cane protection system had not failed. In Jefferson Parish, backflow through pumps resulted in over 10 percent of the flood volume.

Lessons Learned

For Drainage

- Current models for flood forecasting and post-storm evaluations should be maintained. Water levels inside basins can be estimated prior to a storm's landfall, thus facilitating decision-making. After the storm, the estimates can be used to determine the unwatering time, if necessary.
- Water level gauges capable of reporting in real time and of surviving severe storm events should be installed within each of the protected areas or basins.
- A plan for unwatering following a catastrophic event should be developed and practiced annually.

For Pumping Stations

- The continued operation of pumping stations before, during and after a hurricane is essential to prevent, control and eliminate flooding. Pumping stations should be considered an integral part of the hurricane protection system; their design criteria should match that of levees and floodwalls.
- A single entity should control the design, construction, operation and maintenance of pumping stations responsible for unwatering the various parishes.
- Physical improvements are needed to reduce the risk of stations' failure to perform their intended mission. Major considerations include
  1) ensuring the safety of operating personnel during a hurricane
  2) enabling pump station structures to withstand hurricane force winds without significant damage
  3) preventing reverse flow of water through the pumping system
- Anticipating post-Katrina population decreases and consequent income reductions, parishes should also make improvements to their pumping systems that will reduce the costs of operation and management.
- Emergency response planning should encompass needs that are beyond the ability of individual parishes to address.

For more information on this topic, please refer to Volume VI of the IPET Report.

IPET Report Summaries

The Performance — Interior Drainage and Pumping

The U.S. Army Corps of Engineers established the Interagency Performance Evaluation Task Force (IPET) in fall 2005 to provide scientific and engineering answers about the hurricane protection system's performance during Hurricane Katrina. In evaluating the New Orleans and Southeast Louisiana Hurricane Protection System, the IPET looked at the performance of the system's individual components, as well as evaluating how the components performed as part of an integrated system. Volume VI of the IPET's nine-volume report focuses on pump stations and the interior drainage system.

Major components of the hurricane protection system are floodwalls, levees, and interior drainage systems. While floodwalls and levees provide protection from storm surge, the primary function of drainage systems and pump stations is to

remove rainfall from the area. Pumping stations are not officially part of the hurricane protection system.

Drainage canals and the interior drainage system performed well in conveying and storing runoff from rainfall for the pump stations to evacuate from the system. However, the system, including pump stations, was overwhelmed by the large volume of water from the overtopping and breaching of levees and floodwalls. Many of the pumping stations were rendered inaccessible, inoperative or lost electrical power.

In Plaquemines, St. Bernard and New Orleans East, entire basins were overwhelmed by the initial inflow of water from overtopping and breaches. In Orleans East Bank and Jefferson Parish, floodwaters later flowed through the canal and drainage network to fill areas in the basin not initially flooded.

Total pump capacity was significantly reduced during Hurricane Katrina, with only 15 percent remaining operational. Approximately one-third of all pump stations and power supply facilities required repairs or rehabilitation.

Analysis of the interior drainage system focused on the flooding and unwatering of basins — separate areas protected by levees and pump stations. Eight basins were identified for interior drainage analysis, although analyses of the St. Charles East Bank and Orleans West Bank were not completed by the time of this report.

Modeling was used to simulate the water levels caused by Hurricane Katrina and probable outcomes if all the hurricane protection facilities had remained intact and had functioned as intended. Examining three hypothetical scenarios, the study concluded that without levee and floodwall breaches, flood levels would have been lower in all basins. While Katrina's rainfall and overtopping by themselves would have caused dramatic flooding, in some instances, such as St. Bernard and Orleans East, two-thirds of the total flood volume was the result of water flowing through breaches.

Pumping Station Performance

With most of the land in the New Orleans area below sea level, pump stations are needed to pump storm water out of the basins and into adjacent water areas. However, because many pumps stations were rendered inoperative, they played no significant role in reducing floodwaters during Katrina.

The performance analysis covered over 80 pumping stations in four parishes — Jefferson, Orleans, Plaquemines and St. Bernard. (There was no significant dam-

age to the pumping system in St. Charles Parish.) These stations vary significantly in their design, construction and capacity, ranging from large plants built of reinforced concrete to small stations housed in metal frame buildings. Some have recently been completed, while others are approaching 100 years of age.

A combination of four factors rendered many of the pump stations inoperative during the storm:

1) evacuation of operators from the stations to safe locations
2) flooding of station equipment
3) loss of electrical service to the pumps
4) loss of lubricating and cooling water

Storm surge resulted in water levels that exceeded the design discharge level of some pump stations. This condition resulted in reverse flow at a high rate of discharge, causing flooding in areas where the hurri-

For the complete report, visit https://ipet.wes.army.mil