AGING AND FAILING INFRASTRUCTURE SYSTEMS: NAVIGATION LOCKS

December 8, 2015; 1300 EST

PREPARED BY: OPERATIONAL ANALYSIS DIVISION

SCOPE

The U.S. Department of Homeland Security/Office of Cyber and Infrastructure Analysis (DHS/OCIA) produces Critical Infrastructure Security and Resilience Notes in response to changes in the infrastructure community's risk environment from terrorist activities, natural hazards, and other events. This note summarizes the findings related to navigation locks identified in the National Risk Estimate on Aging and Failing Critical Infrastructure Systems, released by DHS/OCIA in December 2014.[1] This Critical Infrastructure Security and Resilience Note supports DHS leadership; other Federal, State, and local agencies; and private sector decision makers.

KEY FINDINGS

- **Fifty-four percent of Inland Marine Transportation System (IMTS) structures are more than 50 years old; 36 percent are more than 70 years old.**
- **Mechanical breakdowns resulting in lock closures steadily increased from 2000 to 2010.**
- **The Inland Waterways Trust Fund (IWTF) is an important funding source for lock construction and rehabilitation, but the barge fuel tax that funds the IWTF has not increased since 1995. This tax would need to increase by more than 50 percent to have the same purchasing power today.**
- **Dam projects are expensive, and funds are limited. As a result, priority projects are often delayed, which leads to more unscheduled lock closures.**

OVERVIEW

For this National Risk Estimate, DHS/OCIA subject matter experts highlighted the current state of critical infrastructure and identified the trends and physical characteristics that increased infrastructure risk of failure. The study also identified market, regulatory, and policy factors that affect infrastructure risk.

Forty-one States, including all States east of the Mississippi River, are served by commercially navigable waterways. The U.S. inland waterway system consists of 12,000 miles of navigable waterways in five systems: the Mississippi River, the Ohio River Basin, Great Lakes-St. Lawrence Seaway, the Gulf Intracoastal Waterway, and the Pacific Coast system. The inland waterway system includes more than 200 locks, which raise and lower river traffic between stretches of water of different levels.[2,3] Navigation locks are generally associated with dams, which provide the majority of the impoundment of water within the upstream pool, and are considered a Subsector under the Dams Sector.

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[1] Office of Cyber and Infrastructure Analysis, National Risk Estimate on Aging and Failing Critical Infrastructure Systems, Washington, D.C.: Department of Homeland Security, December 2014.
[2] American Society of Civil Engineers, "2009 Report Card for America's Infrastructures: Inland Waterways," http://www.infrastructurereportcard.org/a/#p/inland-waterways/overview, accessed April 24, 2014.
[3] The Intracoastal Waterway is an inland waterway consisting of inlets, saltwater rivers, and bays that form a navigable route on the Atlantic and Gulf coasts.

The Nation's inland waterways facilitate the movement of 15 percent of all coal, 56 percent of all petroleum products, 22 percent of all basic chemicals, and 18 percent of all agricultural products transported in the United States. The inland waterway system moves more than 550 million tons of freight each year, valued at more than $152 billion.[4]

The U.S. Army Corps of Engineers (USACE) is responsible for managing and maintaining most of the IMTS, including most of the navigation locks and dams. The U.S. Department of Transportation Saint Lawrence Seaway Development Corporation in cooperation with the Canadian Government maintains some locks.

RISK OF FAILURE

Most locks are designed to last for 50 years, but 54 percent of IMTS locks are more than 50 years old, and 36 percent are more than 70 years old.[5] Many of these locks are in need of repair and replacement, and some lack basic maintenance. Concrete is crumbling at some locks, and some have not been painted in 25–30 years, increasing the risk of corrosion.[6]

Locks lacking maintenance or in need of repair and replacement are more likely to have unscheduled closures. Unscheduled closures are more costly than scheduled closures, because vessel operators and companies are unable to plan to offset the delays from these incidents.[7] The annual number of unscheduled lock closures has steadily increased since 1992. Fewer than 7,000 unscheduled closures occurred every year before 2000, and more than 7,000 occurred every year after 2000, peaking in 2008 with 13,250.[8] Unscheduled closures can result from weather, water surface conditions, tow conditions, lock conditions, or other events; Figure 1 shows that the total length of unscheduled delays specifically from mechanical breakdowns steadily increased from 2000 to 2010.[9]

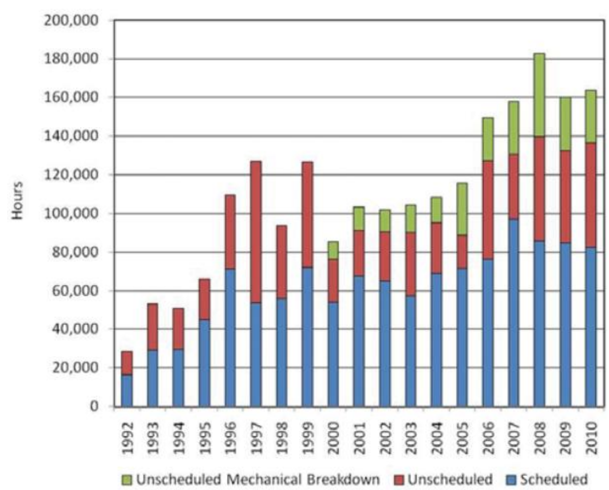

FIGURE 1—UNSCHEDULED OUTAGES DUE TO MECHANICAL BREAKDOWNS[10]

In 2013, unscheduled lock closures were often short, usually lasting fewer than 6 hours. In general, impacts resulting from these short-term closures are economic, but are not as significant as long-term, more catastrophic,

[4] American Society of Civil Engineers, "2013 Report Card for America's Infrastructure," http://www.infrastructurereportcard.org/, accessed April 25, 2013.
[5] U.S. Army Corps of Engineers, Navigation Data Center, "Lock Characteristics," http://www.navigationdatacenter.us/db/lockchar/xls/, accessed April 22, 2013.
[6] Glass, Pamela, "Head Lock: Neglect of locks and dams could result in a failure of the waterway system," https://www.workboat.com/newsdetail.aspx?id=16860, accessed April 29, 2013.
[7] Economic Development Research Group, Inc., Failure to Act: The Economic Impact of Current Investment Trends in Airports, Inland Waterways, and Marine Ports Infrastructure, Reston, VA: American Society of Civil Engineers, 2012.
[8] U.S. Army Corps of Engineers, Navigation Data Center, "Locks by Waterway: Lock Unavailability," http://www.navigationdatacenter.us/lpms/lock2012webunavail.htm, accessed June 13, 2013.
[9] U.S. Army Corps of Engineers, "Sustainable Solutions to America's Water Resources Needs," http://planning.usace.army.mil/toolbox/library/Misc/Sustainable_Solutions-2011-15.pdf, accessed May 13, 2014.
[10] Ibid.

closures that require goods to be transported via other, more expensive, methods, including alternative maritime routes, trains, and commercial vehicles. For some goods, no readily available transportation alternatives exist.

The Economic Development Research Group, Inc., estimated that if current investment trends continue, deterioration of the inland waterways and ports will result in $1.3 trillion in lost business sales by 2020, $270 billion in lost exports by 2020, and almost $2 trillion in lost exports by 2040. In addition, DHS/OCIA assessed that 738,000 fewer jobs will exist by 2020, and 1.4 million fewer jobs will exist by 2040.[11]

Weather can also have negative consequences for the IMTS. Severe droughts can lower the water level of major rivers resulting in barges' inability to safely navigate the waterways. Droughts can last for long periods and have severe economic consequences. High water levels and floods can also prevent barges from safely traveling on portions of rivers.

REGIONS OF INCREASED RISK

Some locks are more economically critical than others based on the amount and type of goods that pass through them and the alternative transport methods used during lock closures. The most economically critical locks and the locks with the most closures are not located in any one region.

DEPENDENCIES AND INTERDEPENDENCIES

Many sectors are critically dependent on navigation locks for transportation, including the Energy (15 percent of coal and 56 percent of petroleum products), Chemical (22 percent of basic chemicals), Food and Agriculture (18 percent of agricultural products), and Transportation Systems Sectors.[12]

Critical manufacturing facilities and coal powerplants may be designed to receive materials via barge, and alternative transportation modes may be insufficient or too costly. These facilities generally have a large enough supply onhand to operate temporarily without receiving new shipments (coal powerplants generally have a month's supply of coal), but a catastrophic lock failure could result in a lock closure lasting longer than the backup supply. For example, Michigan and Minnesota produce 99 percent of usable iron ore in the United States, and 79 percent of it is transported through the Soo Locks, located in the Great Lakes-Saint Lawrence Seaway. About $5.4 billion dollars of iron was transported through the Soo Locks in 2012.

MARKET, REGULATORY, AND POLICY FACTORS

The Inland Waterways Users Board (IWUB) is a federal advisory group responsible for monitoring the IWTF and makes recommendations to USACE and Congress on capital investment priorities. The IWTF, authorized in 1978 to help pay for construction and rehabilitation on U.S. inland and intracoastal waterways, is funded by a fuel tax that commercial towing companies pay when using the inland and intracoastal waterways. The 20 cents-per-gallon tax rate has not changed since 1995 and would need to increase by more than 50 percent to have the same purchasing power today.[13] Figure 2 illustrates the purchasing power of the IWTF from 1987 to 2013.

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[11] U.S. Army Corps of Engineers, "Inland Waterways Trust Fund," http://www.lrl.usace.army.mil/Media/FactSheets/FactSheetArticleView/tabid/10589/Article/9213/inland-waterways-trust-fund.aspx, accessed January 3, 2014.
[12] Economic Development Research Group, Inc., Failure to Act: The Economic Impact of Current Investment Trends in Airports, Inland Waterways, and Marine Ports Infrastructure, Reston, VA: American Society of Civil Engineers, 2012, http://www.asce.org/airports_inland_waterways_and_marine_ports_report/, accessed November 18, 2014.
[13] U.S. Army Corps of Engineers, "Inland Waterways Trust Fund," http://www.lrl.usace.army.mil/Media/FactSheets/FactSheetArticleView/tabid/10589/Article/9213/inland-waterways-trust-fund.aspx, accessed January 3, 2014.

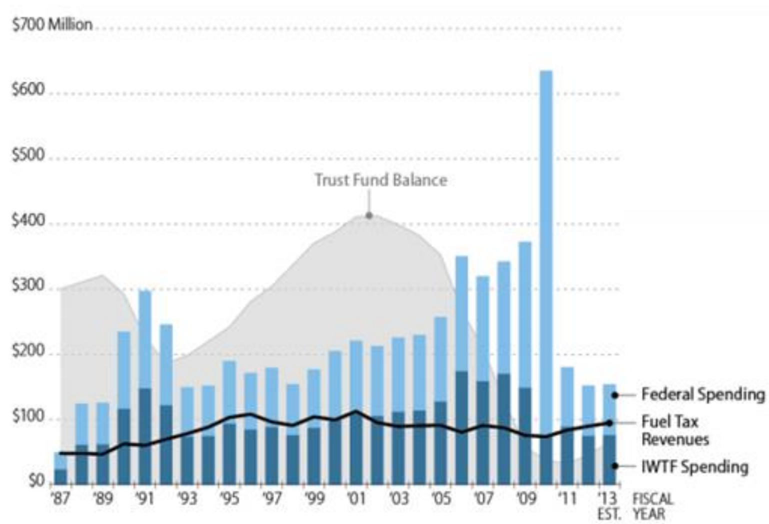

FIGURE 2—FEDERAL INLAND WATERWAY PROJECTS: FINANCING TRENDS, FY1987–FY2013[14]

The IWTF is used to fund construction and rehabilitation costs. These costs are shared with the Federal Government, which also covers operation and maintenance costs.[15] The IWTF has been declining since 2003. Increased amounts of the fund have been used to modernize the inland waterway system, and revenues have been flat or declining. As of 2009, the IWTF balance has decreased to the point that expenditures are limited to annual fuel tax revenues collected for that particular year. This has resulted in a backlog of authorized projects, further decreasing reliability and revenues. Maintenance funding gaps will reach $17 billion by 2040, if funding levels continue at current rates. Planned construction and rehabilitation projects will not be completed until 2090.[16]

Dam and lock rehabilitation can cost millions of dollars, and new construction can cost billions. The project to replace the Olmsted Locks and Dam, located on the Ohio River between Kentucky and Illinois, was authorized in 1988 at a total cost of $775 million. In April 2012, it was announced that the total cost would be more than $2.9 billion and completion was not expected until 2024. To meet this completion date, annual expenditures going forward will need to be approximately $150 million. Under the current rates, only $170 million is expected to be annually available for all inland waterway projects. Therefore, little progress can occur on other priority inland waterway projects until the Olmsted Locks and Dam project is completed.[17]

MITIGATION INITIATIVES

USACE is collaborating with the IWUB to help offset the substantial backlog of authorized projects and the declining reliability of the IMTS. The IWUB has made the following suggestions to mitigate risk to navigation locks and dams:[18]

- Increase the fuel tax by 30–45 percent to account for inflation. This will help develop a balanced IWTF and support repair, rehabilitation, and new construction projects.
- Change the funding structure for lock and dam construction and rehabilitation. The current structure supported by the fuel tax is insufficient to maintain the IMTS.
- Carry out process improvements for rehabilitation, repair, and maintenance projects, including certifying project management and developing risk-based cost estimates.

[14] Stern, Charles V., "Inland Waterways: Recent Proposals and Issues For Congress," http://www.fas.org/sgp/crs/misc/R41430.pdf, Congressional Research Service, July 14, 2011, accessed December 3, 2015.
[15] American Society of Civil Engineers, "2013 Report Card for America's Infrastructure," http://www.infrastructurereportcard.org/, accessed April 25, 2013.
[16] Ibid.
[17] Inland Waterways Users Board, Inland Waterways Users Board 25th Annual Report, 2012.
[18] Inland Waterways Users Board, "General Information," http://www.waterwaysusers.us/, accessed June 14, 2013.

In 2009, the Saint Lawrence Seaway Development Corporation initiated the U.S. Seaway Asset Renewal Program (ARP). The ARP Capital Investment Plan addresses many funding requirements for the U.S. Seaway locks and the Seaway International Bridge connecting Ontario, Canada, and New York State. The ARP is a coordinated effort to repair and modernize the U.S. Seaway infrastructure and includes maintenance, dredging, operational systems, and equipment purchase. The Harbor Maintenance Trust is a similar program to the IWTF used for dredging the Saint Lawrence Seaway.[19] The modernized infrastructure and new equipment made available because of the ARP plan will help to ensure the long-term reliability of the Saint Lawrence Seaway.

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[19] Saint Lawrence Seaway Management Corporation, "Asset Renewal Program," http://www.greatlakes-seaway.com/en/management/slsdc/asset, accessed August 18, 2014.

AGING AND FAILING INFRASTRUCTURE SYSTEMS: DAMS

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PREPARED BY: OPERATIONAL ANALYSIS DIVISION

SCOPE

The U.S. Department of Homeland Security (DHS)/Office of Cyber and Infrastructure Analysis (OCIA) produces Critical Infrastructure Security and Resilience Notes in response to changes in the infrastructure community's risk environment from terrorist activities, natural hazards, and other events. This product summarizes the findings related to dams identified in the National Risk Estimate on Aging and Failing Critical Infrastructure Systems, released by OCIA in December 2014. This note supports DHS leadership; other federal, state, and local agencies; and private sector decision makers.

KEY FINDINGS

- **States, localities, and private entities own 82 percent of all high hazard potential dams. The Federal Government owns 4 percent and public utilities own 2 percent of the dams listed on the U.S. National Inventory of Dams.**
- **States have inspection and regulatory authority over most dams. However, the Dam Safety Act expired in 2011, limiting federal funds available to support state dam safety programs.**
- **Dam safety incidents can occur at any point during a dam's lifetime, but approximately 31 percent of dam safety incidents occur during construction or within the first 5 years of operation.**

OVERVIEW

For the National Risk Estimate on Aging and Failing Critical Infrastructure Systems, OCIA gathered subject matter experts to highlight the current state of critical infrastructure and identify trends and physical characteristics of infrastructure that increase the risk of failure. Dams were one of nine subsectors examined. The study also identifies market, regulatory, and policy factors that affect infrastructure risk.

Dams play a critical role in the Nation's economy and serve a wide range of functions: debris control, fire protection, fish and wildlife conservation, flood control, grade stabilization, hydroelectric power production, irrigation, navigation, recreation, tailings storage, and water supply management.[1] Dams are generally categorized as either embankment or concrete. Embankment dams are either "earthfill" or "rockfill" and are the most common type of dam in use today. Gravity and arch dams are types of concrete dams, and gravity dams are the most common. Approximately 80 percent of dams in the United States were built before 1980.[2] The 2013

[1] A grade stabilization structure controls the grade of land surrounding a dam and reduces erosion. A tailings storage facility is a structure made up of (one or more dams) built for storing the uneconomical ore (ground up rock, sand, and silt) and water from the milling process.
[2] U.S. Army Corps of Engineers, "National Inventory of Dams," http://geo.usace.army.mil/pgis/f?p=397:5:0::NO, accessed 21 April 2014.

National Inventory of Dams (NID), maintained by the United States Army Corps of Engineers (USACE), consists of 87,359 dams.[3]

States, localities, and private entities own more than 89 percent of all dams listed in the NID and 82 percent of high hazard potential dams. The Federal Government owns only 4 percent and public utilities own only 2 percent of the dams on the NID. Local governments own a large percentage of flood control dams, federal agencies and state governments own most navigation dams, and public utilities own a large percentage of hydroelectric dams. Dams serving other purposes are mostly privately owned. States are the primary regulators of dams, although the Federal Government, including Federal Emergency Management Agency (FEMA) and USACE, also play an important role in managing dams and supporting state dam safety programs.

RISK OF FAILURE

Dam safety incidents can occur at any point during a dam's lifetime, but the most common period of dam failure is the first 5 years of operation. The United States Society of Dams conducted a study in 2009 of 1,158 national and international dam failures and safety incidents and found that 31 percent of safety incidents occur during construction or within the first 5 years of operation.[4] The most common causes of failure are overtopping, piping, and foundation defects.[5]

Overtopping caused by flooding and high-water events accounts for 34 percent of dam failures in the United States. Erosion caused by overtopping can compromise embankments and lead to failure. The risk of overtopping increases if the spillway design is inadequate, debris causes spillway blockage, or the dam crest settles.[6]

Piping—internal erosion caused by seepage—accounts for 20 percent of dam failures in the United States. Erosion through piping or seepage can occur through abutments or under the dam. In its initial stage, seepage can be described as a leak in the dam. The term piping applies when the leak carries embankment material, thus creating erosion and the likelihood of sinkholes that could cause structural failure.[7] Piping and seepage are the most common types of failure in the early years of a dam and are important considerations throughout the life of a dam.[8]

Foundation defects such as embankment slope instability and dam settlement, degradation of materials, operational issues, and inadequate maintenance are other common causes of dam failure. Earthquakes can also significantly damage dams.

Droughts affect the ability of dams to function as designed, especially hydroelectric dams. A prolonged drought can prevent dams in the impacted region from operating at full capacity when water levels drop too low.[9] The loss of the largest hydroelectric dams could result in inadequate power generation and lead to rolling blackouts—particularly in Washington and Oregon where more than 50 percent of electricity is hydroelectric.

Another important risk known as "hazard creep" describes urban growth and development occurring downstream of dams, increasing the consequences from failure. Dams designed as low hazard potential dams (those for which failure or improper operation results in no probable loss of human life and low economic or environmental losses; losses are principally limited to the owner's property) may become high hazard because of downstream developments. Although the failure or improper operation of high hazard potential dams could result in the loss of

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3 U.S. Army Corps of Engineers, "National Inventory of Dams," http://geo.usace.army.mil/pgis/f?p=397:5:0::NO, accessed 21 April 2014.
4 Regan, Patrick J., "An Examination of Dam Failures vs. Age of Dams," 29th Annual United States Society on Dams (USSD) Conference, April 2009, http://ussdams.com/proceedings/2009Proc/35-58.pdf, accessed 6 June 2013.
5 Association of State Dam Safety Officials, "Dam Failures and Incidents," http://www.damsafety.org/news/?p=412f29c8-3fd8-4529-b5c9-8d47364c1f3e, accessed 20 February 2013.
6 Ibid.
7 Ibid.
8 Regan, Patrick J., "An Examination of Dam Failures vs. Age of Dams", 29th Annual United States Society on Dams (USSD) Conference, April 2009, http://ussdams.com/proceedings/2009Proc/35-58.pdf, accessed 6 June 2013.
9 Intergovernmental Panel on Climate Change, "Projected Climate Change and Its Impacts," Climate Change 2007: Synthesis Report, https://www.ipcc.ch/publications_and_data/ar4/syr/en/spms3.html, accessed 5 March 2014.

human life, the hazard potential of a dam is determined solely by consequences, not dam condition.[10] Dam safety regulators generally have no control over local zoning laws or developers' property rights. Therefore, regulators will continue to face challenges from hazard creep.

REGIONS OF INCREASED RISK

Dams built near previously undetected seismic zones are more likely to fail if they were not designed to withstand earthquakes. In addition, dams built in areas now experiencing higher than normal amounts of precipitation are more likely to fail from overtopping. The intensity of heavy precipitation events has increased in the past 50 years, especially in the Northeast and Midwest, and the designs for dams in these regions may not be adequate for current weather patterns.[11]

DEPENDENCIES AND INTERDEPENDENCIES

The Water and Wastewater Systems Sector critically depends on dams for all steps of potable water production, including intake, distribution, and treatment. In addition, the Water and Wastewater Systems Sector assets depend on electric power provided by dams.

As of 2013, hydroelectric power accounts for nearly 7 percent of electricity generated in the United States, and a few states in the Northwest, including California, Oregon, and Washington, get more than 50 percent of their electricity from hydroelectric sources.[12]

The Transportation Systems Sector relies on dams and navigation locks for transporting goods and freight on inland waterways. Typically, dams on navigable waterways have navigation locks close by to allow passage around the dam. Dam failures could result in the extended closure of critical locks, requiring that goods be transported via more expensive routes, such as railways and commercial vehicles. An extended closure of some locks would result in insufficient rail and commercial vehicle capacity to transport some goods.

MARKET, POLICY, AND REGULATORY FACTORS

The National Dam Safety Program, led by FEMA, was established in the Water Resources Development Act of 1996 to help states establish and maintain dam safety programs and to train state dam safety inspectors and staff.[13] The legislation appropriated funding for FEMA to implement the NID and to perform technical and archival research to develop devices for monitoring dam safety. However, the Act did not provide funding for dam rehabilitation and repairs. The Dam Safety Act of 2006 reauthorized funding only through 2011 and has since expired.[14,15] Attempts in 2012 and 2013 to renew the Dam Safety Act and to provide grant assistance to states were unsuccessful.[16,17,18] The Association of State Dam Safety Officials estimates that $21 billion will be needed to repair aging critical high hazard potential dams.[19] Inadequate funding and underinvestment limit the ability of dam owners and operators to conduct inspections and perform timely maintenance and repairs.

Another challenge is that states vary in their regulatory capabilities. Approximately 77 percent of high hazard potential dams in the NID are regulated by state dam safety offices, and 14 percent are regulated by federal agencies. Approximately 9 percent of high hazard potential dams are not regulated due to exemptions based on

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[10] Association of State Dam Safety Officials, "Top Issues Facing the Dam Community," http://damsafety.org/news/?p=c0fdade4-ab98-4679-be22-e3d7f14e124f, accessed 17 April 2014.
[11] U.S. Environmental Protection Agency, "Implementing Climate Change Adaptation Planning in Accordance with Executive Order 13514, 'Federal Leadership in Environmental, Energy, and Economic Performance,' Federal Agency Climate Change Adaptation Planning Support Document," http://www.whitehouse.gov/sites/default/files/microsites/ceq/adaptation_support_document_3_3.pdf, accessed 30 December 2013.
[12] U.S. Energy Information Administration, "Electricity Data Browser," http://www.eia.gov/electricity/data/browser/, accessed 25 August 2014.
[13] S.640, Water Resources Development Act of 1996, http://www.gpo.gov/fdsys/pkg/PLAW-104publ303/content-detail.html, accessed 24 April 2013.
[14] S.2735, Dam Safety Act of 2006, http://www.govtrack.us/congress/bills/109/s2735, accessed 7 January 2014.
[15] 33 USC §467, 2012,"US Code–Subchapter VII: Dam Inspection Program," http://codes.lp.findlaw.com/uscode/33/9/VII, accessed 24 April 2013.
[16] H.R.6254, Dam Rehabilitation and Repair Act of 2012, http://www.govtrack.us/congress/bills/112/hr6254, accessed 7 January 2014.
[17] S.3362, Dam Safety Act of 2012, http://www.govtrack.us/congress/bills/112/s3362, accessed 24 April 2013.
[18] H.R.1489, Dam Safety Act of 2013, https://www.govtrack.us/congress/bills/113/hr1489/text, accessed 25 August 2014.
[19] American Society of Civil Engineers, "2013 Report Card for America's Infrastructure," http://www.infrastructurereportcard.org/, accessed 25 April 2013.

size and purpose. Since 2014, every state but Alabama has had dam safety legislation or dam safety programs.[20] Some states have only limited ability to enforce laws; in others, little recourse is available for dam owners who do not complete repairs ordered by the state.[21]

Differences among states make it difficult to aggregate data; no comprehensive national dataset exists. States receiving grant money under the National Dam Safety Program must have in place or be working toward having state dam safety programs with the authority to inspect dams and collect data. The NID receives information from dam regulators, but it can become outdated because the NID data fields are not comprehensive, and the NID is not updated annually. The most current information on the condition of state regulated dams is available through state dam safety offices.

MITIGATION INITIATIVES

FEMA collaborates with federal and state partners to continually improve dam safety and is the lead agency for the National Dam Safety Program. The Strategic Plan for the National Dam Safety Program captures a wide range of strategic goals for improving dam safety, including the following:[22]

- Goal 1—Reduce the likelihood of dam failures: assess all high and significant hazard potential dams for the risks they pose to life, property, and the environment; reduce the number of deficient dams in the United States; learn from dam failures in the United States and worldwide to improve dam safety programs; and support effective federal and state dam safety programs.
- Goal 2—Reduce the potential consequences of dam failures: promote a program of Emergency Action Plan implementation, compliance, and exercises for all high and significant hazard potential dams in the United States; and improve consequence evaluation for dams nationwide.

[20] Association of State Dam Safety Officials, "Top Issues Facing the Dam Community," http://www.damsafety.org/news/?p=c0fdade4-ab98-4679-be22-e3d7f14e124f, accessed 17 April 2014.
[21] Ibid.
[22] Federal Emergency Management Agency, "FEMA Strategic Plan for the National Dam Safety Program," http://www.fema.gov/media-library-data/8025e6039b9aebfa22e9f378347149c4/NDSP%20Strategic%20Plan_FEMA%20P-916.pdf, accessed 14 April 2014.

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