMA flood maps turned out to have provided accurate predictions of the flooding in the watershed.[87] Yet these predictions had no noticeable effect on local planning or development prior to the October 2015 flooding. FEMA predicted that the dams in the Gills Creek watershed area would fail in a 50-year flood event.[88] Many did, and officials were still dealing

with these failures up to 3 weeks after the rain event.[89] Had the Lake Katherine dam (the lowest and one of the largest in the watershed) failed, the damage to the area would have been potentially catastrophic.[90]

In South Carolina, the maintenance and management of dams are the responsibility of dam owners. Most South Carolina dams are privately owned and operated. Regulation of dams is the responsibility of the South Carolina Department of Health and Environmental Control (DHEC). State law allows DHEC to take action, such as orders for inspection, repair, or maintenance, paid for at the owner's expense, if the owner is not maintaining the regulated dam. Fines can be levied on dam owners who do not comply with these orders.[91] Enforcement is difficult, however, as DHEC has very limited staff to support its oversight role. Legislation introduced in the 2016 South Carolina legislative session to increase the oversight and enforcement of private dam owner responsibility failed, in part, because some legislators were concerned it would place an undue burden on private owners particularly in the agricultural sector.[92]

A resident of a nearby home looks at the destruction caused by the Arcadia Lakes dam failure (Source: Matt Walsh)

DHEC does not regulate storm water runoff at the state level. That responsibility lies with cities and municipalities. When a watershed transects an incorporated city or town, there is a gap in the management of storm water runoff from that municipality into the watershed. As a practical matter, this situation renders it nearly impossible to understand and plan for the cumulative impact to any watershed caused by urban storm water run-off. There are provisions in state law that authorize local governments to put in place watershed ordinances when they can substantiate that failure to do so would increase flooding problems.[93] However, localities may be extremely reluctant to take advantage of this capability because of its potential impact on economic development.

South Carolina is struggling in the aftermath of the October 2015 flood with handling the interdependency issues of watershed infrastructure management. The recovery of the transportation system has been significantly affected by the ambiguity of responsibility for roads that cross dams, particularly unregulated dams. The South Carolina Department of Transportation (SCDOT) has easements over a large number of dams most of which are privately owned. Twenty-six roads over dams were lost, and as late as May 2016, seven of these were still not back in service because of disputes over who was responsible for making repairs. Seven of the original 26 dams were unregulated.[94] One supported a primary

transportation route. Authorities continue to be concerned about the continued saturation of embankments caused by rivers and streams that remained at flood stage for long periods of time after the October 2015 record rainfalls.[95] These include the potential damage associated with water scouring of bridge abutments. SCDOT officials clearly expressed a need for better flood and inundation models, particularly models tied to extreme rainfall and water impoundment failure. Similarly-situated communities learning from South Carolina's experience need to consider taking the time in advance to ensure that the inundation maps they plan from are tied to the elevation of roads and bridges. SCDOT identified as a challenge the difficulty of understanding widespread regional flooding to include the impact of water moving from midlands areas of the state to the lowlands near the South Carolina coast.

South Carolina Emergency Management Department (SCEMD) struggled to gather information about potential flooding prior to the storm and in determining actual flooding during the storm. Better models would help. There were also insufficient dam experts to call on before and during a storm event to help anticipate likely dam failures and for undertaking damage assessments. The *Hazus* predictive tool did not work well largely because of the magnitude and duration of the rain event. Inundation maps do not provide officials with information about how much water is coming and how fast that water will be moving. Emergency managers were often not adequately aware of the dams within their areas or of the potential effects of dam failures. For South Carolina, there was no way for an emergency manager to know if and when a dam may fail. In the aftermath of the October 2015 rains, emergency managers recognized that they would have benefitted from a comprehensive means for better understanding and monitoring of watersheds as an infrastructure system to include how that system can fail and cause catastrophic losses.

Recommendations

- **Municipalities** should cooperate to create regional watershed governance organizations empowered with adequate authority and sufficient resources to effectively understand and manage the watershed. A regional approach is required because the boundaries of watersheds often cross the boundaries of multiple jurisdictions.

- **Municipalities** should provide watershed management educational programs for relevant public employees, regional leaders, private businesses and the general population. Examples of existing watershed education programs that can inform the development of these programs include the Watershed Education Network (www.montanawatershed.org); the Watershed Education Center (www.learnnc.org); and the Water Education Program (www.wildlife.state.nh.us/education/watershed/).

- **State legislatures** should provide enabling legislation that allows for the creation of flexible, regional watershed governance organizations, and consider providing tax or other incentives to participants.

- **State governments** should reexamine the criteria under which dams are regulated and the policies for public use (e.g. roadways) of private dams.

- **The Department of Homeland Security** should task its Directorate of Science and Technology to support the development of models for effective watershed governance.

Finding 2

The tension between being responsive to local and private interests versus the requirements of a holistic approach to regional watershed management can compromise effective post-disaster recovery and adaptation if not effectively managed.

An important challenge associated with the fact that watershed systems often involve multiple jurisdictions and owners, is managing the tendency for local and private interests to prevail over broader watershed management imperatives. Local governance inevitably assigns a higher priority to responding to localized needs, even if they are counter to overall system wide objectives. At the same time, the failure to satisfactorily address localized needs may contribute to adverse system-wide consequences.

These homes on Lake Katherine were surrounded by floodwaters. (Source: Churck Burton/AP via ABCNews)

In South Carolina, private home owners and local tax districts reaped the benefits of developing waterfront properties made possible by constructing impoundments to create artificial lakes. Several of the Gills Creek neighborhoods (Lake Katherine, Acadia Lakes for example) represent some of the highest tax districts in Columbia and Richland County. Because the responsibility for maintaining these impoundments rests with private owners, typically in the form of homeowner's associations, repairing damages in the aftermath of a storm becomes dependent on the available resources and timetables determined by these property owners. If, through negotiated easements, public roads have been constructed on these impoundments, restoring the roadways becomes dependent on the private owners being willing and able to underwrite repairs[*]. Additionally, if the artificial lakes cannot be restored, the neighborhoods take a precipitous and immediate loss in value due to the loss of

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[*] South Carolina's Department of Transportation (SCDOT) will not rebuild a road over a dam (regulated or not) until an engineer has certified that the dam meets appropriate structural standards. DHEC has a process for allowing the private owner to abandon a privately-owned dam, but the process is expensive and many owners cannot afford either abandonment or repair. Owners are also reluctant to abandon a dam and forego the possibility that economic conditions may make repairs attractive in the future. Some owners have taken the position that the state has been using the road easement over their private dam for years at no cost. Absent some economic incentive, they have little interest in repairing a dam simply so that a state road may be rebuilt. In many cases it would be more cost effective for SCDOT to repair the dam and rebuild the road at state expense. However, that leaves SCDOT with the responsibility and liability of maintaining the dam as well as the road and brings into question the use of public funds that may also be supporting private purposes.

waterfront property. This not only causes financial hardship on private owners, but depresses the tax base on which a community depends for paying for schools and other public services.

The tension associated with being responsive to local needs while addressing system wide imperatives is also reflected in how communities approach storm water management considerations in the aftermath of a storm. The common impulse is to simply repair damages or to restore a structure to its pre-existing condition. However, future storms that may once again overwhelm watershed infrastructures are inevitable. Ideally, when rebuilding recreational lakes and farm impoundments, investments in stronger mitigation measures to reduce the risk of overtopping or dam failure should be made, particularly if public funds are being used to support restoration. Proactive local ordinances, development codes, or dam regulations should be enacted to support more robust storm management capabilities especially for new construction. However, local officials and state legislators are often reluctant to impose requirements which may result in private owners incurring short-term additional costs even if these requirements would help to advance the larger public good of more effectively managing the watershed as a system over the long run.

Comparable tensions are associated with flood impacts on water impoundments in the agricultural community. Similar to dams used in constructing artificial lakes within suburban areas, the original purpose for constructing rural impoundments is usually not to support watershed flood control. Instead, farmers use the impoundments to meet agricultural needs for irrigation and livestock watering. But they may end up assuming a flood control role if homes are built on neighboring lands.   If, as is the case in South Carolina, there is no requirement for developers to obtain clearance from anyone before building/developing downstream of an agricultural dam or impoundment, then the housing development ends up elevating the liability exposure of the upstream farmers who are responsible for maintaining these structures.

Equitably balancing the responsibility for liability and costs associated with structures that end up playing a storm water management role during extreme precipitation events requires a means to adjudicate localized rules and practices. Efforts to encourage land development and respond to property owners' desire for minimal regulation must be weighed against transferring the resultant risks and their associated costs to other parties including the general public. One such mechanism, for at least empowering property owners to better manage their shared risk at the neighborhood level, is the use of special tax district designations. Such designations are permitted under certain South Carolina Home Rule authorities. Impacted neighborhoods may petition to have a special tax district established for purposes of repairing the dam. If the required number of signatures (determined based on the locale population) is achieved, then a referendum is held on whether the residents are willing to tax themselves for purposes of investing in mitigation measures and financing dam restoration in the event of flood damage.

Recommendations

- **Local officials** should establish or expand the use of special tax districts for neighborhoods built around artificial lakes as a means for financing major improvements and repairs where both public goods and private interests are involved.

- **Local officials** that share a common watershed should work collaboratively in implementing and enforcing ordinances that are consistent with recommended model storm water management codes.

- **States** should regulate dams that impact the safe use of public roadways, bridges, and downstream critical infrastructure.

- **FEMA,** in coordination with other relevant federal agencies, should provide grant opportunities that support the development of model governance mechanisms that advance comprehensive regional watershed management.

Finding 3

Federal processes related to disasters are complex and have generally separated the management of programs for advancing mitigation, response, and recovery. This has created a very challenging bureaucratic environment for state and local officials to navigate, particularly with respect to moving from disaster response to long-term recovery and adaptation.

Disaster recovery planning and operations require standing and coordinated capabilities at the federal, state and local levels that should be in place before disasters strike. A disaster response effort without a complimentary recovery focus inhibits the effective allocation of resources, elevates the risk of misunderstandings, and compromises the ability to take the kinds of decisive actions across multiple levels of government that recovering from a major disaster requires.

In the aftermath of the October 2015 floods, South Carolina Governor Nikki Haley established a state recovery office overseen by a cabinet level official, Colonel Kevin Shwedo, that answered directly to her. The office was charged with directing the state government's energies toward the recovery of its people, places, and functions. Prior to October floods, the recovery mission was lodged within the South Carolina Emergency Management Division (SCEMD), essentially mirroring the approach at the federal level where FEMA has the lead for managing the federal recovery effort. However, also like FEMA, SCEMD's primary focus is on emergency response to include meeting post-disaster life-safety imperatives and restoring essential services as quickly as possible.

The new state recovery office, while effective, found itself on a steep learning curve when it came to developing a working understanding of the federal government's complex recovery protocols. Additionally, it had to navigate the inevitable tensions arising from the pressure to devote all available resources to support time-sensitive actions for short-term recovery needs, with investing in planning and programs that are supportive of long-term state recovery. This challenge was complicated by two unintended consequences of the state receiving an expedited Major Disaster Declaration from the Obama Administration.

Governor Nikki Haley speaks with President Barack Obama on Monday, October 5, 2015 (Source: @RobGodfrey/Twitter via South Carolina Radio

Traditionally, a state has had to conduct a post-disaster damage assessment in order to establish the basis for receiving a Major Disaster Declaration. This can take many days, or even weeks to complete. Under the expedited process, the state preemptively requests and the White House issues a declaration so as to authorize the rapid mobilization and early deployment of federal resources to support the disaster response. The working assumption is that the damages will almost certainly turn out to be extensive enough to qualify for a Major Disaster Declaration so issuing it right away can help speed up the flow of federal assistance to support the efforts of state and local emergency responders. But this new protocol has a downside since it removes one of the primary incentives for the state and local jurisdictions to nimbly carry out a comprehensive post-disaster damage assessment.

For South Carolina, along with its disaster affected counties and municipalities tasked with recovery, the assessment of damage to transportation infrastructure[96], agriculture[97], forestry[98] and in some cases, housing[99] was only assessable months after the flood waters receded. As late as April 2016, additional bridges and associated roadways were closed after discovery of bridge abutment scouring.[100] Overall damage to agriculture could not be determined until the winter crop harvest and spring planting in 2016.[101] In the first few days after a disaster, the damage assessment is often not sufficiently developed to make appropriate resource allocation decisions.

Meanwhile, the early presidential Major Disaster Declaration began a number of federal clocks to include the Federal Coordinating Officer's disengagement timelines. Specifically, reimbursement rates for debris removal are scaled to time – the federal government will provide a higher rate of reimbursement to a state for debris removed within 30 days of a disaster, a lower rate within 60 days and a still lower rate after 90 days.[102] While tornados or earthquakes have clearly defined beginnings and endings for which the current timelines may be appropriate, climate events such as extreme precipitation or drought can be spread over a region for an extended period of time. As such, the disaster effects may be slower developing and take longer to identify.

In most instances, individual claims for assistance to FEMA do not produce a holistic assessment of damage and only account for the cost of restoration to a "safe and sanitary" condition. So, despite federal clocks having begun, South Carolina officials initially lacked a comprehensive picture of the damage, and state agencies reported difficulties making decisions about the effective allocation of recovery resources.

South Carolina officials expressed some frustration with FEMA's post-disaster disengagement timetable. FEMA understandably has to be careful about not being overcommitted in providing direct support to any one impacted location. With an average of over 100 federal disaster declarations each year over the past decade,[103] FEMA must be ready to deploy to the next disaster, to include having the means to support the rarer and truly catastrophic events. Alternatively, it is appropriate for state and local officials to possess a longer view that focuses on full recovery and how to rebuild back better and smarter. A clear challenge for better

managing this tension is the fact that many states and most localities do not have a standing and dedicated planning process supported by trained personnel for managing long-term disaster recovery. This translates into their trying to identify people and putting these recovery management frameworks together only after the disaster has occurred. By the time this happens, FEMA may be well along their direct-support drawdown timetable.

Assessing damages to the agriculture sector was particularly challenging to accomplish within a short time frame. Damage occurred to crops in the field not yet harvested, as well as winter crops planted for spring harvest. In the spring planting season, some areas remained too wet for planting. Assessing and recovering agriculture is a months or years-long process. Crop insurance is specifically not intended to cover disaster. This fact was not well recognized by many officials within the state government. Federal disaster aid cannot be used for direct payments to farmers to cover agricultural losses under current national farm legislation. Some agricultural loss (and particularly forest products loss) was also caused by damage to the transportation system and the subsequent inability to get product to market or workers to logging sites[104]

After the storms, two peanut farmers assess the damage to their crops in a saturated field. The farmer said he expects to lose 75% of his crop (Source: Adam Beam/AP via South Carolina Radio Network)

FEMA's current processes and organizational design place primary emphasis on addressing post-disaster life-safety issues to include an established timetable for drawing down direct support and withdrawing personnel who are deployed for a federal disaster declaration. Just when state and local officials start to focus on recovery, there is typically a precipitous drop off in FEMA support. Additionally, up until 2013, in managing post-disaster federal funding authorized by the Stafford Act, FEMA was only allowed to authorize repairs that restore structures to their pre-existing conditions. The FEMA oversight processes that can support the approval of state and local plans to "build back better and stronger" are still under development. Then there are the rules governing HUD's post-disaster assistance that contain so many conditions and compliance requirements that must be satisfied that it can take years for those funds to be dispensed, compromising a community's ability to bring back residents displaced by the storm and to rebuild its economic base.

Another area where South Carolina officials expressed some concern is the process by which FEMA goes about prioritizing and assigning its limited resources. The current practice is to

A mobile home and car are surrounded by a few feet of water in the Florence, SC. Area. (Source: 960theRef Radio)

assign top priority to areas of "greatest loss," determined by the estimated dollar value from damages. On its face, this approach makes sense. But it can end up translating into missing some areas where there may be far greater need, particularly when it comes to damage of home properties. In the case of flooding in the Gills Creek area, many high-value homes that were adjacent to artificial lakes were seriously damaged when dams failed. At the same time, trailer parks located on flood plains also suffered significant damage, but these losses had a much lower dollar-value. Clearly, residents of higher value homes would be able to manage being displaced by flooding better than those living on low-fixed incomes living in trailers. South Carolina's Office of Disaster Recovery cited the following as examples that federal disaster assistance may need to be better calibrated to direct attention to where there is the greatest need:

- Two of South Carolina's more affluent counties that accounted for 12 percent of the flood damage ended up receiving 38 percent of federal funding.[105]

- A significant portion of the damage to mobile homes came not from the horizontal flow of rising flood waters, but from the vertical flow of torrential rains. Even in the case where mobile homes suffered damage from flood waters, as the rains continued well after the most severe flooding dissipated, the "high-water marks" that are used to confirm damage in post-storm property assessments were often erased. Consequently, many mobile homes ended up not qualifying for disaster assistance both because rain damages were attributed to "pre-existing conditions" that are not covered by FEMA flood damage programs, and because adjusters were unable to identify high water flood marks to substantiate coverage.

Another constraint that inhibited state and local officials from directing emergency relief resources to those with the most need is the difficulty they had in obtaining data that could help identify just who the neediest residents are. This is despite the fact that individual claims filed with FEMA provide a rich source of this data. However, since survivors must provide some of their personal information (PII) when filling out these claims, FEMA must operate under significant federal restrictions associated with handling PII. In South Carolina, FEMA authorized only 7 people in the state system to have access to the claims data because of the PII issue. As a result, most of the state and local officials who are on the frontlines for providing state and local assistance to survivors could not determine: (a) whether those in need

had filed a federal claim, and/or (b) whether they did or were likely to receive federal assistance. Finding a way to more widely share relevant claim information while managing the PI issue would have helped the state to more surgically address its recovery goals.

In summary, the absence of a comprehensive damage assessment deprives recovery efforts of some important baseline information for directing their efforts including where to direct Volunteers Active in Disasters (VOAD) organizations to the areas of greatest need. A Major Disaster Declaration also puts in place firm timeframes that states must satisfy to gain access to federal recovery resources. The time FEMA remains on site can have significant impact on the success of the transition between the Federal Coordinating Officer and the Federal Disaster Recovery Coordinator and an extended presence could be used to support better integration with state recovery efforts.

Recommendations

- **States and major municipalities** should hire full-time recovery planning personnel. Recovery planning personnel should operate separate from, but in close collaboration with, state- and local-level emergency managers.

- **Recovery planning personnel** should coordinate closely with their state and local counterparts involved with economic development so that disaster recovery considerations are incorporated as a part of urban and regional planning.

- **State and local recovery offices** should work to more fully understand federal regulations and practices regarding recovery resources and operations and educate their local constituencies on what can be realistically expected from federal support.

- **States** should develop a better understanding of federal procedures for handling data, determining damage, allocating resources, etc. in advance so that post-disaster recovery operations can be better aligned with federal protocols from the outset.

- **States** should develop and regularly update detailed disaster recovery plans. As a precondition for a federal disaster declaration, states should be required to brief these plans to relevant federal officials.

- **States** should prioritize, as an integral part of the disaster planning process, the need for rapidly conducting a comprehensive post-disaster assessment of damages to better aid response and recovery efforts.

- **States and municipalities** should engage in a coordinated, pre-disaster effort to map social and infrastructure vulnerabilities in order to better understand and contextualize the damage of an event in its aftermath, allowing the initial response effort to enhance long-term recovery.

- **The Department of Homeland Security** could assist states by:

  – Better integrating the exit of federal disaster response personnel with state recovery efforts.

  – Standing up a working group that identifies how information collected by the federal government from disaster claimants can be shared with relevant state disaster recovery personnel.

  – Supporting the prototyping in other regions of tools and applications such as the one used by South Carolina for the post-disaster identification of its most vulnerable populations. The Social Vulnerability Index (SoVI) developed by the University of South Carolina holds excellent potential for wider application and further refinement with DHS support.

  – Enhancing the processes by which federal agencies, states and localities coordinate with Volunteer Organizations Active in Disasters (VOAD).

Finding 4

Decision makers and key stakeholders need information and visualization tools that advance an understanding of complex watershed interdependencies and how they can be best managed.

Key officials in South Carolina frankly acknowledge that when responding to the October floods, they were operating without a preexisting understanding of systematic infrastructure interdependencies, and governance overlaps and gaps for the state's watersheds. This hampered their ability to organize and carry out an optimal response and recovery effort.

"We probably know less about dams and watershed management than anything else in the state right now," remarked one senior South Carolina state official at a workshop in June. This reality made it difficult for the state to anticipate second order impacts of flooding on roads, bridges, water supply, and water treatment systems. Possessing a better understanding of watersheds and the interdependencies of the critical infrastructure that lie within them is a nationwide imperative. What is needed are models that can usefully inform forward-looking economic development decisions as well as emergency response and disaster recovery planning. These models need to provide decision makers with the means to visualize complex interdependencies and the potential for second and third order impacts as well as support their ability to simulate in advance the likely outcomes of various decisions they might make.

"We probably know less about dams and watershed management than anything else in the state right now"

South Carolina emergency managers and state officials found that the *Hazus* flood models they rely on to evaluate flood risk were not up to the task of understanding where flooding would likely occur during this extreme rain event. Discussing the difficulty of getting accurate information about the impact of the event, one official tasked with coordinating emergency response efforts simply said, "decision makers didn't have that information early or fast enough."[106] Even days later, saturated ground from the preceding days of rain followed by the unprecedented rain event limited the flood model's effectiveness. One concern consistently voiced about the visualization capabilities of the inundation models that they had on-hand was that they provided no real insight on how much water was coming and how quickly. Officials unanimously requested a more dynamic, visual, and interactive flood model for use during disasters as well as to support pre-disaster planning. They also pointed out that developing, deploying, and working with these models ahead of time would greatly assist the disaster response and recovery processes.

Compounding this complex technical element of disaster recovery planning, is the need to be able to identify the ownership and operations of various systems that are maintained by both public and private entities, often across multiple jurisdictions. Many of these systems have inputs that are uncontrolled by the systems owners who indirectly depend on them. For instance, creation of even small impermeable surfaces (e.g., driveways, rooftops, small parking lots) when aggregated over time can increase storm water runoff in significant amounts but in ways that may be invisible to planners and regulators prior to major flood events. The often limited knowledge and regulation of agricultural or recreational water impoundments creates another potential blind spot. In some localities, state and local regulators are frequently not aware

A dam in Lexington, SC is breached sending uncontrolled floodwaters downstream (Source: @ruthless1025/Instagram via The Weather Channel)

of, or involved in, the decisions to create these impoundments so potential effects on the watershed are unknown to them.

Recommendations

- **State and local leaders** should work collaboratively with infrastructure owner/operators to assess models and tools that can enhance their understanding of infrastructure interdependencies, the potential impacts of cascading disruptive events, and the effects of infrastructure system changes over time. This should include identifying and removing impediments to accessing relevant data. The resultant knowledge should inform urban and regional economic development planning as well as investment decisions on infrastructure replacement or improvements.

- **The Department of Homeland Security** should task its Directorate of Science and Technology to:
  - Support the development of models and tools that assist state and local governments and owner/operators of infrastructure to understand the effects of.

infrastructure system changes over time and for making prudent investments in infrastructure replacement and improvement;

- Support the development and wide-spread use of automated tools and applications for assessing the damage and vulnerability of dams impacted by extreme water events and subsequent flooding.

- Support the development and wide-spread use of better flood inundation models particularly those that can be used to predict and manage watershed failure events.

Finding 5

State and local expectations of what the federal government will bring to support recovery are misaligned relative to current federal planning and available resources. Also, state and local authorities have difficulty effectively communicating to the federal government the recovery needs of their communities.

One of the consistent themes raised in conducting this study was the pervasive mismatch of expectations for federal recovery resources at every level of engagement. While federal policy, rules and guidelines are written, published and available, they are not well understood before the disaster, and that misunderstanding often lingers well into the recovery period. This discrepancy in expectations manifests itself at the individual level with the belief that FEMA or HUD will make individual losses whole; not that the federal government, through one of its programs, will attempt to provide safe, temporary housing and emergency aid to help individuals weather the crisis and begin recovery. Small businesses do not fully realize the limitations of FEMA to recover their businesses and most do not have business continuity plans.

A South Carolina resident and FEMA officials visit her property. Her home was severely damaged with the October 2015 flooding (Source: Matt Walsh/The State)

The requirement for documentation of damage and expenditures as a prerequisite for federal assistance, while a subject of virtually every disaster after-action report, is not well understood or fully implemented.

This is particularly problematic for flood events. In many cases, flood damage to infrastructure will not reveal itself in the initial days of recovery. Scoured bridge abutments, washed out culverts, slowly eroding soils around buildings and underground conduits often will not be discovered within the time horizon of the federal, on-site response and recovery task forces.[107]

Public officials at all levels are the most significant contributors to this mismatch of expectations to reality, either through misunderstandings of funding limits, or unclear messaging to the general population about when and how many resources will become available.[108] In their rush to assure the public that everything possible will be done to meet the disaster and recovery quickly, their public statements are often not well informed, overly optimistic, and, at times, may be factually wrong. Even when not incorrect, public officials' statements often lack the context or full explanation that can help set realistic expectations. While these statements are

typically made as a part of a natural reflex to try and reassure a traumatized public, they can risk generating high degrees of public frustration and even end up discrediting the sometimes heroic efforts of those responding to the crisis.

Compounding this expectations issue, is the lack of clarity in the implementation of some of the provisions of the *Sandy Recovery Improvement Act of 2013* particularly as they relate to the provisions for "building back better."[109] Clarifying these requirements and allowances may enable more effective use of recovery funds and enable added mitigation effects.
This communication can set the tone for positive local/federal cooperation and provide a hopeful, factual message to the local population that enhances recovery and a return to normal.

Recommendations

- **Local leaders** should have in place a communication plan prior to a disaster that ensures the appropriate personnel understand federal response and recovery policies, practices and procedures and are able to explain these to the public in a way that sets realistic expectations.

- **State and local governments**, in advance of a disaster, should designate spokespersons, formulate message templates, and train local leaders in post-disaster communications.

- **State agencies** should ensure that their communication plans include requirements for explaining federal response and recovery policy and operations to relevant officials and the general public.

- **The Department of Homeland Security** should create a user-friendly guidebook that explains the National Disaster Response and Recovery Frameworks. It should provide examples, guides and checklists that support the practical implementation of a coordinated response and recovery effort.

Finding 6

Recovery and resilience planning at city, state, and regional levels would benefit from active dialogue and close cooperation with the academic community.

As demonstrated by this report, academic institutions such as Northeastern University and the University of South Carolina offer access to research that can helpfully inform the disaster recovery process. In a disaster, local universities are also a part of the impacted community; they provide housing for thousands of students and are deeply embedded into local and regional economies. Similar to a major corporation located in a disaster zone, they have a direct interest in partnering with local and state decision makers to support response and recovery efforts. Building relationships between and amongst major academic institutions and practitioners ahead of a disaster is crucial to capitalizing on the unique capabilities that students, faculty, researchers, and administrators from academic institutions can provide to their communities.

University researchers, local stakeholders and government officials convened in South Carolina in June 2016 to discuss lessons from the storm. (Source: Northeastern University Center for Resilience Studies)

In South Carolina, it was clear the state's universities housed an impressive range of experts who were willing to bring their capability to bear in responding to the historic October flooding. However, formal arrangements that help foster the relationships that enable quick, trusted, and efficient cooperation in the midst of a post-disaster fast-paced environment were not in place ahead of time. Many academics in South Carolina stepped forward and expressed their willingness to provide state-of-the-art modeling and mapping tools to responders in order to help identify unseen flood damage, better understand systemic impacts and response options, and prioritize limited resources. University engineers were eager to support the deployment of new resilience-engineering practices in real-world settings. What they were missing was the mechanism for matching their unique capabilities with the needs of officials tasked with the response and recovery effort.

Similarly, practitioners and those responding on the front lines were enthusiastic about the prospect of receiving more help, innovative processes and enhanced tools that could make response and recovery more efficient and effective. Officials in the state's emergency management office and Department of Health and Environmental Control hailed the long-term analysis capabilities of the academic community and wondered excitedly what a productive relationship could accomplish for planning and recovery efforts. In the days and weeks after the storm, however, these officials were consumed by their efforts to assist survivors and mitigate

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the extensive damages caused by the flooding. They simply had no time to sit down with academics to discuss how best to match research capabilities with real-world needs. The pre-built disaster response structures in place before the event had an understandably difficult time widening their scope to incorporate fresh faces from the academic community in the fast-paced aftermath of a major disaster.

One instance of a productive relationship with the potential for a more expansive practitioner-academic collaboration focused on disaster recovery, emerged once the South Carolina state recovery office was set up in the weeks after the storm. When Governor Nikki Haley tasked Col. Kevin Shwedo, then the head of the state Department of Motor Vehicles, to head up the newly created disaster recovery office, Col. Shwedo knew he had to get to work quickly to help the most vulnerable communities, who were still struggling to recover from the flood. Shwedo and his team found the Social Vulnerability Index (SoVI®), a mapping tool developed by the University of South Carolina's Hazards and Vulnerability Research Institute, and operationalized it with structural damage data from FEMA.[110] After normalizing both vulnerability and damage data, the recovery team created an overlay that provided actionable intelligence on vulnerable population recovery needs at a glance (Figure A below). In addition to providing rapid evaluation of areas with the most need, this process also created an objective measure that was apolitical and highly defensible.
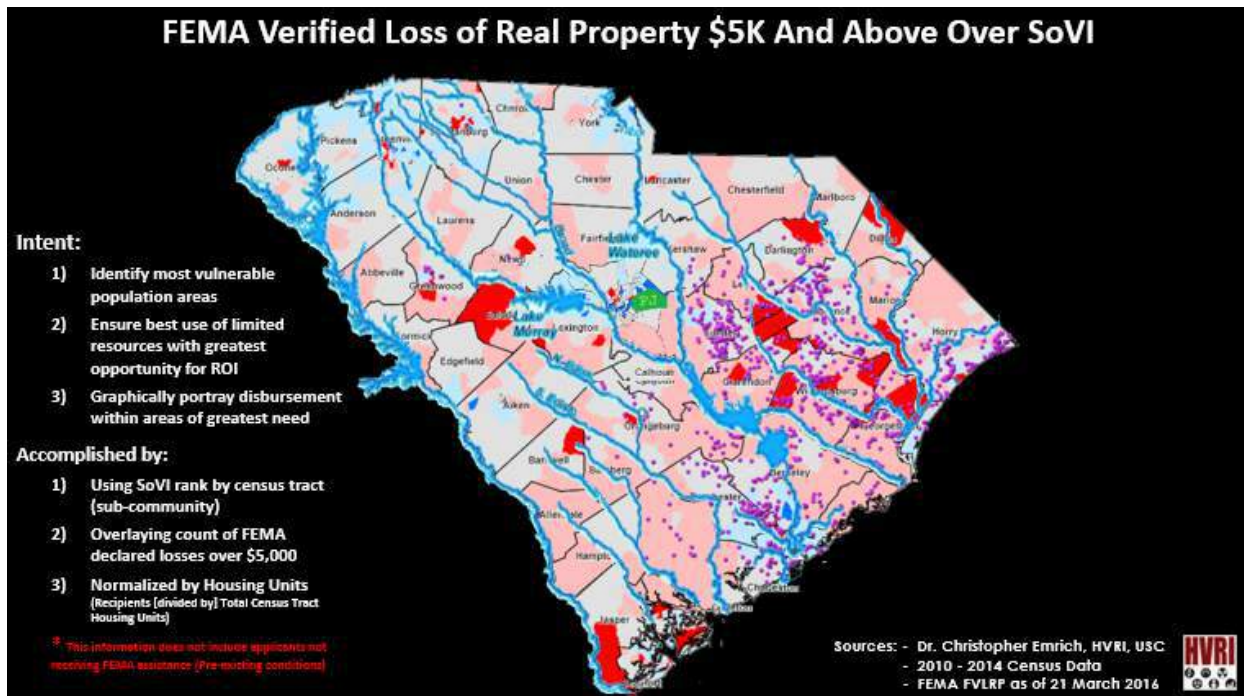
Figure A: A view of the Social Vulnerability Index (SoVI) developed by the Hazards and Vulnerability Research Institute at the University of South Carolina (Source: Dr. Susan Cutter, HVRI, USC)

The visual product clearly showed where the most vulnerable populations intersected with the highest impacted populations. Focusing recovery assistance in these areas provided an approach to ensuring those with the highest need received the appropriate resources – help that could mean the difference between remaining in an area or becoming part of the disaster diaspora. The South Carolina Disaster Recovery Office found that the vast majority of those who understood the SoVI® methodology fully supported it and that VOADs could mass their resources into prioritized areas providing immediate relief.

Recommendations

- **University leaders** should reach out to local and state government officials to forge relationships and identify the needs that their institutions can support in preparing for, responding to, and recovering from a disaster.

- **Local and state government officials** should include university leaders in disaster recovery planning. They should look to leverage university technologies, tools, researchers, and student volunteers.

- In advance of a disaster, **university leaders and government officials** should identify and plan to mitigate potential data sharing and resource hurdles that might arise from closer collaborations.

- **State governments** should work with their universities and community colleges to develop and deploy watershed models, simulations and educational programs.

Conclusion

As this report was nearing completion, record rainfalls led to massive flooding in the metro-Baton Rouge area. The preliminary death toll was thirteen lives lost.[111] More than 60,000 homes have been destroyed and over 100,000 Louisianans have registered for federal assistance.[112] This deluge was the eighth event since May 2015 in which a location within the United States had rainfall within a short period of time that exceeded the amount of precipitation that NOAA forecasts will happen once every five hundred years. In other words, in the span of fifteen months, there were eight rain events across the United States that were individually supposed to have only a 0.2 percent chance of occurring in any given year.[113] In 2016 alone, flood related Major Disaster Declarations have been issued in Western Oregon; Houston and Harris County, Texas; Southeastern Mississippi, Southern Oklahoma; West Virginia; Northern Wisconsin; and Southern Louisiana.[114]

The frequency and intensity of these flooding events along with their wide geographic spread suggests that communities, states, and regions throughout the United States need to step up efforts to better withstand, nimbly respond

Each star on this map represents a Major Disaster Declaration issued by FEMA for severe storm and flash flood related damages since the October 2015 flooding in South Carolina.

and recover, and ultimately adapt to watershed system disasters. To that end, the many public officials, experts, and community leaders from South Carolina who willingly shared their knowledge and insights to support this project have performed a very valuable service. Without exception, these individuals expressed their hope that the lessons they learned may assist others to be better prepared for coping with similar disasters.

Little progress will be made towards advancing community and infrastructure resilience unless Americans abandon their commonplace and fatalistic belief that disasters are rare and unknowable events. In reality, just the opposite is the case. Disasters are becoming more frequent occurrences and there are many recent scientific advances along with new tools and applications that can support making sound decisions before, during, and after these events. At the same time, there must be a commitment to gather and widely share the lessons from disasters when they occur as well as a mustering of the political will to act on findings and recommendations. This project aspires to support this critical imperative.

Works Cited

[1] Wilks, Avery. "Haley Touts SC's Flood Recovery." The State. 30 Jun. 2016. Web. 18 Jul. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article86864497.html.>

[2] Collins, Jeffrey and Martha Waggoner. "Small Creeks Became Deadly Torrents in South Carolina Floods." Associated Press. 17 Oct. 2015. Web. 21 Jul. 2016. <http://www.northjersey.com/news/small-creeks-became-deadly-torrents-in-south-carolina-floods-1.1435078?page=all.>

[3] Underwood, Tut. "D.O.T. Nears Completion of Flood-Damaged Road, Bridge Re-Openings." South Carolina Public Radio. 27 Jun. 2016. Web. 26 Jul. 2016. <http://southcarolinapublicradio.org/post/dot-nears-completion-flood-damaged-road-bridge-re-openings#stream/0.>

[4] Smith, Tim. "South Carolina Agriculture Losses Double From Flood." Greenville News. 18 Nov. 2015. Web. 25 Jul. 2016. <http://www.thestate.com/news/business/article45419760.html.>

[5] Wood, Doug. "SCFC Raises Estimate of Forestry's Economic Impact Loss from Flooding to $100M." South Carolina Forestry Commission. 4 Feb. 2016. Web. 6 Apr. 2016. <http://www.trees.sc.gov/releases/FloodDamageEstimate100Mfinal.pdf.>

[6] Adamczyk, Shelli. "Haley Says Flood Recovery Efforts Are Ongoing." Fox 57. 30 Jun. 2016. Web. 27 Jul. 2016. <http://wach.com/news/local/haley-updates-south-carolina-on-flood-recovery-efforts-06-30-2016.>

[7] The State. "3 Bridges on Bluff Road Closed for Replacement." The State. 14 Apr. 2016. Web. 26 Jul. 2016. <http://www.thestate.com/news/local/article71932107.html.>

[8] FEMA. "South Carolina—Severe Storms and Flooding, FEMA-4241-DR." Federal Emergency Management Agency. 5 Oct. 2015. Web. 21 Jul. 2016. <https://www.fema.gov/media-library-data/1447343113148-eb62b3816918a71d9df56df43c4d5d94/FEMA4241DRSC(Expedited).pdf.>

[9] SCDOT. Personal interview. May 2016.

[10] SCDOT. Personal interview. May 2016.

[11] Wilks, Avery. "S.C. Gets Nearly $157 Million in Federal Aid for Flood Recovery." The State. 29 Feb. 2016. Web. 19 Jul. 2016. <http://www.thestate.com/news/local/article63131177.html.>

[12] News 19 WLTX. "The Best Weather Term to Describe This @WLTX Morning: #blah. Light to Moderate Showers Today. Highs-lower 70s." Twitter. Twitter, 28 Sept. 2015. Web. 20 July 2016. <https://twitter.com/WLTX/status/648431127108042752>.

[13] Cangialosi, John P. "Bulletin: Tropical Storm Joaquin Advisory Number 5." National Oceanic and Atmospheric Administration. 28 Sep. 2015. Web. 19 Aug. 2016 <http://www.nhc.noaa.gov/archive/2015/al11/al112015.public.005.shtml>.

[14] Associated Press. "Hurricane Joaquin Lashes Bahamas as it Heads for US East Coast." The Guardian. 2 Oct. 2015. Web. 27 Jun. 2016. <https://www.theguardian.com/us-news/2015/oct/01/hurricane-joaquin-rain-storm-deluge-east-coast.>

[15] Stockton, Nick. "The East Coast's Heavy Rains Are Not From Hurricane Joaquin." Wired. 2 Oct. 2015. Web. 27 Jun. 2016. <http://www.wired.com/2015/10/east-coasts-heavy-rains-not-hurricane-joaquin/.>

[16] USGS. "Flood-Inundation Maps of Selected Areas Affected by the Flood of October 2015 in Central and Coastal South Carolina—Figure 2." Page 3. U.S. Geological Survey. 2016. Web. 20 Jun. 2016. <http://pubs.usgs.gov/of/2016/1019/ofr20161019.pdf.> and Wiltgen, Nick. "South Carolina's Catastrophic Floods Caused by One of the Most Prolific Rainfall Events in Modern U.S. History." The Weather Channel. 8 Oct. 2015. Web. 20 Jun. 2016. <https://weather.com/news/news/south-carolina-historic-flood-rainfall-record-extreme.>

[17] USGS. "Flood-Inundation Maps of Selected Areas Affected by the Flood of October 015 in Central and Coastal South Carolina—Figure 2." Page 3. U.S. Geological Survey. 2016. Web. 20 Jun. 2016. <http://pubs.usgs.gov/of/2016/1019/ofr20161019.pdf.>

[18] Associated Press. "Despite Improved Weather, More Evacuations Likely for Flooded South Carolina Towns." The Los Angeles Times. 6 Oct. 2015. Web. 20 Jun. 2016. <http://www.latimes.com/nation/latest/la-na-south-carolina-flooding-evacuations-20151006-story.html.>

[19] Gallagher, Hannah. "Number of Deaths Blamed on South Carolina Flooding Goes Up." 9&10 News. 10 Oct 2015. Web. 10 Nov. 2015. <http://www.9and10news.com/story/30232090/number-of-deaths-blamed-on-south-carolina-flooding-goes-up>

[20] Cope, Cassie. "Flood Damage Will Cost State $114 Million." The State. 1 Dec. 2015. Web. 21 Jun. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article47317850.html.>

[21] South Carolina Office of the Governor. "Gov. Nikki Haley and Emergency Management Officials Discuss Statewide Heavy Rain and Flood Preparations." Office of the Governor. 2 Oct. 2015. Web. 20 Jun. 2016. <http://governor.sc.gov/news/Pages/RecentNews.aspx.>

[22] Mass, Cliff. "Extraordinary Flooding Possible in South Carolina." Cliff Mass Weather Blog. 2 Oct. 2015. Web. 23 Feb. 2016. <http://cliffmass.blogspot.com/2015/10/extraordinary-flooding-possible-in.html.>

[23] South Carolina Office of the Governor. "State Upgrades to OPCON 3, Preparations Continue for Severe Flooding." Office of the Governor. 2 Oct. 2015. Web. 20 Jun. 2016. <http://governor.sc.gov/news/Pages/RecentNews.aspx.>

[24] King, Cindi. "South Carolina National Guard Responds to Historic Flood Levels." National Guard. 3 Oct. 2015. Web. 22 Jun. 2016. <http://www.nationalguard.mil/News/ArticleView/tabid/5563/Article/621752/south-carolina-national-guard-responds-to-historic-flood-levels.aspx.>

[25] Wiltgen, Nick. "South Carolina's Catastrophic Floods Caused by One of the Most Prolific Rainfall Events in Modern U.S. History." The Weather Channel. 8 Oct. 2015. Web. 20 Jun. 2016. <https://weather.com/news/news/south-carolina-historic-flood-rainfall-record-extreme.>

[26] The State. "The Latest: Obama Declares SC Major Disaster." The State. 4 Oct. 2015. Web. 20 Jun. 2016. <http://www.thestate.com/news/local/article37749813.html.>

[27] Wiltgen, Nick. "South Carolina's Catastrophic Floods Caused by One of the Most Prolific Rainfall Events in Modern U.S. History." The Weather Channel. 8 Oct. 2015. Web. 20 Jun. 2016. <https://weather.com/news/news/south-carolina-historic-flood-rainfall-record-extreme.>

[28] Fretwell, Sammy. "Flood of 2015 Was a Record-Setter in SC." The State. 22 Oct. 2015. Web. 20 Jun. 2016. <http://www.thestate.com/news/local/article41072694.html.>

[29] CBS News. "Historic Rainfall Pounds South Carolina." CBS News. 4 Oct. 2015. Web. 21 Jun. 2016. <http://www.cbsnews.com/news/south-carolina-nikki-haley-historic-rainfall/.>

[30] CBS News. "6 Dead in Catastrophic Flooding in Carolinas." WCVB 5. 4 Oct. 2015. Web. 21 Jun. 2016. <http://www.cbsnews.com/news/south-carolina-nikki-haley-historic-rainfall/.>

[31] South Carolina Emergency Management Division. "Statewide Response Continuing as Flooding Persists." South Carolina Emergency Management Division. 4 Oct. 2015. Web. 21 Jun. 2016. <http://www.scemd.org/component/content/article/21-home-page/public-information/219-severe-flooding.>

[32] Charleston County. "Operating Condition (OPCON) Levels." South Carolina Emergency Management Division. Web. 20 Jun. 2016. <http://www.charlestoncounty.org/departments/emergency-management/opcon.php.>

[33] South Carolina Emergency Management Division. "Statewide Response Continuing as Flooding Persists." South Carolina Emergency Management Division. 4 Oct. 2015. Web. 21 Jun. 2016. <http://www.scemd.org/component/content/article/21-home-page/public-information/219-severe-flooding.>

[34] Conlon, Kevin and Nick Valencia. "South Carolina Governor Calls Deadly Rain a 'Thousand-Year' Event." CNN. 4 Oct. 2015. Web. 22 Jun. 2016. <http://www.cnn.com/2015/10/04/us/east-coast-rain-flood/.>

[35] Associated Press. "Hundreds Rescued From South Carolina Floods After Over a Foot of Rain Falls Overnight." The Dallas Morning News. 4 Oct. 2015. Web. 22 Jun. 2016. <http://www.dallasnews.com/news/local-news/20151004-hundreds-rescued-from-south-carolina-floods-after-over-a-foot-of-rain-falls-overnight.ece.>

[36] Gills Creek Watershed Association. "Gills Creek Watershed." Gills Creek Watershed Association. 2015. Web. 2 Dec. 2015. <http://www.gillscreekwatershed.org/images/gills_creek_flood_recap.pdf>

[37] Fretwell, Sammy. "Battered Gills Creek Dams Pose Hazard." The State. 12 Mar. 2016. Web. 4 Apr. 2016. <http://www.thestate.com/news/local/article65701742.html.>

[38] Fretwell, Sammy. "1,000 Other Unsafe Dams in SC?" The State. 18 Jun. 2016. Web. 22 Jun. 2016. <http://www.thestate.com/news/local/article84651272.html.>

[39] Gills Creek Watershed Association. "Gills Creek Watershed." Gills Creek Watershed Association. 2015. Web. 2 Dec. 2015. <http://www.gillscreekwatershed.org/images/gills_creek_flood_recap.pdf>

[40] LeBlanc, Clif. "Water Safe for 30,000 Customers; Downtown Plant More Stable." The State. 10 Oct. 2015. Web. 1 Mar. 2016. <http://www.thestate.com/news/local/article38681478.html.> and "Columbia Scrambles to Protect its Drinking Water." CBS News. 8 Oct. 2015. Web. 26 Feb. 2016. <http://www.cbsnews.com/news/south-carolina-scrambles-to-save-drinking-water-in-columbia/>.

[41] The City of Columbia. "City of Columbia Press Releases: Oct. 1-31, 2015." City of Columbia. Web. 29 Feb. 2016. <https://www.columbiasc.net/depts/pr/oct_2015_press_releases_.pdf>.

[42] CBS News. "Columbia Scrambles to Protect its Drinking Water." CBS News. 8 Oct. 2015. Web. 26 Feb. 2016. <http://www.cbsnews.com/news/south-carolina-scrambles-to-save-drinking-water-in-columbia/>.

[43] The City of Columbia. "City of Columbia Press Releases: Oct. 1-31, 2015." City of Columbia. Web. 29 Feb. 2016. <https://www.columbiasc.net/depts/pr/oct_2015_press_releases_.pdf>.

[44] The City of Columbia. "City of Columbia Press Releases: Oct. 1-31, 2015." City of Columbia. Web. 29 Feb. 2016. <https://www.columbiasc.net/depts/pr/oct_2015_press_releases_.pdf>.

[45] The City of Columbia. "City of Columbia Press Releases: Oct. 1-31, 2015." City of Columbia. Web. 29 Feb. 2016. <https://www.columbiasc.net/depts/pr/oct_2015_press_releases_.pdf>.

[46] The City of Columbia. "City of Columbia Press Releases: Oct. 1-31, 2015." City of Columbia. Web. 29 Feb. 2016. <https://www.columbiasc.net/depts/pr/oct_2015_press_releases_.pdf>.

[47] "South Carolina—Severe Storms and Flooding: FEMA-4241-DR." Federal Emergency Management Agency. 5 Oct. 2015. Web. 21 Jun. 2016. <https://www.fema.gov/media-library-data/1447343113148-eb62b3816918a71d9df56df43c4d5d94/FEMA4241DRSC(Expedited).pdf.>

[48] Office of the Press Secretary. "President Obama Signs South Carolina Disaster Declaration." The White House. The White House, 05 Oct. 2015. Web. 13 Aug. 2016. <https://www.whitehouse.gov/the-press-office/2015/10/05/president-obama-signs-south-carolina-disaster-declaration>.

[49] King, Cindi. "South Carolina National Guard Responds to Historic Flood Levels." National Guard. 3 Oct. 2015. Web. 22 Jun. 2016. <http://www.nationalguard.mil/News/ArticleView/tabid/5563/Article/621752/south-carolina-national-guard-responds-to-historic-flood-levels.aspx.>

[50] Collins, Sam. "After Massive Flooding, South Carolina Residents Now Have to Worry About Their Health." Think Progress. 7 Oct. 2015. Web. 7 Apr. 2016. <http://thinkprogress.org/health/2015/10/07/3710141/contaminated-floodwater-in-south-carolina/.>

[51] Collins, Jeffrey and Martha Waggoner. "Small Creeks Became Deadly Torrents in South Carolina Floods." Associated Press. 17 Oct 2015. Web. 21 Jul. 2016. <http://www.northjersey.com/news/small-creeks-became-deadly-torrents-in-south-carolina-floods-1.1435078?page=all>

[52] Heigel, Catherine. "Special Senate Committee Regarding Flood Relief Efforts in South Carolina." South Carolina Department of Health and Environmental Control. 28 Oct. 2015. Web. 11 Apr. 2016. <https://www.scdhec.gov/HomeAndEnvironment/Docs/DamUpdates/Special_Senate_Committee.pdf.>

[53] South Carolina Department of Transportation. "SCDOT's Sunday, Oct 25, Update." South Carolina Department of Transportation. 25 Oct. 2015. Web. 13 Nov. 2015. <http://info.scdot.org/PressRelease/Lists/Posts/Post.aspx?ID=2136>

[54] South Carolina Department of Transportation. "SCDOT's Wednesday, Nov. 25, Update." South Carolina Department of Transportation. 25 Nov. 2015. Web. 3 Dec. 2015. <http://info.scdot.org/PressRelease/Lists/Posts/Post.aspx?ID=2182>

[55] Cope, Cassie. "Flood Damage Will Cost State $114 Million." The State. 1 Dec. 2015. Web. 21 Jun. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article47317850.html.>

[56] Cope, Cassie. "Unclear When Broken SC Roads Over Dams Will Be Fixed." The State. 5 Mar. 2016. Web. 1 Apr. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article64326877.html.>)

[57] Blackwell, K. "Private Dam Owners Face Repair Struggles After Flood." ETV. 7 Mar. 2016. Web. 1 Apr. 2016. <https://www.scetv.org/blog/palmetto-scene/2016/private-dam-owners-face-repair-struggles-after-flood.>)

[58] Adcox, Seanna."South Carolina Puts Dam Owners on Notice for Big Bills." Insurance Journal. 12 Nov. 2015. Web. 18 Nov. 2015. <http://www.insurancejournal.com/news/southeast/2015/11/13/388876.htm>)

[59] Fretwell, Sammy. "Aging Dams Spark Questions in Waterlogged Columbia." The State. 10 Oct 2015. Web. 16 Nov 2015. <http://www.thestate.com/news/local/article38710836.html>)

[60] Jarvie, Jenny. "Emergency Repair Orders Issued for 75 Private Dams in South Carolina." LA Times. 31 Oct. 2015. Web. 2 Nov. 2015. <http://www.latimes.com/nation/la-na-south-carolina-dams-20151030-story.html>)

[61] Cope, Cassie. "Unclear When Broken SC Roads Over Dams Will Be Fixed." The State. 5 Mar. 2016. Web. 1 Apr. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article64326877.html.>

[62] Burris, Roddie. "SC Floods' Damage: $12 Billion, Economists Say." The State. 1 Dec. 2015. Web. 7 Apr. 2016. <http://www.thestate.com/news/local/article47471060.html.> and Wilks, Avery. "Haley Touts SC's Flood Recovery." The State. 30 Jun. 2016. Web. 18 Jul. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article86864497.html.>)

[63] Wilks, Avery. "FEMA Finds $9.7 Million in Extra Aid for Flood Victims." The State. 25 Jan. 2016. Web. 21 Jun. 2016. <http://www.thestate.com/news/local/article56500748.html.>)

[64] Cope, Cassie. "Flood Damage Will Cost State $114 Million." The State. 1 Dec. 2015. Web. 7 Apr. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article47317850.html.>)

[65] Wilks, Avery. "S.C. Gets Nearly $157 Million in Federal Aid for Flood Recovery." The State. 29 Feb. 2016. Web. 7 Apr. 2016. <http://www.thestate.com/news/local/article63131177.html.>)

[66] Webb, Ryan. "SC Left with $204 Million in 'Unmet Needs' After Flood." WIVB 4. 1 Mar. 2016. Web. 7 Apr. 2016. <http://wivb.com/2016/03/01/sc-left-with-204-million-in-unmet-needs-after-flood/.>)

[67] Scoppe, Cindi Ross. "Scoppe: Now That We Realize the Risks of Earthen Dams, What Will We Do About It?" The State. 18 Oct. 2015. Web. 13 Nov. 2015. <http://www.thestate.com/opinion/opn-columns-blogs/cindi-ross-scoppe/article39321417.html> and "October 2015 South Carolina Dam Failure." Stanford University. Web. 18 Jul. 2016. <http://npdp.stanford.edu/2015_SC_Flood_Failures.>)

[68] Scoppe, Cindi Ross. "Scoppe: Now That We Realize the Risks of Earthen Dams, What Will We Do About It?" The State. 18 Oct 2015. Web. 13 Nov 2015. <http://www.thestate.com/opinion/opn-columns-blogs/cindi-ross-scoppe/article39321417.html>)

[69] Fretwell, Sammy. "South Carolina Wants to Beef Up Dam Safety Program in Wake of October Floods." Emergency Management Magazine. 12 Nov 2015. Web. 19 Nov 2015. <http://www.emergencymgmt.com/safety/DHEC-wants-to-beef-up-dam-safety-program-in-wake-of-October-floods.html>)

[70] Fretwell, Sammy. "Aging Dams Spark Questions in Waterlogged Columbia." The State. 10 Oct. 2015. Web. 6 May 2016. <http://www.thestate.com/news/local/article38710836.html.>)

[71] Jarvie, Jenny. "South Carolina Residents Rush to Higher Ground as 14 Dams Fail." Los Angeles Times. 7 Oct. 2015. Web. 13 Nov. 2015. <http://www.latimes.com/nation/la-na-south-carolina-floods-dams-20151007-story.html>)

[72] Miller, Scott. "S.C. Farmers Face Wide Insurance Gap on Flood Losses." Clemson University. 4 Feb. 2016. Web. 5 Feb. 2016. <http://newsstand.clemson.edu/mediarelations/s-c-farmers-face-wide-insurance-gap-on-flood-losses/>.)

[73] Perry, Charles. "Horry County Farmers, Congressman Urging Governor…" Myrtle Beach Online. 23 Jan. 2016. Web. 2 Feb. 2016. <http://www.myrtlebeachonline.com/news/local/article56139325.html>.)

[74] S.C. Legislature Video Archives. "House Ways and Means Committee." 10 Feb. 2016. Web. 11 Feb. 2016. <http://www.scstatehouse.gov/video/videofeed.php>.)

[75] Miller, Scott. "S.C. Farmers Face Wide Insurance Gap on Flood Losses." Clemson University. 4 Feb. 2016. Web. 5 Feb. 2016. <http://newsstand.clemson.edu/mediarelations/s-c-farmers-face-wide-insurance-gap-on-flood-losses/>.)

[76] S.C. State House of Representatives: H. 4717. 121st Reg. Sess. 2015-2016. Web: Accessed 21 Jun. 2016. <http://www.scstatehouse.gov/sess121_2015-2016/bills/4717.htm>.)

[77] South Carolina Legislature Video Archives. "House Ways and Means Committee." 10 Feb. 2016. Web. 11 Feb. 2016. <http://www.scstatehouse.gov/video/videofeed.php>.)

[78] Fretwell, Sammy. "State's Penny-Pinching Ways Crippled Dam Safety Program." The State. 18 Jun. 2016. Web. 21 Jun. 2016. <http://www.thestate.com/news/local/article84662662.html>.

[79] S.C. State House of Representatives: H. 4565. 121st Reg. Sess. 2015-2016. Web: Accessed 19 Apr. 2016. <http://www.scstatehouse.gov/sess121_2015-2016/bills/4565.htm>.

[80] SC Department of Health and Environmental Control. "SC Watershed Atlas." South Carolina Department of Health and Environmental Control. 2015. Web. 19 July 2016. <https://gis.dhec.sc.gov/watersheds/>.

[81] Marcil, Valerie. "Gills Creek Watershed Association's 2015 Flood Response." Gills Creek Watershed Association. 8 Nov. 2015. Web. 19 Jul. 2016. <http://www.gillscreekwatershed.org/gcwa_2015_flood_response.html>.

[82] SC Department of Health and Environmental Control. "Gills Creek." South Carolina Department of Health and Environmental Control. Web. 19 July 2016. <https://www.scdhec.gov/HomeAndEnvironment/Docs/03050110-02.pdf>.

[83] Tetra Tech and BP Barber. "Gills Creek Watershed Management Plan." Page 4 (PDF 18). Tetra Tech and BP Barber. May 2009. Web. 21 Jul. 2016. <http://www.gillscreekwatershed.org/documents/GillsMngmntPlan.pdf>.

[84] Tetra Tech and BP Barber. "Gills Creek Watershed Management Plan." Page 61 (PDF 75). Tetra Tech and BP Barber. May 2009. Web. 21 Jul. 2016. <http://www.gillscreekwatershed.org/documents/GillsMngmntPlan.pdf>.

[85] Gills Creek Watershed Association. Personal Interview. December 2015.

[86] Mack, Charnita. "Six Months After: Environmental Impact." University of South Carolina. 21 Apr. 2016. Web. 26 Jul. 2016. <http://www.datelinecarolina.org/story/31784847/six-months-environmental-impact.>.

[87] Gills Creek Watershed Association. Personal Interview. December 2015.

[88] Richland County. "Floodplain Mapping and Local Hazards." Richland County. Web. 19 Jul. 2016. <http://www.rcgov.us/Government/Departments/Planning/FloodplainManagement/Mapping.aspx.>.

[89] Emergency Management Division. Personal Interview. December 2015

[90] Gills Creek Watershed Association. Personal Interview. December 2015.

[91] SC Department of Health and Environmental Control. "Dams and Reservoirs Safety Act Regulations, Regulation 72-1 thru 72-9." Pages 50-51, 54 (PDF 15-16, 19). Department of Health and Environmental Control. 25 Jul. 1997. Web. 25 Jul. 2016. <https://www.scdhec.gov/Agency/docs/water-regs/r72-1.pdf>.

[92] Fretwell, Sammy. "State's Penny-Pinching Ways Crippled Dam Safety Program." The State. 18 Jun. 2016. Web. 9 Jul. 2016. <http://www.thestate.com/news/local/article84662662.html.>

[93] SC Department of Health and Environmental Control. "Standards for Stormwater Management and Sediment Reduction Regulation 72-300 thru 72-316." S.C. Department of Health and Environmental Control. 28 Jun. 2002. Web. 27 Jul. 2016. <http://www.scdhec.gov/Agency/docs/water-regs/r72-300.pdf>.

[94] SCDOT. Personal interview. May 2016.

[95] SCDOT. Personal Interview. December 2015.

[96] Underwood, Tut. "D.O.T. Nears Completion of Flood-Damaged Road, Bridge Re-Openings." South Carolina Public Radio. 27 Jun. 2016. Web. 26 Jul. 2016. <http://southcarolinapublicradio.org/post/dot-nears-completion-flood-damaged-road-bridge-re-openings#stream/0>.

[97] Smith, Tim. "South Carolina Agriculture Losses Double From Flood." Greenville News. 18 Nov. 2015. Web. 25 Jul. 2016. <http://www.thestate.com/news/business/article45419760.html>.

[98] Wood, Doug. "SCFC Raises Estimate of Forestry's Economic Impact Loss from Flooding to $100M." South Carolina Forestry Commission. 4 Feb. 2016. Web. 6 Apr. 2016. <http://www.trees.sc.gov/releases/FloodDamageEstimate100Mfinal.pdf.>.

[99] Adamczyk, Shelli. "Haley Says Flood Recovery Efforts Are Ongoing." Fox 57. 30 Jun. 2016. Web. 27 Jul. 2016. <http://wach.com/news/local/haley-updates-south-carolina-on-flood-recovery-efforts-06-30-2016>.

[100] The State. "3 Bridges on Bluff Road Closed for Replacement." The State. 14 Apr. 2016. Web. 26 Jul. 2016. <http://www.thestate.com/news/local/article71932107.html>.

[101] Bergengruen, Vera. "Without Aid, 2016 Could Be Even Worse for S.C. Farmers." 7 Mar. 2016. Web. 25 Jul. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article64621712.html>.

[99] Adamczyk, Shelli. "Haley Says Flood Recovery Efforts Are Ongoing." Fox 57. 30 Jun. 2016. Web. 27 Jul. 2016. <http://wach.com/news/local/haley-updates-south-carolina-on-flood-recovery-efforts-06-30-2016>.

[100] The State. "3 Bridges on Bluff Road Closed for Replacement." The State. 14 Apr. 2016. Web. 26 Jul. 2016. <http://www.thestate.com/news/local/article71932107.html>.

[101] Bergengruen, Vera. "Without Aid, 2016 Could Be Even Worse for S.C. Farmers." 7 Mar. 2016. Web. 25 Jul. 2016. <http://www.thestate.com/news/politics-government/politics-columns-blogs/the-buzz/article64621712.html>.

[102] FEMA. "Public Assistance Alternative Procedures Pilot Program Guide for Debris Removal (Version 3)." Federal Emergency Management Agency. 28 Jun. 2015. Web. 20 Jul. 2016. <https://www.fema.gov/media-library-data/1435580301706-b94102af3744952b11345fc13fabf70e/PAAPGuideforDebrisRemovalv3FINAL62515508.pdf.>

[103] FEMA. "Disaster Declarations by Year." Federal Emergency Management Agency. Web. 20 Jul. 2016. <https://www.fema.gov/disasters/grid/year.>

[104] South Carolina Forestry Commission. Personal Interview. May 2016

[105] SC Disaster Recovery Coordinator. Personal Interview. May 2016.

[106] Emergency Management Division. Personal Interview. December 2015.

[107] The State. "3 Bridges on Bluff Road Closed for Replacement." The State. 14 Apr. 2016. Web. 26 Jul. 2016. <http://www.thestate.com/news/local/article71932107.html.>

[108] SC Department of Health and Environmental Control. Personal Interview. May 2016.

[109] U.S. House of Representatives. "Disaster Relief Appropriations Act 2013." Government Publishing Office. Government Publishing Office, 29 Jan. 2013. Web. 13 Aug. 2016. https://www.congress.gov/113/plaws/publ2/PLAW-113publ2.pdf>.

[110] SC Disaster Recovery Coordinator. Personal Interview. May 2016.

[111] Shapiro, Emily. "Deadly Louisiana Flooding Claimed at Least 13 Lives, Damaged 60,000 Homes." *ABC News.* 22 Aug. 2016. Web. 22 Aug. 2016. <http://abcnews.go.com/US/deadly-louisiana-flooding-claimed-13-lives-damaged-60000/story?id=41568812>.

[112] Schleifstein, Mark. "Louisiana Flood of 2016 Resulted from '1,000 year' Rain in 2 Days." *NOLA.com.* The Times-Picayune. 17 Aug. 2016. Web. 22 Aug. 2016. <http://www.nola.com/weather/index.ssf/2016/08/louisiana_flood_of_2016_result.html>.

[113] Jonah Engel Bromwich, "Flooding in the South Looks a Lot Like Climate Change," *The New York Times.* 16 Aug, 2016. Web. 19 Aug. 2016. <http://nyti.ms/2bkXOkk>.

[114] FEMA. "Disaster Declarations." *FEMA.gov.* Department of Homeland Security, Aug. 2016. Web. 19 Aug. 2016. <https://www.fema.gov/disasters?field_state_tid_selective=All&field_disaster_type_term_tid=6837&field_disaster_declaration_type_value=DR&items_per_page=60>.

Appendix A: June S.C. Workshop Agenda

South Carolina October '15 Flood Workshop
Understanding the Path to Resilience, Adaptation and Recovery
Wednesday, June 15, 2016

The Inn at USC Wyndham Garden, 1619 Pendleton St., Columbia, SC

9:30 am	Welcome
9:35 am	Summary of Findings: Understanding Response and Recovery Choices
10:00 am	Research Presentations
10:20 am	Participant Discussion: Recommendations for Response and Recovery
10:45 am	Break
10:55 am	Findings: Roads, Bridges, Dams
11:15 am	Participant Discussion: Recommendations on Infrastructure Interdependencies and Cascading Effects
11:35 am	Findings: Recovery Strategies
12:00 pm	Break (working lunch served)
12:10 pm	Research Presentation (SoVI)
12:25 pm	Participant Discussion: Recommendations for Recovery Priorities and Social Vulnerabilities
12:40 pm	Keynote: Col. Kevin Shwedo, South Carolina Disaster Recovery Coordinator
1:10 pm	Participant Discussion: Federal Recovery Framework and State Recovery Intent
1:30 pm	Concluding Remarks: DHS Deputy Asst. Sec. Bob Kolasky
1:40 pm	Next Steps
1:45 pm	Adjourn

Appendix B: Invited Research Papers

The Social Vulnerability Index (SoVI®) as a Decision Support Tool in Prioritizing Disaster Recovery Efforts

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[††] State of South Carolina Disaster Recovery Task Force, Columbia, SC

The National Response Framework, guided by the statutory authority of the Robert T. Stafford Act of 1988 (and subsequent amendments) provides the guidance for federal response to emergencies and disasters. In addition, the Stafford Act through the process of Presidential Disaster Declarations authorizes the President to make supplemental disaster assistance available to affected communities, generally in the form of public assistance, individual assistance, and hazard mitigation assistance.

Since 2007, the National Response Framework (FEMA 2008, 2013) included ESF-14: Long Term Community Recovery, which provided a coordinating mechanism for federal agencies in assessing and addressing post-disaster long-term disaster recovery needs of impacted communities. However, it was quickly realized that a more comprehensive approach to long-term recovery was needed, one that went beyond the typical FEMA timeframe of initial response, immediate individual assistance, and short-term housing. In 2011, ESF-14 was superseded by the National Recovery Framework creating six new recovery support functions (including the lead federal coordinating agency) aimed at assisting communities with accelerating the process of recovery, redevelopment and revitalization. At the same time, FEMA initiated its whole community approach to emergency management (FEMA 2011a) designed to enhance disaster resilience by working with diverse groups and organizations to improve the ability of local residents to more effectively "…prevent, protect against, mitigate, respond to, and recover from any type of threat or hazard" (FEMA 2011a:3).

FEMA has shown particular interest in understanding the complexity of communities including their capabilities and needs, in particular planning for vulnerable populations following disasters (FEMA 2011b). Social vulnerability is the broad concept that examines the differential impact of disasters on social groups based on existing social conditions and abilities to adequately prepare for, respond to, and rebound from disasters (Cutter 2006; Phillips et al. 2013). General approaches for assessing social vulnerability appear in contexts such as health or planning (Flanagan et. al 2011, Lee 2014, Nelson 2015). For hazard specific contexts there has been considerable research on the empirical relationship between social inequality and hurricane impacts (Burton 2010; Chakraborty et al. 2014; Cutter and Emrich

2006; Cutter et al. 2006, 2014), and social vulnerability and flood impacts and recovery (Collins et al. 2013; Rufat et al. 2015; and Tate et al. 2016). Other studies looking at specific hazards and social vulnerability include earthquakes (Schmidtlein et al. 2006), and tsunamis Wood et al. (2010). The seminal piece on social vulnerability and its measurement (Cutter et al. 2003) remains a strong undercurrent in each of these offshoot efforts not only in the US (as illustrated above), but across the globe—in Brazil (Hummell 2013; Hummel et al. 2016), China (Chen et al. 2013), Norway (Holand 2011), Indonesia (Siagan et al. 2014), and Portugal (Guillard-Gonçalves et al. 2015).

Emergency Management Use of SoVI®

Based on well-known concepts of what makes places socially-vulnerable, the SoVI® methodology was initially designed as a tool to understand the variability in social vulnerability within and between places. SoVI® utilizes a set of consistent census variables to develop a multi-dimensional index of vulnerability to hazards, which is then mapped in order to compare one place (census track, county, or region) to another. It has been applied in a variety of contexts highlighting the differential susceptibility of communities to hazards. For example, when incorporated into hazard mitigation plans, it spatially illustrates where additional resources may be required for preparedness, response, and recovery. SoVI® is part of the state hazard mitigation plans in 12 states including South Carolina (Table 1), in numerous counties across the nation, and is leveraged to understand public health disaster preparedness in both Florida and Texas Public Health Risk Assessment Tools. Multiple versions of SoVI® have been included in NOAA's Digital Coast product toolset (https://coast.noaa.gov/dataregistry/search/collection), Climate Central's Surging Seas (http://sealevel.climatecentral.org/), in Florida's (CDC funded) Building Resilience Against Climate Extremes (BRACE) project (http://www.floridahealth.gov/environmental-health/climate-and-health/brace/index.html), and in political advocacy campaigns focused on climate sensitive hazards (http://adapt.oxfamamerica.org/). In addition to coastal and hazard mitigation applications, SoVI® is one of the most widely used methods for informing the USACE's social effects components in its water resources planning process (Cutter et al. 2013; Dunning and Durden 2013; Durden and Wegner-Johnson 2013).

The Social Vulnerability Index (SoVI®) has migrated from its initial conceptual development to an implementable product for emergency management mainly used in pre-event mitigation planning (Table 1). Advanced by Hurricane Katrina recovery research (Cutter et al. 2014a, Finch et al. 2010) and Hurricane Sandy long term recovery analyses (Cutter et al. 2014b) the connection between SoVI® and long term recovery was empirically identified.   Findings from disaster recovery research prove that the Social Vulnerability Index (SoVI®) has high utility as a decision-support tool for many phases of the emergency management cycle beyond mitigation planning. The SoVI® facilitates lessons learned from historical disaster impacts into actionable information for emergency managers, recovery planners, and decision makers because it empirically measures and visually depicts the

differential ability of a population to adequately prepare for, respond to, and recover from disaster events.

Table 1 Usage of SoVI® in Emergency Management and Disaster Response (2013-present)

Categories	Name
Federal Agencies	NOAA (Digital Coast Product), USACE (Other Social Effects), FEMA (Geospatial Framework)
State Governments (Mitigation Plans)	Arkansas, California, Colorado, Georgia, Illinois, Kansas, Mississippi, Missouri, New Mexico, North Dakota, South Carolina, South Dakota
County Mitigation Plans	Arapahoe County, CO; Beaufort County, SC; Calaveras County, CA; Dillon County, SC; Howard County, MO; La Plata County, CO; Moniteau County, MO; Pitkin County, CO; Richmond County, GA
Regional Mitigation Plans	Central Kansas, KS; Central Midlands Council of Governments, SC; Johnson, Leavenworth, and Wyandotte Counties, KS; Low Country Council of Governments, SC; Northeast Kansas, KS; Northern Virginia, VA; South Kansas, KS; Southeast Kansas, KS.
City Mitigation Plans	City of Galveston, TX

Updates of SoVI® for coastal states have taken place twice since the 2000 census and the latest outputs (SoVI® version ACS 2006-2010) are hosted on FEMA's Geoportal. The Geoportal, an extension of ArcGIS online, provides open access geospatial information for planning, response, and recovery missions, lending itself well to the distribution of SoVI® across the US. Thanks to its scientific track record and operational use, SoVI® is now part of FEMA's Geospatial Framework, the set of spatial products delivered automatically by FEMA upon a Presidential Disaster Declaration.

There are three distinct limitations with the currently available SoVI® products via the FEMA Geoportal. First, SoVI® (version ACS 06-2010) is available at the tract level for every coastal state (n=30) via FEMA's GeoPortal, but not for interior states. This causes data gaps in the product lineup. Second, the SoVI® data on the GeoPortal utilizes data from 2006-2010 5-year ACS, making it dated in terms of its comparability to current socio-demographic trends. Third, while the existing nationwide SoVI® products are a proven asset for planning purposes, less is known about their usefulness for response and recovery operations. SoVI® is scale-dependent meaning that changes to the area of interest (e.g., from state level to sub-state disaster area) may produce different sets of vulnerability drivers. To be used effectively for response and recovery, SoVI® products must be re-run for every unique area of interest (likely disaster impact area, declared counties, or other user defined areas of interest).

During the historical floods of 2015 in South Carolina, SoVI® was truly leveraged into actionable intelligence and targeted response and recovery planning.   The State of South Carolina relied on SoVI® after its catastrophic floods in 2015 to identify priority areas

requiring prolonged outside assistance to rebound from the disaster. SoVI® was coupled with FEMA, NFIP, and SBA data to determine unmet needs—to find those pockets of people who would not be able to bounce back without outside assistance. SoVI® provided an apolitical approach for distributing scarce disaster recovery dollars and rebuilding resources to benefit places that were most impacted and least able to recover from this disaster.

South Carolina's Operational Use of SoVI®: October 2015 Severe Storms and Flooding

During early October 2015 an unusual weather system coupling a strong frontal system with a hurricane's rainfall stalled directly over South Carolina. While not a hurricane, the system produced a continuous 'conveyor belt' of precipitation from 500 miles away that dumped significant rainfall over the state for a period of several days. While the rainfall amount varied across the state, more than half the state's 46 counties received greater than twenty inches of rain over a 24-hour time period. Many flash floods occurred in urban areas inundating homes and business located inside and outside of the official flood zone. The large volume of water also caused several dams to erode and become compromised and others to completely fail. All major rivers, along with their numerous tributaries, carrying water to the ocean remained in flood stage for a week or more. A Presidential Disaster Declaration (PDD) (DR-4241) was proclaimed for 36 of the state's 46 counties, initiating the process for receiving disaster relief and recovery resources from the federal government. Because of the severity and magnitude of the event the Governor asked for an expedited review which meant the requirement for a formal completed preliminary damage assessment to determine the need for federal assistance was waived and the PDD was awarded quickly (October 5, 2015). Twenty-four counties were designated both Individual Assistance (IA) and Public Assistance (PA) disaster areas and an additional 10 counties were only declared for PA.   In hindsight, one adverse outcome of such an expedited process is the absence of a systematic statewide preliminary damage assessment although several counties undertook their own damage assessments. This coupled with the rapid inundation and retreat of flash flooding, and a secondary rain event a week later meant the true extent of the damage to the state was never fully captured.

The Governor appointed a Disaster Recovery (DR) Coordinator and pulled more than 20 state employees from Cabinet level agencies forming a team focused exclusively on recovery operations. The Governor's goal was to accelerate recovery quickly across the state and, most importantly, do it in an apolitical fashion. The South Carolina Disaster Recovery (SCDR) Team's original mission was to focus on the building of Long Term Recovery Groups including extensive coordination of the Volunteer Organizations Active in the Disaster (VOADs). SoVI® provided the tool to focus VOAD efforts in areas of real need rather than areas of convenience or perceived need. After the first few months, the DR office broadened its mission to include development of an action plan, best practices, and state recovery vision/strategy directly connected to HUD Community Block Development Grant – Disaster Recovery (CDBG-DR) program guidance.

Leveraging SoVI®

The Disaster Recovery team partnered with the University of South Carolina's Hazards & Vulnerability Research Institute to gain a full understanding of Social Vulnerability Index scores across the impacted area (PDD counties).   Because SoVI® combines freely available census information on vulnerable populations (age, gender, race/ethnicity, socio-economic status) to create an easily understood maps depicting the most vulnerable census tracks, it provides actionable intelligence at a glance. However, since the selection of the study area influences the relative assessment of vulnerability, customized runs of SoVI® are necessary at the operational level. For example, the geography of the social vulnerability changes when examining the entire state (Figure 1a) compared to just those counties with a Presidential Disaster Declaration for individual assistance (Figure 1b).
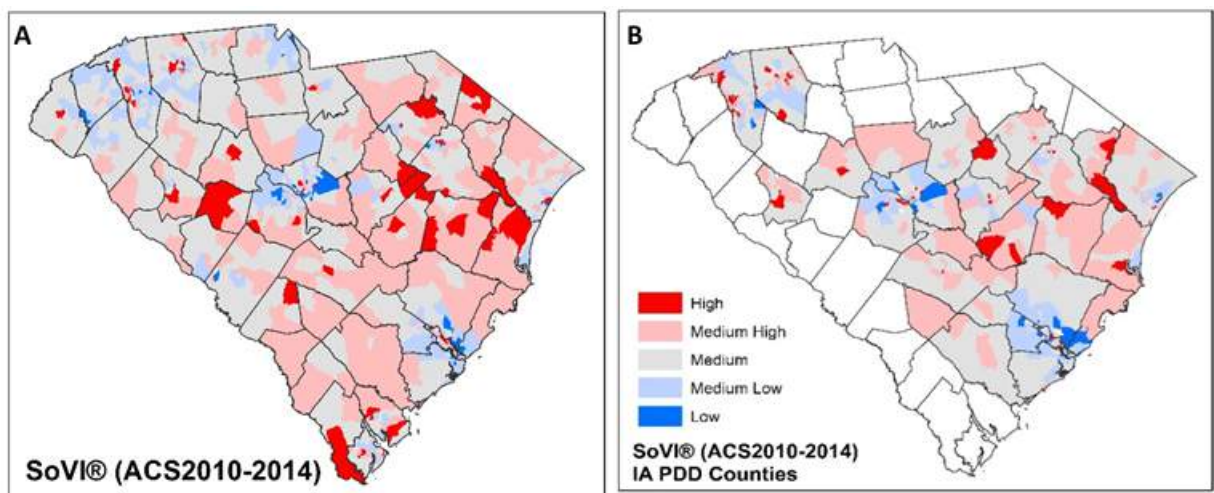
Figure 1 Comparison of SoVI® based on differences in study areas, a) entire state; b) Presidential Disaster Declaration counties for Individual Assistance.

SCDR obtained an address list of Individual Assistance applicants from FEMA and began to focus on those applicants with at least $5,000 in verified structural damage. The presupposition was that since the extent of the flood disaster was not known (across the whole state), the SCDR would need to identify impacted areas by triangulating from a variety of data sources. Using FEMA IA damage data, each $5,000 (an estimated break point between mild and moderate damage based on local housing stock) or greater loss was pinpointed on a map. These "hot spots" of FEMA-verified loss were overlaid on SoVI® to identify areas containing significant numbers of damaged homes. These "target" areas were given to South Carolina's One SC Fund, non-profits, and faith-based organizations to help focus efforts on helping those who needed it most. Normalizing the total number of homes damaged by the total number of homes in an area (creating a percentage comparison) enabled the state to rank order damage in relation to social vulnerability – effectively creating a targeting capability for use by recovery personnel operating on the ground. Using this method, it becomes clear that the swath of counties in the Wateree and Congaree watersheds in the east central part of the state not only contain the highest rate of damaged homes but often also have the highest social vulnerability. Targeting support to these areas

(identified in the dark purple shading in Figure 2) in the immediate and long-term recovery phases of the flood disaster would yield the best outcomes for those giving and receiving assistance.
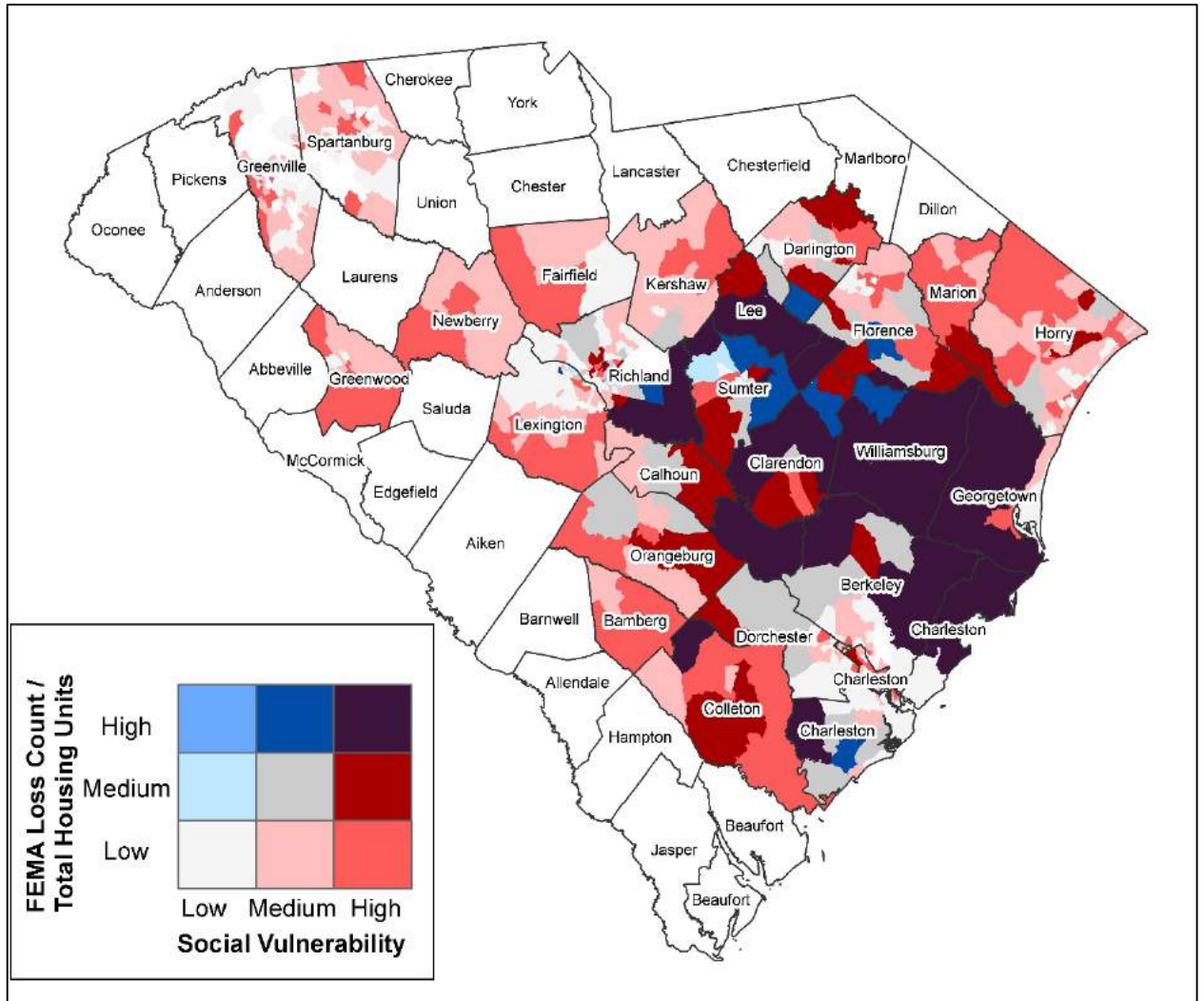

Figure 2: Bivariate representation of need (FEMA-Verified Loss Count/Total Housing Units overlaid with Social Vulnerability). The greatest need areas are shaded dark purple.

Proven Results Using SoVI®

This SoVI®/damage data product (Figure 2) was presented to Volunteer Organizations Active in the Disaster (VOADs), philanthropic organizations (One SC), and government officials (HUD, SC Housing, FEMA) as an apolitical tool for decision making in identifying those areas most in need of recovery assistance. The resultant product clearly showed areas where the most vulnerable populations intersected with the highest impacted areas. Focusing recovery assistance in these areas helped to ensure that those with the greatest need received resources – help that could mean the difference between remaining in the area, or becoming part of the disaster diaspora and moving away. The SCDR Team found

that the vast majority of those who understood the SoVI® methodology were in full support of the approach. In particular it highlighted where the volunteer organizations could mass their resources into a prioritized area providing an immediate relief effort. Further, use of this metric gave volunteer organizations a much needed focal point for their activities based on empirical data allowing them to maximize the benefits of the scarce resources to those most in need.

The Future of SoVI® ® for Emergency Decision Making:

Extend the Application

In recent years, social vulnerability has received greater consideration as states and communities seek to reduce adverse impacts of natural hazards. The operational use of SoVI® now provides actionable information for emergency managers and recovery planners in a post-event context. When coupled with FEMA disaster relief, NFIP payments information, and SBA loan distributions, SoVI® can quickly provide a targeting mechanism to highlight areas with unmet needs. Since the October 2015 SC floods, SoVI® has become a FEMA mitigation "Best Practice" (FEMA 2016) and personnel from the Louisiana FEMA Joint Field Offices have requested SoVI® for their particular areas of recent impact.

Within in this operational environment, SoVI® needs to reflect both temporal and spatial appropriateness, meaning that SoVI® data inputs should include the most up-to-date data and the area(s) of interest. The current social vulnerability data in the FEMA's Geospatial Framework is outdated for planning and response efforts moving forward. To be most useful, SoVI® should be available as two standard sets of products for planning and operational use. First, US (county level) and state (tract) level SoVI® products for planning should use the best available base data (right now this would be ACS 2010-2014) and be routinely updated as new census data become available (normally a five-year interval). Second, a downscaled set of SoVI® products based on user-defined areas of interest provides a place-based understanding of SoVI® at the level of interest for emergency response and disaster recovery, such as Presidential Disaster Declared areas. The geography of the areas of interest is important in understanding the social inequalities in populations and their ability to recover from disasters. Using nationally-constructed comparisons masks locally important differences in vulnerability—a key factor for pre-event planning and post-event recovery. Utilizing SoVI® in all phases of the disaster cycle provides a scientifically vetted, systematic, and apolitical tool for making difficult decisions around allocation of (scarce) resources before, during, and after disasters.

Improve the Science

Far too little is currently understood about the reliability of the leading vulnerability indicators, both in terms of the approaches used to build them and their ability to adequately represent real world conditions. There is a critical need for methodological advancements and better quality data to improve the precision and accuracy of social vulnerability indicators. Without continual advancements in the science behind the metric,

the use of social vulnerability indicators in disaster preparedness, mitigation, and recovery could mislead decision-making and resource allocation.

For example, American Community Survey Data 2010-2014 are available for a SoVI® update at national and sub-state levels. Results (Figure 3) of an update for South Carolina prove that migration patterns and associated changes underlying socio-demographics have resulted in a much different SoVI® picture than was found in 2010. These subtle changes prove that vulnerability assessments require regular updating (5-year cycle) to ensure applicability to emergency management.
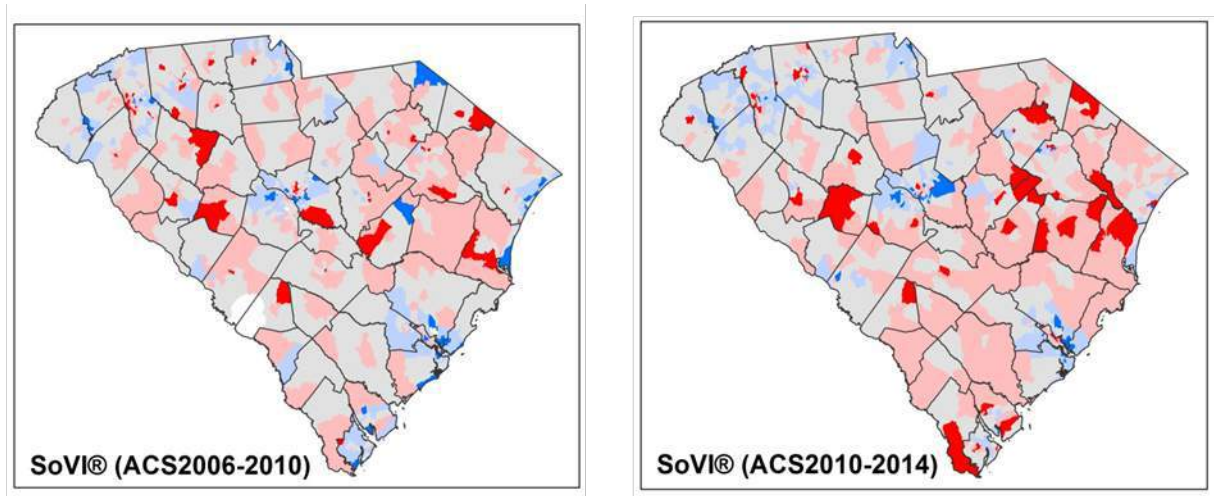
Figure 3 Changes in social vulnerability over time based on SoVI®.

Lessons Learned

Using the Social Vulnerability Index in prioritizing (often scarce) resources before, during, and after disasters allows for a clear and sustained unity of effort among various organizations. More importantly, it overcomes any political debate over prioritization and provides decision makers with a capability to identify and target the most vulnerable geographic areas. SoVI® enables a fiscally conscious approach to resource allocation because it streamlines the process of targeting and prioritization.

There were a number of important lessons learned from the actual deployment of SoVI® in the South Carolina flood recovery. First and foremost was the steep learning curve of emergency managers in understanding SoVI® construction, interpretation, and limitations. The learning involved significant give-and-take between HVRI, SCEMD, and the SCDR team in explaining social vulnerability conceptually and practically. Once response and recovery teams and decision makers were confident in their understanding of SoVI® and its limitations, the acceptance of the tool was rapid among all those involved in the recovery. Second, SoVI® turns what we intrinsically know about recovery needs – that marginalized populations without access to goods, services, information, and assistance are less able to rebound from disasters - into an evidenced-based measure that quickly enabled targeted

decision making rather than the typical "one-size fits all" approach often employed during disasters. Third, the successful application of SoVI® for South Carolina demonstrates the significant positive effects of the evidence-based social vulnerability approach in the emergency management cycle, especially in the response and long-term recovery phases. It also adheres to the principal of good governance by helping those most in need first.

References

Burton, C. G. (2010). Social vulnerability and hurricane impact modeling, *Natural Hazards Review 11*(2): 58-68.

Chakraborty, J., Collins, T. W., Montgomery, M. C., Grineski, S. E. (2014). Social and spatial inequities in exposure to flood risk in Miami, Florida, *Natural Hazards Review*, *15*(3): 10.1061/(ASCE)NH.1527-6996.0000140,04014006.

Chen, W., Cutter, S.L., Emrich, C.T. ,Shi, P. (2013). Measuring social vulnerability to natural hazards in the Yangtze River Delta Region, China, *International Journal of Disaster Risk Science* 4(4):169-181.

Collins, T. W., Jimenez, A. M., Grineski, S. E. (2013). Hispanic health disparities after a flood disaster: Results of a population-based survey of individuals experiencing home site damage in El Paso (Texas, USA), *Journal of Immigrant and Minority Health 15*(2):415-426.

Cutter, S.(2006). The geography of social vulnerability: Race, class, and catastrophe. *Understanding Katrina: Perspectives from the social sciences*, http://understandingkatrina.ssrc.org/Cutter/

Cutter, S. L., Boruff, B. J., Shirley, W.L.(2003). Social vulnerability to environmental hazards, *Social Science Quarterly 84*(2):242-261.

Cutter, S. L., Emrich,C. T. (2006). Moral hazard, social catastrophe: The changing face of vulnerability along the hurricane coasts, *The Annals of the American Academy of Political and Social Science*, *604*(1):102-112.

Cutter, S. L., Emrich, C. T., Mitchell, J. T., Boruff, B. J., Gall, M., Schmidtlein, M. C., Melton, G. (2006). The long road home: Race, class, and recovery from Hurricane Katrina. *Environment: Science and Policy for Sustainable Development*, *48*(2): 8-20.

Cutter, S. L., Emrich, C. T., Morath, D. P., Dunning, C. M. (2013). Integrating social vulnerability into federal flood risk management planning, *Journal of Flood Risk Management*, *6*(4): 332-344.

Cutter, S. L., Emrich, C.T., Mitchell, J.T., Piegorsch, W.W., Smith, M.M., Weber, L. (2014a)*. Hurricane Katrina and the Forgotten Coast of Mississippi,* New York: Cambridge University Press.

Cutter, S. L., Schumann III, R. L., Emrich, C. T. (2014b). Exposure, social vulnerability and recovery disparities in New Jersey after Hurricane Sandy, *Journal of Extreme Events*, *1*(01): 1450002.

Dunning. C. M., Durden, S. (2013). Social Vulnerability Analysis: A Comparison of Tools. IRW White Paper. Alexandria, VA: US Army Engineer Institute for Water Resources http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/Social_Vulnerability_Analysis_Tools.pdf

FEMA (2011a). National Disaster Recovery Framework. Accessed from: http://www.fema.gov/media-library-data/20130726-1820-25045-5325/508_ndrf.pdf

Durden, S. E., Wegner-Johnson, M. (2013). Other Social Effects: A Primer. Alexandria, VA: US Army Engineer Institute for Water Resources, Report 2013-R-02 http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/2013-R-02.pdf

FEMA (2008), National Response Framework. Accessed from https://www.fema.gov/pdf/emergency/nrf/nrf-core.pdf.

FEMA (2011a). National Disaster Recovery Framework: Strengthening Disaster Recovery for the Nation. Accessed from http://www.fema.gov/pdf/recoveryframework/ndrf.pdf

FEMA (2011b). A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action. Accessed from http://www.fema.gov/media-library-data/20130726-1813-25045-0649/whole_community_dec2011__2_.pdf

FEMA (2013). National Response Framework, 2nd Edition. Accessed from: http://www.fema.gov/media-library-data/20130726-1914-25045-1246/final_national_response_framework_20130501.pdf

FEMA (2016). Mapping Risks and Vulnerabilities to Increase Resilience Planning. FEMA Mitigation Best Practices. Accessed from: http://www.fema.gov/media-library-data/1461933984986-bbb94b669d354f1bff4420a8272f46df/20-Mapping-Risks-and-Vulnerabilities_web2.pdf

Finch, C., Emrich, C. T., Cutter, S. L. (2010). Disaster disparities and differential recovery in New Orleans, *Population and Environment 31*(4):179-202.

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., Lewis, B. (2011). A social vulnerability index for disaster management, *Journal of Homeland Security and Emergency Management 8*(1).

Guillard-Gonçalves, C., Cutter, S. L., Emrich, C. T., Zêzere, J. L. (2015). Application of Social Vulnerability Index (SoVI®) and delineation of natural risk zones in Greater Lisbon, Portugal, *Journal of Risk Research 18*(5):651-674.

Holand, I. S., Lujala, P., Rød, J. K. (2011). Social vulnerability assessment for Norway: a quantitative approach, *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography 65*(1):1-17.

Hummell, B.L. (2013). Hazards, Social Vulnerability and Resilience in Brazil: An Assessment of Data Availability and Related Research, in S. L. Cutter and C. Corendea (eds.), *From Social Vulnerability to Resilience: Measuring Progress toward Disaster Risk Reduction, Source 17/2013*, Bonn: United Nations University, Institute for Environment and Human Security, pp. 44-63. Online: www.ehs.unu.edu/file/get/11051.pdf

Hummel, B. L., Cutter, S.L., Emrich, C.T. (2016). Social vulnerability to natural hazards in Brazil, *International Journal of Disaster Risk Science*, forthcoming.

Lee, Y. J. (2014). Social vulnerability indicators as a sustainable planning tool, *Environmental Impact Assessment Review* 44*:*31-42.

Nelson, K. S., Abkowitz, M. D., Camp, J. V. (2015). A method for creating high resolution maps of social vulnerability in the context of environmental hazards, *Applied Geography* 63*:* 89-100.

Phillips, B. D., Thomas, D.S.K., Fothergill, A., Blinn-Pike,L. (eds.) (2013). *Social Vulnerability to Disasters*. Boca Raton, FL: CRC Press.

Rufat, S., Tate, E., Burton, C. G., Maroof, A. S. (2015). Social vulnerability to floods: Review of case studies and implications for measurement, *International Journal of Disaster Risk Reduction* 14:470-486.

Schmidtlein, M. C., Shafer, J. M., Berry, M., Cutter, S. L. (2011). Modeled earthquake losses and social vulnerability in Charleston, South Carolina, *Applied Geography* 31(1):269-281.

Siagan, T., Purhadi, P., Suhartono, S., Ritonga, H. (2014). Social vulnerability to natural hazards in Indonesia: driving factors and policy implications, *Natural Hazards* 70(2):1603-1617.

Tate, E., Strong, A., Kraus, T., Xiong, H. (2016). Flood recovery and property acquisition in Cedar Rapids, Iowa, *Natural Hazards 80*(3):2055-2079.

Wood, N. J., Burton, C. G., Cutter, S. L. (2010). Community variations in social vulnerability to Cascadia-related tsunamis in the US Pacific Northwest, *Natural Hazards* 52(2):369-389.

Rapid Mapping of October 2015 South Carolina Flood using Social Media, Remote Sensing and Stream Gauges

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Abstract

The October rain and flooding disaster caused at least 19 deaths, destroyed thousands of homes, and damaged infrastructure across South Carolina. Rapid assessment of flood impact is important for local authorities and emergency responders to quickly identify areas needing immediate attention. However, real-time data collection in the field is often difficult because of often limited accessibility of affected areas during and immediately following disaster as lifesaving missions take place. Satellite remote sensing provides a partially one effective way of collecting quantitative information for a large spatial extent such as the flooded areas across South Carolina. However, the long revisit cycle of satellites makes it less useful to provide real-time impact assessment. Recently, social media and volunteered geographic information (VGI) were used to assess the disaster impact because these data capture micro-level, real-time information via "human-as-sensors". However, solely relying on social media for the assessment causes concerns of uncertainty and validity. This paper introduced a novel approach to rapid map the October 2015 South Carolina floods by combining near-real time social media data (tweets), remote sensing data (satellite imagery), and stream gauge data. We first summarized the identified spatiotemporal patterns of the citizen-sensed tweets and remote-sensed land surface wetness for better understanding of the social (twitter activity) and physical (land surface wetness) dynamics related to the floods. A flood mapping model is then introduced by combining the multiple data sources and identified spatial patterns. The model is preliminarily evaluated by visually comparing the model output with the official USGS inundation maps.

Keywords: social media, flood mapping, remote sensing, volunteered geographic information

1. Background

During early October 2015, South Carolina experienced widespread historical rainfall caused by an upper atmospheric low-pressure system that funneled tropical moisture from Hurricane Joaquin (Jonathan et al., 2016; Feaster et al., 2015). Some areas (e.g. Mount Pleasant) received over 25 inches record-breaking rainfall over the four-day period (Brennan et al., 2015). The storm led to the devastating floods across central and eastern South Carolina, which caused at least 19 deaths, destroyed thousands of homes, and damaged infrastructure across the state. The estimated agricultural losses alone could conservatively be at least $300 million, with cleanup costs across the State possibly topping $1 billion (Feaster et al., 2015).

Rapid flood mapping and impact assessment is crucial for emergency responders to gain better situation awareness during the event, and thus to quickly identify areas needing immediate attention (Smith et al. 2015). In addition, the ability to rapidly assess flood impacts has a positive effect on recovery and resilience for society, business, and the environment (REF). However, traditional approaches normally require months of processing and quality assurance before the final flood extent and water depth can be mapped and losses calculated. For example, the official flood-inundation maps by the United States Geological Survey (USGS) for the South Carolina floods of 2015 was first released on February 22, 2016, four months after the flooding event[1].

One of the major challenges for rapid flood mapping is the limited data available during or right after the flooding event. Traditional data sources used for flood mapping include field data, stream gauge data, and remote sensing data. Data collection in field is often difficult because of the limited accessibility in affected areas during the immediate disaster and the time following it when lifesaving is paramount and others are kept out of impact areas. Stream gauge data are also not useful when water level either rises beyond the limit of ground-based gauges or the gauges themselves are washed away in the flood. Satellite remote sensing provides an effective way of collecting quantitative information for a large spatial extent such as the flooded areas across South Carolina. However, the long revisit cycle of satellites makes it less useful to provide real-time impact assessment. Voluntary Geographic Information (VGI) draws upon the concept of collaborative user-generated content through crowdsourcing, by which many users with varying levels of expertise contribute geographic data via the web (Goodchild 2007a, 2007b; Hopfer and MacEachren 2007; Crampton 2009; Ashktorab et al. 2014). As one major category of VGI, geo-referenced social media data, such as that generated through Twitter, is emerging as a new data source for disaster management (Ashktorab et al. 2014, Imran et al. 2013, Sakaki et al. 2010), and it has been increasingly used for both collecting and disseminating information during natural disasters (Smith et al. 2015).

Despite the promising practicality, using social media data/VGI for flood assessment is relatively nascent in the literature. For example, Fohringer et al. (2015) integrated the water

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[1] https://pubs.er.usgs.gov/publication/ofr20161019

levels derived from social media (Twitter and Flickr) and stream gauge to quickly generate flood inundation maps, demonstrating that social media provide data more rapidly than traditional sources for flood mapping. McDougall and Temple-Watts (2012) utilized the high water marks collected from the crowdsourced photos and high resolution digital aerial imagery in conjunction with river gauge data to map the flood extent and inundation. Alone this line, combining the non-authoritative social media/VGI data with traditional remote sensing to enhance the flood mapping was further explored for different flood cases (Schnebele and Cervone, 2013; Schnebele et al., 2014).

Inspired by previous studies, and considering the pros/cons of different available data sources, in this research we combine the social media data (tweets), remote sensing data (satellite imagery), and stream gauge data into an integrated modeling framework to rapidly estimate the extent of the October flood in South Carolina. This paper briefly describes our approach and the preliminary result.

2. Data Collection and Preprocessing

Twitter data: A total of 1,279,325 georeferenced tweets were collected from October 1st to October 18th 2015 within the bounding box covering South Carolina using both Twitter Stream API[2] and Twitter REST API[3]. 4268 flood-related tweets containing the keywords "*flood*" or "joaquin" in either message or hashtags were extracted. The wildcard "*" is used to include other variants of "flood" such as "floods" and "flooding". Figure 1 shows the spatial distribution of the flood-related tweets.
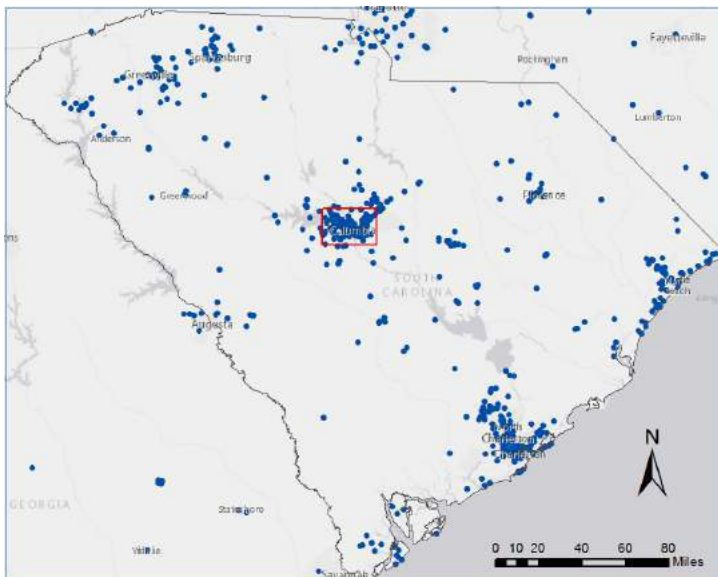
Figure 1. Flood-related georeferenced tweets in South Carolina. Red rectangle indicates the Study Area (Columbia area).

Stream Gauge data: Six USGS Stream gauge stations located within the study area are selected (Figure 2). The data for the five stations were recorded at 15-minute interval and are available from the USGS National Water Information System (USGS, 2016). We developed a JAVA program to fetch the quarter-hourly gage height data from October 1st to October 18th 2015 for each station and stored in a MySQL database to be used for pattern analysis and modeling.

Remote Sensing data: Among all medium- and high-resolution optical systems, we found one image scene acquired on October 8, 2015: the EO-1 Advanced Land Imager (ALI) by NASA. The ALI image has 30-m resolution with a 37-km swatch, which is downloaded from USGS data center. Given its relatively high resolution, this imagery is used for exploring the spatial patterns of land surface wetness during the flood period in the study area. NLCD 2011 land use/cover data is used for reducing the bias for spatiotemporal pattern analysis. (NLCD 2011)

DEM data: 10-foot cell size DEM (Digital Elevation Model) for Lexington and Richland county of South Carolina was retrieved from South Carolina Department Natura Resources (SCDNR, 2016). Derived from light detection and ranging (LiDAR) data, the DEM has 18.5 cm vertical RMSE to support 2-foot contours, 1.0 meter horizontal RMSE, and 95 percent confidence level of accuracy, referencing to a vertical datum of NAVD88[4]. The two DEM files are merged and extracted for the study area using ArcMap.

3. Spatiotemporal Patterns

In this study, we first explored the spatiotemporal patterns of the citizen-sensed tweets and remote-sensed land surface wetness using quantitative approaches to better understand the social (twitter activity) and physical (land surface wetness) dynamics related to the October South Carolina floods. The identified patterns are leveraged to design the weighting scheme in the flood mapping model. Here we summarized our findings as following:

i)   People tend to tweet more about flood when the flooding magnitude increases during the flooding event: significant positive correlation is observed between the number of flood-related tweets and the magnitude of the flood (indicated by stream gage height) over the course of the event (temporal dimension).

ii)   People who are closer to the flooding area tend to tweet more about flood (this is not only true for large spatial scale, but also true in the community level): significant negative correlation is observed between number of flood-tweets (density) and the distance between the tweets and the inundated area (spatial dimension).

iii)   Locations that are closer to the flooding area tend to have higher land surface wetness: significant negative correlation is observed between Normalized Difference Wetness Index (NDWI) and the distance to the flooding area.

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[4] http://www.ngs.noaa.gov/datums/vertical/

4. Mapping the Flood

In this section, we introduce a model for rapid estimation of flood extent. The proposed model takes the following data as input: Water Height Points (WHPs) derived from tweets and stream gauges, flood-related tweets, Normalized Difference Wetness Index (NDWI) raster derived from the EO-1 ALI image, and 10-ft DEM. The final output is a Flood Possibility Index (FPI) surface covering the whole study area. The FPI surface indicates the possibility of being inundated for each location (raster cell) in the study area.

4.1.1. Water Height Point

A Water Height Point (WHP) serves as the best estimation of a flooding situation at a specific location and time based on limited data sources. The model takes a set of WHPs as the initial input. In this research, WHPs are extracted from two sources: tweets and stream gauges. All georeferenced flood-related tweets within the study area were manually checked to select the tweets that indicate flooding. Water height was then estimated for each selected tweet based on the text description and/or visually examination of the photos. Finally, 26 tweets are identified showing flooding situation within the Columbia study area, and 26 WHPs are estimated based on these tweets. In addition, 5 WHPs are derived from the selected stream gauges, using the maximum gauge height as the water height for each gauge location. Figure 3 shows the examples of four different types of WHPs.
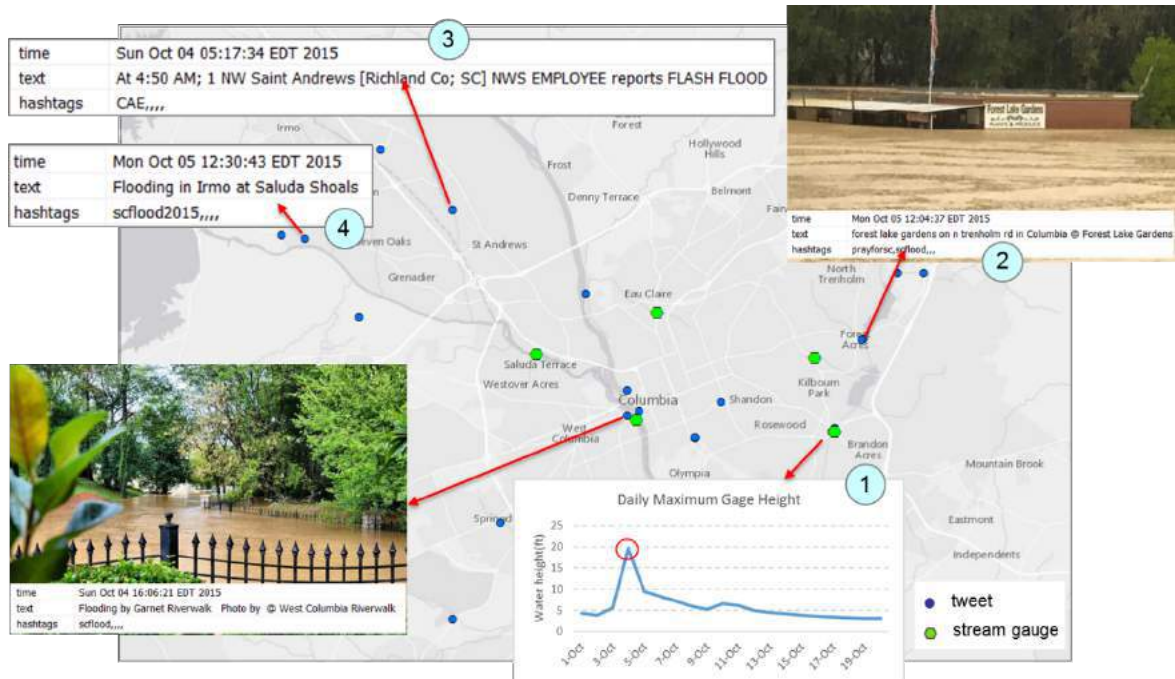
Figure 3. Examples of different types of water height points (WHPs): (1) peaked water height from stream gage (19.57ft); (2) estimated water height based on tweet photo (6.0ft); (3) official flash flood report based on tweet text (0.5ft); (4) unofficial flood description based on tweet text (0.5ft)

4.1.2. Generating FPI surface based on one WHP

If a location p is known to be flooded (e.g. indicated by a WHP), we assume the following statements are true:

- locations closer to location p have a higher chance to be flooded (First law of geography, distance decay)

- locations with lower elevations (relative to p) have a higher chance to be flooded (Law of gravity, nature dictates that water must flow downhill), this effect also follows distance decay.

Based on the two statements, we define a flood possibility index for each location i based on WHP p as Formula 1.

$$FPI_{pi} = (h_{pi})^a \cdot \frac{1}{(d_{pi})^b} \qquad \text{Formula 1}$$

Where, d_{pi} is the Euclidian distance from WHP p to location i. h_{pi} is the water height for location i based on the water height of p (Figure 4), which is calculated with Formula 2. a and b are constant factors ($a > 0$, $b > 0$) used to adjust the impact magnitude of water height and distance. In this study, we set $a = 0.5$, $b = 1.0$.

$$h_{pi} = \max\left\{\left(h_{wp} + h_p \quad h_i\right), 0\right\} \qquad \text{Formula 2}$$

Where h_{wp} denotes the water height of WHP p, and h_p and h_i denote the elevation of location p and i respectively (Figure 4). The *max* operator is used to set h_{pi} to **0** if $h_{wp} + h_p - h_i < 0$. The rationale of doing this is if the elevation for a location is higher than the WHP derived water surface, that location is unlikely to be flooded based on this WHP.
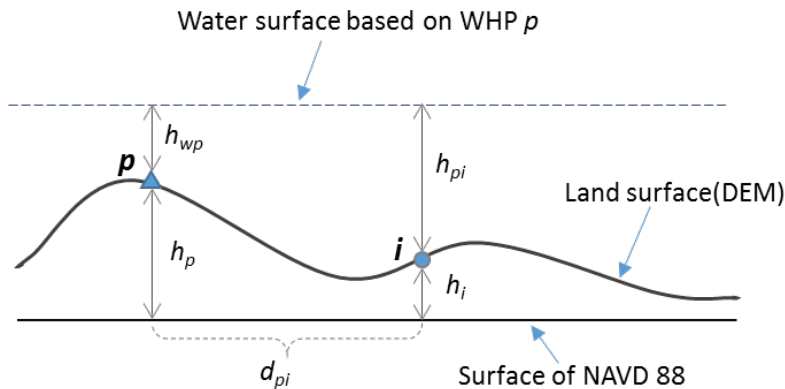
Figure 4. Illustration of the variables used in Formula 1&2. WHP p is represented with ▲, and location i is represented with ●. The dash line represents the water surface based on WHP p.
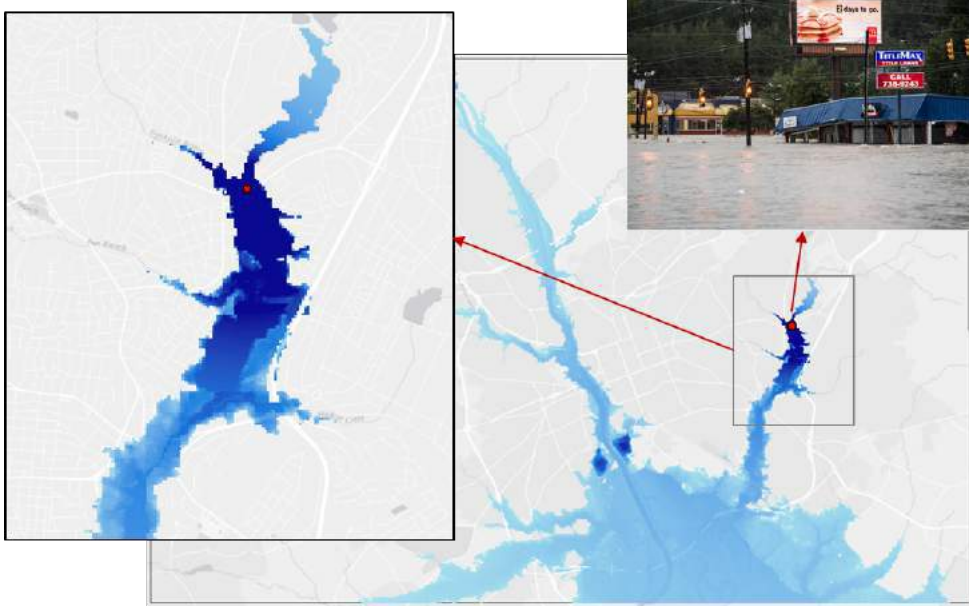
Figure 5. Example of the FPI surface based on a tweet-derived WHP (dark blue indicates high possibility of be flooded)

Once the FPI for every location (raster cell) of the study area is computed, a FPI surface is produced based on WHP p. Figure 5 shows an example of FPI surface based on a WHP derived from a Twitter photo (red dot). Blue area indicates the flooded area, dark blue (high FPI) show high possibility of being flooded. Such a map serves as a good estimation of the flooding situation if this WHP is the only data available at that time and location.

4.1.3. Generating the final FPI map based on all WHPs

Using the method described above, a FPI surface is generated for each WHP. In this study, 31 FPI surfaces are produced. Since each map provides an independent estimation of the flood possibility for each location in the study area (raster cell), strategically combining them together is able to provide a comprehensive estimation of the flooding situation. To archive this, a weighted summation is performed for all the FPI surfaces to produce the final FPI map S (Formula 3).

$$S = \sum_{p=1}^{n} \left(S_p \cdot w_p \right) \qquad \textit{Formula 3}$$

Where S_p denotes the FPI surface (a raster map) generated from WHP p, w_p denotes the weight (a numeric value) for the WHP p, and $\mathbf{n}$ is the number of WHPs. $S_p \times w_p$ is a Map Algebra (Tomlin, 1994) operation where each cell value in S_p is multiplied by the numeric value w_p. The summation is performed for all FPI surfaces on a cell-by-cell basis. The weight w_p is defined with Formula 5.

$$w_p = \frac{w_{p\_den}}{\sum_1^n w_{p\_den}} + \frac{w_{p\_wet}}{\sum_1^n w_{p\_wet}} + \frac{w_{p\_src}}{\sum_1^n w_{p\_src}} \qquad \textit{Formula 4}$$

Where, w_{p_den}, w_{p_den} , and w_{p_src} are three weighting factors based on the flood-related tweet density, land surface wetness (NDWI), and data source types for each WHP. The first two weighting factors are based on the spatial patterns described in Section 3, specifically, we assume the following two statements are true:

- locations with higher flood-related tweet density indicates high possibility of being flooded
- locations with higher land surface wetness indicates high possibility of being flooded

To reduce uncertainties, w_{p_den} and w_{p_den} are kernel-based weights by considering the neighboring values weighted by the inverse distance (Formula 5 &6).

$$w_{p\_den} = \sum_{i=1}^{m} den_i \times \frac{1}{d_{pi}} \qquad Formula\ 5$$

$$w_{p\_wet} = \sum_{i=1}^{m} wet_i \times \frac{1}{d_{pi}} \qquad Formula\ 6$$

Where i denotes a location in the study area, m denotes the number of locations (raster cells). den_i and wet_i denote the flood-related tweet density and land surface wetness at location i respectively, and d_{pi} denotes the distance from WHP p to location i.

The third weighting factor w_{p_src} is based on the reliability/quality of different types of WHP. In this study, we set the weight as following: w_{p_src} = 3.0 for WHP derived from stream gage, 2.5 for WHP from official flash flood report, 2.0 for WHP from tweet photo, 1.5 for WHP from tweet text.

5. Preliminary Result and Evaluation

The model is implemented using ArcPy[5] by programmatically chaining a series of ArcGIS geoprocessing tools such as *RasterCalculator*, *EucDistance* and *KernelDensity*. Taking the water height points, flood-related tweets, land surface wetness (NDWI) image, and DEM as the input, this model produced a Flood Possibility Index (FPI) map with cell values normalized from 0 to 100 (Figure 6). More than binary outputs such as flooded or not in each cell, this FPI map represents a continuous rank of estimated flooding conditions across the study area.

Larger value (darker blue area in Figure 6) indicates higher possibility of being flooded. Note that the FPI does not equal to the probability of being flooded or not, though it indicates the possibility of being flooded. In other words, we cannot infer that a location with FPI=50 has a 50% chance of being flooded; instead, it means that this location has a medium degree possibility of being flooded comparing to other locations within the modeling area. As illustrated in Figure 6, the high flood-possibility areas are distributed along the streams with relatively low elevation. Areas around WHPs show highest possibility, which is expected because WHPs represent flooded locations.
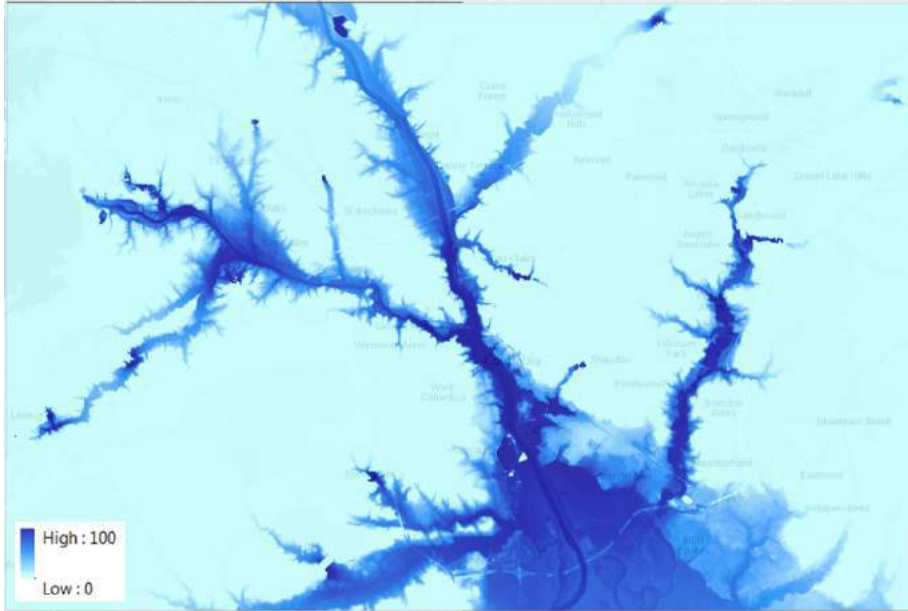
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[5] http://pro.arcgis.com/en/pro-app/arcpy/get-started/what-is-arcpy-.htm

Figure 6. Final flood possibility index (FPI) map

In order to evaluate the FPI map, we compared it with the USGS inundation maps (available at https://pubs.er.usgs.gov/publication/ofr20161019) (Figure 7). By visually comparing the two maps, we can see that the dark blue areas of the FPI map generally matches the inundated areas in the inundation map within the USGS mapping boundary.
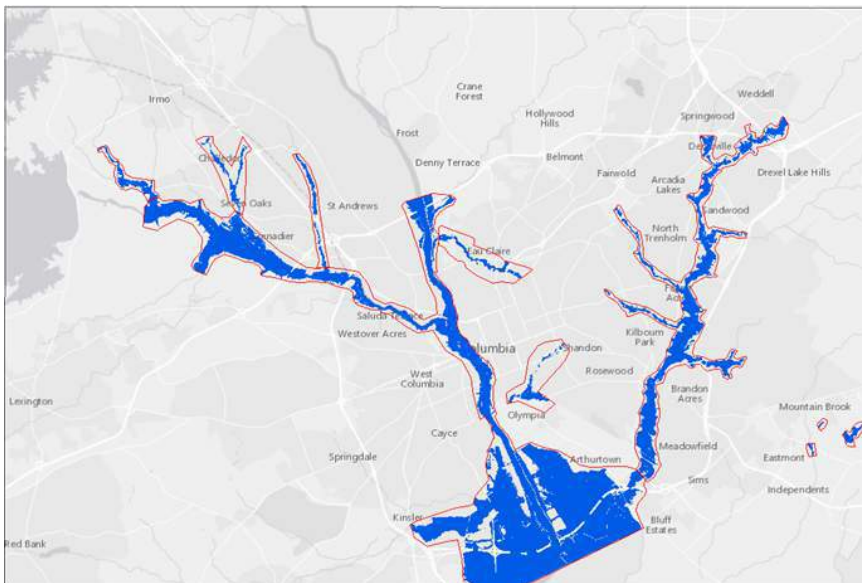

Figure 7. USGS inundation maps (red lines indicate the mapping boundary)

6. Conclusion

This paper introduced a novel approach for rapid mapping the October 2015 South Carolina floods by combining near-real time social media data (tweets), remote sensing data, and stream gauge data. We first summarized the identified spatiotemporal patterns of the citizen-

sensed tweets and remote-sensed land surface wetness for better understanding of the social (twitter activity) and physical (land surface wetness) dynamics related to the October floods. A flood mapping model is developed by integrating multiple data sources and the identified spatial patterns. The feasibility and accuracy of the model is preliminarily evaluated by visually comparing the model output with the official USGS inundation maps. The FPI map, which can be quickly generated, is helpful for improving the situational awareness during or right after the flooding.

In this study, we visually examined the flood-related tweets to identify the flooding evidence (information) on the ground, and then use such information to generate the water height points (WHP). These WHPs are assumed to be the "ground truth" of flooding. Even though we used a weighting factor to consider different reliability levels of WHPs, the reliability and trustworthy of the crowdsourced WHPs requires rigorous investigation. For example, field work is needed to verify location on ground for each WHP as a way to provide a measure of accuracy or validation. Trusted data not only helps us understand today's impacts but also paves the way for future situational awareness application of social media data.

References

Ashktorab, Z.; Brown, C.; Nandi, M.; Culotta, A. (2014) Tweedr: Mining twitter to inform disaster response. In Proceedings of the 11th International ISCRAM Conference, University Park, PA, USA, 18–21 May 2014.

Brennan A., Carbone G., Dow K., Fly L., P. Gao, Konrad C., Lackstrom K. and Tufford D. (2015), The South Carolina Floods of October 2015, available online at: http://www.cisa.sc.edu/PDFs/October%202015%20Flood%20Event%204%20Pager.pdf, last accessed on June 20, 2016

Feaster, T.D., Shelton, J.M., and Robbins, J.C., 2015, Preliminary peak stage and streamflow data at selected USGS streamgaging stations for the South Carolina flood of October 2015 (ver. 1.1, November 2015): U.S. Geological Survey Open-File Report 2015–1201,19 p., last accessed on June 20, 2016, http://pubs.usgs.gov/of/2015/1201/ofr20151201.pdf

Fohringer, J., Dransch, D., Kreibich, H., & Schröter, K. (2015). Social media as an information source for rapid flood inundation mapping. Natural Hazards and Earth System Sciences, 15(12), 2725-2738.

Goodchild, M.F. (2007a). Citizens as voluntary sensors Spatial data infrastructure in the world of web 2.0. International Journal of Spatial Data Infrastructures Research 2: 24-32.

Goodchild, M.F. (2007b). Citizens as sensors: the world of volunteered geography. GeoJournal 69(4): 211-221.

Goodchild, M.F. and J. A. Glennon (2010). Crowdsourcing geographic information for disaster response: a research frontier. International Journal of Digital Earth 3(3): 231 - 241.

Imran, M., et al., 2013. Extracting information nuggets from disaster-related messages in social

media. In: Proc. of ISCRAM, Baden-Baden.

Jonathan W. Musser, Kara M. Watson, Jaime A. Painter, and Anthony J. Gotvald, 2016, Flood-Inundation Maps of Selected Areas Affected by the Flood of October 2015 in Central and Coastal South Carolina, ISSN 2331-1258 (online) http://dx.doi.org/10.3133/ofr20161019

McDougall, K., & Temple-Watts, P. (2012). The use of LiDAR and volunteered geographic information to map flood extents and inundation.ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 1, 251-256.

Sakaki, T., Toriumi, F., & Matsuo, Y. (2011, December). Tweet trend analysis in an emergency situation. In Proceedings of the Special Workshop on Internet and Disasters (p. 3). ACM.

SCDNR, 2016, http://www.dnr.sc.gov/GIS/lidar.html

Schnebele, E., & Cervone, G. (2013). Improving remote sensing flood assessment using volunteered geographical data. Natural Hazards and Earth System Sciences, 13, 669-677.

Schnebele, E., Cervone, G., Kumar, S., & Waters, N. (2014). Real time estimation of the Calgary floods using limited remote sensing data. Water,6(2), 381-398.

Smith, L. C. (1997). Satellite remote sensing of river inundation area, stage, and discharge: A review. Hydrological processes, 11(10), 1427-1439.

Smith, L., Liang, Q., James, P., & Lin, W. (2015). Assessing the utility of social media as a data source for flood risk management using a real-time modelling framework. Journal of Flood Risk Management.

Tomlin, C. D. (1994). Map algebra: one perspective. Landscape and Urban Planning, 30(1-2), 3-12. Chicago

Triglav-Čekada, M., & Radovan, D. (2013). Using volunteered geographical information to map the November 2012 floods in Slovenia. Natural Hazards and Earth System Sciences, 13(11), 2753-2762.

USGS 2016, http://waterdata.usgs.gov/nwis/rt, last accessed on June 27, 2016

Wang, C., Li, Z., Emrich, C. in this report., Remote sensing of surface wetness dynamics during the October 2015 South Carolina Flood, Congaree River Watershed.

Remote sensing of surface wetness dynamics during the October 2015 South Carolina Flood, Congaree River Watershed

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Abstract

While intensive real-time, in-field data collection is not realistic during the flood, remote sensing monitors the event through a synoptic view of Earth surface changes. Following the October 2015 South Carolina Flood event, this study utilizes two medium-resolution satellite images (October 8 and 18) to spatially evaluate flood risks in the Congaree River Watershed at the downstream of Columbia, SC. With a normalized difference wetness index (NDWI), the flooded and highly wet areas are mapped and their changes within 10 days are examined. Integrated with social media data, satellite-extracted spatial information could help us better assess the flood severity and assist the resilience of our society responding to this extreme disaster.

Keywords: the October'15 SC Flood; satellite image; flooding extent; Congaree River Watershed

Introduction

Spatial extents and temporal dynamics of a flooding event are important for rapid risk assessment and post-disaster damage evaluation. In the October 2015 South Carolina Flood event, the Congaree River Watershed at the downstream of Columbia, SC was severely flooded due to intense and large amounts of precipitation. According to the US Geological Survey stream flow records, the Congaree River near the city reached its peak flow at 185,000 cubic feet per second (cfs) on October 4 (Musser et al., 2016). Widespread flooding occurred in many parts of the city and a vast number of flood reports, containing rich geospatial information quickly became available to local authorities. Social media such as Twitter also became a popular online resource for real-time flooding records. However, these field observations were mostly location-based and isolated across the city. With limited points, we could simulate flood development in a spatio-temporal dimension using bathtub-type models, but areas without observations merely rely on model performance.

Satellite observations, on the other hand, provide a synoptic view of Earth surface changes in a large spatial extent. When atmospheric conditions allow (e.g. without heavy cloud cover), satellite images provide continuous coverage of flooded areas within the city and watershed. Images collected at different dates give a straightforward view of flooding development in this period. More than binary outputs such as flooded or not in each cell, multi-spectral imagery could extract a variety of indices to quantify flooding conditions across the spatial coverage. Ji et al. (2009), for example, reviewed a set of water indices for extracting water surfaces from spectral bands of red, green, near-infrared (NIR), and shortwave-infrared (SWIR). They found that the green-SWIR normalized difference wetness index (NDWI) optimally reflected moisture conditions and water boundaries in medium-resolution satellite images. In vegetated lands, our past study also showed that SWIR is most sensitive to surface moisture because of water absorption in this band (Wang et al. 2008).

This study aims to apply the NDWI to assess the spatial extents and temporal dynamics of the SC Flood with two satellite images between October 8 and18, 2015. Assisted with Twitter data, wetness levels are defined to rank the flooding risk, especially flash floods, in the study area. The change of land surface moisture within 10 days is also spatially and statistically evaluated.

Materials and methods

The study area is the upper Congaree River Watershed, an urban watershed at the downstream of Columbia, SC. The northwestern part of Columbia is also included (Fig.1). Two medium-resolution satellite images were acquired in the watershed. Since the peak event occurred on October 4-5, these images represented two post-flooding stages to examine the flooding retreat and land surface moisture movement. Land use and cover patterns of the study area was retrieved from the 2011 National Land Cover Database (NLCD) product. Twitter data served as reference in this study. Among 1,269 tweets collected from our colleagues in the research team, only 37 points were verified with flooding (Li et al., in this report). Therefore, these 37 points are assumed ground "truthing" to be compared with our satellite-extracted results.

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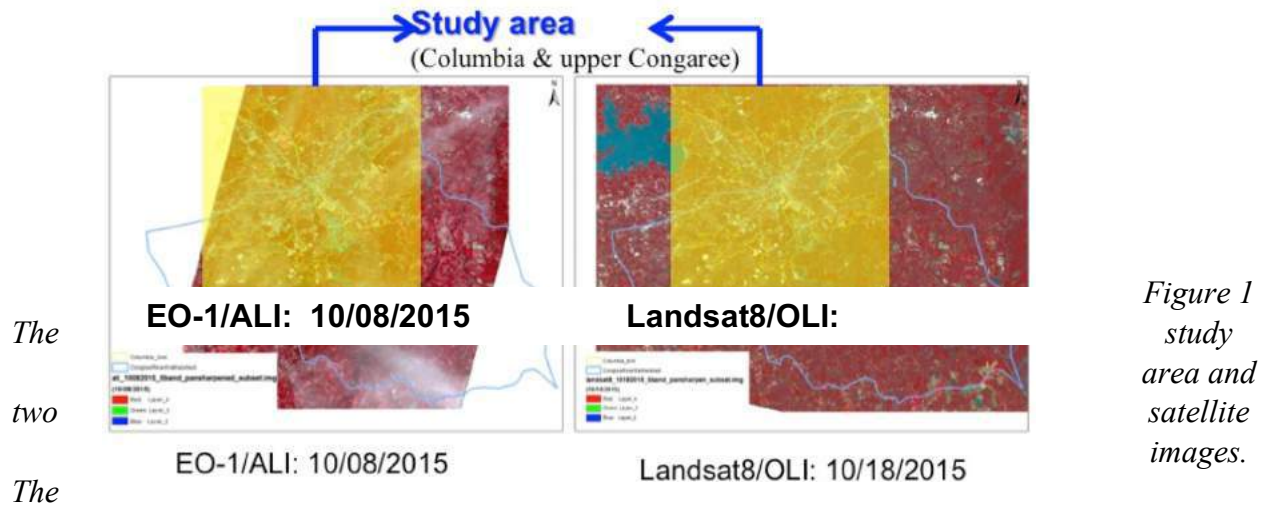
Figure 1 study area and satellite images.

EO-1/ALI: 10/08/2015   Landsat8/OLI: 10/18/2015

boundaries of the Congaree River Watershed and Columbia are marked in the figure.
Both the EO-1 ALI image on Oct. 8 and Landsat8 OLI image (surface reflectance) on Oct. 18 have 30-m resolution for multi-spectral bands. The panchromatic band of ALI image has 10-m resolution and that of OLI image is 15-m. To reach higher spatial resolution, both images were pan-sharpened and re-sized to 10-m resolution. Since the downloaded OLI image has been atmospherically corrected, the ALI image was statistically adjusted by matching its histogram to the OLI image. In this way brightness in the two images were calibrated to the same level.
Here we adopt the NDWI to reflect land surface wetness in the study area. As discussed in Jie et al. (2009), it is the most stable index for extracting water surfaces from satellite images. With their green and SWIR bands, the NDWI is calculated as:

$$NDWI = (\frac{\rho_{green} - \rho_{SWIR}}{\rho_{green} + \rho_{SWIR}}) * 1000 + 1000 \qquad (1)$$

where ρ_{green} and ρ_{SWIR} are surface reflectance of green and SWIR band, respectively. A scale factor of 1000 is used to scale up NDWI from its [-1,1] range to [0, 2000].

The NDWI is positively related to land surface wetness. Cells with higher NDWI represent more moist conditions. Water bodies have the highest NDWI and could be easily delineated. By visually interpreting the NDWI image and the verified 37 Tweeter points, we define the wetness ranks in a step of 50 and group them into 5 levels (Table 1). The last level (Water) is natural water bodies and flooded areas. The High Wet level represents land surfaces that are not 100% flooded in a cell, but are under high risk of flooding because of its high moisture content.

Table 1 The NDWI-extracted wetness levels in the two images.

Rank	Wetness level	NDWI range	
		ALI image[*]	OLI image
1	Low	<500	<500
2	Low	500-600	500-800
3	Low	600-650	800-850
4	Medium	650-700	850-900
5	Medium	700-750	900-950
6	Medium	750-800	950-1000
7	Wet	800-850	1000-1050
8	Wet	850-900	1050-1100
9	High Wet	900-950	1100-1150
10	High Wet	950-1000	1150-1200
11	Water	>1000	>1200

*The histogram-matched ALI is visually darker than OLI. Testing with randomly selected water bodies, non-flooded surfaces (with different land uses) and the 37 Tweet locations, we find that the ALI/NDWI is about 200 lower than the OLI/NDWI.

Results and Discussion

The wetness level maps from the ALI and OLI images are extracted based on the NDWI ranks in Table 1. As shown in Fig.2, urban areas of Columbia are under much higher risk than downstream in the Congaree River Watershed. Water retreat along the river in the southeastern Columbia is apparent. Land surfaces that were flooded under High Wet rank (dark blue), however, were increasing outward of the city.
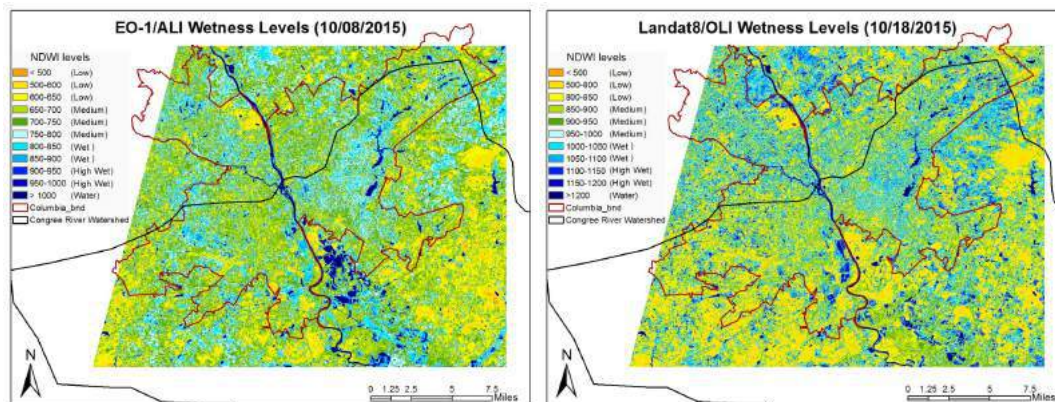
Figure 2 The Wetness Level maps of the study area. The darker blue tone represent areas that are flooded or under high risk (High Wet) of flooding.

Overlaid on the 2011 NLCD map, areas at three wetness levels (Wet, High Wet, and Water) and under different land uses (e.g., urban vs. rural, built-up vs. agricultural) are extracted (Fig.3).

From Oct. 8 to 18, flooded water (dark blue) retreated, especially in the circled areas. However, the overall wetness increased, with more High Wet (bright blue) areas observed off **the urban center of Columbia on Oct. 18.**
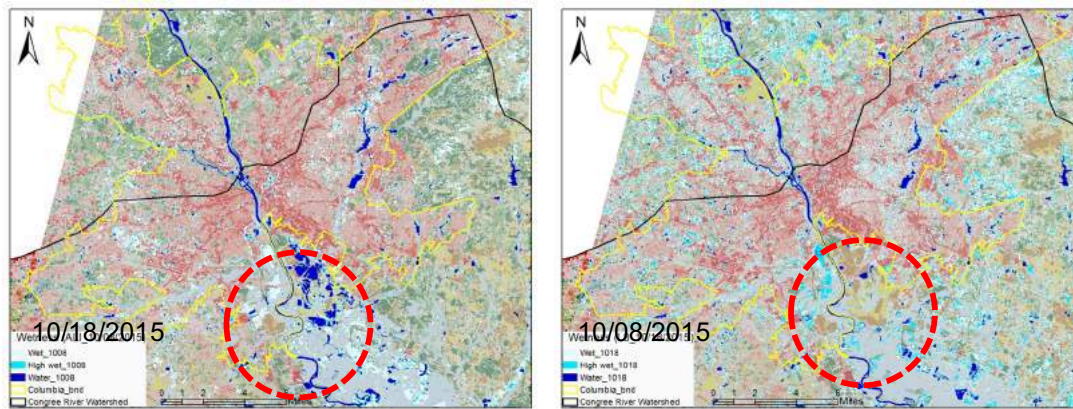

Figure 3 Areas of three wetness levels (Wet, High Wet, Water) overlaid on the 2011 NLCD map.
The wetness in Fig.3 shows a transition of surface wetness distributions from impervious surfaces in Columbia city on 8th to pervious surfaces of downstream on 18th. It is reasonable because developed lands quickly dry up after rain stops, while soil moisture remain for a longer time in vegetated lands. For risk assessment purpose, these High Wet areas deserve our attention because soil water content is approaching to its saturation point, which may result in flash flood in a short term or other damages in a long run.

Summarizing areal coverage of each rank in the study area, wetness change is apparent in the column chart (Fig.4). Although flooded/water areas were apparent on Oct. 8 (as shown in Fig.2 and Fig.3), majority of land surfaces on that day were actually in low-medium ranks. By Oct. 18, areas in Wet and High Wet ranks dramatically increased and those in medium rank decreased.

The flooded water did not change much, but lands in rank 2 (low) greatly increased, reaching to more than 20,000 ha. This indicates the settling of surface wetness after the flood event. The normality of the distributions on both dates remains the same with their mode in rank 5, confirming that the ALI- and OLI-thresholding table (Table 1) is valid and the results from the two images are comparable.
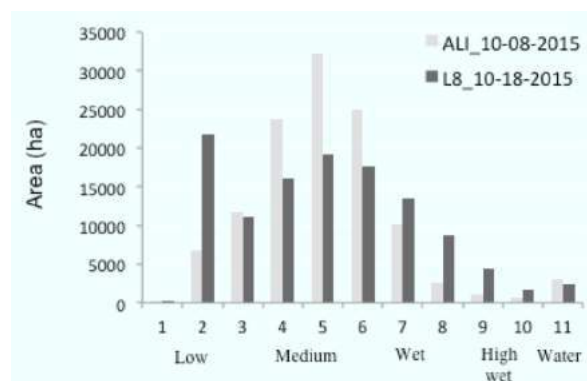
Figure 4 Areas of all ranks in the study area

Finally, the two wetness level maps are compared with the 37 verified tweets. Because people generally take a photo of something in the distance, especially in relation to flood waters, we presume that the tweet locations are not the exact locations of flood water. To account for these spatial differences, we compared the results at tweeted locations and those within a 150-m buffer centered at the tweets points (Table 2). A buffer is defined as a 31x31 window around a tweets point, and the wetness level of this point is assigned based on the maximal NDWI of the buffer.

Table 2 Comparison of the two satellite-extracted results against tweets data.

Image	Date	Tweeted locations					Total
		Wetness levels					
		Low	Medium	Wet	High Wet	Water	
ALI	10/08/2015	2	24	9	1	1	37
OLI	10/18/2015	4	23	7	5	0	37
		Maximal NDWI locations within 150-m buffer					
ALI	10/08/2015	0	2	**11**	**10**	**14**	37
OLI	10/18/2015	0	0	**6**	**9**	**22**	37

As expected, the comparison at the exact tweeted locations did not work. Given the locational differences between the tweeter and the actual flooding event, the 2nd comparison fairly reflected the effectiveness of satellite-assisted wetness level maps. The 37 tweets were verified floods during the event. Majority of the tweeted locations are recognized in the Wet, High Wet and Water levels in the table (highlighted in bold). The OLI results have the highest number of locations with Water. Note that most of these tweets were dated back on Oct. 4 and 5. It has been reported that floods in the city of Columbia were mostly flash flood events. Coming from high amount of precipitation, when a flash flood quickly developed and retreated, areas around this flood still hold high wetness levels that represent high risk of flooding. This study indicates that the real-time tweets data could serve as validation source for satellite assessment of flash floods. With two satellite images, this preliminary study spatially evaluates surface wetness patterns and their temporal dynamics in Columbia/Congaree River Watershed. Assisted with spatial databases of infrastructure network, flooded areas and risk levels along roadways, bridges and dams can be quantified. Broken dams and severity of damages are thus interpreted. Integrated with factors in human dimension that cannot be captured in imagery, satellite-extracted spatial information could help us better assess the flood severity to assist resilience of the society and environment responding to this extreme disaster.

Conclusion

This study conducts satellite image analysis to spatially evaluate post-flood wetness dynamics in Columbia, SC and the upper Congaree River Watershed. With a normalized difference wetness index, surface wetness levels are categorized from two satellite images acquired on Oct. 8 and 18, 2015, in which water and highly wet areas represent high risk for flash flood watch. Within 10 days after peak flooding, wetness patterns transited from impervious to pervious lands. While urban lands dried up, the highly wet areas in the watershed deserve further attention for assessment of long-term flood effects to the watershed.

References

Li, Z., C. Wang, C. T. Emrich, and D. Guo, in this report. Integrating social media and remote sensing for rapid flood mapping: a case study of October Flood in South Carolina.

Ji, L., Z. Zhang, and B. Wylie, 2009. Analysis of dynamic thresholds for the normalized difference water index. *Photogrammetric Engineering and Remote Sensing*, 75 (11): 1307-1317.

Musser, J. W., K. M. Watson, J. A. Painter, and A. J. Gotvald, 2016. Flood-inundation maps of selected area affected by the flood of October 2015 in Central and Coastal South Carolina. Open-file Report 2016-2019, U.S. Dept. of the Interior, U.S. Geological Survey.

Wang, C., Z. Lu, and T. L. Haithcoat, 2007. Using Landsat images to detecting forest dynamics responding to oak dieback in the Mark Twain National Forest, Missouri. *Forest Ecology and Management*. 240(1-3): 70-78.

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The Center for Resilience Studies is a policy research center within Northeastern University's College of Social Sciences and Humanities and is a major activity of the George J. Kostas Research Institute for Homeland Security. The Center is committed to informing and advancing societal resilience around the globe. Communities, companies, and countries can thrive only if the systems and networks that underpin our daily lives, whether physical, technological or social, are able to better withstand, recover from, and adapt to inevitable shocks and disruptive events. Established in 2013, the Center's mission is to learn from disasters and, through partnering with other leading academic research institutions, nonprofits and the public and private sectors, use what is learned to help devise and apply practical, interdisciplinary solutions to resilience-building challenges.

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