

A Strategic Approach to Flood Risk Management

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ABSTRACT

Between 2015 and 2019, 3,475 deaths occurred, and nearly \$400 billion dollars of damage was incurred due to flooding and tropical cyclones in the United States. Despite several initiatives at the federal level, a unified national strategy for flood risk management does not exist in the United States. The approach also varies widely from state to state. Since all communities in a watershed are tied together through river systems, water resource management must take place on a regional basis. This paper outlines the current structure of flood risk management in the U.S., examines present needs, and suggests an organizational restructuring to provide for a more strategic approach to infrastructure security. Chief among the recommendations is to consolidate overlapping federal agencies, create a clear hierarchy of flood risk management at all levels of government, mandate participation in national programs, and require that states take an active role in flood risk planning and infrastructure management.

Keywords: flooding, risk management, infrastructure, dams, cybersecurity, natural disasters

Introduction

Extreme flooding has been witnessed across the United States in recent years. Whether the result of hurricanes, heavy rain and rapid snow melt, or other extreme events, flooding routinely causes serious injuries and death, multiple billions of dollars in damages, and general upheaval in peoples' day to day lives. Between 2015 and 2019, 3,475 deaths occurred and nearly \$400 billion dollars of damage was incurred due to flooding and tropical cyclones (NOAA National Centers for Environmental Information, 2020). In examining the cost-benefit ratio of investment in flood risk management infrastructure, the National Institute of Building

Sciences estimates that one dollar of federal grant funding leverages an average of seven dollars in savings (Multihazard Mitigation Council, 2018). In areas with known high flood hazards, such as along the Mississippi River, the cost-benefit ratio has been estimated to be one to 24 (National Committee on Levee Safety, 2009). Thus, significant investments should be made at all levels of government to minimize flood risk. It is also vital that the country's overall approach to flood risk management be examined in order to ensure that maximum benefits are realized.

In 2014, the American Society of Civil Engineers (ASCE) examined the progress made in flood risk management policy following Hurricane Katrina. After Hurricane Harvey, the ASCE Texas Section also examined the flood risk management strategy in Texas at the local, state, and federal levels. Among ASCE's findings was that the lack of a clearly defined leadership hierarchy at the state and federal levels often creates a disjointed approach to flood risk management and limits accountability (ASCE, 2014; ASCE-TX Section, 2018). This sentiment is echoed by the National Committee on Levee Safety (NCLS), which concluded that states are best positioned to administer flood risk related safety programs (NCLS, 2009); however, few states have programs to manage different infrastructures that work together to reduce a region's flood risk.

Flood risk infrastructure is considered "critical infrastructure" as its individual or systemic failure can cause significant loss to life as well as economic disruptions. At the national level, Presidential Policy Directive 21 (PPD-21), Directive on Critical Infrastructure Security and Resilience, outlines three essential components of the federal government's approach to infrastructure security:

- 1) "Refine and clarify functional relationships across the Federal Government to advance the national unity of effort to strengthen critical infrastructure security and resilience;
- 2) Enable effective information exchange by identifying baseline data and systems requirements for the Federal Government; and
- 3) Implement an integration and analysis function to inform planning and operations decisions regarding critical infrastructure." (White House, 2013)

Additionally, the Department of Homeland Security (DHS) has developed the National Infrastructure Protection Plan (NIPP) to provide a unified approach to critical infrastructure security (DHS, 2013). Key components of NIPP are risk management, collaboration within and across interdependent sectors, and empowering local and regional stakeholders. These concepts are especially important when considering flood risk management due to the number of interested parties and the potentially large distances separating them along connected river systems.

The intent of this paper is to outline the current structure of flood risk management in the United States, examine present needs, and suggest an organizational restructuring to provide for a more strategic approach to infrastructure security that is better positioned to accomplish the goals of PPD-21 and NIPP at the local, state, and federal levels. It should be noted that while the concept of critical infrastructure protection, as outlined in NIPP, is by definition focused on structures of national significance, this paper emphasizes a national strategy geared towards all flood risk infrastructure.

A New Philosophy of “Flood Risk Management”

A watershed is an area of land that shares a common outlet—such as a lake or river—for all the rainwater that falls into it. Watersheds (or basins) can be small or large, depending on the area under consideration and the outlet point of interest. As a result, a watershed can relate to a small creek or a large river. Additionally, large watersheds are composed of many smaller watersheds. For example, the Mississippi River Basin includes both the Ohio River Basin and the Missouri River Basin.

A community’s flood risk is influenced not only by its own flood risk management approach, but also the actions taken by other upstream communities within the same watershed. This is because water runoff volumes accumulate and increase as water flows downstream towards the ocean. Consequently, individual communities can be affected by actions taken hundreds or even thousands of miles upstream.

It should be recognized that all water management infrastructure within a watershed as well as the natural environment influence the flood risk in a region, rather than simply single flood control measures. This is important because many significant structures on waterways are not specifically designed to mitigate flood risk. For example, a dam designed for water supply or hydroelectric power generation might be operated differently than a dam designed specifically to mitigate flood risk prior to and during an extreme flooding event.

In addition, stormwater infrastructure, which primarily focuses on conveying water from developed areas to waterbodies, can have an impact on flood levels. Undeveloped land also serves to retain and infiltrate rainwater, thus reducing impacts on larger water bodies. As a result, an effective strategy for flood risk management must encompass more than traditional flood control infrastructure and instead take a holistic approach to the entire interconnected system of designed and natural water management infrastructure.

When approaching this issue, it is critical to move away from the historical concept of “flood control” and instead adopt a paradigm of “flood risk management,” as this framework emphasizes the strong likelihood that flooding can never

be completely eliminated. Instead, a philosophy of risk management transparently communicates that infrastructure is designed to limit the potential for disasters, but that there are bounds to which nature can be “controlled.” The flood risk management paradigm also looks beyond individual structures and examines risk on a systemwide and watershed basis.

Current Management Structure

The current strategy for managing flood risk in the United States can generally be described as an aggregate approach, where no single authority at the local, state, or federal levels has jurisdiction over or sets policy for all aspects of flood risk management. Instead, regulatory authority is typically based on ownership, type of action being taken, or the infrastructure’s original funding source.

Local level

At the local level, communities plan and implement stormwater infrastructure projects and they adopt and enforce floodplain management rules for future land development. They also develop flood risk management projects, sometimes in partnership with federal agencies. When a local government acts as a sponsor of a federal project—and agrees to take charge of federal infrastructure once constructed—they become beholden to that partner’s construction, inspection, and maintenance requirements. Non-sponsoring agencies have little jurisdictional authority over activities at the local level.

Approximately 23,000 communities voluntarily participate in the National Flood Insurance Program (NFIP), administered by the Federal Emergency Management Agency (FEMA), which makes them eligible to receive federally subsidized flood insurance and federal flood-related disaster assistance. In return, communities must adopt and enforce a prescribed minimum set of floodplain development standards. Communities may also choose to exceed NFIP minimum criteria at their discretion.

State level

While a number of states require communities to participate in NFIP by law, they typically do not take an active role in regional planning activities. Most states have a dam safety program that funds, inventories, inspects, maintains, and often develops emergency action plans for dams. However, few have a similar program for levees and many do not have the authority to regulate levees (Association of State Dam Safety Officials, 2006, 2011). Most states also provide funding for local stormwater projects through grants or loans.

North Dakota is perhaps the most progressive state in implementing a statewide flood risk management program. For many years, the North Dakota

State Water Commission (NDSWC) sought to bring together stakeholders within the state's seven major watersheds through the North Dakota Water Development Plan. Updated every two years, the plan provides a cost-sharing mechanism between state and local sponsors for short- and long-term projects, identifying potential funding needs up to three biennia into the future. The results of this process then become the basis for the Commission's funding request to the governor and legislature (NDSWC, 2019). The Commission also has jurisdiction over development in regulatory floodplains, as defined by FEMA, and is responsible for the inventory and inspection of North Dakota's dams.

Minnesota has also developed a program to comprehensively address water resource management—including flooding, water supply, wetland protection, and fish and wildlife conservation—on a watershed basis (Minnesota Board of Water and Soil Resources, 2016). Additionally, Nebraska, and Texas have statewide initiatives focused solely on flood mitigation.

A number of states, such as Florida and Washington, work with FEMA to address flood risks through the hazard mitigation process, making them eligible for Hazard Mitigation Grant Program funding. While this process does evaluate and address risks on a statewide basis, it should be differentiated from recurrent, watershed-based planning.

Federal level

At the federal level, an assortment of agencies are responsible for funding, managing, and/or developing policies for various flood risk infrastructure. In addition, many other agencies fund, manage, and/or develop policies for water infrastructure—such as dams for water supply or hydro-electric power generation—that have significant impacts on flood risk management strategies. These agencies often oversee similar infrastructure or programs, and they are relatively autonomous—typically collaborating only on a voluntary basis.

Under PPD-21, DHS is the Sector Specific Agency (SSA) responsible for flood risk management infrastructure. Within DHS, FEMA administers NFIP, the national dam safety program, as well as flood risk management grants and assistance programs. As a part of NFIP, FEMA also develops flood insurance rate maps (FIRMs) that define regulatory floodplains, or Special Flood Hazard Areas, with at least a one percent chance of flooding annually, as well as other flood risk information. Similar to NFIP, it is not mandated that States participate in the national dam safety program. Within DHS, the Cybersecurity and Infrastructure Security Agency (CISA) also examines national risk across sectors and works to increase collaboration across the federal government to reduce risk to critical infrastructure.

The United States Army Corps of Engineers (USACE) operates hydro-electric facilities, water supply dams, flood risk management dams, locks, levees, and

other types of water infrastructure. They further partner with local sponsors to develop flood risk management and other water infrastructure projects. Under the 1960 Flood Control Act, the USACE is authorized to assist local governments as well as other federal agencies with a variety of flood risk planning activities. Additionally, the Water Resources and Development Act of 2007 (WRDA) gives the USACE a mandate to maintain a portfolio of the nation's levees and has the authority to inventory and inspect all levees in the United States. Similarly, the USACE maintains the national dam inventory.

The USACE also manages the Silver Jackets program, which brings together local, state, federal, and tribal agencies to address a variety of emergency management and hazard mitigation issues on a state-by-state basis. Participation in the Silver Jackets program is voluntary and initiated at the state level. The primary goals of state Silver Jackets Teams are to minimize gaps between programs, facilitate flood risk reduction efforts, and develop relationships for effective post-disaster response (USACE n.d.).

Through the Natural Resource Conservation Service (NRCS), the U.S. Department of Agriculture (USDA) provides grants and assistance for various types of water planning and infrastructures. The U.S. Forest Service (USFS) also owns, operates, and regulates dams on USFS lands with the primary goals of recreation, wildlife preservation, and wildfire response.

The Department of the Interior (DOI) has authority over a wide range of water-related infrastructure. The Bureau of Land Management (BLM) owns, maintains, inventories, inspects, and regulates dams on BLM lands as does the National Parks Service (NPS). The Bureau of Indian Affairs (BIA) has responsibility for all dams on Native American lands and works with the different tribes to maintain them. While the Bureau of Reclamation (BOR) does not own nor have authority over infrastructure specifically designed for flood risk, it operates hydro-electric facilities, water supply dams, and canals throughout the western states that greatly impact flood risk management activities. Most significantly, BOR is the largest wholesaler of water in the United States. Within DOI, BOR is designated as the department-wide "Coordinator of Dam Safety."

Another significant entity at the federal level is the Tennessee Valley Authority (TVA). TVA is a federal corporation established in 1933 to provide flood risk management and economic development services to the Tennessee River Basin during the Great Depression. Today, TVA manages a host of flood risk, water supply, and power generation infrastructure (including coal and nuclear power) as well as some public lands. Unlike other federal agencies, TVA has jurisdiction over all structures affecting flood risk, navigation, or public lands or reservations in the Tennessee River Basin. TVA is self-financing, primarily through energy sales, and does not require any congressional appropriations (FEMA, 2019).

Table 1 shows a number of the roles and responsibilities of the federal agencies discussed above. Other federal agencies also contribute to the nation’s flood risk management apparatus, including stormwater infrastructure, but are not discussed here. Note the significant overlap that exists between the various federal agencies.

Table 1. Role of Federal Government in Water Infrastructure by Agency

Agency	Department	Planning & Technical Assistance	Levees	Flood Risk Dams	Water Supply Dams	Hydro-Electric Dams	Canals & Water Conveyance	Funding Programs
FEMA	Homeland Security	X		X	X	X		X
NRCS	Agriculture	X						X
USFS	Agriculture		X	X	X			
USACE	Defense	X	X	X	X	X	X	X
BLM	Interior			X	X			
NPS	Interior			X	X			
BIA	Interior			X	X			
BOR	Interior				X	X	X	
TVA	--	X	X	X	X	X	X	X

Current Needs

Mapping

Hazard identification is the cornerstone of risk-based flood management; however, most localities do not have comprehensive flood risk maps (ASCE 2014). Following Hurricane Harvey, the Texas Water Development Board (TWDB) surveyed over 1,200 individuals in 2018 to better understand needs throughout the state. Respondents indicated that improved flood risk mapping was one of their highest priorities (TWDB, 2019). Similarly, California has recognized that flooding is not well understood in large areas of the state and that agencies often lack the mapping necessary to perform risk evaluations (California Department of Water Resources, 2013).

The primary source of flood risk mapping throughout the United States are Flood Insurance Rate Maps (FIRMs). They define regulatory floodplains (areas with at least a one percent annual chance of flooding), define moderate hazard areas (those areas outside the regulatory floodplain, but with at least a 0.2 percent annual chance of flooding), and provide other flood risk information. Typically, FIRMs only include flooding along major studied waterbodies and do not consider all potential sources of flooding, such as overland localized flooding. In areas where no or limited information exists, data is often interpolated from more studied areas. Consequently, there is a difference between the regulatory floodplain and the natural floodplain.

Although FEMA is aggressively moving to update FIRMs nationwide through the Risk Mapping, Assessment, and Planning initiative, many are also out

of date and may not account for changing conditions such as recent development and climate change. By example, the average age of FIRMs in Texas was 13 years old—with some as much as 27 years old—as of 2018 (TWDB, 2019). Despite these limitations, governing authorities have embraced FIRMs and thus the one and 0.5 percent annual chances of exceedance due to a lack of other options.

It should be recognized that the primary purpose of FIRMs is to inform and ensure compliance with NFIP. Therefore, while the term “moderate hazard area” is of regulatory significance, it should not be interpreted as delineating areas that are at risk and areas that are not. Instead, a spectrum of flood risk exists that is not captured solely by markers of the one and 0.2 percent annual chances of exceedance. This is exemplified in Florida, where a most of the state is within the regulatory floodplain and relatively few moderate hazard areas exist (Florida Division of Emergency Management, 2018).

In addition to identifying hazards, another important aspect of flood risk mapping is the way information is communicated. In contrast to Florida, Washington generally does not allow new development within the regulatory floodplain, causing higher density development practices on the floodplain’s border in moderate hazard areas. These areas can be exposed to similar risks as those in the regulatory floodplain, but this fact is generally not appreciated and is difficult to parse from current data (Washington Emergency Management Division, 2018). An analysis of flood insurance claims in Texas’s Clear Creek watershed highlights this issue, showing 55 percent of claims between 1999 and 2009 occurred outside of the regulatory floodplain, with an average distance of 600 feet from its edge (Brody et al., 2013). Consequently, it is imperative that the public and professionals alike have the tools to see beyond the one and 0.5 percent annual chance events shown on FIRMs and to also be encouraged to conceptualize risk on a continuum rather than in discrete risk levels.

Planning

Regardless of the size of a watershed under consideration, it is important to recognize that political boundaries rarely correspond to watershed boundaries. Most political subdivisions encompass portions of several watersheds. In general, communities do an adequate job performing localized flood risk management activities; however, an effective flood risk management strategy must organize communities on a watershed basis. This is taking place in a handful of states, and mostly on a limited basis.

To address coastal flooding, Louisiana has created the Coastal Protection and Restoration Authority (CPRA), which was formed following hurricanes Katrina and Rita to provide continuity and more easily distribute federal funds to local entities. Today, CPRA is charged with developing Louisiana’s coastal protection plan as well as implementing projects, programs, and state policy. The Louisiana

Department of Transportation and Development (LADOTD) also has a statewide flood control program that assists in the funding of risk reduction measures in non-coastal areas of the state. There is not a similar emphasis placed on regional planning. Instead, projects are considered on an individual basis.

In California, 1,300 different entities are responsible for flood risk management activities throughout the state. As a part of their report, *California's Flood Future*, the California Department of Water Resources (CDWR) and USACE interviewed 140 public agencies responsible for flood risk management. More than 80 percent of those interviewed indicated increased coordination was needed between responsible agencies. Many also indicated that a failure to prioritize projects on a systemwide basis missed opportunities to achieve regional benefits (CDWR, 2013). Since that time, the state has developed six Regional Flood Risk Management Plans to address flooding in California's Central Valley. These plans organize local stakeholders to identify short- and long-range projects as well as potential funding sources. The Central Valley Flood Protection Plan also identifies projects and barriers to improve of regional flood risk management. Corresponding plans do not exist statewide.

It should be noted that a voluntary regional water management structure was established in California by the Integrated Regional Water Management Planning (IRWM) Act of 2002 to address the issues previously discussed, but with an emphasis on all water sectors. Under the IRWM Act, local entities are encouraged—but not mandated—to organize themselves into regional planning groups to identify regionally significant projects. To date, 49 regions have been organized, representing 99 percent of the state's population. While this approach is regarded as a step in the right direction, it has also been recognized that a more robust statewide initiative is necessary (CDWR, 2017).

The need for systemwide project development is present in most other states as well, where little to no structure exists for statewide flood risk planning. The ASCE Texas Section examined the flood risk management structure in Texas after Hurricane Harvey. Their report, *Flood Risk Management: A Path Forward for Texas After Hurricane Harvey*, identified a significant leadership gap at the state level. In Harris County alone (where the majority of Houston is located), 34 different entities operated more or less independently to manage flood risk with little involvement from the state to implement projects across jurisdictions. Counties, cities, flood control districts, drainage districts, levee improvement districts, river authorities, etc. all manage flood risk at the local level. Consequently, ASCE Texas Section recommended that a structure be developed within the state to bring stakeholders to the table in order to solve problems on a watershed basis (ASCE-TX Section, 2018). This sentiment was echoed by the 1,200 stakeholders surveyed by TWDB in 2018 (TWDB, 2019). Since Hurricane Harvey, Texas has taken steps to address this issue through regional flood plans as well as a statewide flood plan,

which are currently in development. Regional planning groups were formed in 2020, the initial regional flood plans are due in 2023, and the first state flood plan is due September 1, 2024 (TWDB n.d.).

A similar need for coordination exists at the federal level, not only to organize projects across state lines, but also to provide a clear leadership organization amongst the various state and federal agencies. The National Flood Insurance Act of 1968 required the development of a Unified National Program (UNP) for Floodplain Management that identifies the roles and responsibilities of entities at the federal, state, and local levels for flood risk management. While the UNP had historically been updated on a routine basis, the most recent version was developed by the Federal Interagency Floodplain Management Task Force, chaired by FEMA, in 1994 and was not ratified by the U.S. Congress.

After Hurricane Katrina, Congress called on President Bush to conduct a national flood vulnerability assessment; however, such a measure has not been funded in the 14 years since. Acting together, a flood vulnerability assessment and a UNP for Floodplain Management would identify areas where infrastructure is lacking and provide a structure for addressing needs.

Infrastructure Management

Whether at the federal, state, or local level, a key component of flood risk management is the inventory and evaluation of existing infrastructure. These needs have been highlighted by recent large-scale flooding events such as the 2017 Lake Orville Dam spillway failure, which displaced nearly 200,000 people (FEMA, 2019).

While some states have a robust dam safety program with adequate funding, others do not. The state of Alabama presently does not have a statewide dam safety program (ASCE-Alabama Section, 2015). Additionally, seven states do not have the authority to require emergency action plans for dams whose failure would likely cause loss to human life, known as high hazard potential dams (FEMA, 2019).

In 2015, Texas only inspected 259 of approximately 4,000 non-exempt dams—approximately seven percent (ASCE-TX Section, 2017). (In Texas, the state exempts dams from safety requirements if it meets a variety of requirements including private ownership and being outside of corporate municipal limits.) Dam inspection rates are directly related to funding levels for dam safety. Due to low funding levels, a report published by the Texas State Auditor's Office in 2008 (that has not been updated since) states that, "The Texas Commission on Environmental Quality's ... dam safety program, as currently designed and operating, is not able to accomplish its statutory mandate to ensure the safe construction, maintenance, repair, and removal of dams in the State of Texas" (Texas State Auditor's Office, 2008). Similar conditions exist in other states since 14 percent of high

hazard potential dams in the U.S. were deficient in some capacity in 2016 (ASCE, 2017). In the same year, 24 states failed to meet their own high hazard potential dam inspection requirements (FEMA, 2019).

While the most effort is focused on high hazard potential dams because they pose the greatest public risk, an analysis of 49 dams that failed in South Carolina during 2015 flooding showed that the cumulative failure of multiple low hazard potential dams (i.e., those whose failure would not individually cause loss of life and would likely only impact the owner's property) was a contributing factor in the failure of high hazard potential dams (FEMA, 2016). This exemplifies the need for a holistic approach.

One of the greatest challenges facing the country regarding dam safety is the inventory, inspection, and maintenance of privately owned dams. These structures account for more than half of the country's dams, yet public oversight can be challenging at times and owners often lack sufficient funding mechanisms for repairs (ASCE, 2017). Moreover, these owners often do not have a say in development downstream of their structures and therefore may lack the ability to limit their risk exposure.

Few states currently provide for the inventory, inspection, development of emergency action plans, or other levee safety oversight activities in the U.S. (Carter, 2017). In Louisiana, LADOTD has a program to oversee and assist local levee and other flood control districts with federally mandated inspections required by the USACE or NFIP. Other states, such as New Hampshire, include levees as a part of their dam safety program, but this is rare (Association of State Dam Safety Officials, 2006).

Based on surveys conducted by the Association of State Dam Safety Officials (ASDSO), only 27 states have an agency with any responsibility for levee safety (ASDSO, 2006, 2011). That responsibility has largely fallen to the USACE, which routinely inspects federal and non-federal levees participating in the USACE Rehabilitation and Inspection Program. It should be noted that WRDA has only given the USACE authority to inspect levees that do not participate in the USACE Rehabilitation Program once (USACE, 2018). As a result, the USACE has a limited ability to manage the entire country's levee inventory.

Almost two-thirds of Americans live in a county with at least one levee and 1.3 trillion dollars of property is located inside leveed areas (ASCE, 2017; USACE, 2018). However, it is estimated that nearly 70 percent of all levees in the United States are undocumented, meaning their location and condition are unknown (ASCE, 2017). This has led the USACE to conclude that, "We know little about the condition or risks associated with levees outside those inspected and assessed as part of the USACE levee portfolio. As such we do not have a true national look at the risks and benefits levees provide to the nation or whether people know that they live or work behind a levee" (USACE, 2018).

Compared to dams and levees, every bridge in the United States open to the public must be inspected at least every 24 months (23 CFR § 650). This means that over half of the nation's bridges are inspected every year. The Moving Ahead for Progress in the 21st Century Act and subsequent legislation also requires states to develop a "risk-based asset management plan ... to improve or preserve the condition of the assets and the performance of the [transportation] system." Simply put, a similar concept of asset management does not exist for water infrastructure on a system level. Without broadening national programs, increasing financial resources, and mandating compliance for funding, it will be impossible to sufficiently address local, state, and national flood risk.

Cyber risk

The increasingly interconnected nature of modern industrial control system (ICS) networks necessitates that securing water infrastructure extend beyond the physical realm to include the mitigation of cybersecurity risks. A 2013 breach of the ICS network controlling the Bowman Avenue Dam in Rye Brook, New York, highlights the cyber threat posed to water infrastructure. A hacker working on behalf of the Iranian government was indicted for gaining unauthorized remote access into the dam's control network and would have been able to manipulate the sluice gate but for the functionality being manually disconnected due to maintenance (United States of America v. Ahmad Fathi et al., 2016). This intrusion represents a challenge to any preconceived notions that international norms pertaining to the law of armed conflict and the targeting of primarily civilian infrastructure would be extended to cyber warfare.

Similarly, Russia's cyber-attacks on Ukraine's power grid in 2015 and 2016 and Denmark-based shipping giant Maersk in 2017 has contributed to a growing concern of the cyber threat posed to primarily civilian critical infrastructure, including dams, and the resulting damage that could be inflicted by a hacker. The NotPetya malware that devastated Maersk operations was not only unique in the staggering financial loss incurred—200 to 300 million US dollars—but also in the path through which it was delivered into Maersk networks (Maersk, 2017). Like 80 percent of all Ukrainian companies, Maersk used an accounting software called M.E.Doc. More than two months before the NotPetya attack, Russian hackers gained control of the M.E.Doc update server to deliver a backdoor-enabled version of the software to their customers (United States of America v. Yuriy Sergeyevich Andrienko et al., 2020). The malicious update was then leveraged to deliver NotPetya to Maersk and other users of the third-party software. This type of compromise, known as a supply chain attack, provides malicious actors opportunities at a much larger scale when compared to targeting individual victims directly. Supply chain attacks are particularly insidious because they are delivered through a trusted third-party and thus elude most conventional network defenses. Consequently, any and every trusted partner becomes a risk.

Just as the NotPetya attack demonstrated the potential damage supply chain attacks can have on civilian critical infrastructure, the 2020 SolarWinds breach highlights the potential scale of such attacks. The malicious backdoor included in software updates for SolarWinds' Orion platform is believed to impact nearly 18,000 customers (SolarWinds, 2020a). Potential victims among SolarWinds' extensive customer list include 425 of the U.S. Fortune 500 Companies, all five branches of the U.S. military, and critical infrastructure companies including Siemens, Smart City Networks, and the New York Power Authority (SolarWinds, 2020b).

Cybersecurity professionals have emphasized the possibility that malicious supply chain software may be present on a network unbeknown to management. It is not only possible for personnel to download software outside of approved lists, but software products such as SolarWinds could be used by original equipment manufacturers. At least two original equipment manufacturers have been reported as utilizing the vulnerable SolarWinds software within ICS environments (Miller, 2020).

When assessing the cyber risk of dams and similar critical infrastructure, it is also important to recognize that unauthorized outsiders are only one type of threat actor. A 2018 evaluation by the Inspector General of the U.S. Department of the Interior found that two hydropower dams categorized as critical infrastructure had a high risk from insider threats. While it was determined that network isolation practices at both dams reduced the risk of compromise from external cyber threats through network isolation, account management and personnel security failures increased the likelihood of an employee—whether by mistake or with malicious intent—to cause an ICS loss or disruption (DOI, 2018).

Whether through a compromised supply chain, an insider, or some other vector, the cyber-attack of water control features during a flooding disaster is a distinct possibility. The consequences of such an attack could be catastrophic for those trapped in a floodplain. Several governmental and industry organizations provide sector-specific guidance to federal and non-federal (private, state, and municipal) dam and similar water management asset owners and operators and enable voluntary coordination intended to increase the cybersecurity posture of participating members. Under PPD-21, DHS is the SSA for and has worked jointly with the Dams Sector Coordinating Council to develop a sector-specific plan and related cybersecurity guidance (DHS, 2015, 2016). The Homeland Security Information Network – Critical Infrastructure provides sector-specific training and includes a dam portal that serves as the primary means of sector-relevant information sharing.

Additional guidance has been made available by the National Institute of Standards and Technology (NIST) through their development of a voluntary national framework to provide a common structure for cybersecurity through standards, guidelines, and best practices that are applicable across critical infrastructure

categories (NIST, 2018). NIST also provides technical guidance on cybersecurity control measures tailored for an ICS environment (Stouffer et al., 2015). The International Society of Automation (ISA) has developed a series of sector-agnostic standards that provide cybersecurity guidance and technical requirements for ICS networks and components. Furthermore, ISA has developed accompanying training courses to strengthen the understanding and implementation of ICS-specific cybersecurity standards and principles.

Between international and national standards and public and private collaboration, the challenge for dam owners and operators is typically not a lack of informational resources or guidance, but the consolidation of compulsory and voluntary guidance and the prioritization of available resources. Another noteworthy challenge is the difficulty of governmental bodies and industry committees in providing timely updates to strategic guidance, technical controls, and training that keeps up with the pace at which cyber threat actors update their tactics, techniques, and procedures and the broader cyber threat landscape. Lastly, limited financial resources and appropriately-skilled personnel contribute to difficulties in adoption and implementation of cybersecurity guidance and standards (Marinos et al., 2018).

Recommended Structural Changes

A New Federal Structure

While many agencies are working diligently to address flood risk within their respective jurisdictions, the greatest impedance to progress is the lack of centralized authority at the state and national levels. Based on the current conceptualization put forward in the Flood Insurance Act of 1968, it is the federal government's responsibility to establish a framework for national flood risk management. This is echoed by PPD-21 and NIPP.

When considering the organization of levee management in the United States after Hurricane Katrina, NCLS recommended that, "all federal programs that impact community and individual behavior in the leveed area should be aligned toward the same goals of risk reduction, developing resilient and reliable levees and protection of human life and property" (NCLS, 2009). At the same time, they observed that states are in the best position to administer levee safety programs because they are significantly more in tune with local needs than the federal government and can be more flexible to accommodate them. As a result, an integrated approach must be taken to leverage the national, strategic capabilities of the federal government while increasing authority at the state level and empowering those closest to problems.

NCLS recommendations suggest that an additional federal agency be created to oversee a national levee safety program that would have the authority to

enforce levee safety across all agencies at the federal level as well as state and local levels of government. Under their model, the federal agency would create nationwide policy and set minimum requirements, while states would be responsible for developing and administering a state-specific levee safety program. An example of how this might work is that the federal government might require that all states inspect levees on a regular basis and evaluate their condition based on set criteria. The federal government would also be responsible for ensuring states' compliance with federal standards. States would be responsible for determining inspection frequency, performing inspections or requiring them of owners, developing inspection reports, and determining necessary corrective actions. States would then create their own database of levees as well as report findings to the responsible federal agency. This would shift some of the responsibility currently falling on local communities and the USACE to states, thus creating a more clearly defined structure for organization and accountability. However, it is not sufficient to allow for a national strategy for flood risk management because it only focuses on levees.

In light of the significant impacts that all water management related infrastructure has on flood risk as well as mission overlap between the numerous federal agencies, this article recommends a more holistic approach that consolidates many of the federal water management authorities into a new department tasked with water resource management. The proposed Department of Water Resource Management (DWRM) would serve as the SSA for flood risk management, water supply, and hydroelectric power generation under NIPP and be tasked with developing national policies for risk management, organizing states and national stakeholders, as well as operating and maintaining a majority of the country's federally owned dams, levees, and canals.

The current agencies (or portions thereof) that could be combined to form DWRM are the USACE, BOR, components of NRCS within the USDA, as well as elements of DHS dealing with flood risk management. These entities have been identified due to the significant overlap in mission and expertise as well as their focus on public works. In the case of the USACE and USDA, both act as federal sponsors for local projects and typically work in support of local entities through regional planning and engineering services. Similarly, the USACE and Bureau of Reclamation both operate a large volume of infrastructure for the purpose of water supply and hydroelectric power generation acting as a public utility.

Consolidating these entities would not only provide clear leadership, but also an opportunity to increase sector-wide collaboration and planning, improve information exchange, leverage resources to assess risks, and accomplish strategic goals in a way that is not currently possible at the systems level.

The DWRM would also gain the necessary platform to implement and enhance national programs. As the department responsible for national flood risk reduction, it would be clearly within DWRM's mission to both maintain a national

inventory of dams and oversee compliance with an expanded national dam safety program. Those two programs are currently housed in different departments (Department of Defense and DHS) and the dam safety program does not require owners to implement best practices. The dam safety program would also benefit from the engineering assistance that the USACE and NRCS currently offer to local organizations.

Other programs that would similarly benefit from a realignment of federal agencies are the national levee portfolio and other levee management programs within the USACE. It is recommended that a potential DWRM adopt the suggestions of the National Committee on Levee Safety and create a national levee safety program. Another option could be combining the dam safety program with a levee safety program, which would further integrate risk management activities.

Future cybersecurity initiatives would also considerably benefit from this structure. As noted, one of the primary challenges facing flood risk management in the cyber domain is the need for consolidated guidance and the enforcement of minimum standards. A more centralized authority for water management infrastructure would be much better positioned to meet these needs than the current constellation of agencies. Furthermore, a clearly defined hierarchy would improve incident response.

When assessing which agencies (or portions thereof) that could be merged for national benefit, it is also important to recognize the agencies that maximize their benefit under their current jurisdictions. The water resource management and public works aspect of the previously mentioned agencies is significantly different than say that of the USFS or BLM, which operate water infrastructure as a part of their land management mission. Under the proposed model, the various land management agencies would maintain authority over infrastructure on their respective public lands but would be required to adopt national policies developed by DWRM and participate as a stakeholder in national planning activities. TVA should likewise remain intact but be required to follow DWRM policies.

It is not recommended that NFIP be removed from FEMA. This is because the primary aim of NFIP is identifying which communities are eligible for flood insurance—an extension of FEMA's disaster response mission—and does not provide recommendations for flood risk management. It is similarly recommended that water quality, drinking water treatment, and wastewater treatment (not discussed in this paper) remain under the Environmental Protection Agency.

An alternative federal reorganization

An alternative to the structure previously outlined is to consolidate national flood risk program administration, grants, and engineering support for local agencies into one department, while keeping all federal infrastructure under its current ownership structure. This organization could yield many of the same benefits of

creating a new department—as it would put one agency in charge of national policy making—while allowing other agencies to manage assets within their current missions.

Given that DHS is the SSA for flood risk infrastructure, FEMA currently administers the national dam safety program, and CISA performs regional and national multi-hazard risk assessments, it is logical that DHS absorb these responsibilities. Since this proposal is ultimately a question of resource management, it is also plausible that DOI might assume these responsibilities. It is worth highlighting that although the USACE performs many of the activities that a national flood risk management program would pursue, it may not be politically viable to give the military such vast authority over the nation's public works. An apt comparison is the National Highway System, which, although originally conceived as a means of national defense, is nonetheless administered by the Department of Transportation.

In considering either of the reorganizations proposed, it is important to recognize that a national strategy need not conflict with programs tailored to specific industries and constituencies so long as sufficient coordination exists to meet collective needs. Active collaboration between the proposed DWRM or other agency and those presently managing various water programs would be necessary to leverage subject matter expertise and long-standing relationships to deliver a high quality of service to all stakeholders. This is especially true when considering land management practices as an extension of flood risk management as well as coordination with various Native American stakeholders.

Necessary state programs

Similar to the current structure for transportation projects, a new structure for flood risk management would require significant administrative responsibility at the state level that would be overseen by DWRM. As a condition for federal assistance, states would be required to administer statewide flood risk planning, dam safety programs, and levee safety programs—none of which are currently mandated on such a broad basis—with a focus on asset management and regional risk reduction. States should further take a more active role in flood risk mapping. In addition to assisting local communities with risk assessments, they should also take a leadership role in developing databases of such assessments. A general summary of the federal, state, and local responsibilities under the proposed model can be seen in Figure 1.

Because flood risk accumulates from community to community and grows as a watershed increases in size, local agencies are at the forefront of flood risk management. Any national framework should act to increase an individual community's ability to reduce risks and not impede it. As a result, state planning programs should be careful to create an environment that engages all stakeholders

and does not limit an individual community’s autonomy to develop projects that decrease its own flood risks.

Federal	<ul style="list-style-type: none"> • Operate federal flood risk management infrastructure • Establish minimum national standards and best practices • Require that states develop asset management plans and planning groups • Perform quality assurance activities to ensure compliance • Organize multi-state planning groups for large, interstate watersheds • Maintain national databases of flood risk management infrastructure and its condition • Provide training and subject matter expertise for state and local organizations • Perform national flood risk vulnerability assessments
State	<ul style="list-style-type: none"> • Develop and implement asset management plans • Provide resources for mapping as well as other forms of risk evaluation and manage databases of similar information developed statewide • Establish statewide and regionally appropriate minimum development standards • Create regional planning groups based on watershed condition • Maintain statewide databases of flood risk management infrastructure and its condition • Inspect or assist as needed in the inspection of flood risk management infrastructure
Local	<ul style="list-style-type: none"> • Continue current practices • Develop more robust flood risk maps • Participate as stakeholders in state and federal planning groups

Figure 1. Proposed Flood Risk Management Structure

Due to the significant impacts of Hurricane Harvey on Houston and the surrounding area, the Texas legislature acted in 2019 to create and fund a state-wide flood plan to bring stakeholders together based on common watersheds in order to identify and implement projects of regional importance (SB 7, Texas Legislature (2019); SB 8, Texas Legislature (2019)). Projects are to be developed by these local stakeholders and then evaluated and funded by the Texas Water Development Board based on the state’s priorities. A key component of this approach is that local entities have an active role in proposing and developing projects.

While the program in Texas is still under development, the state has been managing water supply in a similar manner for many years with excellent results. Other states, such as California, have also suggested and are moving towards a similar structure with enthusiastic support from stakeholders (CDWR, 2013, 2017). Thus, this could serve as a model for flood risk planning in other states.

As with the proposed federal structure, it is recommended—but by no means should it be required—that all water related infrastructure programs be managed

by a single agency at the state level. This is the case in North Dakota, which plans and administers a variety of programs under the NDSWC. Similarly, Minnesota is developing integrated planning programs to leverage common benefits.

Conclusion

Extreme flooding events in recent decades have caused significant loss of life and destruction. Despite this fact, water resource management infrastructure remains underfunded, without sufficient regional or national strategies for flood risk management. Communication and coordination between responsible parties is paramount to minimizing risk on a local, regional, and national basis. Thus, a well-defined structure needs to be in place where local communities can have autonomy to meet their own needs and where higher levels of government can act to pursue strategic initiatives.

The following actions are recommended to address the shortcomings of the current approach and align flood risk management activities with PPD-21's stated goals of clarifying relationships, increasing information exchange, and improving planning:

- Adopt a holistic paradigm of flood risk management that examines risk on a system level;
- Develop a current Unified National Program (UNP) for Floodplain Management;
- Conduct a national flood vulnerability assessment;
- Define a clear leadership hierarchy for flood risk management responsibilities;
- Consolidate portions of federal agencies that perform similar functions to increase continuity at the federal level;
- Develop more comprehensive flood risk maps;
- Require states to develop organizations for regional flood risk planning based on watersheds;
- Expand and mandate participation in the national dam safety program as a requirement for federal funding;
- Create a national levee safety program or incorporate levee safety in the national dam safety program;
- Consolidate informational resources and prioritize best practices for cybersecurity

- Increase financial resources and training available to address cyber risk across water resource management sectors; and
- Provide additional funding for water resource management aimed at reducing flood risk.

Some states are recognizing the need for a more integrated approach outlined in this paper and are creating many of the recommended programs; however, national leadership will be necessary to work across state lines and to ensure minimum standards are being met for all citizens. Creating a single entity within the federal government responsible for all water resource management and charging states with the administration of individual programs would provide a platform to accomplish all of the recommendations above as well as the necessary continuity for addressing national vulnerabilities and establishing national priorities in line with PPD-21 and NIPP.

The work is that of the authors and does not reflect the views, policies, or opinions of their employers.

Acronyms

ASCE	American Society of Civil Engineers
ASCE-TX Section	American Society of Civil Engineers – Texas Section
ASDSO	Association of State Dam Safety Officials
BLM	Bureau of Land Management
BIA	Bureau of Indian Affairs
BOR	Bureau of Reclamation
CDWR	California Department of Water Resources
CISA	Cybersecurity and Infrastructure Security Administration
CPRA	Coastal Protection and Restoration Authority
DHS	Department of Homeland Security
DOI	Department of the Interior
DWRM	Department of Water Resource Management

FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
ICS	Industrial Control System
ISA	International Society of Automation
IRWM Act	Integrated Regional Water Management Planning Act
LADOTD	Louisiana Dept. of Transportation and Development
NCLS	National Committee on Levee Safety
NDSWC	North Dakota State Water Commission
NFIP	National Flood Insurance Program
NIPP	National Infrastructure Protection Plan
NIST	National Institute of Standards and Technology
NPS	National Park Service
NRCS	Natural Resource Conservation Service
PPD-21	Presidential Policy Directive 21
SSA	Sector Specific Agency
TVA	Tennessee Valley Authority
TWDB	Texas Water Development Board
UNP	Unified National Program
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFS	United States Forest Service
WRDA	Water Resources and Development Act

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