NWM Development – Current Status and Future Plans

Update to the CAC WP

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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)
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.
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

Reference Time: August 26th, 2017 at 12:00 UTC

PEAK INUNDATION EXTENT
R&R and NWM: 5-Day Forecast

RFC Replace and Route FIM
National Water Model FIM
Experimental National Water Model Guidance

Hurricane Harvey: Flood Inundation Mapping

Reference Time:
August 26th, 2017 at 12:00 UTC

RFC Replace and Route FIM
National Water Model FIM

PEAK INUNDATION EXTENT
R&R and NWM: 5-Day Forecast

Reference Time:
August 26th, 2017 at 12:00 UTC
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

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

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

Expanded Calibration for V2.0

Calibrated basins:
- NWMv1.1: 48 total from USGS GAGESII
- New for NWMv1.2: 1,164 total (including above from USGS GAGESII + CADWR)
- New for NWMv2.0: 1,457 total (including above and Hawaii) from USGS GAGESII + CADWR + RFC

Hawaii basins (28 total)
**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
**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

**Improved Initialization:** New NWM Long-Range Analysis Cycle
Supplies better-matched initial conditions to Long-Range Forecasts

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

**Domain Expansion:** Hawaiian Islands
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
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
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
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.
• **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

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

Track of the storm
Florence (2018): Regional Domain Atmospheric Pressure Reduced to MSL

07-Sep-2018 00:00:00

Latitude (deg)

Longitude (deg)

Atmospheric Pressure (bar)
Work in Progress: Regional Demonstration

Florence (2018): Regional Domain

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.

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**Phase #1**

- Selection of target reservoirs from a basin (6-digit HUC)
- Collection of reservoir data and preprocessing

**Phase #2**

- A simple Neural Network representation
  
  \[ \text{Inflow}_t \rightarrow \text{Storage}_{t-1} \rightarrow \text{Release}_{t-1} \rightarrow \text{Elev}_t \rightarrow \text{Release}_t \rightarrow \text{Release}_{t\text{(desired)}} \]

- Corrector steps to revise the simulated releases based on physical limitations on reservoir storage and releases

- Training the ML model for use in the operational NWM
  
  \[ \text{ML model} \rightarrow \text{Reservoir data for basin #1} \rightarrow \text{Matrices of connecting weights for basin #1} \]
  
  \[ \text{Reservoir data for basin #2} \rightarrow \text{Matrices of connecting weights for basin #2} \]
  
  \[ \vdots \]
  
  \[ \text{Reservoir data for basin #n} \rightarrow \text{Matrices of connecting weights for basin #n} \]
Case Study: ACF basin

**Figure.** Simulated and observed reservoir releases for George reservoir

**Figure.** ACF River Basin
(Source: [Master Water Control Manual](#))
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
Hyper Resolution Demonstration Basins

- Arlington, TX
- Charlotte, NC
- Baltimore, MD