South Carolina Dam Failure Assessment and Advisement

DR-SC-4241

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Acronyms and Abbreviations

AAR	After Action Report
AEP	Annual Exceedance Probability
AFB	Air Force Base
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ASDSO	Association of State Dam Safety Officials
Atlas 14	National Oceanic and Atmospheric Administration Atlas No. 14
CAP	Civil Air Patrol
CoCoRaHS	Community Collaborative Rain, Hail & Snow Network
CDBG	Community Development Block Grant
COA	Certificate of Authorization
CPG	Comprehensive Preparedness Guide
CTP	Cooperating Technical Partner
EAP	Emergency Action Plans
EMA	Emergency Management Agency
EMI	Emergency Management Institute
EOP	Emergency Operations Plan
EPT	Exercise Planning Team
EQC	Environmental Quality Control
ESF	Emergency Support Function
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
H&H	Hydraulic and Hydrology
HMA	Hazard Mitigation Assistance
HMGP	Hazard Mitigation Grant Program
HMP	Hazard Mitigation Plan
HMR	HydroMeteorological Reports
HMR51	National Oceanic and Atmospheric Administration HydroMeteorological Reports No. 51
HMTAP	Hazard Mitigation Technical Assistance Program
HSEEP	Homeland Security Exercise and Evaluation Program
HUD	Housing and Urban Development

JFO	Joint Field Office
MAT	Mitigation Assessment Team
MACS	Multiagency Coordination System
MOU	Memorandum's of Understanding
NDSP	National Dam Safety Program
NID	National Inventory of Dams
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PTB	Positions Task Book
RFC	River Forecast Center
RRCC	Regional Response Coordination Center
SAREX	Search and Rescue Exercise
SC	South Carolina
SC DHEC	South Carolina Department of Health and Environmental Control
SC DNR	South Carolina Department of Natural Resources
SDF	Spillway Design Flood
SFHA	Special Flood Hazard Area
SEOC	State Emergency Operations Center
THIRA	Threat and Hazard Identification and Risk Assessment
TTX	Table Top Exercise
UAS	Unmanned Aerial System
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey
VLOS	Visual Line of Sight
VTTX	Virtual Table Top Exercise

Executive Summary

From October 1 through 5, 2015, heavy rainfall over parts of South Carolina resulted in the failure of 49 state regulated dams, one federally regulated dam, two sections of the levee adjacent to the Columbia Canal, and many unregulated dams. In support of recovery efforts, Federal Emergency Management Agency (FEMA) Mitigation, deployed a team to assist in the assessments of dams and provide expertise and insights to the State of South Carolina, FEMA Headquarters, FEMA Region IV, and Joint Field Office (JFO) leadership.

Development of this document was aided under the Hazard Mitigation Technical Assistance Program (HMTAP) contract No HSFE60-15-0014. This report is a result of the FEMA Mitigation Dam Task Force Strategic White Paper (FEMA, 2015) recommendation to issue a task order under the HMTAP to aid the recovery. The deliverables of this task order provide state and local officials with consolidated data about the 49 state regulated dams that breached during the flooding event which resulted in disaster declaration DR-4241-SC. This data can be used to identify potential Hazard Mitigation Grant Program (HMGP) projects. It can also inform land use decisions, and may impact other comprehensive recovery options that consider vulnerable critical infrastructure and high value mitigation targets. Specifically, the report includes:

- An overview of dam safety in South Carolina including regulatory authority and key regulations
- An overview of Disaster Declaration DR-4241-SC including the meteorological setup, flooding and dam failures
- A detailed assessment of the rainfall that was experienced at each dam in terms of Fractional Probable Maximum Precipitation (PMP) estimates and rainfall return period estimates which is graphically compared to the South Carolina Department of Health and Environmental Control (SC DHEC) Spillway Design Flood (SDF) Design Criteria
- An overview of the process implemented to assess failed dams including background data collection, field assessment summaries and observations, identification of downstream hazards and the development of recovery advisories
- A summary of potential hazard mitigation strategies to improve dam safety
- Recommendations to improve dam safety partner collaboration based on extensive observations and discussions with an array of federal, state and non-governmental organizations involved with the October, 2015 South Carolina flood event response operation, as well as dam safety professionals from FEMA Region IV, the National Dam Safety Program (NDSP) and state officials from Colorado, Georgia and Montana.

Dam Safety in South Carolina

The South Carolina Department of Health and Environmental Control is the government agency responsible for the regulation of state regulated dams and reservoirs in South Carolina.

South Carolina dam regulations are covered in the Code of Laws, Title 49 – Waters, Water resources and Drainage, Chapter 11. Article 3 of Title 49, Dams and Reservoirs Safety Act, is the basis of South Carolina's Dams and Reservoirs Safety Program. The purpose of the Dams and Reservoirs Safety Act is to protect citizen's health, safety, and welfare by creating a regulatory program to reduce the risk of failure of dams. The law confers upon the SC DHEC regulatory authority to accomplish the purposes of the act. This includes the power to promote regulations, require permits, conduct inspections, and take enforcement actions among other things. Below are excerpts from the SC DHEC's *Dams and Reservoirs Safety Act Regulations; Regulation 72-1 thru 72-9, Initially Approved in 1977 and Amended July 25, 1997* for potential dam size classifications, hazard potential classifications and exemptions for dams (SC DHEC, 1997).

72-2. Dam Classifications and Exemptions.

A. General. All dams and reservoirs subject to this regulation shall be classified according to their size and hazard potential. Classifications shall be made in accordance with this section and are subject to final approval by the Department. It may be necessary to reclassify dams as additional information becomes available.

B. Size Classification. The classification for size based on the height of the dam and storage capacity shall be in accordance with the table below. Size classification may be determined by either storage or height, whichever gives the larger size capacity.

Table 1: Size Classification Table

Size	Total Storage (Acre-feet)	Height (ft)
Very Small	< 50	< 25
Small	≥ 50 and < 1,000	≥ 25 and < 40
Intermediate	≥ 1,000 and < 50,000	≥ 40 and < 100
Large	≥ 50,000	≥ 100

C. Hazard Potential Classification. The classification for potential hazard shall be in accordance with the table below. The hazards pertain to potential loss of human life or property damage in the event of failure or improper operation of the dam or appurtenant works. Probable future development of the area downstream from the dam that would be affected by its failure shall be considered in determining the classification. Dams shall be subject to reclassification if the Department determines that the hazard has changed.

Table 2: Hazard Potential Classification Table

Hazard Classification	Hazard Potential
High Hazard (Class I)	Dams located where failure will likely cause loss of life or serious damage to homes(s), industrial and commercial facilities, important public utilities, main highway(s) or railroads.
Significant Hazard (Class II)	Dams located where failure will not likely cause loss of life but may damage home(s), industrial and commercial facilities, secondary highway(s) or railroad(s) or cause interruption of use or service of relatively important public utilities.
Low Hazard (Class III)	Dams located where failure may cause minimal property damage to others. Loss of life is not expected.

D. Exemptions. The following types of dams are exempt from the Dams and Reservoirs Safety Act and the regulations pertaining thereto:

1. Unless the hazard potential as determined by the Department is such that dam failure or improper reservoir operation may cause loss of human life, any dam which is or shall be (a) less than twenty-five feet in height from the natural bed of the stream or water course measured at the downstream toe of the dam, or twenty-five feet from the lowest elevation of the outside limit of the dam, if it is not across a stream channel or water course, to the maximum water storage elevation and (b) has or shall have an impounding capacity at maximum water storage elevation of less than fifty acre-feet.

2. Any dam owned or operated by any department or agency of the federal government.

3. Any dam owned or licensed by the Federal Energy Regulatory Commission, the South Carolina Public Service Authority, the Nuclear Regulatory Commission, the U.S. Army Corps of Engineers (USACE), or other responsible federal licensing agencies considered appropriate by the Department.

4. Any dam upon which the South Carolina Department of Transportation or county or municipal governments have accepted maintenance responsibility for a road or highway where that road or highway is the only danger to life or property with respect to failure of the dam.

5. Any dam, which in the judgement of the Department, because of its size and location could pose no significant threat of danger to downstream life or property. Upon request, Certificates of Exemption (SC DHEC Form 2601(6/94)) are available from the Department for dams in this category.

E. Dams in Series. If an upstream dam has the capability to create failure in a downstream dam because of its failure flood wave, it shall have the same or higher hazard classification as the downstream dam. If the failure wave of the upstream dam will not cause failure of the downstream dam, the upstream dam may have a different hazard potential classification from the downstream dam.

Disaster Declaration DR-4241-SC

Meteorological Setup

The South Carolina Department of Natural Resources (SC DNR) created a website with in-depth information and analysis related to the October 2015 flooding event. The website can be accessed at http://www.dnr.sc.gov/flood2015 (SC DNR, 2016). Much of the following description of the precipitation is taken from the Open-File Report by Mark Malsick of the SC DNR which can be found online at http://www.dnr.sc.gov/climate/sco/flood2015/HRE2015.pdf (Malsick, 2016).

The five day October historic rainfall event produced heavy rains and subsequent catastrophic flooding a week after an extended period of State-wide rain. From September 24 through 29, 2015, rain and heavy rain showers fell across the State triggered by a frontal boundary that stalled along the coast during that period. Rainfall amounts of 1 to 4 inches were recorded by various observing sites. Rainfall amounts in excess of 5 inches were observed in Richland and Colleton counties. The September rain event saturated the ground, and filled lakes, ponds, creeks and rivers ahead of October's event.

On October 1, 2015, a cold front swept across the State and stalled offshore for five days. This boundary tapped into deep tropical moisture over the Gulf of Mexico as it sat offshore the Low Country as seen below in Figure 1. As Hurricane Joaquin rapidly deepened over the Bahamas and interacted with the stalled coastal front, an upper level trough of low pressure migrated and deepened over the eastern United States. An upper level cut-off low within that trough deepened and stalled over southern Georgia blocked in place by a ridge of high pressure to the north.

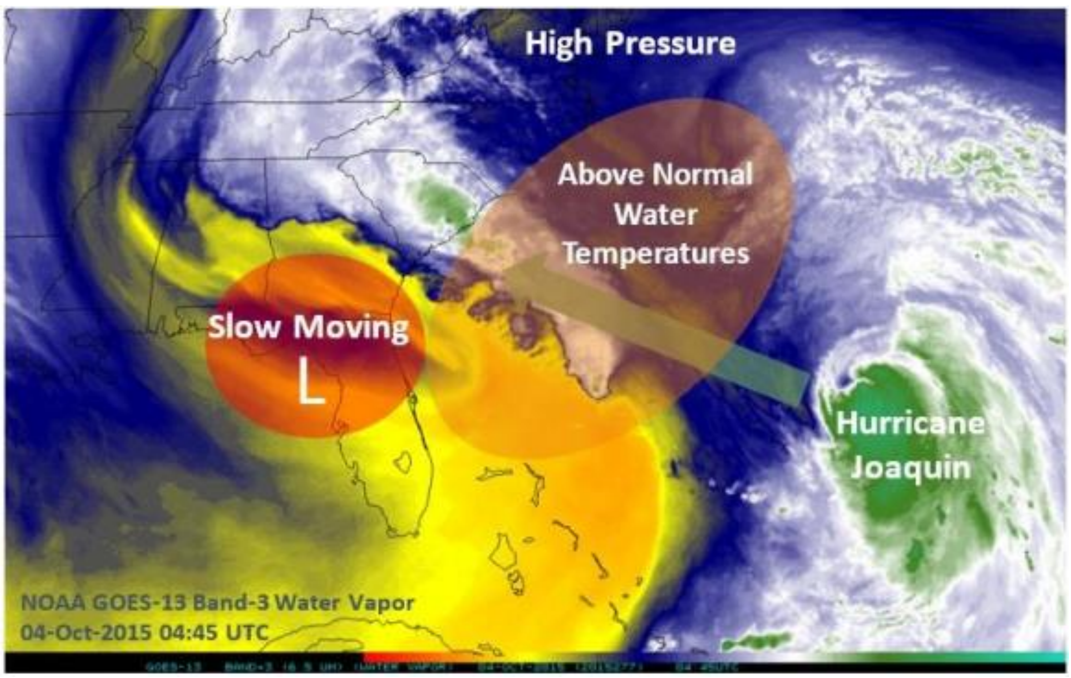

Figure 1: National Oceanic and Atmospheric Administration (NOAA) Water Vapor with Overlay of Parameters Contributing to Heavy Rain (Source: NOAA)

As these features aligned, along with the stalled cold front offshore, they produced light rain and drizzle from October 1 through 3, 2015. Late Saturday night on October 3, with a conveyer of moisture in place from the tropics, the blocked features aloft created a strong divergence mechanism that forced the intense convection that produced the torrential rains before sunrise on Sunday, October 4. The blocking pattern rapidly weakened as the stalled coastal front dissipated and the upper level cold core low drifted eastward over the Atlantic producing lingering light rain over the northeast region of the state on Monday October 5, 2015.

Flooding and Dam Failures

Much of the following description of the flooding is taken from the Open-File Report by Wes Tyler of the SC DNR which can be found at http://dnr.sc.gov/climate/sco/flood2015/octFlood15narrative.pdf (Tyler, 2015). This report can also be found at the SC DNR website for October 2015 flooding which can be accessed at http://www.dnr.sc.gov/flood2015 (SC DHEC, 2015).

Well before sunrise on Sunday, October 4, record and deadly rains expanded into Clarendon, Orangeburg, Williamsburg, Florence, Sumter, Kershaw, Richland and Lexington counties with rainfalls of 10 inches or higher. An automated Forestry Service rain gage near Santee in Clarendon County indicated that as of 1:44 a.m. 9.81 inches of rain had fallen over the previous 24-hours. Figure 2 below shows flooding on a roadway in Clarendon County.

Figure 2: Clarendon County, South Carolina (Source: SC DNR Law Enforcement)

In the hours of intense rain before Sunday's light, fast moving water coursed over heavily used roads and freeways. The intersection of Highway 601 and 378 was closed at 4:29 a.m. Cars were stalled along highway 378 near the McEntire Air National Guard Base. The Interstate 20/Interstate 26 west exit ramp was closed. The SC Highway Patrol closed a portion of Interstate 26 in Clarendon County at 6:00 a.m. due to flooding.

Hourly rainfall rates at the Forest Acres Richland County Emergency Services Gills Creek automated gage (Forest Drive and I-77) recorded 1.76 inches from 2-3:00 a.m., 3.76 inches from 3-4:00 a.m., 3.00 inches from 4-5:00 a.m. and 2.12 inches from 5-6:00 a.m. yielding an unprecedented 10.64 inches over four hours. At 7:00 a.m., the Gill's Creek site had accumulated 12.68 inches of rain since midnight. Spillways and dams along the Arcadia Lakes watershed were overwhelmed. As dawn arrived, so did dam failures including the Pine Tree Lake Dam (just below Windsor Lake), the Havird Pond on Arcadia Road, the Cary Lake Dam at Skii Lane and the Semmes Lake Dam on Fort Jackson, sending a flash flood downstream.

Daylight revealed overflowing roadside ditches moving into streams and creeks and rapidly filling ponds and lakes. Vehicles were swept off of Dentsville's Decker Boulevard near the intersection of O'Neil Court, trapping occupants and requiring teams of rescue response. Hurried swift water specialists from multiple agencies performed emergency rescues throughout the morning removing homeowners from the Lake Katherine community downstream into the Garners Ferry Road business section. Flooding in Richland County can be seen in Figure 3.

Figure 3: Richland County, South Carolina (Source: SC DNR Law Enforcement)

Many one story homes were submerged. A United States Geological Survey (USGS) gage along Gills Creek at Fort Jackson Boulevard was destroyed after recording and transmitting a stage height of 17.1 feet. A USGS post flooding survey analysis would indicate a peak stage of 19.6 feet. At noon, the Forest Acres Gills Creek gage rainfall amount had risen to an incredible 15.51 inches for the past twelve hour period. The Rocky Creek Branch stage at South Main and Whaley in downtown Columbia climbed to its second highest stage of record when it crested at 12.28 feet on Sunday afternoon. So much rain fell over the Twelve Mile Creek basin in Lexington County the historic Lexington Mill Pond earthen dam failed, sweeping away much of the restored mill's business property and taking out a portion of Highway 1. A Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) observer in Lexington reported a 24-hour total, ending at 7:00 a.m. on Sunday morning of 8.40 inches. Urban and rural washouts along rail and roadway beds, shoulders, overpasses and bridges resulted in barricades and lengthy detours from the Midlands south into the Low Country and eastward into the Pee Dee.

The Columbia Metro AP 24-hour rainfall of 8.74 inches established an all-time record for any month. At 6:45 p.m., the Congaree River at Columbia reached a peak and "major flood" stage of 31.81 feet with a calculated flow of 185,000 cubic feet per second. It was discovered during the earliest minutes of daylight on Monday morning, October 5, the 120-year-old Broad River diversionary Columbia Canal breached, compromising the availability of treated drinking water for the service area populace. A combined "around the clock" effort to stabilize the canal failure was performed and completed by the engineering leadership represented by the City of Columbia, the USGS, FEMA, U.S. Army and National Guard.

Georgetown's 12.32-inch total over Saturday and Sunday turned the county into a lake. The USGS Black River gage at Kingstree indicated a Sunday 24-hour rain total of 12.83 inches. The city of Kingstree was surrounded by rising water and residents were evacuated. The Gills Creek gage midnight ending rainfall total of 16.69 inches was the greatest known amount ever measured in South Carolina over 24-hours. According to the National Weather Service Hydrometeorological Design Studies Center, that amount exceeded the 1,000 year average recurrence interval for any location in the state.

At 12:15 a.m. on Monday morning, October 5, Shaw Air Force Base (AFB) in Sumter reported north-northeast winds gusting to 37 mph. There were scattered reports of mature trees toppling onto cars, power lines and residential property as root systems gave way to the overly saturated soils. Periods of rain, sometimes heavy, fell through the day before tapering off during the evening hours. Running "event" rainfall totals reached 21.49 inches for the Forest Acres Gills Creek gage and 19.81 inches at Shaw AFB in Sumter. The USGS gage on the Black River at Kingstree recorded an October 1-5 rainfall amount of 22.91 inches. On Tuesday, October 6 at 9:30 p.m., the Black River at Kingstree reached an all-time record stage of 22.65 feet surpassing the previous record flood stage of 19.77 feet set on June 14, 1973. The corresponding flow rate during this flood event is identified in Figure 4.

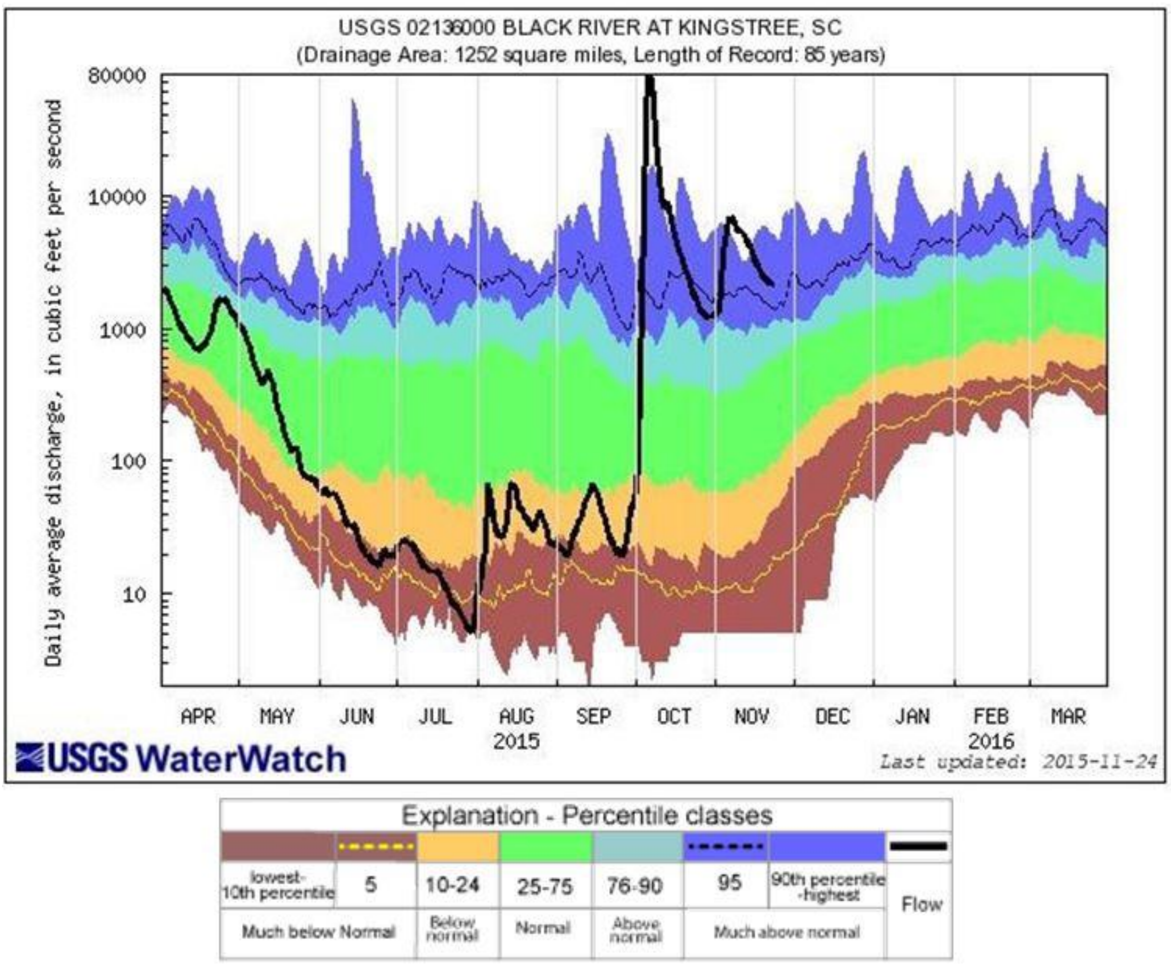

Figure 4: Black River at Kingstree, SC: Daily Mean Discharge (Source: USGS)

Precipitation Reconstruction for Dams

Background and Metrics

To gain a greater understanding of the storm severity and potential loading experienced at each dam, a comparison was performed between the dam specific precipitation totals and the corresponding state spillway design criteria. To determine this, the maximum 6-, 12-, 24-, and 48-hr precipitation totals observed during the storm event were determined for the entire state of South Carolina by radar rainfall reconstruction. This data was then intersected with the drainage areas for each of the dams to determine the rainfall totals. These totals were compared with NOAA HydroMeteorological Reports (HMR) to determine the fraction of the PMP that occurred at each dam and NOAA Atlas 14 (NOAA, 2006) Rainfall Frequency Atlas (Atlas 14) reports to determine the probabilistic rainfall totals that occurred at each dam. The rainfall totals at each dam were compared to the state spillway design criteria specified in Table 1 of the SC DHEC Dams and Reservoir Safety Act Regulations (Table 3, below). The results of the comparison are a valuable metric to the state of South Carolina and the surrounding region to determine the adequacy and effectiveness of the current state dam safety regulations.

Table 3: SDF Criteria (Source: Table 1 of the SC DHEC Dam Safety Regulations)

Hazard	Size	SDF*
High	Very Small	100-yr. to 1/2 PMF
	Small	1/2 PMF to PMF
	Intermediate	PMF
	Large	PMF
Significant	Small	100-yr. to 1/2 PMF
	Intermediate	1/2 PMF to PMF
	Large	PMF
Low	Small	50 to 100-yr. frequency
	Intermediate	100-yr. to 1/2 PMF
	Large	1/2 PMF to PMF

*Note: When appropriate, the SDF may be reduced to the spillway discharge at which dam failure will not significantly increase the downstream hazard which exists just prior to dam failure.

The two metrics sought during the rainfall reconstruction of the October 2015 South Carolina flooding event: (i) the fractional PMP which can be used to estimate the Probable Maximum Flood (PMF), and (ii) the rainfall return periods for various durations. These metrics were estimated for each of the dams that failed during the event. Rainfall data was obtained over the period September 25 through October 10, 2015, from NOAA. However, the findings specifically focus on the October 1 through 5, 2015, period, which represents the greatest rainfall intensities and flood magnitudes. In the following sections, rainfall reconstruction results, including estimates of fractional PMP and rainfall return periods are presented. All calculations were done using a combination of Microsoft Excel (2013) and R statistical software (version 3.2.2).

Rainfall Amounts & Evolution

The rainfall reconstruction for the dams was completed using the NOAA Stage IV dataset which is an hourly quality controlled radar rainfall product. The dam drainage area and watershed boundary was determined using the USGS StreamStats software after manually specifying the dam's outflow position. StreamStats is a web application that incorporates a Geographic Information System (GIS) to provide users with access to an assortment of analytical tools that are useful for a variety of water-resources planning and management purposes, and for engineering and design purposes. StreamStats users can select USGS data-collection station locations shown on a map and obtain previously published information for the stations, including descriptive information, and previously published basin characteristics and streamflow statistics. The drainage area determined from StreamStats represents the total drainage area upstream of the dam. Other sources of information pertaining to individual dams may reference the contributing drainage area which represents only the reduced drainage area downstream of an upstream reservoir and therefore may appear to conflict with drainage areas referenced in this report. Table 4 provides the list of dams, construction dates, the location of the dam's outflow and drainage area using information provided by SC DHEC. Footnotes have been provided to document dates that known modifications were made to the dam. Table 5 identifies the applicable Dam and Reservoirs Safety Act Regulations SC DHEC SDF criteria based on the dam size and hazard potential. It should be noted that many or all of the dams were constructed prior to the enactment of the Dam and Reservoirs Safety Act.

Table 4: Summary of Dam Location, ID and Drainage Area

Name	SC ID	Construction Date	Longitude	Latitude	Impounded stream	Drainage Area (sq mi)
Lake Elizabeth	D0024	1900	-80.98730	34.11230	Crane Creek	21.5
Carys Lake	D0026	1938[1]	-80.95790	34.04890	Jackson Creek	18.8
Murray Pond Dam	D0595	1930	-80.70750	33.98540	Colonels Creek	53.1
Pinewood Lake Dam	D0580	1900	-80.91198	33.94405	Mill Creek	13.1
Weston Pond Dam	D0593	1932	-80.76841	33.88309	Toms Creek	15.9
Wilson Millpond Dam	D0594	1960	-80.74289	33.99993	Jumping Run Creek	5.6
Duffies Pond Dam	D0600	1967	-80.85269	33.84433	Cedar Creek	33.2
Ulmers Pond	D0581	1940[2]	-80.89510	33.96780	Trib to Mill Creek	2.8
Sunview Lake Dam	D0579	1949	-80.91160	33.96670	Mill Creek	8.2
Lower Rocky Creek Dam/Rocky Ford Lake	D0028	1900	-80.95249	34.03591	Gills Creek	22.1
North Lake Dam/Overcreek Rd. Dam/Upper Rocky Creek	D0029	1955	-80.95170	34.03970	Gills Creek	22.0
Walden Place Dam	D0572	1950	-80.84610	34.11660	Spears Creek	3.0
Covington Lake Dam	D0545	1950	-80.97430	34.13480	Roberts Branch	5.2
Beaver Dam Lake/Wildwood Pond #2/Boyd Pond	D0567	1963[3]	-80.88652	34.09651	Trib to Jackson Creek	0.7
Old Mill Pond Dam	D0958	1900	-81.22960	33.97650	Twelve Mile Creek	33.3
Barr Dam/ Barr Lake Dam	D1717	1900	-81.26010	33.95870	Twelve Mile Creek	27.1

Name	SC ID	Construction Date	Longitude	Latitude	Impounded stream	Drainage Area (sq mi)
Gibson Dam/Gibson's Pond Dam	D0959	1900	-81.24493	33.96907	Twelve Mile Creek	49.2
Baileys Pond	D2034	1945	-81.28636	33.59466	Goodland Creek	2.9
Corbett Lake	D2052	1955	-81.21140	33.64890	Hollow Creek	16.4
Able / Corbett Pond Dam	D2048	1955	-81.23400	33.62160	Little Hollow Creek	3.6
JW Smoaks Pond	D3738	1920	-80.93430	33.52510	Mill Branch	5.5
SCNONAME 38036 (Cleveland Street)	D3743	1960	-80.51400	33.52320	Browning Branch	15.2
Busbees Pond	D3701	1960	-81.05704	33.55657	Tampa Creek	4.4
Culler Pond	D3682	1960	-81.15930	33.63690	Salem Creek	7.6
Clyburn Pond Dam	D2412	1930[4]	-80.30240	34.32980	Turkey Creek	7.5
Chapman's Pond Dam	D3533	1957	-79.94180	34.41950	Seed Branch	11.3
O E Rose Dam	D3487	1900	-80.09070	33.80670	Mill Branch	9.2
Lakewood Pond Dam	D3490	1955	-80.09320	33.74990	Lakewood Creek	4.5
Ellerbees Millpond Dam	D1460	1830	-80.54962	34.06844	Rafting Creek	26.2
Cook Pond Dam	D1068	1963	-80.77560	34.15240	Trib to Kelly Creek	0.5
Clarkson Pond Dam	D0599	Unknown	-80.8266	33.87006	Cedar Creek	30.2
Wards Pasture Pond Dam	D3502	1970	-80.2857	33.571809	Trib to Potato Creek	2.9
SCNONAME 09031 (off Community Club Rd.)	D2645	Unknown	-80.5955	33.5848	Trib to Halfway Swamp Creek	8.7
SCNONAME 14003 (off Fox Tindal Rd.)	D3497	1960	-80.4436	33.6525	Big Branch	2.0
SCNONAME 14005 (off Puddin Swamp Rd.)	D3484	1900	-80.0076	33.849058	Horse Branch	19.7
SCNONAME 09040 (off Church Camp Rd.)	D2921	1930	-80.7381	33.5599	Four Hole Swamp	8.2
SCNONAME 28045 (off Tower Rd.)	D2521	1955	-80.7526	34.1129	Trib to Sloan Branch	0.5
SCNONAME 14008 (off Old River Rd.)	D3495	1875	-80.4959	33.652213	Spring Grove Creek	23.8
Dogwood Lake Dam	D2065	1850	-80.3297	33.8016	Trib to Briar Branch	2.6
Drafts Pond Dam	D0601	1967	-80.7256	33.8265	Toms Creek	32.6
Boyle Pond Dam	D1583	1957	-80.4377	33.8800	Cane Savannah Creek	46.6
McCray Lake Dam	D1584	1908	-80.4611	33.8853	Cane Savannah Creek	15.5
M. R. Trotter Dam	D0110	1971	-80.7284	33.8981	Ray Branch	3.1
Smith Millpond Dam	D0510	Unknown	-79.3449	34.0669	Reedy Creek	26.1

Name	SC ID	Construction Date	Longitude	Latitude	Impounded stream	Drainage Area (sq mi)
Boyds Pond Dam	D0592	1964	-80.7555	33.9181	Toms Creek	10.5
Haithcock Pond Dam	D0591	1946	-80.755	33.958	Toms Creek	5.7
Touchberry Lower Pond Dam	D1586	1958	-80.5279	33.6968	Trib to Santee River	1.5
Cuttino Pond Dam	D3482	1960	-80.1956	33.8164	Trib to Tearcoat Branch	1.2
Black Crest Farm Pond Dam	D2063	1970	-80.3275	33.8386	Trib to Pocotaligo River	1.9
Forest Lake Dam	D4434	1900	-80.9627	34.0221	Gills Creek	43.6
SCNONAME 32080	D0957	Unknown	-81.1615	34.0491	Twelve Mile Creek	60.1
Epworth Pines Dam	D0362	1967	-80.9574	34.1449	Roberts Branch	3.5
Hermitage Mill Pond Dam	D0017	1935	-80.573	34.24476	Big Pine Tree Creek	48.6
Fredericksburg Lake Dam	D2539	1975	-80.6907	34.1939	Trib to Gillies Creek	0.9
Windsor Lake Dam	D0571	1965	-80.9403	34.0678	Trib to Gills Creek	7.1
Cola Plantation Dam	D3498	1960	-80.3859	33.6555	Chapel Creek	2.5
Stevenson's Lake Dam	D0546	1960	-80.9753	34.1295	Trib to Crane Creek	5.7
Legette Millpond Dam	D0511	1840	-79.3411	34.044	Reedy Creek	28.6

[1] Dam was modified in 1988. [2] Dam was modified in 1994. [3] Dam was modified in 2010. [4] Dam was modified in 1998

Table 5: SC DHEC SDF Criteria for Field Assessed Dams

Name	SC ID	SC DHEC Hazard Potential Classification	Size Category	SDF
Lake Elizabeth	D0024	High	Small	1/2 PMF to PMF
Carys Lake	D0026	High	Small	1/2 PMF to PMF
Murray Pond Dam	D0595	Significant	Intermediate	1/2 PMF to PMF
Pinewood Lake Dam	D0580	Significant	Small	100-yr to 1/2 PMF
Weston Pond Dam	D0593	Low	Small	50-yr to 100-yr
Wilson Millpond Dam	D0594	Significant	Small	100-yr to 1/2 PMF
Duffies Pond Dam	D0600	Significant	Small	100-yr to 1/2 PMF
Ulmers Pond	D0581	High	Small	1/2 PMF to PMF
Sunview Lake Dam	D0579	Significant	Small	100-yr to 1/2 PMF
Lower Rocky Creek Dam/Rocky Ford Lake	D0028	High	Small	1/2 PMF to PMF
North Lake Dam/Overcreek Rd. Dam/Upper Rocky Creek	D0029	High	Small	1/2 PMF to PMF
Walden Place Dam	D0572	High	Small	1/2 PMF to PMF
Covington Lake Dam	D0545	Significant	Small	100-yr to 1/2 PMF
Beaver Dam Lake/Wildwood Pond #2/Boyd Pond	D0567	Significant	Small	100-yr to 1/2 PMF
Old Mill Pond Dam	D0958	High	Small	1/2 PMF to PMF
Barr Dam/ Barr Lake Dam	D1717	Significant	Small	100-yr to 1/2 PMF
Gibson Dam/Gibson's Pond Dam**	D0959	Significant	Small	100-yr to 1/2 PMF
Baileys Pond***	D2034	Low	Small	50-yr to 100-yr
Corbett Lake	D2052	Low	Small	50-yr to 100-yr
Able / Corbett Pond Dam	D2048	Low	Small	50-yr to 100-yr
JW Smoaks Pond	D3738	Significant	Intermediate	1/2 PMF to PMF
SCNONAME 38036 (Cleveland Street)	D3743	Low	Small	50-yr to 100-yr
Busbees Pond	D3701	Significant	Small	100-yr to 1/2 PMF
Culler Pond	D3682	Low	Small	50-yr to 100-yr
Clyburn Pond Dam	D2412	Significant	Small	100-yr to 1/2 PMF
Chapman's Pond Dam	D3533	Significant	Small	100-yr to 1/2 PMF
O E Rose Dam	D3487	Significant	Small	100-yr to 1/2 PMF
Lakewood Pond Dam	D3490	Significant	Small	100-yr to 1/2 PMF
Ellerbees Millpond Dam	D1460	Significant	Small	100-yr to 1/2 PMF
Cook Pond Dam	D1068	Significant	Small	100-yr to 1/2 PMF
Clarkson Pond Dam	D0599	Low	Small	50-yr to 100-yr
Wards Pasture Pond Dam	D3502	Low	Small	50-yr to 100-yr
SCNONAME 09031 (off Community Club Rd.)	D2645	Low	Small	50-yr to 100-yr
SCNONAME 14003 (off Fox Tindal Rd.)	D3497	Low	Small	50-yr to 100-yr

Name	SC ID	SC DHEC Hazard Potential Classification	Size Category	SDF
SCNONAME 14005 (off Puddin Swamp Rd.)	D3484	Low	Small	50-yr to 100-yr
SCNONAME 09040 (off Church Camp Rd.)	D2921	Low	Small	50-yr to 100-yr
SCNONAME 28045 (off Tower Rd.)	D2521	Low	Small	50-yr to 100-yr
SCNONAME 14008 (off Old River Rd.)	D3495	Low	Small	50-yr to 100-yr
Dogwood Lake Dam	D2065	Low	Small	50-yr to 100-yr
Drafts Pond Dam	D0601	Low	Small	50-yr to 100-yr
Boyle Pond Dam	D1583	Low	Intermediate	100-yr to 1/2 PMF
McCray Lake Dam	D1584	Low	Small	50-yr to 100-yr
M. R. Trotter Dam	D0110	Low	Small	50-yr to 100-yr
Smith Millpond Dam	D0510	Low	Small	50-yr to 100-yr
Boyds Pond Dam	D0592	Low	Small	50-yr to 100-yr
Haithcock Pond Dam	D0591	Low	Small	50-yr to 100-yr
Touchberry Lower Pond Dam	D1586	Low	Small	50-yr to 100-yr
Cuttino Pond Dam	D3482	Low	Small	50-yr to 100-yr
Black Crest Farm Pond Dam	D2063	Low	Small	50-yr to 100-yr
[1]Forest Lake Dam	D4434	High	Intermediate	PMF
[1]SCNONAME 32080	D0957	Low	Small	50-yr to 100-yr
[1]Epworth Pines Dam	D0362	Significant	Small	100-yr to 1/2 PMF
[1]Hermitage Mill Pond Dam	D0017	High	Intermediate	PMF
[1]Fredericksburg Lake Dam	D2539	High	Small	1/2 PMF to PMF
[1]Windsor Lake Dam	D0571	High	Small	1/2 PMF to PMF
[1]Cola Plantation Dam	D3498	Significant	Small	100-yr to 1/2 PMF
[1]Stevenson's Lake Dam	D0546	Significant	Small	100-yr to 1/2 PMF
[1]Legette Millpond Dam	D0511	Low	Small	50-yr to 100-yr

*Note: When appropriate, the SDF may be reduced to the spillway discharge at which dam failure will not significantly increase the downstream hazard which exists just prior to dam failure.
**Hazards observed during assessment suggest possible High Hazard potential
*** Hazards observed during assessment suggest possible Significant Hazard potential
[1] Dam did not fail but was analyzed for comparative purposes.

The NOAA Stage IV rainfall dataset is available on a ~4km grid across the United States. Hourly rainfall is first estimated using radar reflectivity-rainfall relationships, and is then gage-adjusted by the NOAA River Forecast Centers (RFCs) using a comprehensive set of gages. The Southeast RFC is responsible for the South Carolina region. As a quality control measure, Table 6 shows that Stage IV estimates were within about 5% of gage-observed rainfall at Columbia and Orangeburg. A perfect rainfall reconstruction is virtually impossible to achieve due to finite ground observations, and a margin of 5% is typically considered adequate.

Table 6: Comparison of Stage IV Estimated and Measured Rainfall for Columbia and Orangeburg

NOAA Gage Name	Location	Stage IV (in.)	Gage Estimate (in.)	Stage IV Bias (%)
Columbia (KCAE)	33.94N, 81.12W	12.17	11.52	5.60%
Orangeburg (KOGB)	33.46N, 80.86W	10.16	10.64	-4.50%

Figure 5 shows the total accumulated rainfall from 11 a.m. October 1 through 11 p.m. October 5, 2015. The 58 dam drainage areas associated with the assessed dams are shown in black. Vast areas of central and southeastern South Carolina received over 10 inches of rainfall, with many areas from Columbia southeastward towards the coastline exceeding 20 inches. It is notable that the amount shown in Figure 5 does not include up to 5 inches of antecedent rainfall from September 20 through 27 over Central South Carolina. While this earlier event did not cause any major flooding, it reduced the soil infiltration capacity during the main event, exacerbating problems with excessive runoff.

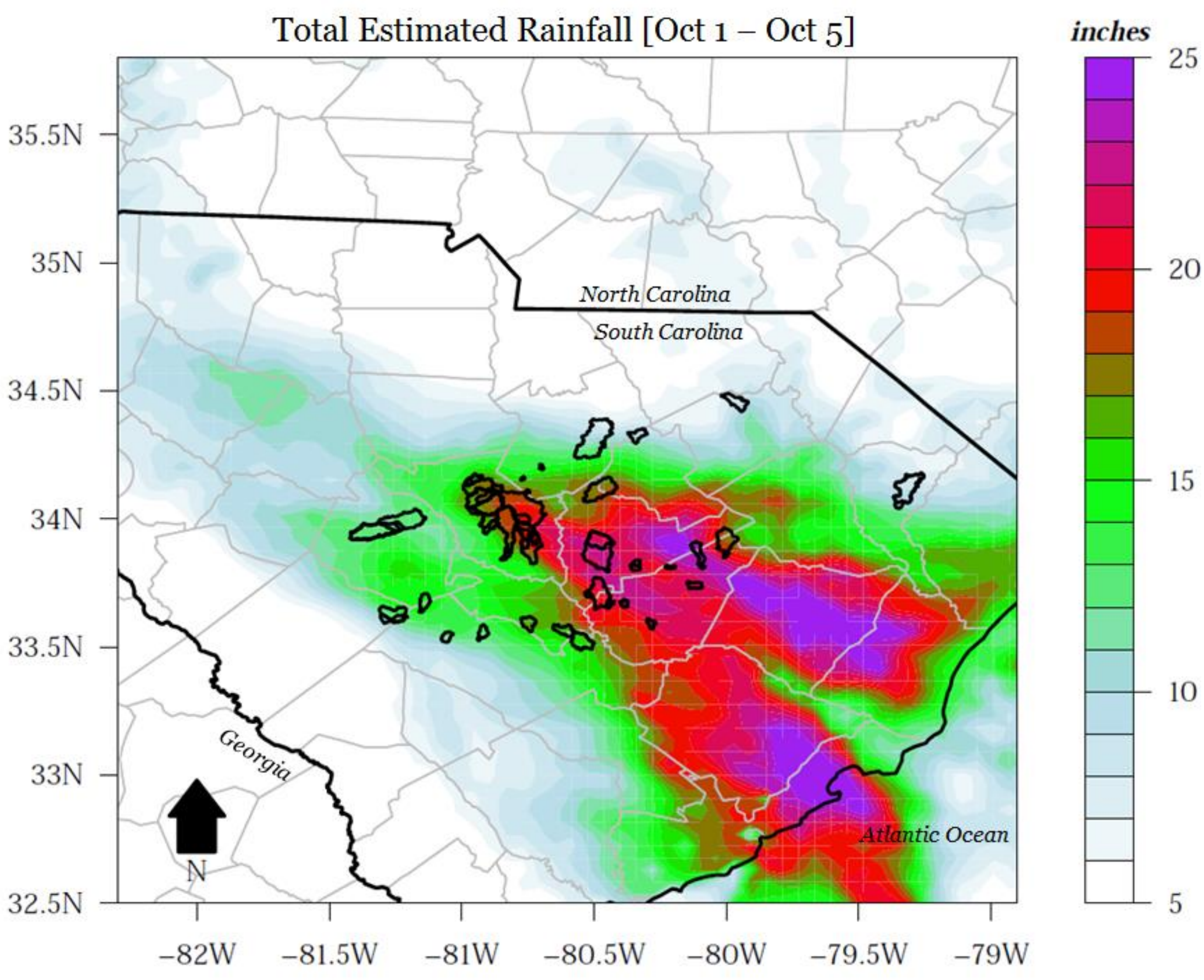

Figure 5: Total Estimated Rainfall in South Carolina for October 1 through October 5, 2015

Although rainfall fell intermittently over the course of a 72 hour period, 80% or more of the rainfall occurred during the 24-hour period starting late in the evening on October 3, 2015. Figure 6 shows a representative hyetograph from the Weston Pond Dam basin (SCID D0593). The red line and red squares highlight the period with the highest 24-hour rainfall.

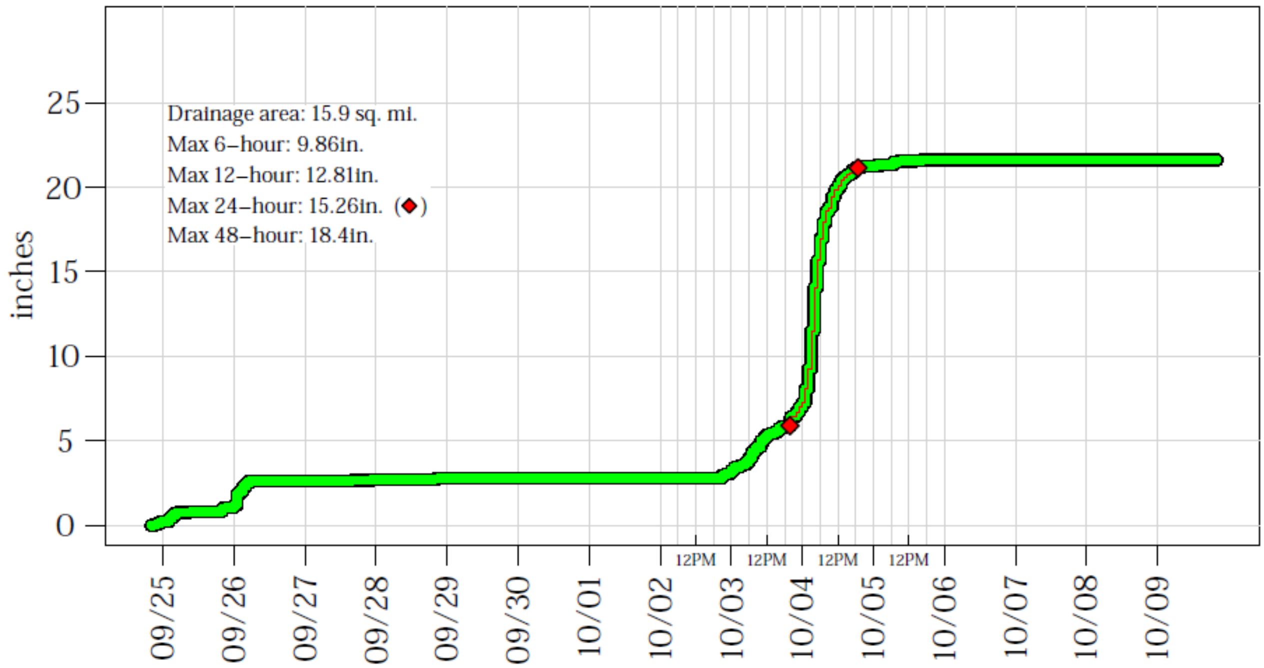

Figure 6: Hourly Hyetograph for Weston Pond Dam

Fractional PMP Estimates

NOAA HMR No. 51 (HMR51) was used to estimate the regional PMP. The USACE Hydrologic Engineering Center (HEC) MetVue software was used to obtain HMR51 values digitally for the four time durations. PMP estimates varied by less than 1% across the study area. Thus, one value of PMP, centered on Columbia, was assumed for all basins. Table 7 shows the PMP for a 10 sq. mi. basin, which is the smallest drainage area considered by HMR51.

Table 7: HMR51 PMP estimates (inches) for a 10 sq. mi. drainage basin in central South Carolina.

6-HR	12-HR	24-HR	48-HR
30.63	36.56	42.92	47.29

For each basin and each time duration, fractional PMP was estimated by dividing the reconstructed rainfall amounts by the HMR51 PMP estimates. Each basin had its own PMP estimate, due to dependence on drainage area. For drainage areas of less than 10 sq. mi., the value for 10 sq. mi. was used. Results showed that fractional PMP ranged from about 0.1 to as high as 0.49, with most values falling in the 0.3 to 0.4 range. Table 8 summarizes the fractional PMP estimates for all dams which can be used as an estimate of the fractional PMF loading that the dam may have experienced.

Table 8: Fractional PMP Estimates

Name	SCID	6 hr PMP Fraction	12 hr PMP Fraction	24 hr PMP Fraction	48 hr PMP Fraction	Minimum PMP Fraction	Maximum PMP Fraction
Lake Elizabeth	D0024	0.3	0.35	0.33	0.36	0.3	0.36
Carys Lake	D0026	0.31	0.34	0.33	0.35	0.31	0.35
Murray Pond Dam	D0595	0.4	0.43	0.41	0.44	0.4	0.44
Pinewood Lake Dam	D0580	0.27	0.3	0.29	0.32	0.27	0.32
Weston Pond Dam	D0593	0.33	0.36	0.37	0.4	0.33	0.4
Wilson Millpond Dam	D0594	0.37	0.39	0.37	0.4	0.37	0.4
Duffies Pond Dam	D0600	0.32	0.35	0.35	0.38	0.32	0.38
Ulmers Pond	D0581	0.29	0.31	0.31	0.33	0.29	0.33
Sunview Lake Dam	D0579	0.29	0.31	0.3	0.33	0.29	0.33
Lower Rocky Creek Dam/Rocky Ford Lake	D0028	0.34	0.36	0.35	0.37	0.34	0.37
North Lake Dam/Overcreek Rd. Dam/Upper Rocky Creek	D0029	0.34	0.36	0.35	0.37	0.34	0.37
Walden Place Dam	D0572	0.28	0.32	0.31	0.34	0.28	0.34
Covington Lake Dam	D0545	0.28	0.32	0.32	0.34	0.28	0.34
Beaver Dam Lake/Wildwood Pond #2/Boyd Pond	D0567	0.31	0.34	0.33	0.35	0.31	0.35
Old Mill Pond Dam	D0958	0.15	0.21	0.23	0.27	0.15	0.27
Barr Dam/ Barr Lake Dam	D1717	0.15	0.2	0.23	0.27	0.15	0.27
Gibson Dam/Gibson's Pond Dam	D0959	0.15	0.21	0.23	0.27	0.15	0.27
Baileys Pond	D2034	0.1	0.12	0.17	0.23	0.1	0.23
Corbett Lake	D2052	0.11	0.14	0.2	0.27	0.11	0.27
Able / Corbett Pond Dam	D2048	0.11	0.14	0.18	0.25	0.11	0.25
JW Smoaks Pond	D3738	0.11	0.17	0.2	0.23	0.11	0.23
SCNONAME 38036 (Cleveland Street)	D3743	0.14	0.19	0.24	0.3	0.14	0.3

Name	SCID	6 hr PMP Fraction	12 hr PMP Fraction	24 hr PMP Fraction	48 hr PMP Fraction	Minimum PMP Fraction	Maximum PMP Fraction
Busbees Pond	D3701	0.08	0.13	0.18	0.22	0.08	0.22
Culler Pond	D3682	0.12	0.19	0.23	0.3	0.12	0.3
Clyburn Pond Dam	D2412	0.09	0.11	0.11	0.18	0.09	0.18
Chapman's Pond Dam	D3533	0.14	0.16	0.15	0.15	0.14	0.16
O E Rose Dam	D3487	0.28	0.34	0.37	0.44	0.28	0.44
Lakewood Pond Dam	D3490	0.19	0.24	0.28	0.37	0.19	0.37
Ellerbees Millpond Dam	D1460	0.23	0.27	0.29	0.37	0.23	0.37
Cook Pond Dam	D1068	0.23	0.28	0.28	0.32	0.23	0.32
Clarkson Pond Dam	D0599	0.33	0.36	0.36	0.39	0.33	0.39
Wards Pasture Pond Dam	D3502	0.19	0.22	0.27	0.38	0.19	0.38
SCNONAME 09031 (off Community Club Rd.)	D2645	0.13	0.18	0.23	0.29	0.13	0.29
SCNONAME 14003 (off Fox Tindal Rd.)	D3497	0.19	0.23	0.27	0.36	0.19	0.36
SCNONAME 14005 (off Puddin Swamp Rd.)	D3484	0.17	0.23	0.25	0.32	0.17	0.32
SCNONAME 09040 (off Church Camp Rd.)	D2921	0.15	0.21	0.25	0.29	0.15	0.29
SCNONAME 28045 (off Tower Rd.)	D2521	0.24	0.3	0.3	0.34	0.24	0.34
SCNONAME 14008 (off Old River Rd.)	D3495	0.23	0.27	0.49	0.4	0.23	0.49
Dogwood Lake Dam	D2065	0.26	0.49	0.32	0.41	0.26	0.49
Drafts Pond Dam	D0601	0.33	0.37	0.38	0.41	0.33	0.41
Boyle Pond Dam	D1583	0.35	0.4	0.4	0.48	0.35	0.48
McCray Lake Dam	D1584	0.34	0.38	0.37	0.44	0.34	0.44
M. R. Trotter Dam	D0110	0.33	0.36	0.37	0.41	0.33	0.41

Name	SCID	6 hr PMP Fraction	12 hr PMP Fraction	24 hr PMP Fraction	48 hr PMP Fraction	Minimum PMP Fraction	Maximum PMP Fraction
Smith Millpond Dam	D0510	0.07	0.1	0.09	0.14	0.07	0.14
Boyds Pond Dam	D0592	0.35	0.37	0.37	0.4	0.35	0.4
Haithcock Pond Dam	D0591	0.36	0.38	0.37	0.4	0.36	0.4
Touchberry Lower Pond Dam	D1586	0.18	0.22	0.25	0.33	0.18	0.33
Cuttino Pond Dam	D3482	0.22	0.29	0.3	0.39	0.22	0.39
Black Crest Farm Pond Dam	D2063	0.23	0.29	0.3	0.39	0.23	0.39
Forest Lake Dam[1]	D4434	0.36	0.38	0.36	0.38	0.36	0.38
SCNONAME 32080[1]	D0957	0.17	0.22	0.24	0.27	0.17	0.27
Epworth Pines Dam[1]	D0362	0.28	0.32	0.32	0.34	0.28	0.34
Hermitage Mill Pond Dam[1]	D0017	0.11	0.14	0.14	0.21	0.11	0.21
Fredericksburg Lake Dam[1]	D2539	0.2	0.24	0.24	0.28	0.2	0.28
Windsor Lake Dam[1]	D0571	0.49	0.33	0.32	0.34	0.32	0.49
Cola Plantation Dam[1]	D3498	0.23	0.26	0.3	0.4	0.23	0.4
Stevenson's Lake Dam[1]	D0546	0.28	0.32	0.49	0.33	0.28	0.49
Legette Millpond Dam[1]	D0511	0.09	0.11	0.1	0.15	0.09	0.15

[1] Dam did not fail but was analyzed for comparative purposes.

Return Period Estimates

NOAA Atlas 14 (Atlas 14) was used to estimate the return periods of the observed rainfall. As in the PMP analysis, the same four time durations were considered. Because Atlas 14 estimates are "point-specific", an Areal Reduction Factor (ARF) was required in order to reduce the value to account for increasing basin area size. The following ARF equation, obtained from Allen and Degaetno (2005), was used:

$$ARF = 1 - \exp(at^b) + \exp(at^b - cA)$$

Where t is event duration (hr) and A is area (km2). The coefficients a and c as well as the exponent b are empirically fit with a=−1.1, c=2.59490−2, and b=0.25. This equation is derived from US Weather Bureau's Technical Paper 29. Thus, ARF depends on the basin drainage area as well as the rainfall duration, implying that each of the 58 basins considered here had four estimated ARFs. For the smallest basins, such as Beaver Dam Lake (SC ID D0567), ARFs were very close to 1. For larger basins, such as Old Mill Pond (SC ID D0958), ARFs ranged from 0.85 (for 6-hour duration) to 0.95 (for 48-hour duration).

In order to estimate rainfall return period, maximum observed rainfall was calculated at each basin for the four time durations. Next, the Atlas 14 values were scaled by the ARF for a given basin and a given time duration. Finally, the observed rainfall was plotted on the scaled Atlas 14 estimates to estimate the return period. Due to the inherent uncertainty in Atlas 14, a range of return periods was given. Figure 7 shows an example of the 6-hour return period estimation for O.E. Rose Dam (SCID 3487). The red dots indicate the Atlas 14 values scaled by the basin's ARF for the 6-hour period (0.84). A return period of between 1 in 500 and 1 in 1,000 years was estimated at this basin. In this case, the maximum observed 6-hour rainfall was slightly over 8 inches, which corresponded to a return period between 1 in 500 and 1,000 years. It is at this point in the analysis where the rare magnitude of this event is fully recognized. Of the 58 dams considered, 19 had return periods exceeding 1 in 1,000 year return period for at least one of the four time durations. An additional 6 basins had return periods between 500 and 1,000 years. In general, the rarest (i.e. highest) return periods were found for the 12-hour, 24-hour and especially 48-hour rainfall amounts. Table 9 summarizes Atlas 14 estimates at Columbia, SC (Site ID 38-1944) and Table 10 summarizes the estimated rainfall frequency estimates for all dams. The 10,000-yr return period rainfall total in Table 9 was extrapolated and is subject to high uncertainty as a results of the limited data used to derive it.

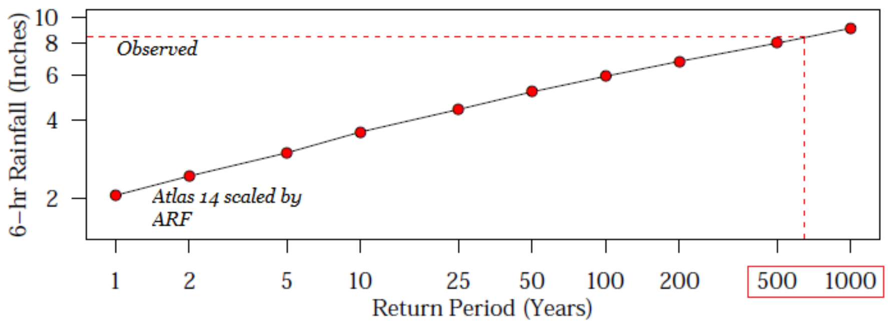

Figure 7: Example of return period analysis using 6-hour rainfall at O.E. Rose Dam

Table 9: Atlas 14 Estimates at Columbia, SC (Site ID 38-1944)

Return Period (yrs)	Return Period (Probability)	Rainfall Depth (in)
1	1	3.00
2	0.5	3.60
5	0.2	4.50
10	0.1	5.26
25	0.04	6.38
50	0.02	7.33
100	0.01	8.36
200	0.005	9.50
500	0.002	11.2
1,000	0.001	12.6
10,000	0.0001	17.5

Table 10: Rainfall Frequency Estimates

Name	SC ID	NOAA Stage IV Maximum 6 hr Estimate	NOAA Stage IV Maximum 12 hr Estimate	NOAA Stage IV Maximum 24 hr Estimate	NOAA Stage IV Maximum 48 hr Estimate	6 hr Return Period	12 hr Return Period	24 hr Return Period	48 hr Return Period
Lake Elizabeth	D0024	8.78	11.89	13.59	15.99	>1000	>1000	>1000	>1000
Carys Lake	D0026	9.37	12.04	13.65	16.04	>1000	>1000	>1000	>1000
Murray Pond Dam	D0595	10.54	13.55	15.36	18.46	>1000	>1000	>1000	>1000
Pinewood Lake Dam	D0580	8.42	10.99	12.64	15.07	>1000	>1000	500|1000	>1000
Weston Pond Dam	D0593	9.86	12.81	15.26	18.4	>1000	>1000	>1000	>1000
Wilson Millpond Dam	D0594	11.33	14.16	15.95	18.97	>1000	>1000	>1000	>1000
Duffies Pond Dam	D0600	8.84	11.78	13.93	16.76	>1000	>1000	>1000	>1000
Ulmers Pond	D0581	8.91	11.47	13.17	15.75	>1000	>1000	500|1000	>1000
Sunview Lake Dam	D0579	8.88	11.49	13.08	15.5	>1000	>1000	>1000	>1000
Lower Rocky Creek Dam/Rocky Ford Lake	D0028	9.93	12.51	14.1	16.48	>1000	>1000	>1000	>1000
North Lake Dam/Overcreek Rd. Dam/Upper Rocky Creek	D0029	9.93	12.51	14.1	16.48	>1000	>1000	>1000	>1000
Walden Place Dam	D0572	8.69	11.64	13.47	16.02	>1000	>1000	>1000	>1000
Covington Lake Dam	D0545	8.61	11.88	13.55	15.91	>1000	>1000	>1000	>1000
Beaver Dam Lake/Wildwood Pond #2/Boyd Pond	D0567	9.64	12.35	14.16	16.61	>1000	>1000	>1000	>1000
Old Mill Pond Dam	D0958	4.3	6.87	8.97	11.72	25|50	100|200	200|500	500|1000
Barr Dam/ Barr Lake Dam	D1717	4.21	6.85	9.06	11.89	25|50	100|200	200|500	500|1000
Gibson Dam/Gibson's Pond Dam	D0959	4.3	6.87	8.97	11.72	25|50	100|200	200|500	500|1000
Baileys Pond	D2034	2.92	4.43	7.09	10.75	2|5	5|10	25|50	200|500
Corbett Lake	D2052	3.38	5.09	8.32	12.59	5|10	10|25	100|200	500|1000
Able / Corbett Pond Dam	D2048	3.45	4.94	7.82	11.75	5|10	10|25	50|100	200|500
JW Smoaks Pond	D3738	3.38	6.04	8.57	11.03	5|10	25|50	50|100	100|200

Name	SC ID	NOAA Stage IV Maximum 6 hr Estimate	NOAA Stage IV Maximum 12 hr Estimate	NOAA Stage IV Maximum 24 hr Estimate	NOAA Stage IV Maximum 48 hr Estimate	6 hr Return Period	12 hr Return Period	24 hr Return Period	48 hr Return Period
SCNONAME 38036 (Cleveland Street)	D3743	4.14	6.58	9.82	13.8	25|50	50|100	100|200	500|1000
Busbees Pond	D3701	2.53	4.7	7.64	10.3	2|5	10|25	50|100	100|200
Culler Pond	D3682	3.79	6.92	9.96	14.05	10|25	50|100	200|500	500|1000
Clyburn Pond Dam	D2412	2.66	3.9	4.57	8.73	2|5	5|10	5|10	50|100
Chapman's Pond Dam	D3533	4.38	6	6.63	7.23	25|50	50|100	25|50	10|25
O E Rose Dam	D3487	8.48	12.42	15.8	20.6	500|1000	>1000	>1000	>1000
Lakewood Pond Dam	D3490	5.69	8.83	11.84	17.52	50|100	200|500	200|500	>1000
Ellerbees Millpond Dam	D1460	6.72	9.33	11.65	16.48	500|1000	500|1000	200|500	>1000
Cook Pond Dam	D1068	7.11	10.2	12.05	15.02	200|500	500|1000	500|1000	>1000
Clarkson Pond Dam	D0599	9.12	12.04	14.13	16.94	>1000	>1000	>1000	>1000
Wards Pasture Pond Dam	D3502	5.93	8.01	11.59	17.79	50|100	100|200	200|500	>1000
SCNONAME 09031 (off Community Club Rd.)	D2645	4	6.71	9.98	13.81	10|25	50|100	100|200	200|500
SCNONAME 14003 (off Fox Tindal Rd.)	D3497	5.89	8.4	11.6	17.23	50|100	200|500	200|500	>1000
SCNONAME 14005 (off Puddin Swamp Rd.)	D3484	5.08	8.24	10.36	14.95	50|100	200|500	100|200	500|1000
SCNONAME 09040 (off Church Camp Rd.)	D2921	4.55	7.53	10.75	13.8	25|50	100|200	200|500	200|500
SCNONAME 28045 (off Tower Rd.)	D2521	7.4	10.9	12.81	15.9	200|500	>1000	500|1000	>1000
SCNONAME 14008 (off Old River Rd.)	D3495	6.52	9.21	12.53	17.86	200|500	500|1000	500|1000	>1000
Dogwood Lake Dam	D2065	8	11.42	13.67	19.62	200|500	500|1000	500|1000	>1000
Drafts Pond Dam	D0601	9.19	12.28	15.02	18.18	>1000	>1000	>1000	>1000
Boyle Pond Dam	D1583	9.5	13.13	15.18	20.45	>1000	>1000	>1000	>1000

Name	SC ID	NOAA Stage IV Maximum 6 hr Estimate	NOAA Stage IV Maximum 12 hr Estimate	NOAA Stage IV Maximum 24 hr Estimate	NOAA Stage IV Maximum 48 hr Estimate	6 hr Return Period	12 hr Return Period	24 hr Return Period	48 hr Return Period
McCray Lake Dam	D1584	10.09	13.58	15.34	20.46	>1000	>1000	>1000	>1000
M. R. Trotter Dam	D0110	10.2	13.07	15.73	19.21	>1000	>1000	>1000	>1000
Smith Millpond Dam	D0510	2.13	3.37	3.71	6.15	1|2	2|5	2|5	5|10
Boyds Pond Dam	D0592	10.76	13.65	15.73	18.8	>1000	>1000	>1000	>1000
Haithcock Pond Dam	D0591	10.95	13.84	15.72	18.81	>1000	>1000	>1000	>1000
Touchberry Lower Pond Dam	D1586	5.37	7.99	10.94	15.81	50|100	100|200	200|500	500|1000
Cuttino Pond Dam	D3482	6.79	10.43	12.98	18.46	100|200	200|500	200|500	>1000
Black Crest Farm Pond Dam	D2063	7.01	10.57	12.72	18.59	100|200	500|1000	200|500	>1000
Forest Lake Dam[1]	D4434	9.67	12.3	13.88	16.25	>1000	>1000	>1000	>1000
SCNONAME 32080[1]	D0957	4.44	6.94	8.79	11.41	50|100	100|200	200|500	200|500
Epworth Pines Dam[1]	D0362	8.61	11.88	13.55	15.91	>1000	>1000	>1000	>1000
Hermitage Mill Pond Dam[1]	D0017	2.87	4.61	5.55	9.11	5|10	25|50	10|25	50|100
Fredericksburg Lake Dam[1]	D2539	6.19	8.69	10.29	13.36	100|200	200|500	200|500	500|1000
Windsor Lake Dam[1]	D0571	9.41	12.13	13.79	16.21	>1000	>1000	>1000	>1000
Cola Plantation Dam[1]	D3498	6.98	9.49	12.81	18.68	200|500	200|500	500|1000	>1000
Stevenson's Lake Dam[1]	D0546	8.59	11.79	13.44	15.76	>1000	>1000	>1000	>1000
Legette Millpond Dam[1]	D0511	2.39	3.7	4.08	6.58	2|5	5|10	2|5	10|25

[1] Dam did not fail but was analyzed for comparative purposes.

Analysis of Precipitation Data

There has been much discussion of the record setting and historic rainfall event that occurred October 1 through 5, 2015, producing widespread and significant flooding across much of South Carolina. Many locations in South Carolina received anywhere from four to seven consecutive days of rainfall during this event. The graph at each NWS Coop stations (Figure 8) indicate the length of rainfall with total inches of precipitation in relation to its Average Recurrence Intervals (ARI). The average return intervals of 25-, 50-, 100-, 200-, 500-, and 1,000-years were used for comparison. NWS Coop stations like Sumter and Andrews received more rainfall than the 1,000 Year average return interval.

However, the term "100-year flood" is generally the most common term used by the media to describe extreme events. It is important to note that storm periodicity is always associated to a time interval, such as 24 hours, seven days, 30 days or a "water year". In hydrology, there are actually three types of comparative assessments: 1) rainfall within a given time interval; 2) peak stream flow; or 3) volume of flow caused by a single storm event or sequence (which may last one to six months). Each of these attributes can be measured and counted as discrete data points, to provide statistical comparison, or frequency analysis. As a consequence, there can be a 100-year storm, a 100-year peak flow event, or a 100-year flood, all of which may or may not be independent of one another.

The information contained in Table 8 and Table 10 provide a foundation to support further detailed analysis including the determination of critical storm durations.

Terminology:

Annual Exceedance Probability (AEP) [1]: The probability associated with exceeding a given amount in any given year once or more than once; the inverse of AEP provides a measure of the average time between years (and not events) in which a particular value is exceeded at least once; the term is associated with analysis of annual maximum series.

Average Recurrence Interval (ARI; a.k.a. Return Period, Average Return Period) [1]: Average time between cases of a particular precipitation magnitude for a specified duration and at a given location; the term is associated with the analysis of partial duration series. However, ARI is frequently calculated as the inverse of AEP for the annual maximum series; in this case it represents the average period between years in which a given precipitation magnitude is exceeded at least once.

100-year Event: Event that statistically has a 1-percent chance of occurring in any given year. In order to accurately predict a 100-year recurrence event, 1,000 years of records are needed.

[1] NOAA website: "Glossary"

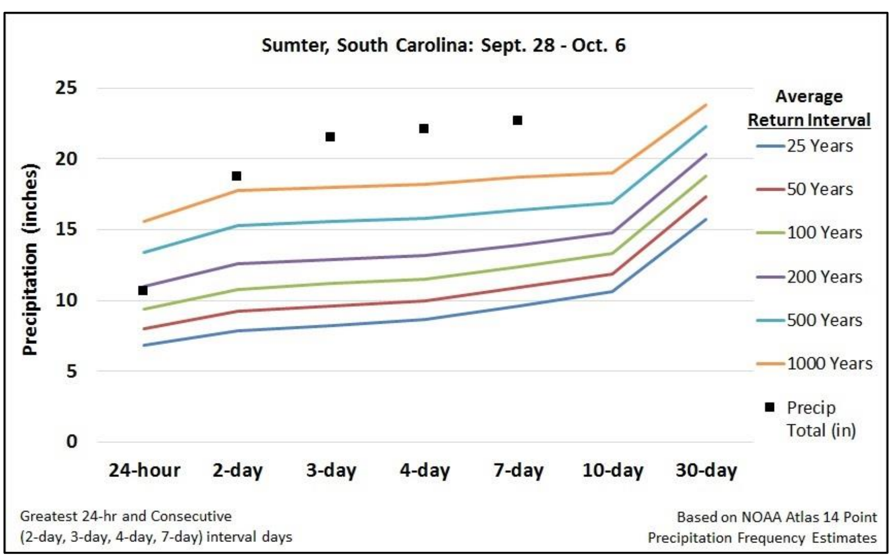

Figure 8: Sumter, SC Rainfall Totals: Sept. 28 – Oct. 6 (SC DNR, 2016)

Peak streamflow and stage during the October 2015 event for 86 USGS stream gages are listed in the USGS report "Preliminary Peak Stage and Streamflow Data at Selected USGS Stream gaging Stations for the South Carolina Flood of October 2015", which can be accessed at http://pubs.usgs.gov/of/2015/1201/ofr20151201.pdf (Feaster et al, 2015). Seventeen of the 86 stream gages had new peaks of record. Of the 61 stations with at least 20 years of record, eight had new peaks of record. Along with the 17 stream gages that had new peaks of record, an additional 15 stream gages recorded new peaks that ranked in the top 5 for the period of record. For stations with at least 20 years of record, 13 recorded peaks ranked in the top 5 for the period of record.

All state regulated dams are required to have a spillway system with adequate capacity to safely pass a SDF in a range as shown in Table 1 of the SC DHEC Dam Safety Regulations (Table 3 of this report) for the appropriate classification unless it is demonstrated by the dam owner that adequate capacity is provided by other means. For this reason, a minimum and maximum SDF can be determined. Figure 9 through Figure 11 display a graphical analysis of the rainfall reconstruction versus the SDF criteria for the 24-hr estimate. As aforementioned (Table 1 of the SC DHEC Dam Safety Regulations), the SDF is based on a flooding event; which for simplification purposes, is related to a stream discharge and not necessarily a precipitation total. However, based on the evidence presented by the USGS report "Preliminary Peak Stage and Streamflow Data at selected USGS Stream gaging Stations for the South Carolina Flood of October 2015", the PMP can be assumed to be roughly equal to the PMF.

To enable a comparison of the estimated hydrologic loading experienced at each dam and the state spillway design criteria, several graphs were developed. The results of the precipitation analysis, can be used as a basic estimate of hydrologic loading for comparison with the state SDF requirements, are illustrated in Figure 9 through Figure 11 which represent the minimum and maximum SDF's, respectively. To better understand the Figures:

- Each of the 49 individual dams that failed are represented individually along the X-axis. High Hazard Potential dams can be seen in Figure 9, Significant Hazard Potential dams can be seen in Figure 10, and Low Hazard Potential dams can be seen in Figure 11.
- 24 hour precipitation totals for individual dams is represented on the left Y-axis with the range limited to the full PMP value of 42.92-inches. The right Y-axis represents the corresponding 24-hour fractional PMP value.
- The observed maximum 24-hour precipitation value for each dam is represented by a golden diamond with a black dot in the center of it to give an estimated representation of the hydrologic loading.
- Dams are arranged from left to right in ascending order based on observed precipitation values.
- The height of the black lines/bars represents the state minimum SDF and maximum SDF range applicable for each individual dam with the assumption that the 24-hour PMP results in a PMF.
- The red stars located along the X-axis indicate that an upstream dam failure occurred in the watercourse.

Upstream breaches were identified by completing a desktop review using the best available aerial photography (where available) from TerraServer. TerraServer uses high resolution satellite imagery for any location on Earth using the world's most advanced commercial satellites. It is important to note that this data should not be used to say whether or not an upstream breach contributed to the downstream dam failure. In many cases, this is quite possible. However, in other cases the upstream dam may have breached after the downstream dam, thus not contributing to the downstream dam's failure.

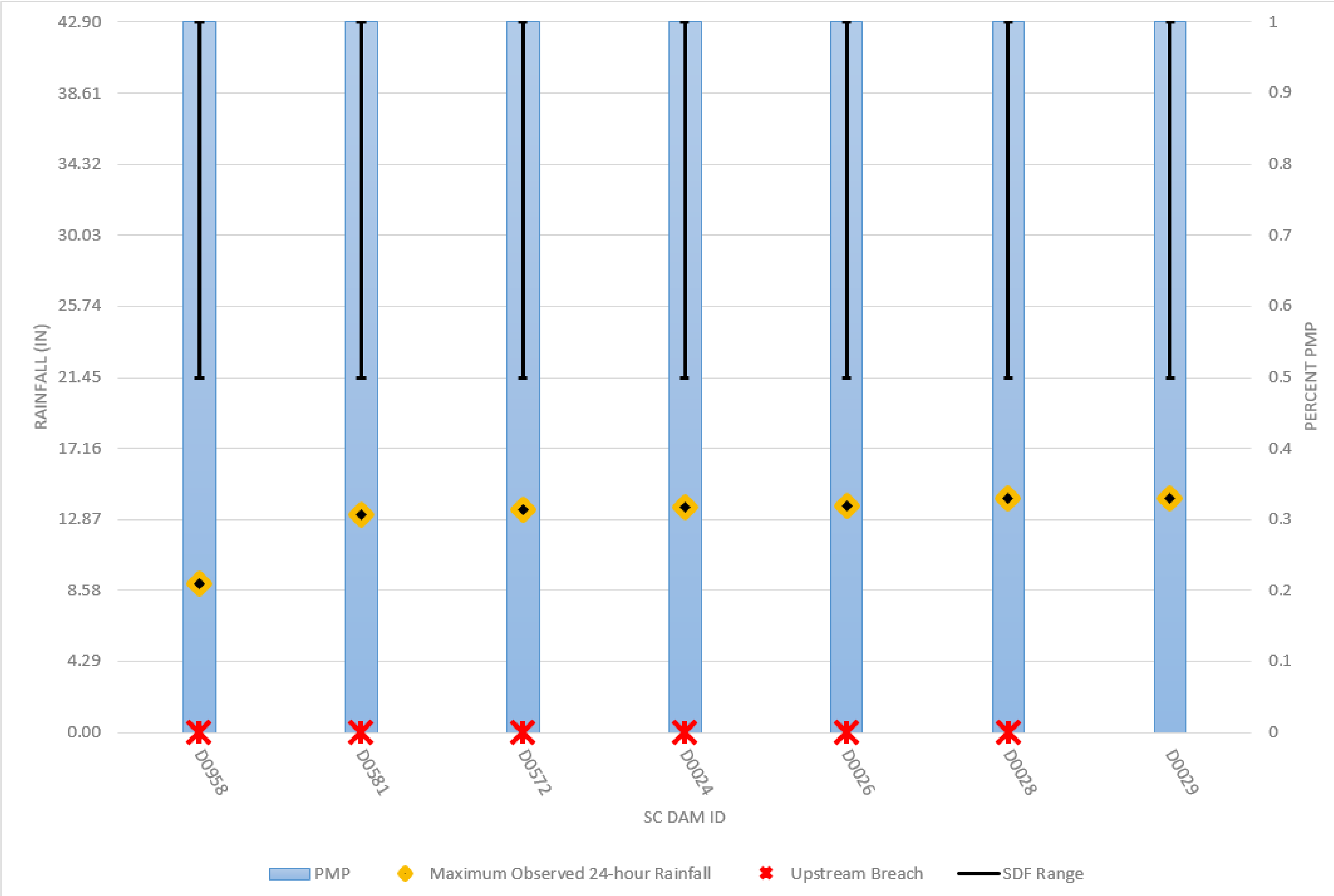

Figure 9: Rainfall Analysis for High Hazard Potential Dams Compared to SC DHEC SDF Design Criteria (Assumes that a 24-hour PMP results in a PMF)

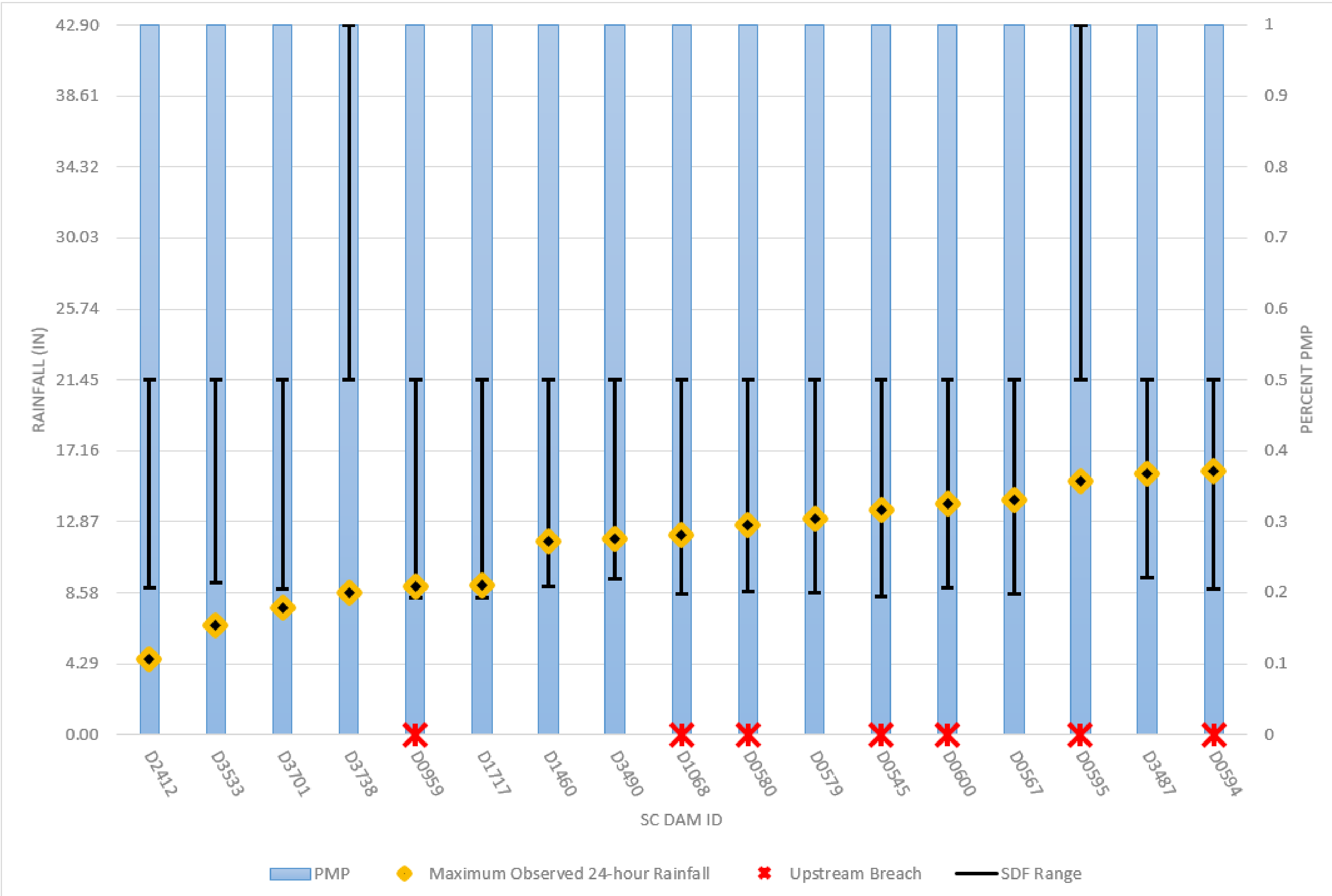

Figure 10: Rainfall Analysis for Significant Hazard Potential Dams Compared to SC DHEC SDF Design Criteria (Assumes that a 24-hour PMP results in a PMF)

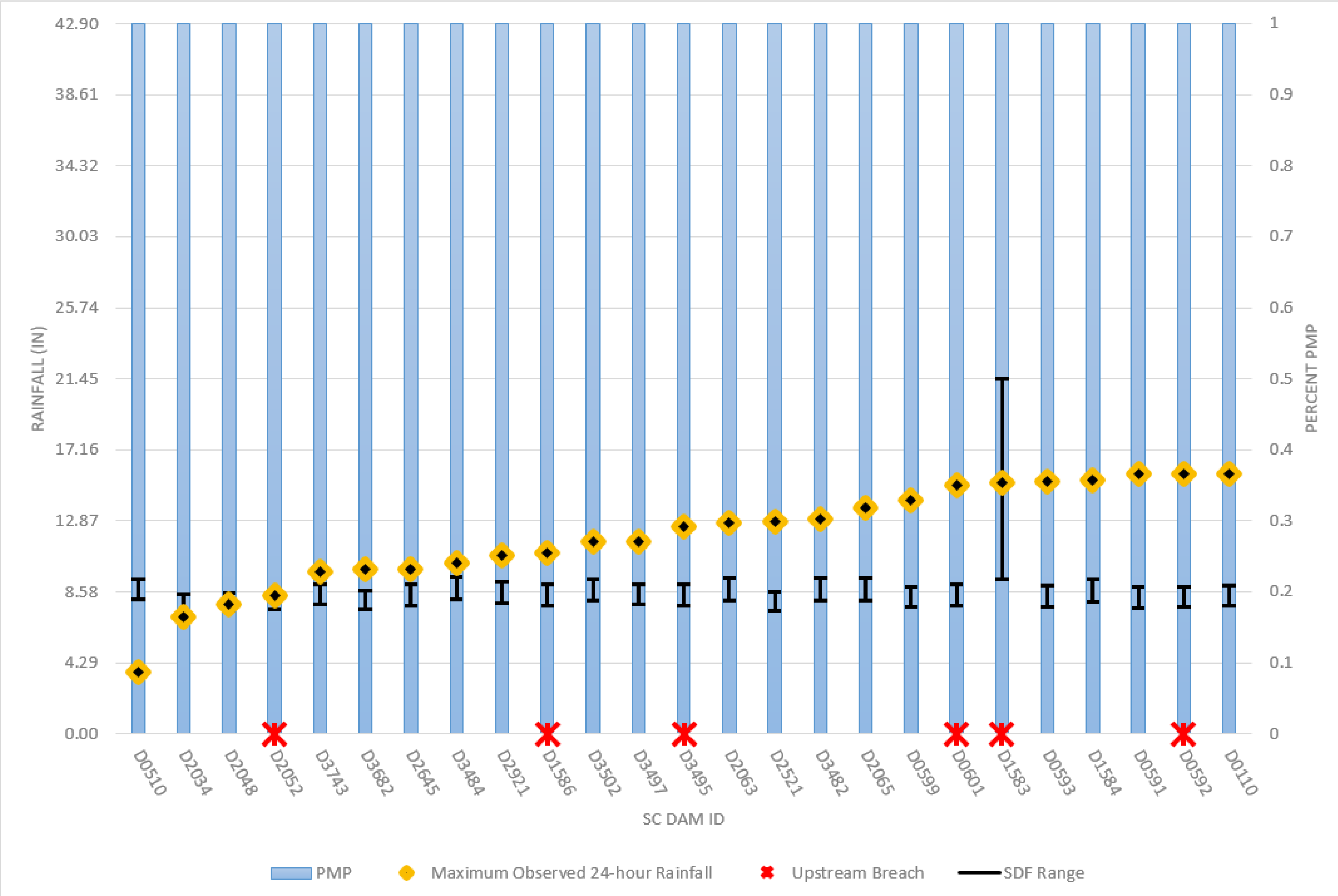

Figure 11: Rainfall Analysis for Low Hazard Potential Dams Compared to SC DHEC SDF Design Criteria (Assumes that a 24-hour PMP results in a PMF)

The following observations should be noted:

- None of the High Hazard potential dams in Figure 9 received a rainfall loading greater than the minimum or maximum SDF design criteria.
    - However, 6 of 7 High Hazard potential dams experienced an upstream breach which may have potentially resulted in increased volumes entering the impoundments and contributing to their failure. Therefore it is possible that peak inflows were higher than what would be expected from the natural flood event and potentially exceeded the state SDF requirements. All dams were constructed prior to the enactment of the Dams and Reservoirs Safety Act, however, dams D0571 and D0026 are known by SC DHEC to have been modified in 1994 and 1988 respectively.

- The majority of the Significant Hazard potential dams (12 of 17) in Figure 10 received a rainfall loading greater than the minimum SDF amount, but less than the maximum SDF amount.
    - One of the dams where the rainfall was less than the minimum SDF required experienced an upstream breach which may have potentially contributed to its failure. Another one is classified as an Intermediate size. Note that the minimum SDF for a Significant Hazard Potential – Intermediate is the ½ PMF whereas the Significant Hazard Potential – Small is the 100-yr flood frequency. It should be noted that the National Inventory of Dams (NID) dataset for this dam shows a Normal Storage of 62 acre-ft and a Maximum Storage of 1125 acre-ft. The field inspection noted that the reservoir normal pool was less than 5' lower than the top of the dam crest which indicates a potential error with the NID data and ultimately a potential error in SDF requirements. The other three dams of this nature received rainfall totals in close proximity to the minimum SDF required. So overall, these failed dams potentially experienced volumes close to and more than what was required by regulations. All dams were constructed prior to the enactment of the Dams and Reservoirs Safety Act, however, dams D0567 and D2412 are known by SC DHEC to have been modified in 2010 and 1998 respectively.

- The majority of Low Hazard potential dams in Figure 11 received a rainfall loading greater than the minimum SDF and the maximum SDF amount.
    - Six dams that experienced an upstream breach which may have potentially contributed to their failure. These failed dams' potentially experienced volumes more than what was required by regulations. All dams were constructed prior to the enactment of the Dams and Reservoirs Safety Act.

Assessment of Dams

Dam assessments were performed in four sequential phases designed to build upon the collection of critical information and to allow each phase to advance the understanding of the dam's design, performance, and impact on downstream infrastructure and facilities.

Phase 1 – Pre-Assessment Coordination and Background Data Collection

Under FEMA's direction, Dewberry staff participated in several coordination meetings with the SC DNR, and SC DHEC to set forth a work plan and to arrange logistics for the field assessments. As a result of this meeting, SC DHEC staff agreed to participate in the field assessments to assist in obtaining the dam owners' consent to access the dam sites and to provide additional background information throughout the visits. Site assessments were organized in geographic clusters central to the SC DHEC Environmental Quality Control (EQC) Regions County offices to accommodate SC DHEC staffing schedules and to maximize efficiency.

Additionally, all available data for each dam was collected and compiled in field tablets for use by the dam assessment teams. This also provided context as to what site-specific issues could be expected or should be identified. This information included:

- Information related to pre-failure dam configuration including spillway, risers, dam crest, etc.
- Geographic and geologic conditions at each site
- Past inspection reports
- Design and maintenance records, if available, to understand performance vs. design
- State dam safety compliance information
- Post-storm data collected by previous assessors with a focus on issues needing special attention

Phase 2 – Dam Assessments

Dam assessments were performed in two rounds. The initial round included the original 49 state regulated dams that were identified in the FEMA Mitigation Dam Task Force Strategic White Paper. These site visits were completed on February 5, 2016. The second round of dams included 18 dams that were later identified by SC DHEC to have also failed. These site visits were completed on July 22, 2016.

The Dewberry team assessors evaluated the current status of the dam site and identified repair, reconstruction, and mitigation alternatives applicable to each facility. Information that was assessed and recorded in the field included:

- Size, type, and function of dam, including discharge structures
- Evidence of dam condition prior to the storm event
- Evidence of operation and maintenance programs for the dam
- Current conditions of dam and discharge structures at time of assessment
- Dam crest stability and soil profile of embankment
- High water marks where available
- Upstream and downstream conditions in the watershed

All data was recorded on field tablets to shorten data recording time, allow comparison of field observations with preliminary data to resolve apparent discrepancies, and provide daily reports to the field team lead. The daily reports allowed the field team to begin to categorize observations and identify common issues that included construction methods, operations and maintenance programs.

Damage Analysis

While multiple potential failure modes were observed, overtopping failure appeared to be the most common. Additional failure modes including structural failure and piping failure were also observed and were most likely triggered by increased hydrologic loading in combination with overtopping failure.

Overtopping Failure

Overtopping failure was evident at most of the dams assessed. Overtopping failure of a dam occurs when water flows in an uncontrolled manner over the dam. It most often is due to inadequate spillway capacity, debris blockage of spillways, or settlement of the dam crest. In the case of many older dams constructed before regulations existed, they may not have been designed to pass a SDF, or not designed to modern standards, or their spillway capacity is of unknown capacity until an engineering analysis is performed on them.

Figure 12 shows an example of overtopping failure at dam SCNONAME 14008. The foreground of the photo shows head cutting at the downstream toe and the background shows a complete failure where the head-cutting has propagated upstream through the road/dam embankment.

Figure 12: Head-Cutting of the Embankment at SCNONAME 14008 (Source: FEMA 2016)

The potential for dam failure during overtopping typically increases when heavy vegetation is present on the crest and downstream face. Vegetation can result in the concentration of overtopping flows resulting in increased velocities and turbulence which increases erosion rates. Additionally the uprooting of woody vegetation by high winds or erosion can leave large holes which compromise the structural integrity of the dam, potentially exposing the phreatic line and increasing the rate of both internal and overtopping erosion. Figure 13 shows an example of a dam overtopping failure at Sunview Lake Dam where erosion of the downstream face was potentially exacerbated by an overturned tree. Additional issues caused by heavy vegetation on a dam include:

- Obscuring the surface of an embankment making it more challenging to perform a thorough inspection of the dam
- Some root systems can decay and rot, providing passageways for water, causing internal erosion
- Growing root systems can lift concrete slabs or structures
- Weeds and woody vegetation can prevent the growth of desirable grass cover

Figure 13. Overtopping Failure Exacerbated by Heavy Vegetation at Sunview Lake (Source: FEMA 2016)

The risk of overtopping failures can be reduced by increasing the spillway capacity. This will require a licensed and qualified engineer review the spillway capacity of the dam and develop a design to upgrade the spillway. The engineer should compare the design assumptions to current and projected watershed conditions to ensure that the dam height and spillway capacities are sufficient to meet projected needs. If the dam design is insufficient for projected future flows and downstream hazard creep, the engineer can recommend methods of upgrading the dam.

Piping Failure and Internal Erosion

Potential piping failure and internal erosion was observed at 6 dams. Figure 14 shows dam SCNONAME 14005 where internal erosion was one of the causes of failure. The outlet pipe at this dam was completely rusted and caved in. The most common form of internal erosion is piping, which is caused by seepage of water through the soil, causing some of the soil particles to wash away from the embankment. It can also be caused by leaking or failing pipes through the dam. Internal erosion is partly a function of the type of soil used to construct the embankment and the degree of compaction achieved when placing the soil; fine-grained, well-compacted, cohesive soils (e.g., clays) are less likely to experience internal erosion than large-grained, poorly compacted, non-cohesive soils (e.g., sands). Internal erosion is dangerous because it may not be readily evident to an untrained observer, and failure can occur without much warning.

Figure 14: Piping Failure at SCNONAME 14005 (Source: FEMA 2016)

Structural Failure

Structural failure was observed to contribute to the failure of 12 dams. Structural failures of earth dams can occur in the embankment itself or in its associated structures. The most apparent signs of embankment failure are cracking, settlement, and sliding. Sloughs, bulges, and cracks are indications of potential failure. Failures of spillways and drains can also cause an embankment to fail. Spillways, which are often constructed of concrete or stones and mortar, can fail when soils supporting their foundations erode, resulting in settlement and cracking of the spillway. Processes such as freezing and thawing, chemical reactions, and erosion can weaken the spillway materials, which also could lead to failure. An example of a structural failure where the connection between the concrete spillway and earthen embankment deteriorated can be seen at JW Smoaks Pond in Figure 15. This dam did not exhibit any significant signs of overtopping and had an open channel emergency spillway that was engaged and functioned properly. Another example of a structural failure can be seen on the next page in Figure 16 from Duffies Pond Dam. While this dam exhibited signs of overtopping, it was deemed a structural failure after discussion with the owner indicated that the dam was manually breached for a repair in that same location years ago, indicating the repair was likely the cause of failure.

Figure 15. Example of Structural Failure at JW Smoaks Pond (Source: FEMA 2016)

Figure 16: Structural Failure at Duffies Pond Dam (Source: FEMA 2016)

A post flood damage analysis was performed to ascertain a trend of probable dam failures modes. While many dams exhibited multiple potential failure modes triggered by increased hydrologic loading, the most likely or dominant failure mode determined through these field assessments are summarized in

Figure *17*. This included 30 overtopping, 6 piping, and 12 embankment failures.

*Note: 49 dams had failed at the time of this report but due to owner access issues, one dam was not assessed.

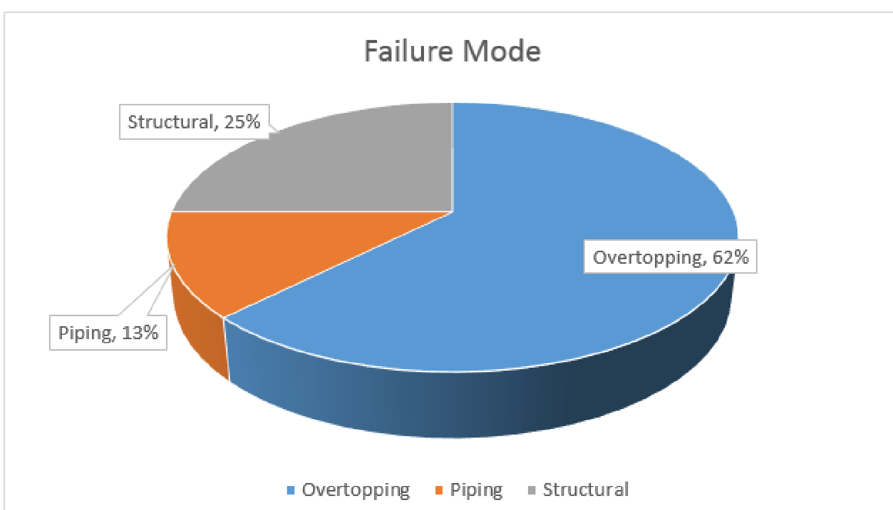

Figure 17: Probable Dam Failure Modes

The dam crest types observed during the assessments are summarized in Figure 18. This includes: 4 dirt road, 26 grass or soil, and 18 pavement (roadway acts as the crest).

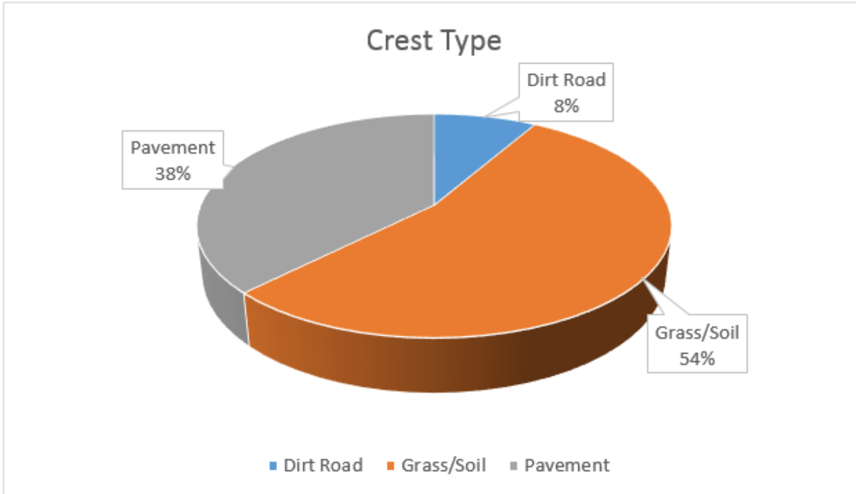

Figure 18: Failed Dams Crest Type

This data was broken down further to determine the number of dams exhibiting heavy woody vegetation which can potentially contribute to failure as illustrated in Figure 19. Woody vegetation penetrations of earthen dams is all too often believed to be a routine maintenance situation, but penetrations of earthen dams and their appurtenances have been demonstrated to be causes of serious structural deterioration and distress that can result in failure of earthen dams. This data was further broken down by failure modes to illustrate the frequency of heavy vegetation on dams. Heavy vegetation was observed at 14 of 30 dams with a probable failure mode determined to be by overtopping, 4 of 6 dams with a probable failure mode determined to be by piping, and 7 of 12 dams with a probable failure mode determined to be structural failures.

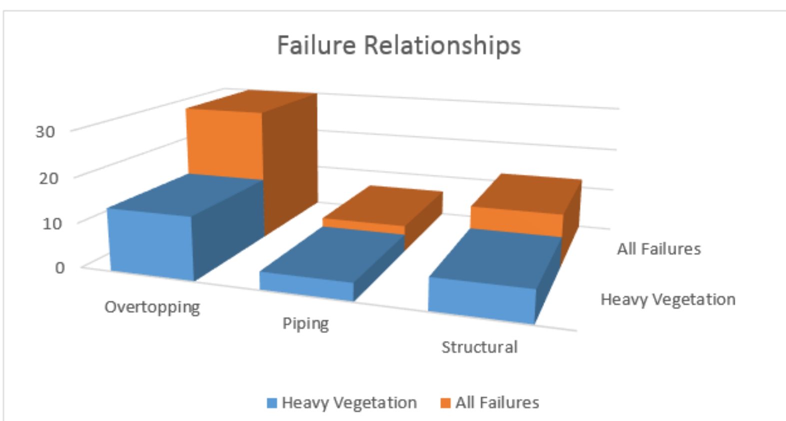

Figure 19: Failed Dams Having Heavy Woody Vegetation

Additionally, a desktop review using the newest aerial photography (where available) from TerraServer was completed to determine if the dams had experienced an additional breach upstream. TerraServer uses high resolution satellite imagery for any location on Earth using the world's most advanced commercial satellites. It is important to note that this data should not be used to say whether or not an upstream breach contributed to the downstream dam failure. In many cases, this is quite possible. However, in other cases the upstream dam may have breached after the downstream dam, thus not contributing to the downstream dam's failure. This indicated that a large number of dams that most likely failed due to overtopping and structural failures were located downstream of another breached dam (Figure 20).

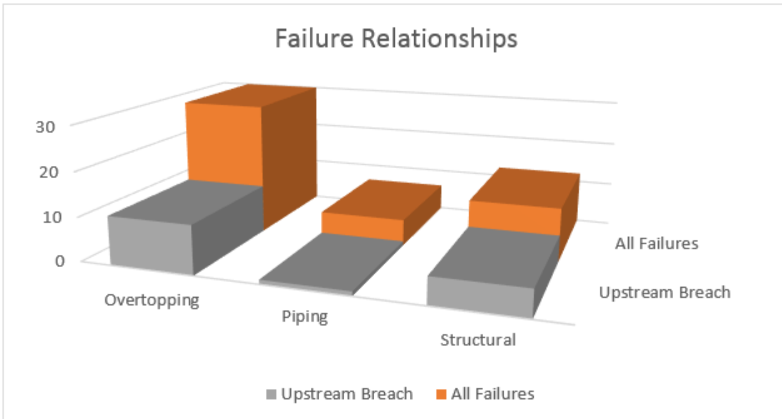

Figure 20: Failed Dams Where Upstream Breach Occurred

Non-Failures

An additional 9 dams that did not fail were visited and assessed by Dewberry separate to HMTAP contract No HSFE60-15-0014. The observations and findings from these assessments were shared with FEMA for inclusion in this report. This information provides insight as to why some dams failed and others did not and helps to identify best practices that may be attributed to the non-failure of certain dams. It should be noted that all 9 dams predate the enactment of the Dams and Reservoirs Safety Act. An overarching observation for many dams that did not fail was the presence of relatively large open channel auxiliary or service spillways which provided increased capacity to pass excess flow and volume to potentially prevent or reduce overtopping of the crest. As aforementioned, Figure 9 through Figure 11 display the rainfall loading versus the minimum and maximum SDF as regulated by SC DHEC. As Table 10 shows, the 9 dams that did not fail received relatively the same amount of rainfall as nearby dams that did fail. All of the High Hazard potential dams that failed, which are required to have a greater SDF, potentially faced additional volumes from upstream breaches. Considering that the average age of all dams included in this report is 80-years, it is unlikely that they were built to pass a capacity consistent with current regulations. The presence of an open channel emergency spillway was likely a mitigating factor in dam failures.

Breach Parameters

During field assessments, limited data was collected to describe the observed breaches for a select number of dams. This included breach height and width through a combination of methods including basic field measurements, post-failure satellite imagery measurements using GIS methods, and visual estimates. Survey grade measurements were not collected for any dams. Table 11 summarizes breach measurements where data was collected.

Table 11 Summary of Breach Measurements

Name	SCID	Measurement Type	Estimated Average Breach Width (Ft)	Estimated Breach Height (ft)
Able / Corbett Pond Dam	D2048	Field/Visual	50-60	12
Baileys Pond	D2034	Field/Visual	30-40	14
Barr Dam/ Barr Lake Dam	D1717	Satellite/GIS	40-50	14
Beaver Dam Lake/Wildwood Pond #2/Boyd Pond	D0567	Field	40	7
Boyle Pond Dam	D1583	Satellite/GIS	40-50	15
Carys Lake	D0026	Satellite/GIS	90	20
Chapman's Pond Dam	D3533	Satellite/GIS	30-40	20
Clarkson Pond Dam	D0599	Field	100	12
Clyburn Pond Dam	D2412	Satellite/GIS	40-50	15
Cook Pond Dam	D1068	Satellite/GIS	20-30	13
Covington Lake Dam	D0545	Satellite/GIS	30-40	16
Culler Pond (SCNONAME 38070)	D3682	Field	54	18
Dogwood Lake Dam	D2065	Field/Visual	45-55	14
Duffies Pond Dam	D0600	Field	75	18
Gibson Dam/Gibson's Pond Dam (High)	D0959	Satellite/GIS	30-40	15
Haithcock Pond Dam	D0591	Field	60	10
JW Smoaks Pond	D3738	Field	25	13
Lake Elizabeth	D0024	Satellite/GIS	30-40	10
Lakewood Pond Dam	D3490	Satellite/GIS	30-40	9
Lower Rocky Creek Dam/Rocky Ford Lake	D0028	Satellite/GIS	60-70	20
M. R. Trotter Dam	D0110	Satellite/GIS	25-35	14
McCray Lake Dam	D1584	Field/Visual	45-55	12
Murray Pond Dam	D0595	Satellite/GIS	60-70	16
North Lake Dam/Overcreek Rd. Dam/Upper Rocky Creek	D0029	Satellite/GIS	60-70	20
O E Rose Dam (2 breach locations along dam)	D3487	Satellite/GIS	50-60	15
		Satellite/GIS	65-75	15
Pinewood Lake Dam	D0580	Satellite/GIS	20-30	6
SCNONAME 28045 (off Tower Rd.)	D2521	Satellite/GIS	20-40	17
Smith Millpond Dam	D0510	Field	50	5
Walden Place Dam	D0572	Field	75	25
Weston Pond Dam	D0593	Field	200	13
Wilson Millpond Dam	D0594	Satellite/GIS	60-70	14

Phase 3 – Identification of Critical Infrastructure, Vulnerable Structures, and Facilities

Inundation maps were not readily available for the dams. In lieu of inundation maps, a visual assessment was performed for each of the 49 failed dams to provide insight into the assets within or immediately adjacent to the effective FEMA Special Flood Hazard Area (SFHA) up to a point 5 miles downstream of the dam. This includes critical infrastructure, homes, buildings, roads, utilities, and other properties. It should be noted that actual inundations due to a dam failure can vary significantly in terms of severity, width and downstream extent when compared to the SFHA. Therefore this information was developed as a guide into the potential assets downstream of the dam and should not be considered as a comprehensive list. FEMA's Hazus database was utilized to identify critical infrastructure which was verified and refined with information observed from the field and through satellite imagery. Figure 21 illustrates the identification of hazards downstream of a dam.

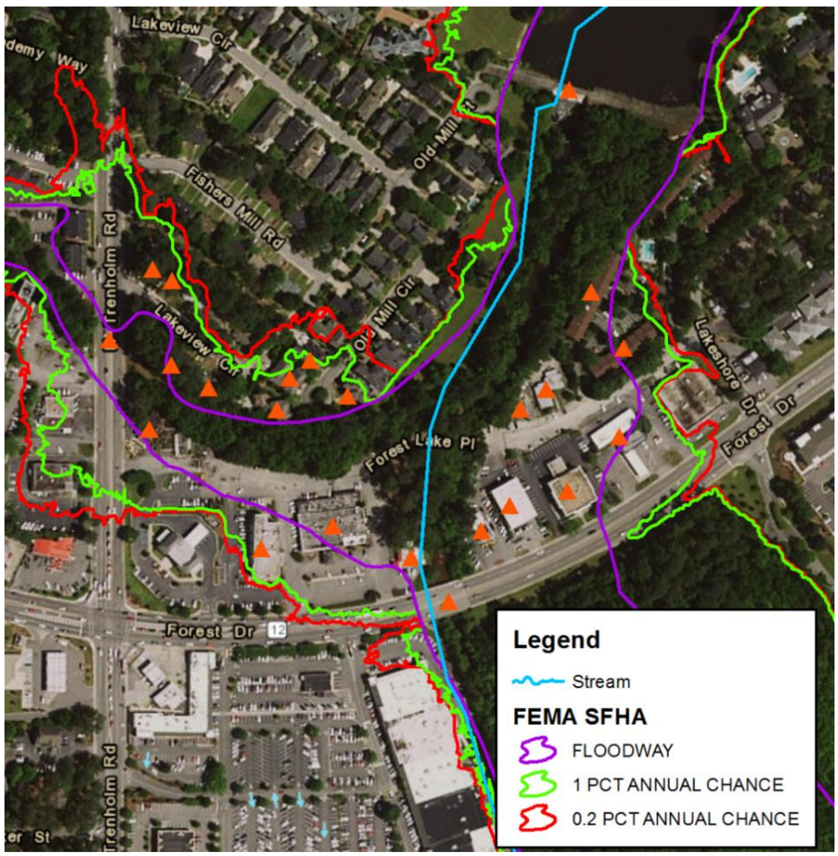

Figure 21: Hazard Identification Process

Phase 4 – Analysis and Recommendations

In coordination with SC DHEC to ensure accuracy and consistency with their regulations and procedures, Recovery Advisories were developed to help dam owners in the post disaster recovery as illustrated in Figure 22. The advisories were provided to SC DHEC for distribution to dam owners and included:

- Overview of dam regulations in SC
- Background information pertaining to the October 2015 storm event and the dam specific rainfall that was observed and damage that was observed through Phase 2 field visits
- Recommendations for rebuilding a more resilient dam including mitigation activities
- A work flow illustrating what is needed to rebuild, repair or decommission a dam (Figure 23)
- Information on hiring a dam safety engineer

- Permit requirements for rebuilding, repairing or removing a dam
- Information on Emergency Action Plans (EAP)
- A summary of potential hazards downstream of the dam using the Phase 3 information
- Resources and useful links

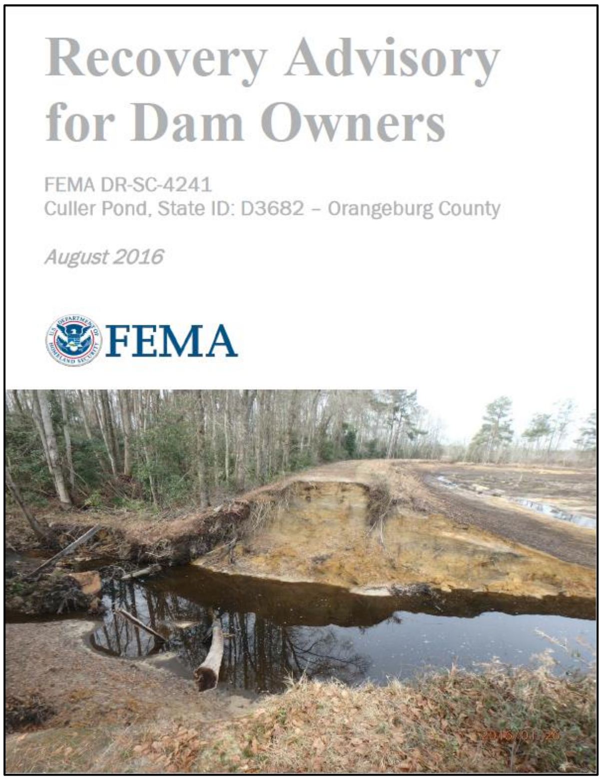

Figure 22: Rebuild Advisories

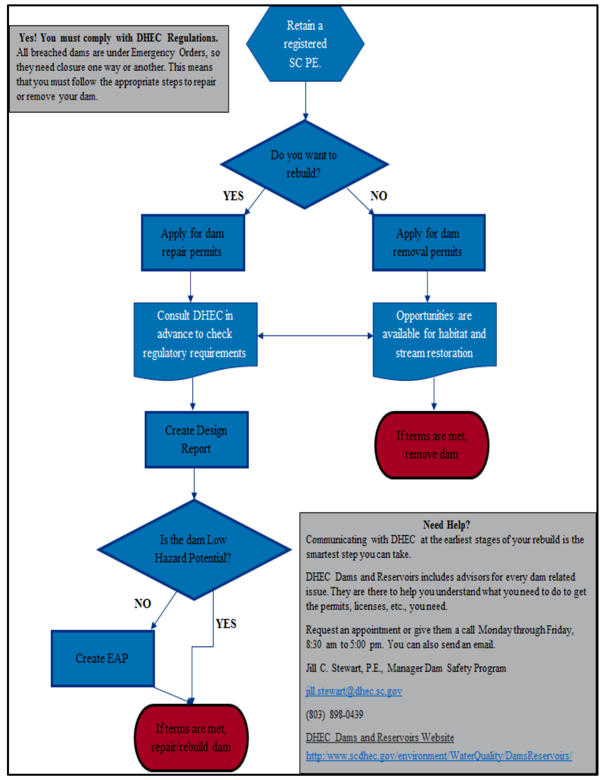

Figure 23: Rebuild/Repair Workflow

Hazard Mitigation Strategies

Of the 49 dams that failed at the time of this report, 24/49 are classified as Significant or High Hazard potential dams. The incremental economic, environmental, and lifeline losses as a result of a dam failure when compared to natural flood impacts is difficult to quantify and characterize without a detailed hydrologic, hydraulic, and consequences forensic assessment. However, numerous media reports and individual accounts claim that dams were the direct causes of these losses, including the cascading failure of dams. It is critical that these and similar dams in South Carolina incorporate hazard mitigation measures to the extent possible to help avert future devastating consequences.

Planning Approaches

Some hazard mitigation strategies involve advanced planning and can be universally applied to all earth embankment dams. These types of mitigation measures are typically aimed at protecting the communities downstream of the dams rather than the dam itself. To qualify for Hazard Mitigation Assistance (HMA) funding, including the HMGP, States must have current, adopted hazard mitigation plans (HMPs) that meet FEMA requirements. HMPs must be updated and adopted every five years. South Carolina's HMP was last updated in 2013 and designates SC DHEC as the agency responsible for conducting mitigation planning and activities associated with dams in the State. The State HMP does include dam/levee failure as a potential hazard, maps each permitted dam in the state, and cites the number of High Hazard potential dams in the state. The State HMP also cites land use planning as a coordinating mechanism to enhance mitigation by limiting development in hazardous areas and minimizing damage from hazards. Land use and zoning ordinances can be used to support land use plans by enforcing limitations on development in hazard areas. For example, open space should be preserved to help to attenuate floods, and properties that are at-risk can be acquired and converted to open space or used for low-impact and buffer zone purposes. Additional information about land use planning is available in the associated FEMA Recovery Advisory "*Land Use Changes Impact on Dam Safety*". Land use change impacts on existing dams and hazard mitigation strategies for changes in upstream land use and downstream land use are discussed more thoroughly.

Even the best HMPs cannot account for every eventuality. Therefore, it is important for dam owners to have EAPs that are coordinated with the local emergency management agency to help mitigate risk to downstream residents and structures should an unplanned and/or uncontrolled release occur. SC DHEC currently requires EAPs for High and Significant Hazard potential dams. Each EAP is required to include notification protocols and contacts, breach analyses, and a list of actions to be taken if the dam is near failure or has failed. Additional information about EAPs is available in the associated FEMA Recovery Advisory "*Emergency Action Plans for Dams*". This Recovery Advisory provides information and recommendations related to preparing EAPs in accordance with S.C. state regulations, best practices, and guidance from FEMA 64 "Federal Guidelines for Dam Safety: Emergency Action Planning for Dams". The use of early warning systems can further support the implementation of EAPs by providing downstream residents consistent warning messaging as quickly as possible. The South Carolina Dam Failure Response Plan requires the EAPs to include the State Emergency Operations Center (SEOC) in the notification plan.

In addition to planning in advance of a dam breach occurring, communities can take steps to improve infrastructure to better protect their residents and infrastructure should flooding occur as a result of a dam being breached. Some buildings and infrastructure may potentially be elevated above the base flood elevation. Buildings that cannot be elevated can be flood proofed to better withstand the impacts of flooding. Best management practices can be employed to help control and route stormwater runoff to bioswales, reservoirs, retention catchments, and other stormwater control structures that promote infiltration and safe runoff.

Federal agencies such as FEMA, the U.S. Department of Agriculture (USDA), and the U.S. Department of Housing and Urban Development (HUD) have grant programs that can be used to help pay the costs of implementing various hazard mitigation approaches. One such HUD grant program is the Community Development Block Grant (CDBG). The CDBG program is a flexible program that provides communities with resources to address a variety of community development needs such as providing decent affordable housing, providing services to the most vulnerable populations in our communities, and creating jobs through expansion and retention of business. There are multiple program areas, including entitlement communities, small cities, Section 108 loans, disaster recovery assistance, and programs targeted at specific geographic areas. While this program is not specifically targeted at dams, it can be used to assist communities impacted by dam-related flooding to become more resilient to future, similar events. The CDBG Grantee Areas for each dam and potential affected habitable and infrastructure assets are listed in Appendix A. Additional information about the CDBG areas of eligibility and other programs is provided in the associated FEMA Advisory, "*Sources of Federal Grant Funds for Dams and Downstream Structures*".

Mitigation of Dam Failures

Dams are owned and operated by individuals, private and public organizations, and the government. The responsibility for maintaining a safe dam rests with the owner. A dam failure resulting in an uncontrolled release of the reservoir can have an adverse impact on persons and property downstream. Fortunately, there are a number of resources that are publicly available to dam owners to help them inspect, operate and maintain their dams. It is important for dam owners to understand their responsibilities, including the state laws that regulate dams, proper operations and maintenance, regular inspections, and repairs and rehabilitation. Additional information for dam owners is available in the associated FEMA Recovery Advisory "*Educational Resources for Dam Owners*". This Recovery Advisory discusses South Carolina Dam Safety laws and regulations, dam features and components, dam size and classification, and additional external education resources for dam owners from organizations like Association of State Dam Safety Officials (ASDSO) and FEMA. While communities can and should take steps to mitigate against threats posed by flooding, dam owners can take steps to mitigate against uncontrolled releases. Both operational and structural approaches can used and will vary based on the type of failure that is being mitigated. Strategies for mitigating earth embankment dams against each type of failure are discussed in the following sections. Additional information about dam failures is available in the associated FEMA Recovery Advisory "*How and Why Earth Dams Fail*".

Overtopping

Overtopping failures, which were the most common failure type in South Carolina can be mitigated using both operational and structural approaches. Operational approaches include controlled releases in advance of an event, permanently lowering the surface elevation of the reservoir, and conducting routine inspection and maintenance activities. Based on observations and conversations with the dam owners, the first two approaches, controlled releases and lowering the reservoir surface elevation, are not likely to be feasible in South Carolina. While it was observed that many of the dams that failed included mechanisms that would allow owners to conduct a controlled release of the water behind the dam, many of these mechanisms were in poor condition. Moreover, it would have taken at least 24 hours for the release to have a noticeable impact on the reservoir surface elevation level. The dam owners also expressed concern about the impacts of a release on the fish and other aquatic life that live in the reservoirs. The third operational approach, routine inspection and maintenance activities, is technically feasible and easily implementable. The associated FEMA Advisory, "*Dam Maintenance*", provides additional information about the types of maintenance that should be conducted and the recommended frequencies of the activities.

Structural approaches to mitigating overtopping of the dams are technically feasible and vary in cost. It is recommended that any designs completed to mitigate future overtopping incorporate planned land use changes so that designs account for future conditions both upstream of downstream of the dam over the life of the dam and not just current conditions. A licensed engineer should review the projected future flows and make design recommendations. FEMA 1015 "*Overtopping Protection for Dams*", (which can be found online at https://www.fema.gov/media-library/assets/documents/97888) provides extensive, detailed information about the approaches that can be used. The most common structural approaches to mitigating dam failure from overtopping includes armoring of the downstream dam face and increasing the spillway capacity. Additional information about armoring is available in the associated FEMA Recovery Advisory "*Embankment Armoring*". Forest Lake Dam, which is located in Columbia, is an example of concrete armoring to mitigate overtopping failure and can be seen below in Figure 24.

Figure 24: Concrete Armoring at Forest Lake Dam (Source: FEMA)

Structural

Structural failures were the second most commonly observed failure mode of dams in South Carolina after the October 2015 event. Conducting routine inspections can allow the inspector to observe cracks, surface sloughing, depressions, or uprooted trees and bushes that could indicate the potential for structural failure and to address them as soon as they are observed so that the condition of the dam does not worsen. A licensed engineer should be consulted on appropriate methods that could be implemented to mitigate a structural failure in earth embankment dams. Some potential methods that could be used include:

- **Ensure use of proper materials** – Embankment dams are comprised of different types of geologic materials, except peat and organic soils (United States Society on Dams, 2011). The type of material used often depends on what is available locally and economically, but should be free of organic materials and trash and other debris. The majority of dams assessed were constructed from sandy clays as seen in Figure 25. Fine-grained soils and clays are commonly used in homogenous dams and in impervious cores of zoned dams.

- **Ensure proper compaction** – Foundation soils should be well-compacted and able to support the weight of the dam as well as the water being retained behind the dam. The soils that comprise the dam also should be well-compacted in accordance with the recommendations of the design engineer. Achieving the proper compaction at or slightly above the optimum moisture content is critical to ensuring the stability and proper performance of the dam.

Figure 25: Typical Soil Profile of Failed Dam. Able/Corbett Pond Dam shown (Source: FEMA)

- **Improve/increase drainage** – Improving drainage helps to reduce pore water pressures in the dam soils and control seepage. Toe drains can be used successfully for low-height dams. Blanket or horizontal drains can be used on moderate height dams. Chimney drains can be used in relatively high dams to intercept horizontal water flow before it reaches the downstream slope.
- **Construct toe berm** – Adding a soil or rock berm at the toe of the downstream slope of an earth embankment dam provides additional weight to resist sliding forces acting against it. Berms can also increase the seepage length, which can serve to lower the hydraulic gradient.
- **Use mesh/geosynthetic/jute mat and vegetation to reinforce slopes** – Reinforcing slopes through the use of a woven material covered by grass, usually placed by hydro seeding, can help to protect slopes from erosion while also controlling surface water flow rates.

Piping

Piping was the third common earth embankment dam failure mode observed in South Carolina. Instituting a regular inspection and maintenance program is a relatively inexpensive and effective way to mitigate against piping failures of earth embankment dams. The inspector's observations of animal burrows, unwanted vegetation, and cracks soon after they occur can be addressed quickly, mitigating further damage to the dam.

Likewise, regular inspections allow the inspector to observe seepage around hydraulic structures such as pipes and spillways and consult with a licensed engineer on appropriate methods of resolving the issue. As is true with mitigation embankment failures, the use of proper materials and compaction can help to mitigate against piping by minimizing the permeability of the dam materials, forcing water to follow engineered pathways through filters and drains. In existing dams, weighted filters can be placed over areas of existing seepage to prevent the migration of dam soils while allowing the passage of the seepage flow. A weighted filter is comprised of a layer of sand placed over the seepage area, covered by a layer of gravel which is then covered by a layer of larger rock. A licensed engineer should be consulted before placing a weighted filter.

Alternative Measures

In conjunction with mitigating risk, the repair or decommissioning of dams should be considered as an alternative means to prevent severe consequences from dam failures. This decision should be determined based on site-specific information and the associated costs, socio-economic, and environmental benefits of the solution.

The surfaces of an earthen dam may deteriorate for several reasons which can ultimately lead to failure. For example, wave action may cut into the upstream slope, vehicles may cause ruts in the crest or slopes, trails left by livestock on the dam can result in erosion of the embankments, or runoff waters may leave erosion gullies on the downstream slope. Other special problems, such as shrinkage cracks or rodent damage, may also occur. Damage of this nature must be repaired continually. The FEMA Advisory, "*Dam Repair Techniques*", provides additional information about proper repair techniques for dams and flood protection structures.

Decommissioning or removing a dam may be the best when: the original purpose of a dam changes, there are significant environmental or economic benefits that result from removing a dam, or a dam becomes damaged to the point that it's not economical to repair or rebuild it. Dam decommissioning can range from partial removal to full removal of the dam and appurtenant works. A dam decommissioning project typically includes all activities associated with full or partial removal of a dam, restoring the stream bed, and planning the project through design and implementation. Additional information about dam decommissioning is available in the FEMA Recovery Advisory "*Dam Decommissioning*".

Mitigation Conclusion

While flooding cannot always be stopped, flood hazards can be reduced. As their definitions attest, the words "hazard mitigation" mean taking measures that minimize or reduce the impacts of flooding on human development. Dam safety should include stakeholders at all levels including state, local and federal government agencies, private entities, nonprofit agencies, and most importantly dam owners. Wherever possible, communication and sharing of information should be encouraged to avoid duplication of efforts, better manage limited resources, and to create greater efficiency, ultimately enabling the dam safety community to mitigate, prepare, respond and recover more effectively to create more resilient communities. Coordination and communication between dam safety and risk management partners is discussed in more detail in the FEMA Recovery Advisory "*Effective Coordination and Communication*". By working together, communities can layer mitigation strategies to reduce the overall risk to their properties while also shortening the duration a flood event will affect their community.

Recommendations to Improve Dam Safety Partner Collaboration

The objective of this section is to identify capability gaps and provide recommendations for improving collaboration with partners both internal and external to FEMA. While many of the observations were made during the October 2015 South Carolina flooding disaster, best practices, incidents and actions from other states were also considered. The recommendations of this report are intended to improve dam safety partner collaboration throughout the whole community of practice.

The National Dam Safety Program (NDSP) has a lead role supporting the efforts of state and federal agency partners to continuously improve dam safety. These recommendations help to lay out a framework to fill capability gaps and improve communications by promoting better and more effective collaboration between dam safety partners. Recommendations are organized into the following five categories:

1. Preparedness Planning
2. Communication
3. Emergency Response
4. Coordinated Recovery
5. Training for Dam Incidents and Failures

An integrated program approach among DHS-FEMA programs coordinated with federal, state and local partners can increase the ability for partners to prepare for and respond to dam incidents and failures. Furthermore, increasing community resilience in vulnerable areas in the downstream inundation and surrounding areas will help result in reduced damages and casualties. Based on interviews with various levels of stakeholders and extensive research, a series of recommendations is presented herein. Interviews and research highlight program strengths, areas for improvement, opportunities and gaps from which a comprehensive approach is derived for consideration to help address some of these key elements. As is the case with other aspects of the Nation's aging and vulnerable infrastructure, improved understanding of the nation's dam inventory and opportunities to reduce risk can help advance community resilience through implementation of the recommendations in this section.

Discussions occurred with an extensive array of federal, state and non-governmental organizations involved with the October, 2015 South Carolina flood event response operation, as well as dam safety professionals from FEMA Region IV, the NDSP and state officials from Colorado, Georgia and Montana.

1. Preparedness Planning

National Incident Management System (NIMS) Annex to Support Dam Safety

The National Incident Management System (NIMS) provides a consistent and common approach and vocabulary to enable the whole community to work together seamlessly and manage all threats and hazards. NIMS applies to all incidents, regardless of cause, size, location or complexity. NIMS is being "refreshed" to incorporate lessons learned from exercises and real world incidents, best practices, and changes in national policy, including updates to the National Preparedness System. The refreshed NIMS should be available during the fall of 2016. Supporting guidance such as Comprehensive Preparedness Guides (CPGs) are being revised, and job title/position qualifications and Positions Task Books (PTBs) will be developed to better define the roles of Emergency Operations Center Emergency Support Function (ESF) team members. Dam Safety issues are usually coordinated through either ESF 3 - Public Works and Engineering or ESF 11 – Agriculture and Natural Resources.

Preparedness Planning Recommendations

Recommendation #1: **Provide inputs to NIMS revision effort**

- The NDSP should consider working with FEMA's National Integration Center to increase inclusion of core dam safety mission capabilities into NIMS support guides, templates and job aids, tailored to specifically help address necessary support roles during dam failure incidents. These should take into account the needs of partner stakeholders, whenever possible.

Recommendation #2: **Develop Emergency Operations Plan (EOP) Dam Incident Annex templates**

- FEMA and the NDSP should consider developing standard state and local EOP Dam Incident Annex guidance and templates based on "best practices." Dam-related incidents fit either in ESF 3 – Public Works and Engineering or ESF 11- Agriculture and Natural Resources. For instance, the Colorado State Emergency Operations Plan 2015 indicates that staff from the Department of Natural Resources would staff both ESF teams. The State's Dam Safety Program is within the Department of Natural Resources. ESF 3 and ESF 11 are both part of the Infrastructure Branch in the Emergency Operations Center organization, which supports close collaboration during dam-related events. Creation of model dam-related incident emergency response protocol language for use by ESF 3 or ESF 11 would help enable an improved understanding of stakeholder roles and responsibilities during an event. This will help stakeholders better align their plans and operations to the NIMS template and facilitate their input or coordination with the development of the state and / or local EOP Dam incident annexes and updates.

Succession Planning

South Carolina's manager of the Dams and Reservoirs Safety Program left the program several months prior to the October 2015 flood event. This led to some communication gaps and challenges that might have been bridged through improved succession planning. While South Carolina had conducted regular interagency dam safety meetings prior to the October flood event, gaps in succession planning may have contributed to some confusion in agency roles, responsibilities and availability of information including inundation mapping during the flood event. Currently the Federal Guidelines on Dam Safety (FEMA 93) and the Model State Dam Safety Program (FEMA 316) guidance does not address succession planning.

Succession Planning Recommendations

Recommendation #3: **Provide federal guidance on succession planning**

- FEMA should consider updating publications FEMA 93 and FEMA 316 to provide guidance for effective succession planning for dam safety officials.
- Agencies with responsibilities for dam safety should consider analyzing their program capabilities, skills and gaps within their agency resources and developing a strategy to effectively bridge those gaps. This might include assessing their department roles, contract capabilities, authorities, depth of staff experience/expertise and continuity planning.

Recommendation #4: **Provide adequate cross training and preparation for unplanned staff attrition**

- All federal, state and local agencies with responsibilities in dam safety should ensure that there is sufficient duplication of staff knowledge and skills to avoid future capability gaps as a result of attrition, sickness, lengthy absence or other. This can be achieved through but not be limited to:
  - Facilitating cross training of staff;
  - Establishing mentor-protégé relationships for key staff;
  - Providing training, policies, procedures and delegation of authority letters to enable positions to act with appropriate authority if or when key personnel up the chain of command are not available; and

- Adequate depth and planning / preparation of staff by management to minimize loss of knowledge as a result of planned or unplanned staff attrition.

This is most challenging and often most critical for roles performed by experienced staff who may be nearing retirement and whose knowledge and skillsets are the most comprehensive. It is recommended that historical attrition rates within an agency are determined and used as guidance for staff planning purposes.

Emergency Action Plan (EAP) Availability

Generally, the primary responsibility for initiating the EAP rests with the dam owner. Notification requirements often vary by state and are usually based on the dam's classification status. In South Carolina, dam owners are responsible for immediately notifying the State and county emergency mangers or public safety officials if unsafe conditions are detected or likely. During the 2013 Colorado Front Range flood, dam owners and operators often notified the local emergency manager who, not familiar with the specific dam EAP and notification procedures and call-down contact charts (where available), contacted the USACE, instead of the state's Dam Safety Program regional engineers who maintain more current information on local dams.

EAP Availability Recommendations

Recommendation #5: **Improve outreach, information sharing and communication**

- State dam safety programs, in coordination with state EMAs, should consider increased outreach to dam owners on EAP development, EAP exercises, and the importance of information sharing with local communities.
- State EMAs, in coordination with state dam safety programs, should consider increased outreach to local communities to ensure that dam EAPs are available and understood for proper inclusion into local emergency operation planning annexes and response during an emergency event.
- State dam safety programs should consider implementing education and outreach for dam owners to help understand the risk and responsibilities of owning and maintaining a dam to enable active participation in the Whole Community approach to dam safety and provide critical information to state emergency management and dam safety officials during a dam incident or failure.

Exercises

The Homeland Security Exercise and Evaluation Program (HSEEP) provides a set of guiding principles for exercise programs, as well as a common approach to exercise program management, design and development, conduct, evaluation, and improvement planning. HSEEP doctrine is flexible, adaptable, and is for use by stakeholders across the whole community and is applicable for exercises across all mission areas – prevention, protection, mitigation, response, and recovery. HSEEP documentation can be found at https://www.fema.gov/media-library/assets/documents/32326.

Federal, State, local, and tribal Emergency Management Agencies (EMAs) as well as many other organizations practice response to and recovery from emergencies and disasters through various exercises, discussion based and table top exercises (TTX) all the way up to operations based, full scale exercises. The most commonly practiced exercise is a TTX. During a common TTX, a facilitator leads stakeholders through a 4 to 8-hour discussion on topics relating to any of the 5 mission areas within emergency management. These exercises are designed to help participants understand their roles, responsibilities, authorities, plans, policies and procedures. HSEEP methodology provides guidance for the design and development of discussion and operations based exercises, however, they are not specific to dams. Montana has developed Dam Incident TTXs which are conducted throughout the state and include participation from emergency managers.

Exercise Recommendations

Recommendation #6: **Develop a Basic Dam TTX**

- The NDSP should consider partnering with FEMA's National Exercise Program to develop a HSEEP-compliant Basic Dam TTX to assist State and local jurisdictions who have not exercised dam failure for small to medium sized non-federal dams. This TTX would provide suggested core capabilities, goals and objectives for jurisdictions of all sizes to begin critical discussions of dam types, ownership, dam failures and overtopping events. In addition, the Dam Safety Program could work with Emergency Management Institute (EMI) to include dam break as a scenario in EMI's Virtual Table Top Exercise (VTTX) series.

Inundation Mapping for Dam Incidents and Failures

Inundation mapping is essential to the planning process by facilitating improved understanding of the dam failure hazard risk and its consequences. The maps better position emergency management and dam safety officials with information needed to effectively plan for, exercise, respond to and mitigate dam-related incidents. Dam failure inundation maps are the basis for evacuation maps developed by and critical to emergency management and emergency response personnel. Inundation maps and the hydrology and hydraulics modeling associated with them, can provide critical information including:

- The extent of the inundation of a dam failure or dam incident
- The depth, velocity, and arrival time of floodwaters at given downstream landmarks
- Potential evacuation considerations
- Dam failure related roadway inundation and potential failures that impact primary emergency response and evacuation routes
- Critical infrastructure facilities potentially impacted
- The population at risk locations relative to inundation

Currently, the FEMA Risk Map Program does not include dam incidents or failure information in Flood Insurance Studies (FISs) or Flood Insurance Rate Maps (FIRMs). FISs and FIRMs are regulatory products used for flood insurance purposes and dam release and failure information cannot be used for flood insurance rating purposes. However, dam release and dam failure inundation information can be included in Risk MAP non-regulatory products. This provides a benefit to communities and other stakeholder through improved risk communication, improved understanding of risk, and potentially improved design of buildings on a voluntary basis.

For example, the state of Georgia Flood Mapping Assessment and Planning program, through the FEMA Cooperating Technical Partner (CTP) program, has been instrumental in integrating dam safety into Georgia's Risk MAP program through collaboration with the Georgia Safe Dams Program. This has included concurrently performing dam inundation studies with Risk MAP studies and performing cross-training between the two programs.

It's important to note that regulatory agencies and dam owners often perform simple dam break studies to fulfill their duties in identifying and classifying a dam as high, significant or low hazard potential. Additionally state dam safety programs may not have the authority to require dam owners to provide inundation maps and EAPs, or these products may only be required when the dam is repaired or modified. Typically, once a classification is determined by incrementally extending a dam failure inundation model downstream until a hazard is identified within the inundation zone, the dam failure inundation assessment ends having determined the hazard potential without capturing the full downstream extent of inundation. By extending these studies further downstream, it could have residual benefits by identifying all hazards within the inundation area and supporting emergency planning and response.

Mapping Recommendations

Recommendation #7: **Improve collaboration and sharing of data among FEMA, State Dam Safety Programs and Risk MAP partners**

- FEMA, state dam safety programs and Cooperating Technical Partners (CTPs) should improve collaboration and share downstream inundation mapping for dam incidents and failures among state dam safety programs and FEMA mapping partners, including CTPs. This should include inundation areas on non-regulatory flood mapping products to help communicate risk. Additionally, digital terrain, hydrologic and hydraulic models developed during a FIS update may be leveraged by state dam safety programs and dam owners when performing inundation studies.

Recommendation #8: **Incorporation of inundation mapping into comprehensive plans and hazard mitigation plans**

- Local communities should consider incorporating inundation mapping into comprehensive plans, zoning regulations and state/multi-jurisdictional hazard mitigation plans to prevent and mitigate hazard creep. This will ensure the hazard is properly documented and appropriate mitigation actions can be taken.

Recommendation #9: **Ensure dam failure is included in state or community Threat and Hazard Identification and Risk Assessment (THIRA)**

- States and local communities should consider dam failure in their THIRA process. As the THIRA report is developed, consideration should be given to high hazard potential dams and/or high risk dams affecting the jurisdiction conducting the THIRA process. This consideration should include the type of dam, location and the impacts of each dam if a failure incident occurred. By including all dams within the THIRA, preparedness, response and recovery discussions as well as overall awareness will be heightened and possibly strengthened.

Recommendation #10: **Require or encourage inundation studies to extend beyond the first hazard**

- When performing dam inundation studies, in collaboration with state EMAs, state dam safety programs should consider requiring that studies and associated mapping be extended downstream to a point where flows from dam failure and incidents are either contained within the receiving stream channel banks, or when modeled the inundation is less than the regulatory 1%-annual-chance floodplain defined by the FEMA FIRMs. This enables inundation mapping efforts to help support EAP map development in addition to determining the regulatory hazard potential classification. The *Federal Guidelines for Inundation Mapping of Flood Risks Associated with Dam Incidents and Failures*, FEMA 946, dated July 2013 provides guidance for determining the flood risks associated with dam incidents and failures including downstream inundation extent.

2. Communication

Inter- and Intra-Agency Communication and Coordination

Several program shifts have recently impacted the NDSP. First, FEMA Headquarters delegated responsibility to regions for various dam related activities including: liaison duties, coordination, working across FEMA directorates, working with dam safety partners, providing SME's at the Regional Response Coordination Centers (RRCC) and JFO's, and grant related issues. While that change occurred in February 2012 with minor revisions occurring in March 2016, it takes many years to establish robust relationships, determine coordination needs, understand vulnerabilities or challenges, develop program plans and priorities and establish adequate funding streams to carry out program needs. Each FEMA region is unique, having different personalities, needs, capabilities, requirements, vulnerabilities, agencies to coordinate, competing priorities for funds and limited resources, along with a host of other factors.

State dam safety programs are typically housed in a variety of agencies including emergency management, conservation, natural resources, environmental protection or health. When state dam safety and emergency management programs are co-located, the dam safety staff is typically more familiar with NIMS and common operating procedures. For example, in South Carolina, regulatory responsibility for dams lies with DHEC, while responsibility for leading the state's emergency management program lies with the SC EMD.

State dam safety and EMAs are often under resourced, and are focused on routine program delivery, regulatory enforcement and technical assistance activities during non-emergency response and recovery periods. Purposeful communication among stakeholders during pre-event planning will improve understanding of agency and partner organization roles and responsibilities and standardize and streamline response and recovery procedures consistent with NIMS.

Following the 2013 Colorado floods, the Dam Safety After Action Report led to development of a comprehensive, stakeholder-based Communications and Emergency Operations Plan that has guided federal, state and local government and organization stakeholders through continued engagement which will improve response in future incidents. Lessons learned from the Colorado experience may be applicable to other states as they consider building cross-communication among agencies and stakeholders.

Communication Recommendations

Recommendation #11: **Develop job aids to assist with dam incidents**

- FEMA should consider developing job aids such as a communication and engagement guide to help all stakeholders' understand and effectively use Emergency Operations Plans. Too often, plans, policies and procedures sit on a shelf until an incident or emergency happens. One page job aids that support specific plans, especially for dam incidents would be beneficial to emergency managers at all levels of government.

3. Emergency Response

Activation and State Capacity Augmentation through Emergency Management Assistance Compact (EMAC)

Even robust state dam safety programs can experience staffing challenges during a major flood event that results in local dam-related emergencies as was experienced in Colorado during 2013 and South Carolina during 2015. The National Emergency Management Association (NEMA), composed of each state's Emergency Management Director, manages the national EMAC. This is a state-to-state mutual aid assistance program that is organized to facilitate state's supporting each other with a variety of technical resources during extreme emergencies and disasters. The Logistics Coordinator in the SEOC would request specific positions. In a dam failure event, it is possible for one state to request dam safety field inspectors and other resources from another state to support dam-related response in the SEOC. EMAC requests for response and support may be reimbursable through the FEMA Public Assistance Program where program requirements are met.

Recommendation #12: **Identify personnel for specific positions for an EMAC request**

- State dam safety and EMAs should identify and coordinate pre-positioning resources for EMAC dam inspection and logistical support. This includes consideration of expanding EMAC training courses to ensure that emergency management and dam safety staff are familiar with EMAC procedures for requesting support during a dam incident or failure.

Dam Safety Emergency Response Support

The February 2012 delegation of authority from FEMA Headquarters to Regions included providing subject matter expertise in the FEMA RRCC and/or JFO during dam-related emergencies and disasters.

During the response to the South Carolina flooding, a Mitigation Division staff member from the regional dam safety program was deployed to the RRCC as an Information Collection Specialist on October 2, 2015. As the focus of the regional response shifted towards heavy rain and flooding with changing weather predictions, reports of dam incidents and failures started coming into the RRCC on October 3, 2015. The Mitigation Division staff assigned to the RRCC began to use his expertise in dam safety to provide an enhanced level of support to the RRCC and other stakeholders. Some of the key benefits to this action included:

- Improved communication and coordination by FEMA staff with dam safety staff from the South Carolina DHEC Dams and Reservoirs Program located in the South Carolina EOC
- Increased awareness of dams and improved relationships between various stakeholders
- Improved situational awareness
- Improved decisions informed by subject matter experts who advised and supported state response staff

Recommendation #13: **Identify personnel to serve as dam safety liaisons**

- FEMA should consider formally identifying dam safety liaisons at the regional level who are ready to provide support in the RRCC, State EOC and the JFO. These liaisons should have expertise in dam safety and established relationships with the regional dam safety community.

FEMA Mission Support Division

The Mission Support Division provides technical support to various divisions during all phases of emergency management. Within the Mission Support Division, the GIS Resource Center provides GIS support, data processing and analysis during response, recovery and mitigation.

Recommendation #14: **Identify methods to coordinate with USACE with the most up to date information**

- It is recommended that the FEMA regional dam safety programs in coordination with the FEMA Regional GIS Resource Center identify methods and a desired schedule to facilitate regular coordination with the USACE and State dam safety programs to ensure that they have the most current inventory of dams in a geospatial format available to support the RRCC, state EOC and JFO in the event of a dam safety event.
- FEMA regional dam safety programs should consider using the FEMA Regional GIS Resource Center to identify the location of GIS-based dam breach inundation data for state regulated dams to be accessed for planning, exercise and dam incident and failure response by FEMA.

Civil Air Patrol (CAP) Mission Assignments

The CAP is a civilian auxiliary of the United States Air Force and is congressionally assigned to perform missions including emergency services. The CAP is an all-volunteer organization typically able to support state and Federal agencies at very low cost. On October 6, 2015, FEMA mission assigned the CAP to collect images of flood impacted areas as specified by FEMA. The CAP made more than 140 flights spending more than 240 hours airborne collecting more than 3,650 photos. However, only limited information specific to dams was collected during this assignment. A post disaster review of the CAP's mission assignment by FEMA Region IV staff indicated that there was no reference to dams. Through this mission, only four images were captured of the more than 50 state-regulated dams that failed.

Recommendation #15: **Improve collaboration with the CAP**

- FEMA should consider including dam-related emergency incidents as an integral part of flood reconnaissance mission assignments for the CAP. Such reconnaissance should be performed concurrently with flood damage assessment and primarily focusing on areas with High Hazard potential dams unless sufficient resources are available to also include significant and low hazard potential dams.
- In coordination with the state EMA, State Dam safety programs should consider using the CAP or other means of aerial reconnaissance to perform rapid screening of dams following a disaster to identify potential issues including damage to or failure of dams. This will support the prioritization of ground based responses, ultimately increasing situational awareness and allowing prioritized responses.
- Federal, state and local agencies with dam safety responsibilities should consider identifying a designated liaison with the CAP who participates in regular CAP meetings and trainings to develop an institutional knowledge of the CAP and build relationships.
- Federal, state and local agencies with dam safety responsibilities should ensure that any Memorandum of Understanding (MOU) or Cooperative Letter of Agreement are in place to provide a mechanism for CAP mission assignments. This will allow the CAP to provide support and dispatch missions more rapidly.
- The CAP should consider coordinating with state dam safety programs to ensure that they have dam locations in a format that can be rapidly accessed to scope missions. This data should at a minimum include spatial coordinates, dam identifiers and dam hazard classification.
- The NDSP should consider developing a visual guidance document that can be provided to the CAP for advanced training, preflight briefings and as an in-flight reference. The guidance document should document the requirements of aerial imagery including illustrations and descriptions to support the recognition and photography of:
    - Damage to dams, including complete or partial failure
    - Developing situations such as an emergency spillways engaging that will result in increased downstream flooding and increased risk of dam structure failure
    - Imminent failure conditions such as a dam overtopping, severe head cutting of earthen spillways, excessive seepage through dam embankments, failure of appurtenance structures and visible deformation of a dam embankment
    - Downstream inundation areas with residences and infrastructure at risk due to the dam incident that should be communicated to emergency responders.
- To increase the effectiveness of CAP missions, FEMA and state dam safety programs should consider identifying key staff with an engineering background and familiarity with dam safety to act as SMEs to work with the CAP when they have been assigned missions. This should include:
    - Supporting CAP incident commanders in scoping and guiding individual missions and sorties
    - Supporting CAP during sorties as in flight observers
        - To most effectively implement this recommendation, agencies should identify qualified and willing staff. Individuals who will potentially support the CAP as aerial observers should be vetted to ensure they are capable of recognizing dam failure characteristics and are suited to small aircraft flights. This includes having awareness of potential work assignments, a basic knowledge of aviation safety, suitable health and physical fitness, a tolerance for potential turbulence, tolerance to motion sickness, and lack of fear for heights and flying.
- To further increase the effectiveness of missions, the CAP should consider performing a member survey that will rapidly allow identification of members with a civil engineering and dam safety background that could provide added value to missions.
- To support planning efforts, the CAP should consider incorporating dam safety into Search and

Rescue Exercises (SAREX). To increase the effectiveness of exercises, partnerships should be encouraged with FEMA, state and local dam safety officials. Using the guiding principles of HSEEP, a core team of personnel from each jurisdiction, known as the Exercise Planning Team (EPT) develop exercises based on plans, policies and procedures as well as After Action Reports (AARs). The EPT should consider pre-flight training, briefings and post exercise mission debriefs looking at the effectiveness of reconnaissance data and areas for potential improvements. This data will be captured in the AAR and improvement plan and can be used to update plans, policies and procedures.

- Nationally, the CAP, FEMA and state EMAs should consider adding levee failure missions in geographies with significant numbers of at-risk levees.
- The NDSP should consider developing guidance for aerial reconnaissance and inspection of dams which can include tiered approaches which range for screening level reconnaissance using fixed wing manned aircraft to more detailed dam inspections using Unmanned Aerial Systems (UAS), commonly referred to as drones (see recommendation #16). The guidance should include best practices, regulatory requirements, restrictions and resources.

Utilization of Unmanned Aerial Systems for Reconnaissance and Inspection of Dams

After the October 2015 South Carolina Flood, the USACE was mission assigned by FEMA through the Region IV RRCC on October 7, 2015, to "Deploy Unmanned Aerial System and operators to provide products including georeferenced high resolution aerial imagery in support of FEMA". USACE flew six UAS missions in which videos were taken of key sites, to include Andrews Airport, Beaver Dam, Columbia West Canal, Forest Lake Dam, Lake Katherine Dam, and Spring Lake Dam.

On August 29, 2016, the Federal Aviation Administration (FAA) issued the Small UAS Rule (Part 107) that included pilot and operating rules. This rule allows for the commercial operations of UASs under 55 pounds. Restrictions on the operation of an UAS include but are not limited to:

- The UAS must be operated by a pilot who has passed a written test and is at least 16 years old.
- UASs must be flown with a Visual Line of Sight (VLOS).
- UASs must be flown at a maximum altitude of 400 feet above ground level and during the day.

Exceptions to these restrictions may be possible through the application of a UAS Certificate of Authorization (COA). The FAA has provided an online system for UAS operators to apply for a COA that, if approved, is valid for 2 years. The FAA rule does not preclude additional regulations set forth by state and local UAS regulations. Numerous FEMA Region IV state dam safety programs including South Carolina and Georgia indicated an interest in the utilization of UASs for both regular and emergency dam inspections.

Recommendation #16: **Utilization of UAS Technology**

- State dam safety programs should consider implementing UAS technology to supplement regular and emergency dam inspections. UASs provide many benefits when compared to manned aircraft including the ability to be deployed with fewer weather restrictions, ability to fly closer to the ground, and the ability to get into areas that would otherwise be too small. Potential sources for UASs may include state and local EMAs, state highway patrol, USACE and the private sector.
- Operators of UASs including state dam safety programs should consider proactively applying to the FAA for dam specific UAS COAs which would allow the use of UASs beyond the VLOS to approved dam locations. This will help to minimize delays performing reconnaissance and inspection of dams due to accessibility issues such as washed out roads to a dam or denial of entry by property owners that could prevent a VLOS.

Emergency Drawdown of Reservoirs

From August 1 through 4, 2016, FEMA Region IV facilitated the Partners in Mitigation & Grants Management Workshop which included a specialty dam safety break out track which was attended by regional FEMA officials, state dam safety officials and members of the private sector. The track encouraged open discussions among attendees which included the challenges associated with emergency draw down of small to medium sized reservoirs. SC DHEC representatives discussed the lack of preparedness and difficulty that dam's owners encountered to draw down reservoirs both ahead of the storm and immediately after the storm. A need was identified during the track for guidance on the emergency drawdown of reservoirs including the use of pumps and siphons. In the December 2012 publication *Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown* by Morrison Maierle, Inc., information is provided to help dam owners determine best methods to employ for reservoir drawdown.

Recommendation #17: **Guidance for Emergency Reservoir Drawdown**

- The NDSP should consider developing a technical manual for dam owners that provides guidance for emergency reservoir drawdown. The purpose of this technical manual will be to advance awareness of the need to facilitate emergency drawdowns and provide guidance on temporary structural methods including pumps and siphons, best practices, maintenance of existing outlet control structures and resources.

4. Coordinated Recovery

Post-Incident Recovery Operations

Once immediate emergency response issues such as life safety, search and rescue and utility restoration have been addressed, disaster response begins to evolve into recovery operations. For dam incidents, this includes post-incident inspection of the dam structure, impoundment, dam appurtenance works and damages to downstream inundation areas. Dam inspections should be conducted by state dam safety engineers coordinated through the state dam safety and EMAs per the EOP. For large, multi-structure incidents such as the 2013 Colorado Front Range Floods and 2015 South Carolina Floods, inspection teams can be supplemented with EMAC technical teams. FEMA and other federal partners may also be able to provide other technical resources.

Publicly owned structures or those which provide a public function such as drinking water supply, flood control, irrigation supply or fire suppression water sources, may be eligible for repair or replacement through FEMA's post-disaster Public Assistance Program or US Department of Agriculture (USDA) programs. Jurisdictions and dam owner/operators are often not well-versed in these programs and may hasten dam repairs without the necessary bid processes and documentation required to be eligible for reimbursement. Fortunately, most communities are rarely struck by disaster and need to use the FEMA Public Assistance Program or USDA programs to support infrastructure recovery, but basic knowledge of these programs can accelerate dam repairs and limit the financial recovery burden on those who own and operate public facilities. Some states also have funds available for dam improvements or repair.

Recommendation #18: **Accelerated situational awareness**

- It is recommended that state dam safety agencies utilize local experts and remotely located experts to review ground based photography and aerial imagery from various sources including the CAP and UASs to accelerate a situational awareness. This can be achieved by screening and prioritizing post-incident recovery efforts to identify potential situations requiring follow up activities such as ground inspections, downstream evacuations or emergency actions to lower reservoirs. The ability to screen a large number of dams through aerial reconnaissance to narrow recovery operations to dams actually impacted will increase resource efficiencies and accelerate recovery efforts. Due to digital photography and data transfers, it is not necessary for all experts to be local to the dams enabling EMAC technical teams to support recovery efforts remotely without the need to travel, potentially widening the cadre of available EMAC experts.

Hazard Mitigation Technical Assistance Program (HMTAP)

During the early stage of the recovery phase in the 2015 South Carolina floods, FEMA used the HMTAP to select a contractor to perform assessments of dams, assess capability gaps, develop rebuild advisories and factsheets to help the coordinated recovery efforts. The contractor was selected through a competitive process that resulted in the contract being awarded almost 12 weeks after the disaster. Due to the delay in awarding a contract and the time required to develop new advisory template documents, many dams had been rebuilt diminishing the benefit of these advisories. Numerous failed dams were identified by DHEC after the original task order issuance that resulted in significant delay in issuing a task order change order to expand the scope of work and increase the number of dams from 31 to 50. The development of new rebuild advisories required significant interaction with DHEC to ensure that the advisements provided a consistent message with the state's permitting processes and other regulatory agencies.

During the assessments, task order limitations did not allow expanding field dam assessments to those which did not fail to allow highlighting of dam structure management "best practices" which enabled many state dam structures to withstand the flood event. DHEC requested that in addition to assessing failed dams, FEMA also assess dams that did not fail to highlight best practices that may have resulted in many dams surviving the flood event.

Recommendation #19: **Customization, Updating and Distribution of Advisories**

- FEMA and state dam safety programs should consider collaborating to create 2-phase advisories targeting dam owners that would enable state dam safety programs to rapidly distribute rebuild advisories in the event of a disaster. This will encourage dam reconstruction without bypassing or overlooking the regulatory process, ultimately increasing resiliency and safety.
    - Phase 1 advisories would be generic and communicate to all dam owners the potential permitting requirements and rebuild considerations without being specific to individual dams. These advisories should be developed proactively to be ready to disseminate at any time.
        - State dam safety programs should disseminated Phase 1 advisories to all dam owners within the impacted area immediately after the disaster.
    - Phase 2 advisories would be customized to individual failed or damaged dams and communicate permitting and rebuild recommendations. This would be based on a desktop review and site assessment for individual dams to be performed by FEMA through HMTAP or by state dam safety programs immediately after a disaster. Phase 2 templates should be developed proactively to be ready to populate and customize in the event of a disaster.
        - State dam safety programs should target dissemination of Phase 2 advisories to individual dam owners 30 to 60 days after the disaster to encourage dam owners to make sound decisions on rebuilding dams while adhering to the appropriate permitting processes.

Recommendation: #20: **Expediting more comprehensive HMTAP task order issuance and minimizing change orders**

- FEMA should consider incorporating post disaster dam assessments into the existing Mitigation Assessment Team (MAT) process or develop a post disaster dam assessment process that operates similarly to MAT. The procurement of these services through HMTAP should include requesting both the upfront cost of mobilizing teams and unit costs for individual dams to allow flexibility as additional dams are discovered and added to the task, avoiding the need to competitively procure an expanded scope.

    - To identify best practices and help state dam safety officials and dam owners understand why some dams failed and others didn't, assessments should include dams that experienced similar hydrologic loadings but did not fail.

- FEMA should consider performing dam failure inundation studies for dams that did not fail but experienced structural damage. This can include dams with emergency orders. This will provide state dam safety programs, local emergency managers and dam owners with inundation maps that will increase situational awareness and facilitate emergency actions to mitigate risks.
- FEMA should consider incorporating the collection of breach information including basics measurements and shapes for failed dams into the assessment process. This data can be collected with minimal effort and will provide valuable information to the dam safety communities. Potential applications include verifying the applicability of breach parameter equations for similar dams as well as supporting new research into breach parameter estimation.

5. Training for Dam Incidents and Failures

Emergency Responder Training

State dam safety and emergency management programs can experience high staff turnover due to workforce aging as well as the high-stress situations of emergency management, long hours and unpredictable schedules. Local emergency managers are often part-time employees or volunteers, especially in sparsely populated rural areas or small towns because financial capacity is not present to support a full-time emergency manager. Knowledge gaps in preparedness planning, emergency response and recovery have been discussed and addressed, and further, more formal efforts to improve communication among all stakeholders will support capacity and capability to address emergency dam incidents including overtopping and failure along with downstream impacts.

Addressing the previously discussed recommendations can greatly increase stakeholder's abilities to manage their dam portfolio, especially for high and significant hazard potential dams.

A formalized, national training program can support the accomplishment of recommendations suggested in this report.

Recommendation #21: **Independent study courses related to emergency management**

- The NDSP should encouraging all dam safety program stakeholders and partners to complete NIMS Independent Study Courses 100 - Introduction to the Incident Command System, 700 - National Incident Management System, An Introduction, 701- NIMS Multiagency Coordination System (MACS) and 800 - National Response Framework, An Introduction.
- In coordination with state dam safety programs, the NDSP through EMI should conduct short, locally-based workshops and seminars for dam owner/operators and emergency managers/responders targeting small earthen dams. This can include the new field deployed training course by the Emergency Management Institute *0291 Community Dam Safety, Preparedness & Mitigation* training. Key modules should include:
    - Unit 1 – Introductions to Dams
    - Unit 4 – NIMS and National Preparedness Goals
    - Unit 5 – Consequences of a dam failure
    - Unit 8 – Risk Communication
    - Unit 10 – Planning and Risk Reduction

Recommendation #22: **Development of additional dam safety material for all stakeholders (in addition to those made in previous sections)**

- While many states already have technical fact sheets and advisories, there are still gaps. FEMA should consider coordinating with state dam safety programs to identify gaps and modify the non-dam specific Fact sheets and technical advisories developed through HMTAP for South Carolina to meet specific state program needs for all states.
- FEMA, in coordination with the SC DHEC program should consider developing fact sheets and technical advisories through HMTAP which would be distributed by SC DHEC to all dam owners statewide, not just those with dams that have failed. This will help to improve dam owner's knowledge of dams and the regulatory requirements, encouraging greater preparedness and resilience.

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CDBG Habitable Assets

Name	SC ID	CDBG Names	All Assets	LMI Assets	Single-Family	Multi-Family	Commercial
Carys Lake	D0026	Columbia & Richland County	210	4	166	3	21
North Lake Dam/Overcreek Rd. Dam/Upper Rocky Creek	D0029	Columbia & Richland County	207	5	167	3	19
Walden Place Dam	D0572	Columbia & Richland County	18	0	6	0	0
Lower Rocky Creek Dam/Rocky Ford Lake	D0028	Columbia & Richland County	208	9	169	3	19
Windsor Lake Dam[1]	D0571	Columbia & Richland County	100	0	67	2	16
Forest Lake Dam[1]	D4434	Columbia & Richland County	232	42	191	2	19
Wilson Millpond Dam	D0594	Columbia & Richland County	4	1	1	0	0
SCNONAME 32080[1]	D0957	Lexington & Richland County	203	0	191	0	5
Lake Elizabeth	D0024	Columbia & Richland County	6	1	3	0	0
Beaver Dam Lake/Wildwood Pond #2/Boyd Pond	D0567	Richland County	27	4	12	0	2
Epworth Pines Dam[1]	D0362	Richland County	21	0	7	0	0
Barr Dam/ Barr Lake Dam	D1717	Lexington County	22	0	8	0	4
Covington Lake Dam	D0545	Richland County	19	3	10	0	0
Stevenson's Lake Dam[1]	D0546	Richland County	15	0	8	0	0
Sunview Lake Dam	D0579	Richland County	12	5	1	0	2
Able / Corbett Pond Dam	D2048	Lexington County	9	3	1	0	0
Murray Pond Dam	D0595	Richland County	7	6	1	0	0
Gibson Dam/Gibson's Pond Dam	D0959	Lexington County	36	4	21	0	4
Old Mill Pond Dam	D0958	Lexington County	37	4	26	0	4
Pinewood Lake Dam	D0580	Richland County	9	2	1	0	2
Ulmers Pond	D0581	Richland County	9	4	0	0	2
Corbett Lake	D2052	Lexington County	6	3	1	0	0
Boyds Pond Dam	D0592	Richland County	5	1	0	0	0

Name	SC ID	CDBG Names	All Assets	LMI Assets	Single-Family	Multi-Family	Commercial
Haithcock Pond Dam	D0591	Richland County	5	0	0	0	0
Weston Pond Dam	D0593	Richland County	18	17	12	0	0
Clarkson Pond Dam	D0599	Richland County	5	1	0	0	0
Lakewood Pond Dam	D3490	Richland County	3	2	1	0	0
Duffies Pond Dam	D0600	Richland County	1	0	0	0	0
Baileys Pond	D2034	N/A	11	0	0	0	0
Clyburn Pond Dam	D2412	N/A	8	0	3	0	1
McCray Lake Dam	D1584	N/A	13	0	8	0	0
Busbees Pond	D3701	N/A	7	0	0	0	1
Smith Millpond Dam	D0510	N/A	4	0	0	0	0
Boyle Pond Dam	D1583	Sumter County	20	0	16	0	0
Cook Pond Dam	D1068	N/A	19	0	14	0	1
M. R. Trotter Dam	D0110	N/A	15	13	12	0	0
Hermitage Mill Pond Dam[1]	D0017	N/A	12	3	0	0	5
Ellerbees Millpond Dam	D1460	N/A	7	0	3	0	0
Chapman's Pond Dam	D3533	N/A	6	0	0	0	1
SCNONAME 28045 (off Tower Rd.)	D2521	N/A	6	0	3	0	0
Culler Pond	D3682	N/A	5	2	2	0	1
JW Smoaks Pond	D3738	N/A	4	1	1	0	0
Cuttino Pond Dam	D3482	N/A	4	0	0	0	0
Dogwood Lake Dam	D2065	N/A	4	0	1	0	0
Fredericksburg Lake Dam[1]	D2539	N/A	4	0	1	0	0
SCNONAME 38036 (Cleveland Street)	D3743	N/A	3	0	0	0	2
Cola Plantation Dam[1]	D3498	N/A	3	3	0	0	0
SCNONAME 09031 (off Community Club Rd.)	D2645	N/A	3	0	0	0	0
SCNONAME 09040 (off Church Camp Rd.)	D2921	N/A	3	0	0	0	0
O E Rose Dam	D3487	N/A	2	0	0	0	0
Black Crest Farm Pond Dam	D2063	N/A	2	0	1	0	0

Name	SC ID	CDBG Names	All Assets	LMI Assets	Single-Family	Multi-Family	Commercial
Legette Millpond Dam[1]	D0511	N/A	2	0	0	0	0
SCNONAME 14003 (off Fox Tindal Rd.)	D3497	N/A	2	2	0	0	0
SCNONAME 14005 (off Puddin Swamp Rd.)	D3484	N/A	2	1	0	0	0
Wards Pasture Pond Dam	D3502	N/A	2	2	0	0	0
SCNONAME 14008 (off Old River Rd.)	D3495	N/A	1	1	0	0	0
Drafts Pond Dam	D0601	N/A	0	0	0	0	0
Touchberry Lower Pond Dam	D1586	N/A	0	0	0	0	0

[1] Dam did not fail but was analyzed for comparative purposes.

CDBG Infrastructure Assets

Name	SC ID	CDBG Names	Dams	WW Facility	Roads	Industrial Plant
Carys Lake	D0026	Columbia & Richland County	4	0	16	0
North Lake Dam/Overcreek Rd. Dam/Upper Rocky Creek	D0029	Columbia & Richland County	4	0	14	0
Walden Place Dam	D0572	Columbia & Richland County	3	1	7	0
Lower Rocky Creek Dam/Rocky Ford Lake	D0028	Columbia & Richland County	3	0	14	0
Windsor Lake Dam[1]	D0571	Columbia & Richland County	2	0	12	0
Forest Lake Dam[1]	D4434	Columbia & Richland County	1	0	15	4
Wilson Millpond Dam	D0594	Columbia & Richland County	1	0	2	0
SCNONAME 32080[1]	D0957	Lexington & Richland County	0	3	3	0
Lake Elizabeth	D0024	Columbia & Richland County	0	0	1	0
Beaver Dam Lake/Wildwood Pond #2/Boyd Pond	D0567	Richland County	3	0	9	0
Epworth Pines Dam[1]	D0362	Richland County	3	0	8	0
Barr Dam/ Barr Lake Dam	D1717	Lexington County	2	2	4	0
Covington Lake Dam	D0545	Richland County	2	0	4	0
[1]Stevenson's Lake Dam	D0546	Richland County	2	0	4	0
Sunview Lake Dam	D0579	Richland County	2	0	6	0
Able / Corbett Pond Dam	D2048	Lexington County	2	0	4	0
Murray Pond Dam	D0595	Richland County	2	0	3	0
Gibson Dam/Gibson's Pond Dam	D0959	Lexington County	1	2	4	0
Old Mill Pond Dam	D0958	Lexington County	1	1	2	0
Pinewood Lake Dam	D0580	Richland County	1	0	4	0
Ulmers Pond	D0581	Richland County	1	0	5	0
Corbett Lake	D2052	Lexington County	1	0	2	0
Boyds Pond Dam	D0592	Richland County	1	0	3	0
Haithcock Pond Dam	D0591	Richland County	1	0	4	0
Weston Pond Dam	D0593	Richland County	0	0	4	0
Clarkson Pond Dam	D0599	Richland County	0	0	3	0

Name	SC ID	CDBG Names	Dams	WW Facility	Roads	Industrial Plant
Lakewood Pond Dam	D3490	Richland County	0	0	2	0
Duffies Pond Dam	D0600	Richland County	0	0	1	0
Baileys Pond	D2034	N/A	2	0	7	0
Clyburn Pond Dam	D2412	N/A	2	0	2	0
McCray Lake Dam	D1584	N/A	1	0	4	0
Busbees Pond	D3701	N/A	1	0	5	0
Smith Millpond Dam	D0510	N/A	1	0	3	0
Boyle Pond Dam	D1583	Sumter County	0	0	4	0
Cook Pond Dam	D1068	N/A	0	0	3	1
M. R. Trotter Dam	D0110	N/A	0	0	3	0
Hermitage Mill Pond Dam[1]	D0017	N/A	0	0	7	0
Ellerbees Millpond Dam	D1460	N/A	0	0	3	0
Chapman's Pond Dam	D3533	N/A	0	0	4	0
SCNONAME 28045 (off Tower Rd.)	D2521	N/A	0	0	3	0
Culler Pond	D3682	N/A	0	0	1	0
JW Smoaks Pond	D3738	N/A	0	0	1	0
Cuttino Pond Dam	D3482	N/A	0	0	4	0
Dogwood Lake Dam	D2065	N/A	0	0	3	0
Fredericksburg Lake Dam[1]	D2539	N/A	0	0	3	0
SCNONAME 38036 (Cleveland Street)	D3743	N/A	0	0	1	0
Cola Plantation Dam[1]	D3498	N/A	0	0	3	0
SCNONAME 09031 (off Community Club Rd.)	D2645	N/A	0	0	3	0
SCNONAME 09040 (off Church Camp Rd.)	D2921	N/A	0	0	3	0
O E Rose Dam	D3487	N/A	0	0	2	0
Black Crest Farm Pond Dam	D2063	N/A	0	0	1	0
Legette Millpond Dam[1]	D0511	N/A	0	0	2	0
SCNONAME 14003 (off Fox Tindal Rd.)	D3497	N/A	0	0	2	0
SCNONAME 14005 (off Puddin Swamp Rd.)	D3484	N/A	0	0	2	0

Name	SC ID	CDBG Names	Dams	WW Facility	Roads	Industrial Plant
Wards Pasture Pond Dam	D3502	N/A	0	0	2	0
SCNONAME 14008 (off Old River Rd.)	D3495	N/A	0	0	1	0
Drafts Pond Dam	D0601	N/A	0	0	0	0
Touchberry Lower Pond Dam	D1586	N/A	0	0	0	0

[1] Dam did not fail but was analyzed for comparative purposes