DAM SAFETY IN THE NORTHEAST: RESPONSE TO HURRICANE IRENE & TROPICAL STORM LEE FLOOD EVENTS

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Introduction

After a busy 2011, dam safety programs in the northeastern U.S. are hoping for a calm 2012. In 2011, the region experienced precipitation that set records at many locations. August and September were particularly busy times for dam safety programs with the arrival of Hurricane Irene and the remnants of Tropical Storm Lee.

The first hurricane to threaten New York City since Hurricane Gloria in 1985, Hurricane Irene bore down on the region after making initial landfall in Cape Lookout, North Carolina. With hurricane-force winds extending 90 miles outward from the center and tropical storm winds extending outward up to 290 miles, Irene was similar in size to Hurricane Katrina (source: NOAA). By the time the storm made landfall again near the Little Egg Inlet in New Jersey on the morning of August 28, it had weakened to tropical storm strength; still, the precipitation it brought to the region was significant.

Close on the heels of Irene, the remnants of Tropical Storm Lee arrived in the region on September 8, resulting in record flooding on many rivers and streams in Pennsylvania and New York. Many dams

CPC Accumulated Precipitation in Inches (27 Aug 2011 - 29 Aug 2011

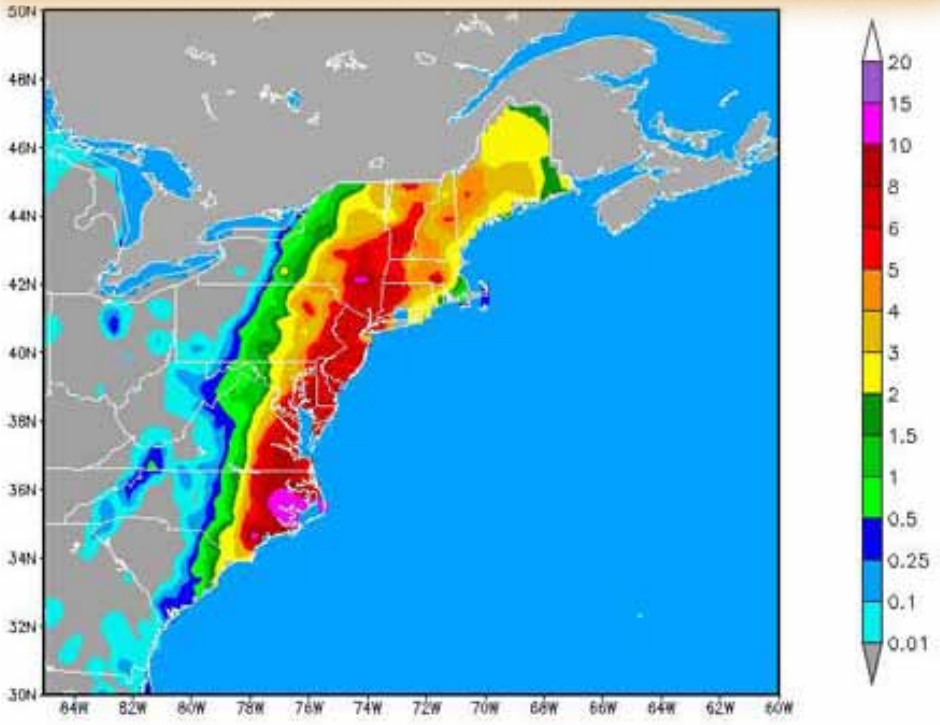

Figure 1. Hurricane Irene precipitation (source: NOAA)

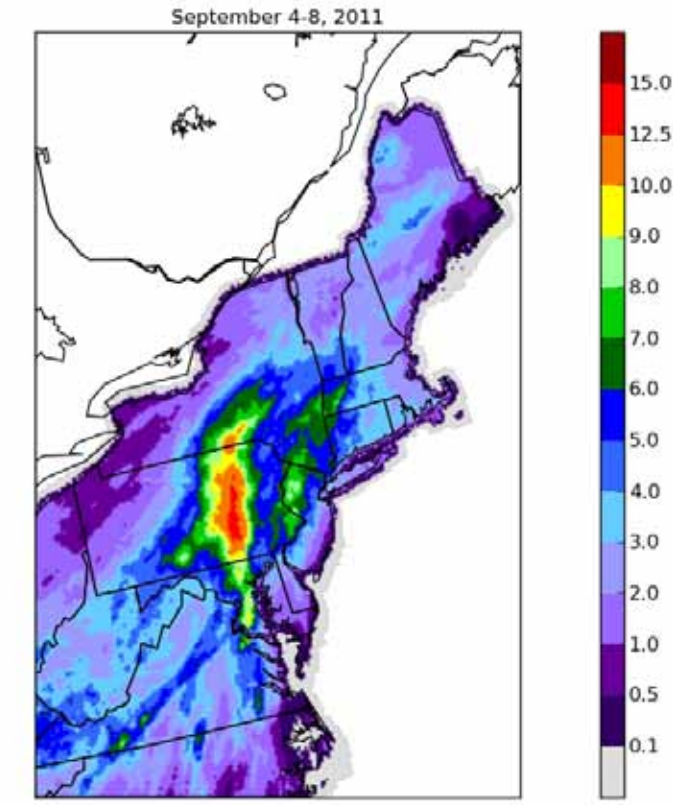

Figure 2. Tropical Storm Lee precipitation (source: NOAA)

were overtopped and damaged, some failed, but, most importantly, there was no loss of life attributed to the failure of a dam in the wake of these events.

With record precipitation and flooding, the year presented many challenges to the dam safety programs in the region. At the same time, the events demonstrated the benefits of strong dam safety programs in preventing loss of life as a result of dam failures.

Following is a state-by-state report on the impacts of the storms on the region's dams, responses of state dam safety programs, and lessons learned.

Connecticut

While many people in New England were thinking about getting back to school and making plans for Labor Day, Connecticut Dam Safety staff began preparing for potential impacts from Hurricane Irene during the week of August 21. On August 23, an earthquake centered in Mineral, Virginia was felt throughout the East Coast. Dam Safety staff responded by contacting owners and operators of the larger dams in the state to discuss post-earthquake status and inspections, as well as preparations for responding to the increasing likelihood of a direct hit by Hurricane Irene, then predicted to make landfall as a Category 2 hurricane. While the earthquake appeared to have had minimal effect on dams in Connecticut, the initiative to contact dam owners enabled us to update dam safety contact information.

During the week of August 21, Department of Energy and Environmental Protection (DEEP) field staff performed inspections and routine debris clearing of the 32 Natural Resources Conservation Service (NRCS) and US Army Corps of Engineers (USACE) flood control dams owned by the state. Because there was such a large lead time for this storm, many dam owners wanted to draw down impoundments in hopes of preventing impending flooding. At first, we tried to explain that this action would not impact final flood elevations in small impoundments, but this explanation quickly evolved into a more tactful explanation of how to perform this task carefully and thoughtfully - carefully, because it would be improper to cause flooding downstream by haphazardly releasing large quantities of water; thoughtfully, because releases can affect neighbors and fishery resources.

One dam owner started drawing down his impoundment three days before the hurricane was predicted to reach Connecticut; however, dissatisfied with the progress of lowering the lake after one day, the owner opened the drawdown gate fully. This led to the complete draining of a 12-acre impoundment, causing a significant fish kill. As one might expect, photographs of a 10-year-old female angler standing on the pond bottom amongst the flopping fish soon appeared in a local newspaper. We're now working towards

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Figure 3. Pratt Pond Dam, Plymouth CT: "Un-permitted work underway" after Hurricane Irene

Figure 4. Pratt Pond Dam, Plymouth CT during Tropical Storm Lee, nine days after Irene

developing guidance for dam owners on appropriate times and procedures to draw down a water body before an impending storm event.

Department staff manned the flood response center and responded to several calls for technical assistance during the storm event. For safety reasons, we delayed most dam inspections until the winds and rain had abated. As soon as the winds slowed to 40 mph, several of our staff were out inspecting dams. All the inspection teams were mobilized starting at 7 am the next morning. In addition, DEEP field services staff inspected all NRCS and USACE flood control dams and DEEP-owned dams following the storm.

The areas of concentration for inspections were selected by looking at rainfall isohyetal maps, with the areas with the largest total rainfalls getting the most attention. A look at the C "high" hazard dams in the area with the most rainfall indicated they were either: 1) owned by DEEP, 2) owned by municipalities, 3) owned by water companies, or 4) were capable of safely passing a minimum design flood of the ½ Probable Maximum Flood (PMF). Department staff believed that these owners would take care of their own dams responsibly and decided to concentrate on the privately owned dams that posed a downstream hazard but were not likely to be inspected after the rain event. These were the class B "significant" hazard and the BB "moderate" hazard potential dams.

As many towns were mopping up the mess left by Irene (precipitation totals shown in Figure 1), along came the remnants of Tropical Storm Lee, with much less fanfare, but significant rainfall and corresponding flooding. As seen in Figure 2, which shows the precipitation

Figure 5. Long Meadow Pond Dam, Bethlehem, CT: Overtopping during Hurricane Irene

Figure 7. Breach of Quist Pond Dam in Washington, CT, recorded after Hurricane Irene

Figure 6. Romford Pond Dam, Washington, CT: Embankment slough after Hurricane Irene

totals related to Tropical Storm Lee, the western and especially northwestern section of Connecticut took another beating.

In the two weeks following Irene, the dam safety unit and several volunteers from other DEEP units inspected 204 dams. These inspections resulted in issuance of 25 letters requiring immediate action, including more comprehensive inspections and the hiring of engineers. In addition, we issued over 70 letters requiring maintenance, noting internally that most of the maintenance items were unrelated to the storm event and most often included tree clearing and removal of vegetation from embankments. Figures 3-7 show several dams inspected after Hurricane Irene and Tropical Storm Lee and the types of problems that developed on Connecticut dams during the rain event.

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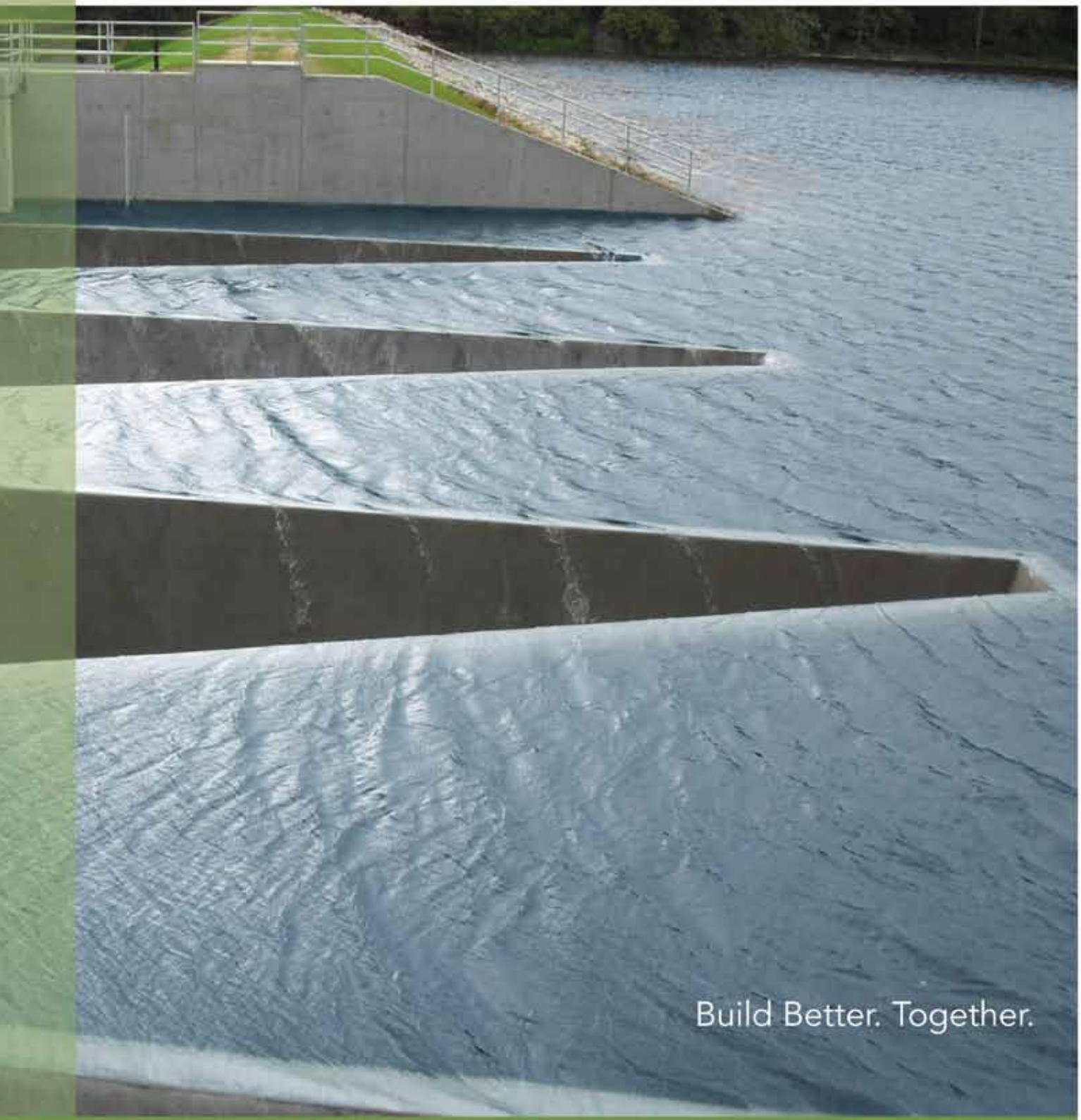

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Delaware

Hurricane Irene
August 27-28, 2011

Rainfall amounts across the state varied from 6.02 inches in Glasgow, New Castle County to 10.43 inches in Ellendale, Sussex County. The period of rainfall was generally 24-28 hours. For comparison, the 24-hour, 100-year rainfall for the state varies from 8.0 to 9.2 inches, depending on the county. No major flooding or damages to inland areas were reported. There was some coastal flooding and damage, due to high tides and storm surge.

Delaware has six municipally-owned regulated dams and 42 state-owned regulated dams. No problems were reported to the state dam safety program by any of the municipal dam owners.

The state-owned dams are operated and maintained by the Delaware Department of Natural Resources and Environmental Control (DNREC) and the Delaware Department of Transportation (DelDOT). Dam inventory data developed by DNREC and DelDOT indicate that only five of these 42 dams have spillways capable of passing the 24-hour, 100-year frequency storm peak discharge without overtopping the dams, and that freeboard above normal pool prior to overtopping is typically two to five feet. Most dams have one or more sections in the spillway with removable flashboards or stop-logs, and state crews occasionally remove boards prior to predicted large storm events to increase the amount of freeboard prior to the onset of the storm. Prior to Irene, these efforts had typically been limited to a handful of dams in a few locations in the state where overtopping or other problems had occurred in the past. Because Irene was predicted to impact the entire state and rainfall amounts were predicted to be near or above the 24-hour, 100-year frequency rainfall, a state-wide effort was made to lower water levels at as many state-owned dams as possible prior to the start of the storm.

Between August 23 and 26, crews removed flashboards at 25 to 30 dams across the state. During the storm, only three state-owned dams overtopped, with minor damage at two dams (Mudmill Pond Dam and Garrisons Lake Dam, Figures 8-9) and no significant damage at the third dam (Masseys Mill Dam, Figure 10). All three dams that overtopped are located in Kent County, near where some of the highest rainfall amounts were recorded. This part of the state had experienced heavy rains in the weeks prior to Irene, and the ground was already saturated. Masseys Mill Dam is located upstream of Garrisons Lake Dam in the same watershed, and it is likely that the overtopping of Masseys Mill Dam caused Garrisons Lake Dam to overtop, although the overtopping of Masseys Mill occurred before daylight on August 28 and was not reported or apparently witnessed. Between August 28 and 30, DNREC and DelDOT inspected and completed damage assessments for all 42 state-owned dams.

Delaware's dam safety regulations were promulgated in December 2009 and, as a result, no emergency action plans (EAPs) have yet been completed for any state-owned dams, although many are in various stages of completion. Consequently, no EAPs were available to be activated during Irene. However, the state Emergency Operations Center was in operation and in the days leading up to Irene the state dam safety program provided the Delaware Emergency Management Agency (DEMA) with estimated inundation area mapping that was developed as part of a statewide dam inventory project in 2008. There were no dam-related evacuations during Irene.

Tropical Storm Lee
September 9, 2011

The northern half of Delaware received very little rain from Tropical Storm Lee, generally less than an inch, but it was a different story in Sussex County and the City of Seaford, in the southwestern part of Sussex County. Most of Sussex County received between three and five inches of rain, which caused few problems, but Seaford received 9.41 inches, 6.82 of which fell between 1 and 4 pm. This intense rainfall caused widespread flooding within the City and surrounding areas, and some residents were evacuated by boat from low-lying areas.

Unlike Hurricane Irene, the dam safety program had little advance warning of the possibility of heavy rainfall from Tropical Storm Lee. As a consequence, no advance preparations were made to lower pond water levels at state-owned dams. In fact, flashboards had been replaced at most dams once the flooding risk from Irene had passed, and when Tropical Storm Lee struck 12 days later most pond levels had just returned to normal.

DelDOT and DNREC use a deficiency ranking formula to prioritize all 42 state-owned dams for maintenance and capital improvements. The formula considers a number of factors, such as embankment condition, spillway capacity and condition, amount of freeboard,

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hazard classification, population and infrastructure at risk. Each factor is assigned different weighting criteria, based on importance. This allows for an across-the-board comparison of all dams, useful for prioritizing funding needs. The top priority dam in the state is Hearns Pond Dam, which is located just north of Seaford.

Hearns Pond Dam is a 14-ft high, 570-ft long earthen embankment, with a concrete spillway structure containing two hand-operated sluice gates. With the pool level at the top of the embankment, the fully opened gates can pass approximately 428 cfs, or 16% of the 100-year storm peak discharge. The watershed draining to the dam is approximately 13 square miles. Freeboard from normal pool to the low point on the dam crest is approximately two feet. There is no auxiliary or emergency spillway.

In 2001 the dam failed completely due to overtopping during a stalled thunderstorm with reports of more than eight inches of rain. In 2002 the failed embankment section was rebuilt with a steel sheet pile and clay core, and the sluice gates were added. In 2006 the rebuilt section overtopped during an unnamed storm with unconfirmed reports of about 15 inches of rain, and the top several feet of the embankment eroded down to the top of the sheeting. There was a federal disaster declaration made for this event and the Federal Emergency Management Agency (FEMA) reimbursed the state to rebuild the failed section of the dam, but since there were no dam safety regulations in place at that time, the state could not be reimbursed by FEMA for making improvements to the dam, and there were no state funds available for improvements. Consequently, the overtopped section was rebuilt to the same configuration as the 2001 design.

Prior to Hurricane Irene, the sluice gates at Hearns Pond dam had been fully opened for several days, dropping the normal pool level by approximately two feet. During Irene the pond level rose to about one foot above normal (total rise of three feet), but still about one foot below the top of the embankment. During the afternoon of September 9 the sluice gates at Hearns Pond Dam were fully opened, but most of the heavy rain had occurred by that time, and the pool level had started to rise before the gates were opened. There is no instrumentation at the dam to monitor rainfall or pool level, and DNREC/DelDOT Dam Safety staff were not aware that heavy rainfall and flooding were occurring in the Seaford area until late in the afternoon of the 9th.

DNREC and DelDOT staff arrived at Hearns Pond Dam about 5 pm and found that the pond water level was about 1.5 feet above normal pool, leaving about six inches of freeboard prior to overtopping. The heavy rainfall had stopped, but the pond level was visibly rising, by four to five inches per hour. Prior to Hurricane Irene, DelDOT had pre-positioned filled sandbags at state maintenance yards, one of which is less than a mile from the dam. The sandbags, unused during Irene, were now put to use. DelDOT personnel delivered pallets of sandbags to the dam, where they were placed in two low spots along the crest in an effort to keep the embankment from overtopping.

Sandbagging started about 6 pm and continued until about 10 pm, when the supply of sandbags, as well as the sandbagging crew, had been exhausted. (The sandbagging crew consisted of a division director, a drainage engineer, a conservation technician, and the dam safety engineer, all from DNREC, and a DelDOT bridge engineer.)

Overtopping of the dam began while the sandbags were being placed, and continued overnight until about 8 am on the 10th. The pool level rose to a maximum of about 2.8 feet above normal, resulting in a maximum overtopping depth of approximately 10 inches in two separate locations. While the two lines of sandbags across the low areas on the crest experienced some displacement from the overtopping flow, only minor erosion occurred on the downstream face of the embankment, which was protected from concentrated flows by the sandbags (Figures 11-12).

While the sandbagging effort was underway at Hearns Pond Dam, DelDOT received a report of overtopping at Craigs Pond Dam, located approximately five miles southwest of Hearns Pond Dam. DelDOT's bridge engineer left Hearns Pond Dam to check the condition of Craigs Pond Dam, but was unable to get there due to flooded roads.

Craigs Pond Dam is a 610-ft long, 14-ft high earth embankment ranked 33rd on the state's priority list. The spillway capacity is approximately 1,700 cfs, or 77% of the 100-year storm peak discharge. The watershed draining to the dam is approximately eight square miles. Freeboard above normal pool is about 3.8 feet, and the dam has no operable gates or flashboards, and no auxiliary or emergency spillway. Craigs Pond Dam overtopped and the roadway was heavily damaged during the same 2006 storm that damaged Hearns Pond Dam, and DelDOT subsequently rebuilt the road.

During Tropical Storm Lee it was reported that the water level on Craigs Mill Road, which runs along the dam crest, was higher than the top of the guardrail along the road, (the top of the guardrail is typically about thirty inches above the road). It is unknown how long the overtopping continued at Craigs Pond Dam, but the roadway was significantly damaged and remained closed for several weeks after the storm. Road repairs cost approximately $300,000 (Figure 13).

Delaware's experience with Hurricane Irene and Tropical Storm Lee confirmed previously learned lessons:

- State-owned dams have very limited spillway capacity and freeboard, and virtually no overtopping protection.
- In order to avoid overtopping and possible failures during large storm events, pond levels must be lowered days before the rain begins.

Since Delaware's dam safety program was established in 2009, DNREC and DelDOT have combined resources to fund dam break inundation mapping, EAPs, engineering studies, dam rehabilitation design, and other projects. The main emphasis of most of these projects has been to move state-owned dams into closer compliance with requirements in the 2009 Dam Safety Regulations. Our experience with Irene and Lee, however, validated the worth of a statewide multi-agency effort to install flood warning instrumentation near dams, roads, bridges and other critical infrastructure within the state (a project underway prior to these two storms) and underscored the need to focus more state resources on dam operation.

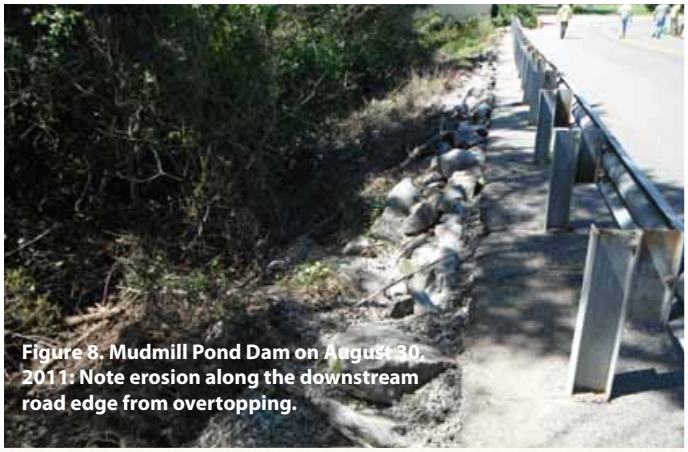

Figure 8. Mudmill Pond Dam on August 30, 2011: Note erosion along the downstream road edge from overtopping.

Figure 9. Garrisons Lake Dam about 10 am on August 28, 2011: Note minor overtopping of earth embankment around the right spillway wingwall.

Figure 10. Masseys Mill Pond Dam on August 29, 2011: Note evidence of overtopping flows.

Figure 11. Hearns Pond Dam on the morning of September 10, 2011: Note sandbags across low area at the left end of the dam crest.

ISSN 1944-9836 - Association of State Dam Safety Officials

Figure 12. Hearns Pond Dam on the morning of September 10, 2011: Note sandbags across low area at the right end of the dam crest.

Figure 13. Craigs Pond Dam on the morning of September 12, 2011: Note damage to the downstream slope and roadway due to overtopping.

Maryland

Hurricane Irene impacted Maryland late on August 27 through early August 29, 2011. Most rainfall occurred on August 28 during a 24-hour period. Rainfall amounts ranged from a few inches up to 14 inches in isolated locations. The heaviest rainfall, in southern Maryland and the Delmarva Peninsula, exceeded the 100-year storm. A few dams were overtopped but no failures of inventoried dams were reported. Many roads and railroads were overtopped and some washed out. Low-lying communities were evacuated in Kent, Queen Anne's, St. Mary's, and Worcester Counties. Hurricane Irene flooded wastewater treatment lagoons and sewage systems across the state, releasing millions of gallons of waste. Power was lost in some areas for several days due to damage from high winds.

Seven EAPs were activated in Anne Arundel, St. Mary's, and Wicomico counties. Evacuations were made below St. Mary's Dam in St. Mary's County when flood levels reached a pre-established trigger elevation just below the emergency spillway crest. None of these dams overtopped during Hurricane Irene, although other low hazard dams overtopped with some damage.

Tropical Storm Lee impacted Maryland on September 6-9, 2011, depositing up to 20 inches of rain and causing major flooding that washed out roadways, closed major highways, damaged government buildings, and damaged or destroyed more than 300 homes and businesses in seven counties. With damages estimated at $24 million, President Obama declared the flooding in Maryland a major disaster.

The EAP for the Conowingo Hydroelectric Dam on the Lower Susquehanna River in Cecil County was activated on September 9, when 43 of its 53 flood gates were opened, releasing 778,000 cfs. The town of Port Deposit, 5 miles downstream, was completely evacuated, and portions of Havre de Grace, 12 miles downstream, were evacuated. Upstream, Lancaster County received up to 15 inches of rain, the worst storm to strike the area since Hurricane Agnes in 1972. Damages to Port Deposit included more than 4 feet of flooding to homes and businesses and heavy deposits of mud and debris. The U.S. Geological Survey estimated four millions tons of sediment and debris dumped into the Chesapeake Bay.

Lessons Learned

- Anticipate travel and communication problems. During Hurricane Irene, cell phone coverage and phone power were lost due to high winds exceeding 50 mph, which made travel dangerous for responders.
- Verify evacuation messages that will be sent to the public. The standardized evacuation message for St. Mary's Dam created the false impression that the dam was about to fail, and word escalated to the national news level. This in turn reached our governor in an undesirable manner, and we had to immediately travel to a distant section of the state to verify the conditions of the dam.
- Update trigger elevations to allow for adequate evacuation time. A year earlier the trigger threshold at St. Mary's was lowered to an elevation below the emergency spillway crest. The new trigger elevation was reached and the evacuation was more efficient with the additional time available.

New Hampshire

Tropical Storm Irene was responsible for heavy rain and wind, widespread power outages and inland flooding across New Hampshire on August 28-29, 2011. A flood warning was issued for nearly all of the state as rain fell at the rate of 1-1½ inches per hour. In anticipation of the storm, the Department of Environmental Services (DES) Dam Bureau managed reservoir levels at state-run dams and worked with private dam owners to prevent flooding.

According to the National Weather Service (NWS), winds exceeded 40 mph in southern parts of New Hampshire. The seacoast regions and higher elevations of the White Mountains reported the strongest winds, including a gust of 63 mph at Somersworth in Strafford County and 120 mph at the Mount Washington Observatory. The NWS estimated rainfall amounts of 2-3 inches in southeastern New Hampshire, and 3-6 inches in the western part of the state. Larger amounts fell on the mountain slopes with over 10 inches reported at higher elevations of the White Mountains. The Seacoast Region experienced some of the strongest winds, but rainfall was 2.5 inches or less. Heavy rainfall led to widespread flooding across northern New Hampshire. Minor flooding was reported along small rivers and streams in Belknap, Merrimack, Sullivan and southern Coos Counties.

Major flooding occurred along the Connecticut, Pemigewasset, Suncook and Saco rivers, with record flooding along the Saco River in Conway. On Sunday, August 29, flows were more than 100 times normal for the Saco River, based on the 89-year period of record.

As a proactive step prior to the storm, an email was sent on August 26 to all dam owners or operators to provide information about what to do prior to the storm, during the storm, and after the storm. It was quickly discovered that many email addresses were no longer active. As a lesson learned, future improvements in record keeping will include ways to keep email addresses more current.

There were no catastrophic dam failures, but many dams were overtopped and suffered minor to extreme damage. A handful of EAPs were activated:

- Campton Pond Hydro Dam, Campton – Portions of the dam were overtopped as the Mad and Pemigewasset rivers flooded. The Pemigewasset, whose flood stage is 9 feet, crested at 16.50 feet at 5:45 pm on Sunday the 29th. The EAP was activated on Sunday evening, as rain-swollen waters of the Mad River began to overflow a low area of the left abutment and adjacent NH Route 175. River flows also overtopped NH Route 49, forcing the evacuations of approximately 90 homes and 200 people from the Six Flags Trailer Park and The Woods senior housing. A limited area of the dam overtopped by 4 inches before being sandbagged. It was determined after the event that the abutment will need to be raised to match the top of the dam. A follow-up study on the extent to which upstream dam operations affected flooding along the Mad River is underway.
- Coy Papermill Dam, Claremont – The EAP was activated when the dam sustained high water up to the decks of the plant.
- Dells Pond Outlet Dam, Littleton – The EAP was activated when a sinkhole developed adjacent to the upstream left spillway abutment wall.
- Glen Road Dam, Lebanon – The dam was overtopped and the EAP activated.

Other significant flood incidents not involving activation of an EAP included:

- Cummins Pond Dam, Dorchester - The crest was sandbagged by more than a foot in some areas to avoid overtopping. The owner excavated a bypass channel in natural ground a safe distance away from the dam to allow for additional outflow. The freeboard at the height of the storm was reduced to 1 inch. The owner of this low-hazard dam kept state and local officials up to date on conditions at the dam while it was in distress.
- Godfrey Dam, Berlin - Erosion of natural material on the downstream of the right downstream embankment occurred. This dam impounds a portion of the water supply for the Town of Berlin. Services were not interrupted, but repairs of the eroded area were required to prevent future damage to the toe of the dam.

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- Lincoln Sewage Lagoons, Lincoln – The structure suffered erosion damage to its river revetment, which caused the failure of a culvert headwall. The lagoon was not breached.

- Pemigewasset River Levee, Lincoln - Overtopping caused erosion of the upstream face and displacement of large areas of the riprap shell. Condominiums adjacent to the levee were flooded and damaged.

- Reflection Pond Dam, Shelburne - High flows overtopped the dam, flooded the powerhouse, eroded embankment material and abutments and caused undermining downstream of the cutoff walls. Power generation from the dam was affected. It was determined that access and operation plans for future high water events need to be revised.

State personnel remained busy before, during, and after the event. A pair of Dam Bureau staff members manned the centralized state Emergency Operations Center, assisting with response and recovery. State dam operators monitored and operated state-owned dams, and Dam Safety staff inspectors were dispatched to problem dams and flooded areas to assist dam owners and local officials with operational and response decision-making. During the crisis, it became apparent that stakeholders were not able to quickly and easily access disaster-related information on the DES webpage. The nature of this event (short duration, but long-term flooding damages requiring extended recovery efforts) highlighted a department-wide need for better guidance and procedures. Some staff felt that the department should consider social media applications such as Facebook and Twitter to streamline communications with the general public. Shortly after Hurricane Irene passed, DES began an effort to evaluate its preparedness and response actions with the goal of implementing ideas to improve future performance.

New Jersey

Hurricane Irene made a second landfall in New Jersey, the first direct hit by a hurricane on the state since 1903. An average of six to seven inches of rain fell across the state in an 18-hour period. Some peak rainfall amounts of 9 to10.3 inches were observed at individual stations. Making matters worse was the fact that the state was experiencing wet antecedent conditions caused by 8 to 17 inches of rain falling across the state during the three weeks preceding Irene. A storm event on August 13 in Salem, Gloucester, and Cumberland Counties resulted in isolated rainfall of up to 14 inches and the overtopping of numerous dams, damaging 26 dam structures and causing the failure of 4 small dams.

As a result of the rainfall from Irene, record high peak flows were recorded at 38 of the 93 gages in the state that have 20 or more years of record. Twenty-four gages recorded their second highest peak of record while another five recorded their third highest peak of record.

The New Jersey Department of Environmental Protection Bureau of Dam Safety and Flood Control began preparations for the Hurricane on August 26 when Governor Chris Christie ordered the opening of the flood gates and the drawdown of the impoundment at state-owned Pompton Lake Dam. Bureau personnel responded and implemented a controlled 3-ft drawdown of the reservoir prior to the arrival of rainfall associated with the hurricane. While not a dam safety concern, this dam has been the center of much controversy since its modification to include flood gates to alleviate upstream flooding. Additionally, in preparation of the pending storm, Bureau engineers spent much of August 25-26 contacting all high-hazard dam owners via phone and email, advising them to locate and review their EAPs and visit their dams, clear the spillways of any debris, inspect impoundment areas, and secure any floatables that could potentially break free and clog the spillway.

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At the peak of the storm, Bureau personnel did not undertake any field operations; however, Bureau Manager John Moyle was stationed at the New Jersey Office of Emergency Management's Regional Operations Intelligence Center (ROIC), to provide information directly to the governor and his staff, also at the ROIC. Near the end of the storm, late in the morning of August 28, engineers from the Bureau initiated their response. First response was concentrated on structures for which the Bureau received a call for assistance or a report of overtopping or damage, with priority of inspection based on hazard classification. Four teams were dispatched covering northern, southern, central and coastal New Jersey.

Structures initially visited included Solitude Dam, a high-hazard dam then being rehabilitated to address spillway capacity issues. Bureau engineers also visited Lake Lefferts Dam, a significant-hazard dam, to ensure that the damaged dam was safe prior to reopening New Jersey Transit's North Jersey Coast Line, a major rail line from the Jersey shore to Newark and New York, which crosses downstream of the dam.

In the days following Irene, Bureau engineers inspected 119 dams statewide. Engineers retained by dam owners performed an additional 148 inspections and submitted findings to the Bureau. Of the dams inspected it was found that 6 had failed and 51 were damaged to some degree.

Figure 14. Safeguarding a vulnerable embankment under reconstruction from rising floodwaters at Solitude Lake Dam, High Bridge, NJ

Figure 15. Severely eroded earthen embankment saved by the sheet piling at Shadow Lake Dam in Middletown, NJ

While Tropical Storm Lee brought significant rainfall to New Jersey, most of the rain stayed west over Pennsylvania. The northwesterly portion of New Jersey experienced up to nine inches of rain as the storm tracked from Pennsylvania to New York. The Bureau sent two teams of engineers to the area; however, only a few dams were overtopped with minor damage and no failures were attributed to Tropical Storm Lee.

The failures that occurred as a result of Irene were all small dams that had no documented downstream impacts. Larger impacts were felt from the failures that occurred with the August 13th storm in the southern portion of the state, as those failures resulted in the closing of a significant county roadway, and the loss of larger impoundments.

Given the magnitude of the rain events experienced in New Jersey, dams in the state functioned very well. The limited number of dam failures can be partially attributed to a strong dam safety enforcement program and the success of the state's $110 million revolving dam restoration loan. Funds from the program have been used to rehabilitate numerous dams that may have been adversely impacted by these events had they not been rehabilitated. With respect to EAPs, overall, dam owners performed poorly. Very few EAPs were activated despite numerous potentially hazardous overtoppings.

Thanks to cellular phones, communications during the events was not a problem; however, a communications breakdown resulted from differences in terminology used by the Bureau, the New Jersey State Police Office of Emergency Management, and local Emergency Management Officials. In Bureau terminology, a 'breach' is a failure of the dam. Local emergency managers on numerous occasions reported dam breaches; upon investigation by the Bureau, it was discovered that the officials were referring to overtoppings.

Access to some sites was impossible due to flooding. In addition, many normal routes to dam sites were blocked by downed trees and wires. Through the use of GPS units pre-programmed with the coordinates of all dams in the state, staff were able to successfully navigate to most critical sites before the flooding subsided and roadways were cleared.

The other major issue faced by the Bureau involved the lowering of impoundments prior to or during the flood events. Many small dam owners believe that lowering an impoundment prior to an event may prevent overtopping or flooding upstream of the dam. While this practice may provide some benefit under small events, events the magnitude of Irene and Lee simply refill the storage void created early in the event and the peak flow is not altered significantly. At the same time, residents downstream of a lowered impoundment often believe that the lowering has exacerbated the flooding downstream. On the other hand, other dam owners have been accused of creating the downstream flooding because they didn't lower prior to an event. The Bureau maintains a position of not requiring or recommending the lowering of impoundments prior to storm events. The Bureau believes that the best defense at a dam that is not designed with flood control measures is to assure that the dam has adequate spillway capacity and can safely pass the expected flood without manipulation of the water level. The Bureau recommends that if lowering measures are to be taken, such measures should be coordinated with the local Office of Emergency Management.

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Figure 16. Operation of the emergency spillway at the rehabilitated Camp Ryker Dam in Sparta, NJ

Figure 17. Breach of the Saffin Pond Dam in Jefferson, NJ, under construction to increase spillway capacity at the time of the event

Figure 18. Workers act to control erosion of the overtopping embankment at the Willow Grove Dam in Pittsgrove, NJ

The danger around dams during flood events is often underestimated by the general public. In one incident during the events, a young man was swept into a breach and survived by clinging to a tree in the downstream channel until rescued by a specialized water rescue team. In another incident after a dam failure, children were playing in the former lake bed only to become mired in mud and unable to escape the soft sediments without the assistance of the local fire department. Therefore, it is important for dam owners to secure their sites during times of extreme events.

New York

During the weekend of August 27-28, Hurricane Irene hit New York, causing significant flooding. Just over a week later, Tropical Storm Lee came through the state, generally west of the areas impacted by Irene. While rainfall from Lee compounded the severity of impacts to several communities and placed additional demands on the state dam safety program, this narrative focuses on the impacts and response due to Irene.

New York Department of Environmental Conservation (DEC) Dam Safety staff watched Hurricane Irene's projected path as it approached New York State. As is usual for this type of event, Dam Safety received frequent and detailed updates from DEC Division of Air meteorologists. The forecast of potentially intense rainfall accompanied by damaging winds put Dam Safety staff on watch leading up to the weekend of August 27-29, 2011.

To prepare for the storm, Dam Safety staff:

- kept senior agency staff advised as to the storm's potential impacts;
- reserved two agency vehicles for use during and after the storm; and
- contacted owners of dams of concern, and state dam owners to inquire about preparations that were being made and recommend impoundments be lowered. These contacts were generally directed to owners of dams where construction was taking place or for dams with known deficiencies, such as inadequate spillway capacity.

Hurricane Irene hit the state between 8 pm, Saturday, August 27 and 8 pm, Sunday, August 28, with storm run-off generally peaking Sunday night through Monday afternoon. Rain was heaviest (totals between 11-18 inches) in the Schoharie Valley, located in the northern Catskill Mountains. Several areas were impacted more severely, including the municipalities of Windham, Tannersville, Shandaken, Prattsville, Margaretville, and Phoenicia, which received 12 to 18 inches of rainfall, primarily in a 12-hour period. Ultimately, 31 of the state's 62 counties were federally declared disaster areas.

The impacts of Irene included:

- Activation of emergency spillways at three high-hazard NRCS Small Watershed flood control dams, all with varying degrees of damage, from severe to moderate erosion (Figures 19-28);
- Failure of 3 low-hazard and 1 intermediate-hazard dam;
- Damage to approximately 20 dams (including the 3 high-hazard dams noted above);
- Breaching of and/or damage to locks and moveable dams at locks 8 – 12 of the New York State Canal System;
- Recording of 8 major, 9 moderate, and 5 minor flood crests at stream gages;

- Widespread power outages;
- Devastation of areas in the Catskills, which are still attempting to recover at the writing of this article.

Dam Safety staff began receiving phone calls on Sunday, August 28, from emergency response officials, dam owners, elected officials, and the public regarding dams that were developing dam safety issues or experiencing or expected to experience high flow. Dam Safety staff also received reports of EAP activations as they occurred. Most EAP activations were due to unusually high water or expected high water, not actual dam incidents. The ongoing flooding limited Dam Safety staff travel; therefore, investigations were limited to personnel already in the area (rangers, conservation officers, dam owners, etc.).

On Monday, August 29, Dam Safety staff received numerous reports of dam incidents, many of them inaccurate. For example, many of the reports of dam failures were due to unprecedented flows from spillways and dams obscured by floodwaters. Staff spent the day collecting, confirming and assessing incident reports, and keeping senior staff informed. In addition, staff also received numerous outside requests to provide information or inspect dams. Dam Safety staff made limited local site visits on August 29 and inspected additional sites of concern in the following days.

Coordination of the various bureaucracies, priorities and reporting requirements was a challenge throughout the event response. A tremendous amount of information, not all of it accurate, was generated very quickly. The biggest challenge was to track and record incoming information accurately and quickly, in a format that allowed us to meet various information needs. We developed an ad hoc tracking system to summarize the information and help plan for the next inspections.

At the request of FEMA, the USACE informed the state that they were available for assistance. This doubled the number of individuals with dam safety experience and added additional vehicles for emergency operations. Dam Safety and USACE staff performed investigations in teams composed of one USACE engineer and one Dam Safety engineer, who provided the benefit of knowledge of the area, navigation, and historical context for the dams. These teams were able to visit more than 100 dams over several hundred square miles in less than two weeks. Challenges associated with this assistance included FEMA directions for USACE staff to inspect only high-hazard dams and to report daily to FEMA, whereas, state dam safety staff also needed to investigate concerns at some intermediate and low-hazard dams. Compromises were made and a process for completing inspections was ironed out.

Several private engineering consulting firms contacted Dam Safety with offers to conduct pro bono inspections on our behalf. We appreciated but declined these offers, since USACE personnel and other DEC staff had volunteered to assist with the inspections. These consultants and others did conduct some dam inspections on behalf of owners soon after the event and reported findings to Dam Safety in the days after the flood. This was extremely helpful as it allowed our staff to focus on dams that had not been addressed.

Hurricane Impacts:

Batavia Kill Watershed Dams (Maplecrest Dam, Nauvoo Dam, and Mitchell Hollow Dam)

Dams significantly impacted during Irene included the Batavia Kill watershed dams: Maplecrest, Nauvoo, and Mitchell Hollow. These dams are flood control dams, normally maintained at a low normal pool level and designed to reduce the peak downstream flows from runoff following a rain/snowmelt event. Each has two earthen emergency spillways (to the right and left of the main embankment dam) designed to pass flows in excess of the 100-year flood event. An earthen auxiliary spillway may erode during floods in excess of the 100-year flood, depending on the intensity/duration of the event. All three of these dams are classified as high hazard.

During the flooding resulting from Hurricane Irene, all three dams' emergency spillways activated, resulting in erosion in the right and left spillways at Maplecrest and Mitchell Hollow, and in the left spillway at Nauvoo (Figures 19-28). The erosion to Maplecrest and

Figure 19. Maplecrest Dam - Storm flow through the left emergency spillway

Figure 20. Maplecrest - Looking downstream from the left emergency spillway

ISSN 1944-9836 - Association of State Dam Safety Officials

Figure 21. Maplecrest - Upstream view of the left emergency spillway

Figure 22. Maplecrest - Erosion of the right emergency spillway

Figure 23. Nauvoo - Right emergency spillway

Nauvoo dams was serious enough to warranted emergency repairs to provide protection during future flood events through spring 2012. Long-term repairs will be made in the summer of 2012.

Following Irene, Tropical Storm Lee was approaching New York with potential for additional high rainfalls. Dam Safety and emergency officials were concerned that the rainfall from Lee could reactivate already deteriorated emergency spillways. Dam Safety staff worked on-site with dam owners, consultants, and the state NRCS office to create plans for monitoring and recording water elevations at the dams. These plans were carried out with the assistance of DEC Environmental Conservation Officers and New York City Department of Environmental Protection (NYCDEP) staff.

Figure 24. Nauvoo - Right emergency spillway

Figure 25. Nauvoo - Right emergency spillway

Figure 26. Nauvoo repairs - Temporary berm at right emergency spillway control section

Ultimately Lee veered to the west, and the water levels remained well below the emergency spillway crests during Lee.

Emergency authorizations were issued for work at Nauvoo and Maplecrest Dams following the storms. At Nauvoo, a temporary emergency berm was constructed in the right emergency spillway to prevent further flow through the spillway. At Maplecrest, reconstruction to repair the erosion in the emergency spillways was significantly completed. Work at all three dams will re-commence in the spring 2012 to complete the rehabilitation of the eroded areas.

Figure 27. Mitchell Hollow - Right emergency spillway

Figure 28. Mitchell Hollow - Right emergency spillway erosion

Gilboa Dam

New York City's Gilboa Dam has received intense public attention (see The Journal of Dam Safety, 2011, V9 n3). The NYCDEP owns and operates this high-hazard dam, one of the tallest in the state. Gilboa Dam is in the middle of a major rehabilitation, and its watershed includes the Batavia Kill dams and the part of the state that received the most rainfall.

Misreporting was one of the primary reasons for concern at Gilboa Dam during Hurricane Irene. Several national news organizations reported that the dam had failed or was failing, even though the dam was secure throughout the entire storm.

Figure 29. Gilboa Dam spillway

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Prior to the storm the National Weather Service predicted that rainfall over the weekend would cause the Gilboa Dam's reservoir (Schoharie) to crest at 1131.4 ft, 1.4 ft over its 1300 ft long spillway. Over 14 inches of rainfall fell in some areas of the watershed causing the reservoir level to rise to an unprecedented peak of 1,137.95 ft, nearly 1.5 feet higher than the previous record level in January 1996. The NYCDEP activated the EAP because of the high reservoir level and loss of communication with electronic monitoring devices at the dam. Following a preliminary assessment on August 29, the NYCDEP deactivated the EAP.

Dam Safety staff were in direct communication with NYCDEP personnel and able to provide state executives and our press office with accurate information, which helped reduce some confusion and concern. Although the dam survived the flood with relatively minor damage, temporary structures and the construction work area were severely damaged and are being restored.

Figure 30. Gilboa Dam spillway

Winnisook Dam

Also significantly impacted during Hurricane Irene was Winnisook Dam, an intermediate hazard dam in the Town of Shandaken, Ulster County. This type of dam would not normally be a serious concern due to its size and hazard class; however, the fact that the Big Indian-Oliveria Fire Department, which served as an emergency service center for the devastated towns of Phoenicia and Shandaken, was located immediately downstream, elevated the importance of this dam.

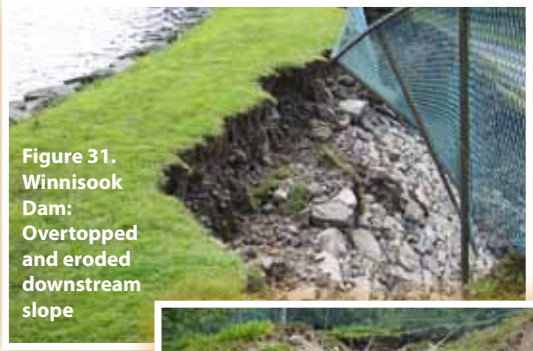

Figure 31. Winnisook Dam: Overtopped and eroded downstream slope

Figure 32. Winnisook Dam: Eroded downstream slope from downstream toe

Following Irene, several conflicting reports were made regarding the condition of Winnisook Dam. There were reports that it had failed, was in the process of breaching, and/or was damaged. Dam Safety was requested to inspect the site, report on its condition and make recommendations to local emergency managers for the dam and the downstream area.

An inspection team of one Dam Safety engineer and another from USACE were taken to the dam by DEC Environmental Conservation Officers using ATVs to bypass washed-out roads. The dam was damaged but appeared stable and not in jeopardy of imminent failure. The inspection team conveyed this to emergency personnel and subsequently contacted the owners and their engineer to review remedial measures.

Lessons Learned

- Staff had two vehicles reserved in anticipation of post-flood work, one car and one utility vehicle. The parking lot where the vehicles are stored became flooded and was eventually closed. Extra vehicles should be reserved prior to major events, and be readily available after hours.
- After-hours office access must be made easily available during an emergency. This includes access for staff temporarily assigned to dam safety work, such as the USACE.
- Our dam safety staff has several navigation GPS units for field work. GPS units generally work well, but not in conditions where roads are impassible and detours must be made. Paper maps must be taken in the field.
- Paper maps (topography, orthoimagery, local road maps) of the areas that are predicted to be impacted should be gathered prior to the storm. Since loss of power is a real possibility, computers and electrical devices cannot be relied upon during and immediately following the event.
- The Dam Safety Section is considering creating its own emergency operations center in the office during large flood events. Files and maps of impacted areas and dams could be maintained in this area to provide for easy access by the individual running the center. For this event, we used a large conference room for much of the time, but the room was not always available.

Conclusion

Although the state dam safety program is a regulatory program, there seems to be widespread misconception that it has owner-like control of dams, including engineering responsibility, coordination of emergency response, and access to resources to address dam concerns, such as heavy equipment. Continued outreach to dam owners and development and understanding of EAPs will further educate the public in these areas.

Initial response was limited to collecting and verifying reports, which transitioned into field assessments and follow-up with owners, and review of emergency authorization requests for dam repairs. Given the magnitude of the event and resources available, our response was effective, but our emergency procedures can be improved.

ISSN 1944-9836 - Association of State Dam Safety Officials

Pennsylvania

The year 2011 was particularly wet in Pennsylvania. It seemed that every week part of the state received heavy downbursts of rain, with 4 to 6-inch totals common. In Harrisburg, the total precipitation for 2011 was 73.73 inches shattering the old record of 59.27 inches from 1972, when the remnants of Hurricane Agnes swept through the central part of the state. (It is interesting to note that for many dams in the state, the flood of record dates from Agnes.).

Prior to Hurricane Irene striking the eastern portion of Pennsylvania on August 28, the area received heavy precipitation on August 14, resulting in high moisture and elevated pool conditions. As the predicted track and speed of Hurricane Irene was very accurate, there was plenty of warning time for dams along Pennsylvania's eastern border. Pennsylvania's Division of Dam Safety (PADDS) maintains a list of "dams with special concerns" to be used by staff, regional office dam inspectors, and the Pennsylvania Emergency Management Agency (PEMA) during flood type of events. This list contains dams considered unsafe by PADDS, dams under construction, and other dams with known deficiencies. Dam owners on this list were contacted by PADDS and PEMA well before Hurricane Irene.

Much of the eastern area of Pennsylvania received 5 to 8 inches of rain from Hurricane Irene and, while there were a few dam related incidents, the severity and number of incidents paled in comparison to that which was to hit the state just over a week later on September 7-8. The rainfall from the remnants of Tropical Storm Lee was much less predictable than that of Hurricane Irene. PADDS watched Doppler radar with increasing concern as fingers of rainfall shot up from the Chesapeake Bay. These fingers were moving end to end like a train and one couldn't help but be concerned of what lay in the path of these "trains." The heaviest rainfall accumulation occurred in a north-south line to the east of state's center and a second dose of heavy accumulations occurred along the eastern border. The greatest accumulations measured over 15 inches.

Of those known to the PADDS, twelve regulated dams were overtopped, four evacuations were ordered, and four non-high hazard dams were breached. Certainly any flooding is a test on the components of a dam, regardless of whether they overtop. One dam that failed this test was Speedwell Forge Dam in Lancaster County, owned by the Pennsylvania Fish and Boat Commission (PFBC). This 35-ft high dam has a 10-ft deep spillway, a near 1000-ft long crest, and forms a 200-acre lake. The peak spillway flow during the flood had a depth of six feet, similar to the flood of record in 1972. Shortly after the flood, PADDS staff and PFBC personnel inspected the dam and noticed only minor damage; however, once spillway flow subsided, PFBC staff noticed many slabs near the stilling basin had heaved and others were cracked. The impoundment was immediately drained and may be temporarily breached until the rehabilitation design is complete and funds are procured (Figure 33).

Almost 100 homes were evacuated downstream of Lock Alsh Dam in Montgomery County. Although not a large dam (16 feet high, with an 8-acre lake), it is located in a populous area. This dam was under rehabilitation that involved placing cabled concrete blocks on the downstream slope to project it from overtopping. While overtopped

several times before, local responders indicated that this flood overtopped the dam by the greatest depth in recent memory. The partially constructed block layer was damaged (Figure 34).

Pennsylvania was very fortunate not to have suffered any loss of life due to dam failures during these flooding events. While there was considerable damage to many high-hazard dams, none of them failed. Other dams at critical phases of construction narrowly escaped the brunt of the storm. Of the evacuations documented, all had and used recently updated EAPs which greatly assisted emergency responders in determining when to evacuate, who should be evacuated, and when they could return to their homes and businesses. Of the greatest lessons learned during these events is that EAPs do work and, while it takes considerable time and expense to develop these plans, they are certainly valuable in the time of need. Pennsylvania looks forward to a hopefully drier 2012. ≋

Figure 33. Heaved and cracked spillway slabs at Speedwell Forge Dam, Lancaster County

Figure 34. Damage to partially placed, cabled concrete block at Loch Alsh Dam, Montgomery County, Pennsylvania

Figure 35. Breach under spillway at Sullivan Dam, Sullivan County, Pennsylvania

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