EXECUTIVE SUMMARY

The Corps values continuous improvement, transparency and accountability to the nation. Following the May 2010 Flood event, the Corps committed to an objective review of this agency's role before, during and after the event. We are equally committed to sharing these findings with the public. We are and will continue to work to improve our procedures for the future. This After Action Report (AAR) demonstrates the first step in fulfilling that commitment. It captures twenty-seven lessons learned from this event and details what worked and needs to continue and what did not work and needs to be improved.

The specific mission and activities of the Corps during periods of flooding are outlined by several guiding laws. The Corps regulates each flood risk reduction and navigation project in accordance with the provisions of its authorizing legislation as well as specific water management criteria defined in reports approved during the planning and design phases of a project or system. The Corps provides support to the state Emergency Management Agencies as authorized by Public Law (PL) 84-99 by providing technical and material assistance for flood fighting. Public Law 93-288, the Robert T. Stafford Relief and Emergency Assistance Act, authorizes the Corps to support the Federal Emergency Management Agency (FEMA) as the lead agency in Emergency Support Function.

The Corps supports flood risk management activities in both urban and rural areas throughout the United States during periods of flooding. The Corps operates projects that reduce flood risk, and conducts emergency management support prior to, during and after a flood event. The Corps' highest priority during flooding is the protection of human life and property. The Corps performs this mission as part of an interagency team consisting of multiple federal, state and municipal agency partners. This report reviews our interactions with other agencies involved in the response to the May event. Those agencies include the National Weather Service (NWS), United States Geological Survey, Tennessee Emergency Management Agency (TEMA) and the Tennessee Valley Authority (TVA).

The National Weather Service (NWS) is a federal agency under the National Oceanic and Atmospheric Administration (NOAA), which is part of the United States Department of Commerce. It has been providing meteorological forecasts and warnings since its original creation as the Army Signal Corps in 1870. The NWS Hydrometeorological Prediction Center (HPC) provides forecast, guidance and analysis products and services to support the daily public forecasting activities of the NWS and its customers, and provides tailored support to other government agencies in emergency and special situations. The HPC publishes Quantitative Precipitation Forecasts (QPFs) twice daily, early morning and late afternoon/evening. The QPFs are then evaluated and used by the NWS River Forecast Centers (RFCs) to prepare river stage forecasts. NWS and the Corps' complementary missions require the collection of meteorological and hydrological data. Both agencies recognized the parallel aspects of these missions and signed a Memorandum of Agreement (MOA) in 1991 that began a formal effort to cooperatively "develop modern, cost-effective, coordinated procedures and techniques for forecasting the status of the Nation's river systems and regulating the Nation's water control systems." The MOA provided a platform to improve information and real-time data sharing as well as to

improve the collaboration between the two agencies. Under the agreement, the NWS will provide the Corps its meteorological forecasts and both agencies will share their hydrological forecasts with one another. The NWS is responsible for disseminating meteorological and hydrological forecasts and warnings to the public.

The United States Geological Survey (USGS) is a federal agency under the Department of the Interior charged with providing reliable scientific data and research for a wide range of earth and life science disciplines. It collects and disseminates hydrological data and information. The hydrological data collected by the Corps, supplemented by this data, is critical to the hydrological forecasts of the NWS and Corps and for the management of the Corps' reservoirs.

The Corps and the TVA have a unique relationship with respect to water management activities within the Tennessee, Cumberland, and Ohio River Basins. Geographically, the Tennessee River Basin falls entirely within the boundary of the Nashville District Corps of Engineers. However, an Act of Congress in 1933 establishing the TVA put in place the sharing of water resources related responsibilities between the two agencies. In general, TVA handles all matters related to hydropower on the Tennessee River and the Corps operates and maintains the navigation features. The Nashville District operates ten multi-purpose projects in the Cumberland Basin. Nine of these ten projects have hydropower facilities. Recognizing the need to coordinate reservoir operations to optimize flood risk management on the lower Ohio and Mississippi Rivers, Congress passed the Flood Control Act of 1944. Section 7 of the Act designates the Secretary of the Army with the responsibility to direct reservoir operations on both the Tennessee and Cumberland Rivers during times of flooding. The Secretary of the Army delegated the responsibility to the Commander of the Great Lakes and Ohio River Division.

A summary follows of the thorough and detailed review found in this report. The summary includes three sections: the event, the response and the communication issues that arose during the event.

Bottom Line Up Front: The May 2010 Cumberland River Basin flood was a historic rainfall event, and the flooding which resulted was devastating to the impacted areas. The Corps' flood risk management projects were able to minimize the flood levels; however, flooding could not have been eliminated given the nature of the event and the design intent of the Corps' flood risk management projects. The twenty-six fatalities associated with this event were not related to the Corps' response. Twenty-five of the twenty-six fatalities were associated with flash flooding of local streams prior to or just as the Cumberland River reached flood stage at Nashville on May 2. One fatality occurred on May 3 when a driver attempted to drive on a flooded roadway.

The federal, state and local responders worked closely together in response to the flooding. The Corps' response (the operation of flood risk management projects) was appropriate given the magnitude of this event. Based on our objective review, the Corps' response did not worsen flooding, but in fact, reduced flood levels and the associated damages in the Nashville area by five feet and many millions of dollars.

Event: In May 2010, portions of the Cumberland and Tennessee River Basins experienced a 36-hour rainfall that produced record flooding. Officials estimated the two-day storm to be far greater than a 1,000-year rain event. Rare weather conditions produced nearly stationary and

intense storm activity on May 1 and 2. These storms created a large-scale flash flood along the Cumberland and Lower Tennessee Rivers and their tributaries.

The Cumberland River Basin is not immune to major flooding. Almost all floods on the mainstem of the Cumberland River occur from November to mid-May, mainly because precipitation amounts are greatest during that time of year and the area is prone to excessive run-off. In almost all historical events, some parts of the basin receive relatively small amounts of rainfall while other portions experience extreme rainfall. For example, three outstanding historic floods—December 1926 – January 1927, January 1937 and March 1975—produced maximum flood heights on much of the Cumberland River. An 8-day storm with three separate rainfall bursts that concentrated heavily above areas now controlled by storage reservoirs produced the December 1926 – January 1927 flood.

Extended periods of rainfall produced the January 1937 flood, but unlike that of 1926-1927, the greatest intensities and the heaviest accumulations of rainfall were downstream from Nashville. This storm produced all-time record stages on the lower 150 miles of the Cumberland River. Prior to the May 2010 event, the last time the Cumberland River reached flood stage at Nashville was in May 1984. The May 1984 flood resulted from a series of rain events spread over an extended period of time; this resulted in a major basin-wide event. The flood crest at Nashville for this event reached a stage of 45.26 feet.

Since 1984 there have been several floods that came within a couple feet of reaching the flood stage (40 feet) at Nashville. These events include significant March events in 1989 (peak stage 39.53 feet), 1994 (peak stage 38.05 feet), and 1997 (peak stage 39.36 feet). The stage at Nashville reached 38.05 feet in a high flow event in May 2003. A series of significant rainfall periods coming in succession over a several week period characterized these events. Any of these storms, taken individually, did not pose a significant threat to the basin; however, collectively, they resulted in significant floods. Multiple follow-on events of this nature produce floods along the Cumberland River.

The May 2010 storm was unique, acting more like a flash flood. Its widespread intensity produced record rainfall. The 3-Day NWS Quantitative Precipitation Forecast (QPF), published Friday morning, April 30, showed increased 3-day rainfall totals of up to 7 inches with a high amount of 7.8 inches in central Tennessee. Widespread 2 to 6 inch totals were forecast over the southeastern US stretching into southern Illinois, Indiana and Ohio. Rain totals of 3-4 inches were forecast for the three-day period starting on May 1 in a band over western Tennessee and Kentucky. Subsequently, the 3-Day QPF issued on May 2 included rainfall totals of 2 to 4 inches with a high amount of 4.65 inches in a wide band spanning most of western and central Kentucky and Tennessee. During this two-day event some areas received rainfall amounts that exceeded 17 inches, the highest amount in more than 140 years of record. The Nashville area received more than 13 inches of rain in 36 hours, more than doubling the previous two day rainfall record set in September 1979. By the end of this historic two-day period, the actual rain that fell was more than double the projected rainfall over most of the area.

In the Stones River Basin, J. Percy Priest Dam utilized 100 percent of its available flood storage capacity in an effort to reduce crest levels downstream. The flood storage capacity in a flood risk management project is the volume of water that a project can contain which is between the

normal pool and near the top of the dam. This capacity is designed to remain empty and utilized during periods of flooding to assist in minimizing downstream flooding. Once the volume of water in a flood risk management project reaches the top of the flood storage capacity, the project must release water so that the project will not be overtopped.

During this event, much of the rain fell in areas downstream of the Corps' flood risk management projects; therefore, they were unable to play a major role in reducing flood crests along the Cumberland. Water from the Harpeth River, Red River, Mill Creek and numerous other small tributaries to the Cumberland flowed unchecked into the mainstem, producing the historic crests observed at Nashville, Cheatham Lock and Dam, and Clarksville. The event set water level and discharge records on numerous tributaries and at several mainstem locations across the Cumberland and Tennessee River Basins during the event.

Response

The Corps sets its primary mission during flood events to protect human life and property by minimizing flood damages. The Corps conducts this mission by managing the outflow of water from flood risk management projects. During these events, the Corps works with federal, state and municipal agency partners.

Water control manuals guide the operation of each flood risk management project. The plan provides instructions on how best to regulate levels of water at the project, thereby minimizing downstream flooding. The Corps bases these plans on the dynamics of the entire watershed system. These dynamics include uncontrolled tributary drainage areas downstream, reservoir storage capacity and the volume and time distribution of inflows from upstream drainage areas into the project. Since each flood is unique, these dynamics are constantly in flux. Therefore, the Corps maintains a constant, on-going analysis of conditions leading up to and during a flood. However, due to the magnitude of the May 2010 flood, the Corps operated its projects in an environment that was far beyond the scope of the guidance provided in the regulation manuals for each project. While projects are capable of operating outside the manuals' scope, the manuals did not cover the full range of the project's capability and will be revised to address extreme events. During the event, Wolf Creek, Dale Hollow, and Center Hill Dams did not use their full storage capacities because the rainfall was concentrated in drainage areas downstream (rather than upstream) of those projects. At the J. Percy Priest Dam, located just upstream of Nashville, waters nearly overtopped the spillway gates. Waters exceeded its flood storage capacity, requiring operation of those spillway gates to avoid overtopping and the potential catastrophic failure of the gates. The water levels submerged the lock and spillway sections of Cheatham Lock and Dam, a Cumberland River navigation project located downstream of Nashville. Although the dam and lock are designed to be overtopped during significant flooding, the Corps abandoned the structure completely when waters inundated the main control building.

The flood event required spillway gate operations at the navigation projects of Cordell Hull and Old Hickory to prevent overtopping of critical structures and losing control of water releases and pushed the Corps' projects of J. Percy Priest, Cheatham, Cordell Hull, Old Hickory, and Barkley to their limits.

During the height of the event, water managers made minute-by-minute decisions for the operation of eight projects in an extremely dynamic and dangerous environment. Operators at the projects literally stood on top of the dams and visually inspected water levels, waiting to within 6 inches of overtopping the gates before opening to release water and prevent overtopping of the dam. The post flood analysis indicated that operations of the Cumberland River Basin projects reduced the flood crest in Nashville by approximately 5 feet. The Nashville District made swift and crucial decisions during the event at these projects. These actions prevented additional flood damages from Nashville down to the mouth of the Cumberland River: Nashville's lone remaining water treatment facility, the Omohundro Water Treatment Plant, would have been left inoperable, thus rendering the city without water; and the Metro Center Levee downstream of Nashville would have been overtopped, likely causing billions of dollars in additional damages.

J. Percy Priest: Late Monday evening (May 3), Corps personnel recognized water levels were going to exceed the flood storage capacity for J. Percy Priest. Therefore, knowing water releases were necessary to prevent overtopping of the spillway gates, Nashville District Water Management dispatched Corps' project personnel at 2300 hours (11 p.m.) to monitor water levels on the four spillway gates with instructions to open each gate 0.5 foot when the water reached the top of the gates. However, one of the gates did not function. A project electrician returned to the dam, diagnosed the problem and quickly repaired the faulty gate. By midnight, the Corps had opened all four gates to the desired level and prevented overtopping the spillway gates. Project discharges were held to 7,000 cubic feet per second (cfs) rather than the 17,000 cfs set forth in the water control manual to minimize downstream flooding to the greatest extent possible. This operation also created an additional 0.5 foot of storage capacity. Thus, for the period starting Monday evening, May 3, and extending through the middle of the day on Wednesday, May 5, this action contributed to reducing the stage at Nashville.

Cordell Hull: Events required rapid spillway gate changes to keep the lake from overtopping the upstream spillway gate. Efforts required close coordination among power plant operators, powerhouse staff, and the Nashville District Water Management office. Ultimately, Cordell Hull set a new pool record and the lake level came within two inches of reaching the top of the spillway gates.

Old Hickory: Spillway gate operations continued day and night. Ultimately, Old Hickory set a new pool record and came within 6.6 inches of overtopping the upstream lock wall.

Cheatham: As the river level rose quickly on Sunday, a group of dedicated Nashville District employees worked tirelessly to salvage equipment from the lock building and move it to higher ground. During this process the river came up so quickly that Cheatham Natural Resource Manager's office team members had to bring lock employees to safety. During this same time period, a Cheatham Lock employee lost his personal vehicle to the flood while assisting fellow employees moving their vehicles to safety.

Barkley: The event required multiple spillway gate changes at Barkley starting during the day on Sunday (May 2). Extremely high water levels during this event required record gate releases at Barkley. The record releases prevented exceedance of the maximum flood control pool and possible overtopping of the dam.

While the Corps does not serve as the "lead" agency for flood fighting operations—state and local first responders are responsible for leading all emergency operations—the Corps supports the state agencies and provides essential technical flood fighting resources and assistance. During the May flood event, the Corps provided sandbags and pumps to local municipalities to assist with flood fighting efforts, as well as technical advice to maximize their effectiveness.

Communications

During the May 2010 event, federal, state and municipal agencies worked together to minimize the damage from this two-day storm, estimated to be far greater than a 1,000-year rain event. Effective communication among and between these entities is critical. It is also extremely important that the public is, to the fullest extent possible, kept informed of all conditions that have the potential to affect life and property.

The National Weather Service has the mission for issuing public flood forecasts and warnings and the Corps has the mission for operating the flood risk management projects. The agencies' complementary missions require the collection and exchange of hydrological (the flow or cycle of water in the area) and weather-related information. Both agencies recognized the need to develop procedures for exchange of data and a Memorandum of Agreement was signed between the agencies in 1991.

Under the agreement, the NWS provides the Corps with its meteorological forecasts, with both agencies sharing their hydrological forecasts with one another. The NWS serves as the federal voice for public notification prior to and during flood events. It also coordinates with state agencies, such as the Tennessee Emergency Management Agency. TEMA coordinates emergency management responses and recovery at the county and local levels. This communication flow works to promote clear and concise communications from one federal source to the public during weather events and to avoid confusion that could be caused by multiple agencies providing potentially conflicting or uncoordinated data to local authorities.

During the height of the event on Sunday, the Corps and NWS conducted conference calls per established protocol to support both offices' operations. These calls were intended to coordinate NWS forecasts for rainfall and flood crests and share information on the Corps' anticipated reservoir releases. However, the events occurring during the day and into the evening changed rapidly and the frequency of the communication proved inadequate for this type of event. This highlighted the necessity to improve communications and an understanding of the operations of each agency.

During the May 2010 flood event, the Nashville District received numerous telephone calls requesting information on the areas being flooded. In the midst of the event on Sunday between 0930 hours and 2005 hours (8:05 p.m.), a Verizon line break caused the Corps to lose its Internet connectivity. The network outage disrupted the flow of rainfall, stage and flow data and the Nashville District lost its ability to obtain and post information for the public's use on its local website. Although the data continued to be posted to the national rivergages.com website, the public may not have been aware of this alternative source of information.

As stated above, the NWS has the responsibility to provide flood forecasts to the public. Its forecast model references a stage at a location on the river. However, the public does not

correlate how this stage information may relate to where they live. In the short term, the NWS is evaluating additional features that could be added to its forecasts that better describe the area related to a flood stage. For the long term, the Corps, NWS and the United States Geological Survey are looking at ways to provide maps for different river flood stages that would be available to the public.

The May 2010 flood also brought to light the common public misconception that all navigation projects hold back floodwaters, just like flood risk management projects do. The Corps recognizes the importance of improving public awareness regarding this misunderstanding. It also recognizes the importance of advising the public about what happened during this historic event.

The Corps will continue to rapidly address lessons learned requiring improvement and institutionalize practices that worked well to better prepare for future events.

An in-depth detailed review of the facts surrounding the May 2010 Nashville flood event follows. The report is organized into seven chapters:

- Chapter 1, Background: provides a general description of the Tennessee-Cumberland-Ohio River system and the storms that occurred during this period.
- Chapter 2, Event Specific Information: covers the meteorological and hydrologic conditions before and during the event.
- Chapter 3, Responsibilities of Federal Agencies During Periods of Flooding: provides an overview of the roles and responsibilities of key federal agencies.
- Chapter 4, Emergency Operations Summary: provides timelines and a description of Corps' emergency management operations in support of the Corps' projects, state governments and local authorities.
- Chapter 5, Corps' Actions: provides a detailed description of Corps' water management and dam safety actions as well as coordination with other agencies.
- Chapter 6, Lessons Learned: provides a general overview of the issues identified during the after action review process.
- Chapter 7, Report Summary: provides a brief summary of the Corps' actions.

Appendix B provides a detailed discussion of the twenty-seven lessons learned. Other appendices provide additional relevant facts and data about the event. On July 23, 2010, the public and other federal, state, and local agencies were invited to review and comment on this AAR. Comments received are included in Appendix K. Issues raised by these comments have been incorporated into this AAR.

Appendix L discusses the August 17-19, 2010 event and shows how many of these lessons learned have already been implemented. During the August 2010 event, heavy rain again fell in the upper Cumberland Basin. However, the physical area impacted by heavy rainfall in the May event dwarfs the amount that was observed in August. As a result of the May event, greater than 10 inches of rain fell over the majority of 17 counties in western and central Tennessee. During the August event, the 10-plus inches of rain was only observed in isolated locations across north central Tennessee. While significant rainfall totals were observed, the August event was

significantly smaller in magnitude in the amount of rainfall as well as area impacted when compared to the May flood event.