Cooperative Institute for Research to Operations in Hydrology (CIROH)
FY23 Research Priorities

CIROH Research Summary

CIROH research addresses needs in one or more of four research themes:

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

The table below lists the major topics of the ongoing CIROH research projects in each research theme. CIROH created summaries of the ongoing projects and previously circulated them. Please contact Amanda Blair if you wish to receive a copy of the project summaries.

Research Theme	Ongoing CIROH Project Research Topics
1. Prediction Capabilities	• Prediction system testbed and test battery • Model and forecast evaluation • Inputs/forcings and data assimilation • Land surface model advancements • Integration with unified weather forecasting • Probabilistic modeling / ensembles
2. Community Water Model	• Digital Twin infrastructure for the NextGen development • Advances in heterogeneous computing for hydrologic modeling • Hydrologic process representation and unification • Hydrologic model integration and coupling • Optimized guidance for hydrologic model, process, scale selection • AI/ML advancements to hydrologic modeling
3. Hydroinformatics	• Flood inundation mapping and modeling • Data management and information sharing • Apps and user interfaces • Novel approaches for user interaction with forecasts • Real-time hydrological information system • Forecast impact and risk assessment analytics
4. Decision Support and Community Resilience	• Determining risk perceptions and decision analysis • User response to forecast products • Value of forecast information • Extending hydrologic prediction to assess water quality, social impacts, and ecosystem services • Improving forecasts in underserved areas • Building community resilience

Overview of CIROH FY23 Research Priorities

The objectives and questions guiding CIROH FY23 research addresses needs for two sponsors:

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

Below are descriptions of the NOAA and USGS priorities. White papers must address either the NOAA or the USGS priorities. Each white paper will also note on the cover page the research theme (RT) and focal area (FA) it addresses. A white paper may address more than one RT and 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 white papers 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

NOAA-RT1-FA1. Hydrologic Modeling

- Can analysis of hydrologic signature (event-scale hydrograph measures) aid in identifying candidate hydrologic model formulations at catchment scales ranging from 3-30 km^2?
- Rather than regionalization of model parameters derived from headwater basins, can automatic calibration be applied holistically to a mixture of models running in higher order basins?

NOAA-RT1-FA2. Hydrologic Model Ensembles

- Can the NextGen framework running ensembles of different hydrologic models help quantify forecast uncertainty?
- How can we better leverage the full suite of available meteorological models (global, regional, high-res, deterministic and ensemble) to produce more accurate probabilistic hydrologic forecasts?

NOAA-RT1-FA3. Data Assimilation

- Can assimilating streamflow, soil moisture, groundwater, snow cover, and other observations allow meaningful updating of internal states for different model formulations?

NOAA-RT1-FA4. Cold Regions Processes

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

NOAA-RT1-FA5. Groundwater

- Can deep learning models provide an accurate representation of groundwater contributions to streamflow at the catchment scale?

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

NOAA-RT2-FA1. NextGen Modeling Concepts

- How can we improve the efficiency of the Basic Model Interface (BMI) model coupling standard developed by the Community Surface Dynamics Modeling System (CSDMS) for implicit coupling of two or more numerical models?
- What are the features of a complete and general perceptual model?
- Can a modeling framework like NextGen automatically evaluate modular model formulation completeness and internal consistency using a perceptual model?

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?).
- Can the NextGen framework efficiently drive memory and CPU-intensive hydrologic model applications (e.g., hyper-resolution modeling)?

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?

Research Theme 3: Innovating Hydroinformatics Applications

NOAA-RT3-FA1. 3D Channels

- 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 hydraulics to HAND?
- 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?

NOAA-RT3-FA2. LiDAR Processing

- Can feature detection algorithms identify small scale and curvilinear topographic features 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?

NOAA-RT3-FA3. HAND FIM

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

NOAA-RT3-FA4. Flood Inundation Modeling

- Under what conditions is two-dimensional hydraulic modeling required to accurately predict flood inundation?

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?

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?
    - 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?

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?

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 integrate, enhance, and expand the temporal and spatial collection of water-quantity, -quality, and -use data using robust, innovative technologies to deliver readily accessible "fit-for-purpose" information with various levels of quantified uncertainty.
2. Modernize the way in which we transmit, process, store, quality-assure, and deliver hydrologic data - with the specific goals of:
    a. Reducing monitoring costs and improving continuous records processing; and
    b. Leveraging the National Water Dashboard to develop innovative, intuitive web-based internal and external data analysis and visualization tools/services to better understand the status and trends of the Nation's water resources.

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
- Research related to sensor testing procedures
- 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 geophysics
    - 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;
    - 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

USGFS-RT1-FA2. Water Hazards Program

The Water Hazards program ensures that response agencies are provided with hydrologic data on temporal scales needed to effectively respond to water-hazard events and mitigate the long-term risks water hazards pose to vulnerable people, property, or environments. Research priorities for the Water Hazards Program include:

- Rapid Deployment Gage (RDG) advancement
- Assistance with alternative methods of stakeholder outreach and analysis of results into recommendations for USGS niche in the water hazards arena.

USGS-RT1-FA3. 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
- R&D into display of data uncertainty on USGS monitoring location pages.

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 three 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.

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

USGS-RT2-FA1. Integrated Water Prediction

The USGS Integrated Water Prediction (IWP) science program focuses on the development of advanced models for forecasting multiple water quality and quantity attributes including water budgets and components of the water cycle. It is also developing the cyberinfrastructure and workflows required to implement national and local-scale models to be used by water resource managers over the decades ahead. There are many opportunities for collaboration with USGS, NOAA, and CIROH in terms of hydroinformatics, operational prediction, and improved terrestrial models, additional USGS research priorities focus on:

- Impact of hydroclimate forcings on water availability through a variety of interpretive approaches at a national scale.
- Improvement of hydrologic models through coupling of groundwater and surface water capabilities through a variety of different modeling approaches at the national scale.
- Development and implementation of processes for co-designing data networks and modeling efforts that links data across national, regional, watershed, and local scales using Observation System and Observed System Simulation Experiments (OSEs and OSSEs) to guide the collection of new data sets that can improve model testing and calibration.

USGS-RT2-FA2. USGS Integrated Water Availability Assessments (IWAAs)

IWAAs will provide nationally consistent assessments of water available for human and ecological needs in the United States and identify factors that limit water availability or could lead to conflict. The designs of the IWAAs are to provide information for meeting the goals of the National Water Census as established through the SECURE Water Act. Specific research needs associated with improved assessment capacity in IWAAs include:

- Focused research and analysis to create a more holistic view of water availability in the US through incorporation of coastal water availability assessment capacity
- Assessment of groundwater quantity and quality in three dimensions at a national scale using innovative methods such as data mining and machine learning
- Research aimed at improving our understanding of how reservoir operations impact the transport of dissolved solids through the system and how this impact changes over space and time

USGS-RT2-FA3. Water Use

USGS is the only federal agency with a requirement to report water use nationally. Historically this has been done via a county level compilation of use by 8 categories every 5 years. Beginning in 2018, the USGS has shifted water use reporting methods from this historical compilation approach to development of models to estimate and predict withdrawal and consumptive uses. Initially this will be done for the thermoelectric, irrigation, and public supply categories, which make up 90% of uses nationally. Upcoming model development will focus on the remaining five categories of use (livestock, mining, aquaculture, domestic self-supplied, and industrial) with the goal of having them completed in FY25, research priorities for water use include support of model development for these categories, including:

- Remote sensing and data science approaches for developing models to estimate livestock, aquaculture, mining, and identification of indoor vs outdoor residential use. These categories are minor categories nationally but locally and regionally impactful. Identification of spectral differences related to on-site technologies or techniques for the different categories is of interest.

USGS-RT2-FA4. Developing Numerically Robust Terrestrial Models

As the USGS looks to address requirements outlined in the SECURE Water Act, advancing our hydro-terrestrial modeling capacity through development of a new integrated framework will be critical. The new framework must allow for the integration of quantity, quality, and use for water resource assessment (current conditions) and prediction (short and long-term). The framework must also be able to incorporate the new types of data being collected through the USGS Next Generation Water Observing System in the Delaware, Upper Colorado, Illinois and Willamette River Basins to improve modeled process representation.

Research Theme 3: Innovating Hydroinformatics Applications

Research Theme 3 is an area where there is already some collaboration with NOAA and USGS and there are opportunities to build off or leverage concurrent research projects to advance USGS hydroinformatic goals, 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 the application of the Internet of Things (IoT) concept of a "digital twin" as related to stream gages and other environmental monitoring locations of interest. Integrating advancements derived the IoT has the potential to improve the operation and systems understanding of USGS monitoring.

USGS-RT3-FA1. National Water Information System Modernization Program

The current version of 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 an 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

USGS-RT3-FA2. Data Cyberinfrastructure and Information Delivery (DCID) Program

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

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

Research priorities outlined in RT2 as part of the WRAP portfolio includes opportunities and needs for research related to RT4.

USGS-RT4-FA1. Socioeconomics

USGS has traditionally focused water availability reporting on hydrologic quantity or quality drivers only, leaving out a large and changing component of water availability – human drivers of use and management. For USGS, being able to represent how decisions are made and how those decisions impact availability is critical for accurate representation and prediction of water availability moving forward. Research priorities for socioeconomics include:

- Economic impacts of drought and management decisions in response:
    - Food insecurity
    - Economic impacts of drought on the agricultural sector
    - Hydroelectric power operations and management
    - Institutional resiliency
- Public health and social impacts of drought (driving water quality issues):
    - Health problems related to low water flows and poor water quality
    - Water management institutions incorporating public health adaptation to their water supply plans
- Environmental justice (EJ) research:
    - Leverage or develop indicators and metrics to screen EJ communities (expand the CEJST Tool)
    - Spatial analyses of disproportionate impacts due to increasing hazards (floods, droughts, wildfire)
    - EJ research should focus on the public supply water use sector

USGS-RT4-FA2. Ecoflows

The SECURE Water Act requires USGS to report on water availability for human ecological uses. USGS is currently developing national fish health models to represent one component of ecological uses, additional research priorities for ecoflows include:

- Physiological proxy/indicator for thermal tolerance that could subsequently be applied to numerous taxa – potentially in a high throughput manner