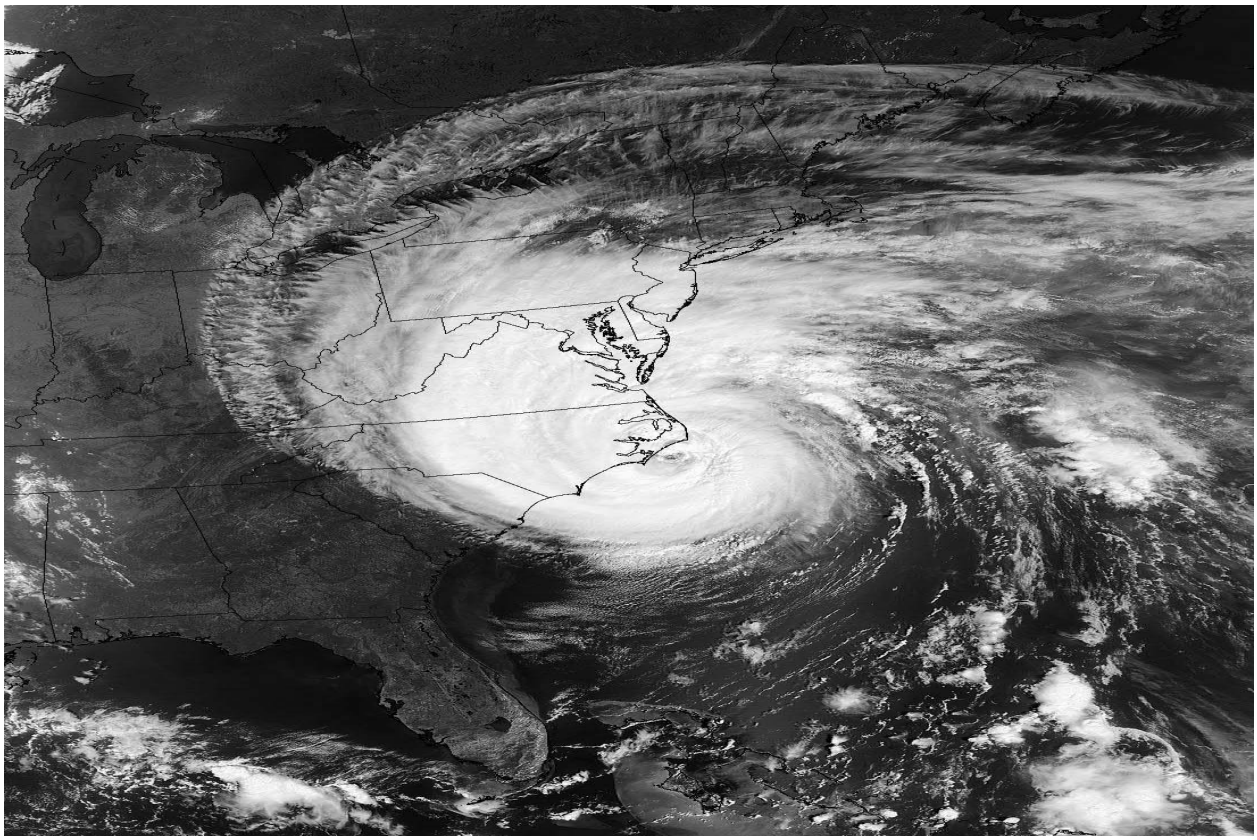
Service Assessment

Hurricane Isabel
September 18-19, 2003



U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover: Moderate Resolution Imaging Spectroradiometer (MODIS) Rapid Response Team imagery, NASA Goddard Space Flight Center, 1555 UTC September 18, 2003.

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May 2004

U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

National Oceanic and Atmospheric Administration
Vice Admiral Conrad C. Lautenbacher, Jr., U.S. Navy (retired), Administrator

National Weather Service
Brigadier General David L. Johnson, U.S. Air Force (Retired), Assistant Administrator

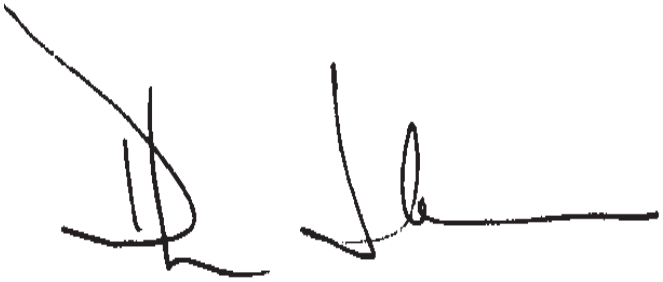
Preface

The hurricane is one of the most potentially devastating natural forces. The potential for disaster increases as more people move to coastlines and barrier islands. To meet the mission of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) - provide weather, hydrologic, and climatic forecasts and warnings for the protection of life and property, enhancement of the national economy, and provide a national weather information database - the NWS has implemented an aggressive hurricane preparedness program.

Hurricane Isabel made landfall in eastern North Carolina around midday Thursday, September 18, 2003, as a Category 2 hurricane on the Saffir-Simpson Hurricane Scale (Appendix A). Although damage estimates are still being tabulated as of this writing, Isabel is considered one of the most significant tropical cyclones to affect northeast North Carolina, east central Virginia, and the Chesapeake and Potomac regions since Hurricane Hazel in 1954 and the Chesapeake-Potomac Hurricane of 1933.

Hurricane Isabel will be remembered not for its intensity, but for its size and the impact it had on the residents of one of the most populated regions of the United States. Isabel is a reminder that if the impact of a Category 2 hurricane can be so extensive, then the impact of a major hurricane (Category 3 or higher) could be devastating.

Due to the impact on such a large number of people, a service assessment team was formed to examine the warning and forecast services provided to emergency managers (EMs), government agencies and the public. Service assessments provide a valuable contribution to ongoing efforts to improve the quality and timeliness of our products and services. Findings and recommendations from this assessment will improve techniques, products, services, and the information provided to the American Public.



David L. Johnson
Assistant Administrator
for Weather Services

May 2004

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Service Assessment Team

This Service Assessment Team was activated on September 25, 2003. The team assembled at the Weather Forecast Office (WFO) in Raleigh, NC, on Sunday, September 28, to begin their work. Team members visited WFOs Newport, NC, Wakefield, VA, Baltimore-Washington (Sterling), VA, the Tropical Prediction Center, Miami, FL, and various emergency management, government, broadcast media and individuals directly affected by the storm. Many telephone interviews were conducted with emergency management officials, local, state, and federal government officials, broadcast media, and the public.

The team consisted of the following persons:

Russell (Rusty) Pfost	*Team Leader*, Meteorologist in Charge (MIC), WFO Miami, FL
Darin Figurskey	MIC, WFO Buffalo, NY
Alan Gerard	MIC, WFO Jackson, MS
Roger Lamoni	Warning Coordination Meteorologist, WFO Reno, NV
Joel Lanier	Senior Service Hydrologist, WFO Tallahassee, FL
David R. Vallee	Science and Operations Officer, WFO Taunton, MA

Other valuable contributors

Wayne Presnell	Office of Climate, Water and Weather Services, NWS Headquarters, Silver Spring, MD
David Miller	NOAA Public Affairs, Washington, D.C.

Acronyms

ASOS	Automated Surface Observation System
AVNN	GFS operational forecast runs without synoptic surveillance data
AVNO	GFS operational forecast runs synoptic surveillance data
AWC	Aviation Weather Center, Kansas City, MO
AWIPS	Advanced Weather Interactive Processing System
AWOS	Automated Weather Observing System
CDT	Central Daylight Time
CPC	Climate Prediction Center
CRS	Console Replacement System (NOAA Weather Radio)
CST	Central Standard Time
CWA	County Warning Area
CWF	Coastal Marine Forecast
EAS	Emergency Alert System
EDT	Eastern Daylight Time
EM	Emergency Management/Manager
EMC	Environmental Modeling Center, Washington, D.C.
EMWIN	Emergency Managers' Weather Information Network
ERH	Eastern Region Headquarters, Bohemia, NY
EST	Eastern Standard Time
FEMA	Federal Emergency Management Agency
FFMP	Flash Flood Monitoring and Prediction
FIC	Forecaster-in-Charge
FSL	Forecast Systems Laboratory, Boulder, CO
GFE	Graphical Forecast Editor
GFS	Global Forecast System
HAS	Hydro-meteorological Analysis and Support
HLS	Hurricane Local Statement
HLT	Hurricane Liaison Team
HMT	Hydrometeorological Technician
HPC	Hydrometeorological Prediction Center, Camp Springs, MD
HRD	Hurricane Research Division, Miami, FL
HSM	Hurricane Support Meteorologist
HURREVAC	Computer program used for hurricane tracking and display
HWO	Hazardous Weather Outlook
IFLOWS	Integrated Flood Observing and Warning System
IFPS	Interactive Forecast Preparation System
IT	Internet Technology
LARC	Limited Automated Remote Collector
LP1	Local Primary 1 (broadcast station)
LP2	Local Primary 2 (broadcast station)

LSR	Local Storm Report
LST	Local Standard Time
LSU	Louisiana State University, Baton Rouge, LA
MARFC	Middle Atlantic River Forecast Center, State College, PA
MD	Mesoscale Discussion
MHX	WFO Newport/Morehead City, NC
MIC	Meteorologist in Charge
MHW	Mean High Water
MLLW	Mean Lower Low Water
MSL	Mean Sea Level
MWD	Marine Weather Discussion
NAWAS	National Warning Circuit
NAVD	North American Vertical Datum 1988
NCO	NCEP Central Operations
NCSU	North Carolina State University, Raleigh, NC
NCEP	National Centers for Environmental Prediction, Washington, D.C.
NDFD	National Digital Forecast Database
NGVD	National Geodetic Vertical Datum 1929
NHC	National Hurricane Center, Miami, FL
nmi	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NOW	Short Term Forecast (NOWcast)
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSH	National Weather Service Headquarters, Silver Spring, MD
NWSI	National Weather Service Instruction
NWSRFS	National Weather Service River Forecast System
OB2	Operational Build 2
OCWWS	Office of Climate, Water, and Weather Services, Silver Spring, MD
OPC	Ocean Prediction Center, Camp Springs, MD
PA	Public Affairs
PEPCO	Potomac Electric Power Company
PNS	Public Information Statement
PSH	Post Storm Hurricane Report
QPF	Quantitative Precipitation Forecast
RFC	River Forecast Center
ROC	Regional Operations Center
SAME	Specific Area Message Encoder
SEC	Space Environment Center, Boulder, CO
SERFC	Southeast River Forecast Center, Peachtree City, GA
SDM	Station Duty Manual

SLOSH	Sea Lake and Overland Surges from Hurricanes
SOO	Science and Operations Officer
SPC	Storm Prediction Center, Norman, OK
SPS	Special Weather Statement
SVS	Severe Weather Statement
UTC	Coordinated Universal Time
T1	Fiber optic digital voice channel telecommunications line
TAFB	Tropical Analysis and Forecast Branch, Miami, FL
TPC	Tropical Prediction Center, Miami, FL
TSB	Technical Support Branch, Miami, FL
UCP	Unit Control Position
UPS	Uninterruptible Power Source
USGS	United States Geological Survey
VDEM	Virginia Department of Emergency Management
VIP	Voice Improvement Processor
VISIT	Virtual Institute for Satellite Integration Training, Fort Collins, CO
WAN	Wide Area Network
WARNGEN	Warning Generation software (part of AWIPS)
WCM	Warning Coordination Meteorologist
WES	Weather Event Simulator
WFO	Weather Forecast Office
WSR-88D	Weather Surveillance Radar-1988 Doppler
WWA	Watch, Warning, and Advisory interface (part of AWIPS)
ZFP	Zone Forecast Product

Service Assessment Report

Executive Summary

Overall, the NWS service to the nation during Isabel was exemplary. Emergency management from the local county and city level to the highest officials in the Federal Emergency Management Agency (FEMA), the media, and the citizens of the communities affected by Isabel recognized and appreciated the outstanding work by the NWS. While Isabel was a Category 2 hurricane and was decreasing in intensity as it crossed the North Carolina coast on September 18, it caused tremendous damage and disruption, felled thousands of trees resulting in massive power outages, and caused unusually high storm surge along the Mid-Atlantic coast.

Isabel became the ninth named storm of the 2003 Atlantic basin tropical cyclone season about 625 miles west of the Cape Verde Islands on Saturday morning, September 6. Isabel began as a strong tropical wave off the West African Coast about three days before, and was upgraded to a hurricane at 11 a.m. EDT Sunday, September 7. Isabel intensified rapidly Monday, September 8, going through Categories 2 and 3 of the Saffir-Simpson Hurricane Scale (**Appendix A**) and reaching Category 4 intensity by 11 p.m. EDT that day.

Isabel remained a strong Category 4 hurricane until reaching the rare Category 5 status, the highest category of hurricane strength on the Saffir-Simpson Scale, Thursday, September 11 at 5 p.m. EDT. Isabel was moving slowly west and had reached a location about 500 miles east northeast of the northern Leeward Islands. Isabel remained at or near Category 5 intensity until Sunday, September 14, when it weakened to a Category 4 storm. Isabel weakened to a Category 3 late Monday, September 15. Weakening continued through Tuesday, decreasing to a Category 2 at 11 a.m. EDT Tuesday, September 16.

Hurricane Watches were issued by the Tropical Prediction Center (TPC) for parts of the North Carolina, Virginia, Maryland, Delaware, and New Jersey coasts at 11 a.m. EDT Tuesday. Hurricane Warnings were issued by the TPC at 11 p.m. EDT Tuesday, and extended northward at 5 a.m. EDT Wednesday, September 17. Isabel made landfall near Drum Inlet, Carteret County, North Carolina, around 1 p.m. EDT Thursday, September 18. Isabel moved northwest to Roanoke Rapids, NC, by 5 p.m. EDT Thursday, and accelerated to northeast West Virginia by 5 a.m. Friday, September 19 as a tropical storm. By 11 a.m. EDT Friday, the center of the storm was losing tropical characteristics and was near Cleveland, Ohio, moving northward into Canada.

Most of the effects of Isabel were experienced between Thursday morning, September 18 and Friday evening, September 19. Isabel is directly responsible for 17 deaths (**Appendix B**), mainly through drowning, or persons or automobiles hit by falling trees or limbs. Thirty-four fatalities were indirectly related to Isabel and several of these have been attributed to carbon monoxide poisoning from generators running in closed spaces without proper ventilation.

The estimated total economic loss from Isabel is $5 billion, according to American Reinsurance Group, a company that monitors disasters and determines their impact. This estimate includes the District of Columbia and Canada (Canadian impact is small). Insured losses from Isabel were approximately $1.685 billion (through private companies) as of November 2003. Economic losses are the total dollar property losses from a given event. Insured losses refer to property losses covered by either private insurance companies or government insurance programs, like the National Flood Insurance Program. The traditional NWS method of estimating total loss is to double the insured losses, or approximately $3.37 billion. A breakdown of losses by state (November 2003) is below:

- Virginia $925 million
- Maryland $410 million
- North Carolina $170 million
- New York $ 45 million
- Pennsylvania $ 80 million
- New Jersey $ 25 million
- Delaware $ 20 million
- West Virginia $ 10 million

Power outages were a significant effect of the storm. From emergency management situation reports as well as individual power company estimates, about 6 million customers lost power at some point during the storm across the states of North Carolina (700,000), Virginia (1,800,000), Maryland, Delaware, West Virginia (1,416,000), Pennsylvania (900,000), and adjoining states (approximately 800,000). Though the power companies anticipated the storm and planned for its effects, the scale of power outages due to fallen trees was far more than expected. Potomac Electric Power Company (PEPCO) Holdings Senior Communications Representative Robert Dobkin called Isabel the "*worst storm they have ever experienced*" and attributed the massive power outages to the extremely wet antecedent ground conditions across the Mid-Atlantic States. The wet ground conditions enabled Isabel's winds to fell more trees across power lines than under normal ground moisture conditions.

Winds from Isabel downed many trees across North Carolina, Virginia, Maryland and the District of Columbia as well as other states. Many of those trees were large and very old, more than 100 years in some cases.

Isabel's storm tide was 1 to 3 feet higher than was forecast, especially in the northern Chesapeake Bay and Potomac Basins including Baltimore, Annapolis, and Washington. Fell's Point in Baltimore, the U.S. Naval Academy and downtown Annapolis, and the Belle View neighborhoods of northern Fairfax County, Virginia experienced severe storm surge flooding. **Table 1** provides measured storm tide crests at several sites in North Carolina, Virginia, and Maryland. From observations of debris lines and data from tide gages, the storm tide was 5 to 11 feet above National Geodetic Vertical Datum 1929 (NGVD) across North Carolina's Outer Banks. The storm tide measured from 6 to 9 feet NGVD in the Chesapeake Bay area and the tidal Potomac River Basin. Many NWS customers expressed confusion over exactly what the NWS forecasts meant, whether it was on top of normal tides or mean lower low water, or mean sea level and at what datum. The North American Vertical Datum (NAVD) of 1988 is an alternative datum in use along the Atlantic Coast of the United States. Storm tide measurements using the NAVD can be obtained by subtracting approximately 1 foot from measurements using NGVD.

Extensive storm tide surveys and measurements of high water marks were ongoing at the time of this writing, not only in the Potomac and Chesapeake Bay areas but also along the Atlantic coast of North Carolina and Virginia. Storm tide measurements quoted in this service assessment were compiled and accurate through December 2003. Final analysis and measurement may result in information different from that contained in this report.

Max Mayfield, Director of TPC, noted in December 2003, that damage from Hurricane Isabel will exceed 2 billion dollars, in spite of a near-perfect forecast. He said that it would take a long term public-private partnership to effect change in the way people live near our coastlines in order to mitigate damages from future storms like Isabel.

Location	Storm Tide (ft. NGVD 1929)	Time LST	Date	Remarks
Wilmington, NC	3.22	1618	9/18	
Beaufort, NC	5.03	1342	9/18	
Cape Hatteras, NC	7.7	918	9/18	Fishing Pier (gage destroyed - partial record)
Oregon Inlet Marina, NC	5.84	2300	9/18	
Duck, NC	7.0e	800e	9/18	wave action 10-15 ft. higher on top
Money Point, VA	7.76	1454	9/18	
Chesapeake Bay Bridge/Tunnel, VA	7.12	1318	9/18	highest sustained wind 73 mph highest gust 87 mph 1625 and 1710 9/18
Sewell's Point, VA	7.53	1600	9/18	
Scotland, VA	6.74	1518	9/18	Gage destroyed-partial record
King's Mill, VA	6.29	1524	9/18	Gage destroyed-partial record
Gloucester Point, VA	5.78	1200	9/18	Gage destroyed-partial record
Colonial Beach, VA	5.45	1836	9/18	Gage destroyed-partial record
Kiptopeke, VA	6.07	1418	9/18	
Wachapreague, VA	7.09	1500	9/18	
Richmond, VA	9.0e	Late eve	9/18	City Locks James River (estimated)
Washington, D.C.	7.5	342	9/19	Water St., Police and Fire Harbor Patrol, Potomac River
Baltimore, MD	8.34	706	9/19	Chesapeake Bay
Annapolis, MD	7.47	642	9/19	Chesapeake Bay
Tolchester Beach, MD	8.07	742	9/19	Chesapeake Bay
Cambridge, MD	6.15	542	9/19	Chesapeake Bay
Ocean City Inlet, MD	3.62	112	9/19	
Philadelphia, PA	7.01	630	9/19	Delaware River
Reedy Point, DE	6.73	406	9/19	Delaware River
Lewes, DE	5.27	1424	9/18	Delaware Bay
Cape May, NJ	4.87	1354	9/18	Delaware Bay
Burlington, NJ	7.57	700	9/19	Delaware Bay

Table 1 - Storm Tide crest data table. Datum is NGVD 1929 (NAVD subtract 0.99 ft.)

Extreme rainfall from the storm occurred in the Shenandoah Valley and the Blue Ridge Mountains of Northern Virginia. More than 20 inches of rain fell at Upper Sherando, just south of Waynesboro in Augusta County, Virginia. This rain caused flash floods over several tributaries of the South River and a major flood on the South River at Waynesboro and downstream on the Shenandoah River at Lynnwood, Front Royal, and Millville. Major flooding also occurred in parts of the Potomac River Basin.

President George W. Bush declared disaster areas in all categories of hazard mitigation for 77 counties and independent cities in Virginia and 36 counties in North Carolina on September 18. He declared the entire state of Maryland a disaster area on September 19, the entire state of Delaware and the District of Columbia on September 20, and 6 counties in the panhandle of West Virginia on September 24.

In particular, the NWS TPC did an outstanding job forecasting Isabel. The storm was a complete triumph for the new five day forecast as well. NWS Weather Forecast Offices (WFOs) did very well with their local services to their individual county warning areas (CWAs) according to comments and quotes from emergency management personnel and media. Bob Dobkin, senior communications representative with PEPCO Holdings said, "*We were prepared for it . . . you guys did a good job*!" Charles McRorie, the Emergency Manager for Alexandria, said NWS forecasts were, "*timely, accurate and reliable.*"

An assessment team headed by W. Robert Herbert for the Commonwealth of Virginia's response during Isabel concluded its work with a final report in December 2003. The survey included several questions about the NWS. Virtually everyone expressed satisfaction with the NWS and the accuracy of its forecasts. Results from the survey show ***96% of the respondents said the advance warning and notification system was adequate in indicating the level of damage that occurred.*** Only two respondents said that forecasts were not adequate, particularly with regard to tidal surge notification. Even with the best forecasts and warnings, though, noted one respondent, "*unless people have actually been in high sustained winds or high tide surges, they cannot appreciate the damage that can be done.*"

Warning and Forecast Services

A. Tropical Prediction Center

Overview

The Tropical Prediction Center (TPC) is an arm of the National Centers for Environmental Prediction (NCEP). NCEP is also home to the Hydrometeorological Prediction Center (HPC), the Ocean Prediction Center (OPC), the Storm Prediction Center (SPC), the Aviation Weather Center (AWC), the Climate Prediction Center (CPC), the Environmental Modeling Center (EMC), the Space Environment Center (SEC), and the NCEP Central Operations (NCO). The TPC consists of the much more widely known National Hurricane Center (NHC), which provides operational real time forecasts, watches, and warnings in text and graphical form for tropical cyclones from May 15 in the eastern Pacific and June 1 in the Atlantic through November 30; the Tropical Analysis and Forecast Branch (TAFB), which provides staffing assistance to the NHC forecasters, year-round marine weather analysis and forecast products over the tropical and subtropical waters of the eastern North and South Pacific and the North Atlantic basin; and the Technical Support Branch (TSB), which provides support for TPC computer and communications systems, maintains a small applied research and techniques development unit, and has a storm surge group that provides information for developing evacuation procedures for coastal areas.

The TPC/NHC augmented its hurricane forecasters with volunteers staffing TPC's informal round-the-clock "Hurricane Support Meteorologist" (HSM) position. The HSM program and its predecessors for years have provided the critical mass of personnel required to handle the surplus of data synthesis, analysis and forecasting, media and emergency management interviews, and telephone calls during such events. HSMs are drawn from trained staff in other TPC units contributing many hours over several days of overtime/compensatory time, as well as drawn from student volunteers and technically-inclined visitors from other organizations. This staffing deficiency was noted in the Program, Planning, Budgeting and Execution System documents for the Tropical Storm program. The TPC would like to eventually introduce a formal HSM position, possibly as an "intern" but is realistic about the constraints on increasing full time employees (**Best Practice 1**).

The TPC did an outstanding job forecasting and warning for Hurricane Isabel. The storm was remarkably well behaved, with no unusual loops or changes in forward speed or any unexpected changes in path. As a result, the skill of the TPC in forecasting Isabel was exceptionally good (**Figure 1**). The intensity forecast verification for Isabel was about the same as the 10 year average, except slightly worse at 72 hours (**Table 2**).

Forecast period	Isabel average official track error (nmi)	10 year average official track error (nmi)	Isabel intensity forecast error (KTS)	10 year average intensity forecast error (KTS)
24 hrs (1 day)	39	81	11	11
48 hrs (2 days)	60	150	17	17
72 hrs (3 days)	80	225	23	18
96 hrs (4 days)	104	282 (2 year avg.)	26	n/a
120 hrs (5 days)	146	374 (2 year avg.)	28	n/a

Table 2 - Hurricane Isabel track and intensity forecast verification data

Interviews with hurricane forecasters and TPC leadership showed a general satisfaction with, and optimism for, the new five day forecast as far as forecast track, but much less as far as forecast intensity. Hurricane Isabel was indeed a big success for the five day forecast track but was not as strong as forecast at landfall. Skill for tropical cyclone intensity forecasts has been roughly plus or minus 20 knots at 5 days, and for Isabel the 5 day intensity forecast error averaged 28 knots. A 20 knot error is equivalent to a little over 1 Saffir-Simpson Scale category, or the difference between a high end Category 1 and a low end Category 3 hurricane.

From a TPC Tropical Cyclone Report on Isabel by Beven and Cobb (2003), there appears to be three primary reasons for the excellent track forecasts. First, Isabel was a large and strong hurricane, and this type of tropical cyclone is typically associated with relatively low errors. Second, Isabel moved slowly through the central and eastern Atlantic in a relatively predictable steering pattern. And finally, when Isabel reached the western Atlantic, synoptic surveillance missions began using both the NOAA Gulfstream-IV jet and Air Force Reserve aircraft to deploy dropsondes in the hurricane's environment. According to a preliminary assessment by the Hurricane Research Division (HRD), this data, which helped resolve a complex steering flow pattern around Isabel, had an unusually strong positive impact (of roughly 30%-40% beyond 48 hours) on the track forecast guidance from the NWS Global Forecast System model (AVNO in Table 3). However, total samples of verification data from 1999-2003 show only slight improvement beyond 72 hours.

FORECAST ERRORS (KM) FOR ISABEL

	12 h	24 h	36 h	48 h	60 h	72 h	84 h	96 h	108 h	120 h
AVNN	30.9	45.6	69.5	128.7	198.6	281.0	359.7	382.2	429.6	463.0
AVNO	33.1	40.6	52.0	93.9	121.6	159.1	193.9	202.5	228.0	275.2
%IMP	-7%	11%	25%	27%	39%	43%	44%	47%	47%	41%
#CASES	16	16	16	16	14	12	10	7	6	4

Table 3. Forecast track errors (km) for Isabel from the operational GFS model (AVNO) using synoptic surveillance data including dropsondes from aircraft reconnaissance compared to parallel runs without the synoptic surveillance data (AVNN).

The forecast discussion products issued by TPC were already mentioning the United States East Coast as potentially threatened by Isabel as early as Thursday, September 11, a full week before landfall in North Carolina. At 5 p.m. EDT, September 15, TPC issued the first Public Advisory mentioning areas from the Carolinas northward to New England as possible landfall targets for Hurricane Isabel. A Hurricane Watch, issued for a part of the coastline at risk of hurricane conditions within 36 hours, was issued at 11 a.m. EDT Tuesday, September 16, 50 hours before landfall of the eye. A Hurricane Warning, issued for a part of the coastline expecting hurricane conditions within 24 hours, was issued at 11 p.m. EDT Tuesday, September 16, 38 hours before landfall of the eye. Thus, TPC provided the impacted areas sufficient time to prepare for the arrival of Hurricane Isabel.

Figure 1 shows the Isabel track forecast error by NHC forecasters out to 5 days compared with historical track errors for 1964-1973 (red), 1974-1983 (purple), 1984-1993 (sky blue), 1994-2002 (green), and 2003 (yellow). It is interesting that the 120 hour (5 day) forecast track error for Isabel was less than the 36 hour (1.5 day) forecast track error from 1964-1983. The 48- hour position forecast error was 60 nautical miles (nmi), which is 90 nmi lower than the 10-year average error of 150 nmi, and 70 nmi lower than the 2003 error of 130 nmi.

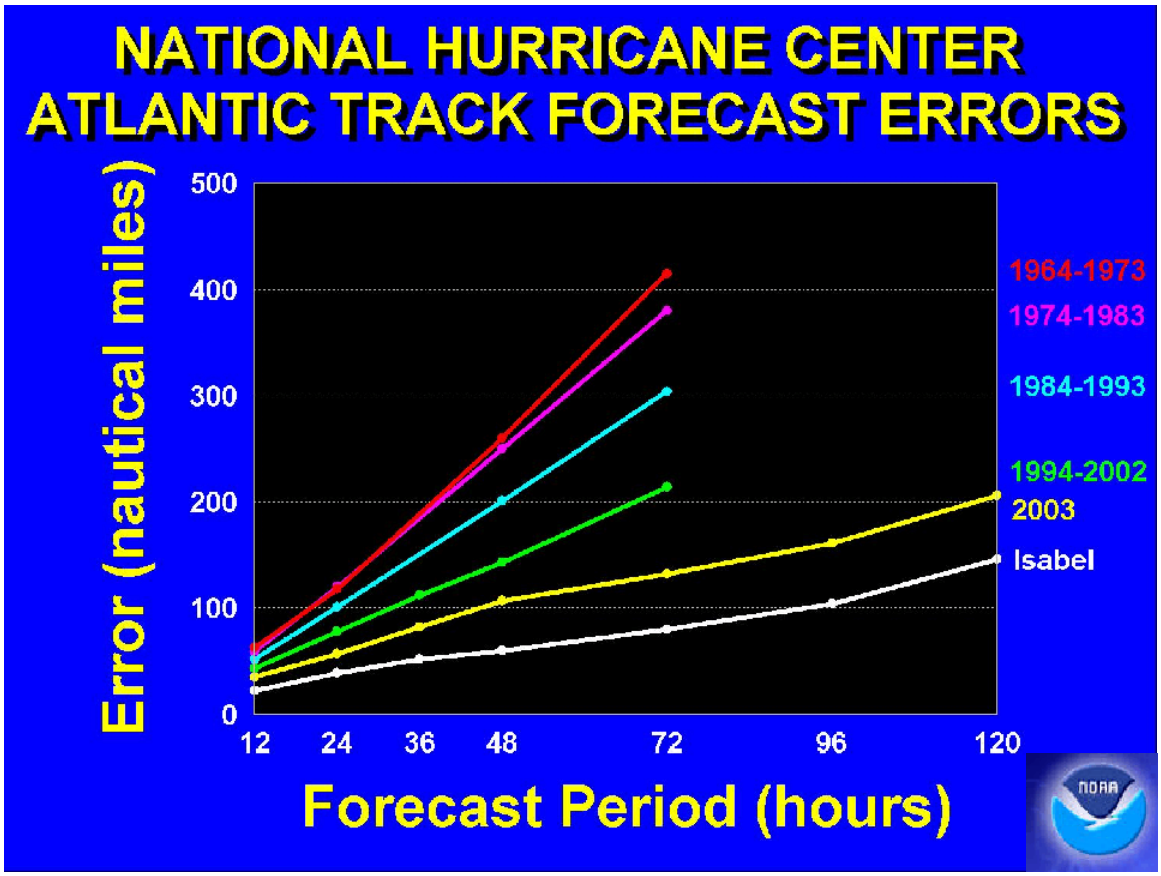

Figure 1. Hurricane Isabel track errors compared with historical track errors. From the National Hurricane Center.

The TPC did an outstanding job forecasting the track of Hurricane Isabel! The TPC provided more than a week's notice that the east coast of the United States would be impacted, and provided more than 48 hours notice with the Hurricane Watch, and more than 36 hours notice with the Hurricane Warning. While the intensity forecasts were not as outstanding as the track forecasts, they were still good. TPC's products, including forecast and public advisories, discussions, updates, and strike probabilities, were consistently well written and timely.

Emergency Management Liaison

The FEMA Operations Center strategically places personnel at the TPC during a hurricane threat for the United States to facilitate the flow of information between the two agencies. In addition, a Hurricane Liaison Team (HLT) may be activated when a tropical cyclone in the Atlantic, Gulf of Mexico, Caribbean or eastern Pacific threatens the United States or its territories, and the Director or Deputy Director of TPC decides HLT assistance is required. The HLT activated for Hurricane Isabel performed in an outstanding manner. In fact, during one of the HLT video teleconference briefings on Isabel with FEMA and several state Emergency Operations Centers, Eric Tolbert (Director of the FEMA Response Directorate) said, *"If we* (referring to those involved with federal and state preparedness and response) *could have done*

this any better, I don't know how we would have done it." Director Tolbert then asked everyone at FEMA headquarters on the video teleconference to give all the NWS folks a hand for the great job on forecasting Isabel. Dr. Ken Taylor, the Director of Emergency Management for North Carolina, added his agreement with Director Tolbert's sentiments.

North Carolina emergency managers also praised the forecasts and products of the TPC for Isabel. They were particularly impressed with the consistency of the landfall forecast from advisory to advisory, and several stated that this gave them added confidence in the forecast of the track and associated impacts expected from the hurricane.

TPC Products to WFOs

Interviews with the WFOs most affected by Isabel (WFOs Newport, NC, Wakefield, VA, and Baltimore-Washington) did reveal some problems with Interactive Forecast Processing Systems (IFPS) procedures and the grids provided by the TPC for Isabel. NWS Instruction 10-503, section 2.2.3 on Issuance Time for the Zone Forecast Product (ZFP) reads as follows:

2.2.3 Issuance Time. The ZFP is an event-driven product and may be issued at any time. However, at a minimum the ZFP will be issued twice daily to remove the outdated first period of the forecast. These mandatory issuance times will occur no later than 4 a.m. and 4 p.m. local time.

Tropical cyclone advisories are issued by TPC at 5 a.m./p.m. and 11 a.m./p.m., which means that WFOs affected by tropical cyclones must meet the 4 a.m./p.m. deadline for their ZFP packages and then issue an update (which usually means a new complete set of grids and products) to incorporate and be consistent with the new advisory. While this directive did not go into effect until October 1, 2003, which was after the Isabel event, WFOs nevertheless have strived to meet the 4 a.m./p.m. deadline beforehand.

The same is true for the coastal marine products. NWS Instruction 10-310, section 2.2.3 on Issuance Time for the coastal waters forecast (CWF) is as follows:

2.2.3 Issuance Time. Coastal Waters Forecasts are routinely-scheduled products. WFOs should issue Coastal Waters Forecasts based on the following:

Region/Office	**Scheduled Issuance Time (UTC)**
Eastern (Winter/Summer)	0830/0730 2030/1930
Southern (EST/CST)	0930/0930 2130/2130
(EDT/CDT)	0830/0930 2030/2130
WFO San Juan	0830 2030

Fact - It is a great deal of extra work for the WFO synoptic forecaster to completely issue a forecast package by 4 a.m./p.m. and then have to issue it again to incorporate the 5 a.m./p.m. advisory from TPC in an update package.

Finding # 1 - NWSI 10-310 Section 2.2.3 and 10-503 Section 2.2.3 require that WFOs issue the ZFP no later than 4 a.m./p.m. local time each day and the CWF no later than 430/1030 a.m./p.m. local time each day. Tropical cyclone advisories are issued by TPC at 5/11 a.m./ p.m. each day, requiring a complete update to the forecast package issued only a half-hour to one hour earlier by the WFOs. This is a significant workload issue.

Recommendation # 1: NWSI 10-310 Section 2.2.3 and 10-503 Section 2.2.3 should be updated to give WFOs an option, during a tropical cyclone event, to delay the issuance of morning and/or afternoon Public Forecast and Coastal Waters Forecast products until after TPC issues its advisories.

TPC can issue tropical cyclone watches and warnings at any time for coastal locations using regular and special advisories. Issuing a watch or warning with the 11 p.m. EDT advisory can be a problem in rural locations in the Eastern and Atlantic Time Zones. Many radio and television stations (even Local Primary 1 and 2 stations) are not routinely staffed 24 hours, and are difficult to contact late at night. This should not be as much of a problem in time zones further west across the U.S. TPC will consider this potential problem in its future operations.

B. Hydrometeorological Prediction Center

Overview

The Hydrometeorological Prediction Center (HPC) of NCEP 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. HPC supports TPC whenever tropical cyclones move west of 60 degrees west longitude by forecasting tropical cyclone position before each hurricane coordination conference call. Because quantitative precipitation forecasts (QPF) are major focuses of its responsibilities, HPC provides expected QPF for inclusion in the TPC public advisories. HPC is also a routine participant in the HLT briefings to FEMA senior staff and senior state emergency management officials. HPC assumes responsibility for issuance of public advisories for tropical systems once they make landfall and are downgraded below tropical storm strength or become extra-tropical. HPC is also the emergency backup office for TPC should they become incapable of fulfilling their mission.

Before the Event

Hurricane Isabel made landfall on September 18. For more than a week before that time, the HPC assisted the TPC by providing guidance forecasts of the position of the storm for seven days into the future. As Isabel approached land, HPC issued QPFs for the storm. For the three days before until one day after landfall as a part of its HLT functions, HPC also supported FEMA and state EMs by delivering twice daily, live televised briefings on the expected precipitation

from Isabel. One of these briefings was attended by Department of Homeland Security Secretary Thomas Ridge and many were attended by White House staff.

Pre-landfall planning by HPC managers provided for additional coverage by the managers to handle phone, media and HLT duties. Contingency planning for housing forecast staff nearby in a hotel, as well as the in-house provision of extra food and water were completed although they were not used.

During the Event

Before and during Isabel, HPC coordinated extensively with affected WFOs and RFCs, especially on predicted precipitation amounts. HPC QPFs served as a starting point for the RFC forecasts and were modified as needed by the RFC staff based on RFC expertise and up-to-the-minute information and observations in the RFC's area of responsibility. WFOs also use HPC QPFs and during Isabel frequently contacted HPC to collaborate on these QPFs. Telephone calls and 12Planet chat room, an instant messaging service, coordination /collaboration were used.

HPC provided many media interviews and hosted Fox Channel 5 (Washington, D.C.) for 3-4 hours the two mornings before landfall by providing live interviews and background shots. HPC also prepared graphics several times for special briefings to White House staff and the President. Some of these activities were accomplished while the Federal Government in the Washington area was shut down because of the storm.

A comparison of HPC QPF issued early September 18 with the analysis of observed rainfall shows HPC's QPF of 6 inches was very close to the observed band of 3-6 inch rainfall, extending from northeastern North Carolina northwest into central Virginia. Within that band HPC predicted a core of greater than 7 inches.

HPC forecasts were very close to observed in the core of the track from North Carolina through Virginia, but with a high bias developing from northern Virginia through West Virginia and Pennsylvania. The forecasts included a larger area of QPF greater than five inches than actually occurred. In particular, the QPF for portions of southeastern West Virginia and western Pennsylvania was high. Overall, the precipitation forecasts from HPC were excellent and were a major reason HPC set a number of records for precipitation forecasting skill in September 2003.

C. Ocean Prediction Center

Overview

The Ocean Prediction Center (OPC) of NCEP provides warnings, forecasts, and analyses of the marine atmosphere and upper ocean for the North Atlantic and North Pacific Oceans extending from the east coast of the U.S. to the west coast of Europe and Africa and from the west coast of the U.S. to the east coast of Asia. OPC products are distributed in real-time through the U.S. Coast Guard radio broadcast facilities, the World Meteorological Organization

Global Telecommunication System, the Inmarsat marine communications satellite system, and the, among others.

A critical function of the OPC is to provide mariners with forecasts of wind and sea conditions, particularly marine warnings of gale, storm, and hurricane force winds, in the offshore and high-seas areas. OPC works closely with the TPC and WFOs to coordinate such information. In the case of Isabel, the OPC predicted extremely high waves (40 to 55 ft) up to 48 hours in advance for the offshore waters. OPC was the first office of the NWS to note these extreme conditions and informed the affected WFOs. The conditions were subsequently verified by buoys and other instruments. These high seas set the stage for the storm surge and flooding along the coast and in the bays and estuaries.

OPC's Marine Weather Discussion (MWD) was updated more frequently than the usual four times per day. The MWDs and OPC's three-hourly sea state analyses provided guidance to the WFOs and marine community as to the expected evolution of the extreme conditions up to five days in advance. The WFOs, using 12Planet chat and special OPC-initiated telephone conferences, collaborated with OPC to develop the appropriate coastal, offshore, and high seas forecasts. As a result, maritime interests were well prepared for Isabel and were able to take avoidance measures.

D. WFO Newport, North Carolina

Overview

Hurricane Isabel was well forecast by the TPC days before landfall on the outer banks of North Carolina. Interviews with customers and partners show the WFO performed well during the event. The staff was already well prepared through prior Warning Event Simulator (WES) training, excellent guide material, and experience from previous tropical cyclones. Coordination between the office and community was close and frequent. The quality of the NHC forecasts and localized, accurate surge forecasts enabled WFO Newport to provide emergency managers and customers and partners with excellent guidance about impacts from Isabel, allowing for the proper deployment of emergency assets.

Before the Event

Hazardous Weather Outlooks, Area Forecast Discussions, and Marine Forecasts from WFO Newport began indicating a threat from Isabel to eastern North Carolina several days before September 18, the day of eventual landfall. A Flood Potential Statement was issued Tuesday, September 16, which highlighted flash flooding as a significant threat. Discussions with emergency managers showed they also used the five day forecasts from NHC for planning purposes, and found the forecasts accurate and useful, using them as planning tools several days before the event.

Management at the WFO began planning to ensure the office was prepared for a potential landfall a full week before the event. The MIC worked with the office Union Steward to prepare a contingency work schedule to ensure all shifts would be adequately staffed. Management canceled travel to ensure sufficient staffing would be available during the event. Extra staff was made available through Eastern Region Headquarters (ERH), including a former WCM at the WFO. WFO Newport staff said having someone in the office already familiar with the area and office operations was a tremendous help before, during, and after the event. ERH also made extra electronics technicians available (**Best Practices 2 and 3**).

During the Event

Outer bands from Hurricane Isabel began to affect the Outer Banks of WFO Newport's CWA during the evening of Wednesday, September 17. The weather gradually deteriorated through the morning hours of Thursday, September 18. The eye of Hurricane Isabel made landfall in the early afternoon between Cape Lookout and Ocracoke Inlet, and moved north northwest across the northeastern part of the Newport CWA.

The highest storm surges of 6 to 10 feet NGVD 1929 occurred across the lower reaches of the Neuse and Pamlico Rivers, with a 10 foot storm tide along the lower Neuse River being the highest surge recorded (**Figure 2**). This surge caused significant flooding over parts of Craven, Carteret, Beaufort, and Dare counties. The surge moved rapidly up the Neuse, Pamlico and Tar rivers. Emergency managers reported many eyewitness accounts of high velocity, waist deep water moving homes, trailers and other object many yards inland. As the water retreated, these objects were then dragged back towards the sound.

Along the Outer Banks, storm surges of 6 to 8 feet, with battering waves of 15 to 25 feet, caused major surge damage and beach erosion, particularly in Kill Devil Hills, Buxton, Rodanthe, Hatteras Village, and Ocracoke. The Kill Devil Hills area experienced severe road and building damage. South of Kill Devil Hills, it was apparent in many locations the waves surged through cuts in the sand berms and washed sand across Highway 12 from Nags Head to Hatteras. Sand layering was also extensive near Rodanthe. A new inlet was carved just south of Frisco cutting off Hatteras Village. Three Hatteras Village homes were washed out to sea near the new inlet. Two families who did not evacuate were nearly swept out to sea when their home was destroyed. Local rescue was unable to reach them; however, they were ultimately able to reach safety. The new inlet destroyed all utility connections to Hatteras Island, isolating the residents there.

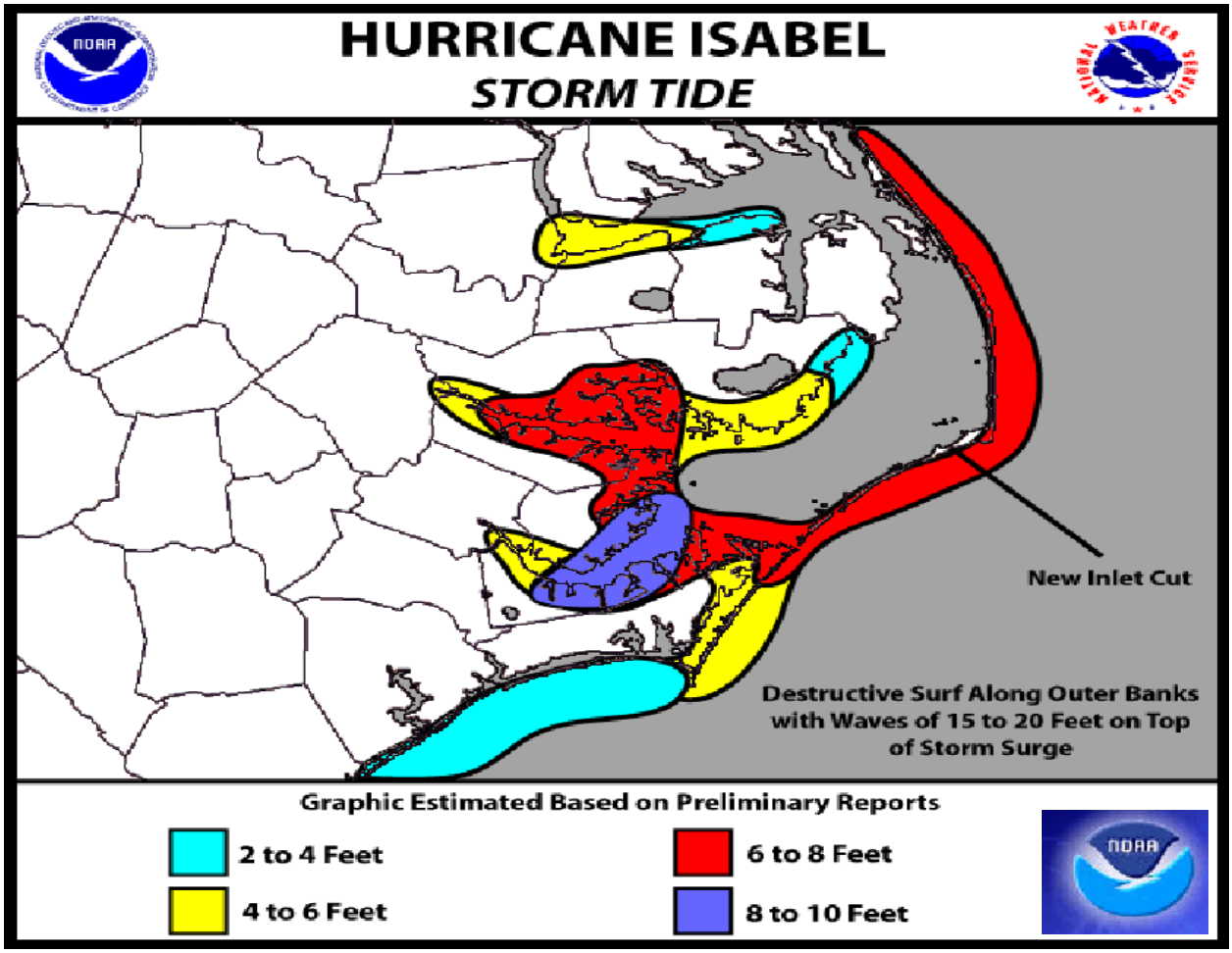

Figure 2. Storm Tide graphic from WFO Newport's web site. Tide listed in feet above MSL.

A large part of the damage from Hurricane Isabel in the WFO Newport CWA occurred in the Outer Banks. Isabel's rapid movement caused only minor freshwater flooding at the height of the storm in a few counties and no significant damage was reported. No tornadoes were reported in the CWA. No direct fatalities occurred, with one indirect fatality occurring after the storm. Many rescues were performed, however, by emergency personnel due to people who had not evacuated and had become trapped by storm surge flooding.

WFO Products and Services

WFO Newport's products and services were timely, accurate, and met their customers' needs. The office was well staffed during the event. At the height of the storm, all but three staff members were present. Discussions with the staff suggested operations went smoothly during the event.

HLSs were well written, and highlighted the danger posed by Hurricane Isabel. Initial HLSs gave general forecasts of conditions, but as landfall approached and a Hurricane Warning

was issued by TPC, the statements focused on impacts for specific areas. This was particularly true of the storm surge forecast, which gave surge forecasts targeted to local areas 24 hours before landfall. For example, the HLS from 5:50 p.m. EDT Wednesday, September 17, stated:

"As northeast winds increase tonight and Thursday, water levels along the Neuse and Pamlico Rivers will begin to rise. Water levels could rise to 8 to 10 feet above normal, especially near New Bern, Washington, eastern Pamlico County, and downeast Carteret County along the Neuse. Storm surges on the Outer Banks are expected to be around 6 to 8 feet on Thursday. Storm surge in Onslow County…and in Carteret County west of Cape Lookout is expected to be in the 2 to 4 foot range. Storm surges on the Albemarle Sound are expected to 3 to 5 feet along the southern shore of the sound from Tyrrell County eastward. Storm surges over the western Albemarle Sound are expected to reach 5 to 7 feet, with tidal flooding expected in the lower reaches of the Roanoke River."

The HLS also highlighted the potential for battering waves of 10 to 15 feet with major beach erosion along the Outer Banks. Responses from EMs and media showed that this specific surge information was accurate and very useful.

Hazardous Weather Outlooks (HWO) were issued daily in the early morning hours. HWOs issued early in the week discussed the possibility of Isabel affecting the area later in the week. The HWO products issued the day before landfall and on the day of landfall gave a brief overview of valid watches and warnings, discussed the threat of tornadoes, and on the day of landfall stated, *"Hurricane conditions will be seen over eastern North Carolina through this evening."* The HWO was not updated for any changes in watches or warnings and referred the users to the HLS product for more detailed information.

Updates were provided through the event with frequent Short Term Forecast (NOW) products. Nineteen NOW products were issued in a 24-hour period from 6 p.m. EDT Wednesday, September 17 through 6 p.m. EDT Thursday, September 18. The NOWs were well written and described the hazardous weather conditions affecting the region. In particular, for the time when the eye of the hurricane was passing over the region, the NOWs issued gave detailed forecasts of expected wind speeds and rainfall amounts. They also gave detailed, easily understandable forecasts of the areas that would be affected by the eye of the storm, and advised not to venture out when the eye was overhead.

All of the EMs interviewed by the team stated the WFO has a very effective outreach and preparedness program. The WFO conducted many hurricane outreach talks and seminars before and during hurricane season. This included their annual Emergency Manager/Media day which was held in conjunction with Hurricane Awareness Week in late May.

Eight of the 13 counties in the WFO area of responsibility were StormReady. The EM from Pamlico County stated the StormReady process had paid off in this event by ensuring all of their

Picture 1. Looking south toward Hatteras Village at the new channel cut by Isabel. Photo taken by assessment team members Joel Lanier and Alan Gerard on October 1, 2003.

public facilities had NOAA Weather Radios, something that likely would not have happened without the StormReady process.

Systems and Equipment

Three of the Automated Surface Observing Systems (ASOS) in Newport's area (Hatteras, New Bern, and Beaufort) failed during the height of the storm and all three were due to loss of power. The staff used reports from spotters to supplement the missing ASOS data, but the ASOS failures were problematic. One staff member said, *"ASOS going out was a problem, but it happens every storm."* He also commented the HLS and NOW products could have been better if they would have had the ASOS observational data.

NOAA Weather Radio performed well during this event. WFO Newport uses the new Voice Improvement Processor (VIP) voices for all products except the HLS, which is broadcast manually. No problems with VIP or the Console Replacement System (CRS) were noted. The WFO staff routinely monitors the broadcast during hurricane events to ensure the broadcast cycle is as short as possible, and does reduce the length of routine products to focus on critical

information. One NOAA Weather Radio (NWR) site failed during the event. The Mamie, NC, site failed due to a loss of commercial power followed by a failure of the site generator, which is maintained by a contractor.

The staff reported the Advanced Weather Interactive Processing System (AWIPS) performed well and no problems were noted. No issues with the Graphical Forecast Editor (GFE) or the Interactive Forecast Preparation System (IFPS) of the AWIPS were reported, and in fact, several staff members commented they found using GFE during the event was easier than they had anticipated.

Some staff members reported some problems with the Watch, Warning, and Advisory (WWA) software package. WFO Newport had just upgraded to Operational Build 2 (OB2) of AWIPS, which resulted in several changes to the operations of the WWA software. Several problems with WWA in this build had already been identified, and some of these did cause issues for the staff, including the inability to edit Call-to-Action statements and the inability to test a product without sending it out. One staff member stated he had little time to become familiar with the software before the event. However, none of the WWA issues caused significant delays in product issuance or any major operational problems.

WFO Newport used the tropical weather checklist for the Weather Surveillance Radar -1988 Doppler (WSR-88D) prepared by the WFO in Melbourne, FL. This list is also recommended by the Radar Operations Center.

Feedback from Customers and Partners

Emergency managers and coordinators praised the performance of WFO Newport. Stanley Kite, Emergency Manager of Craven County, North Carolina, estimated he had talked to between 1,200 and 1,500 people whose homes had been damaged by storm surge flooding, and, "*only one person,*" felt inadequately warned of the magnitude of surge and wind.

All of the emergency managers stated the office was always available to provide briefings and information, and the information provided was timely and accurate. Several praised WFO Newport for calling them to provide briefings, and to ask if there was any emergency management information the EMs would like disseminated through the office HLS product. The emergency managers stated the ability to disseminate critical community information through the HLS was very beneficial to their operations.

The North Carolina state emergency management holds a conference call three times a day during a hurricane event, with the WFOs servicing eastern North Carolina (Newport, Raleigh, Wakefield, and Wilmington) and all impacted local EMs participating. The local EMs all spoke very highly of the effectiveness of this call, and praised not only the Newport WFO, but all of the participating WFOs, for their briefings during this call (**Best Practice 4).**

WFO Newport has developed a password protected Emergency Management briefing page, on which they routinely post graphics detailing the threats from a tropical cyclone, including the hurricane track, severe weather potential, flooding potential, and storm surge. The EMs

interviewed all stated they use this page extensively, and found it to be of tremendous help during their operations. *"It is a very useful tool, and we commend them for it,"* said Dare County Emergency Manager Sandy Sanderson (**Best Practice 5**).

WFO Newport uses this website to post graphics for emergency management. About 24 hours before landfall, NHC provided the WFO a deterministic Sea, Lake, and Overland Surges from Hurricanes (SLOSH) storm surge forecast based on the actual forecast track of Isabel. The WFO posted this graphic on the password-protected EM page, and briefed each emergency manager on the graphic and its potential uncertainty. Several EMs stated this SLOSH forecast graphic was of tremendous benefit during the event. Stanley Kite, Emergency Manager of Craven County, North Carolina, stated this SLOSH forecast confirmed earlier forecasts of a 10 foot surge into a part of his county which does not typically experience heavy surge, giving him the confidence to move "*swift water*" rescue equipment into that part of the county the night before landfall. This equipment was then instrumental in performing several rescues during landfall. The EMs also stated even though the forecast surge from a deterministic SLOSH run would obviously have significant uncertainty due to possible errors in forecast track.

Several emergency managers also stated the WFO does an excellent job of applying their local knowledge of the area to give accurate forecasts of surge and wind for specific locales. The EMs (and some media) stated WFO Newport gave surge estimates for individual streams and other specific locations, which the EMs found very beneficial to their operations. Tim Harvey, Assistant Emergency Manager for Craven County said, *"They have the local knowledge, and they put the local spin on things."*

Media perception of the performance of WFO Newport was very favorable. A radio station and two television stations were contacted and each spoke positively of the WFO. Skip Waters, Chief Meteorologist for WCTI-TV in New Bern stated, *"In my 27 years of television, I don't know if there's a better office anywhere. They do a great job."* He stated the localized storm surge forecasts provided by the WFO were particularly useful, citing historical data which showed surge in New Bern of 8 to10 feet was possible, but the WFO forecast of a lower 6 foot surge was right on target and helped reassure residents in that area. Mr. Waters uses the HLS extensively, and his staff, "*waits by the printer,*" to get the latest HLS. He felt the WFO provided frequent updates of surge and rainfall forecasts, and that the information was, "*right on.*"

Mr. Waters expressed concern over the timing of advisory releases from the NHC. He stated advisories are issued too late to be of value for certain newscasts, particularly the 5 p.m. and 11 p.m. broadcasts. He felt an additional problem was the WFO had to wait for the new advisories to create their HLS, which meant the HLS was often too late to be used for these newscasts.

WFO Newport broadcast the advisories which initiated the Hurricane Watch and Hurricane Warning for Isabel with tone alert and SAME coding. The WFO has three Local Primary-1 (LP1) radio stations for the Emergency Alert System in its CWA, with three corresponding Local

Primary-2 (LP2) backup stations. Contacting the LP1 and LP2 stations to ensure the advisories for Hurricane Watches and Hurricane Warnings are broadcast with EAS activation is part of the WFO's Hurricane Watch/Warning checklist.

The checklist for Isabel's Hurricane Warning showed the WFO was unable to reach the LP1 or LP2 station for Onslow County, and the warning was not broadcast by either station with EAS activation. The warning was not issued until 11 p.m. EDT on September 16, and by that time of night both stations were either closed or very sparsely staffed, making it difficult to contact them. This was not a significant problem since Onslow County did not receive much impact from Isabel. However, the hurricane warning checklist also suggested difficulty reaching other LP1 stations due to the late hour, forcing the delay on another LP1 of the EAS activation until the 5 a.m. EDT advisory. The issuance of the warning so late at night could have caused other EAS activation problems since eastern North Carolina is predominately rural and many radio stations do not operate 24 hours. Some EMs said the issuance of the warning late at night caused problems with their operations, and one stated there were several EMs on the 6 p.m. North Carolina EM conference call on September 17, who voiced concern the warning had not been issued at 5 p.m. EDT.

Other Issues

Interviews with the forecasters who worked this event showed significant problems with the timing of the gridded wind fields issued by NHC. Because these wind fields are issued from the Tropical Cyclone Marine Advisory, they are often not available until after the advisory times of 5 p.m., 11 p.m., 5 a.m., and 11 a.m. EDT. This can be a problem, particularly for the 5 a.m. and 5 p.m. advisories. The main daily text products, (e.g., Zone Forecasts) generated from the gridded fields, are issued about 1 to 2 hours before these times, and the main grid editing is completed just before issuance of the text products.

Forecasters were confused about how to handle this situation. Editing the wind fields is a time-consuming process, and editing them again when the NHC advisory is issued is inefficient. Forecasters were also unsure of processes involving the text and graphical products issued from these grids. They were concerned if they issued the products at their regular time, and then had to update them to account for the new wind grids just an hour or two later, customers and partners could become confused. They also feared delaying the release of the text products would cause problems for the media and emergency managers. To avoid this potential problem, WFOs should educate their customers and partners of the possibility of a delay in some products during a tropical cyclone event.

Interviews with the public and emergency managers showed many people base their preparedness decisions for a hurricane threat on "*reference storms*" i.e., how they were impacted by a previous tropical storm or hurricane of similar track and intensity. For example:

- In the community of Swan Quarter, significant storm surge flooding affected many homes and businesses. A few people in this community indicated they were completely taken by surprise by the amount of water that came into town, and water was observed in places

where it had never been. The County Manager for Hyde County (Swan Quarter is the county seat) and the North Carolina Emergency Management Area Coordinator responsible for the area stated WFO Newport had told them to prepare for a surge about 2 feet higher than the surge which accompanied Hurricane Floyd in 1999. This forecast was close to the observed surge in Isabel. However, some people unfortunately did not prepare for such a storm surge since none that high had ever been observed.

- Mike Adderton, the EM for Carteret County indicated the people living along Cores Sound were surprised by the amount of water they received from surge flooding. He said the problem was these people had not been flooded by Hurricane Dennis in 1999, so they felt they would not be flooded by Isabel, a storm of similar intensity and track. The EM stated he felt the NWS forecasts of surge were right on target, and the people in the area had been warned adequately. He said, *"We had told everyone in the low lying areas that there would be 6 feet of water, and that's what happened. The information we received (from the NWS) was right on, but these people just would not move."*

While the WFO did not state in any products, reviewed by the team, Isabel would have similar impacts to a particular storm, interviews with WFO personnel revealed the WFO is often asked to provide "*reference storms*." From interviews with the WFO, public and EMs, while a "*reference storm*" can clearly provide the benefit of helping the public understand the potential impact from an impending storm, it can also give people who survived a given "*reference storm*" without any problems a false sense of security. No two tropical systems are identical. One EM stated he would prefer no references to previous storms.

The WFO worked very quickly after the event to conduct detailed damage assessments. This information was placed on the office's Internet site. Feedback from partners and customers indicate this post-storm page is a tremendous resource for the community. The Emergency Manager for Carteret County sent an e-mail to the MIC regarding the site stating, *"The Isabel summary on your web page is fantastic and will be referred to many, many times over the next few weeks."* (**Best Practice 6**).

E. WFO Wakefield, Virginia

Overview

Over the inland areas of WFO Wakefield's CWA, winds from Isabel produced areas of damage more characteristic of microbursts associated with severe thunderstorms. In southeast Virginia and northeast North Carolina, the character of the wind damage was far more severe and widespread. In parts of Perquimans, Chowan, Pasquotank, Hertford, and Camden counties (North Carolina), scores of trees were completely uprooted and often snapped in half. Nearly 60 percent of all homes and business in Chowan County, North Carolina suffered some structural damage due to wind, many of which were the result of large falling trees.

One of the highest storm surges on record for the Chesapeake Bay region of Virginia accompanied Isabel. WFO Wakefield referenced the 1933 hurricane storm surges and water elevations as a historical comparison. In this case, emergency managers, local decision makers, and the public in coastal flood prone areas said the reference helped them prepare for potential impacts. Storm surges of 3 to 5 feet occurred along the Atlantic Coast resulting in significant erosion and structural damage to homes and roadways. Hardest hit areas included the James River estuary, where a surge of 8 feet occurred as far upstream as the Richmond Locks, 103 river miles from its confluence with the lower Chesapeake Bay. Many homes were significantly damaged or destroyed, especially in the towns of Claremont, Sunken Meadow and Burwells Bay. The surges in several tidal rivers caught some residents by surprise, both in height and severity.

A similar situation occurred along the northern shore of the Albemarle Sound in North Carolina, where a 3 to 5-foot surge impacted the eastern portion, and a 5 to 8-foot surge inundated the western portion. Some of the most significant storm surge flooding on the sound occurred on the western shore of the Chowan River estuary where it meets Albemarle Sound, just west of Edenton. A small cluster of four homes occupied year-round were completely destroyed by the surge, two of which were moved up to 20 feet off their concrete block foundations.

Isabel produced localized heavy rainfall with 5 to 10 inches of rain falling across the Wakefield CWA resulting in widespread river flooding. The James River at Richmond Locks experienced two separate flood crests; one late Thursday evening associated with the storm surge, and the second crest two days later associated with runoff from the heavy rainfall in the headwater region of the James River Basin.

The Wakefield staff was well trained and ready for Isabel. Products and services provided by WFO Wakefield were rated outstanding by many customers. This included emergency managers, state and local officials, the media, and local residents. The MIC of WFO Wakefield relayed a compliment from Senator George Allen of Virginia, "*We also emphasized [to Virginia Senator George Allen] the number of coordination calls we had with emergency managers. Senator Allen told us he talked to many local Virginia citizens and everyone had praise for the job that the NWS did. People were prepared and lives were saved because of our work.*"

Every member of the WFO Wakefield experienced some tree damage on their personal property and all of them lost power, some for as long as eight days. Three members commuting to work during the early afternoon on Thursday were unable to make it to the office due to winds downing large trees and blocking every major roadway leading to the office. One forecaster was able to return home, while some employees were turned away by police. They took up refuge at a Red Cross storm shelter which had been established at one of the local elementary schools. Ten staff members were in the office more than 24 hours since no relieving staff could commute to the office due to fallen trees. The office ran on backup power for six days.

The staff at WFO Wakefield commended the TPC for outstanding track forecasts throughout the duration of the event. ERH was very helpful through its Regional Operation Center (ROC) pre-coordination calls and made extra personnel available (**Best Practice 2**). ERH was proactive in reassigning normal service backup responsibilities away from Wakefield (to WFO Charleston, WV) when WFO Blacksburg lost communications during the storm (**Best Practice 7**).

Some residents across the region, whether inland or along the coast, simply could not relate to the impending strength of the storm and potential for damage. Some coastal residents failed to evacuate, or did so at the last minute. Others across the interior were stunned by the magnitude of the devastation to the trees and power infrastructure.

Home generators are becoming more available and it appeared new owners used them during and after Isabel with little knowledge of safety rules and appropriate ventilation. Three of the 34 indirectly related storm deaths in Virginia were caused by improper ventilation of home generators resulting in carbon monoxide poisoning. From the final report of the Commonwealth of Virginia's service assessment team:

> **In some areas no power meant contaminated water, loss of most forms of communications, activation of emergency back-up systems, and a rush to purchase generators, batteries, and portable radios. Despite warning labels and in some cases, information flyers sometimes distributed at the point of sale, people did not always follow safety precautions. Ignorance about the inherent dangers of generators and carbon monoxide poisoning contributed to three of the 34 (Virginia) hurricane-related deaths.**

Picture 2. A small cluster of four homes about 5 miles west of Edenton, NC, occupied year-round were completely destroyed by the surge, two of which were moved up to 20 feet off their concrete block foundations. (NWS Isabel Assessment Team photo by Dave Vallee.)

Fact - Home generators are becoming more easily available and affordable. The threat to life from carbon monoxide poisoning due to improperly ventilated generators is increasing proportionally. At least three people died of carbon monoxide poisoning in Virginia alone during Hurricane Isabel.

Finding # 2 -While carbon monoxide poisoning is considered by the NWS an indirect threat to life from the storm, a "call to action" statement for carbon monoxide poisoning included in NWS products could help reduce the threat.

Recommendation # 2 - Regions should work with their WFOs to develop a "call to action" statement for carbon monoxide poisoning to be used whenever a threat of extended power outages exists (e.g., not only hurricanes but also ice storms). This statement should be included in NWS warning generating programs and outreach materials.
Before the Event

An HWO issued by WFO Wakefield early in the morning on September 14 first mentioned the possibility of a threat from Hurricane Isabel. That afternoon, the WFO issued a Public Information Statement (PNS) containing hurricane preparedness information and a Special Weather Statement (SPS) highlighting increasing chances of Isabel affecting the area later in the week.

Frequent coordination calls began early in the week with state and local officials, while the office continued to headline increasing chances of a direct impact from Isabel with HWOs and SPSs. The office enhanced river and small stream flooding awareness with the first of several Hydrologic Outlooks issued on the morning of September 16. Coordination extended to the Southeast River Forecast Center during the day which was already running river model guidance with basin average rainfall of 2 to 5 inches. These forecasts indicated the potential for moderate flooding along the Meherrin, Nottoway, and Blackwater rivers in southeast Virginia.

On September 17, the HWO stated, *"An extremely large wind field will cause many trees to be downed."* This statement was repeated in an HWO issued at 5:35 a.m. September 18. The WFO was also vigilant concerning rip currents; HWOs issued before Isabel's landfall highlighted the risk of rip currents.

During the event

ERH has a policy to initiate a pre-coordination call 1 to 2 hours before the actual TPC lead coordination call. This process allows the WFOs and TPC to coordinate watch/warning breakpoints and track forecast reasoning before the full coordination call. This did not occur for the initial issuance of the Hurricane Watch Tuesday morning September 16. Neither ERH nor the affected offices were contacted by TPC before the 10 a.m. full coordination call during which the watch issuance decision was made. Both ERH and WFO Wakefield believe that even a brief advance notice of TPC's intent would have given them more time to discuss the issue and offer any suggestions or concerns.

The TPC wind grids based on their updated 4 a.m. EDT Wednesday, September 17, conference call, were not available until after 5 a.m. This resulted in Wakefield holding text products and grid forecasts until 6:30 a.m. Wednesday morning. On Thursday morning, an early suite of forecasts was issued by 3:30 a.m. rather than hold the products through the conference call. Another suite of forecasts and grids were produced between 6:30 a.m. and 7 a.m. to reflect the refined wind radii and timing of landfall (**see Recommendation 1**).

Most forecasters suggested six hourly TPC wind grids did not provide enough temporal resolution. NDFD requirements call for three hourly wind grids for all forecast offices. At six hour intervals, the core of the hurricane was never physically present over the CWA. As a result, forecasters had to manually create a grid depicting the core of the hurricane for the periods between the six hourly guidance grids. Future development work by NOAA's Forecast Systems Laboratory (FSL) in Boulder, CO, is expected to solve this problem.

As all WFOs are doing, WFO Wakefield produces text products from the forecast grids using the GFE formatters. In order to automatically insert headlines for watches and warnings

into the text products, a headline grid is created in GFE. WFO Wakefield found this method to be very cumbersome. When multiple headlines are required in complex weather situations, the grids became difficult to read. Due to small and complex county boundaries, some counties were inadvertently included in some headlines and missed in others. It took a significant amount of manual intervention to ensure the proper locations had the appropriate headlines for various events.

The WSR-88D 8-bit reflectivity and velocity products were invaluable products for short-term analysis. These high resolution products clearly depicted very fine mesoscale features in the wind field and captured the reorganization of the eye wall as Isabel approached Albemarle Sound. The 8-bit product, when compared with the 16-level data product, was far superior in identifying details in the wind field. Wind speeds near 133 mph were visible on velocity products at the 5,800 foot level, with speeds as high as 116 mph at the 1,800 foot level, 80 mph at the 1,000 foot level and 74 mph at the 300 foot level during the event. This information enabled WFO Wakefield to issue highly detailed and urgent SPSs for parts of its service area addressing the imminent threat of high winds and the recommendation for residents to remain in a secure place.

Real-time deterministic SLOSH runs were beneficial in highlighting the most likely areas of greatest storm surge. SLOSH verified quite well along the eastern shore of the Chesapeake Bay, the Hampton Roads area, and over the lower portions of tidal rivers of Virginia and Maryland. SLOSH was also showing the potential for surges greater than 6 feet on the tidal reaches of several rivers and on the west side of Albemarle Sound. The consensus in the Wakefield office was that the deterministic SLOSH runs were beneficial.

WFO Products and Services

External customers believed WFO Wakefield was accurate and consistent in its forecasts. All said the forecasts matched the resulting magnitude of the event and there was no confusing or conflicting information between WFO Wakefield and adjacent offices or national centers. WFO Wakefield issued 130 hazardous weather products of various types, including 43 Flood Statements and Warnings combined. The vast majority of the information contained in the products was considered excellent. For example, Jim Mathias, mayor of Ocean City, MD, stated, "*Forecasting and information was excellent.*" He added that the five-day forecast by TPC was extremely helpful in his preparedness and awareness.

WFO Wakefield forecasters believe the potential for damage to trees and the resulting power outages could have been highlighted better. External customers, despite the consensus opinion they received adequate strength and track forecasts, did not anticipate the breadth of tree damage, power loss, and high wind speeds so far inland. There was some inconsistency in the expected tree damage and its effect on infrastructure provided by WFO Wakefield in its written products. A PNS issued on September 14, discussed the potential for strong winds inland with the phrase, "*...strong winds...coastal and inland areas...*" On September 16, a PNS contained the statement "*assume power and water may be off for several days to several weeks after the hurricane*

passes." Unfortunately, the PNS was only coded for coastal counties. An Inland Hurricane Wind Watch and an Inland Tropical Storm Wind Watch, issued at 6:40 a.m. September 17, contained the statement, "*widespread power outages will be possible*." In an update to the product issued at 11:19 a.m., the following statement was included: "*numerous trees and branches may be blown down.*" At 4:20 p.m., when an Inland Hurricane Wind Warning and an Inland Tropical Storm Wind Warning were issued, the inland risk was downplayed, stating that only large branches, and small-to-medium sized rotting trees, would be downed by the winds of the storm.

WFO Wakefield also used WSR-88D storm relative wind products for the issuance of Tornado Warnings. The WFO issued three Tornado Warnings during the event, in effect for four counties. One warning did not have a follow-up SVS. The only tornado (F0) occurred in the City of Norfolk outside the warning times.

Also, two county Flood Warnings were issued by WFO Wakefield. No Flood Statements were issued as a follow-up to these warnings. NWS Directive 10-922, section 4.6.4a 7.2.2, states that one issuance criterion for Flood Statements is, "*cancellation or expiration of a Flood Watch or Warning*."

River flooding at gaged sites was handled very well by WFO Wakefield. A total of 43 Flood Warnings and Flood Statements were issued for various river basins in the WFO Wakefield Hydrologic Service Area (HSA) between 7:22 p.m. EDT September 18, and 4:43 a.m. EDT September 25. These statements gave good detail on flood stages, flood intensity, crest stages and times, and comparisons to past events.

Detailed PNSs were issued by WFO Wakefield at 8:50 p.m. and 11:20 p.m. September 19 describing preliminary wind, rain, storm surge, and tornado information from the storm. Comprehensive Post-Storm Hurricane Reports (PSH) were issued by WFO Wakefield at 4:45 p.m. September 22, 6:57 p.m. September 22, at 11:05 p.m. September 24, and 3:25 p.m. September 26.

Several storm surveys were completed in the aftermath of Hurricane Isabel. Following one storm survey, at Claremont in Surry County, Virginia, the Wakefield MIC issued a detailed PNS on the findings of the survey. Members of the assessment team learned first-hand from Claremont citizens of the value of this survey to work with FEMA and insurance agencies on damage claims.

WFO Wakefield issued only nine Short Term Forecasts during the entire storm, all between 8:21 a.m. and 2:01 p.m. September 18, and three SPSs between 3:31 p.m. and 4:44 p.m. as the eye moved into the Wakefield CWA (**See Recommendation 8**). The wind information contained in WFO Wakefield's products, while general at the beginning of the event and through the watch phase, more precisely indicated the threat to life and property due to strong winds and long duration power outages in later statements.

WFO Wakefield staff was well prepared for the arrival of Hurricane Isabel. The office training plan routinely includes sessions addressing tropical cyclone forecasting issues. During the spring of 2003, WFO Wakefield hosted a TPC Hurricane Specialist as one of its primary presenters at an office meeting. WFO Wakefield routinely incorporates the WES to address operational forecast and warning issues concerning tropical cyclones. Over the past two years, this has included tornadoes associated with land falling tropical cyclones. WFO Wakefield frequently participates in pertinent VISIT teletraining sessions, which for 2003 included the Flash Flood Monitoring and Prediction System (FFMP). WFO Wakefield routinely conducts program drills, which in 2003 included a spring severe weather drill and an August hurricane drill. Several forecasters commented that they used the hurricane drill as a ready reference throughout Hurricane Isabel.

WFO Wakefield is active in providing public presentations on hurricanes and severe weather. Their activities have included many public safety fairs directly addressing the hurricane concern. One such event, in Norfolk, VA, was conducted just one week before Hurricane Isabel. Likewise, the office has a well-developed Skywarn program and spotter network. Seminars are provided frequently during the year and are well attended. The Wakefield office continues to pursue StormReady communities, and has established one in Newport News, VA.

Systems and Equipment

NWR equipment at the office worked well during the event. Hazardous weather products were disseminated using the proper tone alerts and EAS SAME codes. Instructions for issuing hazardous weather products via tone alerts and EAS SAME codes are mounted on the wall of the NWR broadcast room at WFO Wakefield. The Heathsville NWR went off the air during the height of the storm, and it does not have a back-up power source. WFO Wakefield received complaints regarding the loss of the Heathsville transmitter during the hurricane. One person stated, "*I purchased NWR hoping to rely on it, then it went down when it was needed the most. There should be back-up power at NWR sites*." The transmitter was still out of service seven days after the event. This transmitter is located in a very remote area with poor security, the tower is in poor condition, and vandalism has occurred. The transmitter has corroded components, and relays and mounts for the antenna show signs of rusting and fatigue.

ERH and WFO Wakefield are working with the U.S. Navy to move the location of the Heathsville NWR to a better location just west of Reedville, VA. The Naval facility has a secure, sturdy tower with back-up power. The Reedville site, being closer to the Chesapeake Bay, would improve NWR coverage for the Chesapeake Bay and the lower Delmarva Peninsula.

Fact - The Heathsville NWR site was not reliable. Many complaints about the site's lack of service during Hurricane Isabel were received by NWS employees.

Finding # 3 - The Heathsville NWR site is quite important since it provides NWR coverage for Chesapeake Bay shipping and the residents of east-central Virginia counties. It is important that this site be more reliable in its operation.

Recommendation # 3 - ERH and WFO Wakefield should acquire a new transmitter and work with the U.S. Navy to ensure consistent, improved NWR services for east-central Virginia.

Also, the NWR site at Mamie, NC located in Currituck County was out of service due to a loss of commercial power and the site back-up generator failed. This is a privately owned site using space leased from a TV station.

The cycle length on NWR during Isabel averaged 25 minutes due to lengthy products such as HLSs. As a result, critical information important to customers was only broadcast twice an hour. The NWR Console Replacement System (CRS) offers limited ability for products to be broadcast at only selected times.

Power to the ASOS and Automated Weather Observing System (AWOS) sites became a significant issue. Sites in the southeast part of the Wakefield CWA failed late Thursday morning as winds began to reach sustained tropical storm force. By mid-afternoon on September 18, all but three ASOS sites were down and remained out through the storm. This had a significant impact on the office's ability to determine what percentage of wind speeds shown on the 8-bit WSR-88D velocity products was making it to the ground in either sustained winds or gusts. The ASOS outages also affected the official climate record for several sites due to the inability to determine maximum and minimum temperatures, precipitation, and highest sustained wind and gusts (**Recommendation 11**). Only the Norfolk site continued to provide reports, thanks to the dedication of the contracted observers, who called in their observations at hourly intervals. Rainfall data for the storm was not collected by contract observers because that is not a current requirement in the agreement.

Only one third of the ASOS sites in the WFO Wakefield CWA have a 30 minute uninterruptible power source (UPS) unit for short duration power outages. Once that 30 minute period has passed, the site becomes inoperative. Three sites have no short duration UPS units at all, including Wallops Island, Hanover and Ocean City. Once power returned, service was not restored because phone lines remained out. Power surges after the commercial power was reestablished resulted in other component failures.

The Unit Control Position (UCP) connection from WFO Wakefield to the Dover, DE WSR-88D Radar was lost Thursday afternoon, September 18. The Dover WSR-88D data continued to flow but the WFO lost the ability to control the radar. The radar had been configured for hurricane operations in advance, so the loss of the connection had little impact on operations.

Feedback from Customers and Partners

In preparation for the event, conference calls were held twice daily between the Virginia Department of Emergency Management (VDEM), 18 Virginia counties and communities, and the NWS. All believed the calls were very helpful. The information provided in the conference calls was considered timely and accurate overall. VDEM Director Michael Cline said, "*Unless you were deaf, dumb, and blind you had to know [what to expect].*" Jim Mathias said, "*The forecasting and information was excellent.@* Members of the conference call interview also praised the consistency of the forecasts. Comparisons to the 1933 storm raised awareness as well.

Despite the fact sufficient forecast information was provided, those interviewed found it hard to believe the impact of downed trees and lost power would be as significant well inland. One individual said, "*The products were there and the information was in front of us, but we may not have had as much belief and that is our fault.*" VDEM strongly believes the wet antecedent conditions were a major factor to the wind blowing down so many trees.

The VDEM believed all NWS offices serving Virginia provided excellent support to the state. VDEM stated NWS services provided for them are much better than 15 or 20 years ago. WFO Baltimore-Washington was not initially invited onto the Virginia conference calls because of the impact expected primarily in the WFO Wakefield CWA. Upon discovering that the conference calls were being held, representatives of WFO Baltimore-Washington were proactive in asking to be allowed to participate in the calls. VDEM considered the WFO's information valuable.

The VDEM considers mean lower low water (MLLW) to be a very confusing term. Explanations of the term from the NWS had to be provided several times. Several employees of VDEM frankly admit they still do not understand (**See Recommendation 7**).

The VDEM believes emergency services and the public of inland counties did not prepare well for Isabel, especially in areas from Richmond northward. VDEM stated, "*Sufficient word went out,"* but there was "*some true disbelief at the local level."* VDEM is convinced a larger percentage of the population was better prepared than during previous storms, partly due to comparisons with the 1933 storm. Even so, the threat was perceived to be less far inland.

Wayne Robinson, of Dorchester County, Maryland, Emergency Management recalled a statement made in a conference call at 8:30 p.m. September 18, stating the worst of the rain and wind was over. Mr. Robinson felt this was misleading, since around 10 p.m. storm surge inundated areas in the south part of Dorchester County, lasting until September 19.

The only tidal gauge near Dorchester County, Maryland, is on the north end of the county, near the community of Cambridge. The Chesapeake Bay narrows near the south end of Dorchester County, and the storm surge measured at Cambridge was not representative of the surge in the south end of the county. WFO Wakefield staff members described how the

Cambridge readings and actual observations in the south part of Dorchester County could differ by as much as 2 feet. Dorchester County is a growing area of southeast Maryland.

Fact - The tide gage at Cambridge, MD is unrepresentative of tide conditions for the southern shore of Dorchester County. EM officials in Dorchester County need better information for the southern shore in order to carry out their responsibilities.

Finding # 4 - The network of coastal water level monitoring stations was strategically designed. Recent growth and development require continual adjustment of this network and possibly the development and installation of additional monitoring stations or related statistical schemes to describe conditions away from gaging locations.

Recommendation # 4 - NWS should study adequacy of tide gage monitoring sites and develop a priority list to implement new gages.

NWS Wakefield also participated in conference calls with emergency services officials from Delaware, Maryland, and North Carolina. Several NWS Wakefield staff members participated in these calls, primarily members of the NWS Wakefield management team (MIC, SOO, or WCM). Sometimes conference calls among different agencies were being held simultaneously and the NWS Wakefield staff ensured staff members were available to handle all calls efficiently.

Consensus of the television meteorologists was NWS Wakefield did a great job in its forecast, and the, "*information was great even as early as the Saturday before.*" They believe the magnitude of the event matched the information received from the NWS.

The media believes forecasts and other information were disseminated with substantial advance notice, giving the public plenty of preparation time. John Bernier from WRIC TV in Richmond, said, "*TPC is on a hot streak,*" and gave TPC a lot of credit for good forecasts not only for Isabel, but for Fabian and Juan. Jim Duncan, of WWBT TV, also in Richmond said, "*Everything was right on,@* and he remembered WFO Wakefield discussing significant tree damage in its statements as early as September 14.

All of the on-air meteorologists took the NWS information and portrayed the impending hazards to their viewers. Jon Cash, of WAVY TV in Norfolk, said he advised viewers of the potential for loss of power for days or weeks, with trees down, "*all over.*" Such information was conveyed by NWS Wakefield in a PNS issued on September 16, "*Assume power and water may be off for several days to several weeks after the hurricane passes*." John Bernier told his viewers, "*Thursday may be the most arduous day of your life.*" Bob Burnett-Curie, from WBOC TV in Salisbury, MD, felt WFO Wakefield sent out the appropriate message of a strong storm, but it would not be a superstorm. Mr. Burnett-Curie thought the public heeded messages, and in the Salisbury area businesses closed down on time.

Mr. Burnett-Curie claimed the rainfall forecast was high. Reports showed rainfall amounts between 2 to 4 inches in the Salisbury area. Some of his weather spotters, along with reports from Wallops Island, VA and Pocomoke, MD, reported rainfall totals under an inch. The NWS forecast rainfall was consistently between 6 and 10 inches in Flood Watches issued by WFO Wakefield from September 17, through September 18.

Bob Burnett-Curie and Jon Cash believe the HLS product is too lengthy. Both suggested the updates to HLSs should more effectively describe the changes being made. Mr. Cash pointed out the difficulty in finding minor changes in an HLS. Despite WFO Wakefield issuing 14 LSRs between 10:15 a.m. and 11:57 p.m. September 18, Mr. Cash requested more current damage information in NWS products.

Bob Burnett-Curie contends that determining the tide when NWS offices use MLLW is difficult, suggesting few people know what that term means. A term is needed which will simply explain how much water will occur (**See recommendation 7).**

WGH Radio is the LP1 station for EAS serving the Norfolk area. Station engineer Keith O'Malley stated the EAS worked well until the Norfolk/Driver NWR transmitter stopped functioning. After the NWR stopped working, Mr. O'Malley coordinated with forecasters at Wakefield and was told he would need to rely on the Internet to get copies of NWS products. Mr. O'Malley said his biggest concern was for tornadoes, and without the NWR functioning, he was left, "*hanging in the wind*," and, "*out on their own*." The Wakefield office has explicit, detailed procedures in place to activate local EAS systems when NWRs are off the air (**Best Practice 8**). The procedures include a contact telephone number for WGH; text to give over the telephone highlighting the weather emergency, providing authentication; and provisions to contact the Virginia State Emergency Operations Center if NAWAS is also down. However, the procedures are only to be used in case of Tornado or Flash Flood Warnings. The Wakefield office did not issue any Tornado or Flash Flood Warnings after the Norfolk/Driver NWR stopped working.

F. WFO Baltimore/Washington

Isabel will be remembered in the Baltimore-Washington area for the very large field of tropical storm force winds which caused a great deal of tree damage, the extensive flash flooding it caused in the Shenandoah Valley, and the unusually high storm surge in the Chesapeake Bay and Potomac River Basin. Fallen trees and limbs were the overwhelming reason for widespread power failures and damage and destruction to nearly 8,000 homes, which will likely make Isabel one of the most expensive storms in Virginia history. Four people lost their lives in the WFO Baltimore-Washington area directly because of Hurricane Isabel (**Appendix B**).

Overall, WFO Baltimore-Washington did well in providing products and services to customers in its CWA. Through an excellent conference call infrastructure developed by the

Washington, D.C. Metropolitan Area Council of Governments, jurisdictions in the D.C. area received timely briefings from the WFO before and during the event. The National Warning Circuit (NAWAS) was used extensively for outlying cities and counties. The main topic of confusion pointed out by emergency managers was the reference height used in storm surge forecasts (**See Recommendation 7**).

Although the information flow from the WFO to the media was good before Isabel, the flow of information decreased during the event. The Tropical Storm Warning was broadcast on NWR but the product was not SAME coded with the 1050 MHz tone. This was not used because specific codes do not exist for Tropical Storm Warnings. Therefore, EAS was not activated for this product.

WFO Baltimore-Washington's response and service during Isabel were excellent. The team received commendations from the public, emergency management and the broadcast media on WFO Baltimore/Washington's performance. The forecasts, watches, and warnings for Isabel were accurate, timely, and well done. WFO Baltimore-Washington advised customers five days before landfall Hurricane Isabel could affect the region. Preparedness information was provided to customers four days before the event. Extra staff was provided to the WFO by ERH and WSH from Wednesday, September 18 through Friday, September 19 (**Best Practice 2**). Extensive coordination via telephone, NAWAS, and in-person briefings took place before and during the event between WFO Baltimore-Washington and emergency managers in its CWA (**Best Practice 9**). The workload on the WFO staff was huge, especially conducting more than 500 briefings and calls. Richard McKoy, Emergency Manager for the City of Baltimore, stated his office spoke with WFO Baltimore-Washington several times via NAWAS. He was satisfied with NWS services. He specifically singled out the Baltimore-Washington WCM as providing excellent service to the EM community. He did note that storm surge height was under-forecast but he said they had ample advance notice to plan for the event.

Before the Event

Several conference calls were held with the Metropolitan Washington Council of Governments Tuesday and Wednesday, September 16 and 17. A conference call Wednesday resulted in a decision by the Metropolitan Transit Authority to stop running buses and light rail at 11 a.m. Thursday, September 18. Based on this decision, regional schools cancelled classes for Thursday and the Federal Government's Office of Personnel Management closed federal buildings on Thursday. Washington's Reagan National and Dulles International Airports planned for Isabel impacts to begin Thursday afternoon. Airlines moved aircraft and personnel out of the area to lessen impact on their operations. Local governments and jurisdictions planned for storm surge impact along Chesapeake Bay Thursday night. Fairfax County advised residents along the Potomac River that flooding could result in evacuations Thursday night.

ERH assigned extra personnel from other offices to the Baltimore-Washington WFO from Tuesday, September, 16 through Friday, September 19 (**Best Practice 2**). WFO MIC James Travers also requested assistance from nearby NWSH. Several volunteers from NWSH and NOAA Public Affairs helped the WFO with media interviews Wednesday and Thursday.

During the Event

Rain and wind increased over the southern portion of the CWA Thursday morning. This spread into the Washington metropolitan area at mid afternoon and into the Baltimore area by late afternoon. Peak wind gusts during the event ranged from 48 mph at Dulles International Airport to 78 mph at Quantico Marine Corps Air Base. The MIC estimated thousands of trees were blown down across the Baltimore-Washington CWA. More than 700 trees were destroyed in the District of Columbia alone. Due to the massive tree fall, commercial power was lost to most of the region overnight Thursday and remained out of service in many locations for several days. More than 2 million customers were without electricity in the Baltimore-Washington CWA because of Isabel. Although storm-caused tree damage is a common problem in Baltimore-Washington CWA, tree falls likely increased with Isabel due to wet antecedent conditions across the region. Precipitation in the Baltimore-Washington CWA was 10 to 20 inches above normal before Isabel.

WFO Products and Services

The first product mentioning a threat from Hurricane Isabel was the HWO issued on Thursday, September 10, 2003, a full week before Isabel made landfall in North Carolina. WFO Baltimore-Washington began their planning and response to Hurricane Isabel's threat as early as Sunday, September 14, with a PNS specifically advising residents of the CWA of Hurricane Isabel's potential impacts. It also included specific actions for immediate preparation.

WFO Baltimore-Washington's products before, during, and after the Hurricane Isabel were very good overall. The products were well written, accurate, specific and contained valuable advice to residents about winds, tides, rainfall, flood potential, and the possibility of isolated tornadoes. Appropriate watches and warnings were composed and transmitted with appropriate lead times according to the Directives. HLSs were issued regularly. Based on opinions from emergency management and the media, more emphasis and detail concerning storm surge flooding were needed in the HLSs.

Rainfall forecasts contained in products from HPC, TPC, and the WFOs, were consistently 3 to 6 inches in the Baltimore-Washington metro area and 6 to 10 inches with local amounts to 15 inches possible elsewhere. These forecast amounts were well above flash flood guidance. The WFO issued a Flash Flood Watch at 11 a.m. EDT Wednesday, September 17, from Thursday night through Friday night.

The most rainfall occurred in the Shenandoah Valley and the Blue Ridge Mountains where 4 to more than 20 inches of rain were reported. The maximum 24-hour rainfall, 20.20 inches, in the CWA was reported by an Integrated Flood Observing and Warning System (IFLOWS) gaging site at Upper Sherando in Augusta County, Virginia. This gaging site is in the headwaters of the South River, which flows through the city of Waynesboro, VA. Reports in excess of 10 inches were received from Devil's Knob (10.70 inches) in Nelson County and Big Meadows (11.10 inches) in Page County for the same 24-hour period. Rainfall across northern Virginia, Maryland and the District of Columbia was less, ranging from 1 to 3 inches and from 2 to over 6 inches in

eastern West Virginia. Extensive flash flooding accompanied the rainfall in eastern West Virginia and the Shenandoah Valley of Virginia. WFO Baltimore-Washington issued Flash Flood Warnings for 28 counties and independent cities during Hurricane Isabel. Moderate to major main stem river flooding occurred in the North Branch of the Potomac Basin, the South Branch of the Potomac Basin, the Shenandoah Basin, the main Potomac Basin, the Rapidan Basin, and the Rappahannock Basin.

The WCM contacted officials and emergency managers for the City of Waynesboro and for Augusta County, and based on the report of 20.20 inches at Upper Sherando and a briefing by the WCM, over 100 people were successfully evacuated from the area.

The torrential rains in Augusta County caused flash floods on Back Creek, the St. Mary's River, Mill Creek, and Coles Creek, all tributaries of the South River, which flows through Waynesboro and north through the Shenandoah Valley. Extensive runoff in the high terrain caused flows over emergency spillways, including a stage of about 2.5 feet above the emergency spillway at Mill Creek Dam which caused substantial damage to the dam. The water also caused a rapid rise to a crest near 13.9 feet between 4 and 5 a.m. EDT Friday, September 19, on the South River at Waynesboro, where the record flood is 15.3 feet. The flood caused 2 to 3 feet of water in downtown businesses in Waynesboro, where emergency management personnel evacuated about 300 people and about $250,000 damage was caused to public property. About 200 FEMA claims had been filed as early as October 1, 2003, in Waynesboro due to the flooding.

The only forecast problem mentioned by VDEM was the Quantitative Precipitation Forecast (QPF) for parts of northern Virginia. Though the heaviest rain occurred in a small location at the head of a valley, the VDEM reported that flash flooding picked up mobile homes and washed the backs out of some houses. WFO Baltimore-Washington continued to mention the possibility of up to 6 inches of rainfall after totals had exceeded 6 inches in some locations. Flood watches were in effect, but VDEM believes the NWS products could have raised the level of flood awareness sooner for areas with excessive rainfall.

Some WFO staff believes the QPF from HPC was conservative and this led to low river forecasts on September 18. Since HPC issues QPF on a broad scale for the entire nation, it will not necessarily capture small scale rainfall maxima. The WFO did request contingency river forecasts with higher QPF amounts later that same day, but the official river forecasts issued from the WFO did not include the higher WFO QPF. Flood warnings using river forecasts containing QPF were also not issued.

The Middle Atlantic River Forecast Center (MARFC) main stem river forecasts for the WFO Baltimore-Washington HSA were low on Thursday, September 18, because the QPF included was low for the basins where the heaviest rain fell. The MARFC uses QPF from the HPC adjusted by the HAS unit as standard procedure for main stem river forecasts. MARFC will often adjust QPF used in the main stem river forecasts based on coordination calls with WFOs in the MARFC service area. QPF made by WFO forecasters in the GFE for the IFPS grids is not used by RFCs for use in their river forecasts, and therefore the coordination calls between the

WFOs and the RFCs remain necessary to ensure the appropriate amount of QPF is used by the RFC. The Service Hydrologist position must be a vital player in coordination of this type.

River forecasts issued by MARFC were included in Flood Warnings and Flood Statements issued by WFO Baltimore-Washington and these were accurate, timely, and properly formatted. Coordination between MARFC and WFO Baltimore-Washington was not always accomplished, however, as the event progressed.

Issuance Date	Issuance Time	Office	Forecast Crest	Crest Date	Crest Time
9/18	10:40 p.m.	MARFC	15.0	9/19	8:00 p.m.
9/19	2:54 a.m.	WFO-BW	23.0	9/19	6:00 p.m.
9/19	3:38 a.m.	MARFC	19.1	9/19	3:00 p.m.
9/19	9:24 a.m.	MARFC	23.5	9/19	2:00 p.m.
9/19	2:25 p.m.	MARFC	23.9	9/19	8:00 p.m.

Table 4. Chronological listing of the products from the MARFC and the WFO for the Shenandoah River near Lynwood, VA during the period 10:40 p.m. September 18 to 2:25 p.m. EDT, September 19.

Fact - WFO Baltimore-Washington updated the forecast for the South Fork of the Shenandoah River near Lynnwood without coordinating with MARFC. Thus, the forecast crest for Lynnwood from MARFC differed from the forecast crest in the Flood Warning issued by WFO Baltimore-Washington from 2:54 a.m. EDT until 9:24 a.m. EDT Friday, September 19. NWS Directive 10-921 section 3.1.2 states that for large scale forecast points, WFOs must coordinate changes or disagreements with the RFC forecast with the responsible RFC. In the event consensus cannot be reached, the WFO must use the RFC values in the official forecast.

Fact - The crest forecast issued by WFO Baltimore-Washington at 2:54 a.m. EDT Friday, September 19 was more accurate than the crest forecast issued by MARFC at 3:38 a.m. EDT Friday, September 19.

Fact - There is no evidence that the inconsistency between the forecasts issued by WFO Baltimore-Washington and MARFC for the Lynnwood forecast point caused confusion or resulted in bad decisions by local emergency management agencies but it could have. The inconsistency occurred late at night and early in the morning.

Fact - The WFO Baltimore-Washington Service Hydrologist position is part time, 24 hours per week. Several WFO Baltimore-Washington employees, MARFC employees, and emergency management personnel in Virginia interviewed believe a part time Service Hydrologist position at WFO Baltimore-Washington hurts the program.

Finding # 5 - The WFO Baltimore-Washington Hydrologic Service Area contains complex terrain, including mountains, plains, valleys, and coastal effects across 3 states and the District of Columbia, with a population of approximately 8 million people. Flash flooding is a very real threat in the mountains and valleys, not to mention main stem river forecast responsibility and flooding potential. Coordination between WFO Baltimore-Washington and MARFC was not consistent during Isabel, and the team believes a part-time Service Hydrologist is part of the problem. The WFO Baltimore-Washington HSA desperately needs a dedicated full-time Service Hydrologist who can handle the training, coordination, field work, and technical responsibilities inherent with this position.

Recommendation # 5 - Eastern Region should maintain the Service Hydrologist position at WFO Baltimore-Washington equal to one full-time equivalent.

Storm surge late Thursday night and Friday morning in the Chesapeake Bay at Baltimoreand Annapolis, MD reached the highest levels since a hurricane in August 1933. The peak water level at Baltimore was 8.1 feet above NGVD at 8:06 a.m. EDT Friday, September 19 and at Annapolis the water level peaked at 7.3 feet NGVD at 7:42 a.m. EDT Friday. At Washington, D.C., (Water Street headquarters of the police and fire harbor patrol) the Potomac River water level peaked at 9.7 feet NGVD Friday morning around 4:42 a.m. EDT.

Flooding caused by Hurricane Isabel caused extensive damage at the Naval Academy in Annapolis, MD (**see picture 4 page 39**). Half the classrooms were unusable. Lab equipment, plumbing and ventilation systems were also damaged. Several buildings were sandbagged, but officials say they underestimated the storm. Some parts of campus were covered by eight feet of water. Spokesman Rod Gibbons said the flood damage was, "*unprecedented*."

Significant flooding occurred in the low-lying areas of Old Town Alexandria. Portions of King Street near the intersection of Union Street were under as much as 5 to 6 feet of water. The area is about two blocks from the Potomac River. Sergeant Steve Carr with the city's police department called the amount of water, "*very unusual.*" One resident who has lived in the area for 20 years said the situation was, "*insane*." In northern Virginia, flooding was the worst ever in the Belle View subdivision south of Alexandria in Fairfax County. Fairfax County emergency management declared a mandatory evacuation of the Belle View neighborhood, but many residents chose to stay anyway.

Fairfax County's Stormwater Planning Division (SPD) conducted town hall meetings for Belle View residents and distributed flyers concerning the expected flooding. Carl Bouchard, P.E., Fairfax County SPD, calculated storm surge levels to MSL rather than MLLW. He was then able to map likely flood/evacuation areas based on their elevation maps. The county was then able to pinpoint where action was needed. Mr. Bouchard suggested storm surge forecasts be converted to shape (.shp) files so that they can be sent electronically to cities, counties and the media for application to topographic and land use maps. The electronic data then could be

referenced to either MLLW or MSL. With the focus in the HLSs on rainfall and river flooding rather than storm surge flooding, there was some confusion on the part of local governments and citizens during the event itself. When the storm surge began flooding Belle View and Old Town Alexandria, only 1.5 inches of rain had fallen thus far at Dulles International Airport. Again, HLSs and supporting statements need to emphasize the most important threat first.

Picture 3. Storm surge flooding in Baltimore's Inner Harbor from Hurricane Isabel. Courtesy of Maryland Historical Trust Internet site.

WFO Baltimore-Washington forecasted the surge height to reach 9 feet MSL in these areas in advance of the storm causing the emergency manager to block the streets below 10 feet MSL in preparation for the storm. The water reached 9.5 feet MSL.

Reactions from residents varied considerably. One woman from the Belle View Apartments said, "*I evacuated after hearing about the storm surge on the evening news* (TV)." Another resident did not evacuate stating, "*When I went to bed, water was not over the road. It did not look as bad as Agnes (1972), so I didn't think it would get that bad*." His home sustained 3-4 feet of water from storm surge.

Picture 4. Storm surge flooding from Isabel at the U.S. Naval Academy in Annapolis, MD. Courtesy of U.S. Naval Academy Public Affairs.

In Baltimore, the most extensive flooding was at Fell's Point and Inner Harbor, near downtown. There, several feet of water inundated streets and alleys. The Police Headquarters was flooded with damage to backup generators.

WFO Baltimore-Washington policy is to have HLS composition assigned by the Forecaster-In-Charge (FIC) on each shift. During the event, HLSs focused more on rainfall-driven inland flooding at the expense of awareness of storm surge flooding. Little was added to storm surge flooding detail over that issued by TPC. Veronica Johnson, local television meteorologist at WRC-TV, expressed a desire for more information for points along Chesapeake Bay so surge flooding could be applied to specific communities. She said, "*The Baltimore-Washington office did well in preparing the media and everyone for the storm. However, the broadcast media could have used more frequent NWS info during the event as television was providing continuous coverage (wall to wall). Also, storm surge info was not detailed enough to make it easy for the*

media to apply the forecast to specific neighborhoods and communities along the Potomac and Chesapeake Bay." Several emergency managers expressed a desire for more accurate storm surge forecasts and using mean sea level as the elevation on which to measure storm surges. Other aspects of the HLSs were well done and understood by emergency managers and media. Wind effects were well covered in Tropical Storm Inland Wind Watches and Warnings.

Fact - Substantial flooding from storm surge was experienced by residents and businesses in Baltimore, Annapolis, northern Virginia, and Washington, D.C., as well as along the coast of the mouth of the Potomac River and the coast of Chesapeake Bay. While not record flooding, it was the highest storm surge since at least 1942.

Finding # 6 - The NWS/TPC has a responsibility to convey information about storm surge in advisories on tropical cyclones. That information is enhanced and expanded to the local level in WFO HLSs. The WFO Baltimore-Washington HLSs did include information about storm surge along the Potomac River and Chesapeake Bay for Hurricane Isabel, but only in very broad and general terms. In fact, it was for the most part repeating the information in the TPC advisory. The WFO did not include vital information about the expected time of the maximum surge or specific information available from emergency managers about evacuations or areas that would likely experience the worst flooding.

Recommendation # 6 - WFOs affected by Isabel should use the high water mark information from Isabel's storm surge flooding in their CWAs to enhance knowledge and ability to predict future storm surges. Future HLS issuances from WFOs should include specific information concerning localized effects from storm surge including forecast times of the maximum water level and potential effects. Information from emergency managers on voluntary or mandatory evacuations should also be included as available.

Fact - Interviews with media, and emergency management and storm water drainage personnel revealed confusion over the exact height of the storm surge expected.

Finding # 7 - Emergency Managers, media and storm drainage personnel could use Storm Tide forecasts (a forecast of the total height of water expected) more effectively than storm surge and normal tide forecasts.

\Recommendation # 7 - WFOs should highlight any Storm Tide forecasts in their tropical cyclone products and emphasize the total height of water expected. Any Storm Tide forecasts should be referenced in NGVD 1929 since most storm surge maps are referenced in NGVD 1929.

Fact - Only seven short-term forecasts (NOWs) were issued by WFO Baltimore-Washington during the Isabel event (from Wednesday, September 17, evening through Friday, September 19, noon). Nine NOWs were issued by WFO Wakefield during the Isabel event, and 19 NOWs were issued by WFO Newport. Guidance on the issuance of NOWs varies widely from region to

region and even from WFO to WFO. Some WFOs embrace the NOW product whole-heartedly and issue them frequently, while other WFOs have all but abandoned the product.

Finding # 8 - Interviews with emergency managers and media in both the Wakefield and Baltimore-Washington CWAs revealed a need for more real time information on short-term trends in the hurricane's progress. Real-time damage reports, times of onset of tropical storm force winds, onset of gusts to hurricane force , heavier rainfall including short-term QPF, and convective trends are areas where NWS forecasters can provide much needed information and excel in service to our users.

Recommendation # 8 - The NWS should re-evaluate the short-term forecast (NOW) program and more uniform guidance should be provided to WFOs nationwide on how to issue short term forecasts during extreme events such as a hurricane. If NOWs are not the best way to communicate short term forecast information in a timely manner, other methods should be investigated (perhaps Special Weather Statements SPS and/or Convective Alerts).

WFO Baltimore-Washington has a hurricane drill each year. This year the drill was done in June. The hurricane focal point for the WFO participated in a large regional tabletop hurricane exercise presented by the State of Maryland in June.

WFO Baltimore-Washington has an "Adopt-A-County" program for its staff. Members of the staff who participate in the program take responsibility to represent the WFO and NWS to the emergency manager, media, school districts and other customers in the county adopted. This program has resulted in excellent relations between the WFO and emergency managers in the CWA and aided coordination between the WFO and affected counties during Isabel (**Best Practice 10**).

The WFO holds media workshops twice per year, once in the fall for winter weather and again in the spring for summer weather. NWS products and services are reviewed with the media at these workshops. The WFO also maintains a good Emergency Manager web page (**Best Practice 5**).

WFO Baltimore-Washington has more than 2,000 spotters in its CWA, as well as an active amateur radio program. Two amateur radio volunteers staffed a voice/packet radio station in the WFO Thursday and Thursday night. Many helpful spotter reports were received during the event via telephone, amateur radio and e-mail.

There are four approved StormReady jurisdictions in the Baltimore-Washington CWA, Hartford County (MD), Alleghany County (MD), Fairfax County (VA), and the University of Maryland.

Systems and Equipment

The initial Hurricane Watch issued at 11 p.m. EDT Tuesday, September 16, was 1050 Hz tone alerted and coded for the Specific Alert Message Encoder (SAME) by WFO Baltimore-Washington as required. The Tropical Storm Warning was neither tone alerted (using 1050 Hz) nor coded for SAME. Neither the Inland Tropical Storm Wind Watch nor the Inland Tropical Storm Wind Warning were 1050 Hz tone alerted or coded for SAME. At the time, the only authorized SAME codes for tropical cyclone watches and warnings were HUA and HUW for hurricane.

Fact - Appendix G of NWS Directive 10-1710, Use of NWR SAME Codes and 1050 Hz Tone Alarm, is required for Hurricane Watches and Warnings and optional for Hurricane Local Statements, High Wind Watches, and High Wind Warnings.

Finding # 9 - New SAME codes have been authorized for NOAA Weather Radio and will be a welcome addition for the effective dissemination of NWS products. However, the new codes will require Emergency Alert System stations to purchase compatible equipment for decoding. While this equipment is not expensive (estimated less than $100), at present the purchase of the new equipment is voluntary.

Recommendation # 9 - Because NOAA Weather Radio will truly become an all-hazards radio with the ability to broadcast Amber alerts, terrorist threat information, and nuclear incident information as well as weather information, NOAA and the NWS should work with the states' emergency management agencies to promote the purchase of the new equipment by Local Primary 1 (LP1) and Local Primary 2 (LP2) stations.

The satellite version of the Emergency Managers' Weather Information Network (EMWIN) failed from approximately 4 p.m. EDT Thursday, September 18, to 11:30 a.m. Monday, September 22, due to T1 data communications line failure between Suitland, MD and Wallops Island, VA. The Internet version of EMWIN remained available, however, and EMWIN users were notified of this.

Fact - Four (Charlottesville, VA, Frostburg, MD, Hagerstown, MD, and Manassas, VA) of the seven NOAA Weather Radio sites in the WFO Baltimore-Washington CWA have emergency back-up power. Two (Baltimore, MD and Moorefield, WV) do not. The transmitter at Charlottesville was out approximately 8 hours from Thursday night September 18, to Friday morning September 19, due to loss of phone line. The transmitter at Baltimore was out approximately 24 hours from Thursday evening September 18, to Friday evening September 19, due to loss of phone line and power.

Finding # 10 - NWR is fast becoming an all-hazards radio and a resource that must be available to the country during emergencies.

Recommendation # 10 - Emergency back-up generator power should be provided for all NWR transmitters across the entire country.

Hurricane Local Statements were not set up for automated broadcast on NWR using the Console Replacement System (CRS) at several WFOs. The HMT staff had to read them manually**.** WFO Baltimore-Washington still has a telephone recording service. This is not automated and HMTs must also record messages manually for the recording.

Fact - There are eight ASOS sites in the Baltimore-Washington CWA. Only data from the Annapolis ASOS site was lost due to flooding of the building that supplied electricity and telephone service. Tide gage data from the National Ocean Service (NOS) was lost at some locations Thursday night September 18.

Finding # 11 - ASOS has become the official data collection platform for climatological and current weather information. Without ASOS data in severe weather events, no verifying information is available for NWS or private meteorologists. NOS tide gages are vital sources of information for many users concerning tidal levels. Without tide gage data in severe weather events, government officials and emergency management personnel must rely on manual readings of staff gages. Even if communications are lost, the record itself is valuable information and could be salvaged if properly protected.

Recommendation # 11 - A source of emergency power should be installed for all ASOS sites and key tide gage sites where possible.

Feedback from Customers and Partners

Feedback from emergency managers was nearly all positive. The emergency managers were impressed with the availability of the WFO to their requests for briefings and to answer questions. Emergency managers in the Washington Metro area obtained briefings via conference calls with the WFO. Emergency managers outside the Washington area, including Baltimore, relied on NAWAS for group briefings and individual calls. Many one-on-one calls were conducted between individual jurisdictions and the WFO. The WCM used the NWS Meet-Me conference call capability to coordinate with and brief emergency managers in West Virginia due to the threat of flooding and flash flooding.

Some emergency managers wanted storm surge forecasts to be more accurate and specific. There was also a desire that mean sea level (MSL) be used as the common reference elevation for storm surge/tidal flooding. Emergency managers were confident that use of mean sea level would reduce confusion both in their jurisdictions and with the public.

Media relied on private services and the WFO web site to obtain NWS and WFO products during the event. Most media also made individual telephone calls to the WFO both for updates as well as interviews. Print media quoted the WFO frequently in stories throughout the event. WFO staff did mention that the Washington Post has several field bureaus in the region and each bureau called the WFO independently, often asking the same question(s). This became a workload issue for the WFO staff.

Broadcast media noted that the WFO was excellent in preparing for the event and providing very useful information in early HLSs. However, the broadcast media thought that the WFO did not supply enough short term and local information during Thursday night and Friday morning (**See Finding and Recommendation 8**).

G. River Forecast Centers

Overview

The two NWS River Forecast Centers (RFCs) impacted by Hurricane Isabel's landfall were Southeast RFC (SERFC) in Peachtree City, GA, and the Middle Atlantic RFC (MARFC) in State College, PA. Both RFCs have had extensive experience with torrential rainfall and extensive flooding from past hurricanes (e.g., Agnes, 1972; Fran, 1996; and Floyd, 1999). Each RFC planned well for the event, went to 24 hour staffing during the event, and overall performed very well with accurate and timely forecasts, updates, and discussions.

Middle Atlantic RFC

In the MARFC area, extensive flooding occurred from Isabel's rains, including the Shenandoah, Potomac, Rapidan, and Rappahannock River basins. The worst flooding from Isabel's heavy rainfall occurred in the Shenandoah and Potomac River Basins of Virginia and West Virginia, especially on the South River at Waynesboro, VA; the South Fork of the Shenandoah River near Lynnwood and at Front Royal, VA; the Shenandoah River at Millville, VA; and the South Branch of the Potomac River at Franklin, WV. Moderate to major main stem river flooding also occurred in the main Potomac Basin, the Rapidan Basin, and the Rappahannock Basin.

WFO Blacksburg, VA, lost AWIPS and NOAA Weather Radio capability when workmen accidentally cut fiber optic cables to the office Thursday, September 18. Not only did this require secondary back-up (primary back-up for Blacksburg is WFO Baltimore-Washington, and because of the storm, ERH assigned WFO Charleston, WV, to assume Blacksburg's operational responsibilities), but the IFLOWS data stream was interrupted. Although more than 20 NWS offices participate in collection of IFLOWS data, WFO Blacksburg is a single point of entry for IFLOWS data in their area.

Fact - WFO Blacksburg lost AWIPS and NOAA Weather Radio capability Thursday, September 18, when workmen cut the fiber optic cables to the office. WFO Blacksburg lost not only T1 WAN capability for AWIPS but also dial backup capability. Because WFO Blacksburg was down, IFLOWS data was available only through redundant back-up sources, but not via the primary AWIPS interface at Blacksburg.

Finding #- 12 - Losing both T1 and dial backup capabilities for AWIPS is devastating to operations at any office in the NWS. IFLOWS data are critical for accurate and timely weather monitoring at WFOs as well as RFCs.

Recommendation # 12 - Because the IFLOWS data stream is very important to NWS operations, NWSH should assure all WFO and RFC operational staff understand how IFLOWS data can be obtained from redundant sources in the event of an AWIPS failure.

Uncertainty concerning a rainfall report of 20.20 inches in just a few hours from an IFLOWS tipping bucket gage at Upper Sherando, VA, caused some problems with the forecast for the South River at Waynesboro, a mountainous headwater forecast point, which normally crests within 12 hours of a heavy rain event. The Flood Warning issued by WFO Baltimore-Washington at 10:15 p.m. EDT on September 18 (first forecast from MARFC was issued at 10:40 p.m. EDT on September 18) called for a crest near 13.0 feet at 8 a.m. EDT on September 19. At that time, the river at Waynesboro was at 8.5 feet and rising rapidly. This forecast was accurate. An update from MARFC issued at 3:38 a.m. EDT on September 19, 2003 for the South River at Waynesboro (flood stage 9.5 feet) raised the forecast to 15.2 feet and warned of a possible record flood. The river crested near 13.9 feet around 4 a.m. EDT, approximately 9-12 hours after the heaviest rainfall in the basin. Six homes were destroyed, and about 55 homes and 28 businesses sustained major damage. Approximately 450 persons were evacuated due to flooding in Waynesboro and Augusta County.

Forecasts for river locations, such as Waynesboro, which crest in less than 12 hours after heavy rainfall, are very difficult for NWS hydrologists when they are modeled on a 6 hour time step. The National Weather Service River Forecast System (NWSRFS) can be implemented at various time steps from 1 to 24 hours but is most often used at 6 hour time steps because of the availability of real-time data and historical data for calibration. For any basin that crests in 12 hours or less, a 6-hour time step is not optimum for an accurate forecast since the actual crest could easily fall between time steps.

As discussed in WFO Products and Services section (**Table 4**), the MARFC guidance for the next downstream point on the Shenandoah from Waynesboro, the South Fork near Lynnwood, was updated several times during the event culminating in a crest forecast of 23.9 feet on September 19, around 8 p.m. EDT. The observed crest was 22.5 feet late in the evening of Friday, September 19.

The South Fork at Front Royal is the next downstream point from Lynnwood. Here the MARFC forecast was much too high. MARFC issued an updated forecast at 3:38 a.m. EDT

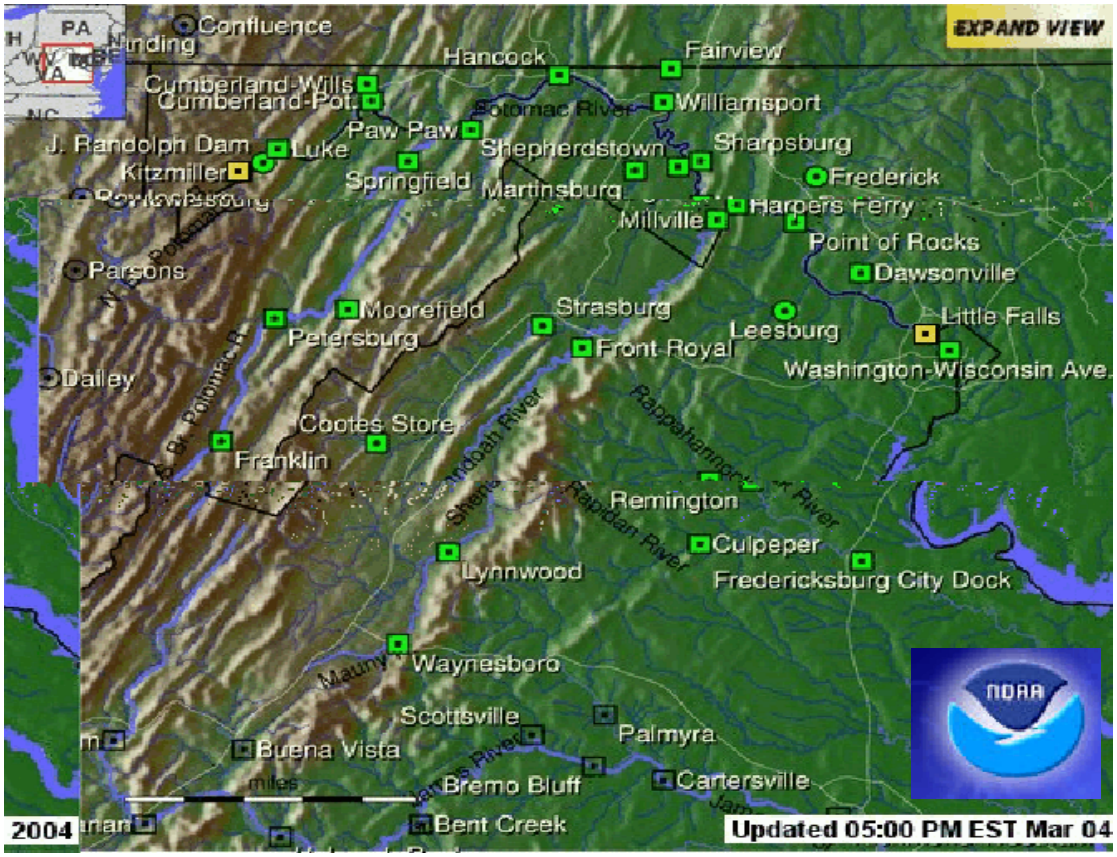

Figure 3. MARFC river forecast points across northern VA, western MD and eastern WV.

September 19, calling for a crest of 19.2 feet around 8 a.m. on September 20, which was raised in a further update at 9:46 a.m. on September 19 to a forecast crest of 24.6 feet and a mention of "major flooding" around 2 a.m. on September 20. The actual double crest at Front Royal was 18.1 feet around midnight and again around 6 a.m. on September 20. To help understand why the Front Royal Forecast was so high, the input data and hydrologic modeling at Front Royal should be examined. Among the factors to consider are the observed rainfall distribution and the routing hydrology. The high forecast at Front Royal contributed to an over-forecast at the next downstream point, the Shenandoah River at Millville, as well.

Fact - NWS River Forecast Centers use a default 6 hour time step at most of their daily operational river forecast locations. Smaller time steps (anywhere from 1- 4 hours) can be and are being implemented in NWSRFS in river basins that respond rapidly during heavy rainfall.

Finding # 13 - A shorter time step (less than 6 hours) would be more effective in producing accurate river forecasts for river basins that respond rapidly during heavy rainfall. Implementation of shorter time steps may be dependant on the availability of data, both real-time and historical.

Recommendation # 13 - RFCs should evaluate forecast procedures for basins that rapidly respond during heavy rainfall. Forecast procedures should be updated where inadequate. Southeast River Forecast Center

In the SERFC area, Isabel brought 4 to 6 inches of rainfall to the Tar and Chowan River Basins, most falling in 12 hours or less. The storm caused widespread moderate flooding, primarily in the Chowan Basin, where major flooding occurred at 4 of the 6 forecast points (Nottaway River near Rawlings, VA, near Stony Creek, VA, and near Sebrell, VA, and the Blackwater River near Franklin, VA, as well as along the Meherrin River). The SERFC has had several flood events in recent years in North Carolina and Virginia due to hurricanes, most importantly Hurricane Floyd in 1999, and is therefore quite experienced with the effect of hurricane rainfall in their basins of responsibility. Because of this experience, SERFC was proactive for this event, issuing contingency forecasts several days before Isabel's landfall.

SERFC is internet-savvy using many graphical web page products including graphical hydrometeorological, significant flood, and river flood outlooks, and an event-specific web page for Hurricane Isabel. SERFC also conducts an e-mail alert service for key customers. SERFC's

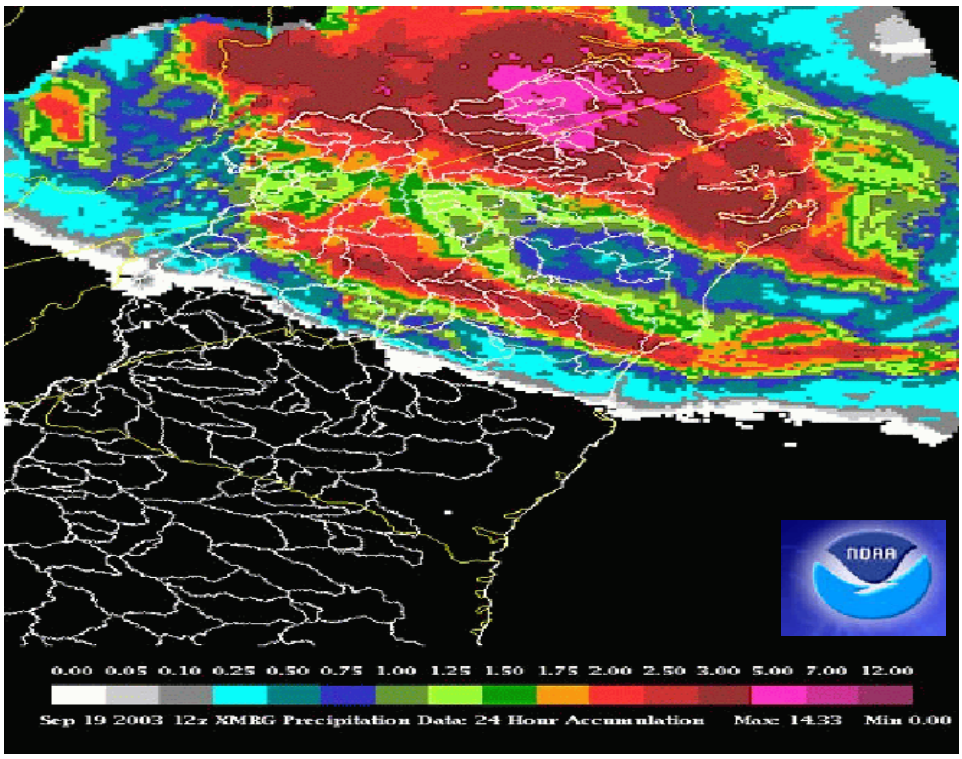

Figure 4. 24 hour WSR-88D estimated rainfall, adjusted by observed data, associated with Hurricane Isabel during the period 12 UTC September 18 to 12 UTC September 19, 2003.

Internet Technology (IT) capabilities, including color graphics and specialized web pages, greatly enhanced their service to their users. Most RFCs now provide these graphics to their users. The implementation of dynamic routing on the Tar River by SERFC and the capability to produce specific reach and point inundation maps for placement on the Internet is a wonderful tool which enhances service to users**.**

H. NOAA Public Affairs

Overview

Media interest in Hurricane Isabel intensified when the storm reached Category 5 strength the weekend of September 13. For the period September 15-19, NOAA Public Affairs (PA) assisted more than 600 media inquiries at the National Hurricane Center (NHC) and approximately 200 by NOAA PA personnel in the Washington D.C. metro area and NWS ERH. The broadcast pool operation at the NHC aired approximately 315 broadcast updates on Isabel to national network and affiliate stations. The NHC also handled more than 300 print, radio, and television inquiries from national and international outlets. The prearranged broadcast pool operation at NHC commenced Monday, September 15 at 5 p.m. EDT. This operation continued on a daily basis through 3 p.m. EDT Thursday, September 18, the day of landfall. Operations were supervised by two NOAA Public Affairs personnel on site working 12 hour shifts. The pool operation worked well except for a lack of a dedicated telephone line for the pool producer. The pool producer is assigned from Miami metro affiliates and they currently use their own telephone when on duty. This means there can be two different lines each day depending on which affiliate is coordinating the pool operation.

Fact - An advisory was prepared and distributed Tuesday, September 16, listing media contacts for specific hurricane issues**.**

Finding # 14 - This advisory proved invaluable, redirecting many inquiries from the NHC to NWS headquarters, the WFOs, NCEP or NWS ERH. This provided more timely responses to media inquiries.

Recommendation # 14 - Continue this practice but distribute the advisory before establishing broadcast pool operation. This will entail advance planning to ensure experts are lined up and available.

I. Sea Lake and Overland Surges from Hurricanes (SLOSH) Model

The Sea Lake and Overland Surges from Hurricanes (SLOSH) program provides a tool for WFOs and emergency managers predicting a maximum envelope of water accompanying a land falling tropical cyclone. For many coastal offices, evacuation times to clear flood prone areas

along the coastline can be more than 36 hours. WFOs therefore must provide a specific assessment of the surge threat over a broad area, knowing that the highest realized values may only occur over a small portion of the mentioned coastline.

Coastal surge models require best track guidance, including the accompanying wind field and intensity at landfall. A small adjustment in track, sustained wind speeds or radii location (or the presence of localized wind maxima) can have a tremendous impact on surge produced along the coastline. TPC fears that placing too much emphasis on a very specific track dependant deterministic surge forecast could result in the communication of far too much confidence in exact water elevations, and lead to a less than adequate response to evacuation orders or at worst, the non-evacuation of areas more seriously at risk.

During Isabel's approach, WFOs along the coast had access to a series of track specific deterministic SLOSH runs for their coastal basins. These runs are usually generated only within 24 hours of a tropical cyclone affecting the coast. The model is run at TPC, where storm track, and intensity, and wind radii information is manually entered. Coastal offices were pleased with the runs but believe they should start within 12 hours of landfall. SLOSH did extremely well along the east coast and into Chesapeake Bay, but may have under-forecast surges which traveled up some of the tidal rivers as well as the upper reaches of the Chesapeake. Because Isabel's winds affected Chesapeake Bay for a considerable time after landfall, at least one SLOSH developer believes the deterministic SLOSH runs should routinely start within 24 hours of landfall. SLOSH runs accomplished after the storm showed that the additional runs more accurately predicted the timing and maximum surges which impacted the upper reaches of the Chesapeake. Also, significant manual modification and expansion of the forecast wind radii needed to be done to more accurately capture the surges on Chesapeake Bay because the storm surge guidance did not account for the unusual (non climatological) size of the storm**.**

In the last several years, Dr. Lian Xie at North Carolina State University (NCSU) has been running a three dimensional surge model for portions of the Mid-Atlantic coast. These images and output were available during Isabel's approach, via the NCSU meteorology department website. Coastal offices were very impressed with its detail. Several WFOs believe the added resolution and sophistication of the model should be explored further within the NWS in an attempt to provide more accurate surge forecasts.

While the ability to provide deterministic specific elevation forecasts and more site accuracy is desirable, given the intrinsic errors in track, intensity and wind field forecasts, the NWS could ultimately be providing very detailed but grossly incorrect surge information. This could have a devastating impact if the deterministic forecast was wrong and evacuations were not conducted in advance for the magnitude of the threat. Several sources at TPC, the WFOs, and NWSH noted that NOAA has funded advanced surge modeling at universities like Louisiana State University (LSU) and NCSU, but funding for SLOSH development and operations within the NWS and NOAA has not been a priority. Dr. Lian Xie with NCSU stated that the SLOSH model is viewed by most modern day coastal zone modelers as, "*an older two dimensional model which needs*

updating." At present, there is no development work being done with SLOSH. With so much damage potential from tropical cyclones in the coastal zone, perhaps the storm surge effort within the NWS and NOAA should be re-tasked to a dedicated and well-funded group. WFOs should continue to use the storm specific SLOSH runs with the knowledge they are subject to track and intensity errors. The storm specific runs should be supplemented with information using the Maximum Envelope of Water (MEOW) files in SLOSH.

Fact - Coastal offices appreciated deterministic SLOSH model runs made available within 24 hours of Isabel's landfall**.**

Fact - Deterministic SLOSH model runs under-predicted the storm surge from Isabel in the Chesapeake Bay.

Fact - NOAA has funded advanced surge modeling at universities like LSU and NCSU but funding for SLOSH development and operations within the NWS and NOAA has not been a priority. No updating of the SLOSH model is currently underway within the NWS and NOAA.

Fact - The SLOSH model is still a tool which can be used effectively to predict storm surge with land-falling tropical cyclones. However, it is in need of updating, both in mechanics and in methodology

Best Practices

1. The TPC/NHC augmented its hurricane forecasters with volunteers staffing TPC's informal round-the-clock "Hurricane Support Meteorologist" (HSM) position. The HSM program and its predecessors for years have provided the critical mass of personnel required to handle the surplus of data synthesis, analysis and forecasting, media and emergency management interviews, and telephone calls during such events. HSMs are drawn from trained staff in other TPC units contributing many hours over several days of overtime/compensatory time, as well as drawn from student volunteers and technically-inclined visitors from other organizations. This staffing deficiency was noted in the Tropical Storm program PPBES documents. The TPC would like to eventually introduce a formal HSM position, possibly as an "intern" but is realistic about the constraints on increasing FTEs.

2. ERH detailed extra staff to affected offices. Detailed staff already familiar with the CWA of the office as well as the operations of the office proved especially valuable during Isabel.

3. WFOs Baltimore-Washington, Newport, and Wakefield had continuous electronics technician staff available during the event, supplemented by ERH.

4. Each state held regular coordination conference calls several times daily during the hurricane event with WFOs and all impacted local EM officials participating. The local EMs praised the effectiveness of these calls, especially the contributions of the WFOs

5. WFOs Newport, Wakefield, and Baltimore-Washington have a section of their web page dedicated solely to emergency management use.

6. WFO Newport worked very quickly after the event to conduct detailed damage assessments. This information was then placed on the office's Internet site. Feedback from partners and customers indicate this post-storm page is a tremendous resource for the community.

7. ERH also was proactive in reassigning service backup responsibilities away from Wakefield (to WFO Charleston, WV) when WFO Blacksburg lost communications during the storm.

8. The Wakefield office has explicit, detailed procedures in place to activate local EAS systems when NWRs are off the air. The procedures include a contact telephone number for the LP1 station, text to give over the telephone highlighting the weather emergency, providing authentication, and provisions to contact the Virginia State Emergency Operations Center if NAWAS is also down. The procedures are only to be used in the event of Tornado or Flash Flood warnings.

9. WFOs Baltimore-Washington, Newport, and Wakefield conducted extensive pre-event briefings with emergency managers, customers and partners.

10. The Adopt-A-County program assigned to WFO Baltimore-Washington staff improved relationships and communications between the WFO and emergency managers.

Appendix A

The Saffir-Simpson Hurricane Scale

The Saffir-Simpson Hurricane Scale is a 1-5 rating based on the hurricane's present intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Note that all winds are using the U.S. 1-minute average.

Category	**Sustained Winds in mph**	**Barometric Pressure in millibars**	**Storm Surge in feet above normal**	**Damage**
1	74-95	> 980	4-5	Minimal
2	96-110	965-979	6-8	Moderate
3	111-130	945-964	9-12	Extensive
4	131-155	920-944	13-18	Extreme
5	>155	< 920	>18	Catastrophic

Appendix B

Summary of Fatalities

Date	*State*	*County*	*Details*
9/13/03	FL	Nassau	Drowning (body surfer pulled under by rip current), male, 43 (1)
9/18/03	VA	Chesterfield	Falling tree, male, 27, Asian-American (2)
9/18/03	VA	City of Richmond	Tree fell on home, female, 45, African-American (3)
9/18/03	VA	New Kent	Falling tree, male, 47, white, non-Hispanic (4)
9/18/03	VA	Accomack	Tree fell on trailer, male, 53, African-American (5)
9/18/03	VA	City of Harrisonburg	Drowning (canoeing in high water), male, 21, white, non-Hispanic (6)
9/18/03	VA	Isle of Wight	Drowning (car attempting to cross high water on James River bridge washed off the road), male, 62, African-American (7)
9/18/03	VA	City of Hopewell	Falling tree limb, male, 48, white, non-Hispanic (8)
9/18/03	NC	Chowan	Tree fell on vehicle, female, 32 (9)
9/18/03	NY	Nassau	Drowning (police officer body surfing pushed into rocks), male, 42 (10)
9/18/03	RI	Washington	Drowning (swept off rocks by high seas), male, 66 (11)
9/19/03	VA	Henrico	Drowning (car found in creek), male, 54 (12)
9/19/03	MD	Baltimore	Storm surge drowning in Turner Station area of Dundalk, male, 27 (13)
9/19/03	NJ	Warren	Tree fell on car, female (14)
9/20/03	NJ	Cape May	Drowning (rough surf off Wildwood Crest), male 51 (15)
9/21/03	VA	Rockingham	Two drownings (Mennonite horse and buggy washed away crossing low water bridge), male, 85, female, 43, both white, non-Hispanic (17)