



# River Forecasting in the US and the Evolution of Field Services

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# River Forecasting in the US – an evolving process

- Past – How did we get here?
- Present – What are we doing today?
- Future – What is the vision for water resources services in the future



# River Forecasting History in the USA

The Congressional Organic Act of October 1, 1890, assigned to the Weather Bureau the duties of "...the forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers..."

Development of the present service began in 1946 with the establishment of two River Forecast Centers, staffed by professional hydrologists, to prepare river and flood forecasts and refine hydrologic forecast procedures for specified areas. Over the next 33 years, 11 additional River Forecast Centers were established.

# Hydrologic Forecast Evolution in the US

Forecasting in the late 1940s

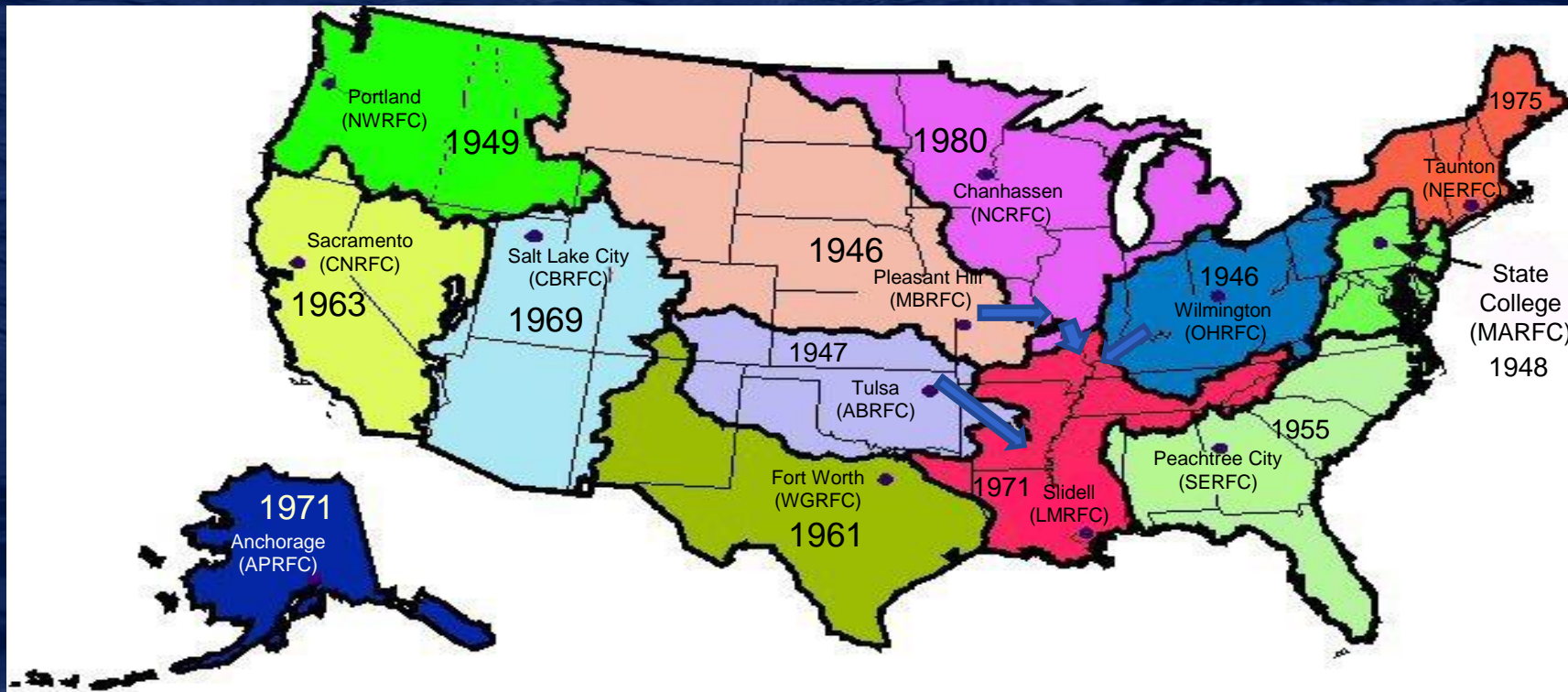




# Advent of the Computer in the 60's

- Each RFC had a unique system for forecasting.
- First RFC in the nation to have an on-site computer; the IBM 1620 computer was installed in April 1962 at West Gulf.
- Consultant hired to write most of the forecast software.
- Program developed locally to estimate missing rainfall for the RFC in 1964.
- Computer had 8K of memory and was about 6 feet long and waist height. With an upgrade to 16K, a forecaster said “we now have dual carburetors and four in the floor capability.”

# 13 River Forecast Centers (RFCs) based on River Basin Boundaries





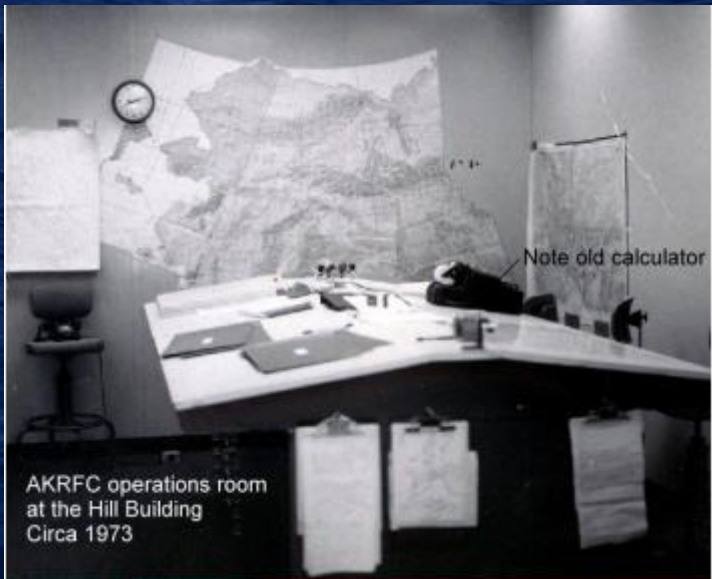
# The 70's

## Arkansas-Red Basin RFC (originally known as the Tulsa RFC)



Meeting at Tulsa RFC with Service Hydrologists

Clockwise from bottom left: Dave Brandon (SH WSFO-TOP), Sol Summer (SH WSFO-DEN), Tony Haffer, Phil Weigant,???, Randy Tetzloff, Jim Smith, Jack Yates and Eldon Beard (SH WSFO-OKC) (~1976)



Note old calculator

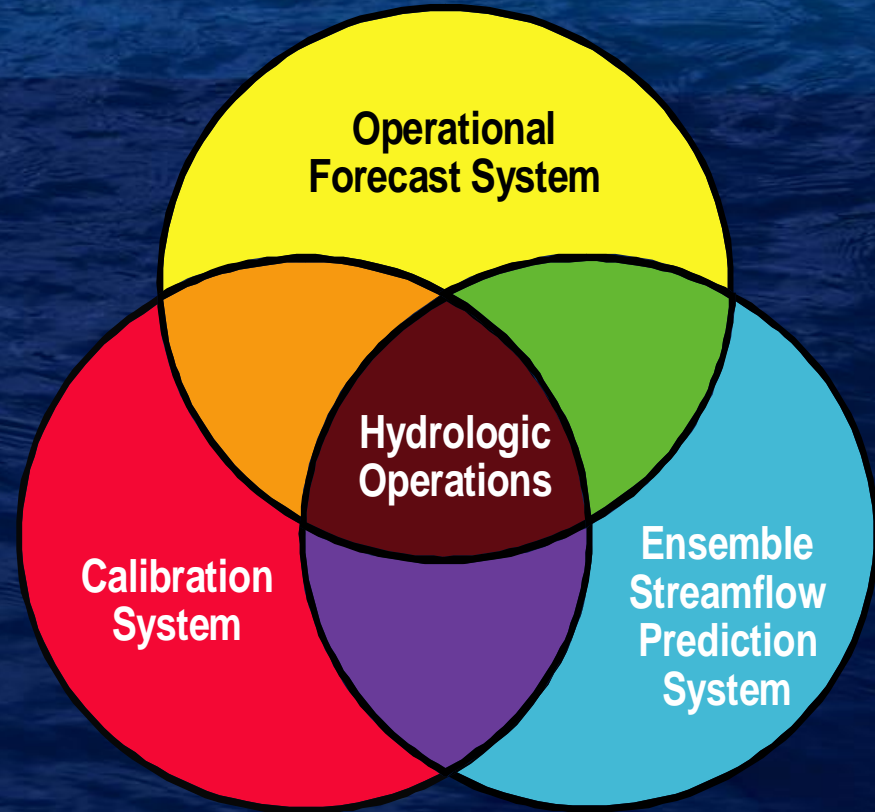
AKRFC operations room  
at the Hill Building  
Circa 1973

# Big Changes in the 70's

- Birth of the National Weather Service River Forecast System (NWSRFS)
- Initial use of continuous models at some RFCs
- Sacramento Soil Moisture Accounting model and Snow-17 formed core of NWSRFS
- Run on a main-frame computer
- Initial testing at Tulsa in 1979



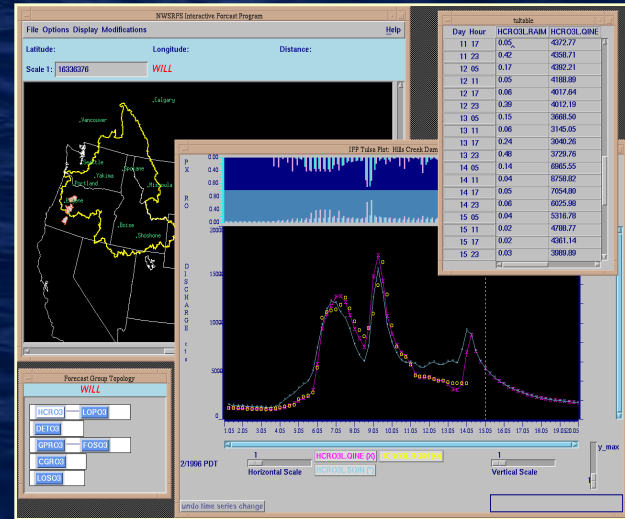
- **Calibration System (CS)**
  - Generate time series based on historical data
  - Determine model parameters
- **Operational Forecast System (OFS)**
  - Uses calibrated parameter values to:
    - Generate short-term river and flood forecasts
    - Maintain model state variables
- **Ensemble Streamflow Prediction System (ESP)**
  - Uses current model states and an ensemble of time series to:
    - Generate an ensemble of hydrographs
    - Generate probabilistic short- or long-term forecasts based only on climatology



***All 3 systems used the same hydrologic and hydraulic models***

# From the 1970s to 2009

- Initially NWSRFS ran on a mainframe computer
- Graphical User Interface known as the IFP was created in early 1990s, NWSRFS ported to run on IBM-Unix Workstations
- System ported to HP-Unix
- System ported to Linux
- Fortran and binary database

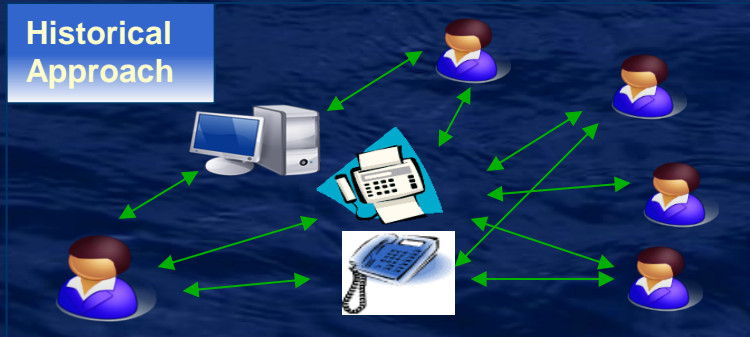




# Community Hydrologic Prediction System (CHPS) brought a New Business Model

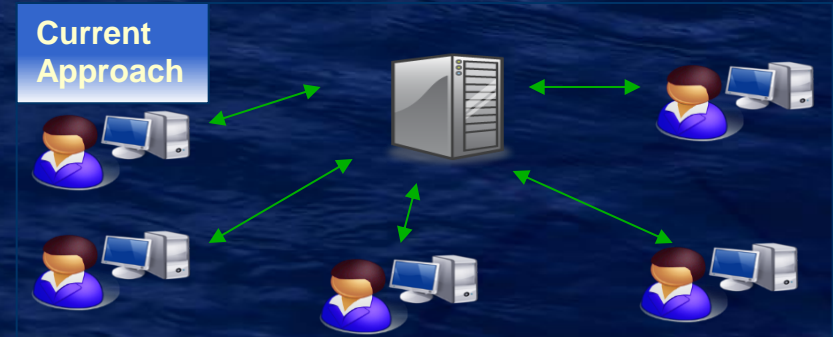
Historically, organizations and groups:

- Worked independently
- Developed their own unlinked systems
- Duplicated efforts
- Used disparate tools and processes



The current approach strives for

- Data flowing among linked algorithms across organizational boundaries
- Open architecture that is flexible enough to utilize existing applications and services



# Phased approach for CHPS/FEWS Implementation

- Pilot programs were conducted for about 18 months through the end of 2007
- Project preparation at the national level during 2008
- 4 River Forecast Centers initially received hardware, training and support during 2009
- 9 RFCs came on board during 2010

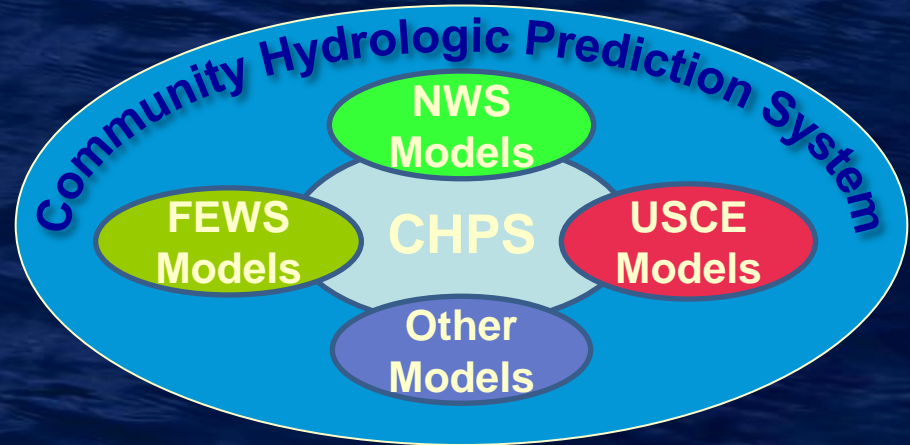


# What is CHPS?

Flexible, open modeling architecture *linking* program elements

- Modular software to enhance collaboration and accelerate R2O
- Extension of the Flood Early Warning System (FEWS) architecture:
  - Easily incorporates NWS models with models from other Water Agencies, Corps of Engineers, USGS, and Academia

✓ All RFCs operational on CHPS since late 2011



# Where are we today?





Susquehanna River  
Forecasts

Collocated with  
Weather Forecast  
Office

HAS Forecaster: Analyzes  
Observed & forecast weather  
that affects the rivers, i.e.  
precipitation and temperature.



Delaware, Passaic &  
Raritan Basin Forecasts

Potomac, James  
& Appomattox  
Basin Forecasts

# Forecast Product Evolution

## 1993

HYDROLOGIC SUMMARY  
NATIONAL WEATHER SERVICE DES MOINES IA  
13:17 PM CDT THU JUN 12 2008

HOURLY RIVER STAGES

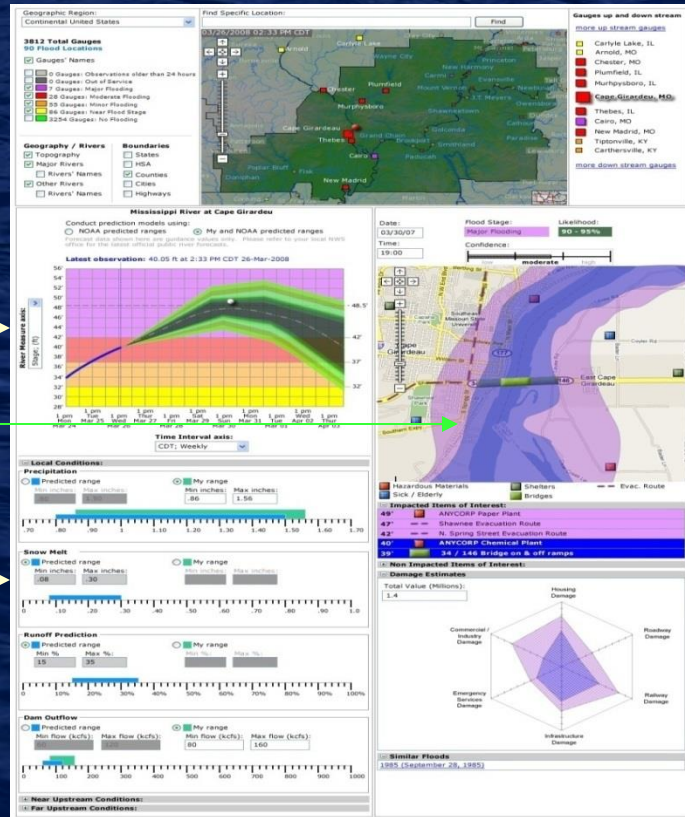
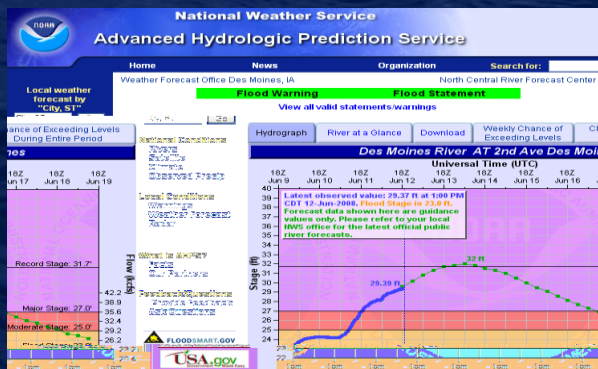
LOCATION	ID	BF	FS	CUR STG	6HR OBS CHG	TIME (LCL)
<b>BOONE RIVER</b>						
WEBSTER CITY	WBC14	9.0	12.0	14.15	-0.23	13:00
<b>EAST FORK DES MOINES RIVER</b>						
ALGONA	AGN14	12.0	14.0	18.25	0.63	13:00
DAKOTA CITY	DAK14	0.0	20.0	16.43	0.04	13:00
<b>WEST FORK DES MOINES RIVER</b>						
ESTHERVILLE	ESV14	6.0	7.0	8.13	0.04	13:00
EMMETTSBURG	EMT14	10.0	10.0	8.23	0.28	13:00
HUMBOLDT	HBT14	0.0	8.0	9.07	-0.09	13:15
<b>DES MOINES RIVER</b>						
FORT DODGE	FOD14	0.0	10.0	10.70	-0.17	13:00
STRATFORD	STR14	14.0	14.0	23.08	-0.27	13:00
SAYLORVILLE TAIL	SDT14	0.0	M	M	M	M
2ND AVE DES MOINES	DMO14	0.0	23.0	29.37	0.38	13:00
DES MOINES SE CTH	DES14	0.0	24.0	33.29	0.34	13:00
TRACY	TRC14	13.0	14.0	19.85	1.42	13:00
OTTUMMA	OTM14	8.0	10.0	12.96	0.58	13:00

2016  
Geographical  
Depiction

Probabilistic  
Inundation  
Mapping

2010

User Tools





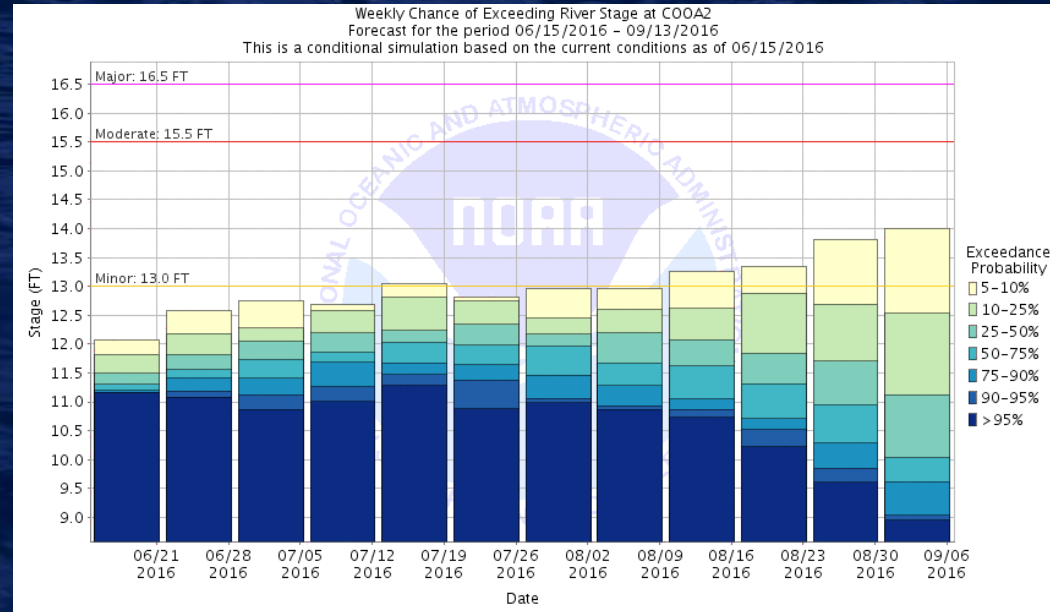
# Advanced Hydrologic Prediction Service

<http://water.weather.gov>

Number of forecast points has grown steadily to around 4000 locations.

Primary forecast tools are still single value deterministic forecasts.

We also have probabilistic forecasts based primarily on climatology.



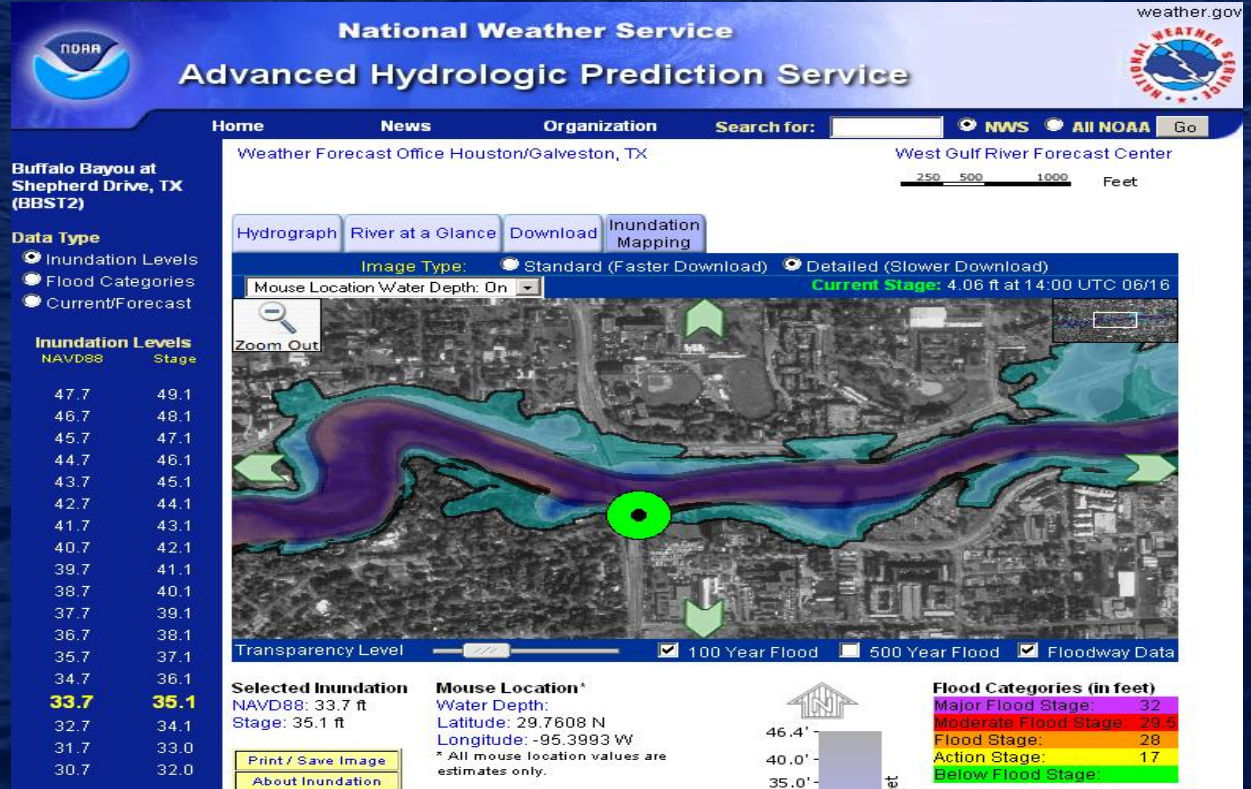
# NOAA/NWS Flood Inundation Mapping

User Tools tied to NWS river forecast locations

Depicts flooding from minor to historical levels

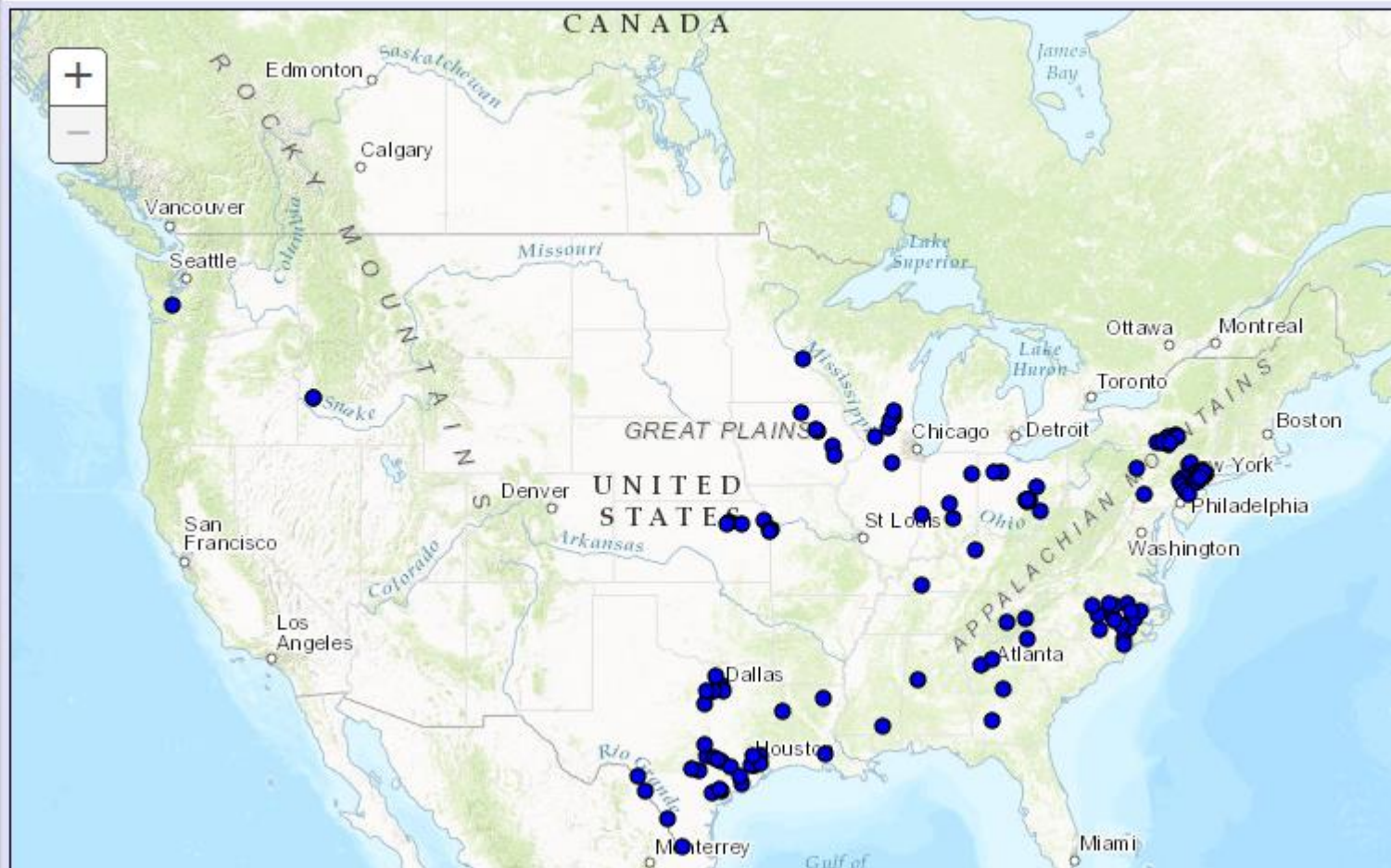
Communities can see potential impacts to the flood-prone areas


NOAA is working with FEMA, USGS, and USACE to communicate Flood Risks





# NOAA PARTNERED GUIDELINES FOR THE DEVELOPMENT OF ADVANCED HYDROLOGIC PREDICTION SERVICE FLOOD INUNDATION MAPPING



 Inundation Gauges

[About Inundation](#)  
[FAQ](#)  
[User Guide](#)

User guide video on  


[Map Help](#)

[Disclaimer](#)

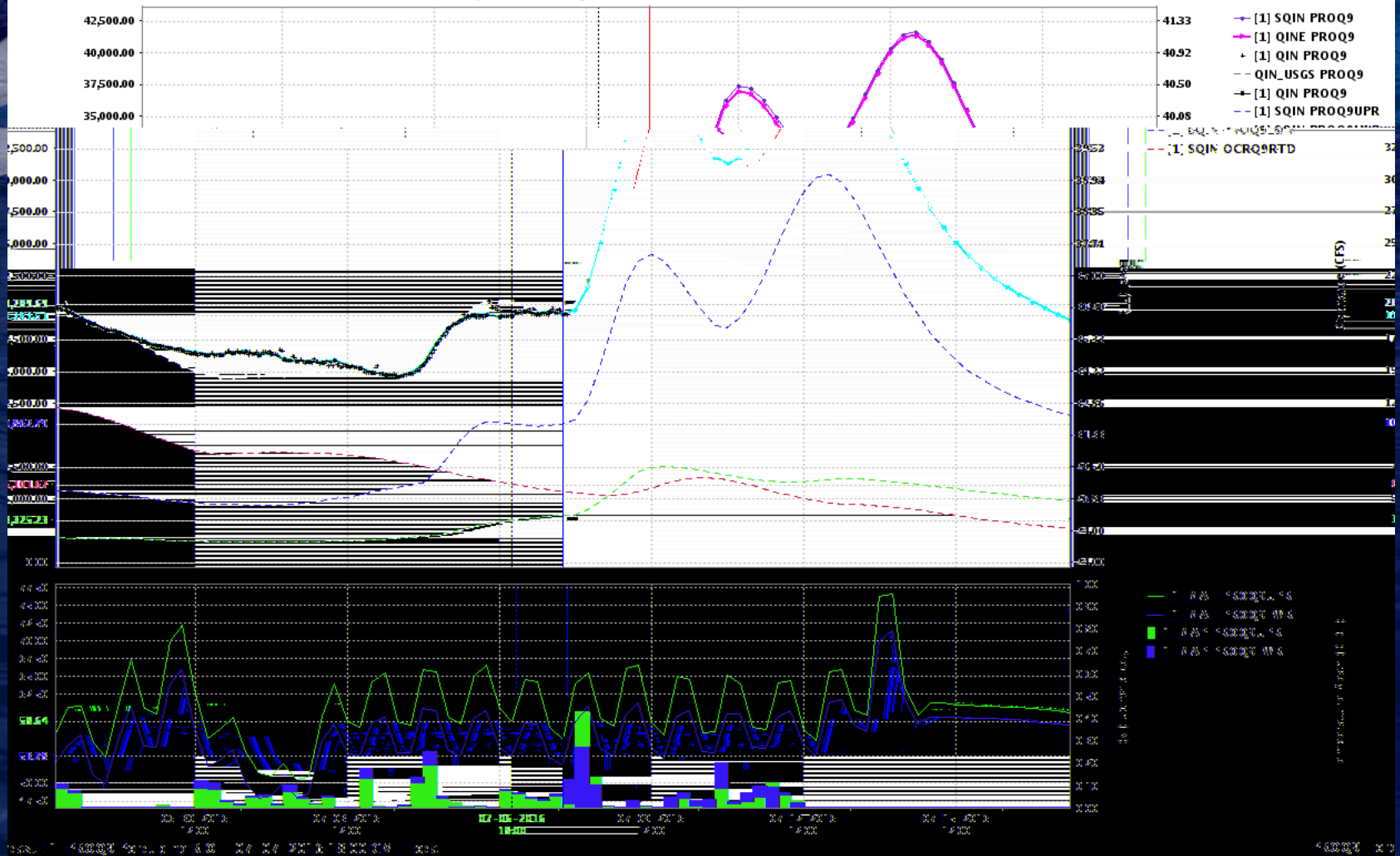


# Run-time Modifications (Mods)

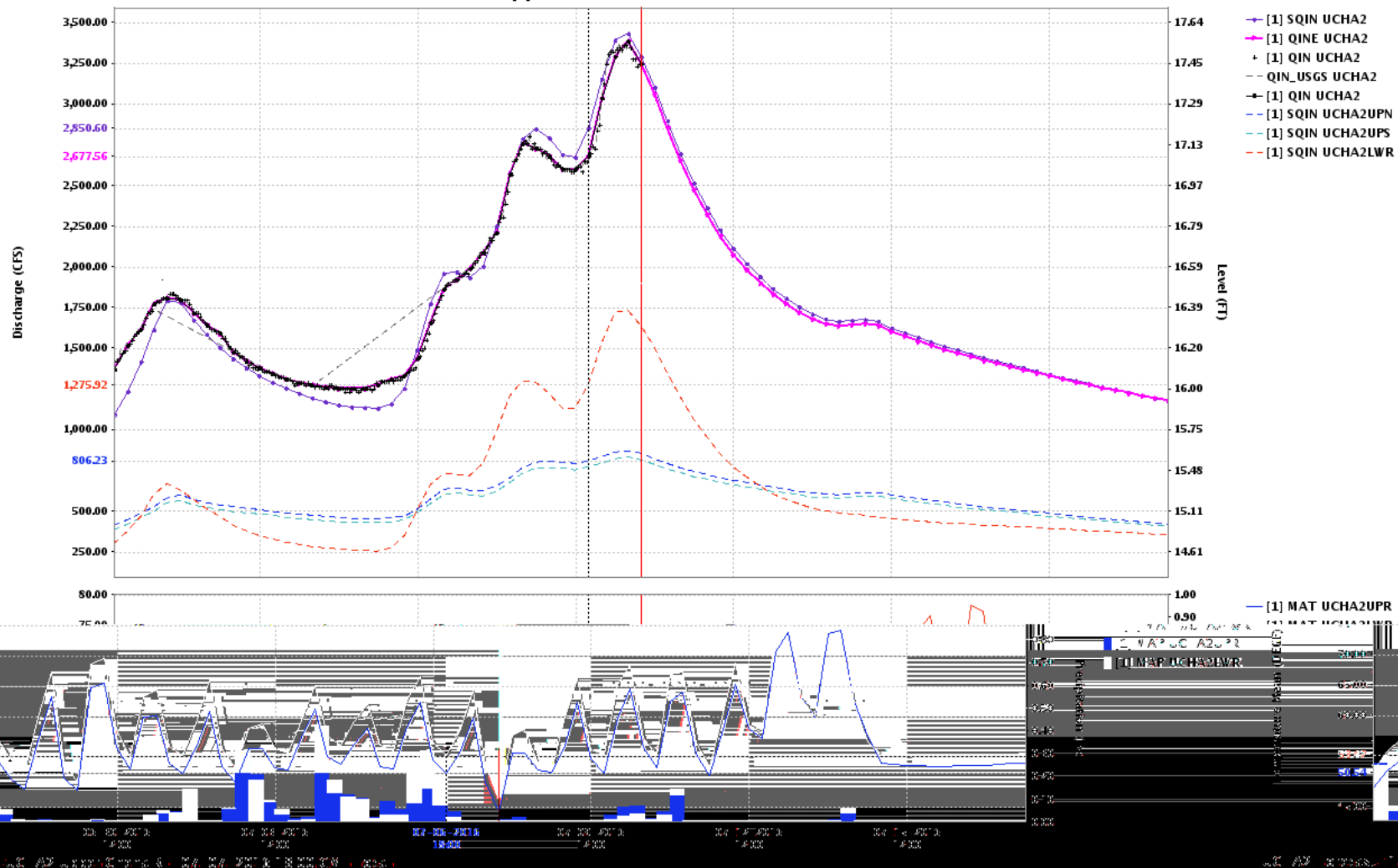
- What does a hydrologist do to produce a forecast today?
- Lots of modifications to forcings, model states, and model parameters to “get the forecast right”!
- Analogous to editing the grids on the weather side.
- Many degrees of freedom – lots of Mods can get the hydrograph to look “pretty”, but if they don’t represent the physical process that will cause issues for future runs
- Lack of rigorous validation tools to measure the value of forecaster modifications
- Forecaster extensively “in the loop”



# PROQ9 - Porcupine River at Old Crow



# UCHA2 - Upper Chena River at Two Rivers





# National Academy of Sciences Report: *Weather Services for the Nation: Becoming Second to None*

## Findings



## Recommendations

NWS Modernization and Restructuring (MAR) did not directly address hydrologic prediction services

A significant gap exists between the state of hydrologic science today and current NWS hydrologic operations

The level of sophistication, representation of processes, and characterization of uncertainties in external research and operational communities outpace those used in NWS hydrology operations

NWS Hydrologic Forecasters are extensively *“in the forecast loop”*

Qualifications for hydrologist positions were not updated in the MAR to require degreed hydrologists

Lack of skill in modern computational programming, construction and use of new Earth System Models, current hydrologic data assimilation methodologies, and preparation and interpretation of meaningful ensemble predictions

Prioritize core capabilities - a MAR-like effort is needed to address long-standing and deep-seated issues in hydrology

Improve pathways for collaboration & accelerate R2O

Establish a hydrologic prediction testbed as part of the National Water Center

Implement a consistent framework for hydrologic prediction skill assessment

Transition RFC forecasters to “over the loop” enabling a shift in focus to model and product development, forecast interpretation, and decision support

Hydrologist staff require re-education and continual retraining to enable adoption of state-of-the-art prediction methodologies

Instill evolutionary culture

Add value to hydrologic forecasts through the use of more advanced models, data assimilation and employment of more sophisticated ensemble techniques

# Current Service Paradigm

- AHPS forecast points – about 4000 locations around the country (100,000,000 people in areas with no forecast)
- Limited number of flood inundation maps
- Deterministic (single value) forecasts
- Climate based ensembles (Ensemble Streamflow Prediction)
- Proven but old scientific approach
- Lots of forecaster time spent doing Mods to adjust the simulated and forecast flows



# What does the future look like?

- National Water Model (NWM) implementation on WCOSS occurring now
- All CONUS RFCs have started to ingest NWM data into CHPS and are participating in the validation process
- First phase of Hydrologic Ensemble Forecast Service (HEFS) implementation at all 13 RFCs completed in 2015
- National Water Center Initial Operating Capability (IOC) reached in 2015
- Leap ahead in science and services has begun

# National Water Model Version 1.0

- **WCOSS Implementation and experimental product availability in FY16 Q4**
  - Leveraged strong Office of Water Prediction (OWP)/NCAR/NCEP partnership
  - Build upon NCAR's, community-based, WRF-Hydro coupling architecture
  - Implementation accelerated by 2 years, and benefited from close collaboration with CUASHI through NSF
- **Foundation for sustained growth in nationally consistent operational hydrologic forecasting capability**
- **Goals for NWM V1.0**
  - Provide forecast streamflow guidance for underserved locations
  - Produce spatially continuous national estimates of hydrologic states (soil moisture, snow pack, etc.)
  - Implement a modeling architecture that permits rapid infusion of new data and science, and allows for geointelligence linkages



# Transforming NOAA Water Prediction

## TODAY

## THE FUTURE

Approximately 4000 forecast locations at points

Approximately 2,700,000 forecast stream reaches

Forecast river flow/stage, from summit to coastal zone

Forecast all hydrologic parameters which define the water budget, from summit-to-sea

Driven by large catchment “lumped” modeling

Driven by high/hyper resolution Earth System modeling

Forecaster “in the loop” – serial, basin to basin, modeling of flow through the river network

Forecaster “over the loop” – simultaneous modeling of the nation’s entire river network

Average basin size greater than 420 square miles

Average basin size  $\sim 1$  square mile

13 RFCs developing separate versions of the same regional model

13 RFCs, OWP, academia, and federal partners developing/evolving same state-of-the-science national, community-based, model (working with NSF, CUASHI, and other Federal agencies to establish community development version of NWM)

RFC-generated river forecasts coordinated with WFOs to deliver Impact-based forecasts at selected points

National Water Model-based predictions coordinated among NWC Operations Center, RFCs, and WFOs and linked with detailed local infrastructure data to communicate street level impacts

**For the hydrology community, the implementation of the NWM and the leap ahead capability it provides parallels the implementation of mesoscale atmospheric models in the 1970s (i.e., model resolution substantially greater than available observational network)**

So what does all of this  
mean for Services coming  
from your River Forecast  
Center???



# Current State

- Hydrologists are “in the loop” extensively developing excellent forecasts and providing great service for ~4000 locations. If the forcing inputs are minimal, it doesn't take long and efforts are shifted to development projects, training and outreach
- If significant rainfall and/or snowmelt has occurred, the forecaster spends up to their entire shift modifying inputs, model states, parameters, etc. to try to simulate the physical processes with a conceptual model
- Generally, forecasts are produced once or twice per day (more often during flood situations) at 6 hour intervals.
- Ensemble guidance has been based solely on climatology until the recent implementation of the Hydrologic Ensemble Forecast Services (HEFS)
- Lack of National Consistency: RFCs utilize different sources and time frames for forcing data – some use WFO QPF, some use WPC QPF and some use HAS QPF. Some use 12 hours of non-zero QPF while others use 10 days of QPF.

# Next Phase (~1 to 5 years)

- Forecasters have National Water Model (NWM) data to look at every hour at several orders of magnitude of the number of AHPS points complementing current modeling capability.
- Forecasters can compare NWM model performance against RFC model performance at the AHPS locations.
- Model Output in hydro-blind areas is now available and can be used for guidance, examined, validated and verified.
- National Water Center (NWC) Operations Center staffs up in 2017? and provides central point for collaboration of hydrologic inputs and outputs between WPC, HPC, RFCs and WFOs.
- NWC Ops Center provides a single point for National IDSS for agencies embedded at NWC (currently USGS and FEMA), National Media, and other national level partners for large-scale events (Irene, Sandy, Katrina) and long-term events requiring significant IDSS (widespread drought).

<b>RFC</b>	<b>NHD Streamlines</b>
ABRFC	163,188
CBRFC	218,346
CNRFC	205,473
LMRFC	278,617
MARFC	105,033
MBRFC	463,117
NCRFC	275,054
NERFC	106,351
NWRFC	254,852
OHRFC	186,698
SERFC	302,605
WGRFC	130,531



# Target on the Wall – 5 to 10 years

- Hydrologists are “over the loop” utilizing National Water Model guidance to highlight threats on all time scales providing appropriate decision support and running additional models for water quality guidance or to identify areas where hyper-resolution grids need to be run for short-fuse high impact events.
- Provide range of new water resources services including real-time flood forecast inundation mapping and grids describing entire water cycle.
- Ensemble guidance from National Water Model (currently 30 days of CFS) provides uncertainty information for time frames needed by partners to make informed decisions (days to months to years)
- National Water Center Operations Center in coordination with WFOs, RFCs, ROCs, WPC , and NHC as well as other NOAA Line Offices (NOS) creates daily, national water situational awareness products and participates in routine coordination calls.
- Current development time at RFCs spent developing regional models will be spent developing and improving NWM and improvements are available for all users.

# Summary

- The Blanco at Wimberley rose from near 5 ft to near 41 ft in 4 hours in May of 2015. It rose 20 ft in 1 hour. 12 died just in that area. We can't model that type of event with a lumped conceptual model running at 6 hr time steps.
- We need to continue the improvements in QPF both in time and space that WPC is leading
- We need the National Water Model validated and verified
- It's not just about flooding! We need HEFS for short, medium and long-term probabilistic forecasts and to provide objective uncertainty estimates
- We need the help of the broader water community to help improve the National Water Model and to get the message to those in harm's way.





Thank you



# Additional Slides