Shifting Left: Building a collaborative integrated hydrological model for the Murray-Darling Basin

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Abstract: The Murray–Darling Basin (MDB), Australia's most complex water system, spans five jurisdictions. There are over 20 hydrological models required to model a complete Basin scenario. To support integrated, basin-scale decision-making, the Australian Government supported the $66 million Integrated River Modelling Uplift (IRMU) program, resulting in the development of the Framework for Integrated River Modelling (FIRM). FIRM is a modular, metadata-driven platform deployed within the Murray–Darling Integrated River Assessment System (MDIRAS), a cloud-based environment. Models are onboarded through the FIRM Onboarding Manager (FOM) and managed via automated pipelines, integration files, and metadata standards that ensure reproducibility, modularity, and fault isolation.

FIRM was developed under tight deadlines to support the Basin Plan Review, leading to challenges in communication, development and training. A "Shift Left" approach, whereby valley model integration into the FIRM configuration was tested earlier in the overall workflow, helped identify and resolve integration issues earlier, maintaining model ownership within each Jurisdiction. Furthermore, the use of Azure DevOps (DevOps) Boards, Git repositories, and Wikis embedded in the DevOps environment enabled greater collaboration across distributed teams. The platform has not only modernised model integration but has also transformed the Murray Darling Basin Authority's (MDBA) modelling culture from single-modeller workflows to collaborative, specialised roles. FIRM is successfully on the path to improve jurisdictional collaboration and whole-of-basin integrated water resource planning overall.

Keywords: *Hydrology, Model integration, Cloud-native, Scenario Analysis, Murray-Darling Basin*

1. INTRODUCTION

The Murray-Darling Basin (MDB) is one of the world's largest managed river basins, spanning over 1 million square kilometres, across five jurisdictions including Queensland, New South Wales, Victoria, South Australia, and the Australian Capital Territory (ACT). Not only is the basin of immense economic value to Australia, it is also a place of internationally recognised environmental significance. With a rich cultural heritage for First Nation Australians dating over 45,000 years, managing the MDB since European settlement has been of significant complexity and contention, as competing interests in agriculture, environmental sustainability, and Indigenous rights continue to shape its governance. This complexity is heightened by the Basin's division across multiple state and territory jurisdictions, each with its own laws, priorities, and water management frameworks. High variability in water availability from year to year has driven the Commonwealth to manage water in a more coordinated way through the development of the Basin Plan: a legally binding framework that sets sustainable limits on water use while ensuring water is shared between the environment, communities, and industries across the Basin.

Competing management interests require long range planning for equitable river operations and sustainable water sharing. This is best achieved through sophisticated hydrological models which simulate tributary and major river system operations and are individually owned by each jurisdiction. Whilst these models often use different software and modelling assumptions, they are also highly interdependent, with each relying on upstream inflows, downstream demands, and other hydrologic data from neighbouring models to accurately capture and predict the movement of water throughout. Historically, the management of data sharing between jurisdictions required coordination, formal agreements, and reconciliation to ensure consistency across boundaries, which was undertaken on an ad hoc basis. This was a time-consuming process, often delaying decision-making. In addition, a lack of transparency between models where, for example, assumptions and calibration methods are not always openly shared, can further hinder integrated basin-wide management. The Murray-Darling Basin Authority (MDBA) is required under the Water Act (2007 §127) '*to develop, in consultation with the Basin States, an integrated water model for the Murray-Darling Basin'*. This underpins the need for a collaborative, basin-scale modelling platform.

1.1. Iteration 1: The Integrated River System Modelling Framework (IRSMF)

The first iteration of an integrated basin model was the Integrated River System Modelling Framework (IRSMF), developed by the CSIRO as part of the 2007/08 Sustainable Yields Project (Yang 2010). The IRSMF was a platform that linked surface water and groundwater models to enable modelling of a connected hydrological system in the MDB. It was initially developed to inform policy makers and researchers on how upstream changes would impact downstream users. This project identified 24 individual river system models within the Basin. Whilst it served its purpose within this context, major enhancements to the platform were identified as key in achieving better integrated Basin-wide modelling and management.

1.2. Iteration 2: The Integrated Modelling Uplift (IRMU) program

In 2022, the Australian Government provided a $66 million investment into the Integrated Modelling Uplift program (IRMU). The program's key objectives were to:

- enhance access to leading technology across Basin jurisdictions.
- enable faster integration and application of new insights and data across jurisdictional boundaries.

To achieve the objectives of IRMU, the MDBA collaborated with project partners Deltares, HARC and Flow Matters with ITC support from a23, to develop the Framework for Integrated River Modelling (FIRM). The core objectives of FIRM were to:

- Streamline the integration of state-based river-system models into a single framework
- Improve consistency and transparency across jurisdictions
- Reduce duplication of effort in model development and maintenance
- Provide a flexible, scalable platform that supports multiple users and agencies
- Enable collaborative, basin-wide scenario analysis and decision-making

2. FIRM WORKFLOW

Achieving the objectives of IRMU and the FIRM required the implementation of a structured approach to data management and model sharing. This was accomplished through the development of the Murray–Darling Integrated River Assessment System (MDIRAS), a collaborative cloud environment for hydrologic modellers. MDIRAS utilises the Microsoft Azure cloud computing platform arranged in a hub-spoke model for both networking and security, providing a private virtual machine (VM) based modelling workspace specific to each jurisdiction. MDIRAS is organized into three key DevOps project types, each containing forked repositories that are linked between projects. Each project serves a distinct purpose, with a defined workflow connecting them.

This is described in more detail in the following section. Altogether, the structure of the MDIRAS DevOps environment enables the effective organisation, storage, and sharing of all associated model binaries and state datafiles.

2.1. MDIRAS

The MDIRAS DevOps environment contains multiple projects, of three key types of projects (Figure 2):

- **MDBA/Jurisdictional Spoke Projects** – MDBA or Jurisdictionally-owned platforms consist of forked model repositories from the Collaboration Hub, where local modifications can be made to adapt and integrate jurisdictional models seamlessly into FIRM. The Spoke projects also house repositories for other non-FIRM related projects and models.
- **MDIRAS Collaboration Hub Project** – A shared space for both jurisdictional and MDBA modelers. Consists of a central repository of agreed-upon and FIRM-ready data sets, models and other components key to FIRM development.
- **FIRM Project** – Development-side platform consisting of forked model repositories from the Collaboration Hub, as well as software specific repositories for the configuration of the FIRM application. Here, a series of Pipelines exist to execute tests to check successful 'onboarding' of models from Collaboration Hub into the.

The MDIRAS tiered structure facilitates controlled separation of concerns between collaboration, local development, and system integration. It also supports traceability, consistency, and reduces duplication of effort. All model repositories leverage version control systems (e.g. Git) to ensure reproducibility and transparency of model changes.

2.2. FIRM

While FIRM sits within MDIRAS, there is considerable overlap between the various components that make up what is referred to as the FIRM or MDIRAS platform. The FIRM can more broadly be defined as the overarching system that encompasses the entire metadata model (see Gijsbers et al. 2025), as well as these four key components (figure 2):

- **MDIRAS Git repositories** store the valley model repositories, which hold metadata information on model output parameters and location information. There are additional repositories for the registry of models into FIRM. These repositories store assets such as model software binaries, adaptor code, and other FIRM configuration data.
- **The FIRM Onboarding Manager (FOM)** is a tool which can be run to update the configuration of FIRM (Gijsbers et.al. 2025). The tool takes information within the various Git repositories to generate the configuration for FIRM. FOM can also be used to test the configuration of models and their compatibility within FIRM.
- **FIRM application** is a specific instance of the Delft-FEWS Platform. This is the primary tool used to run scenarios and visualise results. There are four instances of FIRM, three of which are hosted on a distributed server infrastructure which are referred to FIRM-OC, to allow for collaboration and storage. The Dev environment is reserved for system and software development, whereas Test and Prod are both used by hydrological modellers. The Prod environment intended use is for runs that will inform key organisational decisions, while the Test environment is used for testing different model configurations (Gijsbers et.al., 2025).
- **FRAME** is a web-based data viewer that provides some additional model output information, allowing users to easily see key metrics such as water balances. FRAME accesses this information via the Delft-FEWS API (see Gijsbers et al. 2025),

The overall FIRM workflow – from onboarding a new model to producing results in the FIRM application – is a relatively complex process, with many system checks and review points in place to enable seamless, successful integration. The workflow can be broken-down into 12 key steps, which are described in figure 1.

Figure 1: A summary of the general FIRM workflow and responsible party.

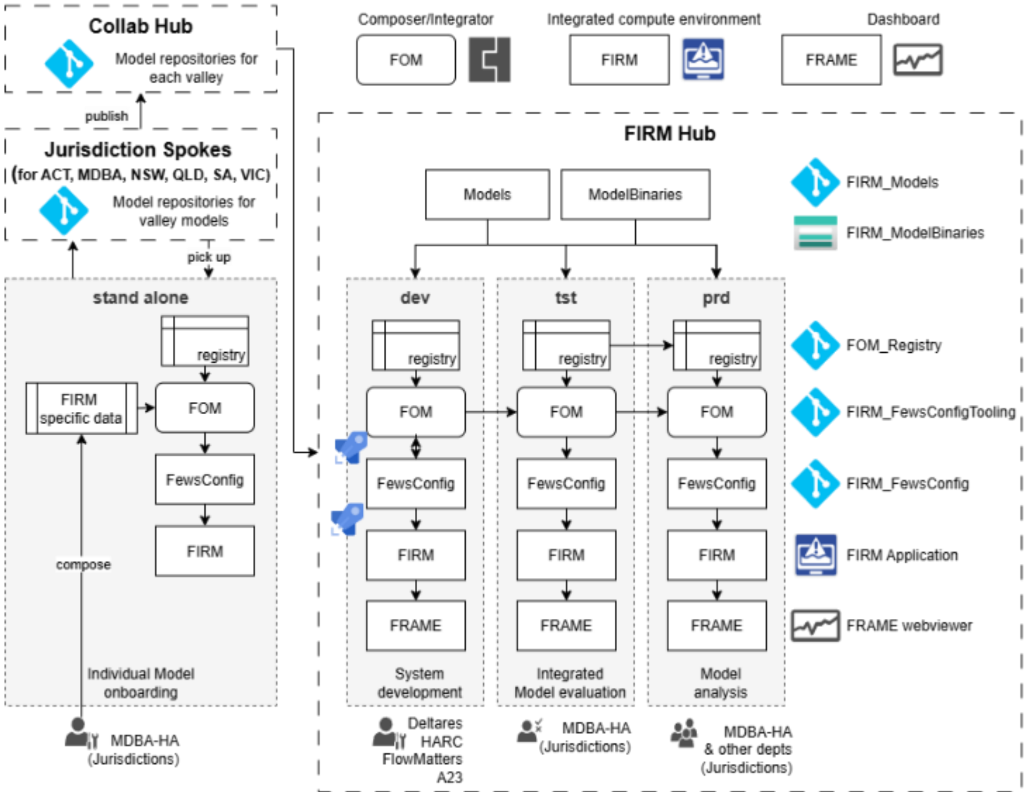

Figure 2: FIRM architecture

2.3. Shifting-Left

As shown in Figure 2, any of the three FIRM environments (dev, tst, prd) can be configured locally in what is called the FIRM "Stand Alone" (SA) environment. This is an instance of FIRM that is not connected to the server which allows for local model runs on modeller virtual workstations. It's intended use is for jurisdictions to test whether they have appropriately configured model integration files before onboarding new models into the FIRM configuration. This is achieved using the FOM command line application, available within the FIRM FewsConfigTooling repository.

In this way, Jurisdictions can build confidence in their models' performance and compatibility within the FIRM metadata model in a controlled, offline setting, before deploying the model to the shared, "official" environment. This is generally referred to as a Shifting-Left approach, wherein testing of model integration occurs at the beginning of the workflow and before models are committed into the Collaboration Hub. The alternative approach would be to shift this process further to the right, when models are pulled from the Collaboration Hub into the FIRM. Integrating the FOM on the Spoke-side of the workflow reduces the need for additional PRs between MDIRAS repositories and ensures that any issues with the model configuration or integration files sit with the jurisdictional modeller, maintaining their ownership of the model and the model's configuration.

2.4. DevOps for hydrologists

The MDIRAS DevOps environment was developed and designed to allow effective management of work, capture individual valley models' onboarding status and whole-of-basin model integration status, as well as allowing automation of both modelling and documentation as a part of an easier workflow. One of the more utilised tools of Azure DevOps is the Pipeline functionality and its ability to automate tasks that would otherwise be time consuming, such as the development and policy settings of new model scenario branches. The automation of small, but critical tasks ensure consistency between each model scenario and reduces the risk of human error in a collaborative environment.

When a PR is made between a CollabHub and FIRM valley repository, a Pipeline is automatically triggered that executes an instance of the FOM. This makes it possible to track the status of new model commits within the DevOps environment and specifically review and confirm that new commits can be successfully integrated into FIRM before a PR is accepted and merged. While every model is ideally tested outside of the Framework and outside of this end-stage Pipeline in the SA environment, the PR-triggered instance of FOM works as an integration safeguard, whilst also recording and automating the final testing and logging of valley models before they are pushed into the FIRM configuration. As a result, better provenance and tracking is established for each model, allowing for ways of working that ensure reviews and checks by multiple modellers.

Another key component of DevOps that supports the development of FIRM is the DevOps Wiki. The Basin system is complex, and it's modelling more so. As a result, the DevOps Wiki – a resource located within any of the DevOp's projects - allows users to collaboratively create, edit, and link pages of information. The FIRM Wiki has been used to effectively capture and store knowledge of both FIRM and the Basin from a variety of sources. As a benefit of the DevOps system, tools have been developed that can update wiki pages with recent model or software configuration changes, most notably the Wiki's "Basin Reference" page, which is dynamically generated based on the current FIRM model configuration.

2.5. Boards and more Boards

A major component of the successful development of FIRM and the initial integration of models into the platform was the use of DevOps boards to coordinate workflows and manage tasks across teams, both within the MDBA and between external partners A23, HARC and Deltares. The boards were particularly valuable in facilitating continuous feedback loops between software development and software testing, allowing issues to be quickly identified, documented, and resolved. By providing full visibility of tasks and their status, the Kanban boards ensured developers and testers could collaborate effectively, reduce bottlenecks, and maintain a high level of quality throughout the development cycle. Furthermore, in an internationally collaborative workplace where increasingly, teams are distributed across different countries and time zones, this approach facilitated quick, clear communication, improved transparency, and ensured that priorities were aligned across all stakeholders, ultimately enabling faster resolution of issues and more efficient delivery of new features.

The key purpose of the FIRM DevOps board was to record and track 'Bugs' and generate 'Feature Requests' using a ticketing system. 'Bug' tickets were used to document issues or defects during the onboarding of models into FIRM. Other uses of bug tickets included capturing modelling issues post-onboarding within the FIRM application itself. These tickets could be linked to specific PR instances or Pipelines, where the issue was identified. They could also be assigned to a specific user with an account in the DevOps environment, who would take ownership of resolving the issue. 'Feature Request' tickets were a core element of the software development phase and captured suggestions for enhancements or new functionality as 'testers' of FIRM began trialling the platform.

The DevOps Board itself was divided into 7 workflow stages, which moved from left to right. The workflow stages provided an overview of the status of the Bug or Feature Request ticket, such as "New Item", "To Do", "In Progress", "In Review", or "Done". This enabled the team to track progress, prioritise tasks, and maintain transparency throughout the development cycle.

2.6. Continuous integration of hydrological models

Leveraging Git repositories, PR's and a system of review policies using DevOps, the integration of new or updated hydrological models can be done in steps, where one model can be updated or modified without affecting the functionality of any of the of other models in the scenario workflow. The result is a network application that will not be impacted by "broken" models or models lacking appropriate integration files when onboarded.

The whole of the MDB is simulated with more than 20 individual valley models (depending on the scenario) from five jurisdictions. Therefore, there are many complexities in managing and linking those models together, such as different software which is used for building the models, different parametrisation or varied ways that inputs are handled. FIRM handles valley models as unique and independent black boxes, which are then linked to one another via various integration files (Gijsbers et.al., 2025). Models can be updated and re-integrated into repositories and the FIRM configuration without affecting the current configuration of the whole system. This brings a dynamic nature to whole-of-basin modelling, which can be done in small steps with a focus on separate scenarios, and without the need to undertake major updates.

When the FIRM team is satisfied that new or updated models will not negatively impact the FIRM configuration after reviewing the FOM report produced by the automated pipeline (step 7 in Figure 3), the model (or updated version of the model) is included in the registry for the tst FIRM environment to re-build the application, making those models available in the GUI (Figure 2).

3. WORKING AS A TEAM AND LEARNING TO USE AN INTEGRATED MODEL

The first use case for FIRM is to deliver modelling outputs to support the MDBA's commitments for the Basin Plan Review (BPR). This has been a monumental undertaking and collaborative effort. Statistics for a thirty-day July/August period saw 1,237 commits by forty unique authors, which involved 243 pull requests and 151 generated work items. To date, there are 26 independent valley models and approximately 80 unique model scenarios onboarded successfully. Over 600 unique sites and locations have been registered across the basin, with the option for over 90 different outputs or measurand types to choose from. Six climate change scenarios have also successfully been incorporated into the framework using a scaling method. To date, basin-wide model outputs for four core modelling scenarios, which will be used to evaluate BPR, have successfully been generated.

With the ambitious delivery timeline for BPR, there was often overlap between providing model outputs and results to user requests while still developing core functionality. While on one hand, this encourages early testing of platform functionality, it also required balancing the benefits of early feedback with the risks of working with partially completed features. This demanded strong communication, clear expectations, and adaptive workflows to ensure that early outputs remained reliable, and that development stayed aligned with project objectives.

The use of the Azure DevOps environment has many advantages; however hydrological modelling is distinct from software development, and there were instances throughout the project's lifespan where this created difficulties. Limited in-house expertise on leveraging the Azure DevOps environment and its functionality (such as Git version control) resulted in slower adoption of best practices for version control, collaboration, and deployment. This gap underscored the importance of targeted training and tailored workflows to bridge the divide between expertise in modelling and the technical requirements of a collaborative cloud-based development environment.

The development of FIRM has been a highly collaborative effort involving many contributors, and through this collective work, significant improvements in modelling software across the Basin have been achieved. The IRMU project has also marked a major shift in the way the Hydrological Analysis Branch at the MDBA approaches modelling. In contrast to the previous model of operation, where a single modeller might hold sole knowledge and expertise over a particular model or framework, the scale and complexity of the Basin have necessitated a more integrated, collaborative approach. This transition has streamlined the integration of state-based river-system models into a unified framework, achieving the objectives of the IRMU project. By moving to a system with specialised roles, stronger communication channels, and a flexible, scalable platform that supports multiple users and agencies, the project has created the foundation for collaborative, Basin-wide scenario analysis and informed decision-making.

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