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.

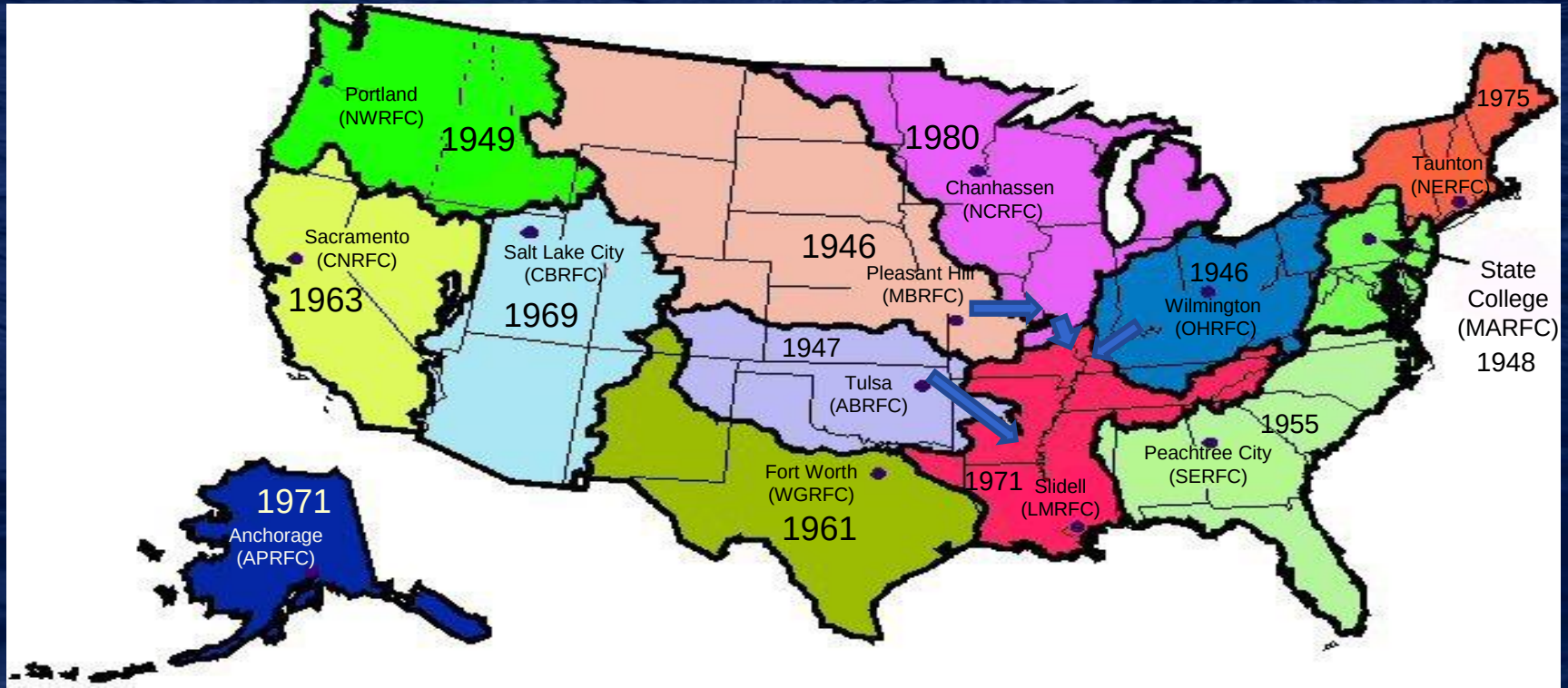
Hydrologic Forecast Evolution in the US

Forecasting in the late 1940s

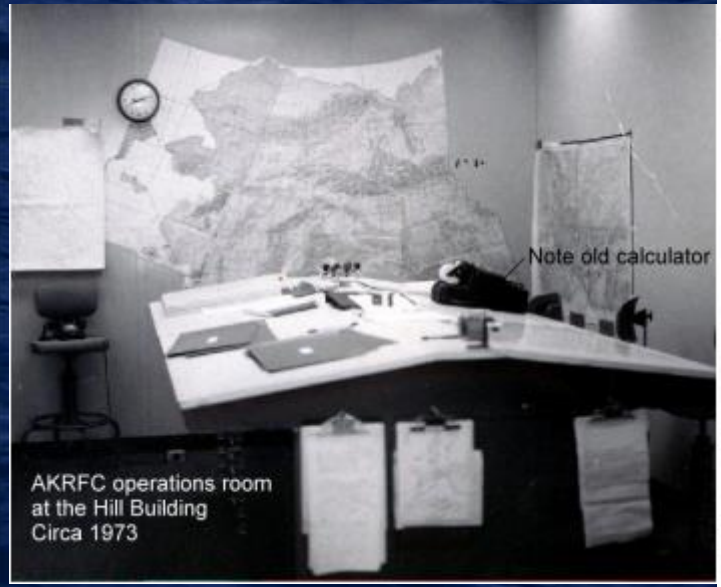
Advent of the Computer in the 60's

- 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



AKRFC operations room
at the Hill Building
Circa 1973

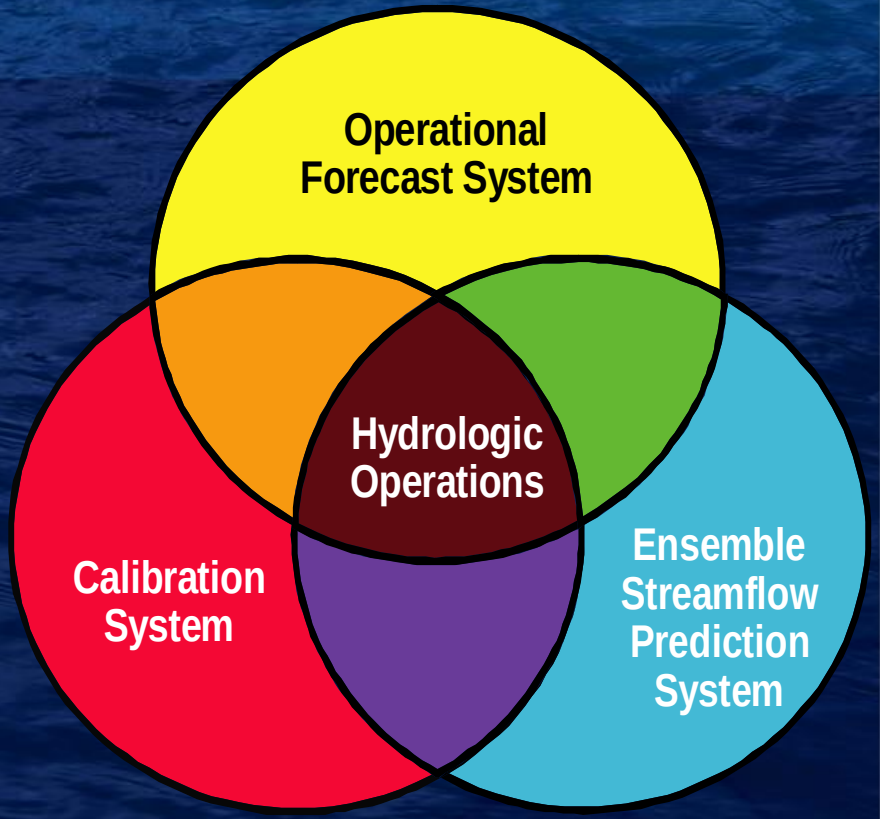
Arkansas-Red Basin RFC (originally known as the Tulsa RFC)

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)

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

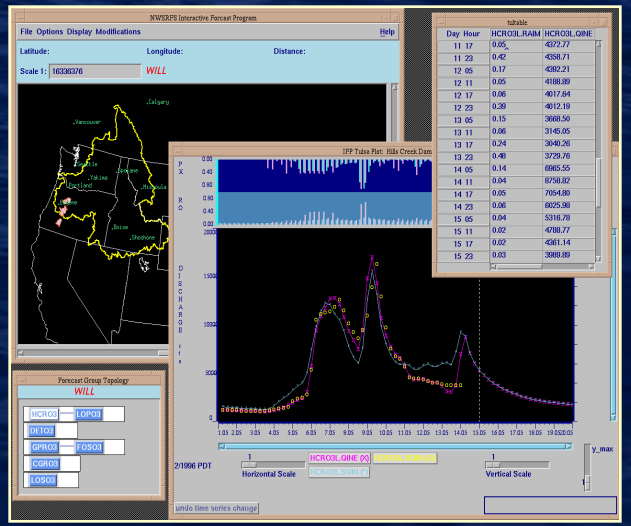
- Calibration System (CS)
  - Generate time series based on historical data
  - Determine model parameters
- Operational Forecast System (OFS)
  - Uses calibrated parameter values to:
    - Generate short-term river and flood forecasts
    - Maintain model state variables
- Ensemble Streamflow Prediction 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



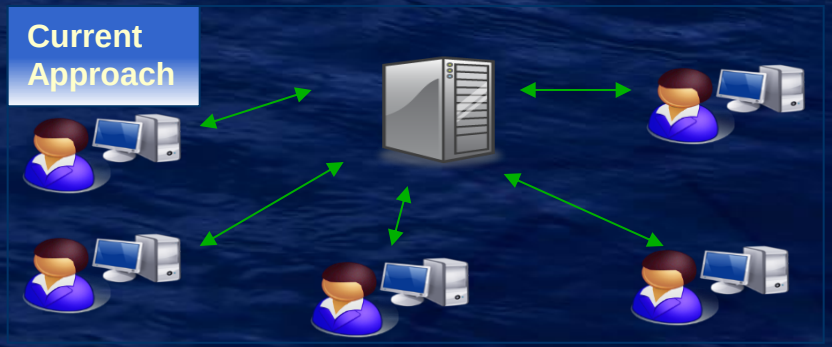
Community Hydrologic Prediction System (CHPS) brought a New Business Model

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

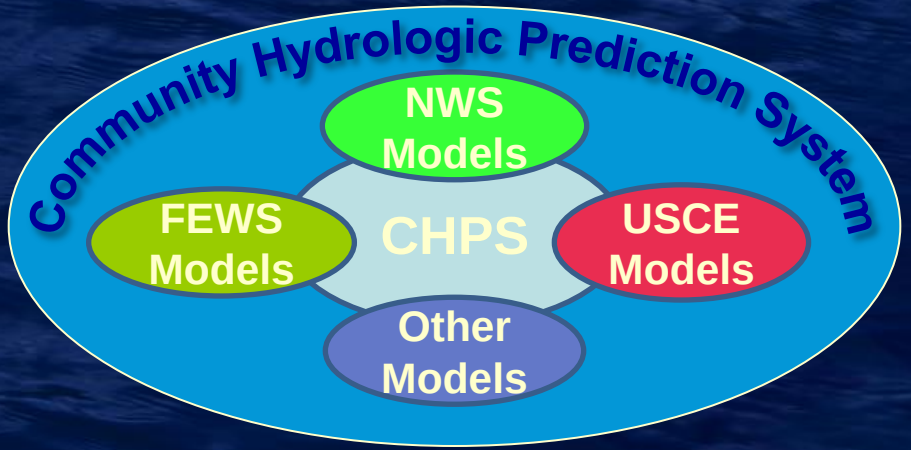
- Pilot programs were conducted for about 18 months through the end of 2007
- Project preparation at the national level during 2008
- 4 River Forecast Centers initially received hardware, training and support during 2009
- 9 RFCs came on board during 2010

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

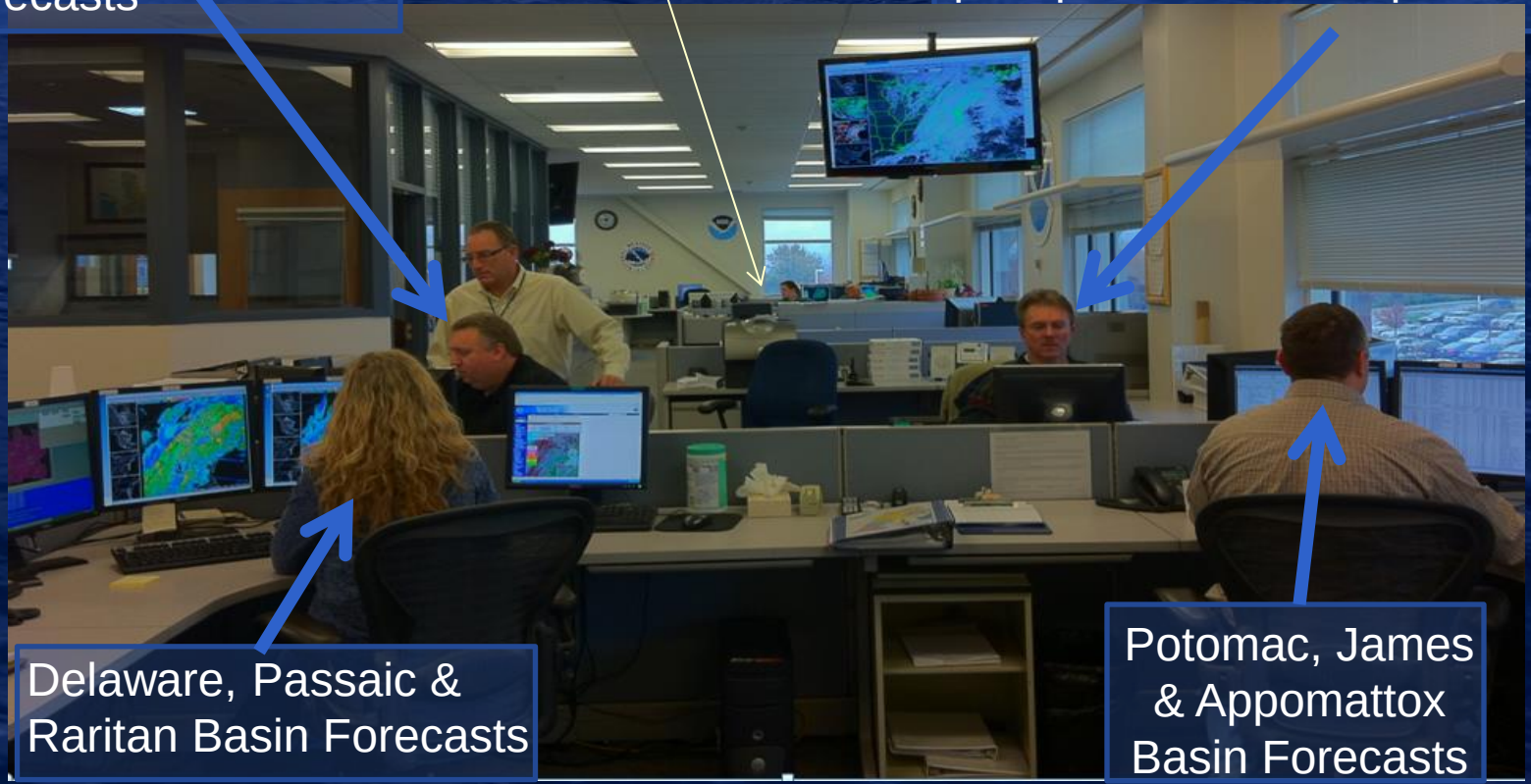


Where are we today?

Collocated with Weather Forecast Office

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

Susquehanna River Forecasts



Delaware, Passaic & Raritan Basin Forecasts

Potomac, James & Appomattox Basin Forecasts

Forecast Product Evolution

1993

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HYDROLOGIC SUMMARY
NATIONAL WEATHER SERVICE DES MOINES IA
137 PM CDT THU JUN 12 2008

HOURLY RIVER STAGES

                                                CUR       6HR OBS
LOCATION                      ID       BF       FS       STG       CHG TIME(LCL)
-------------------------------------------------------------------------------

BOONE RIVER
 WEBSTER CITY                 WBCI4     9.0     12.0     14.15     -0.23  13:00

EAST FORK DES MOINES RIVER
 ALGONA                       AGNI4    12.0     14.0     18.25      0.63  13:00
 DAKOTA CITY                  DAKI4     0.0     20.0     16.43      0.04  13:00

WEST FORK DES MOINES RIVER
 ESTHERVILLE                  ESVI4     6.0      7.0      8.13      0.04  13:00
 EMMETSBURG                   EMTI4    10.0     10.0      8.23      0.28  13:00
 HUMBOLDT                     HBTI4     0.0      8.0      9.07     -0.09  13:15

DES MOINES RIVER
 FORT DODGE                   FODI4     0.0     10.0     10.70     -0.17  13:00
 STRATFORD                    STRI4    14.0     14.0     23.08     -0.27  13:00
 SAYLORVILLE TAIL             SDTI4     0.0      M        M         M      M
 2ND AVE DES MOINES           DMOI4     0.0     23.0     29.37      0.38  13:00
 DES MOINES SE 6TH            DESI4     0.0     24.0     33.29      0.34  13:00
 TRACY                        TRCI4    13.0     14.0     19.85      1.42  13:00
 OTTUMWA                      OTMI4     8.0     10.0     12.96      0.58  13:00
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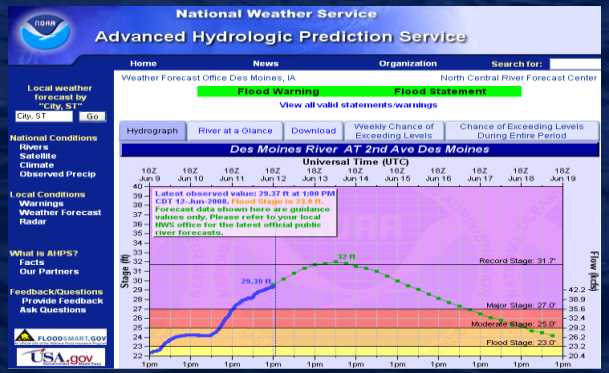
2010



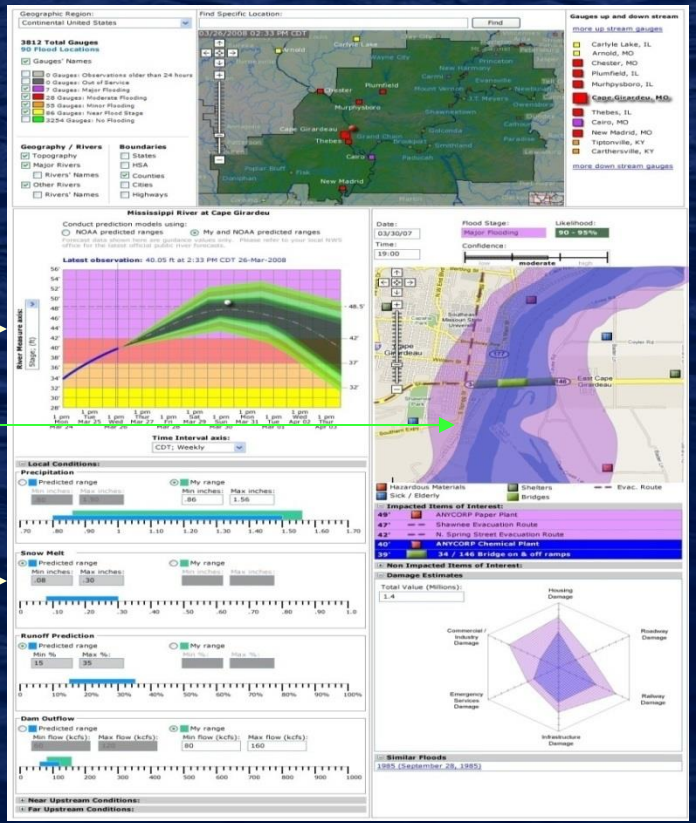
2016

Geographical Depiction →

Probabilistic →

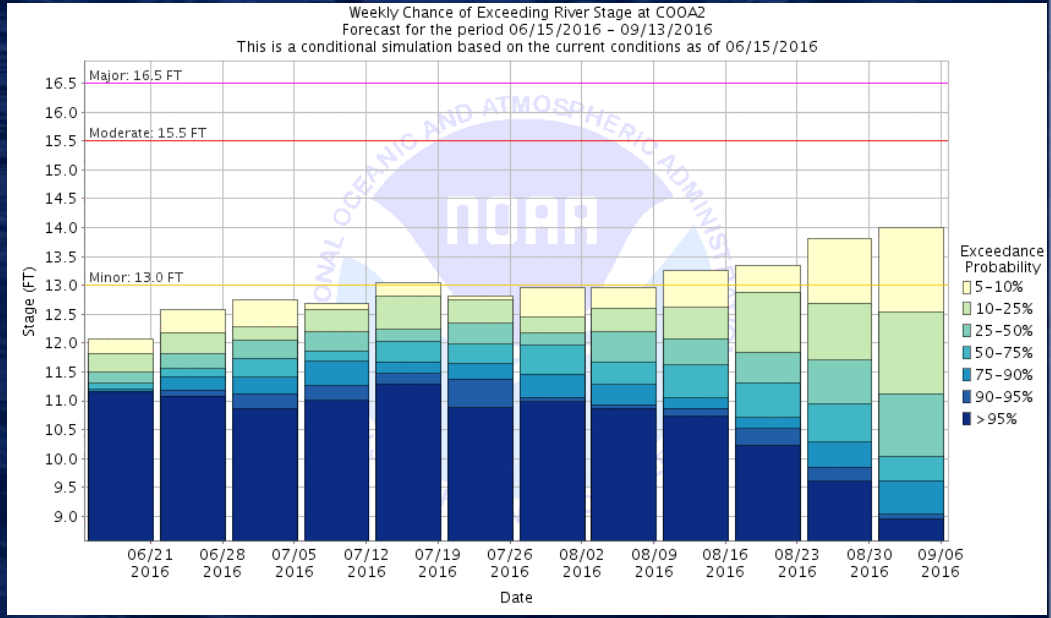
Inundation Mapping →

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.



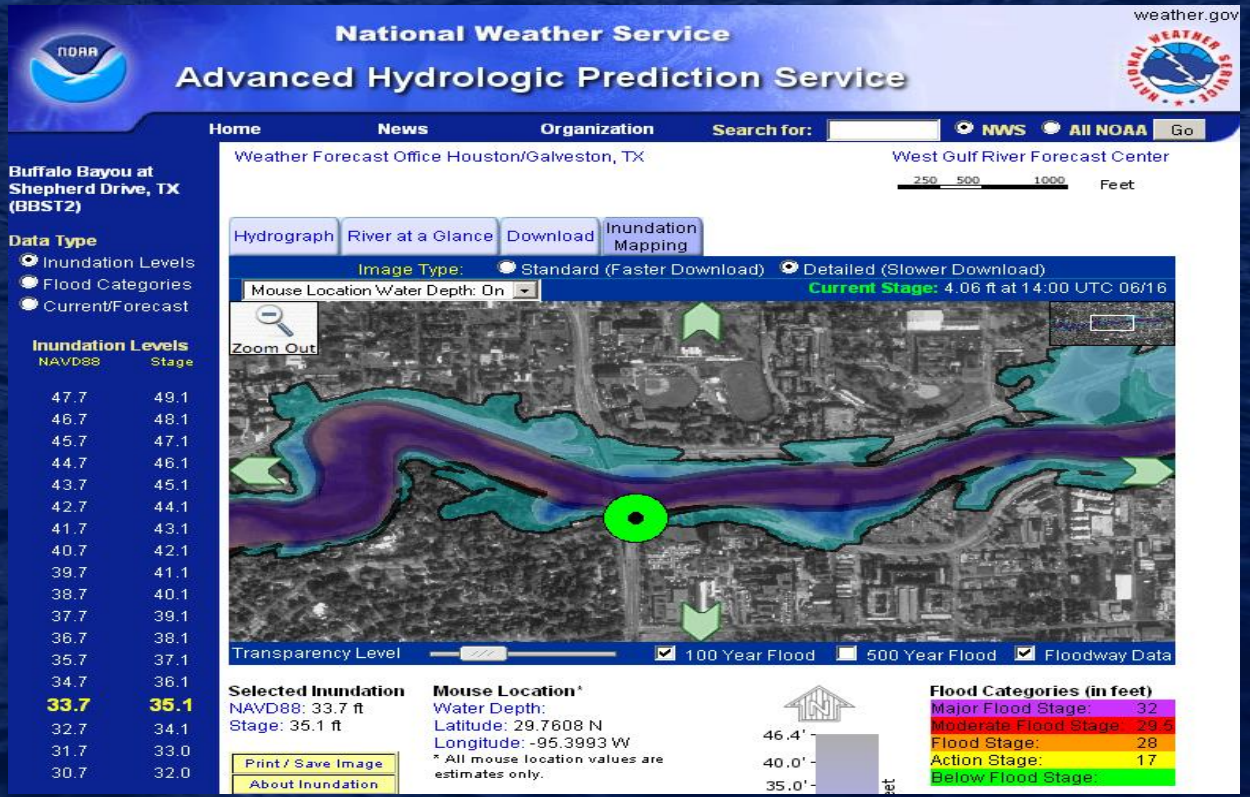
NOAA/NWS Flood Inundation Mapping

User Tools tied to NWS river forecast locations

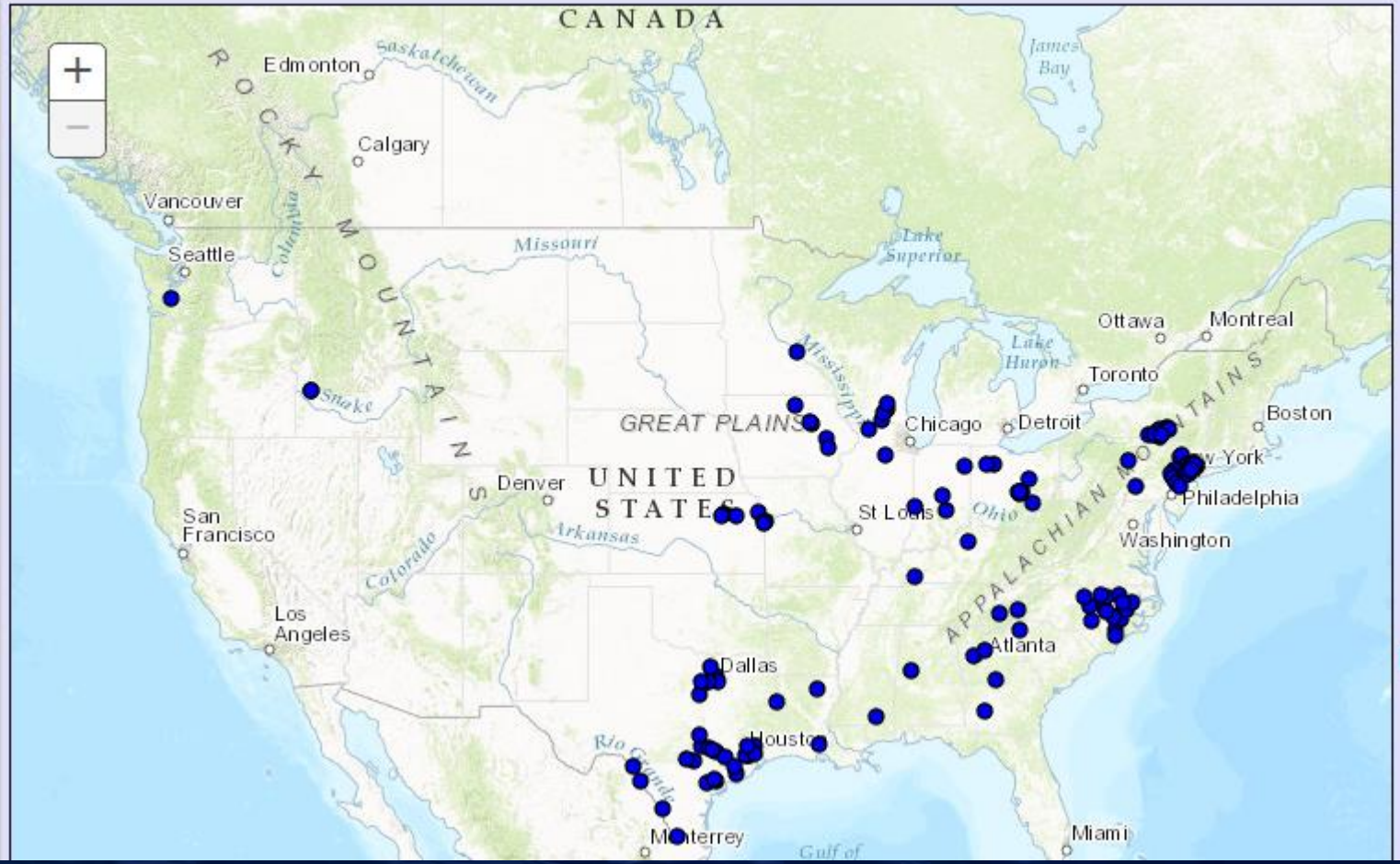
Depicts flooding from minor to historical levels

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 YouTube

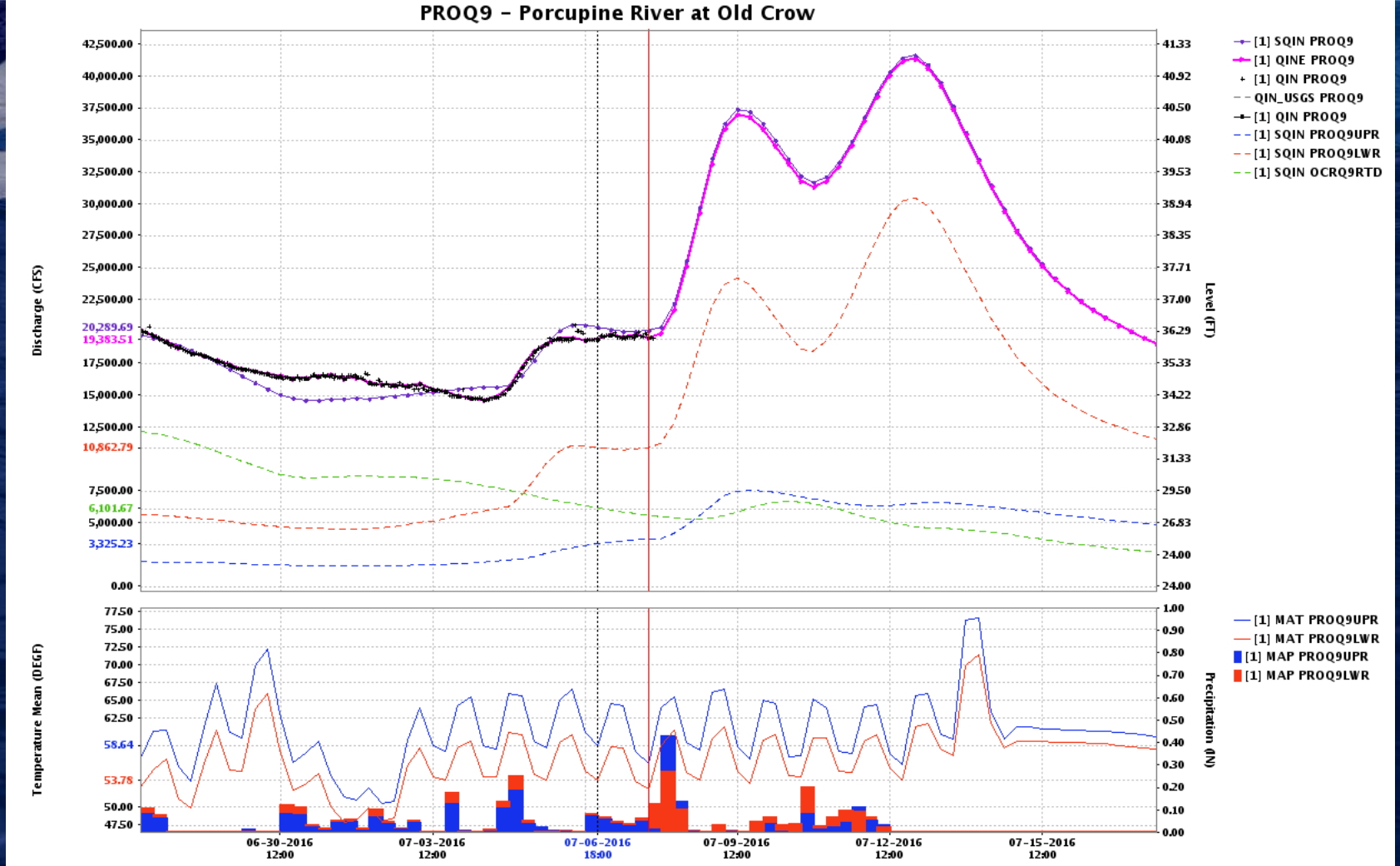
Map Help

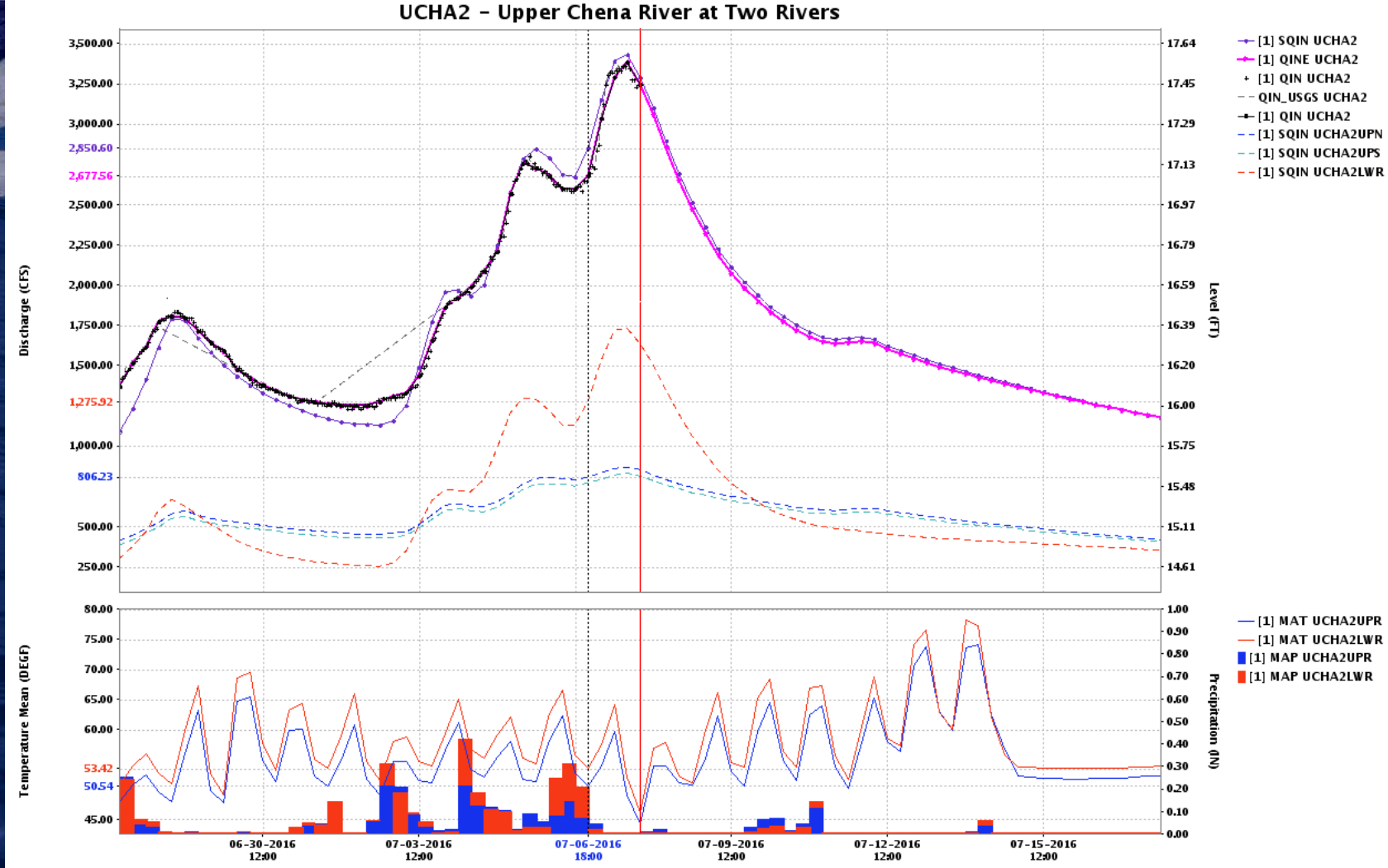
Disclaimer

KML

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
Discharge (CFS)
Level (FT)
42,500.00
40,000.00
37,500.00
35,000.00
32,500.00
30,000.00
27,500.00
25,000.00
22,500.00
20,289.69
19,383.51
17,500.00
15,000.00
12,500.00
10,862.79
7,500.00
6,101.67
5,000.00
3,325.23
0.00
41.33
40.92
40.50
40.08
39.53
38.94
38.35
37.71
37.00
36.29
35.33
34.22
32.86
31.33
29.50
26.83
24.00
24.00
[1] SQIN PROQ9
[1] QINE PROQ9
[1] QIN PROQ9
QIN_USGS PROQ9
[1] QIN PROQ9
[1] SQIN PROQ9UPR
[1] SQIN PROQ9LWR
[1] SQIN OCRQ9RTD
Temperature Mean (DEGF)
Precipitation (IN)
77.50
75.00
72.50
70.00
67.50
65.00
62.50
58.64
53.78
50.00
47.50
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
[1] MAT PROQ9UPR
[1] MAT PROQ9LWR
[1] MAP PROQ9UPR
[1] MAP PROQ9LWR
06-30-2016 12:00
07-03-2016 12:00
07-06-2016 18:00
07-09-2016 12:00
07-12-2016 12:00
07-15-2016 12:00
PROQ9_Forecast: [1] PROQ9 Porcupine R Ol... 07-07-2016 18:00 GMT Local


UCHA2 - Upper Chena River at Two Rivers
Discharge (CFS)
Level (FT)
Temperature Mean (DEGF)
Precipitation (IN)
[1] SQIN UCHA2
[1] QINE UCHA2
[1] QIN UCHA2
QIN_USGS UCHA2
[1] QIN UCHA2
[1] SQIN UCHA2UPN
[1] SQIN UCHA2UPS
[1] SQIN UCHA2LWR
[1] MAT UCHA2UPR
[1] MAT UCHA2LWR
[1] MAP UCHA2UPR
[1] MAP UCHA2LWR
3,500.00
3,250.00
3,000.00
2,850.60
2,677.56
2,500.00
2,250.00
2,000.00
1,750.00
1,500.00
1,275.92
1,000.00
806.23
500.00
250.00
17.64
17.45
17.29
17.13
16.97
16.79
16.59
16.39
16.20
16.00
15.75
15.48
15.11
14.61
80.00
75.00
70.00
65.00
60.00
53.42
50.54
45.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
06-30-2016 12:00
07-03-2016 12:00
07-06-2016 18:00
07-09-2016 12:00
07-12-2016 12:00
07-15-2016 12:00
UCHA2_Forecast: [1] UCHA2 Upper Chena Ri... 07-07-2016 18:00 GMT Local

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	Prioritize core capabilities - a MAR-like effort is needed to address long-standing and deep-seated issues in hydrology
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	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
NWS Hydrologic Forecasters are extensively *"in the forecast loop"*	Transition RFC forecasters to "over the loop" enabling a shift in focus to model and product development, forecast interpretation, and decision support
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	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 ~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).

RFC	NHD Streamlines
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