Introduction

The creation of CIROH was guided by four research themes:

1. Expansion and improvement of water resources prediction capabilities
2. Advancement and acceleration of community water resources modeling
3. Innovative hydroinformatics applications
4. Applying social science, economics, and impact modeling to strengthen decision support and build community resilience

These four research themes are the foundational guide for CIROH's scope, federal research priorities, and white papers for new research projects. CIROH has more than 100 active projects across these research themes. As you begin to develop white paper ideas, please check ongoing CIROH research and other research in the field to be sure your idea is not already being addressed with an ongoing project funded by CIROH or other organization. For your convenience, the table below lists the topics of the ongoing CIROH research projects in each research theme. You may learn more about CIROH projects on the web site. Please contact Charity McCalpin if you need further information related to ongoing projects or if you wish to set a meeting to learn more about ongoing CIROH projects.

Research Theme	FY22, FY23, FY24 CIROH Project Research Topics
1. Expansion and Improvement of Water Resources Prediction Capabilities	• Enhancing collection and application of hydrologic data with new sensor deployment and mesonet creation • Gridded precipitation post-processing for Ensemble Streamflow Forecasts • AI/ML methods to enhance meteorological forecasts and ensemble predictions for NextGen • Evaluation of quantitative precipitation forecast accuracy • National scale snow modeling and methods to improve rain/snow determination in mountains • Monitoring of reservoir variables by integrating SWOT and deep learning • Advancements to land surface models • Integration with the Unified Forecasting System • Enhanced streamflow data assimilation methods, benchmarking, and testbed • Use of hydrologic signatures to suggest dominant processes and suitable model formulations • Performance evaluation of model structures for representation of land surface and forcing spatial variation • Improved infiltration process representation and unification

	• Improved characterization of drought and groundwater driven low-flow conditions • Representation of fire effects on hydrologic behavior • Methods for flash drought assessment • Improved cold regions process models, snow, ice, ice jams • Improved streamflow temperature and HABs forecasting • Understanding impacts of hydroclimate forcing product uncertainties on water availability • AI/ML advancements to hydrologic modeling • Guidance for hydrologic model, process, scale selection • Hydrologic model integration and coupling to coastal and water management models • Developing/refining ensemble streamflow forecasts in NextGen and the RFC Hydrologic Ensemble Forecast Service • Evaluation of models and forecasts • Calibration of multi-model mosaics • Development of a prediction system testbed
2. Advancement and Acceleration of Community Water Resources Modeling	• Development of heterogeneous computing in support of CIROH research • Tools and cyberinfrastructure for community NextGen development • Community accessible NextGen in the cloud • Adapting the Iowa Flood Center's Hillslope Link Model for NextGen • Improved community collaboration through Hydroshare enhancements • Creation of a research portal for CIROH web applications
3. Innovative Hydroinformatics Applications	• Data management and information sharing • Quality control of hydrologic observations • Development of apps and user interfaces • Novel approaches for user interaction with forecasts • Real-time hydrological information system • AI-augmented immersive digital twin and visual analytics framework for hydrology • Novel geospatial channel and floodplain morphological attributes representation in hydrofabric • Exploring critical attributes of 3D channels for FIM • Flood inundation mapping and modeling • ML-based flexible flood inundation mapping and intercomparison framework • Collaborative development of comprehensive FIM output, models, and methods

	• Forecast impact and risk assessment analytics
4. Applying Social Science, Economics, and Impact Modeling to Strengthen Decision Support and Build Community Resilience	• Determining risk perceptions and decision analysis • Audience segmentation to improve FIM by engaging and testing with technical users and impacted communities • User response to forecast products • Value of forecast information • Improving forecasts in underserved areas • Scoping water forecasting needs and NOAA product use in Indigenous communities in Northeast Oklahoma • Optimizing flood warning information sharing • AI-enhanced flood storytelling for mobilizing action • Community crowdsourcing application of water hazards • Coupled human-water systems modeling • Social water use modeling • Extending hydrologic prediction to assess water quality, social impacts, and ecosystem services • Evaluating nature-based solutions • Building community resilience with hydrologic modeling

The objectives and questions guiding CIROH FY25 research addresses needs of two sponsors:

1. NOAA Priorities. Advancing operational forecasting across NOAA, especially in the Office of Water Prediction, National Water Center, River Forecast Centers, and National Ocean Service.
2. USGS Priorities. Improving capability to assess waters of the U.S. for the U.S. Geological Survey (USGS).

Additional sponsor priorities will be provided in future updates to this document or as additional documents. Below are descriptions of the NOAA and USGS priorities. Project ideas, when solicited, must address either the NOAA or USGS priorities. An idea may address more than one research theme (RT) and focal area (FA).

NOAA Research Priorities

NOAA research priorities align with the CIROH research themes outlined on page 1 and in the original CIROH proposal. Further, NOAA has identified a few focal areas in each research theme and provided **sample** priority research questions. CIROH encourages project ideas addressing research needs to the below focal areas, CIROH research themes outlined on page 1, and those proposed in the original CIROH proposal.

Research Theme 1: Expansion and Improvement of Water Prediction Capabilities

<u>NOAA-RT1-FA1. Hydrologic Modeling</u>

- Do generalized methods exist to formulate and evaluate parsimonious, novel, BMI streamflow prediction models driven by NOAA estimated and forecast forcings in the NextGen framework?
- Can ML approaches solve the ungauged basin problem?
- Can we identify completeness criteria for hydrologic models in different hydroclimatic regions? Are there hydroclimatic/physiographic regions within the NWM domain for which no performant formulations exist?

<u>NOAA-RT1-FA2. Hydrologic Model Ensembles</u>

- How can the NextGen Framework quantify forecast uncertainty using ensembles?
- How can we better use the full suite of available meteorological models (global, regional, high-res, deterministic and ensemble) to produce more accurate probabilistic hydrologic forecasts?
- What is the useful lead time for forecast informed reservoir operations using hydrological models with different structures driven by available NOAA forcing ensembles?

<u>NOAA-RT1-FA3. Cold Regions Processes</u>

- How can the NextGen Framework simulate river ice cover formation, breakup and decay? (e.g., process modules, machine learning)

<u>NOAA-RT1-FA4. Groundwater Processes</u>

- What minimum model complexity is needed to accurately simulate groundwater effects on streamflows at different scales, particularly during droughts and in predicting seasonal water supply?
- How can we improve long-range (30-90 day) lead time streamflow forecasts, with an emphasis on climatological drought?

NOAA-RT1-FA5. Reservoir Simulations

- Is there a generalizable open-source reservoir simulation code available for use in the NextGen framework that allows optimization of reservoir operations and meet multiple stakeholder needs using probabilistic streamflow forecasts?
- Can we quantify the influence of reservoir operations on the uncertainty of streamflow predictions regionally and seasonally?

NOAA-RT1-FA6. Effects of forcing Uncertainties on Water Predictions

- How can we validate both estimated and forecasted precipitation and other meteorological variables and quantify the effects of their uncertainties on water resources forecast plausibility and accuracy?
- How does streamflow prediction uncertainty vary regionally and seasonally when forced using analysis datasets (e.g. AORC) versus reforecast datasets (e.g. GEFS 31-year reforecast)?

NOAA-RT1-FA7. 2D Coastal Coupling and Total Water Level

- Considering the available coastal total water level models available in the (DFLOW, SCHISM, and SFINCS) what factors determine their performance and are there any general predictors of performance?
- How much can data assimilation improve Total Water Level simulations?

NOAA-RT1-FA8. 3D Coastal Coupling

- How can we optimally connect inland hydraulics to 3D coastal hydrodynamic models to accurately simulate compound flooding?
- What techniques best calibrate 3D coastal models coupled to inland hydraulic models?

NOAA-RT1-FA9. Water Temperature, Salinity, and Sediment Modeling

- Do the coastal models in the NextGen Framework (DFLOW-FM, SCHISM, SFINCS) accurately simulate the effects of water temperature and salinity on total water level?
- Is it possible to improve coupled coastal/inland-hydraulic total water level model performance by assimilating water temperature and salinity observations?
- Is it possible to predict shoaling in navigable waterways (inland hydraulics and coastal/estuaries) using coupled models in the NextGen framework?
- Is there a generalized solution to forecast stream temperature in the NextGen framework based National Water Model?

NOAA-RT1-FA10. Flash Flooding

- How can we produce timely and actionable pluvial flood forecasts?
- How can we increase flash flood forecast lead times?
- What techniques exist to more accurately predict short lead time extreme rainfall responsible for pluvial flooding?

Research Theme 2: Advancement and Acceleration of Community Water Resources Modeling

NOAA-RT2-FA1. NextGen Modeling Concepts

- What information is needed to implement a perceptual model checker for the NextGen Framework that evaluates formulation completeness, internal consistency, and enforces conservation laws?
- Can models running in the NextGen Framework be stopped and restarted using the existing BMI 2.0 standards with no change in performance? If not, what extensions are required?

NOAA-RT2-FA2. NextGen Community Framework Development

- What community advantages arise from coupling the NextGen Framework with other modeling frameworks? (e.g., NOAA Unified Forecasting System)
- What is the research to operations process? (e.g., How to determine that a new hydrological model formulation or module provides a performance advancement and is ready for NWS operational forecasting?

NOAA-RT2-FA3. NextGen Applications

- What objective calibration measures are most appropriate for predicting floods, droughts, etc.?
- How can open-source technologies, standards, and software development best practices accelerate R20 and O2R for common operating infographics, picture tools, and dashboards leveraged by operational water prediction forecasters?
- How can the community leverage development of NextGen Framework training/educational modules using virtualization and/or cloud implementations to speed the discovery process?

NOAA-RT2-FA4. Conducting Informative Evaluations

- What evaluation methodologies and metrics can be used to decompose the total error or uncertainty in a hydrologic model into constituent parts or sources that can usefully guide model improvements? Are there simple approaches, as well as more rigorous schemes? Are there methods that can be applied operationally that account for all sources of uncertainty, yet are computationally feasible at the resolution and scale of the NWM?
- What existing or novel metrics can be used to evaluate the utility of hydrologic models for specific applications, such as flood forecasting or water supply, where utility includes the quality of the model predictions, i.e., magnitude of error, as well as the sensitivity of the applications to those errors (e.g., measured as cost or loss)?
- What are the best approaches to mitigate or otherwise account for non-stationarity when conducting statistical evaluations of hydrometeorological and hydrological models? For example, how can we best evaluate models that regularly evolve and for which reforecasts are unavailable (e.g., National Blend of Models) or when observations are influenced by climate change?

- What are the best strategies for producing informative evaluation statistics in river basins with highly mixed or variable streamflow regimes, such as ephemeral streams or basins with strong seasonalities or river regulations?
- What are the best strategies for producing informative evaluations in situations where sample sizes are inherently small, such as for rare events or water supply forecasts that are issued infrequently?
- The current nudging-based data assimilation approach leads to unreasonable forecasts in some locations, however more sophisticated (state-adjusting) methods are computationally expensive at the resolution and scale of the NWM and may cause increased latency time. Are there alternative methods of data assimilation that are feasible at continental scale and will lead to more reasonable results than nudging?

Research Theme 3: Innovating Hydroinformatics Applications

<u>NOAA-RT3-FA1. 3D Channels</u>

- What properties does a flexible, extensible data model for topo-bathymetric data (e.g. channel cross-sections, bathy rasters, banklines, hydraulic geometry) need to support flood inundation modeling across a wide range of scales using techniques varying from HAND to fully dynamic hydraulic routing?
- How should topobathy data compiled from disparate data sources, collection methods and estimation techniques be organized to support continental scale hydraulic routing and inundation mapping?
- What means of estimating bathymetry exist? Do LiDAR point clouds before the hydro-flattening process create value for flood inundation mapping purposes?

<u>NOAA-RT3-FA2. LiDAR Processing</u>

- Can feature detection algorithms identify small scale (e.g. bridge openings and culverts) and curvilinear topographic features (e.g. embankments, flood walls) that strongly influence flood extent from LiDAR data?
- How do we further the science on the processing of (filtering, gridding, etc.) LiDAR point clouds and what novel means of resampling and mosaicking can be developed to coarsen DEM's while preserving the most important features (flow divides, bathymetry, anthropogenic features, etc.) for hydraulic modeling and inundation extent and depth prediction?

<u>NOAA-RT3-FA3. HAND FIM</u>

- What is the most effective methodology for simultaneously optimizing interacting variables, roughness and bathymetry, to maximize the skill of HAND based FIM?

<u>NOAA-RT3-FA4. Flood Inundation Modeling</u>

- Under what conditions is two-dimensional hydraulic modeling required to accurately predict flood inundation?
- Can AI/ML approaches be applied to solve the fluvial flood inundation modeling problem?

- Can AI/ML approaches be applied to solve the pluvial flood inundation problem?

NOAA-RT3-FA5. Dams, Levees and Waterbodies

- What is the most effective means of accounting for reservoir flooding with the NWM and HAND based FIM?
- What is the availability of data, models and tools to build a continental scale system allowing operational forecasters to quickly predict inundation extent and depth for dam and levee overtopping or break scenarios?
- How can repeat observations of water surface elevation (e.g. SWOT/Sentinel) in natural lakes and reservoirs inform development of reservoir modeling approaches?

NOAA-RT3-FA6. Probabilistic FIM

- How do we account for various sources of uncertainties to advance beyond deterministic flood inundation maps (extents and depths) to probabilistic forecast inundation maps?
- What techniques allow determination of forecast uncertainty based on the temporal evolution of forcing model predictions?

NOAA-RT3-FA7. Machine Learning Informed FIM

- How can machine learning technology enhance HAND based synthetic rating curves and inundation mapping solutions?
- To what extent and at what spatial scale can machine learning technology predict inundation extent and depth from National Water Model forecasts?
- How can machine learning methods function as surrogate models (meta-models, emulators) to 1-dimensional (1D), 2D, or quasi-2D hydrodynamic models to deliver rapid inundation extents and depths (Liu, 2022)?
- How can physics informed deep learning methods leverage automatic differentiation to optimize the 1D/2D Saint Venant Equations and provide advantages over traditional numerical solvers (Raissi et al., 2019)?
- How can deep learning models trained as surrogate models or solvers generalize in a transfer learning paradigm across different yet still similar sets of problems (different regions, parameter values, boundary conditions etc.)?

NOAA-RT3-FA8. Advance Quality and Access of Key Datasets of Interest to the Water Enterprise

- How can the following key datasets be improved to benefit hydrologic prediction?
    - Bridge mounted stage-only river observations
    - Remotely sensed water surface observations (e.g. SWOT)
    - Water Prediction Hydrofabric Data
    - Operational National Water Model (NWM) Forecasts
    - National Water Model Retrospective Simulations
    - Analysis of Record for Calibration (AORC) Dataset
    - Hydrologic Ensemble Forecast System (HEFS) Forecasts

NOAA-RT3-FA9. Dissemination and Visualization Research

- How can cloud native technologies and geospatial data dissemination standards support the sharing of large quantities of water prediction data following FAIR (findable, accessible, interoperable and reproducible) guidelines, enhance emergency response, and promote open science?

Research Theme 4: Application of social, economic, and behavioral science to water resource products and services

NOAA-RT4-FA1. Communication and Visualization

- How can CIROH effectively survey and regularly interact with NOAA-NWS RFCs to identify and document local knowledge for use in NextGen, and transfer that knowledge into projects?
- What non-traditional visualizations enhance the communication and utilization of FIM data? (e.g., NOAA Sea Level Rise Viewer – https://coast.noaa.gov/slr/)
- How can the NWS best communicate probabilistic forecasts, including FIM services, to support risk-informed decision making?
- How can we effectively communicate water-related risks at different timescales given climate non-stationarity?
- How can we effectively communicate Total Water Level flooding risks in a across timescales from short-term (weather) to longer-term (monthly/seasonal)?

NOAA-RT4-FA2. Communities and End-users

- How can we best incorporate guidance from ungauged rivers produced by the NWM into an early flood warning system?
    - What are the barriers for use of FIM to inform underserved and socially vulnerable populations, and what are the most effective means to provide FIM services to underserved communities?
    - How do end users perceive the applicability and ease of use/understanding of NWM and FIM services?
    - Who are the end users for Total Water Level information? What decisions do these end users make, and how can NWS products help inform those decisions?
    - What Total Water Level information do end users need for different time scales (short-term to monthly/seasonal)?
    - What are the timeliness requirements and uncertainty constraints for total water level outputs?
    - For different end-users and applications, what factors are most important for continental-scale streamflow forecasts to be useful? For example, to what extent do forecast uncertainty, accuracy, latency time, lead time, or other factors cause a forecast to be not useful?

USGS Research Priorities

USGS research priorities align with the CIROH research themes outlined on page 1 and in the original CIROH proposal. USGS has specific requests outlined here.

Research Theme 1: Expansion and Improvement of Water Prediction Capabilities
The USGS Water Resources Mission Area (WMA) is developing the National Water Census (NWC), which will provide on-line model results for water quantity, quality, and use components of the Nation's surface and ground water, in a supply and demand context. When fully realized, the NWC will provide information on past conditions over multiple decades, updated information on current or near-current conditions, and forecasts of future conditions in the short and long term. While the timeline and components delivered differ from the mission of the NWS, there is potential for overlapping research needs in Research Theme 1.

The Water Observing Systems Portfolio (WOSP) encompasses Programs that aim to carry out the WMA's objectives to collect, manage, and disseminate consistently high-quality and reliable water information in real-time and over the long-term. The primarily overarching priorities of the WOSP are the following:

1. Strategically enhance and expand the spatial and temporal collection of high-quality water observations to address national and local needs; and
2. Sustain and evolve secure enterprise data systems to manage operations and ingest, process, store, and deliver high-quality water observations

The following research focal areas provide an overview (organized by the individual science programs of the WOSP) of the research topics that are of specific interest to advance the objective and overarching priorities for the WMA-WOSP.

<u>USGS-RT1-FA1. Next Generation Water Observing System (NGWOS) Program</u>
The NGWOS program designs and implements water observation networks in targeted basins across the Nation by the USGS to provide high-fidelity, real-time data on water quantity, quality, and use necessary to support National modern water resource availability prediction and decision support systems with lower uncertainties, and rapid and informed hazards response. The NGWOS program is also the research arm of the WOSP tasked with developing new and innovative techniques, methods, and instrumentation using Technology Readiness Levels and Product Maturity Levels as frameworks for eventual migration into our National monitoring networks. Research priorities for NGWOS include:

- Develop an OSSE "factory" - conduct Observing System Simulation Experiments (OSSEs) using Regional or National models to help guide our monitoring investments
- Establishing Electrical Engineering students at the HIF and develop curriculum around sensor innovation/design, power systems, telemetry /IoT technologies and autonomous vehicles.

- Developing Smart Gaging Network approaches and technologies targeting deployment at the national, regional, or local scales and could include the following:
    - Technologies that support the seamless data collection, integration and delivery of data from mobile assets (drifters, autonomous underwater vehicles, rapid deployment gages) with our fixed site networks;
    - Technologies for increased spatial and temporal coverage through improved integration of IoT sensors at or near USGS fixed sites which may include mesh networks and custom 5G networks;
    - Systems designed using MQTT data, command/control, and integrated edge-computing capabilities;
    - Technologies that increase edge computing capabilities on dataloggers at the gages or within a network of gages that may include artificial intelligence / machine learning (AI/ML);
    - Improved infrastructure for the rapid integration of new sensors and/or platforms.
- Remote sensing research or associated curriculum, including Uncrewed Aircraft Systems, and advancements in image processing and edge computing for imagery
    - Methods and techniques for assimilation and fusion of satellite data to combine multi-sensor sources and increase spatial and temporal coverage based on periodic satellite overpasses;
    - Machine learning methods for rapid processing of high-rate satellite data into hydrologic variables;
    - Calibration and validation of wide-area satellite observations with USGS fixed site or UAS monitoring;
    - Design and test Internet of Things (IoT) sensors and edge computing resources which collect imagery and/or video
    - AWS or other cloud platform data handling and analysis, including custom coding
    - Online display and dissemination of geospatial and satellite raster data
    - Radar data analysis for monitoring of hydrologic variables
- Specific priority areas of instrumentation R&D:
    - IoT telemetry
    - Camera-based monitoring
    - Surface velocity methods
    - Power systems
    - HABs and PFAS sensors
    - Low-cost autonomous underwater vehicles
    - Rapid deployment gages
    - Water use monitoring
    - Soil moisture sensors
    - Urban hydrology

USGS-RT1-FA2. National Hydrologic Monitoring (NHM) Program

Through the National Hydrologic Monitoring (NHM) program, the USGS WMA operates, modernizes and strategically expands its streamflow, groundwater and water-quality monitoring enterprise to provide impartial, timely, rigorous, and relevant data for short- and long-term water decisions by stakeholders across the United States. Research priorities for NHM include:

- Research and testing of various observational data uncertainty analysis approaches
- Research and development into display of data uncertainty on USGS monitoring location pages
- Research associated with automated water data records processing algorithms
    - Automated estimation techniques for filling in gaps in timeseries records for streamflow and water quality parameters
    - Automated anomaly detection for timeseries records for streamflow and water quality parameters
    - Automated shifts (e.g. sensor drift or fouling) for timeseries records for streamflow and water-quality parameters

Research Theme 2: Advancement and Acceleration of Community Water Resources Modeling

The Water Resources Availability Portfolio (WRAP) is a portfolio focused on research, model development, and assessment of integrated water availability for human and ecological uses both regionally and nationally, directly in response to the SECURE Water Act of 2009. The following two focal areas provide an overview (organized by the individual science programs of the WRAP) of the research topics that are of specific interest to advance the objective and overarching priorities mentioned above.

USGS-RT2-FA1. Hydroclimate

The Water Budget Program's Groundwater Dynamics project will quantify precipitation and temperature trends, and regime shifts and their effects on groundwater recharge, storage, and interaction with surface water (lakes, wetlands and streams). To do this, past, present, and future meteorological observations and models will be essential for identifying and forecasting trends for statistical comparison to groundwater recharge and baseflow metrics of interest across space and time. However, such forcing data often require bias correction and downscaling for practical use, and trends are often best interpreted by scientists with a deep understanding of parent datasets used to derive forecasted model futures. Additionally, researchers that focus on hydroclimate can often provide additional insight on inter- and intra-annual atmospheric processes / cycles that may be driving or exacerbating observed trends in temperature and precipitation. Consequently, the Groundwater Dynamics project, and specifically the development of an adaptable framework to address the overarching science questions related to factors influencing seasonal and interannual fluctuations in groundwater recharge, storage, and discharge, would benefit from a CIROH partner with expertise in hydroclimate. This task encompasses a bulk of the analysis proposed in the Groundwater Dynamics project with goals of quantifying the role of climate, landscape, and subsurface factors on groundwater dynamics, and would directly benefit from reliable observations at project relevant scales from existing hydroclimate models (e.g., CONUS-404) and assistance with the interpretation of observed trends and their attribution to specific atmospheric drivers. This would enable groundwater experts on the team to identify areas sensitive to future change and contextualize derived sensitivities with future climactic forecasts. These would be key products for recharge and baseflow representation in USGS hydrologic models and future water availability scenarios, as process-based sensitives to change could be compared to existing data collection networks and USGS model outputs. *Research products that support FY 25 and 26 project goals that would benefit from collaboration with CIROH partner with expertise in hydroclimate:*

- **CIROH Partner research product:** Downscaled and bias corrected catalog and assessment of existing hydroclimate data for selected IWS basin.
    - **Associated joint USGS project and CIROH partner research product:** Identification of basins sensitive or forecasted to have the largest changes in hydroclimatic forcing and attribution to basin geologic or physiographic properties.
- **CIROH Partner research product:** Adaptable framework for linking observed trends in groundwater dynamics (e.g., derived from tracers, streamflow, or groundwater observations) with atmospheric drivers that can be applied in other IWS basins or other regions.
    - **Associated joint USGS project and CIROH partner research product: I**nvestigate areas whose groundwater dynamics are most susceptible to forecasted perturbations in hydroclimate and compare to existing USGS data collection networks and model outputs to identify areas where more robust observations or model process representation might improve water availability forecasts.

<u>USGS-RT2-FA2. Data Assimilation</u>

Riverbeds are critical zones of spatiotemporal variability of groundwater discharge (i.e., baseflow) and recharge (i.e., losing reaches). Identifying areas of seasonal dynamics across a watershed is essential to improve hydrologic predictions. At present, streams are typically categorized as either gaining or losing systems, but this binary approach neglects the seasonal variability in baseflow. These seasonal fluctuations have substantial impacts on recharge estimates, groundwater storage, and overall water budget estimation. In collaboration with CIROH partners, we propose to determine seasonal components of baseflow and streambed losses by leveraging NGWOS data, including major ion chemistry, stable isotopes, temperature, water table gradients, discharge measurements, and stream morphology. The IWAAS basins have dense arrays of modern sensors where we can evaluate the merit of assimilating observational water quality data to improve hydrologic estimates that impact groundwater storage. We will focus on determining which specific types of data are most useful for characterizing seasonal patterns of baseflow and differentiating gaining from losing recharge pathways. A machine learning framework will provide a basis to incorporate multiple datasets and to compare the contribution of each data type to characterizing temporal variations of baseflow. The work would advance existing Groundwater Dynamics project research outputs -

specifically related to Task 2.2 – to investigate factors influencing seasonal and interannual fluctuations in baseflow.

National-scale models, such as NHM-PRMS and WRF-Hydro, often exhibit significant uncertainties in recharge estimates. These models typically simplify stream-aquifer interactions and may not adequately account for the seasonal variability in baseflow, nor the role of gaining and losing streams. As a result, the outcomes of our observational findings will be compared with predictions from the national-scale models to evaluate their performance and improve the accuracy of water budget component estimates. Specifically, we aim to assess how well these models capture seasonal baseflow dynamics and where their assumptions about stream-aquifer interactions deviate from observational data.

- Research products will identify key data points that are most effective to reduce uncertainties in seasonal baseflow and recharge estimates and improve hydrologic prediction. Furthermore, our results can guide future investments in monitoring networks to advance the application of water quality data in hydrologic estimation.

Research Theme 3: Innovating Hydroinformatics Applications

Research Theme 3 is an area where there is already some collaboration with NWS and USGS and there should be plenty of opportunities to build off or leverage this research theme to advance USGS goals more broadly, especially in terms of advanced tools and technologies, services, and compute resources. The USGS could benefit from the application of data fusion to obtain more accurate or complete water datasets at varying scales. Two data types of interest are bathymetry and river corridor geometry and characteristics, leveraging USGS datasets in addition to other datasets available from governmental or academic institutions. Another beneficial area of hydroinformatics research would involve application of the Internet of Things (IoT) concept of a “digital twin” as related to stream gages and other environmental monitoring locations of interest. This area of research has the potential to make improvements in the operation and systems understanding of such monitoring locations.

<u>USGS-RT3-FA1. National Water Information System Modernization Program</u>

The current version of the National Water Information System (NWIS) is inflexible, suffers from extensive technological debt and is at increased risk of system failure because of aging infrastructure. There is a need for a modernized NWIS to support a robust, authoritative enterprise water information system to advance the Water Mission Area priorities and meet the needs of USGS and WMA stakeholders. The focus of the NWIS Modernization program is to provide the necessary improvements to NWIS. Research priorities associated with NWIS Modernization include:

- Research around automated records processing algorithms
- Advancements in image processing and edge computing for imagery
    - Design and test Internet of Things (IoT) sensors and edge computing resources which collect imagery and/or video
    - Design and test of novel Unoccupied/Uncrewed (UAS) platform, sensor packages, and techniques which utilize remote sensing data in new ways.

    - Design a machine learning "gamification" project to build-well labeled and/or segmented imagery data sets using USGS monitoring station imagery data utilizing public involvement in data production (through playing the game).
    - Test citizen science contributed imagery research to determine if it is feasible to include a publicly supplied “scientific imagery” resource as valid hydrologic data.
- Software development capacity (anything from full-stack development to simple scripting)
- Hydroinformatics
    - Advancing standards for water data models (e.g., WaterML, Hydrologic Features) and the way in which they are applied in modern software (standard exchange methods or service patterns)
    - Research to advance the internet of things for water monitoring

<u>USGS-RT3-FA2. Data Cyberinfrastructure and Information Delivery (DCID) Program</u>

The DCIID program ensures that water data and other hydrologic information are seamlessly delivered, and that state-of-the-art tools are used to develop hydrologic information and visualization products to meet the ever-evolving needs of our users and cooperators to make informed water resource decisions. Research priorities associated with the DCID Program include:

- Advancing water data visualization techniques, including intuitive representation of uncertainty values

<u>USGS-RT3-FA3. LiDAR Processing to assist with determining flood impacts</u>

Currently, flood impacts are surveyed; however, there is growing interest in using Light Detection and Ranging (LiDAR) data to obtain location and elevation of the flood impact locations. Research is needed to compare the accuracy of LiDAR to acquired point location and elevation of the lowest bridge driving surface elevation (bridge deck) and bridge low-steel (low-chord) utilizing two different bridge extraction scripts develop by (1) University of Texas and (2) National Weather Service. The bridge extraction scripts will be compared to actual field survey and the USGS Elevation Point Query Service. Such research will prove/disprove the validity of using LiDAR data in lieu of actual surveyed data to acquire location and elevation of critical infrastructure features such as bridges and roads for the purpose of the USGS Real-time Flood Impact Map. The USGS Real-Time Flood Impact Map displays the locations (called “Flood Impact Location”) where the USGS measures the height of critical safety or infrastructure features that may be vulnerable to flood impacts. Some examples of flood impacts include the stream and river embankment; roads and bridges; pedestrian paths; buildings; and more.

Appendix:

NOAA Project Questionnaires

FY25 CIROH PROJECT QUESTIONNAIRE – OWP 1

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   NWM does not presently explicitly consider seasonality using observations of LAI, etc. in estimating time-varying model parameters. The WRF-Hydro code does include some gross seasonality logic, but remotely sensed observations are not used that would allow models to detect the beginning/end of growing season, emergence of crops, etc. Future versions of the NWM constructed using the NextGen framework could assimilate dynamically-estimated parameters through its "data assimilation engine", which is envisioned to accommodate not only data for pure data assimilation (e.g. stream flow), but also dynamically estimated parameters. Calculations of ET provide the best example of where this might be accomplished, but there might be other opportunities depending upon the model. Another example might be effect of river water temperature on hydraulic roughness (e.g. Manning's n) a significant factor. Other examples may exist that PI's can suggest.

   A number of agencies produce remote sensing and in-situ data streams that NOAA can take advantage of to improve model representation of seasonal processes. Potential PIs are invited to apply their awareness of such data to improve water prediction.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Yes. This will require development of a test "data assimilation engine" that can pass updated ET or other model parameters to model codes and testing it in the NWM test bed. Such a system could test the approach in an operational-like environment.

3. **Related to the above, what are key research questions to answer and advance your work?**
   How much improvement in model performance is achieved using assimilation of unsteady model parameters estimated using remote sensing or other observations?

4. **What is a short title for your project idea?**
   Simulated Real-Time Assimilation of Unsteady Model Parameters to More Accurately Model (Name of Process)

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – OWP 2

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   The NextGen Framework high level design envisions existence of an "evaluation manager" that is used by the framework to execute codes that perform point-to-point, point-grid, and grid-grid evaluations on both single value and time-series model forcings, inputs, and outputs. This evaluation manager is under development by Raytheon. However, Raytheon has not been tasked with identification of optimal, standards-based data schemas and formats for this purpose.

   OWP has identified a critical need for identification or creation of a foundational data model standard for point, gridded, unstructured, and other geospatial inputs/outputs, for both single observations and time-series observations (e.g. TEEHR data model) as discussed at the 2024 DEVCON. Identification and codification of appropriate data schemas provide a standard layout for all NextGen evaluation tools. Definition of optimality criteria for post-processing aids in selection of output types depending on purpose (e.g. parquet vs. maps, etc.).

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Yes. Given the importance of standardization to the NextGen Framework philosophy, this approach provides a common set of data schemas/formats for all evaluation projects.

3. **Related to the above, what are key research questions to answer and advance your work?**
   What data schemas exist having characteristics of accessibility, efficiency, and universality to ease development of water prediction evaluation tools and effective post-processing to produce meaningful water prediction forecast outputs?

   What gaps exist in existing standards for point, gridded, unstructured, or other geospatial inputs/outputs for both single and time-series observations?

   If gaps exist, can extension of existing standards for point, gridded, unstructured, or other geospatial inputs/outputs for both single and time-series observations fill those gaps?

4. **What is a short title for your project idea?**
   Evaluation of existing data schema standards for point, gridded, unstructured, or other geospatial inputs/outputs for both single and time-series observations for

evaluating model inputs and outputs and effective forecast communications.

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – OWP 3

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   The NextGen Framework high level design includes a "forcing engine" which will ultimately allow use of a variety of forcing data sources. The design also envisions an "assimilation engine" that will allow execution of BMI compliant modules that can operate on forcing data to perform bias adjustments and creation of ensembles.

   OWP identified the need to understand the relative improvement of hydrologic predictions due to correcting imperfect forcing inputs to our hydrologic models. Is it better to (1) run the NWM using multi-model forcing ensembles, or (2) perform bias correction of single source forcing data?

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Yes. Evidence provided by studies designed to answer this question will shape the final operational configuration of the NextGen based NWM.

3. **Related to the above, what are key research questions to answer and advance your work?**
   Given the forecast meteorological data contain uncertainties, which approach improves water prediction model forecasts most: bias correction of single forcing data sources, or execution using multi-model forcing ensembles?

4. **What is a short title for your project idea?**
   Relative improvement of water prediction using forecasts using bias adjusted single model (deterministic) forcing forecasts vs. multi-model ensembles.

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – OWP 4

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations.**
   As forecast lead time increases from short-range (18 h) to long-range (30 d) meteorological uncertainty increases tremendously. Due to this, current weather model forecast skill extends a few days at most except in highly predictable situations (e.g. stalled hurricanes like Harvey). Therefore, the focus of the long-range forecast for water prediction modeling is most appropriately placed on drought. Given that during non-rainy periods many hydrological model processes become inactive or decoupled from the atmosphere (e.g. soil moisture at wilting point so AET=0), groundwater state and contributions to base flow predictions become dominant. This means that we can run simpler models for long-range drought predictions.

   The present NWM short-range (forced with HRRR), medium-range (forced with GFS), and long-range (forced with CFS) forecast models all execute the WRF-Hydro version of the NWM. Evidence suggests that execution of different model formulations specifically formulated for different forcing data sources might both improve forecast accuracy and significantly reduce computational expense.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Yes. Evidence provided by studies designed to answer this question will shape the final operational configuration of the NextGen based NWM.

3. **Related to the above, what are key research questions to answer and advance your work?**
   In terms of water prediction model accuracy, how does forecast time horizon affect selection of model formulation? Are some classes of model formulations superior to others in terms of short-, medium-, and long-range forecasts?

4. **What is a short title for your project idea?**
   Identification of Most Performant Water Prediction Model Formulation Type & Structure for Short-, Medium-, and Long-Range Forecasts

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – OWP 5

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   Shoaling events in navigable rivers represent expensive natural disasters for the U.S. When they occur they result in reduced barge loading and traffic flow, both of which negatively impact the economy, particularly in terms of agricultural exports. NASA has teamed up with the US Army Corps of Engineers, Engineer Research and Development Center to develop a digital twin of the navigable waterways of the U.S., and they see the NWM as an example that offers synergistic benefits.

   At present the NWM does not consider sediment transport. One possible use case for NWM output is prediction of shoaling events on navigable rivers. This use case is the current focus of a joint NASA/USACE project that NOAA is peripherally involved in, aimed at developing a "digital twin" of the navigable rivers of the U.S. The NWM is considered an example "digital twin" that might provide utility for prediction of shoaling events, and give actionable lead-time for deployment of dredging in high-risk river reaches before shoaling events occur. This will offer significant economic benefit to the U.S., consistent with the mission of the National Weather Service, NOAA, and Dept. of Commerce.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Research aimed at identifying appropriate methodologies for improving the NWM long-range forecast in navigable rivers and using NWM output from the long-range forecasts to simulate changes in bed morphology due to bed, suspended, and bedform sediment transport can be run in the cloud, forced with streamflow forecast outputs from the long-range NWM.

3. **Related to the above, what are key research questions to answer and advance your work?**
   How can long-range NWM streamflow forecast outputs be best used to forecast shoaling events in navigable rivers?

4. **What is a short title for your project idea?**
   Use of Long-Range NWM Streamflow Forecasts to Predict Shoaling Events in Support of River-Bourne Commerce

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE - OWP 6

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   Presently, coastal flood inundation modeling employed by NOAA/NWS involves simultaneous execution of a coupled set of models simulating the open ocean, littoral zone/estuaries, inland hydraulics, and coastal compound flooding. This coupled set of models is expensive to run, and due to uncertainties in the track, speed, and central pressure of landfalling tropical storms and extratropical low pressure systems, uncertain. The US Army Corps of Engineers, Engineer Research and Development Center, created a library of compound flooding due to landfalling systems on all coasts of the U.S. which is called the "Coastal Hazards System", or "CHS". Over 100,000 core-years of supercomputing time was expended in developing this simulation output, which varied the landfall location, direction and speed of travel, central pressure, and tide state. The CHS archive is available for use as a "virtual model" to help NOAA/NWS in producing probabilistic forecast model outputs for coastal flooding due to landfalling low pressure systems.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   The Coastal Hazards System represents a point of collaboration, wherein an enormous amount of computational effort creates the ability for partner agencies such as NOAA to access the model output archive as a "virtual model".

3. **Related to the above, what are key research questions to answer and advance your work?**
   How well do archived USACE/ERDC Coastal Hazards System (CHS) model flood inundation outputs from tide, surge, riverine, and wave sources perform compared against observed events in the observational record for landfalling tropical and extratropical low pressure systems?

   How can NOAA use the archived USACE/ERDC Coastal Hazards System (CHS) to improve forecast accuracy, deliver actionable probabilistic forecasts, and better acknowledge uncertainty without relying on a single deterministic forecast?

4. **What is a short title for your project idea?**
   Evaluating the USACE/ERDC Coastal Hazard System Probabilistic Model Output Archive to Augment Coastal Inundation Modeling in the NextGen Framework.

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – OWP 7

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   OWP has a need to forecast pluvial flooding in urban environments. The traditional approach to perform this task is to run a hyper-resolution (sub 100 m resolution) 2-D hydrologic/hydraulic model. However, this approach is subject to input dataset limitations, labor intensive model setup, and prohibitively computationally expensive to issue timely forecasts for larger urban areas (Smith et al. 2020). Operational forecasting of pluvial flooding in urban areas requires execution of pre-setup models. Service equity requires that if NWS sets up a hyper-resolution model for one city, it must set them up for all cities. One possible solution might rely on the use of AI/ML to emulate a hyper-resolution model on a grid to simulate not the dynamics of stormwater inundation as the forecast event occurs, but predict the maximum level and extent of inundation during an event given a storm-total amount of precipitation on the grid and duration of the event.

   Smith, M., Patrick, N., Frazier, N., Kim, J., Flowers, T. and Ogden, F., 2020. Hyper-Resolution Modeling of Urban Flood Inundation. Available at: https://repository.library.noaa.gov/view/noaa/25231/noaa_25231_DS1.pdf

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   AI/ML might provide a computationally inexpensive means to provide equitable delivery of inundation forecasts to all urban areas.

3. **Related to the above, what are key research questions to answer and advance your work?**
   Can output from a hyper-resolution hydrologic/hydraulic model effectively train an AI/ML approach to predict the spatial extent and depth of flood inundation given an amount and duration of precipitation?

   Can an AI/ML model trained in such a way be transferred to a different city and produce actionable outputs?

4. **What is a short title for your project idea?**
   Use of AI/ML to Emulate the Ability of a 2-D Hyperresolution Hydrologic/Hydraulic Model to Predict Pluvial Flooding Inundation Extent and Depth in Urban Areas

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – OWP 8

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   OWP has a need to forecast pluvial flooding in urban environments. Ad-hoc analysis of HRRR model output used in the short-range (18 h) forecast cycle indicates that it frequently differs significantly from radar observations both at 0 hours from the issue time, and henceforth. These differences include spatial errors in rainfall location of up to 10 or more km, and significant differences in rain rate. Pluvial flooding is responsive to rainfalls with duration up to something approximated by the "time of concentration" of the catchment under concern. Because most urban areas are well drained, this time-of-concentration is typically less than 2-3 hours, while most extreme rainfall events last fewer than 8 hours. Is there an alternative approach we can use to estimate the short-range forecast to drive pluvial flooding models of urbanized catchments? The literature suggests that the answer to this question is yes (e.g. French and Krajewski, 1992).

   French, M.N., Krajewski, W.F. and Cuykendall, R.R., 1992. Rainfall forecasting in space and time using a neural network. Journal of hydrology, 137(1-4), pp.1-31.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   AI/ML might provide a computationally inexpensive means to produce better short-term rainfall forecasts with lead times up to several hours for pluvial flood modeling. This would benefit pluvial flood modeling approaches under development for the U.S. using the NextGen Framework.

3. **Related to the above, what are key research questions to answer and advance your work?**
   Can contemporary AI/ML approaches more accurately forecast the space-time distribution of rainfall at the pluvial flooding scale than the HRRR model?

4. **What is a short title for your project idea?**
   Use of AI/ML to Produce Rainfall Rate and Location Forecasting at Smaller Scales Suitable for Prediction of Pluvial Flooding in Urban Areas.

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Fred Ogden, 307-399-5132 (mobile), fred.ogden@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE - OHRFC

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   NWS River Forecast Centers develop and maintain continuous soil moisture accounting models for their entire domain of responsibility. These models are lumped-parameter model, and were initially developed in the Ohio Valley using a period of record spanning roughly from 1950 to 2000.

   During the past 25 years, however, the gradual implementation of field drainage tiles in the vast majority of agricultural landscapes has had a documented impact to streamflow responses, and presents a challenge for calibrating lumped and distributed hydrologic runoff models. We are looking for meaningful ways of leveraging available data regarding the progression of drain tile installation - which is limited, and largely indirectly determined - in order to improve both RFC-based modeling systems and inform regionalization of National Water Model calibration strategies.

   King, K.W., Fausey, N.R. and Williams, M.R., 2014. Effect of subsurface drainage on streamflow in an agricultural headwater watershed. Journal of hydrology, 519, pp.438-445.

   Miller, S.A. and Lyon, S.W., 2021. Tile drainage causes flashy streamflow response in Ohio watersheds. Hydrological Processes, 35(8), p.e14326.

   Schilling, K.E. and Helmers, M., 2008. Effects of subsurface drainage tiles on streamflow in Iowa agricultural watersheds: Exploratory hydrograph analysis. Hydrological Processes: An International Journal, 22(23), pp.4497-4506.

   Sloan, B.P., Mantilla, R., Fonley, M. and Basu, N.B., 2017. Hydrologic impacts of subsurface drainage from the field to watershed scale. Hydrological Processes, 31(17), pp.3017-3028.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Successful guidance would have direct applicability to RFCs in the greater Mississippi River valley where drain tile installation has been most commonplace in the past 20 years.

3. **Related to the above, what are key research questions to answer and advance your work?**
   What is the appropriate conceptual / perceptual model to accurately capture the impact of drain tiling on infiltration and streamflow response at the catchment scale?

   How can calibrations account for the increasing drain tile density over time?

   Can derived spatial datasets estimating drain tile installation density be leveraged in auto-calibration strategies?

4. **What is a short title for your project idea?**
   Agricultural Drain Tile Impacts on Watershed Response and Hydrologic Calibration

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Brian Astifan, Ohio River Forecast Center. 937-383-0528, brian.astifan@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – APRFC ROF

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   Across the NWS hydrologic program there is a need for probabilistic forecast guidance. This need is being addressed initially with the Hydrologic Ensemble Forecast System (HEFS) at existing river forecast locations. The goal of HEFS is to provide an analysis of 'probable outcomes' of the flood forecast and minimize model bias.

   Hawaiʻi does not have any existing river forecast locations due to the nature of the flash flood hazard with floods developing within six hours of the immediate cause. This project would help to expand probabilistic guidance to a region that has not benefited from the implementation of HEFS and will also demonstrate how to bring this probabilistic guidance to small basins in other parts of the country that are not typically included in River Forecast Center products.

   The current operational version of the National Water Model (NWM) for Hawaiʻi involves a single, deterministic run for each model cycle. The output from these runs are generally not adequate for use in Impact-based Decision Support Services (IDSS). Large run-to-run changes in quantitative precipitation forecasts (QPF) for specific small stream basins results in significant variability in flow forecasts and lower confidence in potential outcomes. Ensemble hydrologic forecasts for small stream basins in Hawaiʻi are needed for effective IDSS. These forecasts must be forced by QPF data from an ensemble of convection allowing model (CAM) runs that can then be used to produce a reasonable range of potential flow outcomes and, ultimately, probabilistic guidance on flood inundation extent. There is currently no available operational method providing this type of support.

   Regonda, S.K., Rajagopalan, B., Clark, M. and Pitlick, J., 2005. Seasonal cycle shifts in hydroclimatology over the western United States. Journal of climate, 18(2), pp.372-384.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Rapid-onset flooding in small stream basins from convective precipitation is not an issue unique to Hawaiʻi. These types of flood events occur in Puerto Rico, Texas, SE Alaska, Pennsylvania, Arizona, Guam, American Samoa, and many other locations across the U.S.

   This project would evaluate improvements gained through the use of an ensemble of CAM runs in Hawaii for small stream basins. If successful, a similar approach could be used for small headwater basins in other areas of OCONUS and the CONUS. There would be a clear path to operationalize this across the NWM domain in areas where probabilistic guidance is needed. Hawaiʻi would be the testbed to evaluate forecast and service improvement through probabilistic guidance.

3. **Related to the above, what are key research questions to answer and advance your work?**
   Can useful probabilistic NWM guidance for rapid-onset flooding be generated based on forcing from an ensemble of QPF data from CAMs, and can probabilistic flood inundation maps for small stream basins be generated from this guidance?

4. **What is a short title for your project idea?**
   Probabilistic hydrologic forecasts for rapid onset flooding in small stream basins

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Kevin Kodama, (808)973-5276, kevin.kodama@noaa.gov
   Crane Johnson, (907)266-5158, benjamin.johnson@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE - CBRFC

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   Probabilistic weather-informed hydrology is increasingly used in reservoir management plans to complement short-term deterministic and long-range hydrologic information.

   Downscaling methods make ensemble forcing output more usable for finer-scale hydrologic modeling and topographically diverse areas for forecasting future streamflows. Future precipitation uncertainty over the Colorado River Basin is much less certain than temperature change; ensemble information from weather models can help RFCs provide impact-based decision support to resource managers and stakeholders.

   Currently the RFC HEFS system utilizes forcing (i.e. precipitation and temperature) ensembles generated from statistically relating an ensemble mean to historical climatological data. This technique worked well when meteorological ensemble forecasting was limited in the amount of ensemble members they could generate. However, meteorological ensemble forecasting has advanced such that models can now generate at least 30 ensemble members. These models are run at a resolution of .25 to .5 degrees grid size. Downscaling this output to 800m to 1km would benefit hydrologic model input, particularly in the West, where topographic changes over small spatial scales can be significant, resulting in large gradients and variability in weather conditions.

   Regonda, S.K., Rajagopalan, B., Clark, M. and Pitlick, J., 2005. Seasonal cycle shifts in hydroclimatology over the western United States. Journal of climate, 18(2), pp.372-384.

   "Climate Model Downscaling". Climate Data User Guide. EPRI, Palo Alto, CA: 2024.3002028078.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Yes, this would allow all RFC's to utilize the ensemble members of a meteorological model to improve forecasts.

3. **Related to the above, what are key research questions to answer and advance your work?**
   How to effectively downscale a model in areas of complex terrain?

Can downscaled weather information improve forecasts over topographically diverse areas such as the American West?

Which downscaling methods are most beneficial to providing substantive guidance with regards to forecasts over the American West? For instance, can dynamical downscaling improve ensemble performance over statistical methods (e.g., Localized Constructed Analogs, Bias Corrected Spatial Downscaling, etc…)?

How to verify the downscaled inputs?

The overall spread of potential future hydroclimatic changes for the West, has not been reduced over the past decade; can downscaling methodologies improve resource management and uncertainty due to natural climate variability?

4. **What is a short title for your project idea?**
   Downscaling Techniques for Meteorological Model Ensemble Forcings

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   John Lhotak
   801-524-5130
   john.lhotak@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE – ISED

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   Currently, there is limited knowledge pertaining to the evaluation of hydrologic models in terms of their utility for specific applications, such as flood forecasting and water supply management. Existing metrics primarily focus on the accuracy of predictions but do not adequately address how errors impact operational forecasting. There is a need for comprehensive metrics that not only evaluate prediction quality but also quantify the sensitivity of the applications to prediction uncertainty.

   For example, relatively small errors in river stage predictions during flood conditions may translate into large differences in flood inundation extent and impacts, yet these errors may be difficult to distinguish from observational and other error sources. Understanding the practical consequences of forecast error and the extent to which they can be quantified may help to guide operational decisions and downstream applications, such as whether (or when) to adopt a precautionary approach.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Yes, by providing a better understanding of how total forecast error and uncertainty impact flood forecasting and water management operations, the outcomes could enhance decision-making processes and operational efficiency across different regions. Ultimately, it would be up to each RFC to evaluate the operationalization of the researched solution, given their own nuances and limitations. That being said, this would promote better risk management and resource allocation, benefiting RFCs and their associated stakeholders.

3. **Related to the above, what are key research questions to answer and advance your work?**
   - What existing or novel methods can be used to evaluate the utility of hydrologic models for specific applications, such as flood forecasting or water supply? (i.e. What are effective methods for quantifying the cost and loss associated with varying levels of prediction accuracy and precision in flood forecasting and water supply management?)
   - How can existing and/or new methods be effectively combined to assess both the accuracy of hydrologic model predictions and their impact on application-specific outcomes?
   - How sensitive are different hydrologic applications to errors in model

predictions, and how can this sensitivity be measured and incorporated into evaluation methods? How do evaluations of past error translate into uncertainty in a current forecast and how sensitive a given decision/application is to the level of uncertainty in a forecast, e.g., risk aversion?

- What is the minimum level of model prediction accuracy and precision required to support different hydrological forecasting applications (flood forecasting, water supply, etc.)?
- How can information about the cost/loss associated with model error be presented in non-technical ways and incorporated, practically, into operational decision processes to help identify the economic value of potential improvements to operational forecasting systems, such as the relative value of probabilistic and deterministic forecasts, or which investments are likely to achieve the best utility for a given cost?

4. **What is a short title for your project idea?**
   "Comprehensive Metrics for Evaluating Hydrologic Model Performance and Utility in Flood Forecasting and Water Supply"

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   None provided.

FY25 CIROH PROJECT QUESTIONNAIRE - WPOD

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**

   Flash flooding is one of the deadliest weather phenomena; however, it remains challenging to simulate ahead of an event. The Office of Water Prediction (OWP)'s Water Prediction and Operations Division (WPOD) uses the National Water Model-derived visualization service called rapid onset flooding (ROF) forecast guidance for CONUS, Hawaii, PR/USVI, and Alaska (See Image 1 below). For CONUS, ROF services are available using the NWM Medium Range and Short Range Forecast configurations. The NWM ROF services are publicly available, updated multiple times a day, and offer vital information to many.

   The WPOD forecasters; for example, uses the ROF services to issue its product called Area Hydrologic Discussion (See Image 2 in the Reference section) that communicates actionable intelligence for potential rapid onset flooding with the partners, especially local National Weather Service forecasters who then issue necessary watches and warnings to protect life and property. ROF is derived by two criteria based on NWM stream flow: a flow increase of 100% or greater within one hour (to define flashiness) and a flow exceeding the high water threshold within 6 hours of the aforementioned increase in flow (to define magnitude). The definition of the ROF service needs to use a scientifically proven method that offers an improved skill than the current threshold.

   There is a study by Li that is relevant:
   (https://essopenarchive.org/users/306276/articles/649472-introducing-flashiness-intensity-duration-frequency-f-idf-a-new-metric-to-quantify-flash-flood-intensity) related to this study that could offer useful information for this study.

   Zhi Li, Shang Gao, Mengye Chen, et al. Introducing Flashiness-Intensity-Duration-Frequency (F-IDF): A New Metric to Quantify Flash Flood Intensity. ESS Open Archive. June 23, 2023.
   DOI: 10.22541/essoar.168748464.41784321/v1
   https://essopenarchive.org/users/306276/articles/649472-introducing-flashiness-intensity-duration-frequency-f-idf-a-new-metric-to-quantify-flash-flood-intensity

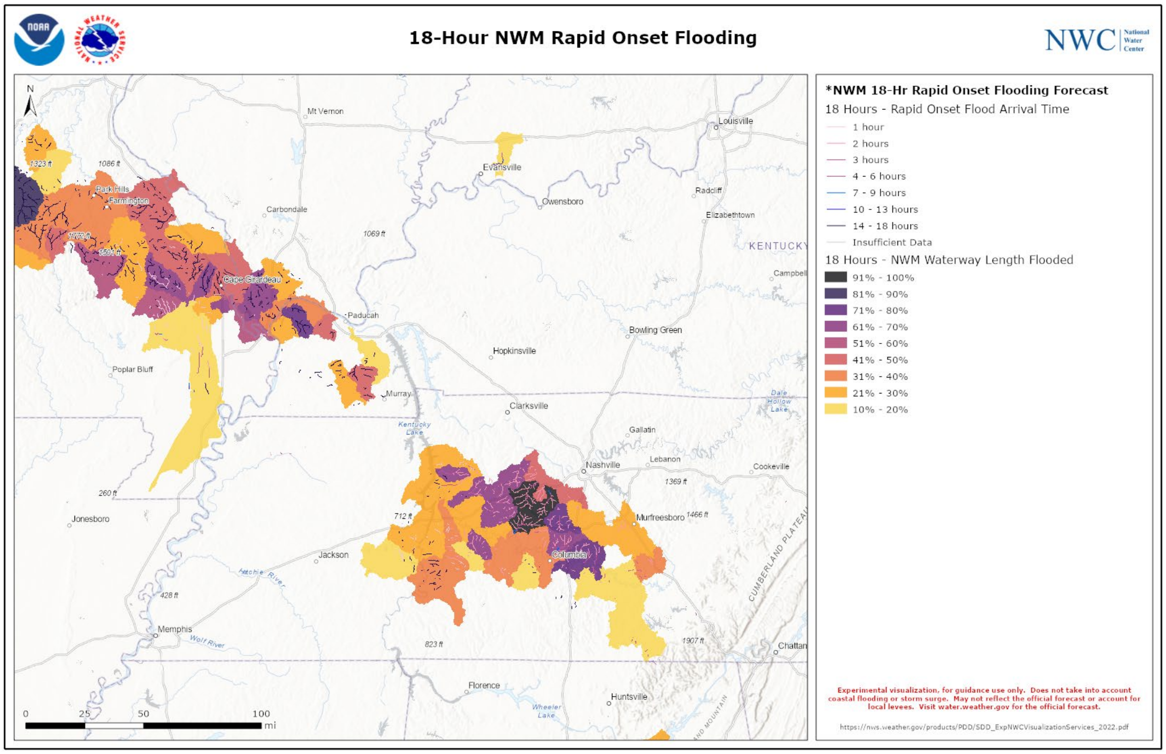

Image 1: Rapid Onset Flooding visualization services based on the NWM Short Range Forecast configuration.

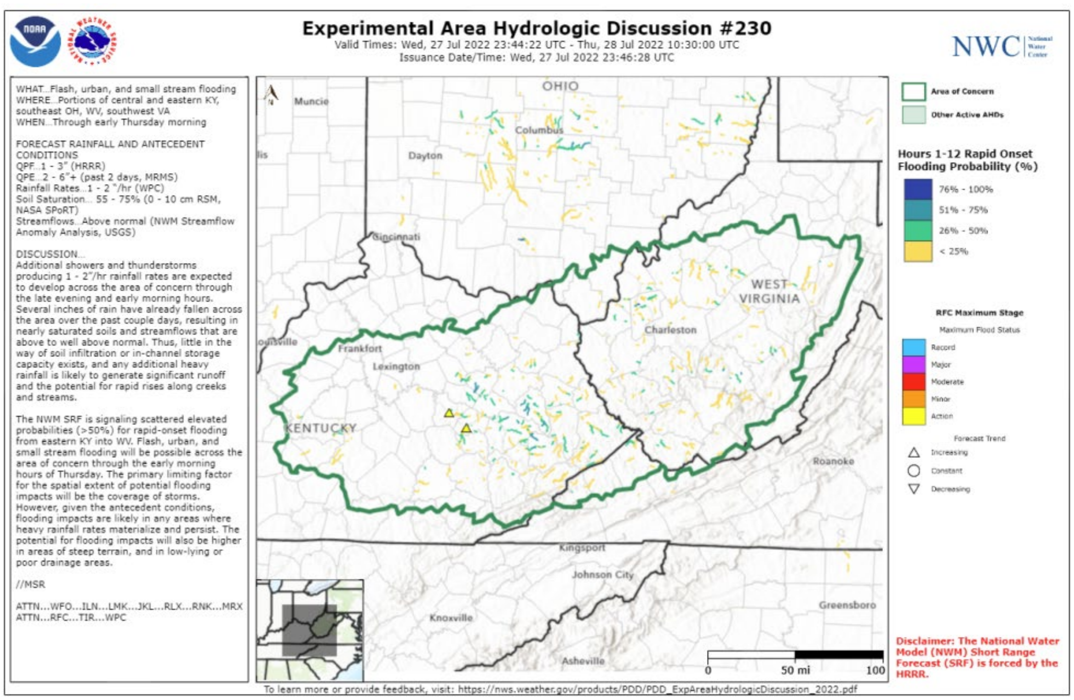

Image 2: An example of Area Hydrologic Discussion using a Rapid Onset Flooding visualization service

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   Yes. Scientifically supported methods may significantly improve the National Weather Service's ability to simulate rapid onset flooding for CONUS, HI, PR/USVI, and Alaska. Since this involves using NWM output rather than separate modeling, this can be easily operationalized provided the compute demand is equal to or less than the current method.

3. **Related to the above, what are key research questions to answer and advance your work?**
   Are the criteria for ROF scientifically defensible and effective to communicate short range flooding (< 12 hours)?

   Can these criteria be improved? (I.e. would different criteria be more effective?)

   Is it reasonable to apply a single set of ROF criteria for the full NWM domain?

4. **What is a short title for your project idea?**
   Forecasting rapid onset flooding along 3.6 million river miles

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   Peggy Lee, (205)347-1500, peggy.lee@noaa.gov

FY25 CIROH PROJECT QUESTIONNAIRE - NWRFC

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**
   The Western Region River Forecast Centers (RFCs) are crucial in delivering reliable and efficient decision support services to key partners, including the U.S. Bureau of Reclamation (USBR), the Army Corps of Engineers, and local water supply agencies. Effective water management in the American West is essential to the U.S. economy, with National Weather Service (NWS) forecasts playing a significant role in guiding reservoir management since the inception of RFCs.

   While the National Water Model (NWM) has produced numerous beneficial products and services, it predominantly focuses on flood forecasting within short time horizons (less than 10 days). However, reservoir management necessitates accurate flow forecasts over both short and long-term periods, accompanied by reliable probabilistic information. Currently, the NWM does not meet these requirements.

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
   The Western Region RFC stands to benefit significantly from this research, as it addresses a critical gap in the National Water Model's (NWM) capabilities that currently hinders its integration into RFC operational workflows. Furthermore, it may lead to the development of techniques that enhance the existing Ensemble Streamflow Prediction (ESP) methods used for seasonal water supply forecasts by RFCs.

3. **Related to the above, what are key research questions to answer and advance your work?**
   - How can NWS seasonal water supply products be enhanced through the utilization of the NextGen framework?
   - The NWM currently offers short-range forecasts across all river reaches in the United States. Can similar spatial coverage be achieved with seasonal water supply products, or will compromises be necessary due to computational constraints?
   - The RFC Ensemble Streamflow Prediction (ESP) product incorporates uncertainty in future weather conditions but does not account for uncertainty in current model states, such as basin snowpack and soil moisture content. Are there techniques that could address this gap and be adaptable to the various configurations of the NextGen model?

4. **What is a short title for your project idea?**
   Seasonal water supply forecasting within the NexGen framework.
   Incorporating aleatory and epistemic uncertainty in NWS Water Supply Forecasts

5. **If known, list the recommended NOAA champion(s) for this project idea.**
   None provided

FY25 CIROH PROJECT QUESTIONNAIRE - PE

1. **Describe scientific knowledge gap that you have identified in your current work that you believe support from the academic research community might provide knowledge benefit for your operations:**

   RFCs routinely recalibrate hydrologic models for a variety of reasons, for example, to improve accuracy by leveraging new forcing data sets, to account for basin land use changes, to add new forecast locations, or to take advantage of new modeling techniques.

   A typical RFC formulation to model a river basin network might include Snow-17, the Sacramento Soil Moisture Accounting (SAC-SMA), and a Unit Hydrograph in each subbasin, with some combination of reservoir model, river routing (e.g. LAG-K, HEC-RAS), and perhaps a channel loss model to move water through the larger network. Implementation of the Snow-17 and SAC-SMA require precipitation, temperature, and potential evaporation (PE*) data. Reservoir models and channel loss models may also use PE data.

   For model calibrations, a historical data set of 10 years or greater is necessary for all three of these major forcings. It is essential that the calibration data forcings be spatially and temporally consistent with the data used in real-time forecasting. More specifically, long-term accumulated statistics in both historical and real-time forcings should not exhibit any temporal shifts relative to surrounding locations. If not careful in preparing calibration data sets, systematic shifts in data characteristics may arise due to changes in observing networks or other factors. While RFCs generally have fairly robust and consistent techniques to prepare archives of precipitation and temperature suitable for use in calibration, RFCs lack standard approaches to developing PE forcing data.

   The gap is that there is no standard historical data set for PE available to all RFCs. In addition, the nationally supported database/software (SYNTRAN) that computes consistent daily PE values at selected stations only provides data through 1999. Formal NWS guidance on deriving PE was last updated in 2003 (NWS OHD 2003). The recommended method is to compute daily PE values at stations using observed pan data and meteorological variables. Due to lack of pan data, this is no longer practical. The alternative recommendation is to apply the Penman method using daily values of air temperature, dewpoint temperature, wind, and solar radiation.
   Influenced by the lack of maintenance of SYNTRAN and the transition from NWSRFS to CHPS, some RFCs have developed their own codes for computing PE. For example, MARFC computes PE from ASOS stations data with locally developed codes. One challenge MARFC found is that correction factors are needed to account for data differences among ASOS stations. In particular, methods to estimate sky cover may vary between nearby stations, which strongly impacts solar radiation calculations

and yields significant biases in PE if not corrected. MARFC has also been applying station corrections to ensure that the PE climatologies match NOAA Standards published in Atlas 33; however, is this 42 year old standard a good baseline? In 2010, ABRFC developed a more rigorous, grid-based technique to estimate PE using NWS Real-time Mesoscale Analysis (RTMA) data. ABRFC has used these data operationally since 2012 and have archived data for their region. Note that the NWS OWP Analysis of Record (Fall et al. 2023) contains forcing data that could be used to compute PE but their analysis does not include an assessment of the forcing data for this purpose. Thus, we don't have a national standard retrospective dataset of gridded PE.

Benefits of creating a historical gridded data set of PE for hydrologic model calibration:
(1) RFCs would have a robust PE data set to use for model calibration and there would be more consistency among RFCs with calibrations moving forward,
(2) The research would also benefit future implementations of any NextGen models that require PE as an input forcing.
(3) A rigorously developed and evaluated PE data set could potentially replace the 42 year old standard, NOAA Atlas 33. This could be a new baseline for many other water resources applications beyond just river forecasting.
(4) Consistent PE data is required for HEFS hindcasts - currently ASOS site upgrades during modernization create inconsistencies in the data used to calculate PE, and missing data is filled in with local climatology calculations.

*Terminology: In this document Potential Evaporation (PE) is assumed quantitatively equivalent to other terms used in the literature such as Reference Crop Evapotranspiration and Free Water Surface Evaporation. In the context of the SAC-SMA model, PE is distinguishable from PET (Potential EvapoTranspiration Demand) because PET includes seasonal adjustment factors to account for the activity level of vegetation. Research on developing these adjustment factors or using more complex evaporation formulations that directly model plant physics is beyond the scope of this questionnaire.

Two real-time techniques that might be applicable in retrospective analysis:

- ABRFC technique referenced above and applied to RTMA.
- Experimental Forecast Reference EvapoTranspiration project (FRET, https://www.weather.gov/cae/fretinfo.html).

NWS OWP Analysis of Record (Fall et al. 2023) forcings could potentially support retrospective calculations of PE.

The USGS has also created a global archive of daily potential evapotranspiration estimates at a 1 degree resolution (https://earlywarning.usgs.gov/fews/product/81).

The concept of the USGS archive is the same as what we are looking for, but a higher resolution data set is desirable.

Recommendations for approach:

- Explore the possibility of creating retrospective PE from URMA or RTMA archives.
- Compare new grid-based calculations to ASOS station-based calculations or other sources (e.g. USGS archive described in item 11).
- Because of challenges with ASOS data, use research quality stations with observed solar radiation to validate grids where possible.
- Evaluate spatial consistency.
- Provide estimates of the uncertainty in the PE grids if possible.

Fall, G., Kitzmiller, D., Pavlovic, S, Zhang, Z., Patrick, N., Laurent, M., Trypaluk, C., Wu, W., Miller, D., The Office of Water Prediction's Analysis of Record for Calibration, version 1.1: Dataset description and precipitation evaluation, Journal of the American Water Resources Association, July 2023.

FRET, https://www.weather.gov/cae/fretinfo.html , Sep 2024.

NOAA Technical Report NWS 33, Evaporation Atlas for the Contiguous United States, June 1982.
NWS OHD, Calibration System Mean Areal Potential Evapotranspiration (MAPE) Computational Procedure, NWSRFS User's Manual II.5-CALB-MAPE, 13 p., 2003.

SYNTRAN, https://hdsc.nws.noaa.gov/hdsb/data/archived/legacy/syntran.html , Sep 2024.

The ASCE Standardized Reference Evapotranspiration Equation, American Society of Civil Engineers (2005).

2. **If research undertaken to address this knowledge gap is successful, do you foresee a path to operationalization of these research outcomes that benefits more than one RFC?**
Yes. The research should produce a retrospective gridded PE data set immediately useful for improving calibrations and increasing consistency in calibration methods across RFCs. By requirement, the technique used to generate retrospective data would be consistent with real-time forecasting calculations.

3. **Related to the above, what are key research questions to answer and advance your work?**
How long of a retrospective data set can be generated that is consistent with current

operational data?

How do we begin to use satellite data yet maintain consistency with longer-term, in-situ, observations?

Would there be any data quality issues in archived gridded forcing datasets used that might cause biases in a retrospective PE dataset? If yes, could these biases be removed?

What spatial resolution should be selected for a retrospective data set?
Can the same resolution and length of gridded PE data be generated for both CONUS and OCONUS regions?

4. **What is a short title for your project idea?**
   Generate and evaluate a standard gridded Potential Evaporation data set suitable for model calibration (10+ years in length).

5. **If known, list the recommended NOAA champion(s) for this project idea.**
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