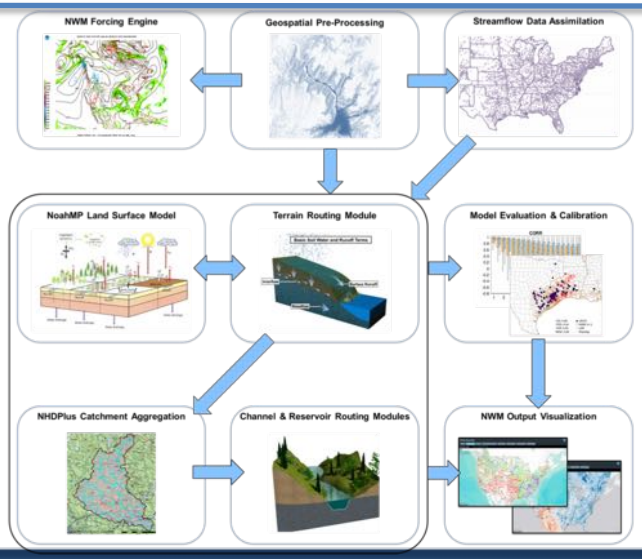
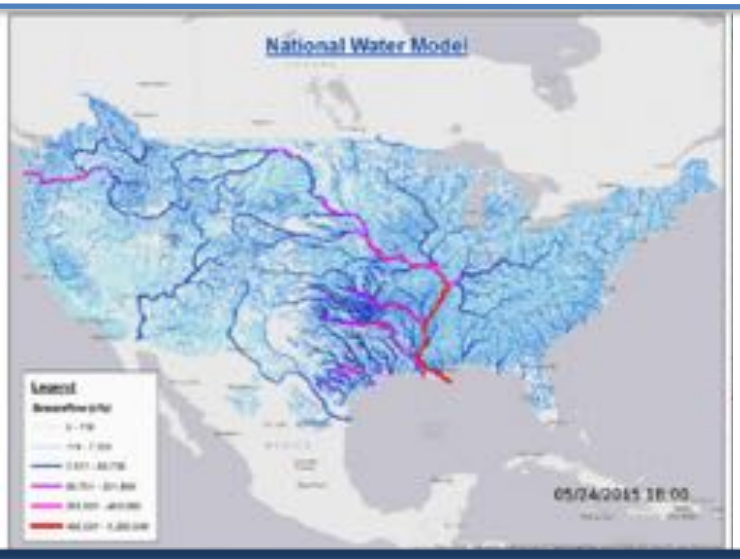
NWM Development – Current Status and Future Plans

OWP | OFFICE OF WATER PREDICTION





Update to the CAC WP

December 13, 2018

Thomas Graziano
Director, Office of Water Prediction
NOAA, National Weather Service

Edward Clark
Director, National Water Center
NOAA, National Weather Service

Trey Flowers
Director, Analysis and Prediction Division
NOAA, National Weather Service

Office of Water Prediction

Vision – A *Water*-Ready Nation

Mission – Collaboratively research, develop and deliver timely and consistent, state-of-the-science national hydrologic analyses, forecast information, data, guidance, and decision-support services to inform essential emergency management and water resources decisions across all time scales.

Community Advisory Committee for the Office of Water Prediction (CAC-WP)

Purpose:

- Conduct a thorough independent review of OWP's water modeling capabilities with emphasis on the National Water Model (NWM), other modeling innovations, and related data and information services.
- Bring independent expertise and perspectives from across the community to provide recommendations to improve OWP's water modeling capabilities and related data and information services.
- Consider the various activities OWP has already undertaken to address documented requirements and associated science and service gaps.

Composition and Scope:

- Two-Co Chairs and 12+ member committee comprised primarily of hydrologists, civil engineers, and other water resources science and data science experts.
- Administratively managed by UCAR
- Any review and recommendations will be those of committee members and not of UCAR
- Meet every 12-18 months and produce a written report of its findings and recommendations.

Community Advisory Committee for the Office of Water Prediction (CAC-WP)

The CAC-WP scope is broad and initial review provided advice regarding:

1. The National Water Model, including:

a. The current and future elements of the NWM as described multi-year strategic science and services framework, as well as future adjustments to that framework;

b. In-situ and remotely-sensed observations for assimilation and validation;

c. Physiographic data sets such as terrain data, stream network, land use land cover, soils data, reservoir characteristics, and other relevant data sets;

d. Hydrometeorological forcings;

e. Improved representation of physical processes;

f. Accounting for anthropogenic processes;

g. The establishment of a community developmental testbed and associated governance;

h. Performance metrics to assess overall model performance and objectively evaluate potential model upgrades;

i. Involvement of NWS RFCs, WFOs, and NCEP Centers in using, validating and improving the NWM;

j. Requirements for HPC resources and associated implementation strategies to optimally use available computing resources;

k. Integration into a broader unified Earth System Prediction Capability (ESPC)

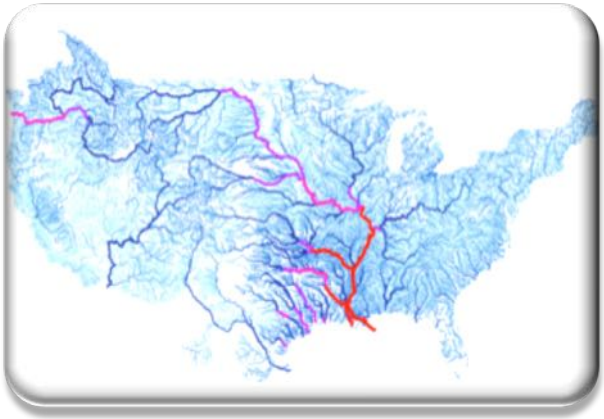
2. The evolution of the OWP water resources data services;

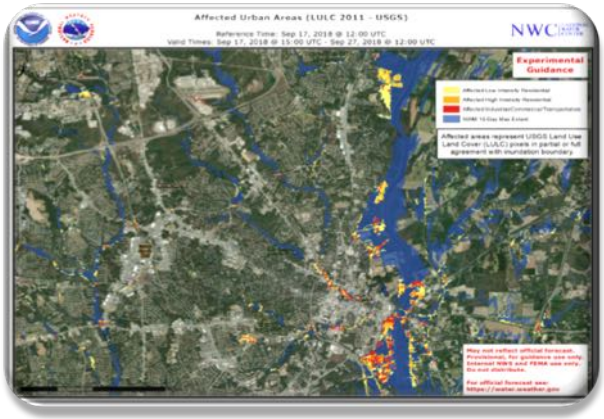
3. Integrating the broad spectrum and large volume of water resources and related geospatial information for new product development, and enhanced impact-based decision-support services.

OWP Strategic Priorities

- **Staff, and define concept of operations for the NWC Operations Center to provide IDSS**
- **Continued development of the National Water Model (w/NOAA LOs, NCAR, USGS, CUASHI, others); Activities include:**
  - ✓ *Enhance specification of Channel Geometry*
  - ✓ *Improve Hydrologic Routing and implement Hydraulic Routing*
  - ✓ *Couple with shallow groundwater model*
  - ✓ *Couple with ADCIRC and WaveWatch III (ESTOFS)*
  - ✓ *Leverage AI/Machine Learning to account for Anthropogenic Processes*
  - ✓ *Demonstrate Hyper-Resolution nested modeling capability*
  - ✓ *Continue to Engage Water Resources Enterprise and Establish Community Development Environment*
  - ✓ *Provide Training to field staff*
  - ✓ *Make retrospective analysis available to Water Resources Community*
- **Develop and apply informatics capabilities (e.g., inundation mapping) to enhance RFC forecast & NWM interpretation/communication**
- **Accomplish DOC FY18-19 Agency Priority Goal**
  - ✓ *Freshwater flood inundation maps for 8% of U.S. population*
- **Work with USGS to define requirements for next generation observing system in support of high resolution hydro-terrestrial modeling.**
- **Develop and Implement Water Resources Evaluation Service (WRES)**
- **Establish and broaden Data Services for emerging capabilities and critical datasets**
- **Complete the validation and implementation of Hydrologic Ensemble Forecast Service (HEFS) version1, implement HEFS v1.1 (GEFS v12 reforecasts), and develop HEFS v2**
- **Complete RFC Service Backup demonstration (2017-2020) and operational implementation (2021)**

Setting the Stage for Transformation





Centralized Water Forecasting Demo

(2015)

- National Water Model (NWM) Development and Demonstration
- Centralized Water Resources Data Services
- Water Resources Test and Evaluation Service

Enhanced Water Prediction Capability

(2016)

- Hyper-Resolution Modeling
- Real-Time Flood Forecast Inundation Mapping
- Enhance Impact-Based Water Resources Decision Support Services

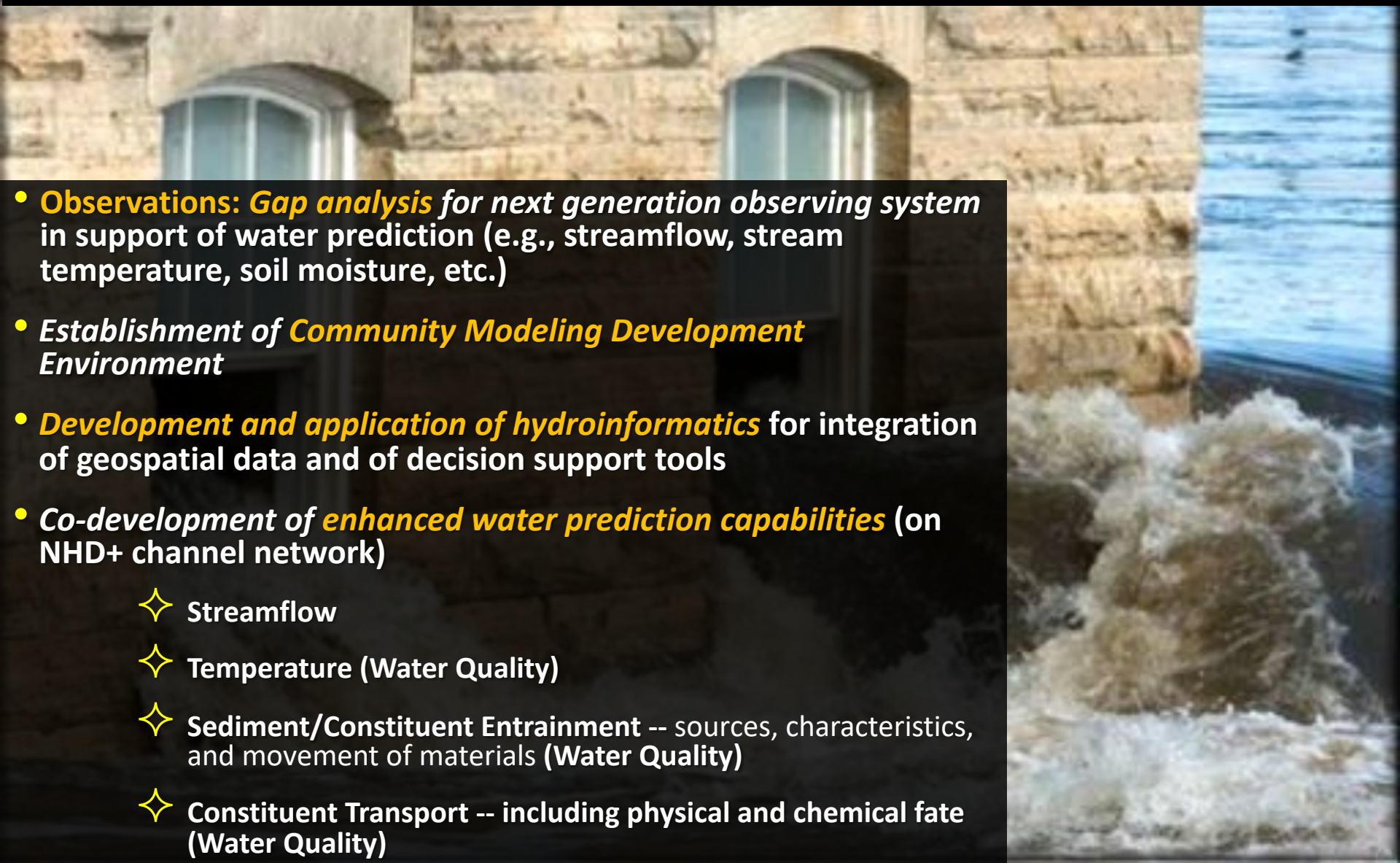
Integrated Water Prediction

(2017 Omnibus)

- Stand up the NWC Operations Center
- Increase HPC capacity
- Couple terrestrial freshwater and coastal estuary models for total water prediction

NOAA-USGS National Water Model Collaboration

Supported by the USGS Water Prediction Work Program



- **Observations:** ***Gap analysis*** ***for next generation observing system*** **in support of water prediction (e.g., streamflow, stream temperature, soil moisture, etc.)**
- ***Establishment of Community Modeling Development Environment***
- ***Development and application of hydroinformatics*** **for integration of geospatial data and of decision support tools**
- ***Co-development of enhanced water prediction capabilities*** **(on NHD+ channel network)**
  - **Streamflow**
  - **Temperature (Water Quality)**
  - **Sediment/Constituent Entrainment --** sources, characteristics, and movement of materials **(Water Quality)**
  - **Constituent Transport -- including physical and chemical fate (Water Quality)**

FY18-19 DOC/NOAA Agency Priority Goal

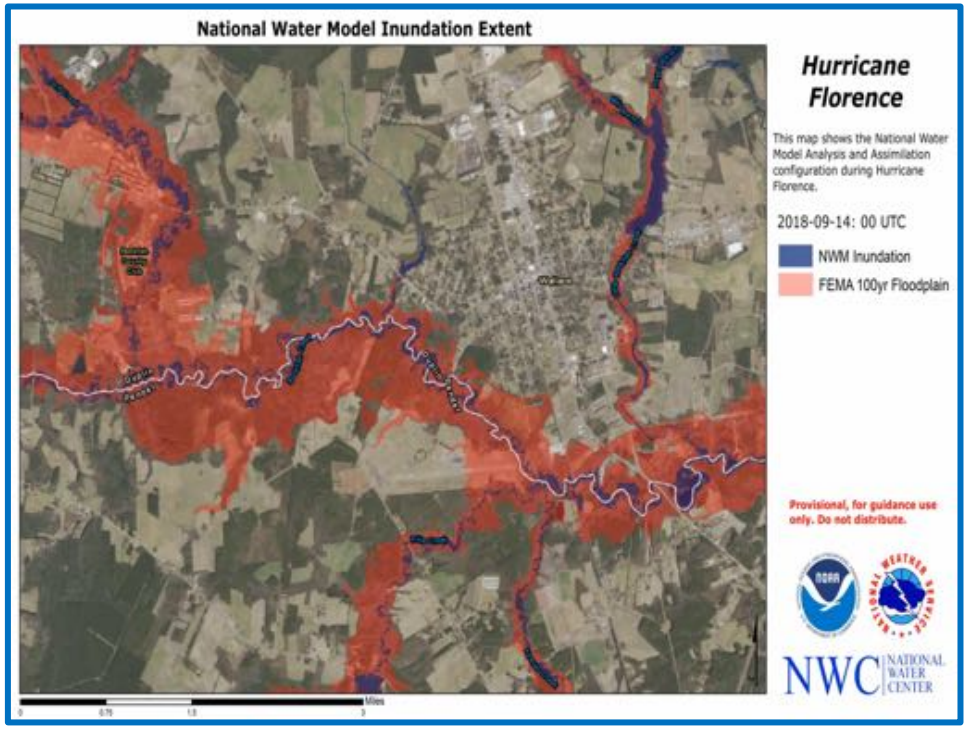
Mitigate Flood Impacts by Demonstrating Improved Decision Support Services to Emergency Managers

Goal Statement: By September 30, 2019, NOAA National Weather Service will improve its flood related decision support services by **(1) demonstrating a new flood inundation mapping capability serving 25 million people (approximately 8%* of the U.S. continental population) residing in flood-vulnerable freshwater basins, and** (2) delivering an enhanced excessive rainfall outlook product, with lead time of "High Risk" predictions extended from two days to three days. Emergency Managers will use this information to more effectively mitigate flood impacts by prepositioning resources, ensuring critical infrastructure (e.g., hospitals, evacuation routes, etc.) are viable, and ordering evacuations.

***Future out-year goal is to incrementally expand flood inundation mapping to near 100% of the continental U.S. population residing in flood-vulnerable freshwater basins.**

NWM Support for DOC Agency Priority Goal: Flood Inundation Mapping

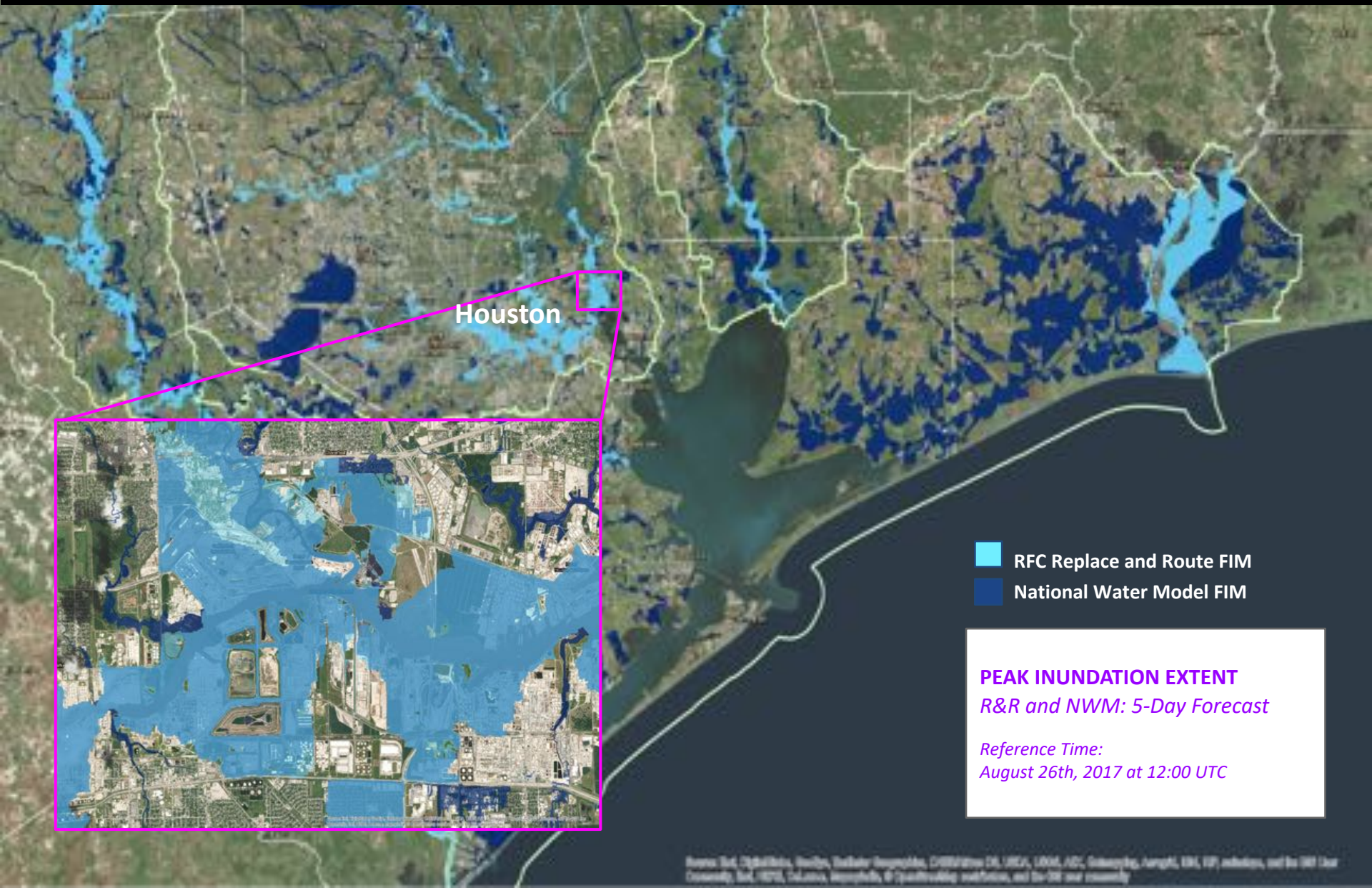
- **Goal: Develop Real-time Flood Inundation Mapping Systems**
- **Two sources of data:**
  - Official RFC Forecasts
    - Use NWM "Replace and Route" to route RFC streamflow
    - Available below AHPS points
  - NWM Forecasts
    - Operational NWM used as input
    - Available along ~2.7 million NHDPlus CONUS river segments
- **Use Height Above Nearest Drainage (HAND) method to translate streamflow to inundation forecasts**



Provides actionable information as to the timing and extent of flood waters

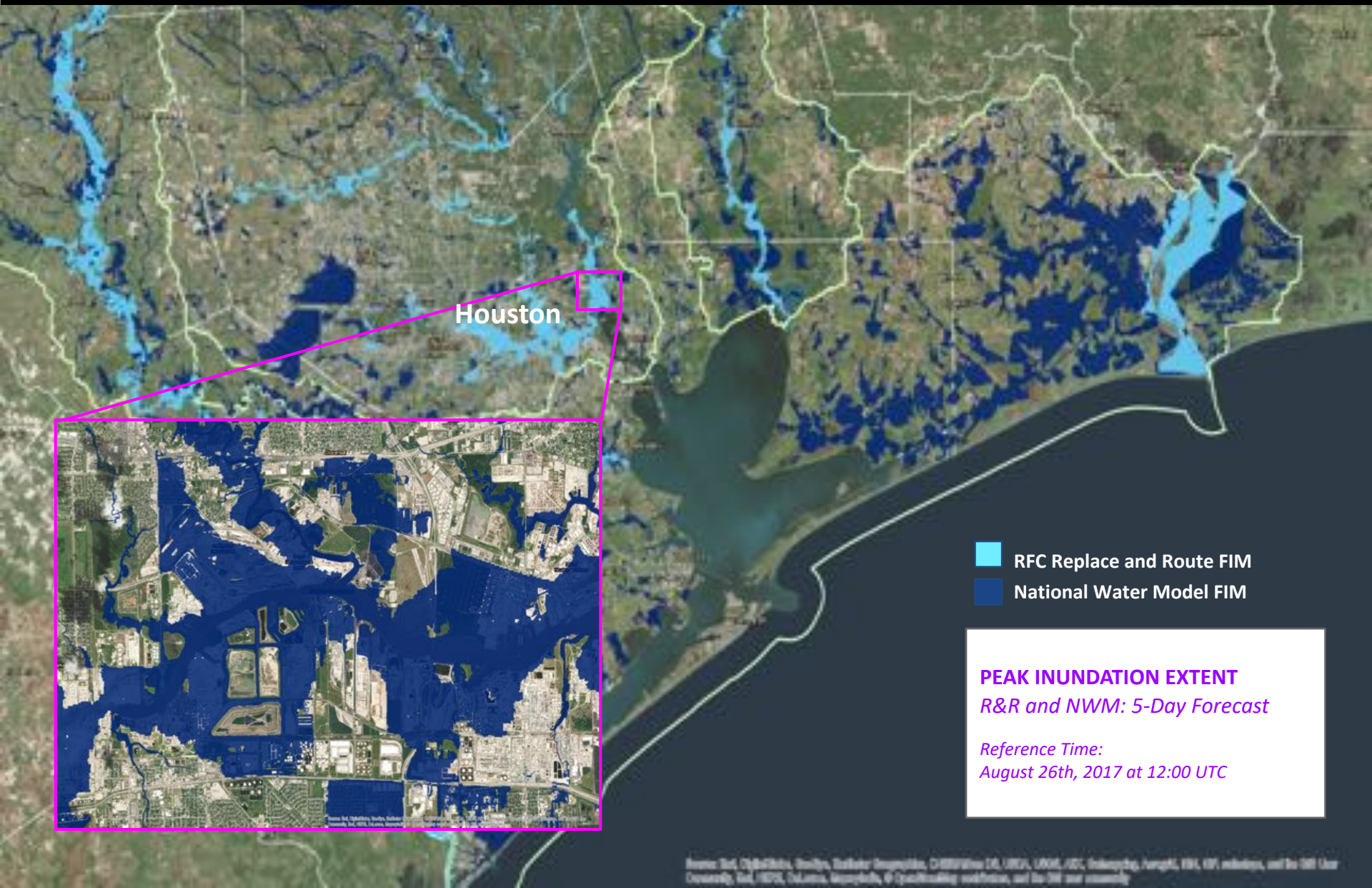
Experimental National Water Model Guidance

Hurricane Harvey: Flood Inundation Mapping



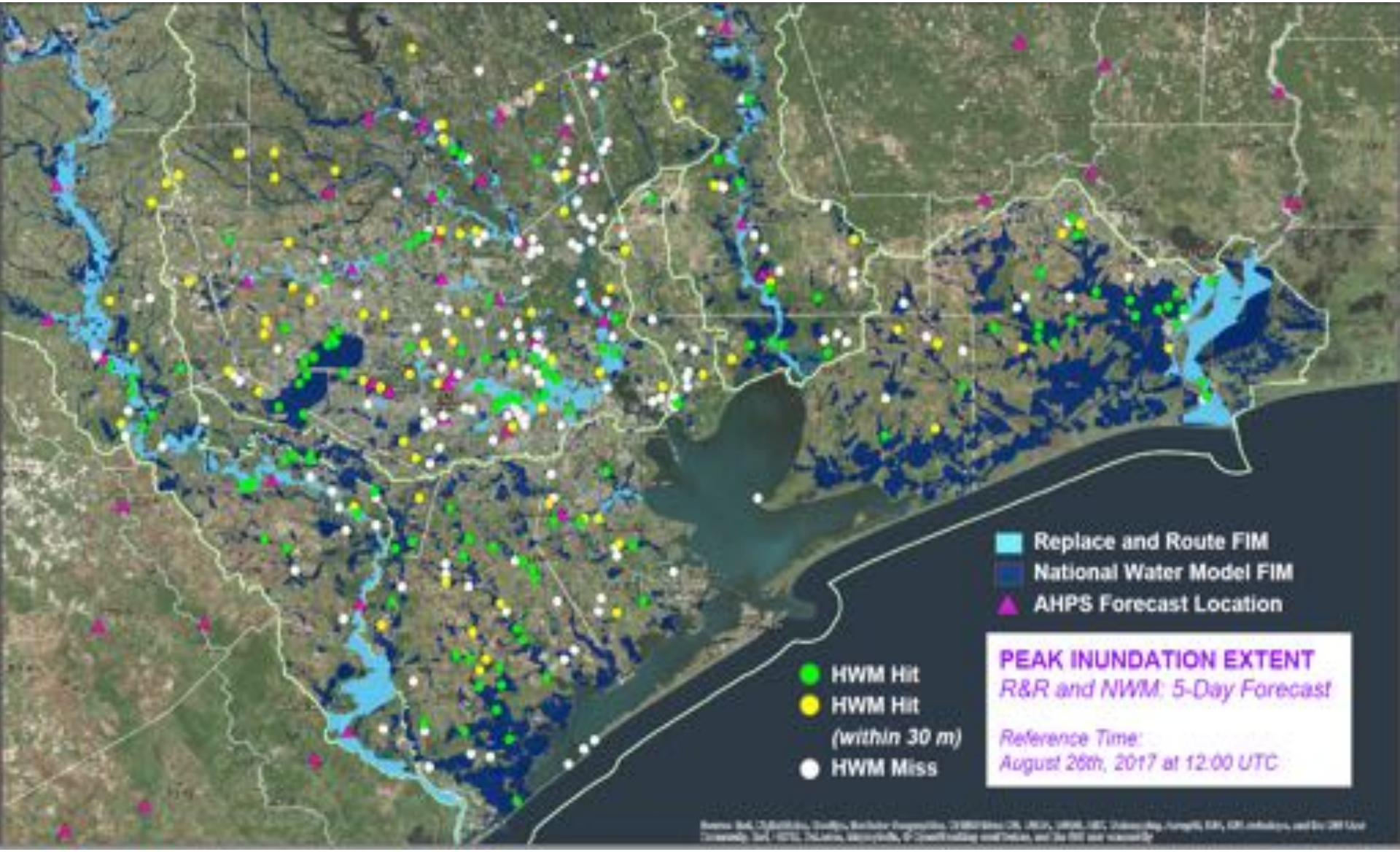
Experimental National Water Model Guidance

Hurricane Harvey: Flood Inundation Mapping



Experimental National Water Model Guidance

Validation



Experimental National Water Model Guidance

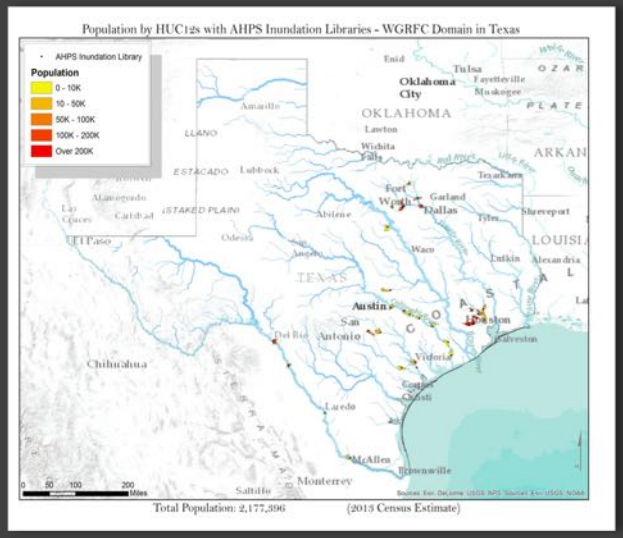
Hurricane Florence

11-Day, Hourly FIM Animation from 12 UTC Sep 12 – 18 UTC Sep 21

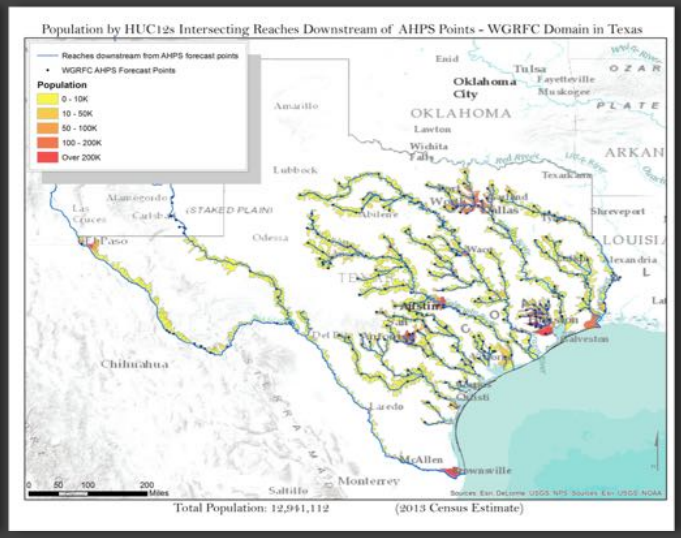
Key Indicators (for Flood Inundation Mapping)

Population served by inundation information, considering areas within NWS West Gulf Forecast Center service area in Texas.*

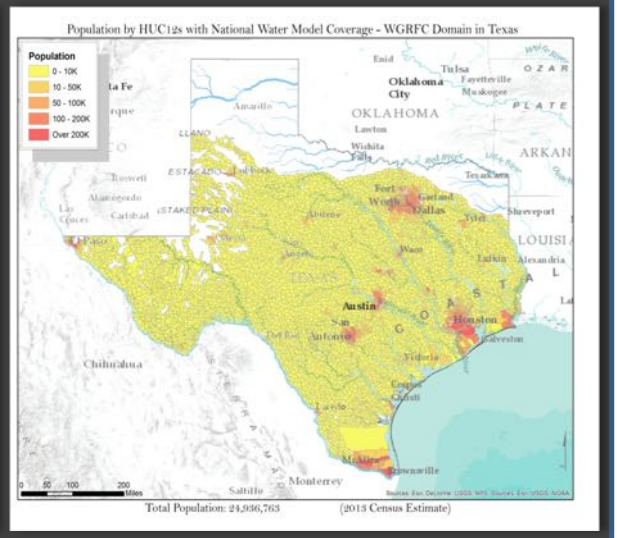
- **Baseline:** < 1% of population (2.2M) served by current Advanced Hydrologic Prediction Service (AHPS) static inundation maps near specific river locations
- **FY18 Q3:** Initiate demonstration on 4% of population (12.9M) served with NWM hydrography and Height Above Nearest Drainage (HAND) technique near NWS official forecast locations.
- **FY18 Q4:** Initiate demonstration on 8% of population (24.9M) served with NWM guidance and HAND technique along full river/stream network.
- **FY19 Q4:** Complete demonstration on 8% of population (full WGRFC domain) and incorporate emergency manager feedback.
- **Out-year:** ~100% of CONUS population (317M) served by NWM model and HAND technique



Baseline



FY18 Q3



FY18 Q4

*Population totals based on 2013 population in adjacent hydrologic areas, defined by Hydrologic Unit Code (HUC) 12 delineations.

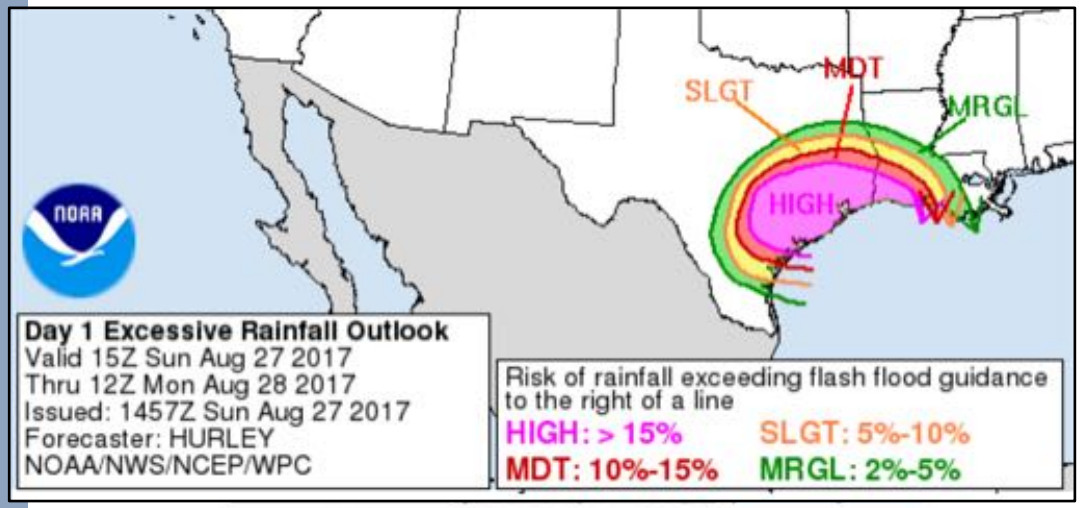
Excessive Rainfall Outlook

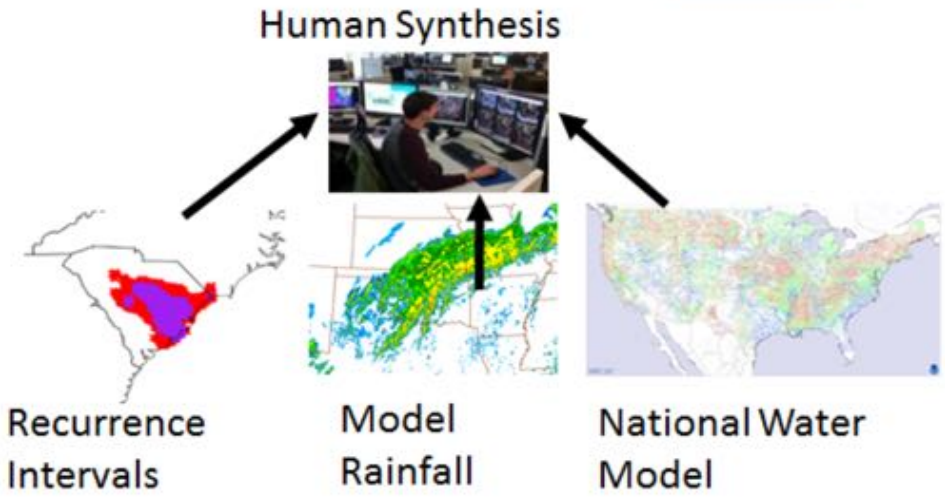
The Excessive Rainfall Outlook (ERO) provides a national summary of rainfall threat by expressing the probability of rainfall exceeding flash flood guidance.

The ERO raises situational awareness that conditions are favorable for impactful rainfall.

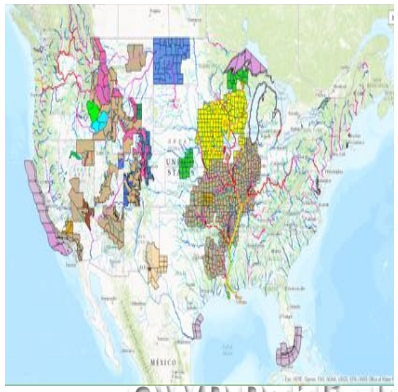
The risk of excessive rainfall is expressed both probabilistically and categorically (e.g., Marginal 5-10%, Slight 10-20%, Moderate 20-50%, and High >50%).

“High” risk forecast days have been correlated to events with fatalities and large damages. Currently “High Risk” is only used in Day 1 and Day 2 products.





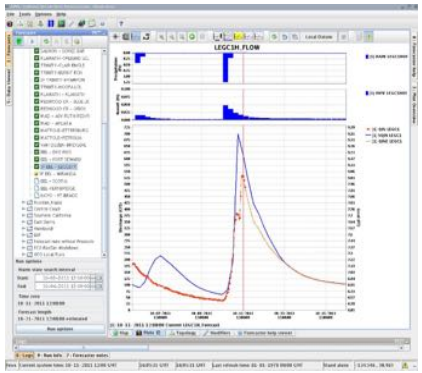
Viewing and Accessing NWM Output Data



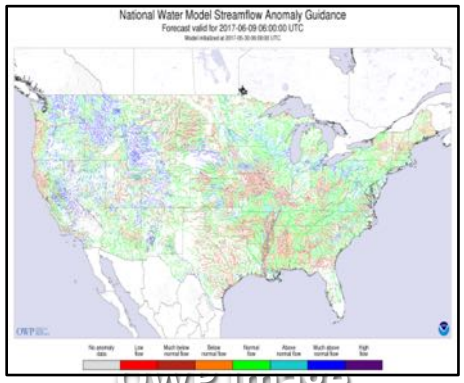
OWP Public Interactive Map Viewer (zoomable images, point-and-click hydrographs)

OWP GIS Portal (NWC network, extending to RFCs)

NCEP NOMADS (download NetCDF files)

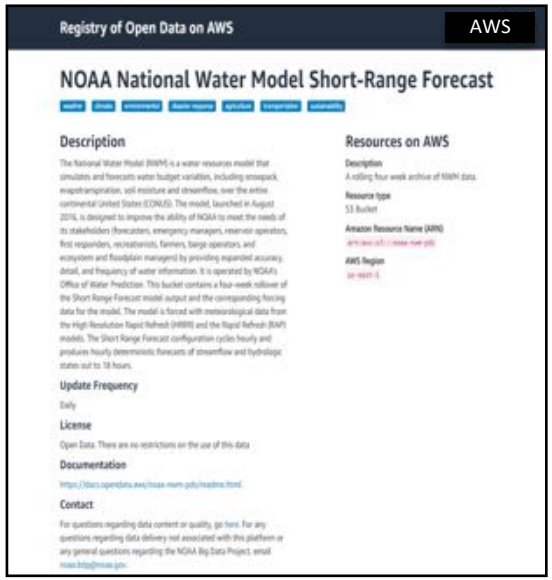


NCEP NOMADS (for RFC CHPS Ingest)

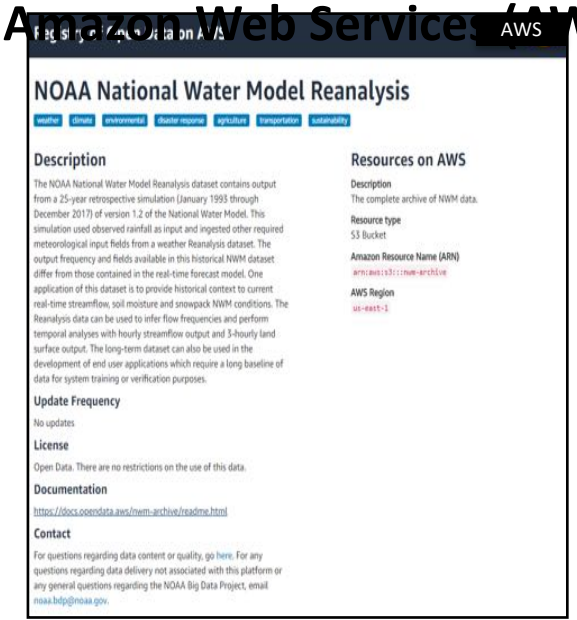


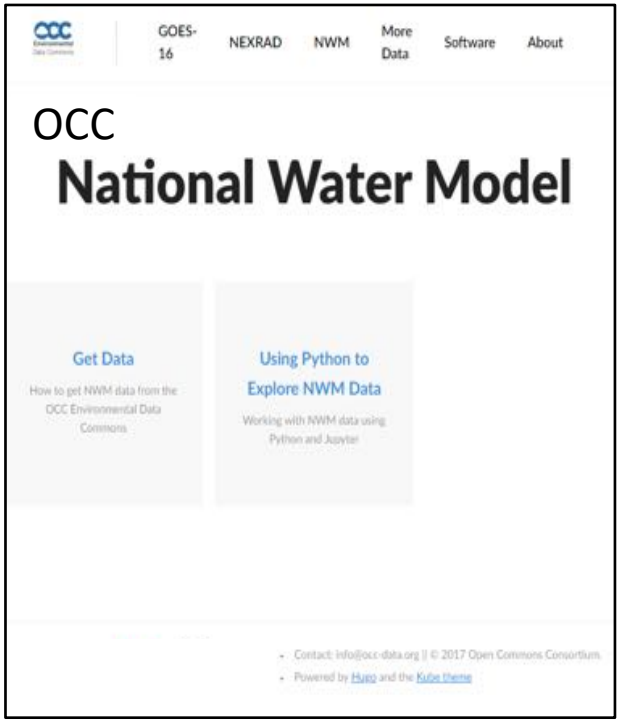
OWP Image Viewer (view and loop images)

National Water Model (NWM) Data Hosted by Big Data Providers



Both real-time short-range forecasts and retrospective NWM data is hosted by Amazon Web Services (AWS)





Retrospective NWM data is hosted by the Open Commons Consortium (OCC) and will soon be hosted by

Google

National Water Model

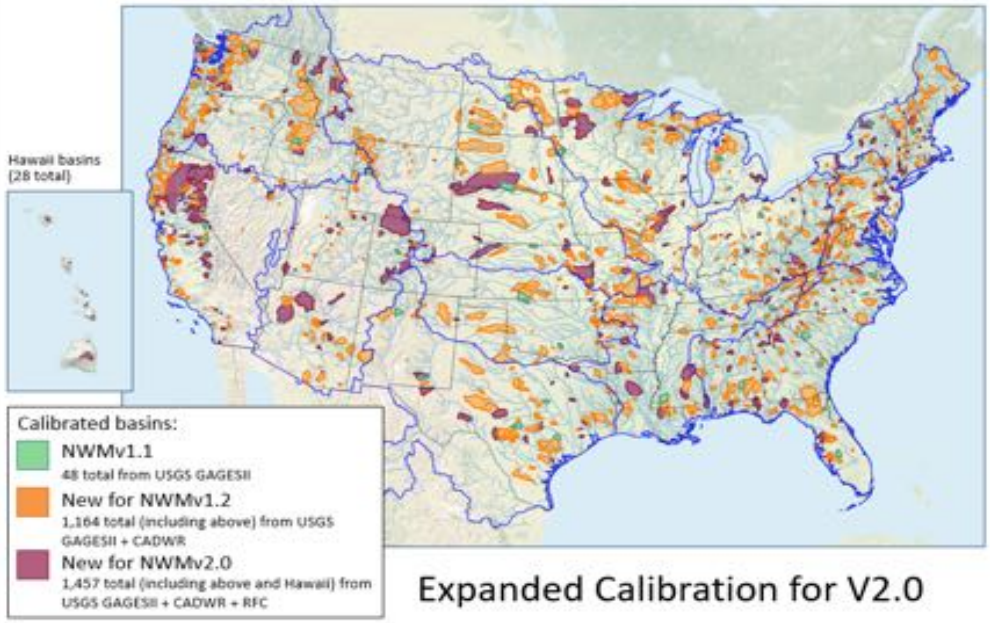
Future Plans: Upgrading to NWM V2.0 and Beyond

v1.0 → v1.1/1.2 → v2.0

Foundation Established August 2016
Water Resource Model for 2.7 Million Stream Reaches

First/Second Upgrade May 2017/March 2018
Increased cycling freq. and forecast length, improved calibration, soil/snow physics and stream DA

Third Upgrade March 2019
Expansion to Hawaii, medium range ensembles, compound channels, increased modularity, improved calibration, longer Analysis w/MPE



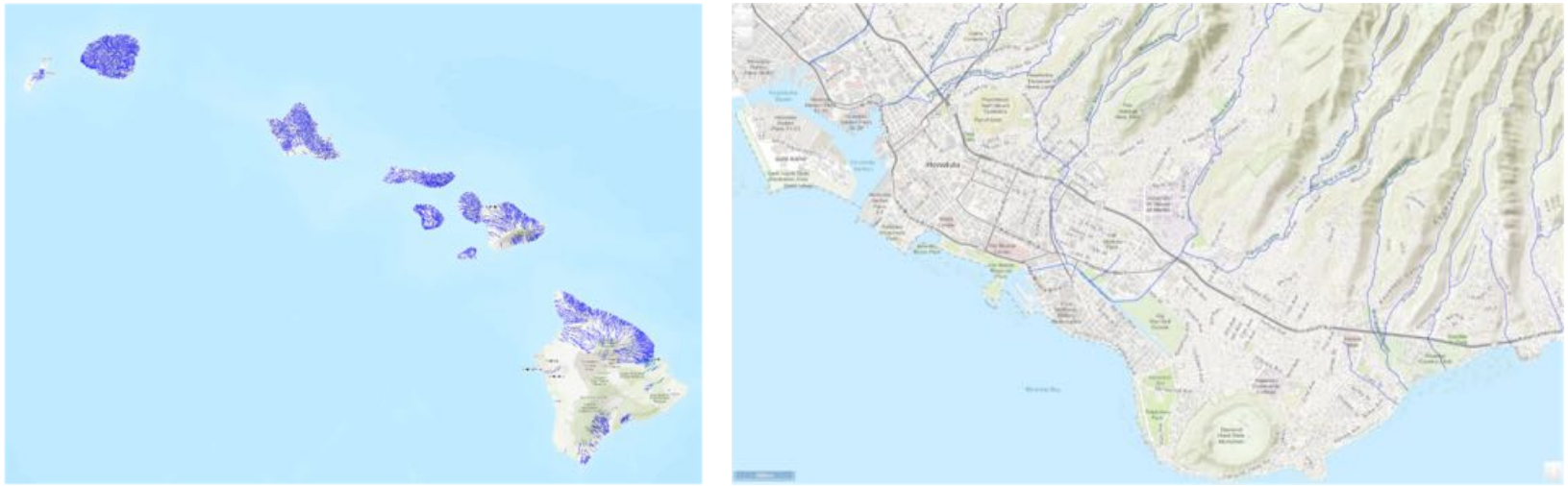
Expanded Calibration for V2.0

v2.1

Fourth Upgrade March 2020
Dynamic parameters, expansion to PR and Great Lakes, enhanced reservoir module, forcing bias-correction, improved ensembles, calibration and Hawaii QPE

NWM Version 2.0 Enhancements

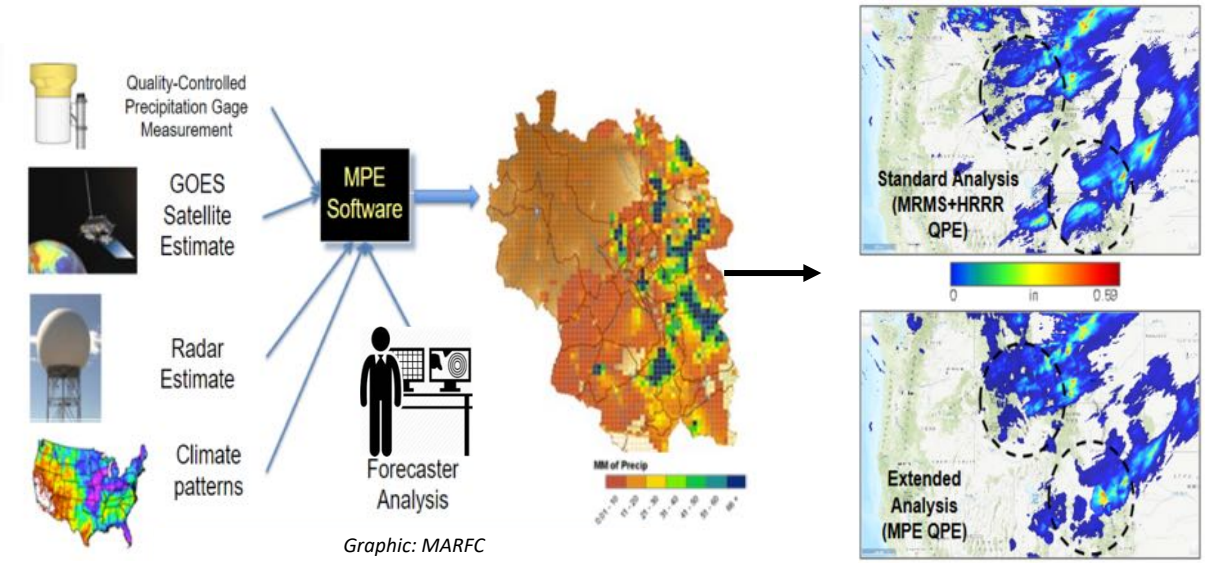
- **Updates**
  - Addition of Hawaii to NWM domain (including Analysis and 60-hr Short-Range forecast)
  - Addition of Extended Analysis configuration (daily 28-hour lookback)
  - Addition of separate Long-Range Analysis configuration to initialize Long-Range forecasts
  - Addition of Medium Range ensemble forecast configuration
    - 7 members 4x day (mem1=current GFS to 10 days, mem2-7=time lagged GFS to 8.5 days)
  - Use of 13km GFS forcing (versus 0.25 degree)
  - Improved downscaling of GFS and CFS forcing via Mountain Mapper approach
  - Improved physics (out-of-bank flow via compound channel, improved snow physics)
  - Improved waterbody parameters from 30m DEM, inclusion of 3,995 additional reservoirs
  - Improved calibration of hydrologic parameters, expanded from 1,100 to 1,400 basins
  - Corrections to stream connectivity
  - Improved code modularity
  - Bugzilla fixes and file metadata updates



New Hawaii Domain

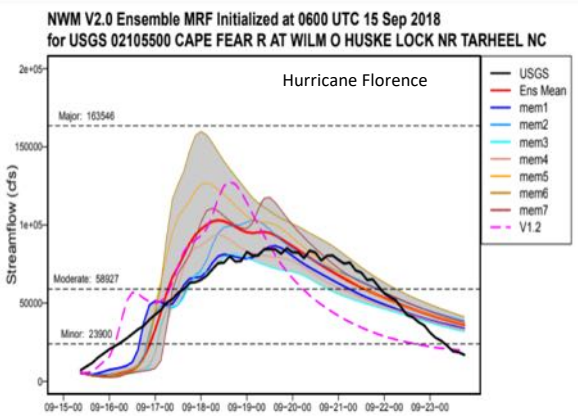
NWM V2.0: Four New Configurations

Key Link to Field: New NWM Extended Analysis Cycle (28-hr lookback)
Daily run, anchors NWM states to RFC MPE observed precipitation product, promoting hydrologic operational consistency



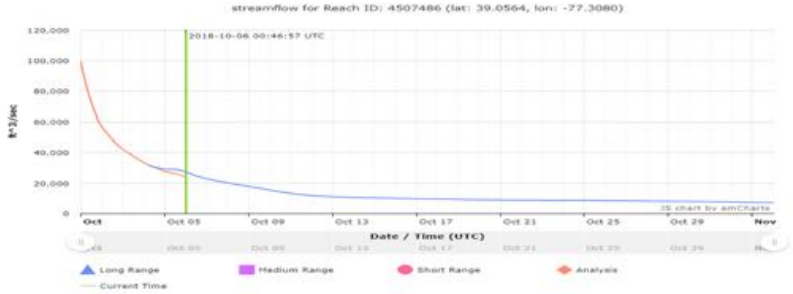
Graphic: MARFC

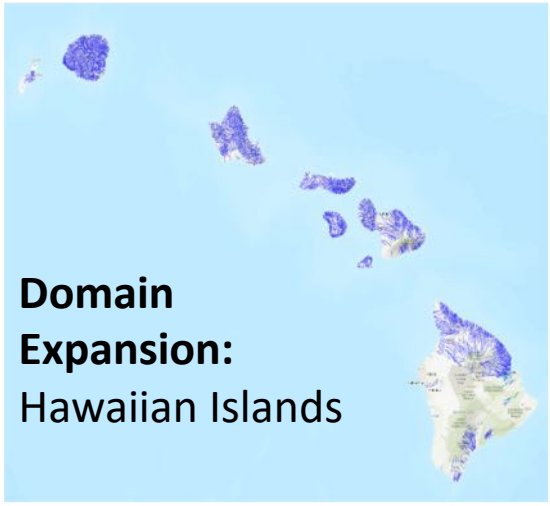
New Ensembles: New Medium-Range ensemble forecast cycle with time-lagged FV3/GFS to capture forcing uncertainty



Improved Initialization: New NWM Long-Range Analysis Cycle

Supplies better-matched initial conditions to Long-Range Forecas





NWM Version 2.1

Task Area 1: NWM Domain Expansion to relevant oCONUS Territory

Task 1: Implement an operational Puerto Rico and U.S. Virgin Islands domain

Task 2: Support implementation of the Great Lakes tributary domain

Task 3: Enhance support for Hawaii domain - *Improved Hawaii parameter data, forcing data and hydro-geo fabric*

Task 4: Enhance HydroInspector viewer utility for display of expanded domains

Task Area 2: Model Physics Enhancement

Task 5: Water management and reservoir management enhancement - *reservoir routing module*

Task 6: Improve snowmelt generated runoff dynamics

Task 7: Complete implementation of the variable soil depth formulation

Task 8: Support coastal and inland hydraulics formulation

Task 9: Support hyper-resolution model assessment project

Task 10: Support ongoing review and upgrade of the baseflow bucket formulation

NWM Version 2.1

Task Area 3: Geospatial and hydrofabric development and improvement

Task 11: Ongoing hydrofabric corrections, refinements and training

Task 12: Hydrofabric refactoring

Task 13: Coastal hydro-geofabric development support

Task Area 4: NWM Forecast Optimization and Evaluation

Task 14: NWM calibration and evaluation and associated training

Task 15: Improved forcing data bias correction and downscaling

Task 16: Improve channel parameter estimates

Task 17: Implement dynamic land cover parameter updates for burned and other disturbed areas and associated training

Task 18: Implement an extend lookback for the Long Range NWM configuration

Task Area 5: Support ongoing operational data assimilation needs

Task 19: Support ongoing observational data assessment, review of station quality control parameters, testing of new parameter and physics with DA and associated training

NWM Version 2.1

Task Area 6: Support expanded ensemble forecast system development

Task 20: Expand the NWM Meteorological Forcing Engine to include support for additional meteorological forcing ensembles

Task 21: Enhance the NWM driver and workflow system to permit ensembles of initial conditions via parameter perturbations

Task Area 7: Support Ongoing Community Development Efforts

Task 22: Support code modularization efforts

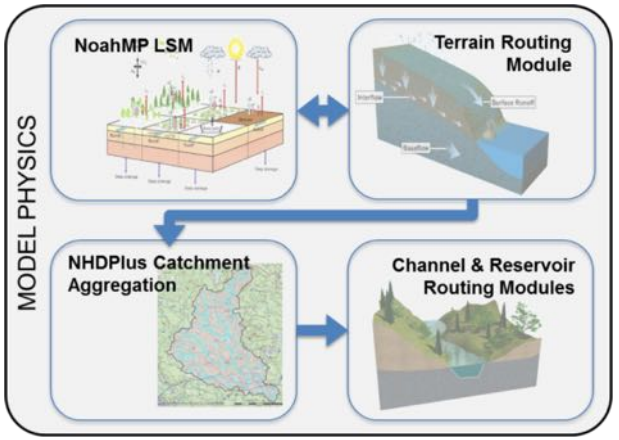
Task 23: Continue code refactoring efforts to improve computational performance and incorporate modern FORTRAN code practices

Task 24: Collaborate with non-OWP NOAA Laboratories and external agency partners in NWM development

Task 25: Provide live, hands-on training for NWS RFC forecasters and NWC staff

NWM Development: Modularity and Community Collaboration

- Community development and collaboration is central to the NWM enterprise effort
- OWP is embarking upon a major, multi-year effort, building on and expanding community
  - Improve on existing modularity of NWM processes using a step-wise, version-over-version approach
  - Spin-up a community code management system
  - Implement a development sandbox with uniform NWM code base and supporting data
- Formulation of this sandbox is ongoing, input will be gathered from the USGS, DOE, CUAHSI, NCEP, NASA, ACE and others
- End Goal: A system which supports community development and funnels innovation into a common platform that can be leveraged for both research and operations across a wide range of scales and applications.



Example of existing modular components within the National Water Model

NWM Development: Coastal Coupling

- **Vision**
  - Couple NOAA's freshwater models with coastal models to provide an integrated flood forecast to approximately 100 million people in the coastal zone.
- **Scope**
  - The initial phase of this project will demonstrate coupling between the National Water Model, an inland water resources model, and appropriate ocean models at a local scale.
  - Couple the National Ocean Service Extratropical Surge and Tide Operational Forecast System (ESTOFS) / Advanced Circulation Model (ADCIRC) to the National Water Model (NWM) in the coastal zone.
  - Scaling this local-scale solution to regional and national domains will be the focus of subsequent iterations of this project.

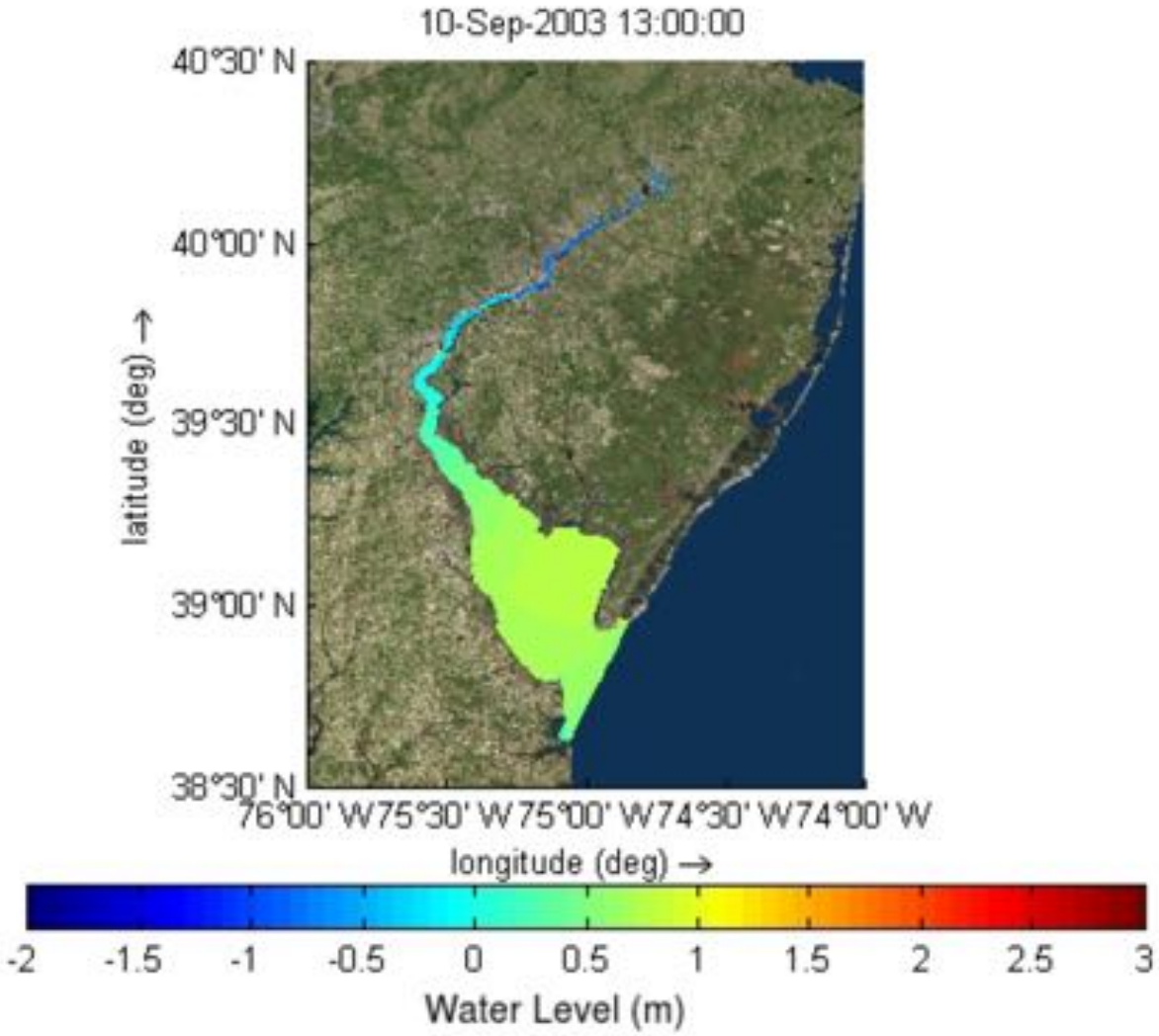
Over 100 million people who live near the coast currently don't get an integrated flood forecast

Initial Development: Total Water Predication – Delaware Bay

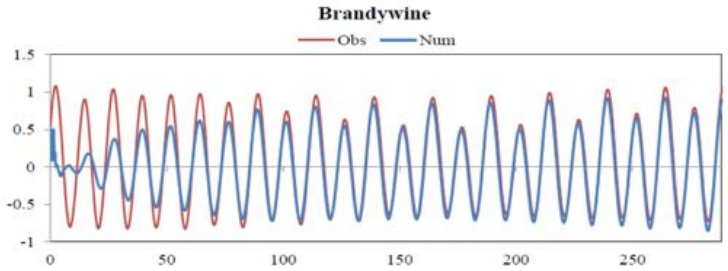
OWP OFFICE OF WATER PREDICTION

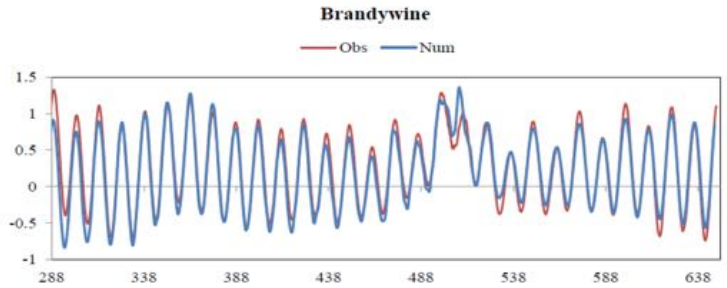
Isabel (2003): Delaware Bay/River Basin

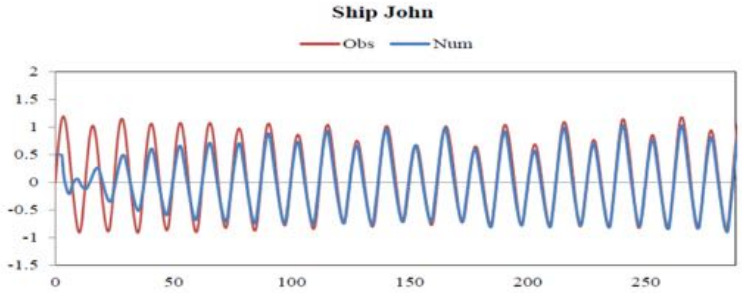
Water Level

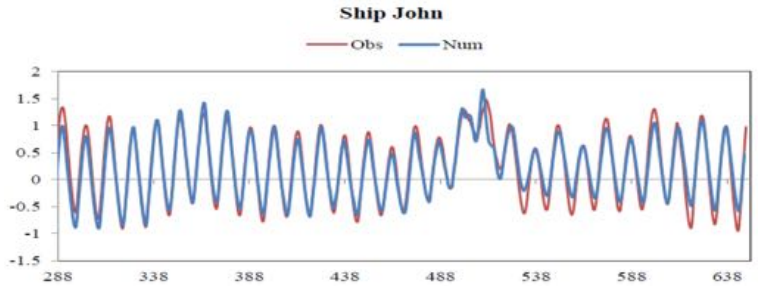


Coastal Coupling: Hurricane Isabel Results









Tide and water level (m) prediction comparison with NOAA observed data during spin-up (left) and Hurricane Isabel 2003 (right)-Horizontal axes show time in h

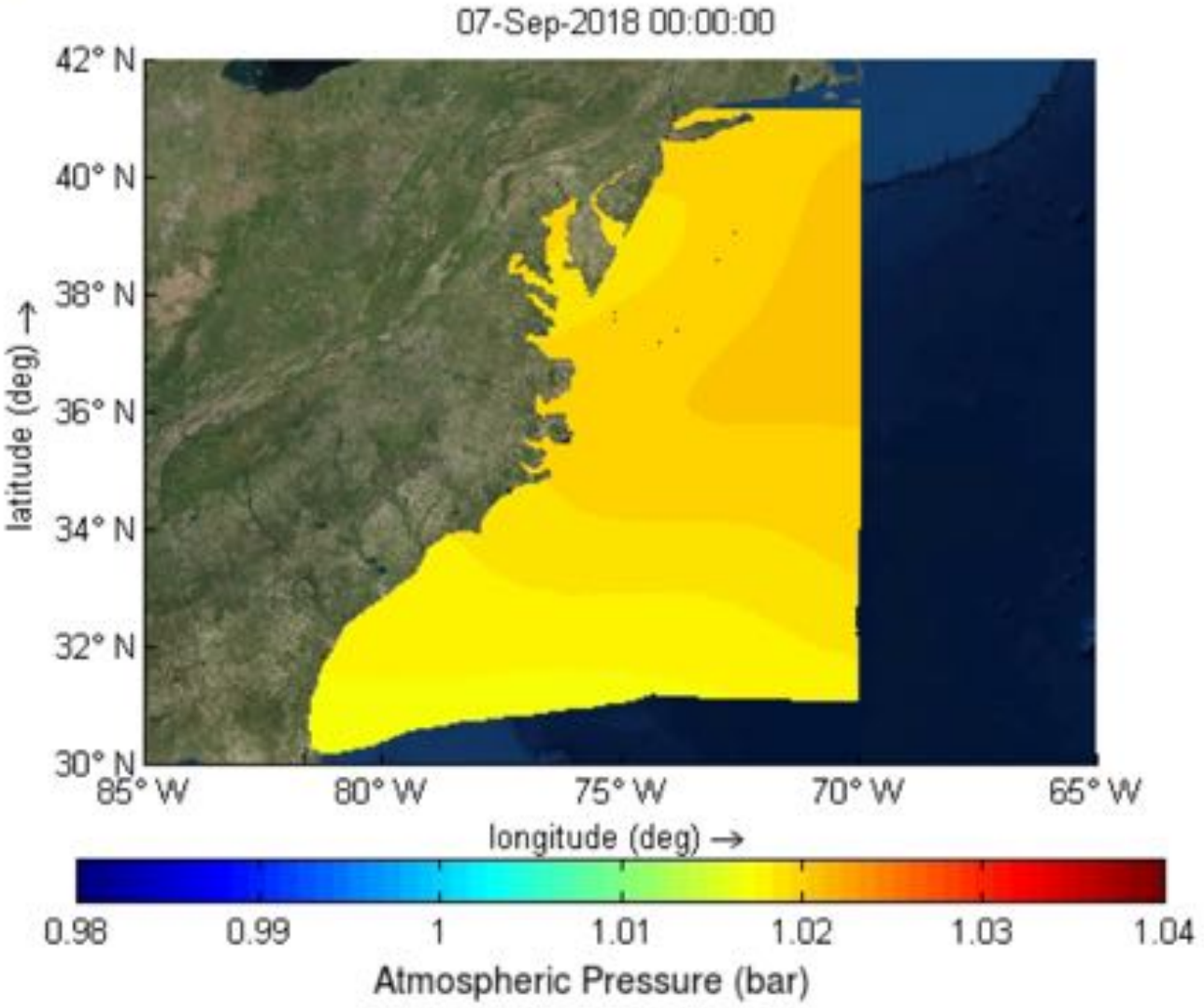
Spin-up: From Aug. 29, 2003 to Sep. 12, 2003
Hurricane Isabel: From Sep. 13, 2003 to Sep. 24, 2003

Track of the storm

Work in Progress: Regional Demonstration

OWP OFFICE OF WATER PREDICTION

Florence (2018): Regional Domain
Atmospheric Pressure Reduced to MSL

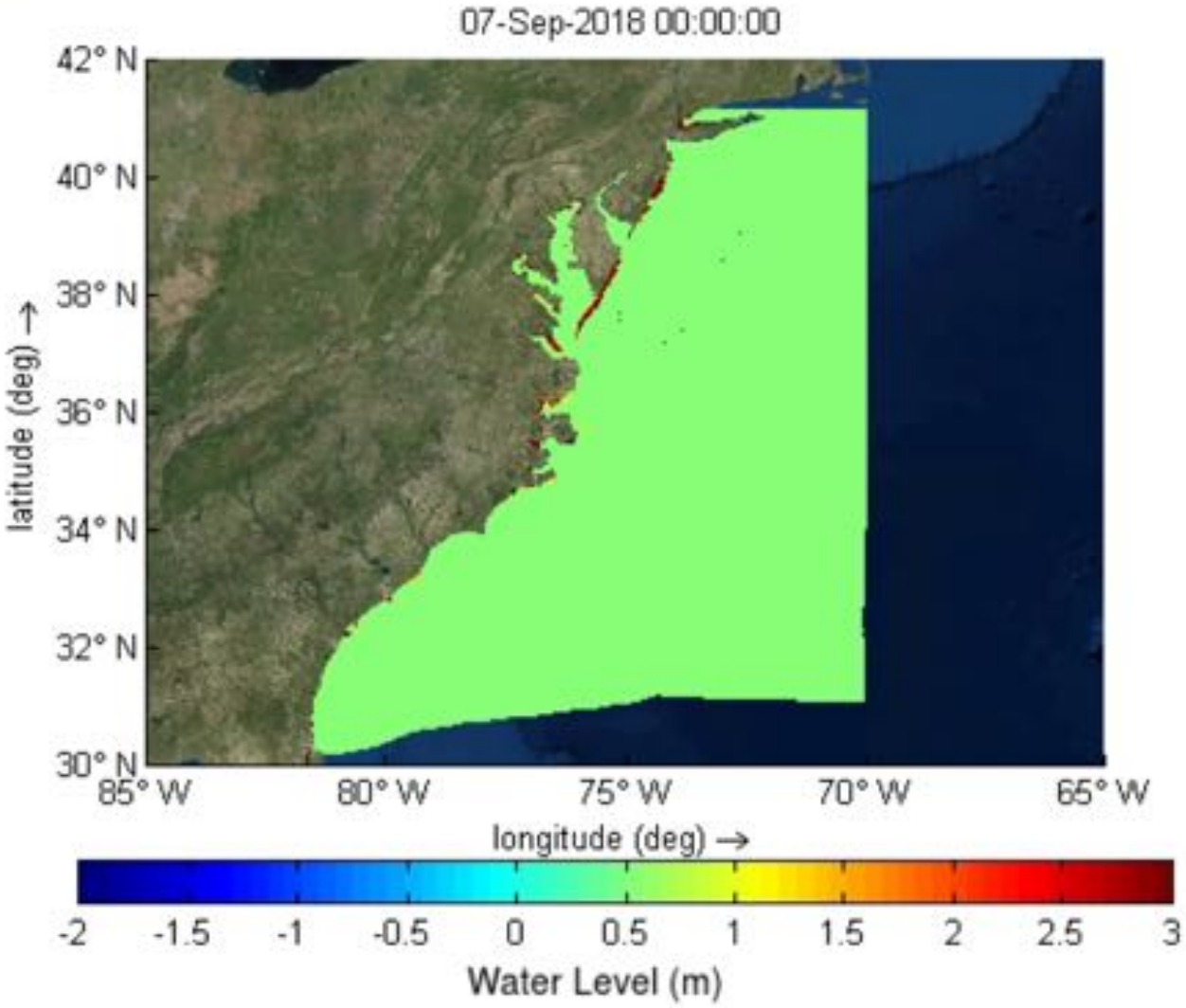


Work in Progress: Regional Demonstration

Florence (2018): Regional Domain

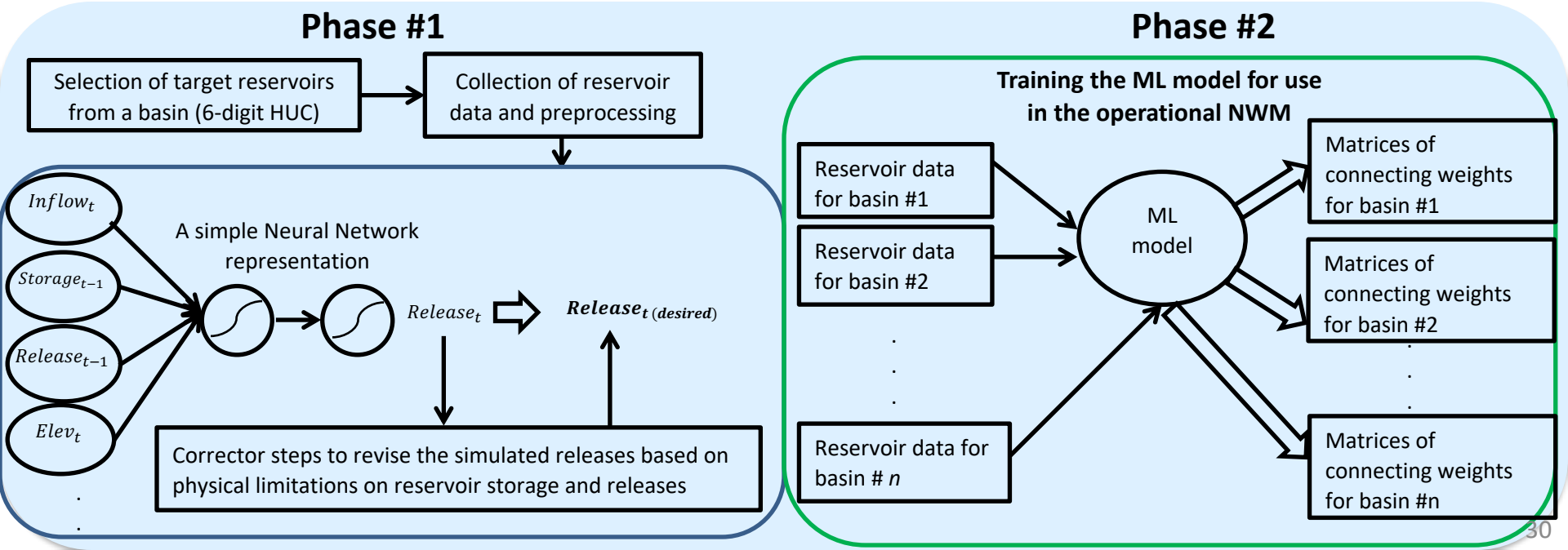
OWP OFFICE OF WATER PREDICTION

Water Level



NWM Development: Anthropogenic Process Representation

- **Problem Definition**
  - Dams have an enormous impact, yet are represented in only a basic way in the NWM
  - 1,506 Reservoirs currently represented in the NWM V1.2, with expansion to > 5,000
  - Dams are operated in different ways, each reservoir has a unique set of operating rules
  - Rule curve availability makes direct use in 1000's of NWM reservoirs impractical
  - Objective is to design, construct, integrate and test new modules necessary to accurately simulate reservoir releases within the NWM
- **Methodology/Expected Outcome(s)**
  - By utilizing machine learning (ML) techniques, the relationships between inputs and outputs (i.e., reservoir releases) are captured and utilized as a part of the NWM.



Case Study: ACF basin

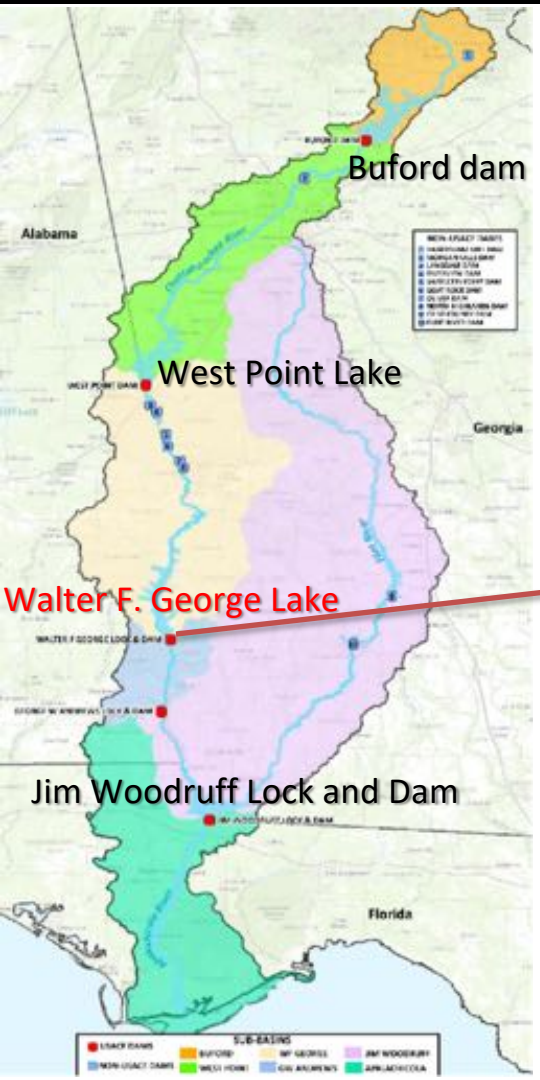


Figure. ACF River Basin
(Source: Master Water Control Manual)

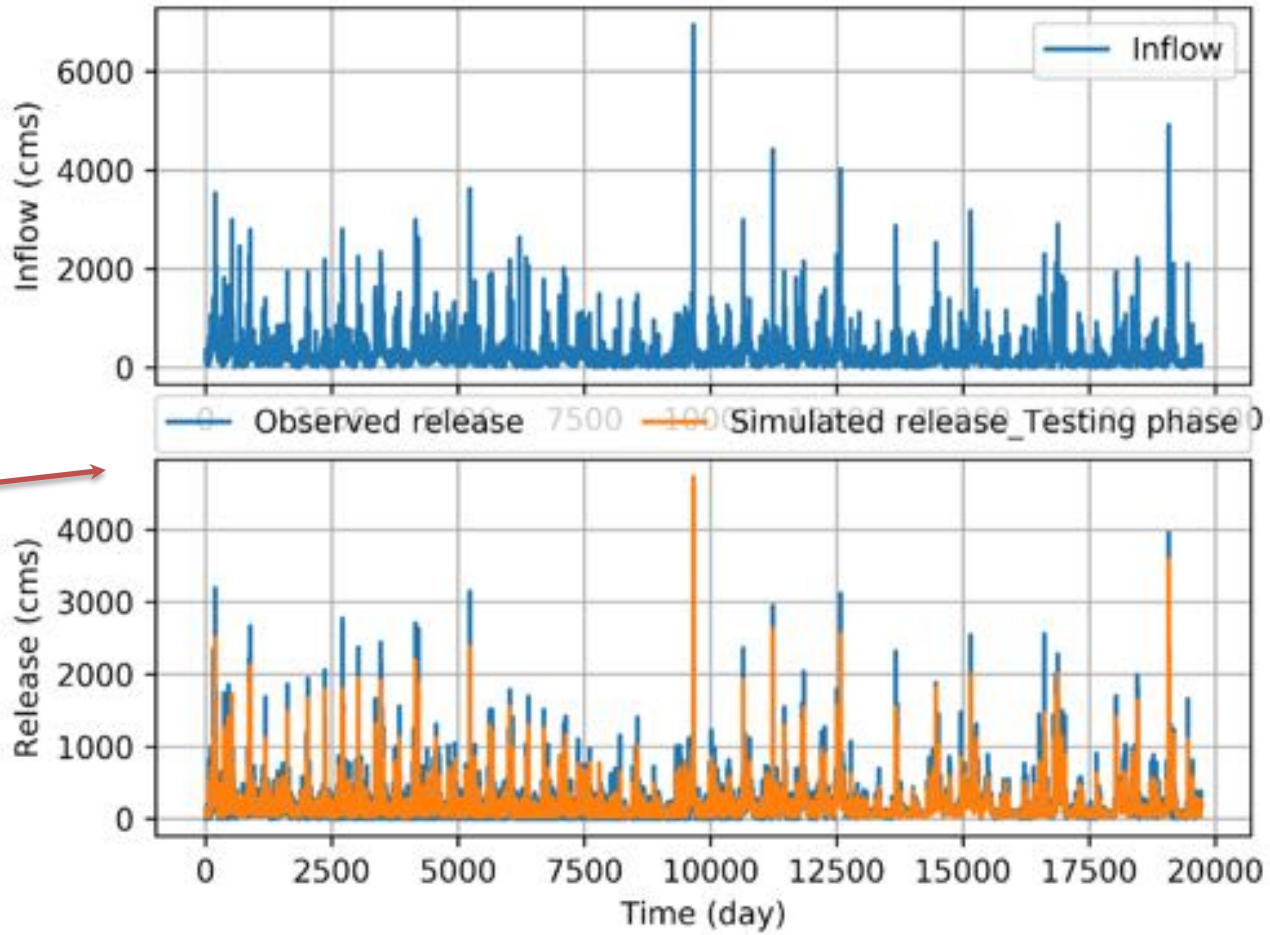
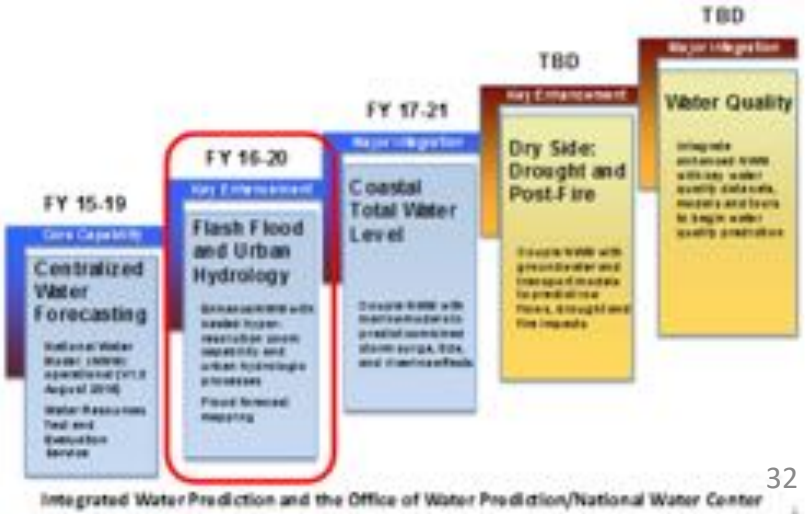


Figure. Simulated and observed reservoir releases for George reservoir

NWM Development: Hyper Resolution Modeling

- Goal: demonstrate pre-operational hyper resolution window modeling capability to provide street-level inundation information
- Mandated by Congress and due by Q4 of 2020
- Needed for areas of complex terrain and built environment
- Triggered by conditions seen in the CONUS NWM
- Will be demonstrated on three urban areas
- Status
  - Developed overall strategy white paper
  - Identifying candidate models and basins

Flash flooding in Charlotte, NC



Integrated Water Prediction and the Office of Water Prediction/National Water Center

Hyper Resolution Demonstration Basins