

**Title:**

**Accelerating community research applications of the NextGen water modeling framework through CUAHSI HydroShare linked with CIROH-2i2c JupyterHub**

**Authors (Affiliations and Email Addresses)**

Ayman Nassar<sup>a\*</sup>: [ayman.nassar@usu.edu](mailto:ayman.nassar@usu.edu)

David G. Tarboton<sup>a\*\*</sup>: [david.tarboton@usu.edu](mailto:david.tarboton@usu.edu)

Furqan Baig<sup>b</sup>: [fbaig@illinois.edu](mailto:fbaig@illinois.edu)

Josh Cunningham<sup>c</sup>: [jcunningham8@ua.edu](mailto:jcunningham8@ua.edu)

Arpita Patel<sup>c</sup>: [apatel54@ua.edu](mailto:apatel54@ua.edu)

James Halgren<sup>d</sup>: [james.halgren@byu.edu](mailto:james.halgren@byu.edu)

Benjamin Lee<sup>c</sup>: [blee60@ua.edu](mailto:blee60@ua.edu)

Homa Salehabadi<sup>a</sup>: [homa.salehabadi@gmail.com](mailto:homa.salehabadi@gmail.com)

Anthony M. Castronova<sup>e</sup>: [acastronova@cuahsi.org](mailto:acastronova@cuahsi.org)

Irene Garousi-Nejad<sup>e</sup>: [igarousi@cuahsi.org](mailto:igarousi@cuahsi.org)

**Affiliations**

<sup>a</sup> Department of Civil and Environmental Engineering, Utah Water Research Laboratory, Utah State University, Logan, UT, USA

<sup>b</sup> Department of Geography & Geographic Information Science, University of Illinois at Urbana-Champaign, IL, USA

<sup>c</sup> Alabama Water Institute, The University of Alabama, Tuscaloosa, AL, USA

<sup>d</sup> Department of Civil and Construction Engineering, Brigham Young University, Provo, UT, USA

<sup>e</sup> Consortium of Universities for the Advancement of Hydrologic Science, Inc., Boston, MA, USA

Corresponding authors: [ayman.nassar@usu.edu](mailto:ayman.nassar@usu.edu), [aymnassar@gmail.com](mailto:aymnassar@gmail.com);  
[david.tarboton@usu.edu](mailto:david.tarboton@usu.edu)

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## **Accelerating community research applications of the NextGen water modeling framework through CUAHSI HydroShare linked with CIROH-2i2c JupyterHub**

Ayman Nassar<sup>a\*</sup>, David G. Tarboton<sup>a\*\*</sup>, Furqan Baig<sup>b</sup>, Josh Cunningham<sup>c</sup>, Arpita Patel<sup>c</sup>, James Halgren<sup>d</sup>, Benjamin Lee<sup>c</sup>, Homa Salehabadi<sup>a</sup>, Anthony M. Castronova<sup>e</sup>, Irene Garousi-Nejad<sup>e</sup>

<sup>a</sup> Department of Civil and Environmental Engineering, Utah Water Research Laboratory, Utah State University, Logan, UT, USA

<sup>b</sup> Department of Geography & Geographic Information Science, University of Illinois at Urbana-Champaign, IL, USA

<sup>c</sup> Alabama Water Institute, The University of Alabama, Tuscaloosa, AL, USA

<sup>d</sup> Department of Civil and Construction Engineering, Brigham Young University, Provo, UT, USA

<sup>e</sup> Consortium of Universities for the Advancement of Hydrologic Science, Inc., Boston, MA, USA

Corresponding authors: [ayman.nassar@usu.edu](mailto:ayman.nassar@usu.edu), [aymnassar@gmail.com](mailto:aymnassar@gmail.com); [david.tarboton@usu.edu](mailto:david.tarboton@usu.edu)

### **Abstract**

This research integrates existing cyberinfrastructure tools and modeling workflows to support application of the Next Generation Water Resources Modeling Framework (NextGen) for research-scale subdomains across the U.S. We linked the CUAHSI HydroShare data and model repository to the CIROH 2i2c-JupyterHub cloud computing platform to establish a flexible, scalable collaborative environment for research applications of NextGen. This approach allows a user to specify the subset domain and time period over which they want to run a research instance of NextGen, generate model input files, execute the model, and analyze the results. Comparison of outputs to retrospective National Water Model (NWM) results and ground-based observations using TEEHR (Tools for Exploratory Evaluation in Hydrologic Research) serve as a starting point for research to improve NextGen. The cyberinfrastructure and workflows developed lowers barriers for hydrologic researchers to engage with NextGen, facilitating broader community participation in research targeting improvement of the NWM.

### **Highlights:**

- Cloud cyberinfrastructure supporting the Next Generation Water Modeling Framework.
- Link JupyterHub computing platform with HydroShare repository for community modeling.
- Collaborative research environment to improve the Next Generation National Water Model.
- Workflows and results encapsulated in Jupyter Notebooks and shared via HydroShare.
- Facilitates community research contribution to operational models.

**Keywords:** NextGen; cyberinfrastructure and cloud computing; CUAHSI HydroShare; 2i2c; CIROH; JupyterHub

## 1. Introduction

Hydrologic models are among the tools that are increasingly used across large domains for operational forecasting (Kauffeldt et al., 2016; Yu et al., 2015). The U.S. National Oceanic and Atmospheric Administration’s Office of Water Prediction (NOAA-OWP) has developed the Next Generation Water Resources Modeling Framework (NextGen) for large-scale hydrologic modeling designed to serve as the foundation for the future versions of the U.S. National Water Model (NWM) used for operational forecasting across the United States (Araki et al., 2025; Foroumandi et al., 2025; Hamidi et al., 2025). While NextGen offers unprecedented flexibility and scalability, its inherent complexity and reliance on advanced cyberinfrastructure (CI) present significant challenges for researchers and graduate students. Lowering these technical barriers is critical for broadening community participation, enabling collaborative hydrologic research, and creating a more open and inclusive environment for model development for accelerating the translation of modeling research findings into operations.

The NextGen framework (Ogden et al., 2026) is a modern, modular approach that enhances interoperability across different modeling systems by utilizing standardized interfaces (Hamidi et al., 2025), such as the Basic Model Interface (BMI) (Hutton et al., 2020; Peckham et al., 2013), and the Hy\_Features data model for representing hydrologic catchments (divides), flowpaths, and nexuses (Blodgett et al., 2023). This flexibility allows for the coupling of models across diverse domains. The motivation behind the modular design of NextGen is the premise that no single hydrologic model performs best across all regions, time scales, and hydrologic processes (Clark et al., 2016). By allowing the coupling of models with different strengths and structures, NextGen enables the tailoring of model configurations to specific hydrologic contexts—thereby improving accuracy, flexibility, and scientific understanding across a range of forecasting applications. However, in practice, setting up and testing a specific spatial subset is challenging for researchers due to the complexity of extracting the spatial and temporal input data and setting up the computing environment consistent with the NextGen configuration. In addition, NextGen requires a large amount of spatial data, including domain (hydrofabric) and meteorological forcing data from various sources (Blodgett et al., 2023; Patel et al., 2025), all of which need to be prepared based on specific formats. Furthermore, the configuration and execution of the model for a subset area may require scripting and compilation of the model code, both of which may create further barriers for researchers with limited programming skills.

Challenges in setting up NextGen, especially for researchers who were not involved in its development or are new users, necessitate developing streamlined, shareable modeling workflows that enhance accessibility, transparency, and reproducibility, while also fostering broader community engagement. NextGen In A Box (NGIAB) (Patel et al., 2025) has been developed as an approach to address these challenges. NGIAB provides an all-in-one distribution of the NextGen framework that uses Docker and Singularity containers to simplify deployment across local machines, on-premise clusters, and HPC environments. For users who prefer browser-based

access without local software installation, such as graduate students in classroom settings or researchers seeking rapid prototyping, cloud-hosted solutions provide a complementary pathway. To address this need, we developed a cloud-based approach consisting of a domain-specific data repository and linked cloud computing services.

The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) HydroShare domain-specific data repository and linked cloud computing services comprise a cloud-based, open-source, collaborative ecosystem developed to facilitate data sharing, analysis, and modeling in the hydrologic sciences, supporting research aligned with findable, accessible, interoperable, reusable (FAIR) principles, and computational reproducibility. HydroShare integrates data and metadata archival, and discovery capabilities with connectors to cloud computing services, enabling users to build end-to-end hydrologic modeling workflows ([www.hydroshare.org](http://www.hydroshare.org); Tarboton et al., 2014). Integration of on-demand Jupyter-based cloud computing resources has been effective at broadly engaging the community for both research and education (Castronova et al., 2023). For example, Choi et al. (2021) demonstrated the integration of HydroShare with two computational environments, CUAHSI JupyterHub and CyberGIS-Jupyter for Water (Yin et al., 2019), and an API interface (pySUMMA) (Choi et al., 2021) to the SUMMA modeling system (Clark et al., 2015a). Their goal was to use these tools to fully reproduce the research results of a set of previously published hydrologic modelling case studies (Clark et al., 2015b). Cyberinfrastructure for the reuse and reproducibility of hydrologic modeling studies that combines model APIs and Jupyter notebooks to document modeling workflows was key to this work (Maghami et al., 2023). In another example, Gan et al. (2020) demonstrated the integration of hydrologic modeling web services with HydroShare to support web-based simulation for the Utah Energy Balance (UEB) model. In this framework, HydroShare served as the data/model repository, while hydrologic modeling services provided on-demand data preprocessing and model execution. These approaches allow users to work within an online environment to create, describe, share, discover, repeat, modify, and analyze hydrologic model experiments entirely through a web interface.

In this research, we developed new capabilities for using cloud-based computing platforms linked to HydroShare to configure, run, and analyze research-scale applications of NextGen. Specifically, we created a pre-configured container image for the Cooperative Institute for Research to Operations in Hydrology (CIROH) 2i2c JupyterHub environment (<https://ciroh.awi.2i2c.cloud/>) that, based on NGIAB (Patel et al., 2025) holds the software needed to set up and run NextGen. This is referred to as the CIROH Community NextGen Hub (CCNH). A HydroShare web app connector enables using the HydroShare "Open With" feature on a HydroShare resource to select CIROH Community NextGen Hub and launch the Resource directly into this environment. This integration delivers an end-to-end workflow that encompasses the essential tasks every modeler must complete: (1) defining a spatial domain and simulation period, (2) generating model input files, (3) calibrating and executing NextGen simulations, and (4) evaluating and analyzing outputs, including comparison against observations and retrospective National Water Model (NWM) results. The contribution of this work is not only that it provides

these capabilities in one integrated workflow, but also that it does so on a ready-to-use, cloud-hosted platform that requires no local installation or specialized computing expertise for model software installation, configuration and setup. All a user needs is an account to access the system, making it possible for a hydrology graduate student or researcher with basic coding knowledge to move directly into hydrologic and process-based analysis without being hindered by software configuration or computational setup. By capturing each step in these essential tasks in Jupyter notebooks and sharing them through HydroShare, this framework promotes accessibility, transparency, and reproducibility, to provide a practical entry point for learning how to set up, run, and interpret NextGen model experiments serving as a starting point for research to improve the National Water Model as it adopts the NextGen framework.

This paper is organized as follows. Section 2 describes the cloud-based software and platform design, including the general modeling framework and deployment architecture. Section 3 introduces the Logan River watershed case study. Section 4 presents the end-to-end NextGen workflow applied to the Logan River watershed and summarizes key modeling results. Section 5 discusses broader implications, potential extensions, and opportunities to strengthen community modeling cyberinfrastructure in support of collaborative development of NextGen models. Finally, Section 6 provides the conclusions.

## 2. Software and platform design

This section outlines the general framework for cloud-based hydrologic modeling for NextGen followed by details of the deployment architecture comprised of the JupyterHub platform, containerized software environment, HydroShare connectivity software and modeling tools.

### 2.1 General cloud-based modeling framework

The software framework is designed to provide a unified cloud-based environment for running the NextGen modeling workflow, enhancing model accessibility, scalability, and reproducibility. The design couples CIROH-2i2c JupyterHub with HydroShare, which functions as both the gateway and the repository for workflows, data, code, and associated metadata (Figure 1). In the HydroShare data and model repository (yellow box Figure 1), content that can include Jupyter notebooks, data, and metadata files are held in what are collectively referred to as *resources*, the primary unit of digital content. These are intended to combine scientific data, models, scripts and code in a manner that is FAIR-aligned and can support reproducible, transparent, and trustworthy modeling and analysis. HydroShare web app connectors establish a link between the HydroShare repository and a computing service, allowing HydroShare to serve as a gateway to computing. The HydroShare "Open with" tool launches content from HydroShare directly into a linked computing service so that it may be executed there. Here the computing service is CIROH-2i2c JupyterHub platform (blue box Figure 1) running a pre-built containerized image, CIROH Community NextGen Hub (<https://github.com/CIROH-UA/awi-ciroh-image/blob/ngen-2i2c/Dockerfile>), that bundles the NextGen framework with all required tools,

libraries, and system dependencies to run NextGen. This provides a consistent runtime environment for users that is scalable and removes the need for users to own or provision a computing platform and manually configure its software. This design uses HydroShare to store and manage data and software, and relies on containerization to handle workflow dependencies. Together these features lower the barrier to entry, standardize workflows from data preparation through model execution, and calibration to evaluation, and make modeling more accessible to the hydrologic community, helping accelerate NextGen research and development. The subsections below give details on key elements of the platform.

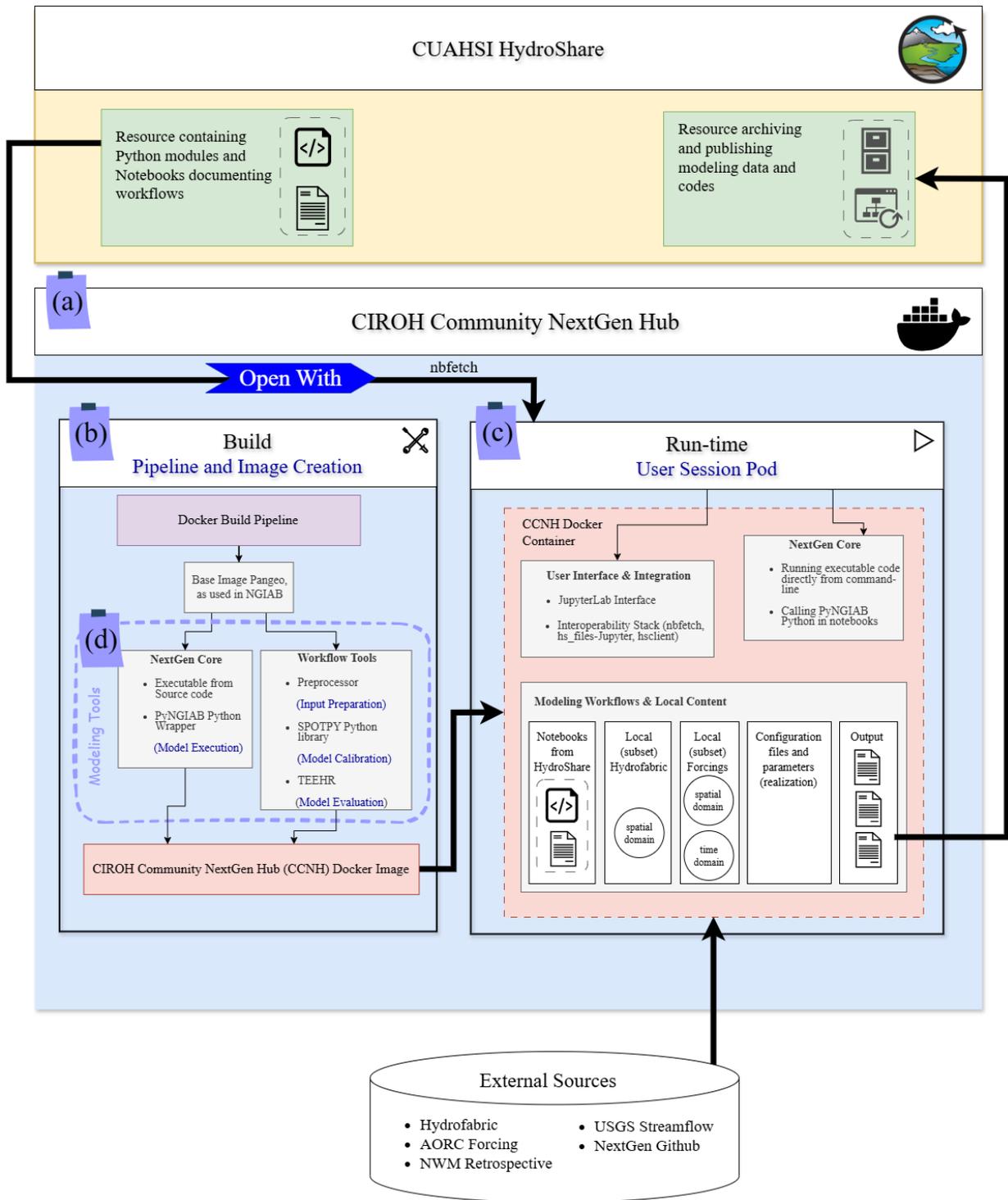


Figure 1. General cloud-based hydrologic modeling framework used for CCNH, designed to enhance accessibility, scalability, reusability, and reproducibility of hydrologic simulations.

## 2.2 Deployment architecture

The deployment architecture is built around the containerized CIROH-2i2c JupyterHub environment and is organized into build-time and run-time components. During the build phase, a container image is constructed to encapsulate the NextGen modeling framework, preprocessing utilities, and supporting analysis and calibration tools. At run time, the constructed image is instantiated as a user session that integrates HydroShare interoperability, enabling access to modeling workflows, data, and evaluation capabilities. Together, these components form an integrated software ecosystem that supports an end-to-end NextGen modeling workflow, spanning data preparation, model execution, calibration, and evaluation. The following sections describe each component of the deployment architecture.

(a) CIROH-2i2c JupyterHub platform

The CIROH-2i2c JupyterHub (<https://docs.ciroh.org/docs/services/cloudservices/2i2c/>) offers a dedicated JupyterHub environment on Google Cloud specifically designed for hydrological researchers using Pangeo ecosystem (i.e. Xarray, Dask, and Jupyter-based workflows). It functions as the computational backbone for Community NextGen modeling workflows in this deployment architecture. It delivers an interactive cloud environment, enabling users to launch Jupyter notebooks and execute NextGen simulations without local software installation or configuration requirements. The JupyterHub is deployed over Kubernetes, which is responsible for container scheduling, resource allocation and user isolation, allowing multiple users to run independent NextGen simulations within the same cluster. Each JupyterHub user session is launched from the shared CCNH container image with a complete NextGen software stack, including model code, routing modules (such as T-Route), compilers, libraries, and Python utilities. The platform offers multiple server configurations, ranging from small (5 GB RAM, 2CPUs) to huge compute profiles (52 GB RAM, 16 CPUs), to support simulations of varying scale and complexity. This scalable infrastructure allows both exploratory analyses on small basins and parallelized model runs for larger domains.

(b) Containerized software environment

The CIROH-2i2c platform uses Docker to encapsulate all required software, dependencies, and configurations. This containerization is essential for complex frameworks like NextGen, which rely on diverse system libraries and modeling components. The CCNH Docker image was based on the NGIAB (Patel et al., 2025) Docker container that enables modular workflows that can be deployed on local machines, on-premise clusters, or cloud platforms. The CCNH Docker-based container image is built upon the Pangeo/Notebook base image (<https://pangeo-docker-images.readthedocs.io/en/latest/>), which provides a pre-configured stack of scientific Python libraries, JupyterLab, and distributed computing capabilities, enabling researchers to perform large-scale scientific computations directly from a web-based notebook interface.

The CCNH container build process is derived from the NGIAB Dockerfile (Patel et al., 2025; <https://github.com/CIROH-UA/NGIAB-CloudInfra>) and adapted for the Pangeo-based 2i2c JupyterHub environment. The CCNH Dockerfile (<https://github.com/CIROH-UA/awi-ciroh-image/tree/ngen-2i2c>) must be manually updated to incorporate changes from the upstream

NGIAB image, including NextGen framework updates, dependency patches, and model component revisions. NextGen source code, originally written in Fortran and C/C++, is cloned from the NOAA-OWP GitHub repository and compiled using CMake and GCC with optimization flags appropriate for high-performance computing architectures (e.g., ARM or x86). The compiled binaries and configuration files are then copied into the final Pangeo image, which serves as the base execution runtime for the hub. This synchronization is coordinated with the CIROH DevOps team to ensure compatibility. Once updated, GitHub Actions automate the container build and deployment to the 2i2c registry via pull request to <https://github.com/2i2c-org/infrastructure> repository, ensuring correctness and end-to-end validation of each CCNH release. The NGIAB project maintains a robust CI/CD pipeline that automates container builds, testing, and deployment across multiple architectures, providing a reliable foundation for derivative deployments such as CCNH.

The CCNH containerization approach leverages the continuous integration infrastructure established for NGIAB (Patel et al., 2025). The NGIAB project (<https://github.com/CIROH-UA/NGIAB-CloudInfra>) maintains GitHub Actions workflows that automate multi-stage Docker builds, support both ARM64 and AMD64 processor architectures, and perform automated testing to ensure container stability across releases. This CI/CD foundation enabled CCNH development to focus on Pangeo-specific adaptations rather than rebuilding fundamental containerization automation. The CCNH build configuration, maintained in the `ngen-2i2c` branch of the AWI CIROH image repository (<https://github.com/CIROH-UA/awi-ciroh-image>), inherits from the NGIAB Dockerfile patterns while incorporating JupyterHub-specific dependencies such as the `nbfetch` and `hs_files-jupyter` extensions. This inheritance model ensures that improvements to the upstream NGIAB container—including security patches, model updates, and performance optimizations—can be efficiently propagated to CCNH, maintaining consistency across the NextGen deployment ecosystem.

### (c) HydroShare and CIROH-2i2c JupyterHub interoperability

In our design, we used HydroShare (<https://www.hydroshare.org>) as a gateway for the workflow to set up NextGen model instances. Within our workflow, HydroShare served two purposes: (1) storage of the model workflows and associated datasets, and (2) gateway to opening the CCNH CIROH-2i2c JupyterHub cloud computing environment pre-configured with NextGen tools and model. CCNH includes the specially configured software to enable JupyterHub deployments to respond to a HydroShare web app connector "Open With" application programming interface (API) call (<https://www.hydroshare.org/hsapi/>). This software includes two jupyter extensions (`nbfetch` and `hs_files-jupyter`) and one general-purpose HydroShare library (`hsclient`). The `nbfetch` extension downloads content of the resource selected in "Open With" to the user's JupyterHub environment. The `hsfiles-jupyter` extension enables transfer of files between JupyterHub and HydroShare using the Jupyter native file browser interface. Both of these utilize the `hsclient` python library, specifically for interacting with HydroShare resources via API web calls. With these software in place, users navigate to a HydroShare resource containing a NextGen

workflow Jupyter Notebook, click the "Open With" button to launch the CIROH-2i2c JupyterHub instance, and the resource files are transferred to the JupyterHub computational environment to be used there. Similar linked HydroShare-to-JupyterHub deployments include CyberGIS-Jupyter for Water (Yin et al., 2019) and CUAHSI JupyterHub (<https://help.hydroshare.org/apps/CUAHSI-JupyterHub/>).

#### (d) Modeling tools

In addition to the pre-compiled NextGen software, the CCNH environment includes the NGIAB preprocessor tool ([https://github.com/CIROH-UA/NGIAB\\_data\\_preprocess](https://github.com/CIROH-UA/NGIAB_data_preprocess)) developed as a core component of the NGIAB ecosystem by CIROH to automate model input preparation. It also includes the SPOTPY (Statistical Parameter Optimization Tool for Python) library for model calibration, and TEEHR (Tools for Exploratory Evaluation in Hydrologic Research) tools for model output analysis and evaluation. Jupyter notebooks hosted in HydroShare (Nassar et al., 2026) were developed to guide users through the complete modeling workflow using these tools.

#### (1) Preprocessor tool

The preprocessor tool serves as the foundation for the NextGen modeling framework, orchestrating the retrieval, preparation, and assembly of all required model inputs. In this study, we leveraged the NGIAB preprocessor tool to automate model input preparation on the CIROH-2i2c JupyterHub environment. The tool integrates nationally available datasets (Figure 1, external sources shown at the bottom), including the continental U.S. (CONUS) Hydrofabric Dataset (Blodgett et al., 2023; Patel et al., 2025), which provides detailed representations of landscape characteristics, flow networks, and topological connectivity, as well as meteorological forcing datasets such as the NOAA Analysis of Record for Calibration (AORC) (<https://noaa-nws-aorc-v1-1-1km.s3.amazonaws.com/index.html>) and the NWM retrospective (<https://noaa-nwm-retrospective-3-0-pds.s3.amazonaws.com/index.html#CONUS/zarr/forcing/>). The preprocessor tool subsets these datasets to the designated research domain and simulation period, extracting domain-specific inputs. This approach eliminates manual configuration, reduces setup errors, and ensures a reproducible and consistent NextGen model setup. With these study-area-specific inputs in place, the model can proceed to execution and calibration.

#### (2) Model execution

NextGen model execution may be performed either by directly calling the NextGen executable from the command line or through the PyNGIAB Python wrapper developed to encapsulate the interaction between the user and the NextGen executable. The wrapper provides high-level abstractions for executing simulations directly from Python notebooks. The interface automatically handles file system mapping between JupyterHub user directories and the containerized runtime environment, while also managing input validation and error reporting. PyNGIAB comes with built-in environment isolation, enabling model execution without the need for explicitly activating a kernel or virtual environment in Jupyter. PyNGIAB serves a similar purpose for NextGen to PySUMMA developed previously for the SUMMA model (Choi et al., 2021; Maghami et al., 2023).

The NextGen framework executes hydrologic simulations through a set of modular components that are coupled using BMI to represent interacting physical processes. The NextGen framework is designed to enable the coupling of alternative models across diverse domains under the premise that no single model performs best everywhere. The CCNH deployment defaults to models configured in NGIAB. Land surface processes, including interception, snow accumulation and melt, evapotranspiration, and surface energy balance, are represented by the Noah Land Surface Model – Office of Water Prediction (Noah-OWP) (<https://github.com/NOAA-OWP/noah-owp-modular>) and are coupled with the Conceptual Functional Equivalent (CFE) model (<https://github.com/NOAA-OWP/cfe>), which simulates runoff generation and soil moisture dynamics at the catchment scale (divide). The lateral inflows produced by these coupled hydrologic components are routed through the river network using T-Route (Tree-Based Channel Routing) (<https://github.com/NOAA-OWP/t-route/>), the NextGen channel routing model, producing streamflow at specified network features that can be directly compared with observations from U.S. Geological Survey (USGS) gage locations.

### (3) Model calibration

The general-purpose SPOTPY library (<https://spotpy.readthedocs.io/en/latest/>) was added to CCNH to provide a variety of model calibration algorithm options (Houska et al., 2015). SPOTPY provides a unified platform for uncertainty analysis and parameter estimation, including Monte Carlo sampling, Latin Hypercube sampling, and evolutionary optimization methods such as DREAM (DiffeREntial Evolution Adaptive Metropolis) and SCE-UA (Shuffled Complex Evolution-University of Arizona). By coupling PyNGIAB with SPOTPY, researchers can automate parameter calibration workflows for catchment-scale or regional simulations within the same Jupyter notebook.

The calibration workflow begins by defining the required inputs, including the USGS gage ID, the corresponding NextGen feature ID (HydroFabric ID), the simulation start and end dates, and the path to the model configuration file (realization.json), where model parameter values are stored. The notebook also retrieves hourly observed streamflow from USGS water data for the nation sources (<https://waterdata.usgs.gov/>) and prepares it for comparison with the NextGen simulated streamflow. The calibration workflow generates a new parameter vector for each iteration. For every parameter set produced, the notebook reads the current realization.json file, updates the CFE and Noah-OWP parameter values with the proposed parameters, and writes the revised configuration back to disk. After the configuration file is updated, the notebook initiates a new NextGen model run within the container, producing a new T-Route NetCDF output file containing simulated streamflow for the specified feature ID. The notebook then extracts the simulated hydrograph from the output and aligns it with the processed USGS observations for the calibration period. The agreement between simulated and observed streamflow is evaluated using the selected objective function, such as Kling–Gupta Efficiency (KGE), or Root Mean Square Error (RMSE) (e.g. Knoben et al., 2019). This evaluation score is used to guide the selection of the next parameter vector. At the end of calibration, the notebook returns the parameter set that achieved the best performance.

#### (4) Model evaluation

An advantage of working within the standards-based NextGen framework is the ability to incorporate tools and developments created by others using the same standards. TEEHR is an advanced set of model evaluation tools developed for NextGen (<https://rtiinternational.github.io/teehr/>). Here these were included in CCNH to support model evaluation. TEEHR uses Apache Spark as its underlying framework with distributed computing capabilities that can perform large-scale benchmarking studies across thousands of catchments or multiple NextGen realizations. It included links to Amazon Bucket repositories with USGS and NWM retrospective results for use in these evaluations.

Beyond advanced tools such as TEEHR, the general-purpose Python computing and visualization capabilities available in the CIROH-2i2c JupyterHub environment, built on the Pangeo ecosystem, enable flexible and exploratory evaluation of model outputs. In this work, general-purpose Python libraries were used to visualize input and output datasets, compare simulated streamflow to observations, and evaluate water-balance consistency by examining the partitioning of precipitation (P) into evapotranspiration (ET), streamflow (Q), and storage change ( $\Delta S$ ) across the NOAH-OWP and CFE components of the NextGen configuration. By combining statistical performance metrics with water-balance diagnostics, the evaluation ensures that the model not only fits observed data but also represents hydrologic processes realistically within the study domain. These analyses identify model limitations in specific settings and serve as a basis for initiating research to improve NextGen model formulations.

### 3. Test case study: The Logan River watershed

In this research, the Logan River watershed, located in the Bear River Range on the Utah–Idaho border (Neilson et al., 2021), serves as the test case study (Figure 2). It is a semi-arid, snowmelt-dominated basin, with an area of approximately 554 km<sup>2</sup> and elevations ranging from about 1,422 to 3,041 m, with a mean elevation of approximately 2,300 m.

We selected the Logan River watershed for two reasons: (i) to evaluate how the NextGen modeling framework computes the water balance in a natural, snow-dominated mountain basin; and (ii) Logan River watershed is representative of watersheds within much of the Rocky Mountain region of the U.S. with snowmelt driven hydrology. It is a watershed with a good observational record (Longyang et al., 2024) and one for which we have local knowledge of hydrology and data.

Land cover is predominantly forest and rangeland with minimal development. Annual precipitation ranges from approximately 450 to 1250 mm, with long term mean about 876 mm, and mean annual potential evapotranspiration is approximately 624 mm. Streamflow peaks during spring snowmelt and tapers down through summer and fall to low flows in winter; average discharge at the outlet (USGS station 10109001) is about 6.5 m<sup>3</sup> s<sup>-1</sup>. The basin includes significant karst geology, which presents a challenge to surface hydrologic modeling (Neilson et al., 2021).

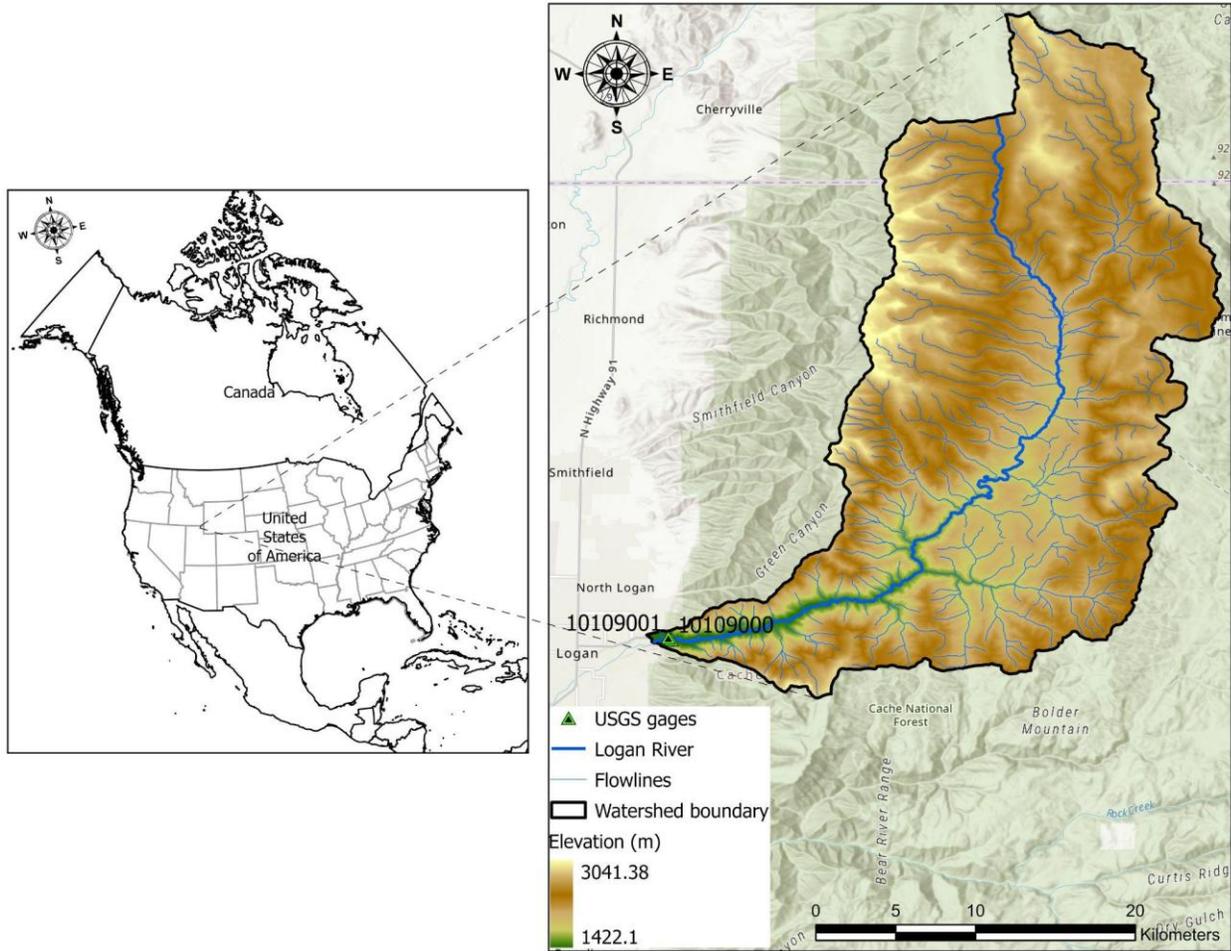


Figure 2. Map layout of the Logan River watershed showing the watershed boundary, USGS gage locations, river flowlines, and elevation.

## 4. Results

This section presents the results of implementing the deployed NextGen modeling workflow using the Logan River watershed as a representative case study. The workflow was executed entirely within the CIROH-2i2c cloud-hosted Jupyter environment, demonstrating the full sequence of operations from input data preparation and model configuration to calibration and evaluation. The Logan River watershed use case illustrates how the integrated framework supports reproducible hydrologic simulations, parameter calibration and result evaluation, in a transparent and scalable containerized environment.

### 4.1 NextGen model data input architecture

The NextGen data preprocessor was used to prepare the files holding model configuration and parameters, linking the model components together with BMI. The preprocessor organizes all domain-specific data and configurations into a well-defined directory structure. The directory structure layout (Figure 3) was populated automatically during preprocessing and includes

everything needed for model setup, calibration, and analysis. Each top-level directory, named for its `domain_id`, represents a specific modeling unit, such as a USGS streamflow gage ID, a catchment ID, or a Vector Processing Unit (VPU). The `config` folder contains the main input files, including the hydrofabric subset (`geopackage`), and model setup file (`realization.json`). It also includes routing information (`troute.yaml`) and separate folders for model components such as CFE and Noah-OWP. The `forcings` folder stores the meteorological input data in both raw and processed NetCDF formats. Model results are saved in the `outputs` folder, which includes results from the NextGen and the routing model (T-Route). The “`ngen`” folder contains CSV files with simulated hydrologic variables, such as streamflow, soil moisture, and storage for each individual divide (catchment) within the spatial domain. The `calibration` folder stores the outputs from model calibration, with an `iterations` subfolder that records parameter values and performance metrics for each run. The “`teehr`” directory provides a structured workspace for data validation and evaluation using the TEEHR toolkit, including scripts, formatted datasets, and intermediate cache files. Additional files in the `metadata` folder and the `partitions_16.json` file support model parallel processing.

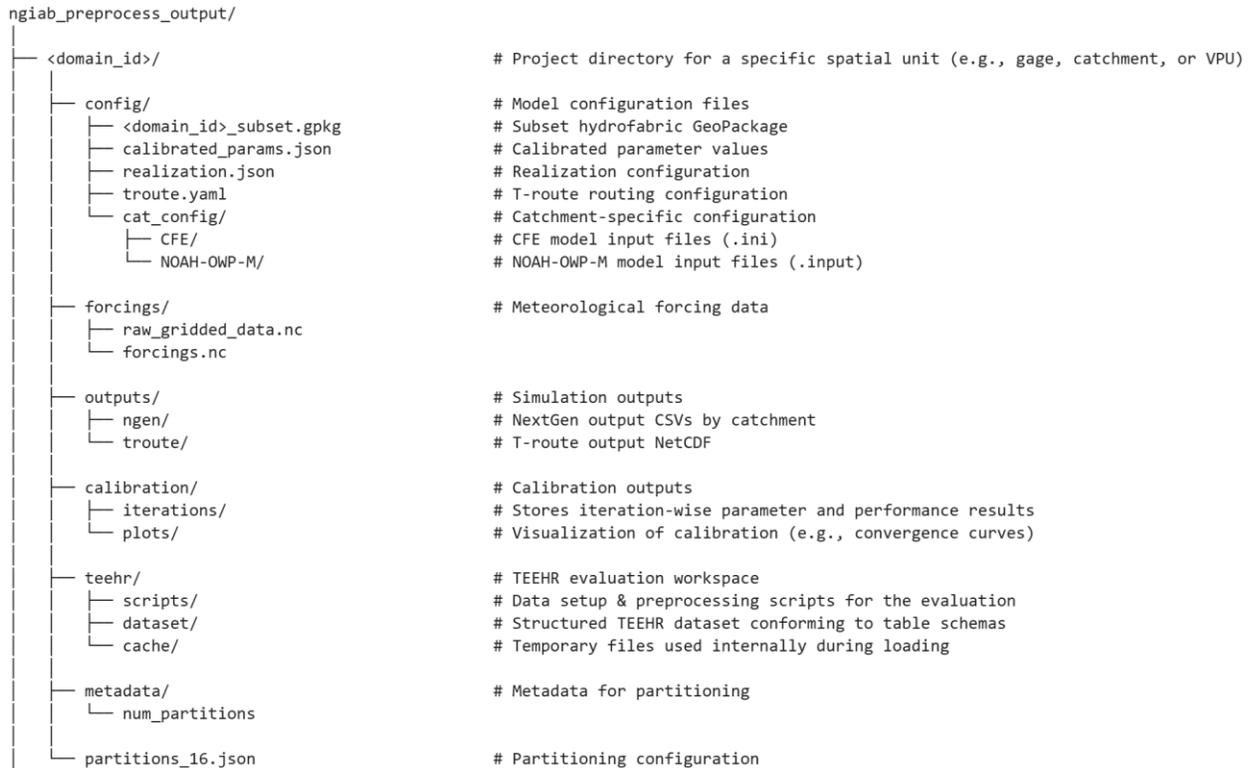


Figure 3. Directory structure of a NextGen project for a specified spatial domain.

#### 4.2 Preprocessing model inputs

Steps for preparing model inputs and configuring the NextGen model, including spatial subsetting of hydrofabric and forcing datasets and setup of model configurations/realizations were documented in a Jupyter notebook (Figure 4).

(a) Hydrofabric subset: The spatial domain for the model can be defined multiple ways, such as by catchment ID, outlet USGS gage ID, or Vector Processing Unit (VPU). In this study, we used the USGS gage 10109001 to define the outlet of the Logan River watershed. Once the spatial domain is defined, a command is executed (as shown in Figure 4) to extract the hydrofabric data for that specific area. The extracted data are stored as a GeoPackage file (`divide_id_subset.gpkg`) inside the “config” subfolder, as shown in Figure 3. This GeoPackage contains several spatial layers, including divides, flowpaths, nexus, network, hydrolocations, points of interest (POIs), and lakes. Details about each layer are provided in Table A in the Appendix. An interactive map is also generated to help visualize the hydrofabric features (Figure 5). On this map, divides (catchment boundaries) appear as black polygons, flowlines as blue polylines, nexus points as red markers, and USGS streamflow gaging stations as highlighted points. This visualization helps users better understand the spatial relationships and hydrologic connectivity within the watershed.

## 1. Prepare the Python Environment

```
# ----- Importing Required Libraries -----  
  
import json  
import pandas as pd  
import xarray as xr  
import matplotlib.pyplot as plt  
import matplotlib.dates as mdates  
from hydrofabric_visualization_utils import display_hydrofabric_map  
from forcings_utils import (  
    process_time_series,  
    get_var_label,  
    get_var_full_name,  
    get_var_units,  
    list_supported_variables,  
    compute_mean_annual, # main function that calculates the annual mean values  
    join_to_gpkg, # merges result statistics to polygon divides GPKG  
    save_csv_and_gpkg, # writes CSV + merged GPKG output files  
    plot_mean_annual_map, # makes the map visualization  
    make_mean_annual_map  
)
```

## 2. Set inputs

### Inputs Defined in the Next Cell:

- **Hydrofabric ID:** Specifies the spatial domain of interest. This can represent:
  - A *catchment ID* (e.g., `cat-7080`)
  - A *gage ID* (e.g., `gage-10154200`)
  - A *Vector Processing Unit (VPU)* code (e.g., `01`)
- **Start Date:** Defines the beginning of the simulation or data extraction period (format: `YYYY-MM-DD`).
- **End Date:** Defines the ending date of the simulation or data extraction period (format: `YYYY-MM-DD`).

```
# Define your Hydrofabric ID
hydrofabric_id = "gage-10109001" # This can be a catchment ID (e.g., 'cat-7080'), a gage ID (e.g., 'gage-10154200'),
                                # or a Vector Processing Unit (VPU) code (e.g., '01')

# Start date
start_date = "2017-10-01" # Specify the start date in the format 'YYYY-MM-DD'

# End date
end_date = "2021-09-30" # Specify the end date in the format 'YYYY-MM-DD'
```

### 3. Subset Hydrofabric using Catchment ID, Gage ID, or VPU

```
# Subsetting the HydroFabric Dataset
# This step subsets the HydroFabric dataset using the `hydrofabric_id` variable defined in the previous cell.

!source /ngen/.venv/bin/activate && python -m ngiab_data_cli -i $hydrofabric_id -s
```

### 4. Generate Forcings for a Specific Catchment ID

```
# Subsetting the Forcings Dataset
# Use the variables defined earlier (`hydrofabric_id`, `start_date`, `end_date`) to
# subset and preprocess the AORC forcings for your HydroFabric subset.

!source /ngen/.venv/bin/activate && python -m ngiab_data_cli -i "$hydrofabric_id" -f --start "$start_date" --end "$end_date"
```

### 5. Create Model Configuration/Realization

```
# Set-up Model Configurations / Realization
# Use the variables defined earlier (`hydrofabric_id`, `start_date`, `end_date`) to
# generate the model configuration and realization files needed to run the model

!source /ngen/.venv/bin/activate && python -m ngiab_data_cli -i "$hydrofabric_id" -r --start "$start_date" --end "$end_date"
```

Figure 4. Key code snippets for the workflow for preparing input data and setting up the NextGen model from the Model Preprocessing Jupyter Notebook.

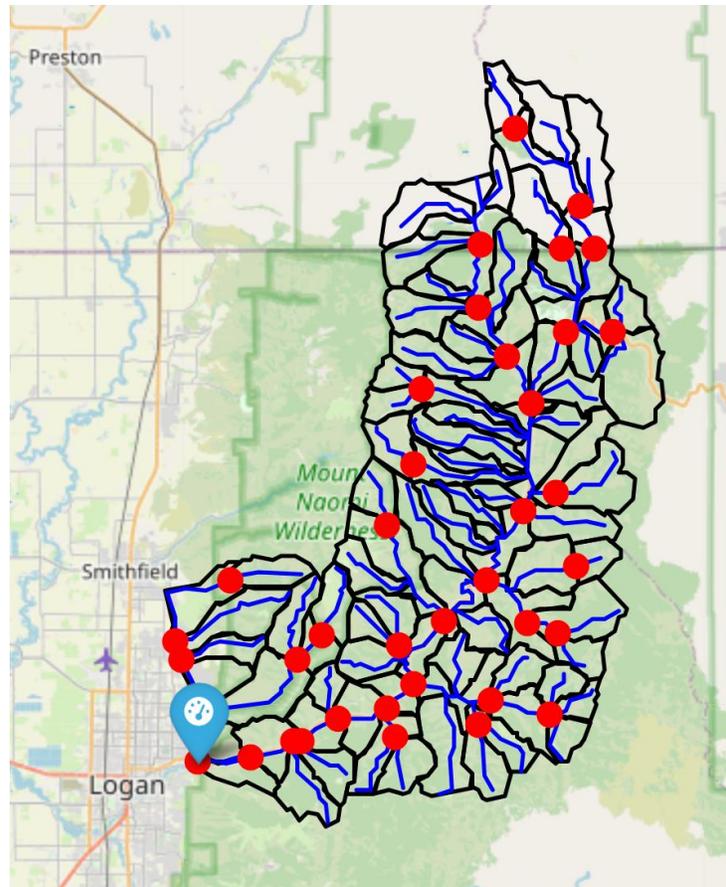


Figure 5. Screen shot of interactive hydrofabric subset map for the Logan River Watershed displayed in Jupyter Notebook

(b) Forcings subset: As part of the input-preparation workflow (Figure 4), the AORC meteorological forcing dataset was spatially subset to the extent of the Logan River watershed for the specified simulation period (October 2017–September 2021). The resulting subset was exported in NetCDF format (`raw_gridded_data.nc`) and stored in the preprocessing directory. This gridded dataset was then used to compute the hourly spatial mean of each forcing variable for each divide within the watershed and saved in the preprocessing directory as “`forcings.nc`”. Using this processed forcing file (`forcings.nc`), we aggregated the divide-level forcings to the watershed-scale using an area-weighted averaging approach to produce representative time series for each forcing variable. These aggregated inputs were evaluated using time-series plots of selected variables (Figure 6) and cumulative plots illustrating their temporal evolution (Figure 7). Figure 8 presents a spatially averaged map of mean annual precipitation derived from the `forcings.nc` file, highlighting the spatial distribution of precipitation across the model domain. These diagnostic plots were produced through the preprocessing Jupyter notebook and serve as visual checks on the data for spatial and temporal consistency and provide context for interpreting hydrologic model behavior and performance.

(c) Model configurations/realization: The final step in preparing the model inputs is to create configuration and realization files (Figure 4 last cell). For each divide, the workflow generates configuration files for each model used in the model formulation for each catchment. In the default formulation used here there is a configuration file for each catchment in each of the Noah-OWP and CFE module folders, as this model formulation is comprised of these two models. NOAH-OWP handles surface and energy balance processes while the CFE module simulates hydrologic processes such as runoff and groundwater flow. An overarching realization file (realization.json) defines the BMI linkages between the model components that dictate how the model will run. The realization file also includes model setup information, input data paths, routing configuration, time period of the simulation, and the variables to be saved as outputs. The organization of these files documenting parameters and connectivity settings makes the model easier to reproduce, understand, and update for future simulations.

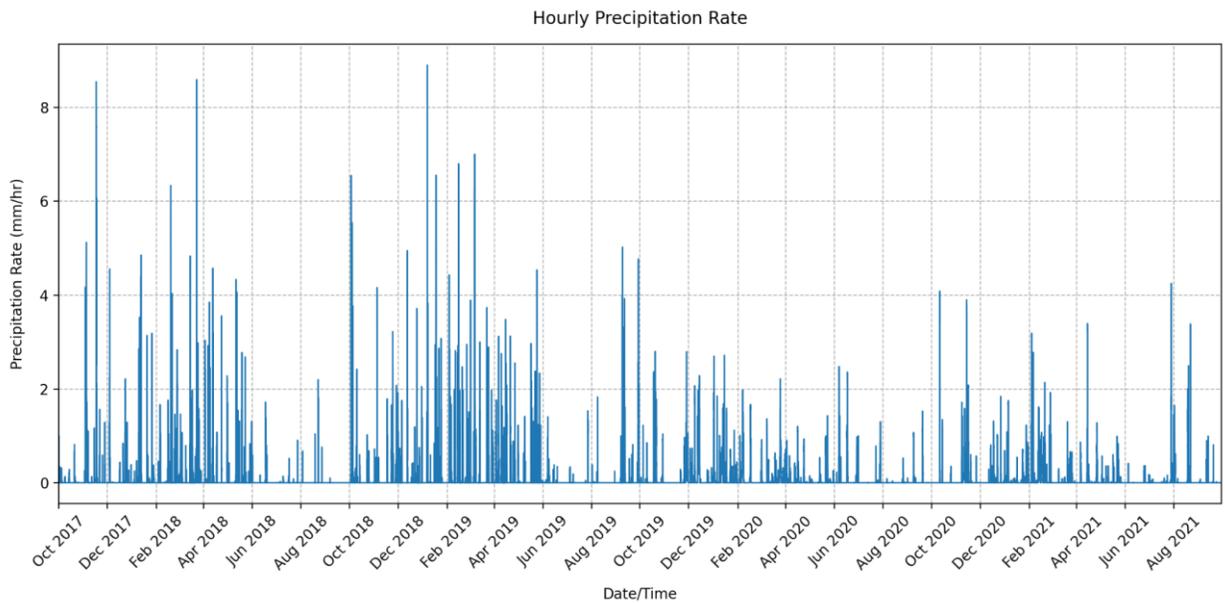


Figure 6. Time series of AORC precipitation aggregated across the entire Logan River watershed.

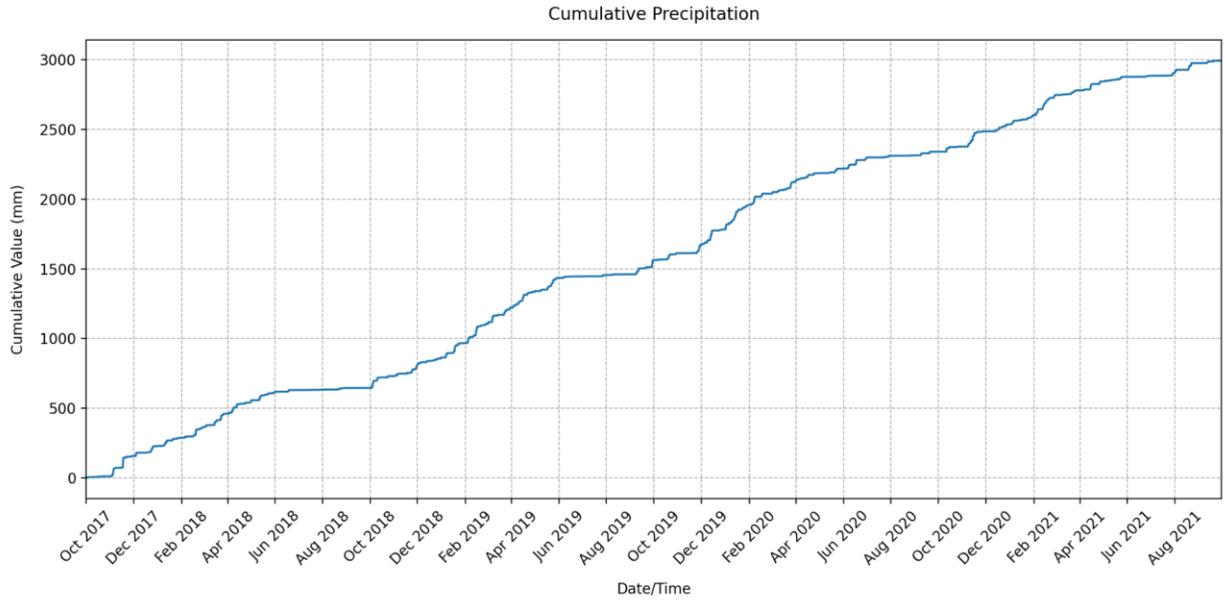


Figure 7. Cumulative precipitation for the entire Logan River watershed, aggregated from AORC forcing data.

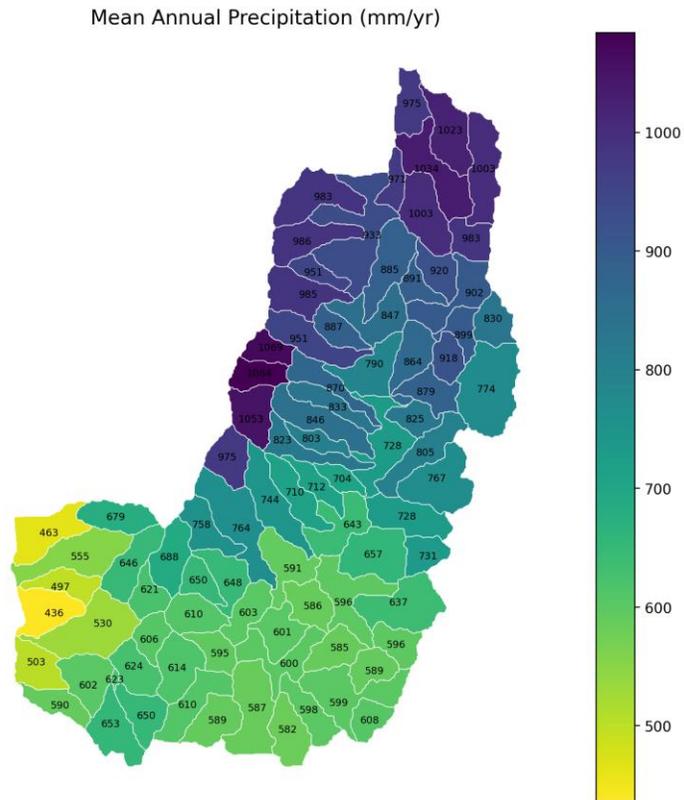


Figure 8. Mean annual precipitation from the NextGen preprocessing workflow, spatially averaged over each divide in the HydroFabric subset.

### 4.3 Model execution

The NextGen model is executed using the Python wrapper PyNGIAB, which streamlines the process of running the model with preprocessed inputs. The modeler provides as input the directory path where the prepared data are stored, including the hydrofabric, forcings, configuration files, and model realization. Once the data path is specified, the model is initialized for execution through the PyNGIAB class. The workflow supports both serial and parallel execution modes, allowing flexibility depending on the size of the study area and available computing resources. In the example shown in Figure 9, the model is run in parallel mode by defining the data directory (e.g., `/home/jovyan/ngiab_preprocess_output/gage-10109001`) and calling the `run()` function to start the simulation.

```
1. Prepare the Python Environment

# ----- Importing Required Libraries -----

from pyngiab import PyNGIAB

2. NextGen Run

# Specify the HydroFabric subset ID and locate the directory where the NGIAB
# preprocessing workflow stored the forcing data, configuration files, and realization setup.
hydrofabric_id = "gage-10109001"
data_dir = f'/home/jovyan/ngiab_preprocess_output/{hydrofabric_id}'

# Initialize the model for serial execution
test_ngiab_serial = PyNGIAB(data_dir, serial_execution_mode=False)

# Run the model
test_ngiab_serial.run()
```

Figure 9. Example of running the NextGen model using the Python wrapper PyNGIAB

### 4.4 Model calibration

The model was run for the period October 1, 2017, to September 30, 2021, corresponding to four complete water years. The simulation started at the beginning of the water year (October 1) to ensure that the model captures the full annual hydrologic cycle, including snow accumulation, melt, soil moisture evolution, groundwater storage dynamics, and seasonal flow variations. The first two water years (2017–2019) were used as a spin-up period which, based on our experience, was sufficient to allow the model’s soil moisture, groundwater, and internal storage components to reach a stable condition. The following two water years (2019–2021) were used for model calibration. During calibration, the workflow automatically adjusted model parameters to improve agreement between simulated and observed streamflow. Parameters from both the CFE and Noah-OWP modules, such as `b`, `satpsi`, `satdk`, `maxsmc`, `max_gw_storage`, `K_nash_subsurface`, `MFSNO`, `MP`, and `SCAMAX`, were updated at each iteration. The model was then executed with these new

parameters, and the simulated hourly streamflow was compared with the observed data from the USGS gage. Calibration was carried out by configuring SPOTPY to use the Dynamically Dimensioned Search (DDS) algorithm with the Kling–Gupta Efficiency (KGE) as the objective function. Model evaluation was conducted using the TEEHR toolsets, in which the NextGen simulation and the NWM v3.0 retrospective analysis were evaluated as secondary datasets relative to the primary USGS observations. Performance was quantified using the KGE and Nash–Sutcliffe Efficiency (NSE) metrics computed within TEEHR. During the spin-up period, the NextGen simulation achieved a KGE of 0.200 and an NSE of  $-0.410$ , while the NWM v3.0 retrospective simulation yielded a KGE of 0.418 and an NSE of 0.428. Following calibration for 200 iterations, model performance improved substantially, with the NextGen simulation achieving a KGE of 0.893 and an NSE of 0.785, compared to a KGE of 0.735 and an NSE of 0.752 for the NWM v3.0 retrospective simulation (Figure 10).

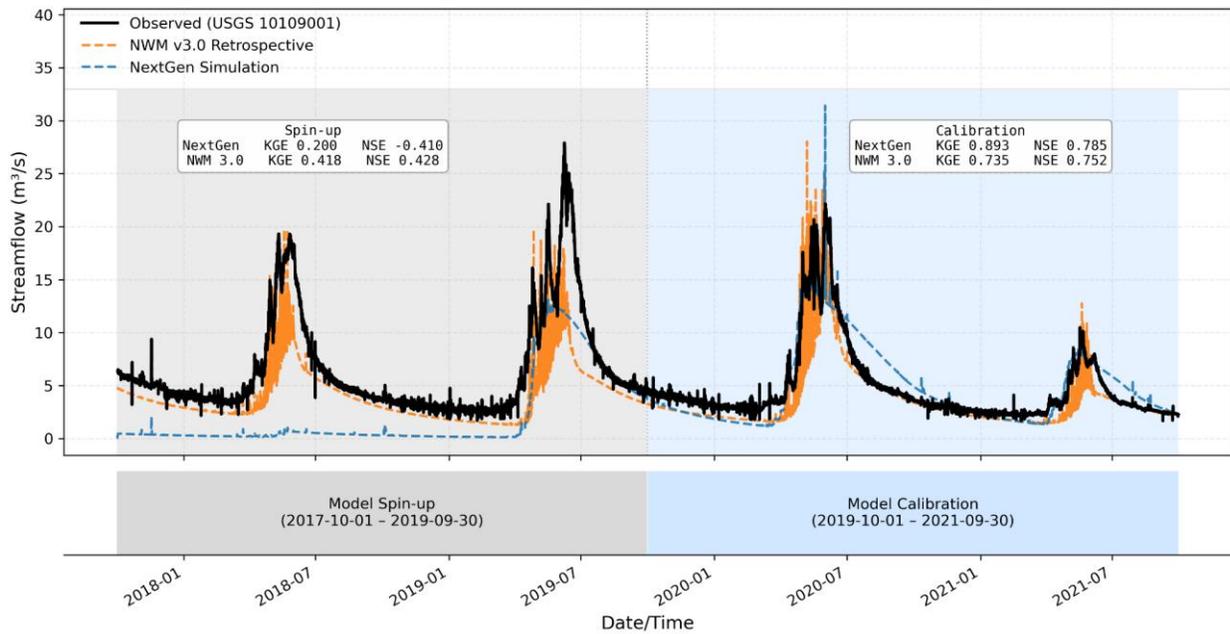


Figure 10. Comparison of simulated and observed streamflow at the Logan River watershed outlet (gage ID: 1010900) obtained from the NextGen model calibrated using the SPOTPY-DDS algorithm. The best calibration achieved a KGE of 0.893 and an NSE of 0.785.

#### 4.5 Model output evaluation

Figure 11 illustrates the cumulative time series of major hydrologic fluxes and storage changes simulated by the NextGen workflow for the Logan River watershed from October 2019 through September 2021. This diagnostic plot serves as a water-balance examination tool and demonstrates how the model partitions incoming precipitation into various components. It provides users and researchers with insight into how water moves through the model’s internal processes and where imbalances or inconsistencies may occur.

The results presented in this figure arise from the coupled configuration of NextGen, which integrates both the NOAH-OWP and CFE models. In the cumulative plot, the top blue curve

represents the total AORC precipitation input to the system. Immediately below it, the orange curve shows the cumulative surface water input passed from NOAH-OWP to CFE. The gap between these two curves reflects snow-related processes within NOAH-OWP, including storage and sublimation. The inferred upward flux (sublimation), shown as the olive dashed curve, represents part of this difference. Cumulative modeled actual evapotranspiration (red dashed curve) increases gradually over the simulation period and represents a major loss term from the watershed. Outflow (green solid curve) accumulates more slowly, consistent with the baseflow-dominated hydrogeologic behavior of the Logan River basin. This watershed is heavily influenced by karst features, including high-elevation sinkholes, losing reaches underlain by permeable fluvioglacial deposits, and diffuse hillslope infiltration that recharges a regional karst aquifer. These properties lead to significant subsurface storage and delayed discharge, which is reflected in both the cumulative outflow trajectory and the modeled groundwater and soil storage terms.

The cumulative storage change curves (brown and purple lines), representing soil moisture, groundwater storage, and snow-related states, capture the seasonal and interannual dynamics of subsurface water redistribution. These storage components help close the water balance by showing how much water is temporarily retained within the watershed before contributing to ET, streamflow, or sublimation.

Overall, this cumulative diagnostic view provides a detailed look into how NextGen partitions precipitation among snow processes, evapotranspiration, storage, and streamflow. Although the simulated patterns align with the general hydrologic behavior expected for the Logan River watershed, some differences arise because the CFE land-surface model does not explicitly represent hydrogeologic processes. This limitation contributes to discrepancies in partitioning, particularly those associated with snow accumulation, sublimation and sub-surface storage and highlights opportunities for further research and improvement in land-surface and snow-process representation.

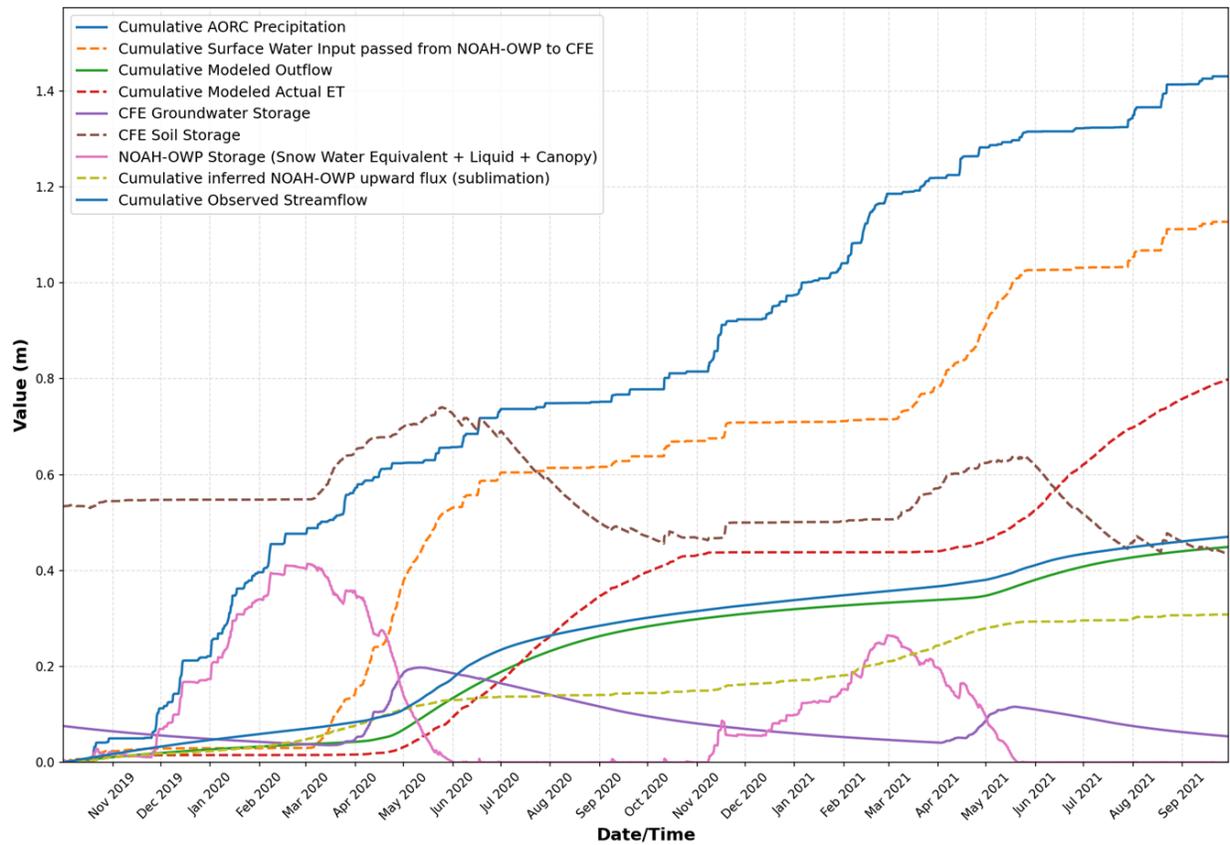


Figure 11. Simulated cumulative NextGen output variables for the Logan River watershed using NextGen, covering the period October 2019 to September 2021

## 5. Discussion

Server hosted ready to use cloud based environments are emerging as a powerful computing paradigm that eliminates the need for users to install complex software (Castronova et al., 2023; Chastang et al., 2022; Yin et al., 2019). This study addressed the challenge of providing access to the NextGen hydrologic modeling framework on a cloud-based platform. Core software components for the NextGen modeling ecosystem were deployed on a 2i2C JupyterHub platform hosted by CIROH to provide community access and serve as an entry point for research to advance NextGen. The approach allows users to rely on a uniform, pre-configured environment rather than troubleshooting software installation and configuration issues across diverse computers. In addition, data access workflows, ensuring consistent access to the data resources without the need for local downloads or storage. This architecture enables users, students, and researchers to access applications as part of broader cloud-native workflows that integrate notebook-based analysis with modeling and analysis tools, all within a web browser and without local software installation, thus lowering technical barriers to advanced hydrologic modeling research.

### 5.1 Cloud-based cyberinfrastructure for NextGen modeling

The Logan River Watershed case study demonstrated the feasibility of a cloud-based platform supporting a research instance of a NextGen model that could serve as a starting point for community contributions that lead to NextGen improvements. The specific results, in terms of performance metrics, are less than one would hope for, but the point is that these were obtained on a completely cloud-based system available to any user of the CIROH 2i2c based CCNH, and provide a starting point for evaluating hydrologic process reasons for discrepancies through analyses such as in Figure 11. The CCNH platform represents the beginnings of a modeling ecosystem that includes the NextGen framework where multiple BMI wrapped models can be included in and specific model instance or configuration. The modeling ecosystem incorporates best of practice tools such as TEEHR and SPOTPY, and links to data sources and data preparation tools. These remove some of the drudgery from initial research model instance development and allow a researcher to quickly focus on the aspects of modeling of interest to them. There are limitations associated with this approach. Computational capacity on 2i2c JupyterHub platforms is finite and bounds the size of model domains, limiting it to research-scale, appropriate for investigating relatively local or regional scale problems. Multiple runs associated with calibration are time consuming. Changing model code, a quite advanced, but important aspect of model improvement is currently not feasible on CCNH.

## **5.2 Data, HydroShare and reproducibility**

The workflow developed starts with data and workflow scripts in Jupyter notebooks and python code that is publicly accessible in HydroShare. This aligns with FAIR principles and reproducibility concepts. However, results generated in CCNH reside in the users' file system on 2i2C JupyterHub. HydroShare interoperability tools were developed and are part of CCNH and facilitate the saving of results to the HydroShare repository. However, the burden of transferring and organizing results in a HydroShare resource still falls on a user and there is a need to improve practices as well as develop more automated tools that help users share findings in FAIR-aligned ways.

## **5.3 Pre-configuration of tools that provide a software ecosystem for modeling research**

Advanced hydrologic modeling relies on multiple tools that comprise the modeling and analysis software ecosystem. A cloud-based pre-configure environment enables best of practice tools to be integrated and made available to all users rather than, as is common in local research, users working expediently with what is easy for them to obtain. The platform we developed included, beyond what is required to run NextGen, SPOTPY and TEEHR tools that provide advanced calibration and analysis. There will be researchers who seek to improve models by working with the models themselves. For these researchers having access to best of practice calibration and evaluation tools enables their direct focus on, say, model process physics. There will be other researchers who seek to improve models, by getting better input data, or better calibration. They are enabled in this ecosystem by being able to focus on these aspects, while

taking the model they are using as a given. There are also researchers who explore advanced evaluation methods, and need model use cases for their evaluation. The software ecosystem of CCNH enables all these different types of users, letting each focus on what is their area of interest or inquiry, and relying on best of practice implementations in other areas.

Such an approach is, however, not without shortcomings. The learning required to properly use some of the tools is quite significant and there is a burden on the community for this documentation and learning to be available. The ability of HydroShare to hold Jupyter notebooks, and other metadata that documents tools and models, and for this to be shared and collaboratively advanced, does help with this process, but there is no getting around the effort of proper documentation and learning material associated with software ecosystem components.

#### **5.4 Opportunities for enhancing NextGen models computation and performance**

The case study revealed several practical limitations as well as opportunities to strengthen the computational efficiency and scientific performance of the NextGen modeling workflow. Despite access to scalable cloud resources, the iterative calibration process, which involves updating multiple parameters across numerous model runs, is time-consuming. Improving this aspect will require shifting the heavy computation outside the interactive notebook while keeping JupyterHub as the user-facing interface. This enhancement would enable more robust, and efficient calibration and would greatly expand the scope of experiments the platform can support.

Our results also highlight the scientific insights gained and the limitations encountered when applying NextGen to a complex watershed. Although calibration improved the model performance, the comparison between simulated and observed streamflow indicates that further refinement is still needed. The remaining discrepancies reflect uncertainties that may arise from the model structure, the model inputs, including the hydrofabric, configuration parameters, and meteorological forcing data, or interactions among these components. For instance, the current NextGen configuration uses only the AORC dataset as the meteorological forcing. Uncertainties in the forcing data, including biases or misrepresentations of local precipitation and temperature patterns, can propagate through the model and lead to discrepancies in simulated streamflow even when the internal components/settings are appropriately chosen. While alternative datasets such as PRISM, gridMET, and DayMET are available, incorporating or testing them within the present modeling workflow is not yet streamlined and still requires manual effort. This limitation reduces the ability to diagnose whether performance gaps arise from model structure, model inputs uncertainty, or an interaction between the two.

## 6. Conclusion

The complexity of the NextGen framework and its reliance on advanced cyberinfrastructure have limited access for many researchers and graduate students seeking to experiment with and improve hydrologic models. This work demonstrates that integrating NextGen into a cloud-based, preconfigured environment can substantially reduce these technical barriers while supporting reproducibility and collaborative research. By linking CIROH-2i2c JupyterHub with HydroShare and leveraging the containerized tools provided through NextGen In A Box (NGIAB), we established a unified cloud workflow that supports the full modeling process, from data preparation through calibration and evaluation, within a browser-based Jupyter notebook environment. In doing so, responsibilities for software installation and dependency management are shifted from individual users to the platform, allowing hydrologic researchers to focus on model behavior and scientific inquiry. The case study shows that this approach enables users with modest programming experience to engage with the NextGen framework as a practical entry point for exploring enhancements to the U.S. National Water Model.

This approach is aligned with FAIR and reproducible modeling practices. The HydroShare software stack, particularly the `nbfetch` and `hs_files` tools, make it straightforward to move workflow folders between HydroShare and the JupyterHub environment. This capability allows users to push updated notebooks and configuration files back to HydroShare for sharing, archiving, and citation, ensuring that workflows remain transparent and reusable. While large model outputs are not stored due to size constraints, the preserved configurations and notebooks provide all the information needed to regenerate results reliably.

Overall, these capabilities provide a practical foundation for community-driven research on NextGen framework to help broaden participation and accelerate the collective advancement of NextGen modeling. The framework presented here positions the hydrologic community to explore new scientific questions, test emerging model components, and contribute more effectively to the future evolution of the U.S. National Water Model.

### **CRedit authorship contribution statement**

**Ayman Nassar:** Writing – original draft, Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Data Curation, Visualization. **David G. Tarboton:** Writing - Review & Editing, Conceptualization, Methodology, Supervision, Project administration. **Furqan Baig:** Writing - Review & Editing, Software. **Josh Cunningham:** Software. **Arpita Patel:** Writing - Review & Editing, Resources. **James Halgren:** Writing - Review & Editing. **Benjamin Lee:** Resources. **Homa Salehabadi:** Validation. **Anthony M. Castronova:** Review & Editing. **Irene Garousi-Nejad:** Review & Editing

### **Software and data**

Name of software: Cloud-based NextGen workflow and CIROH Community NextGen Hub (CCNH)

Developers: Ayman Nassar, Furqan Baig, and Josh Cunningham

Contact: [ayman.nassar@usu.edu](mailto:ayman.nassar@usu.edu), [aymnassar@gmail.com](mailto:aymnassar@gmail.com), [fbaig@illinois.edu](mailto:fbaig@illinois.edu), and [jcunningham8@ua.edu](mailto:jcunningham8@ua.edu)

Date first available: Jan 31, 2026

Program language: YAML, Shell and Python

Source codes: The workflows and Jupyter Notebooks used in this study have been archived on HydroShare, and upon acceptance will be permanently published with a citable DOI (Nassar et al., 2026). The Notebooks retrieve data used from publicly available sources. CIROH Community NextGen Hub, NextGen In A Box, NextGen Data Preprocessor and NextGen Python wrapper software are available on GitHub at the links below.

- CIROH Community NextGen Hub (CCNH) container build configuration: <https://github.com/CIROH-UA/awi-ciroh-image/blob/ngen-2i2c/Dockerfile>
- NextGen In A Box (NGIAB) containerization and CI/CD infrastructure: <https://github.com/CIROH-UA/NGIAB-CloudInfra>
- NextGen data preprocessor: [https://github.com/CIROH-UA/NGIAB\\_data\\_preprocess](https://github.com/CIROH-UA/NGIAB_data_preprocess)
- NextGen Python wrapper (pyNGIAB): [https://github.com/CIROH-UA/ciroh\\_pyngiab/](https://github.com/CIROH-UA/ciroh_pyngiab/)
- TEEHR tools: <https://github.com/RTIInternational/teehr/>
- SOPTPY calibration: <https://spotpy.readthedocs.io/en/stable/>

Documentation: Detailed documentation for the entire workflow is available in the HydroShare resource (Nassar et al., 2026).

Data required for use of software: The workflow subsets the required data, including the HydroFabric and AORC forcing data, and sets up the model configuration/realization files. Observed streamflow data are used for model calibration and evaluation, and the NWM 3.0 retrospective analysis is used for model evaluation.

### List of relevant URLs

- CUAHSI HydroShare: <https://www.hydroshare.org/>
- CIROH-2i2c JupyterHub: <https://ciroh.awi.2i2c.cloud/>

### Declaration of competing interest

The authors state that they have no conflicts of interest to declare.

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### Data availability

The software and data used are shared in the Software and Data Availability section.

### Appendix A.

**Table A. NextGen hydrofabric dataset content and description.** Each layer represents a different type of hydrologic feature in the standardized national hydrofabric, as a subset for the Logan River Watershed case study.

Layer Name	Layer Type	Description
Divides	Polygon	A watershed catchment unit defined by a drainage divide (outlet) that encapsulates where all surface water flows to that outlet.
Flowpaths	Line	Stream flowlines representing the paths that water follows through the landscape, including attributes such as reach length, stream order, etc.
Nexus	Point	Convergence points where hydrologic features meet (e.g., confluences or outlets connecting divides and flowpaths).
Network	N/A	Describes the connectivity and hierarchy among flowpaths, divides, and nexus points, defining the hydrologic network for routing and modeling.
Hydrolocations	Attribute Table	Specific points of interest for hydrologic modeling (e.g., stream gauges, monitoring sites), with metadata like IDs and coordinates.

POIs	Attribute Table	Additional Points of Interest relevant to the model (may overlap with hydrolocations), identified by unique IDs and linked to network features.
Lakes	Polygon	Lakes or reservoirs, with attributes such as surface area, elevation, and relevant hydraulic characteristics (e.g., outlet type).

**Table B. AORC meteorological forcing variables (as used in the NextGen/NWM framework).** Each variable is measured near the land surface and was subset for the Logan River Watershed.

Variable Name	Abbreviation	Unit	Measured At
Precipitation (1-hour total)	apcp	mm (kg m <sup>-2</sup> )	Surface (ground level)
Air Temperature	tmp	K	2 m above ground
Specific Humidity	spfh	g/g	2 m above ground
Air Pressure	pres	Pa	Surface (ground level)
Downward Shortwave Radiation Flux	dswrf	W m <sup>-2</sup>	Surface (incoming solar)
Downward Longwave Radiation Flux	dlwrf	W m <sup>-2</sup>	Surface (incoming IR)
Eastward (U) Wind Speed	uwnd	m s <sup>-1</sup>	10 m above ground
Northward (V) Wind Speed	vwnd	m s <sup>-1</sup>	10 m above ground

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