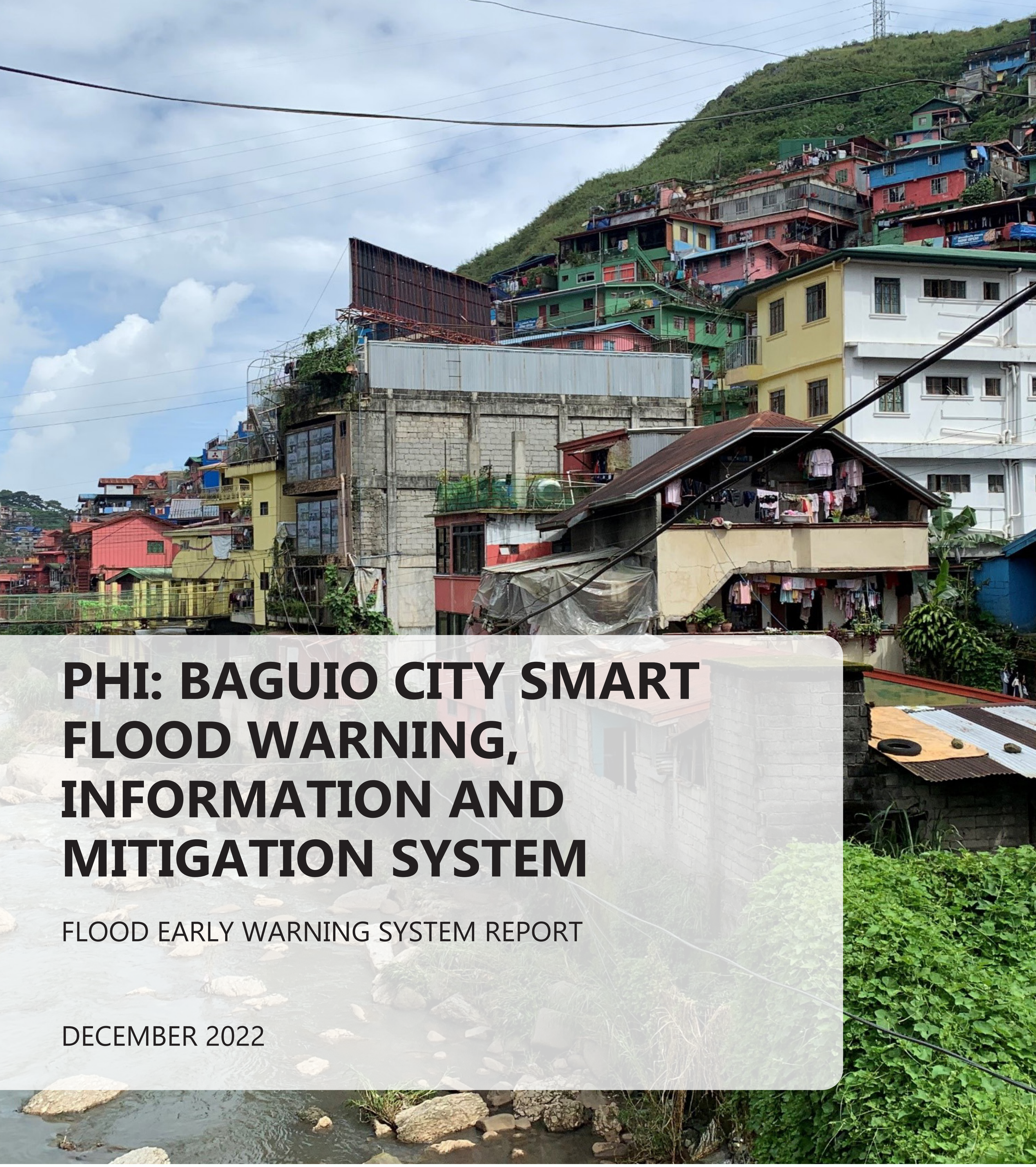

PHI: BAGUIO CITY SMART FLOOD WARNING, INFORMATION AND MITIGATION SYSTEM

FLOOD EARLY WARNING SYSTEM REPORT

DECEMBER 2022

ASEAN AUSTRALIA SMART CITIES TRUST FUND
Asian Development Bank

Australian Government
Department of Foreign Affairs and Trade

ADB

Source: Adobe Stock

Project no.	1100040737-005
Recipient	Asian Development Bank
Document type	Report - Final
Version	1
Date	12/22/2022
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ABBREVIATIONS

1D	One dimensional
AASCTF	Australia ASEAN Smart Cities Trust Fund
ADB	Asian Development Bank
API	Application programming
ASEAN	Association of Southeast Asian Nations
BCDEO	District Engineering Office
CBAO	City Buildings & Architecture
CCA	Climate change adaption
CDRRMC	City Disaster Risk Reduction and Management Council
CDRRMO	City Disaster Risk Reduction and Management Office
CDRA	Climate and Disaster Risk Assessment
CEO	City Engineers Office
CPDO	City Planning & Development
CRDRRMC	Cordillera Regional Disaster Risk Reduction and Management Council
CSO	Chief Security Officer
CSWDO	City Social Welfare & Development Office
DA	Data Assimilation
DEM	Digital Elevation Model
DFAT	Department of Foreign Affairs and Trade (Government of Australia)
DHI	Danish Hydraulic Institute
DOST-ASTI	Department of Science of Technology – Advanced Science and Technology Institute
DOST-CAR	Department of Science and Technology in Cordillera
DRRM	Disaster Risk Reduction and Management
FEWS	Flood Early Warning System

GIS	Geographic Information System
HD	Hydrodynamic
HSO	Health Services Office
IDF	Intensity Duration Frequency
LGU	Baguio City Local Government Unit
MITD	Management Information Technology Division
MO	Mike Operations
MoA	Memorandum of Agreement
NAM	Rainfall Runoff
NbS	Nature-based Solutions
NDRRMC	National Disaster Risk Reduction and Management Council
OCD	Office of Civil Defense
OPCEN	Baguio City Emergency Operations Centre
OTJ	On-the job
O&M	Operations and maintenance
PAGASA	The Philippine Atmospheric, Geophysical and Astronomical Services Administration
PWDAO	Persons with disability Affairs Office
RR	Hydrological Rainfall-Runoff
SCCC	Smart City Command Center
SOPs	Standard Operating Procedures
SMA	Service Maintenance Agreement
TOF	Time of Forecast Interface
WL	Water Level
WRF	Weather Research Forecast

EXECUTIVE SUMMARY

In April 2019, the Asian Development Bank (ADB) approved the establishment of the ASEAN Australia Smart Cities Trust Fund (AASCTF or the Fund) under the Urban Financing Partnership Facility, with financing provided by the Government of Australia, through its Department of Foreign Affairs and Trade (DFAT). Through this mechanism, the ADB is supporting Baguio City in implementing the Smart Flood Early Warning, Information and Mitigation System project, which will include three outputs: (i) smart flood early warning information system (FEWS) established and operational; (ii) real-time data capture system established in four river basins in Baguio City; (iii) flood mitigation action plan prepared.

The design of an inclusive people-centric FEWS aims at reducing the climate change-enhanced risk of flooding by providing appropriate and applicable early warning to Baguio's residents. The FEWS is developed with Baguio Local Government Unit (LGU) and other key stakeholders to improve community disaster preparedness, raise awareness, and ensure ownership. This report presents the overall design approach for the FEWS and outlines the main components of the technical and institutional setup, including efforts to further solidify and enhance long-term sustainability through capacity buildings and partnerships.

At the core of its design, the FEWS is an IT system, composed of a back-end and front-end development. The FEWS IT system has been designed and built using MIKE OPERATIONS, an online modelling framework designed for water forecasting and operational control, developed by DHI. The FEWS system has successfully been migrated to the LGU servers at Baguio City Hall and configured to run automated jobs to acquire the currently available real-time data and information from external data sources, perform data checking for timeseries analysis and visualization, and run forecast models to predict time series of flows and water levels in the rivers of Baguio. The front-end development of the system includes a dashboard that triggers warning messages on the basis of pre-defined thresholds. The data outputs from the system are translated into flood warnings which can, following a system testing and validation phase, be disseminated to various stakeholder groups through different channels. As part of the real-time data acquisition, a total of 5 new gauging stations (4 water-level stations and 1 tandem station) have been installed on the main rivers in Baguio.

To enable effective operation and maintenance of the FEWS for Baguio, a FEWS Operation and Maintenance (O&M) Team has been formed. The ownership of the FEWS is anchored at the Local Government Unit (LGU) and thus, the O&M core team consists of LGU staff with support from a peer team of representatives from academia and selected relevant agencies (i.e. PAGASA, DOST-CAR, BCDEO). The team members have completed a 'Targeted Capacity Building and Training Program', a year-long program consisting of online instructor-led and self-paced training modules and on-the-job training. To further enhance long-term sustainability of the FEWS, the LGU should continuously ensure that the O&M team members are available to perform the required tasks. It is crucial that O&M team is institutionalized and well-trained, and that team members have the mandate to prioritize the required tasks. Standard Operating Procedures have been prepared for the FEWS which contribute to enhancing sustainability by outlining specific activities and tasks to be undertaken by the FEWS O&M team and serving as a guide for the team throughout the different operation and maintenance phases (i.e. pre-monsoon, monsoon, post-monsoon).

The FEWS has been fully installed at the LGU servers but it was not possible to complete online testing and operational acceptance during the 2022 monsoon. The finalized system with the calibrated models and WRF inputs was not running during the monsoon of 2022, and therefore a full-scale test of the system during real-time operation has not yet been completed. Furthermore, given the starting point of the O&M team, it has not been possible to bring the O&M team to the necessary professional level to enable them to be fully responsible for the operation and maintenance of the FEWS system once the pilot project is completed in 2022. More training and technical support is required, as the team needs to gain experience in collaborating on operating and maintaining the FEWS and refining internal communication lines and work procedures as well as establishing confidence in working as a team before they can be expected to successfully operate the system independently. Thus, to validate and test the FEWS the LGU will continue to require technical assistance in preparing for a full-scale monsoon testing, running troubleshooting and feedback loops during the monsoon, and fine-tuning the system during a post-monsoon period. The need for testing is not limited to one single monsoon season, as any FEWS requires proper validation (several monsoons) before it's publicly launched. Launching a FEWS without proper testing and troubleshooting time can have serious consequences on the credibility of the LGU and ultimately on the confidence in the system itself.

1 INTRODUCTION

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1.1 PROGRAMME (AASCTF)

In April 2019, the Asian Development Bank (ADB) approved the establishment of the ASEAN Australia Smart Cities Trust Fund (AASCTF or the Fund) under the Urban Financing Partnership Facility, with financing provided by the Government of Australia, through its Department of Foreign Affairs and Trade (DFAT). The Fund's envisioned impact aligns with ADB's Strategy 2030, as well as ASEAN's Sustainable Urbanization Strategy which aims to promote high quality of life, competitive economies, and sustainable environments. The expected outcome of the Fund will be that through the adaptation and adoption of digital solutions, across three core functional areas (planning systems, service delivery and financial management), systems and governance in participating ASEAN cities are improved, in particular by:

- Strengthening city planning processes by enhancing the collection, storage, analysis, and utilization of data on geospatial platforms.
- Promoting the use of integrated and smart network management systems to strengthen operational systems and to improve quality and efficiency of service delivery.
- Introducing integrated financial management information systems to improve institutional credit worthiness and fiscal standing.

The Fund acts as a mechanism for facilitating and channeling resources and financing for eligible projects, as well as activities agreed between DFAT and ADB for project preparation, implementation, and capacity development.

1.2 BACKGROUND AND PROJECT RATIONALE

The occurrence of flooding and landslides, both regular phenomena in Baguio City, threaten Baguio's sustained and long-term economic development. Baguio City is considered the "summer capital of the Philippines", attracting 1.8 million tourists in 2018, with an annual growth rate of ca. 16%. In 2009, Baguio was significantly impacted by Typhoons Ondoy and Pepeng, resulting in more than 3,000 people being affected by flooding, and almost 2,500 people being affected by landslides. Japanese researchers from National Research Institute for Earth Science and Disaster Prevention have concluded that the underlying causes behind the 2009 flooding were related to a limited drainage capacity due to obstructions caused by the accumulation of waste, and also by the presence of built-up structures (urban sprawl) [1]. In addition, the presence of illegal settlers in flood prone areas worsens Baguio's exposure and vulnerability towards flood disasters. By being exposed and having a high vulnerability to climate hazards, combined with the expansion of impervious paved areas within the city and its surroundings, Baguio is experiencing increasing runoff volumes and flood damages. All these impacts are expected to be compounded by climate change, which will very likely cause an increase in the frequency and intensity of extreme rainfall events and further exacerbate flooding events and rain-induced landslides.

The ADB, through the AASCTF, is supporting Baguio City in implementing the Smart Flood Early Warning, Information and Mitigation System project. The project will assist the city with both the planning for flood mitigation and the delivery of the services of flood early warning and responses, using smart technologies. The project outcome is improved flood early warning system, responses, and mitigation measures of Baguio City. The project also has three outputs: (i) smart flood early warning information system (FEWS) established and operational; (ii) real-time data capture system established in four river basins in Baguio City; (iii) flood mitigation action plan prepared.

In parallel to the Smart Flood Early Warning, Information and Mitigation System project, City Twinning activities in partnership with the City of Perth are supported by the AASCTF. The overall aim of the twinning collaboration between Baguio and Perth is to use some of the learnings from Perth, a city that have a network of smart sensors monitoring different parameters (i.e. environmental parameters, pedestrians, cars, etc.), by installing smart sensors and utilizing data to improve urban planning and service delivery.

The FEWS is developed with Baguio Local Government Unit (LGU) and other key stakeholders to improve community disaster preparedness, raise awareness, and ensure ownership. The FEWS is also set to become an integral element within the overall vision of Baguio City to become a truly resilient, dynamic, and smart city.

1.3 PROJECT APPROACH AND OUTPUTS

The overall approach followed in producing this project's three outputs (outlined in section 1.2) is to breakdown the project into working tasks, with each task containing key activities, and where interdependencies between tasks/activities are accounted for by defining milestones while keeping close contact with the project's working group. The project tasks and associated key activities and deliverables are shown in Table 1-1.

Table 1-1 Activities and deliverables for Baguio City Smart Flood Warning, Information and Mitigation System.

Task	KEY ACTIVITIES AND DELIVERABLES
Task 1 – Baseline Assessment	• Setup working group, conduct scope consultations, revise workplan • Data and Information Collection • Establish baseline on climate change data and information • Plan the on-the-job (OTJ) training component • **D1: Baseline Assessment Report** (delivered January 2021)
Task 2 – Hydraulic model setup, including hazard and risk mapping	• Collect additional data, if needed, including river surveys • Confirm boundary conditions and target design levels for the hydraulic model and for inclusion of potential nature-based solutions (NbS) • Develop hydrologic model for all 4 rivers • Develop hydraulic model for the primary drainage system, incl. calibration • Hazard and Risk Assessment • OTJ training • **D2: Hydraulic Model and Hazard and Risk Mapping Assessment Report** (delivered August 2021)
Task 3 – Design of a Flood Early Warning System (FEWS) (this report)	• Planning the framework of the FEWS • Procuring and installing measurement devices in selected locations for pilot river (Balili) • Development of the pilot river real-time data acquisition system • Design the data storage and management system • Overall forecast system framework (database) • Setting up of FEWS at the LGU, and start of the real-time online simulations, before the monsoon • OTJ training • **D3.1: FEWS offline setup** (delivered September 2021) • **D3.2: Flood Early Warning System report** (This report)
Task 4 – Data dissemination and outreach plan	• Design dissemination and outreach activities, including: Website/Dashboard, web applications – SMS alerts, mobile apps, e-mail chimps, etc. • Define dissemination roles and responsibilities among key stakeholders • Development and dissemination of FEWS O&M plan. Maintenance will be undertaken during the monsoon period (documented in D3.2) • OTJ training (documented in D3.2) • **D4: Data Dissemination and Outreach Plan** (delivered December 2022)
Task 5 – Flood Mitigation Action Plan	• Review and gap analysis of urban drainage data, including recommendations for actions. • Finalization of review of drainage data, documents, and guidelines for drainage infrastructure, initiated in task 2. • Development of multifunctional NbS typology toolbox, including key enabling criteria for implementation of typologies. • Demonstrate applicability and benefits of NbS typologies for 3 pilot-sites, including preliminary site-specific hydraulic calculations. • OTJ training • **D5: Flood Mitigation Action Plan** (delivered December 2021)
Task 6 – Replication of real-time data capture, and Monitoring & Evaluation	• Procuring and installing measurement devices in the remaining three rivers • Evaluation of the FEWS (post-monsoon period) • Finalize data assimilation and forecast modelling • System Performance Assessment • OTJ training
Task 7 – Project completion	• Wrapping up everything • **D6: Final Report**

Task 8 – Targeted Capacity Building Programme to Enhance Delivery of a Sustainable FEWS	• Implementation of 3-module Targeted Capacity Building Programme led by DHI and supported by Ramboll
	• E-Learning Platform with course material and training videos
	  • **D2.5A: Scoping & Training Course Design Report** (delivered April 2022)
	  • **D2.5B: Module 1 and Module 2 Course Evaluation Reports** (delivered August 2022)
	  • **D2.5C: Module 3 Course Evaluation Report** (delivered December 2022)

Source: Ramboll

In an effort to further solidify and enhance program effectiveness and sustainability (beyond the completion of the pilot project in December 2022), an additional component, comprising a year-long 'Targeted Capacity Building Program to Enhance Delivery of a Sustainable FEWS' was added, effective from end-December 2021 and implemented throughout 2022. The main objective of the targeted capacity building program is to garner increased confidence in the ability of the project intervention to foster long-term sustainability of the established FEWS by securing the required local capacity for operating and utilizing the FEWS as an active risk mitigation instrument beyond the timeframe of the pilot project.

1.4 FLOOD RISK IN BAGUIO

Baguio City is drained by four major rivers, Balili flowing northwards, Bued flowing southwards, Galiano to the west and Ambalanga to the east. Out of the four rivers, Balili, Bued and Galiano drain most of the city, while Ambalanga drains very sparsely populated areas near the eastern boundary of the city.

Balili river's primary stream originates and traverses for approximately 2 km within the city. The rivers of Ambalanga, Bued and Galiano originates near the city boundary, where they are joined by their tributaries within Baguio City. Ambalanga river originates just beyond the city boundary. Throughout Baguio City, surface runoff drains to natural streams and transports water to the primary streams that drains to the lower lying areas outside the city boundary. Confluence points where river tributaries meet the major streams are of importance for river overflow, as large quantities of water may arrive at these points.

Local depressions in the terrain are likely to be flood prone due to limited drainage capacity. Flooding generally occurs as flash floods caused by intense rain events or by prolonged rain causing the rivers to overflow. Urban areas are particularly vulnerable to flash floods as built-up and paved areas provide limited infiltration, increasing runoff. The hydrological regime of Baguio is shown in Figure 1-1.

The above underlines that a FEWS could yield significant benefits in Baguio and serve as a tool to provide timely flood warnings to Baguio's residents. The design of an inclusive people-centric FEWS aims at reducing the climate change-enhanced risk of flooding by providing appropriate and applicable early warning to those who might be left behind — that is, the most vulnerable and marginalized.

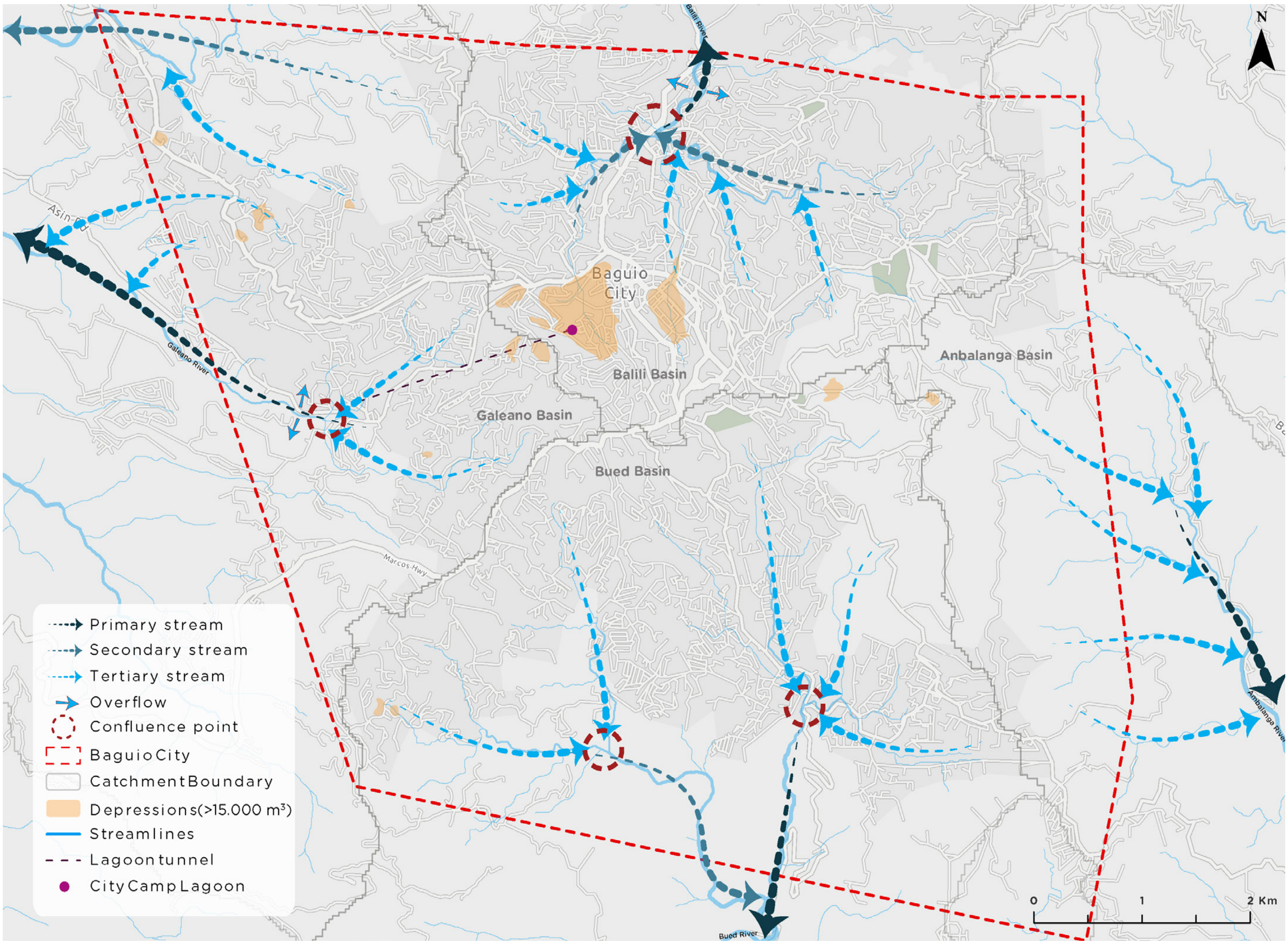


Figure 1-1 The hydrological regime of Baguio City.
Source: Ramboll

1.5 A SMART BAGUIO CITY

The Baguio Smart City Command Center (SCCC) was established in 2021 with the aim of 'collecting, gathering and analyzing data; making decisions that protect life and property, maintaining continuity of the organization within the scope of applicable laws; and dissemination of decisions to all concerned agencies and individuals'. The SCCC is a key tool for Baguio in its ambition to become a truly resilient city, catering to the needs of all its citizens.

It contains a state-of-the art platform which consolidates all system applications and digital data for a smarter city. The major components include the integrated command center for disaster monitoring and response, artificial intelligence-enabled video surveillance system, environmental monitoring, smart traffic signalization, smart mobility as well as serving as a digital hub for all data and information that are accessible to the policymakers, local planners, and the public.

The SCCC is to be the anchor for all smart city solutions/initiatives in Baguio, which is a key argument for eventually migrating the FEWS to this center and thereby gathering smart capabilities in one location. The ambition for SCCC is to be a center that allows for data-driven decisions in near real-time which is truly in line with the scope of the FEWS.

1.6 REPORT OBJECTIVES AND STRUCTURE

This Flood Early Warning System report is report number eight out of eleven reports to be produced in this project. The primary intended audience comprises technical personnel from the LGU and ADB. Other intended audiences comprise policymakers, city planning officials and the broad general audience with knowledge and/or interest in smart flood early warning systems, real-time monitoring systems, city resilience, data storage and management.

This report aims at answering the following questions:

- What are the main benefits and the overall design approach of the FEWS?
- What are the supporting IT infrastructure requirements?
- What are the supporting institutional requirements?
- How is the FEWS to be operated and maintained to ensure long-term sustainability?
- What efforts are required in testing and validating the FEWS?

This report summarizes the key findings related to the questions above, while all technical details can be found in the Technical Notes in the Appendices. This setup ensures that all technical aspects of the system are documented in detail, while the technical level of the main report remains at a level suitable for policy makers and city planners.

- Section 1 in this report introduces the AASCTF programme, describes this project's rationale and overall approach as well as the main questions to be answered by this report.
- Section 2 presents the overall design approach for the FEWS and introduces the main components of the technical and institutional setup.
- Section 3 summarizes the IT infrastructure setup.
- Section 4 describes the overall modelling framework together with the calibration process and approach for data assimilation.
- Section 5 describes the FEWS design in MIKE Operations.
- Section 6 outlines the institutional framework supporting the FEWS.
- Section 7 summarizes the main outcomes of the capacity building and training.
- Section 8 presents the operation and maintenance framework for the FEWS.
- Section 9 summarizes the main conclusions.
- Section 10 presents the recommendations for the FEWS moving forward.

2 FEWS OVERALL DESIGN FRAMEWORK

Source: Adobe Stock

The end-goal of the Flood Early Warning System (FEWS) development for Baguio City is to improve the city's resilience to flooding and facilitate early preparedness. The value added by the FEWS is an increase in reaction lead time by way of forecasting future water levels in the main rivers, with linked risk of flooding in Baguio. At the core of its design, the FEWS is an IT system, composed of a back-end and front-end development. The FEWS essentially hosts calibrated hydrological and hydraulic models based upon historical data and measurements which take in real-time and forecasted inputs to predict time series of flows and water levels in a river system.

The data outputs from the system are translated into flood warnings which can be disseminated to various stakeholder groups through different channels.

The FEWS framework including its main components are show in Figure 2-1 below.

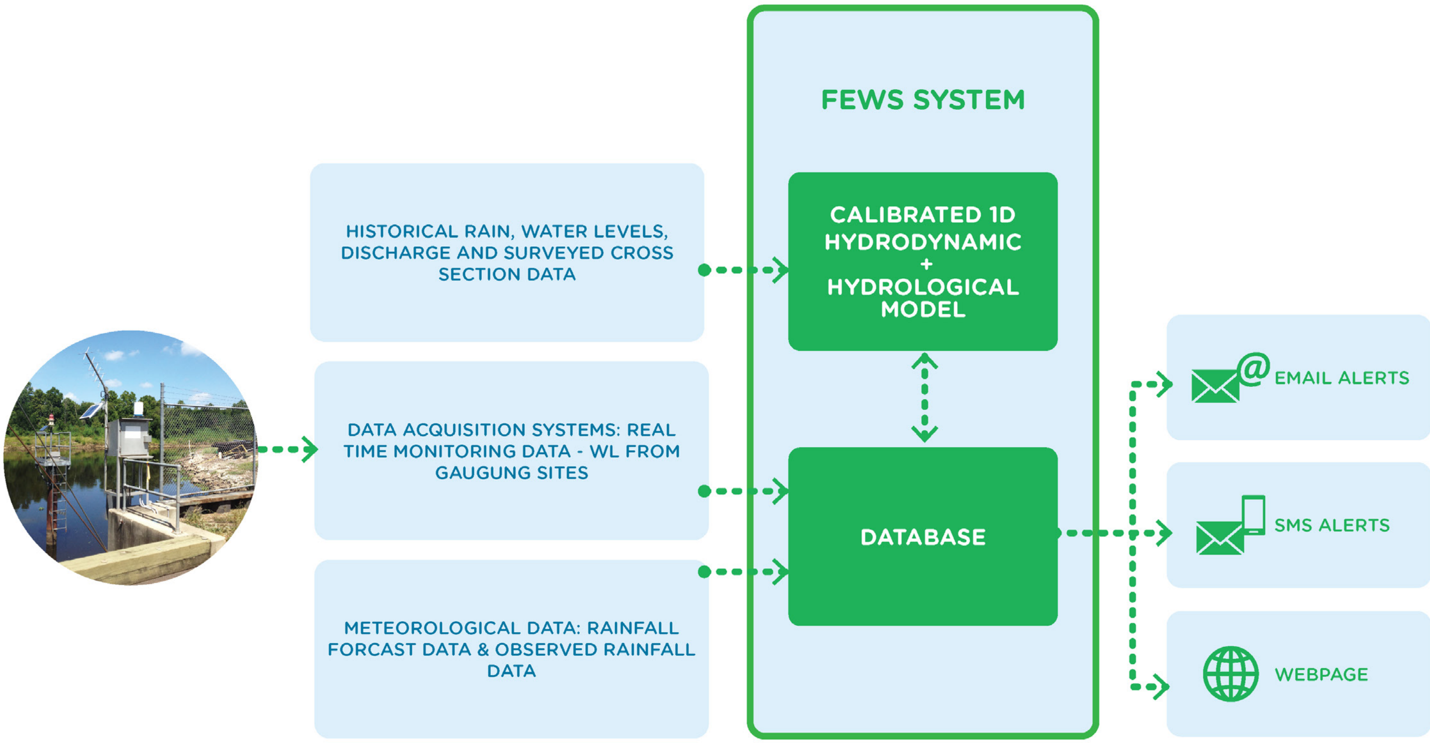


Figure 2-1 The framework for FEWS.
Source: Ramboll

The hydraulic and hydrological models are calibrated in parallel with respect to recorded water level data and discharge data to allow for the replication of expected routing in the rivers and the hydrological response of the catchments to rainfall events. The rainfall forecast is the main input for the calibrated coupled Hydrodynamic-Rainfall Runoff (HD-RR) model along with real-time rain data and water level from telemetric stations for data assimilation. The models are setup using the MIKE HYDRO River software, a state-of-the art modelling tool by the Danish Hydraulic Institute (DHI).

The FEWS IT system is designed and built using the MIKE OPERATIONS product by DHI. The real-time flood forecasting domain within MIKE OPERATIONS is configured for LGU specific forecasting and warning requirements.

The FEWS is configured to run automated jobs to acquire all the required real-time data and information from external data sources, perform data checking for timeseries analysis and visualization, run forecast models and issue automated alerts. All the processes such as downloading the real-time data, forecast rain data, updating model inputs, triggering model runs and updating model results are automated.

The main components of the FEWS are:

Calibrated backend models in MIKE HYDRO (see Section 4):

- 1-Dimensional (1D) Hydrodynamic module (HD): The 1D hydrodynamic model takes the runoff inputs from the RR model and routes it through the defined river network.
- Hydrological Rainfall-Runoff module (RR): The hydrological model simulates the catchment reactions and essentially routes rainwater to the rivers and drains.
- Data assimilation module (DA): The data assimilation uses the available real-time measurements of water level on the river to calculate error patterns and then applies the same to the water level forecasts. Real time data assimilation is an essential prerequisite for an accurate flow forecasting system.

MIKE OPERATIONS setup (see Section 5):

- MIKE Workbench: Interface to input data into the database and apply data analysis, process tools interactively, configure automated workflows, write scripts for automation and configure custom-made data reports.
- MIKE OPERATIONS Desktop: Interface to interact with PostgreSQL database for configuring dashboards and establishing publishing rules.
- MIKE OPERATIONS WEB: Interface that allows for visualization of the dashboards that are setup through MIKE OPERATIONS Desktop.

As evident from the above, the FEWS is heavily data dependent; hence, reliability and quality are key to ensuring the success of the project. A highly technical, smart, and resilient IT framework to house the systems, see Section 3, as well as an active participation from relevant agencies is important to ensure the sustainability of the project. The operation and maintenance activities for the FEWS are outlined in Standard Operating Procedures (SOPs), which contribute to achieving efficiency, quality output and uniformity of system performance, while reducing miscommunication and failure to comply with standards.

2.1 MIKE BY DHI

The state-of-the-art modelling software product MIKE by DHI is utilized for the Baguio FEWS. Other FEWS software products available on the market, Hecras and Delft FEWS, were assessed, and a decision was made to use MIKE by DHI. It is the best tool available on the market, requiring the least efforts of tailoring and programming compared to the other options, where more significant and complex programming is needed. The MIKE software products ensure a smooth link between a robust, well-proven software, and the path of building capacities which is facilitated within the entire MIKE software suite by established training modules provided by DHI. No capacities within any FEWS tools existed within the LGU prior to the kick-off of the project, and thus this did not directly influence the choice of tool. By having a proprietary software anchored at the LGU, a stronger ownership is ensured and it "forces" the LGU to build capacities, which is deemed a more sustainable way of starting a strong FEWS process. The choice of MIKE software enabled a close project-partnership with DHI and the Targeted Capacity Building and Training Program facilitated in partnership with DHI throughout 2022 has successfully increased LGU's knowledge and capacities within FEWS and MIKE software. The support the LGU can get from DHI in the short- and long-term (through a Service and Maintenance Agreement primarily, but it could be purchased at any time) is invaluable. This level of support is not possible to obtain with any of the other software options available.

A perpetual license (DHI Internet License) for MIKE by DHI was purchased for the project in 2021. This entails that there is no expiry date for the license for the purchased version of the system. A one-year Service and Maintenance Agreement (SMA) was included in the purchase. A decision was made to not continue the SMA following its expiration, due to high costs, and instead keep on using the software as it is, given that no significant changes are expected in at least a period of 5 years after the software was purchased. By that time, a decision can be made to re-buy all the modules/licenses. The LGU will assess the need to tie the cost for maintenance of the system to the annual city budget.

3 IT INFRASTRUCTURE

Source: Adobe Stock

This section describes the IT infrastructure framework housing the FEWS. All technical details can be found in the Technical Note on IT Infrastructure, see Appendix A. This section of the report describes the key IT configurations, assumptions, and risks.

3.1 FEWS IT INFRASTRUCTURE FRAMEWORK

The FEWS IT system has been designed and built using MIKE OPERATIONS, an online modelling framework designed for water forecasting and operational control, developed by DHI . MIKE OPERATIONS is a framework consisting of a large set of components and an organized and structured set of rules and infrastructure that makes it possible to tailor and customize to the specific needs of the LGU.

The FEWS system is configured to run automated jobs to acquire the currently available real-time data and information from external data sources, perform data checking for timeseries analysis and visualization, and run forecast models. The front-end development of the system includes a dashboard that triggers warning messages on the basis of pre-defined thresholds, for river water-levels and for Barangays (to be developed further at the scale of Barangays). The system is likewise designed to issue automated alerts in the form of email and SMS messages.

3.2 SERVER CONFIGURATION

The Deployment of the Mike Operations platform at the LGU premises (the MITD office) comprises three key servers:

1. MIKE Operations Web Server Hardware Information
2. MIKE Operations Platform Server Hardware Information
3. Backup Server

All servers have been inspected during the site visits of the consultant's team during June and September 2022. The FEWS IT system has initially been installed at the servers located in the Management and Information Technology Division (MITD), at the Baguio City Hall. In time, it is expected that the system will be moved to the Smart City Command Center (SCCC). The current specifications for these servers are outlined in the following tables.

Table 3-1 MIKE Operations Web Server Hardware Information

CPU	2.70 Ghz and 8 cores	Ethernet	1x10 Gb
RAM	128 GB DDR4 RAM	Raid Support	High availability
HDD	1.8 TB of disk storage with SAS SSD (15k) in RAID-1 configuration	Options	VMware
OS	Windows Server 2019 64 bit	Power	Hot swap redundant power supply 750 watts

Source: Ramboll

Table 3-2 MIKE Operations Platform Server Hardware Information

CPU	2.70 Ghz and 8 cores	Ethernet	1x10 Gb
RAM	128 GB DDR4 RAM	Raid Support	High availability
HDD	1.8 TB of disk storage with SAS SSD (15k) in RAID-5 configuration+ 8X2.5 TB of SSD, all hot swappable	Options	VMware
OS	Windows Server 2019 64 bit	Power	Hot swap redundant power supply 750 watts

Source: Ramboll

Table 3-3 MIKE Operations Backup Server Hardware Information

CPU	2.70 Ghz and 8 cores	Ethernet	1x10 Gb
RAM	32 GB	Raid Support	High availability
HDD	2 tb (scalable if needed)	Options	VMware
OS	Windows Server 2019 Standard	Power	Hot swap redundant power supply 750 watts

Source: Ramboll

3.3 ASSUMPTIONS AND RISKS

The Technical Note on IT Infrastructure, Appendix A, outlines all identified assumptions and risks, as well as proposed mitigation measures and the current status at the LGU premises. The most relevant risks which should be addressed in the short-term are highlighted here:

- Lack of redundancy, as the FEWS IT infrastructure, the MIKE Operations Web server and the MIKE Operations Platform server are single instance nodes, meaning that hardware failure in anyone of the nodes will make the FEWS system unavailable for the end users. This can specifically occur during periodic maintenance activity such as applying windows updates, security patches etc. A way to mitigate this risk is for the LGU to implement a “cold standby”, i.e., an identical instance of the current server which would allow to implement any hotfix while still keeping the FEWS running without interruption.

- IT Security. This relates to the exposure of the FEWS, as it engages with external interfaces to acquire forecast and real-time water level data, increasing therefore the likelihood for malicious attacks to exploit the security vulnerabilities of the FEWS IT system. To solve this, vulnerability and penetration tests must be carried out to address critical issues (if any) prior to the production release of the FEWS IT system. This should be done before the full-scale testing of the system takes place.

4 HYDROLOGICAL AND HYDRAULIC MODELLING FRAMEWORK

Source: Adobe Stock

This section describes the key aspects in the development of the entire hydrological and hydraulic modelling framework for the backend models of the FEWS. The setup of the backend models is a one-time process in the overall setup of the FEWS system. All technical details can be found in the Technical Note on Hydrological and Hydraulic Modelling Framework, see Appendix B. This section of this report deals primarily with the key assumptions, constraints, and findings.

Hydraulic and hydrological modelling are key tools for achieving the overall goal of developing a Smart Flood Early Warning Information and Mitigation System in Baguio. The models are the backbone of all key technical components in this project and play an integral role in the FEWS setup. The models also provided the foundation for the flood risk assessments (Task 2) on which were directly used in the development of the flood mitigation action plan (Task 5).

4.1 OVERALL MODELLING FRAMEWORK

The Balili River Basin is prioritized as the pilot basin for the hydrological- and detailed hydrodynamic model setups and calibration. Though river cross-section surveys have been carried out in all four rivers of Baguio, Balili river was prioritized with 63 surveys completed and used in the river model. The Balili basin has been selected as the pilot river basin due to the following reasons:

- The Balili River drains a larger and more populated area in the city.
- The assessment of the flood risk (Task 2) indicated that areas in the Balili basin have the highest flood risk.
- The assessment of the available gauging stations showed that the Bailli river has the most available historically observed data which is important to assess the level of calibration that can be achieved.

While the Balili river is identified as an integral part of the urban drainage system in Baguio, for the three other rivers it has been observed that although there are lower order streams originating within the city boundary, the main channel of the rivers start well beyond it. This is also the reason why limited cross section surveys have been carried out for Bued, Galiano and Ambalanga within the city. Based on an assessment of the pilot model, the performance of the FEWS will be evaluated before carrying out similar extensive river surveys for the three additional river basins Galiano, Bued, and Ambalanga in the coming years.

The models are setup using the MIKE HYDRO River software, a state-of-the art modelling tool by DHI. The modules used for the setup of the FEWS are Hydrodynamic (HD), Rainfall-Runoff (RR - NAM) and Data Assimilation (DA). The model setup has been done in two stages, as indicated in Table 4-1:

- Backend model setup: This is the stage wherein all available data is analyzed, appropriate historical hydro-meteorological data is identified for the study area, cross-section data for the rivers are processed, catchment analysis is carried out followed by sub-catchments delineation, calibration period is identified based on period of data availability and finally the calibration of the hydrological and hydrodynamic models is carried out. The backend model setup is explained further in section 2 of Appendix B.

- Initialization of backend model: In this stage, all additional processes and modules required to run the calibrated model using forecast data is included in the model setup. This includes the setup of the data assimilation module and the inclusion of forecast rainfall timeseries. During this stage, the setup for hotstart is also included to ensure that the model always starts with the appropriate initial conditions from previous simulations while running in forecast mode. The initialization of backend models is further explained in section 3 of Appendix B.

Table 4-1 The two stages of the model setup

Backend Model Setup	Initialization of Backend Model
• Assessment of historical hydro-meteorological data • Cleanup and preprocessing of historical data • Catchment analysis • NAM (RR) model setup and calibration • Cross-section analysis • Cleanup and preprocessing of cross-section data • Coupled HD-RR model setup • Coupled model calibration based on historical data	• Updating model setup to include appropriate initialization conditions (also known as hotstart) • Updating model setup to include data for forecast period • Inclusion of data assimilation

Source: Ramboll

4.1.1 MODELS FOR PILOT RIVER BASIN

Two models have been prepared for the pilot river basin, Balili:

- Model 1: Observed rain calibration
- Model 2: Forecasted rain calibration

Model 2 has been setup as an alternate model for Balili river using only forecasted rain data as input. The system is heavily data dependent; hence, reliability and quality are key to ensuring an effective FEWS. Throughout the development of the system, it was noted that the operation of the real-time monitoring stations is not reliable, as the stations were observed to be intermittently offline without a pattern or source of failure identified. Thus, a model independent of real-time monitoring station input data was created to ensure that a calibrated system can run at all times, testing the other operation processes in the FEWS setup, until real-time operation of the monitoring stations is secured. It should be noted that good calibration results are not expected for Model 2 as only forecasted rainfall data is used as input for calibration. Results from Model 2 are not expected to be used for generation of flood warnings. Both models are being used in the current FEWS setup in parallel to ensure that there is always a model running based on the available data at any point in time but outputs from Model 2 are not meant to be used for the generation of flood warnings.

Figure 4-1 presents the modelling framework of the two models in greater detail for the pilot river, with the only difference between the two being the input rainfall data during the backend model setup stage.

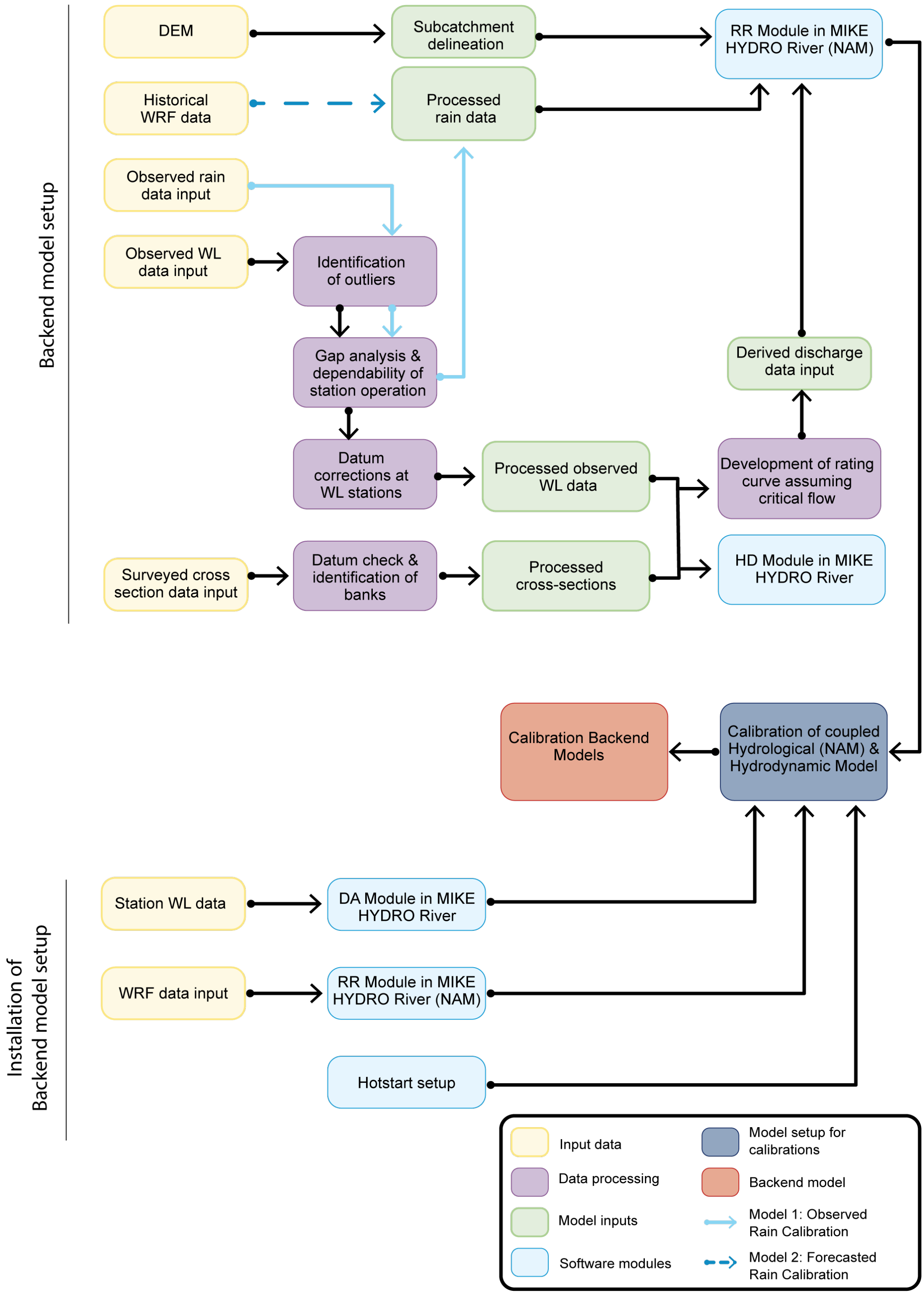


Figure 4-1 Modelling framework for the pilot river basin, Balili.
(DEM – Digital Elevation Model, WRF – Weather Research Forecast, WL – Water Level, HD – Hydrodynamic, DA – Data Assimilation, RR – Rainfall Runoff). Source: Ramboll

4.1.2 MODEL FOR SECONDARY RIVER BASINS

A single model 'Model 3: Bued, Ambalanga and Galiano' has been prepared for the three rivers, Bued, Galiano and Ambalanga. The model has been calibrated using observed rainfall data. Figure 4-2 presents the modelling framework of the Model 3.

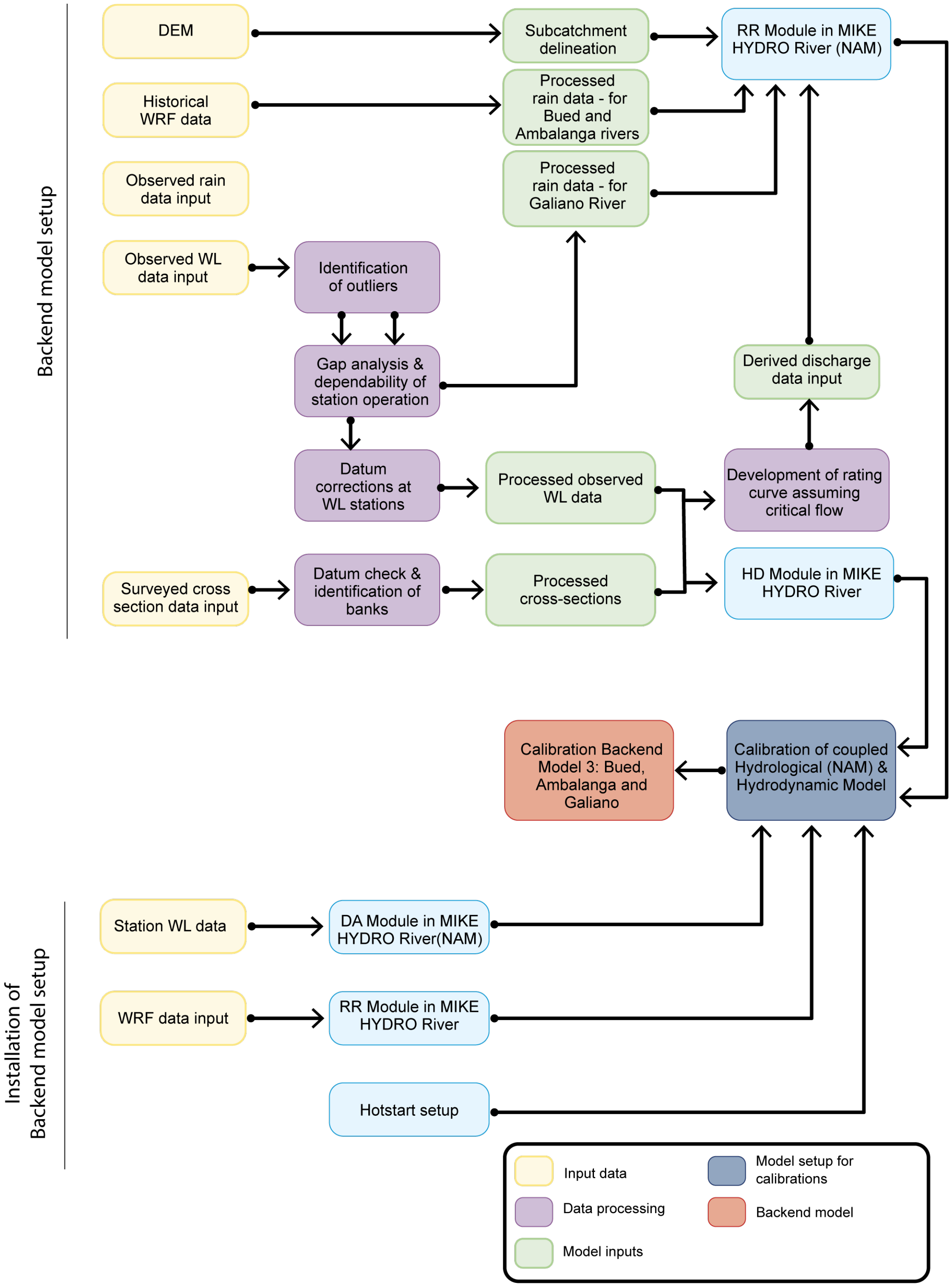


Figure 4-2 Modelling Framework for the secondary river basins, Bued, Galiano and Ambalanga.
(DEM – Digital Elevation Model, WRF – Weather Research Forecast, WL – Water Level, HD – Hydrodynamic, DA – Data Assimilation, RR (NAM) – Rainfall Runoff). Source: Ramboll

4.2 BACKEND MODELS

The backend hydrological and hydraulic models provide the foundation for the FEWS. The hydrological and hydraulic models are calibrated with respect to historically recorded data and are automated to utilize real-time data and forecasted meteorological data. Real-time data from monitoring stations is used as initial conditions in the models after which model simulations are triggered with forecasted rainfall as input data to predict water levels and potentially damaging floods. As outlined in Section 4.1, three backend models are prepared:

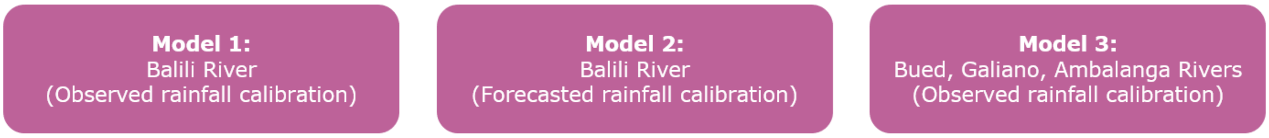


Figure 4-3 Backend models prepared for the Baguio FEWS.
Source: Ramboll

4.2.1 INPUT DATA

Key to the model set-up is data. The main inputs that will be used for the development of the backend models for the FEWS are:

1. Cross-section Data
2. Rain Data
3. Water Level Data

The models are setup using historical and real-time data from monitoring stations, surveyed river cross-sections, elevation data as well as forecasted rainfall data. While the real-time data is briefly described below, Appendix B includes all the details related to input data for the models.

Countrywide Weather Research and Forecasting (WRF) models are run at PAGASA for Philippines. For the FEWS, the rainfall forecast from PAGASA is key as this data input is essentially a primary driver for the flood forecast. Historical WRF rainfall forecast data is also utilized for model calibration. The outputs for the WRF models are produced every 3 hours and the different resolutions for the available gridded meteorological output is the following:

- Hourly data at a 3 km x 3 km grid and at 12 km x 12 km grid
- 3-hourly data at a 3 km x 3 km grid and at 12 km x 12 km grid
- 6-hourly data at a 3 km x 3 km grid and at 12 km x 12 km grid

The 3 km x 3 km hourly data is produced for 48-hour forecasts and the 12 km x 12 km hourly data is produced for 72-hour forecasts.

Real-time data from monitoring stations, rainfall and water level, is used in the real-time operation of the system to run the models. It is crucial for the real-time operation of the system that the stations are operating continuously. Unfortunately, the existing stations have not worked properly (i.e. they have been intermittently offline) for the duration of this project. Despite efforts to understand the precise nature of the problems, the accessibility and data-related problems with the existing gauging stations persist. An assessment of the stations completed by DOST-CAR in October 2022 (see Appendix B) concluded that the equipment at some stations will need to be replaced for the stations to become fully operational, however, the technical issues have not been fully understood.

In addition to the existing stations, five new stations, one tandem station (i.e. monitoring rainfall and water level) and four water level stations, that have been procured and installed as part of the project to be used for the FEWS setup. The new stations are owned by the LGU and ensure greater spatial real-time data coverage of the river basins in Baguio. The stations are linked to the PhilSensors website [2], where real-time data from the existing stations is being published, and API access is provided by DOST-ASTI. An overview of the real-time monitoring stations in Baguio City and surroundings is seen in Figure 4-4.

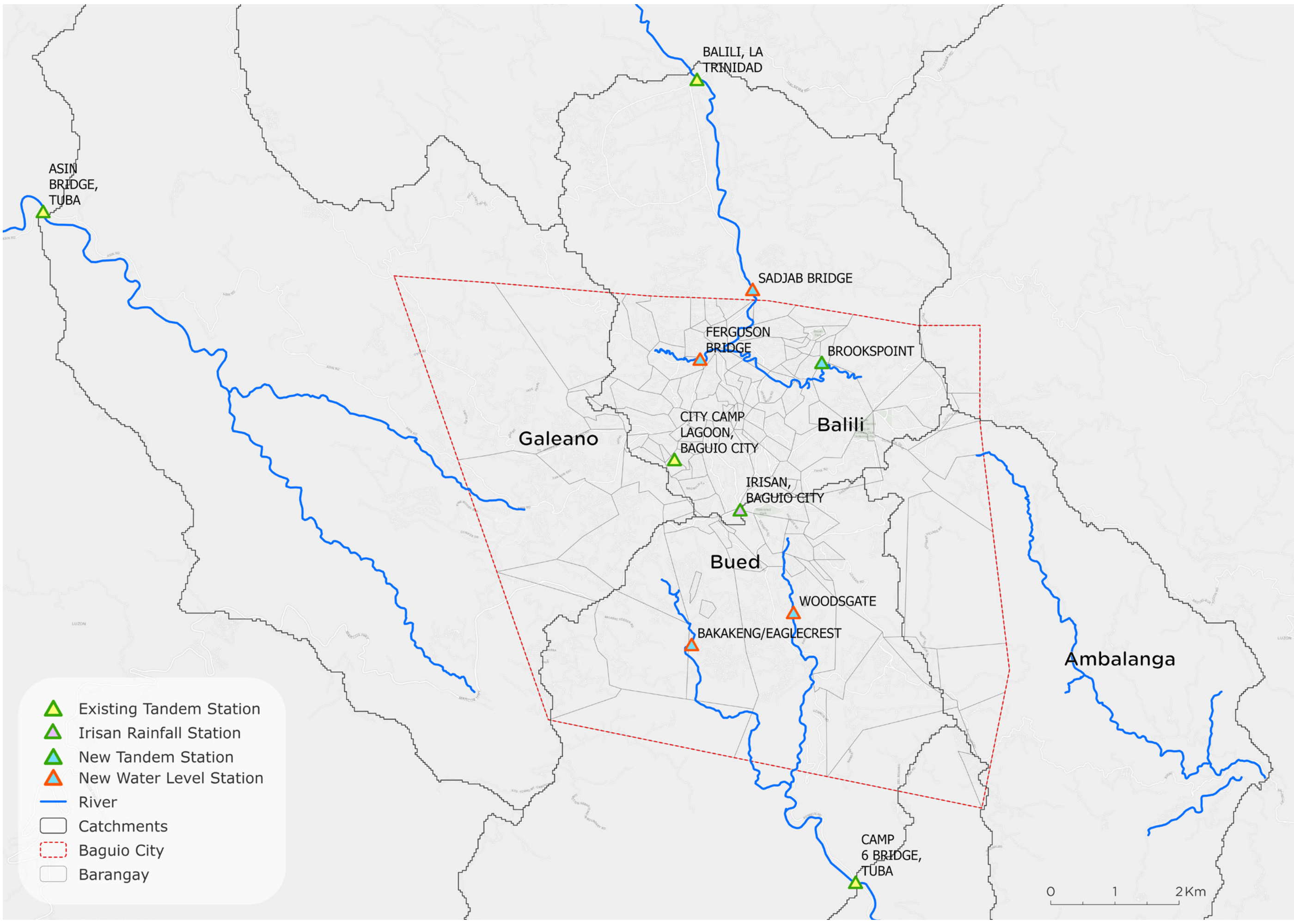


Figure 4-4 Overview of existing and new gauging stations within Baguio City and surroundings (excl. Mamat-ing Bridge station).
Source: Ramboll

4.2.2 MODEL DOMAINS

In MIKE HYDRO, the backend models are setup using the Hydrodynamic (HD) module and the Rainfall-Runoff (RR) module:

- The Rainfall-Runoff (RR) module is utilized to compute runoff generated from the catchments into river channels using rainfall-runoff relationships established for all the catchments of the basin.
- The Hydrodynamic (HD) module is utilized for dynamic, one-dimensional river modelling to model the river flows. Hydrodynamic models are setup for all the rivers with varying levels of detail, depending on the number of surveyed cross-sections available.

Finally, the backend models have been prepared as HD-RR coupled models, where the discharge input for the hydrodynamic models is the output of the hydrological models. The calibrated RR models have been coupled to the HD models by setting up appropriate catchment to river links. The model domain for Model 1 and Model 2 for Balili River and the model domain for Model 3 for Bued, Galiano and Ambalanga is seen in Figure 4-5.

4.2.3 CALIBRATION OF HYDROLOGICAL AND HYDRAULIC MODELS

Model calibration and validation based on water level and flow observations is a necessary step to determine any model's ability to reproduce reality. The models which are used to forecast flooding are simplified and conceptual in their nature and the parameters do not necessarily match a physical value. Parameter values must be calibrated by assessing the ability of the model to capture the timing and magnitude of historical events for which we have data.

4.2.3.1 MODEL 1: BALILI CALIBRATION USING OBSERVED RAINFALL

Through stand-alone RR model calibration, a 75% correlation has been achieved between the simulated discharge and the historical discharge at the Balili Bridge station in the stand-alone RR model. The calibration result has been achieved using historical data from monitoring station rainfall inputs for the 2017-2019 monsoon seasons, and the water-level data available for the same period. As additional attenuation in the HD model is expected along the rivers causing lowering of peak flow outputs of the RR model, the coupled RR-HD model has been calibrated by re-adjusting the NAM model parameters and the assigning appropriate roughness coefficients in the model. Through the coupled model calibration, an average correlation close to 80% in the monsoon period at Balili Bridge station has been achieved, as indicated in Table 4-2. The calibration result indicates that the model is able to capture the timing and magnitude of the observed runoff to a satisfactory degree.

Table 4-2 Correlation coefficient of coupled RR-HD model at Balili Bridge station

Simulation Period	Correlation – simulated vs. observed discharge at Balili Bridge station	Correlation – simulated vs. observed water level at Balili Bridge station
06/25/2017 – 12/15/2017	0.825	0.876
06/15/2018 – 12/15/2018	0.785	0.879
06/15/2019 – 08/10/2019	0.733	0.812

Source: Ramboll

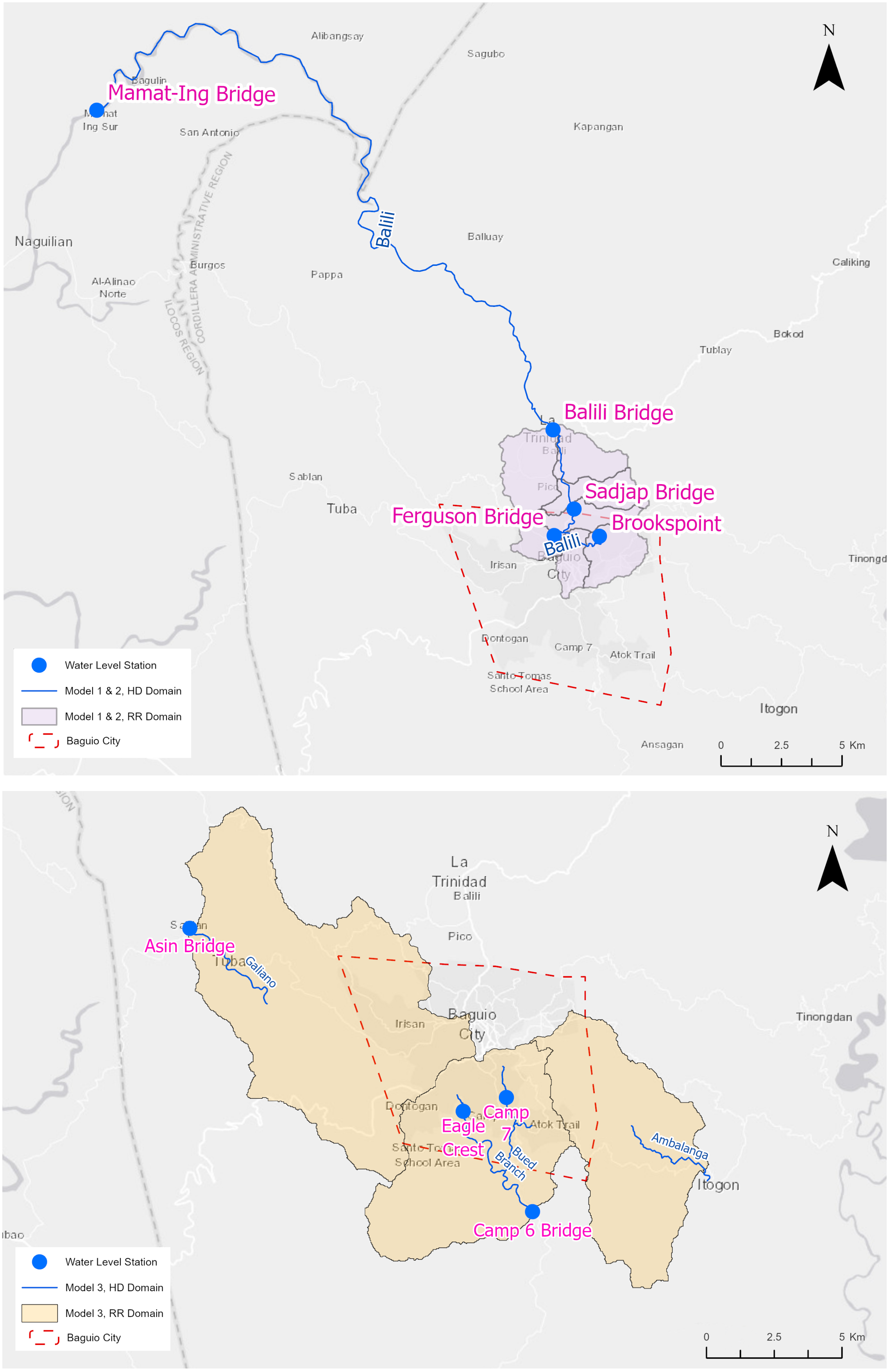


Figure 4-5 Model domains for Model 1 and 2 for Balili River Basin (top) and for Model 3 for Bued, Galiano, and Ambalanga Rivers (bottom).

Source: Ramboll

4.2.3.2 MODEL 2: BALILI CALIBRATION USING FORECASTED RAINFALL

Historically recorded rainfall forecasts are used for calibration of this model. The main concept in the calibration approach has been to focus on capturing some of the runoff peaks and not the overall correlation which is not expected to be good. Bias correction of the WRF data based on the real time station data is expected to improve the results, however, it is recommended to prioritize pursuing consistent operation of the monitoring stations to ensure continuous utilization of Model 1. The purpose of having this model in the FEWS setup, despite the poor calibration, is explained in section 4.1.1.

4.2.3.3 MODEL 3: BUED, AMBALANGA AND GALIANO CALIBRATION USING OBSERVED RAINFALL

Through the coupled model calibration, an average correlation close to 85 % in the monsoon period at Asin Bridge station has been achieved, as indicated in Table 4-3. The calibration result indicates that the model is able to capture the timing and magnitude of the observed runoff to a satisfactory degree.

Table 4-3 Correlation coefficient of coupled RR-HD model at Asin Bridge station.

Simulation Period	Correlation – simulated vs. observed discharge at Asin Bridge station	Correlation – simulated vs. observed water level at Asin Bridge station
06/25/2017 – 11/15/2017	0.873	0.847
06/15/2018 – 11/15/2018	0.79	0.88

Source: Ramboll

4.3 INITIALIZATION OF BACKEND MODELS

Initialization of backend models is a necessary step to be completed before starting the real-time operation of the calibrated models in forecast mode as part of the FEWS within the MIKE Operations software. The platform includes the automations required for running the system in real-time with continuously updated model inputs with respect to Time of Forecast (TOF).

For Model 1, the rainfall input data in the time period prior to TOF, also referred to as the hindcast period as shown in Figure 4-6, is the station rainfall data. The rainfall input data post the time of forecast will be the WRF data. For Model 2, the WRF data is the only input rainfall data before and after time of forecast. In Model 3, for the Galiano river, the rain data input is the same as for Model 1 and for Bued and Ambalanga rivers, it is the same as for Model 2.

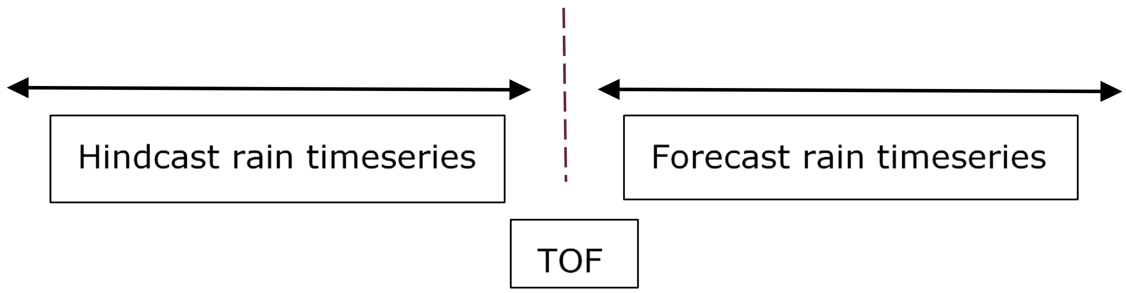


Figure 4-6 The rainfall timeseries preparation for Model 1 and Galiano river in Model 3.
TOF: time of forecast. Source: Ramboll

As a step to initialize the backend models and for the preparation of the full rainfall timeseries to include the data from post time of forecast, a linkage to the WRF rainfall timeseries has been included in the hydrological module.

Data Assimilation (DA) is included in the backend models during the model initialization. Data assimilation is applied to ensure that the initial water level in the model is set accurate in accordance with the observed water level. Ultimately, inclusion of data assimilation contributes to improving the forecasts by continuously adjusting the simulated water levels based on the observed water levels. The technical details related to the concept of data assimilation are further described in Appendix B.

5 FEWS DESIGN IN MIKE OPERATIONS

Source: Adobe Stock

This section describes the MIKE OPERATIONS Framework infrastructure framework housing the FEWS. All technical details can be found in the Technical Note on FEWS setup in MIKE OPERATIONS, see Appendix C.

5.1 MIKE OPERATIONS FRAMEWORK

As outlined in previous sections of the report, the FEWS setup has been developed using the MIKE OPERATIONS Software by DHI. MIKE OPERATIONS is a software product designed for model-based forecast services and for facilitating the building of manual or automated workflows for data acquisition, data validation, model execution and information publishing.

The FEWS has been setup using the three user interfaces of MIKE OPERATIONS which allows interaction with a PostgreSQL database storing all the data relevant to the FEWS:
- MIKE Workbench
- MIKE OPERATIONS Desktop
- MIKE OPERATIONS Web

The MIKE OPERATIONS Framework also interacts with a "Floodwatch" folder which has been setup on the local C-drive on the FEWS platform server. This folder contains various objects/files used by the FEWS which includes external scripts, initialized backend models, intermediate file formats created during data processing and the final processed data inputs for the models. The overall MIKE OPERATIONS Framework and 'Floodwatch' folder is detailed in Figure 5-1. The framework uses PostgreSQL which is an object-relational database system. It has a proven architecture that has earned it a strong reputation for reliability, data integrity, and correctness.

The FEWS has been setup, including the database and the MIKE operations framework, on the 'MIKE OPERATIONS Platform' server, as described in Section 3.

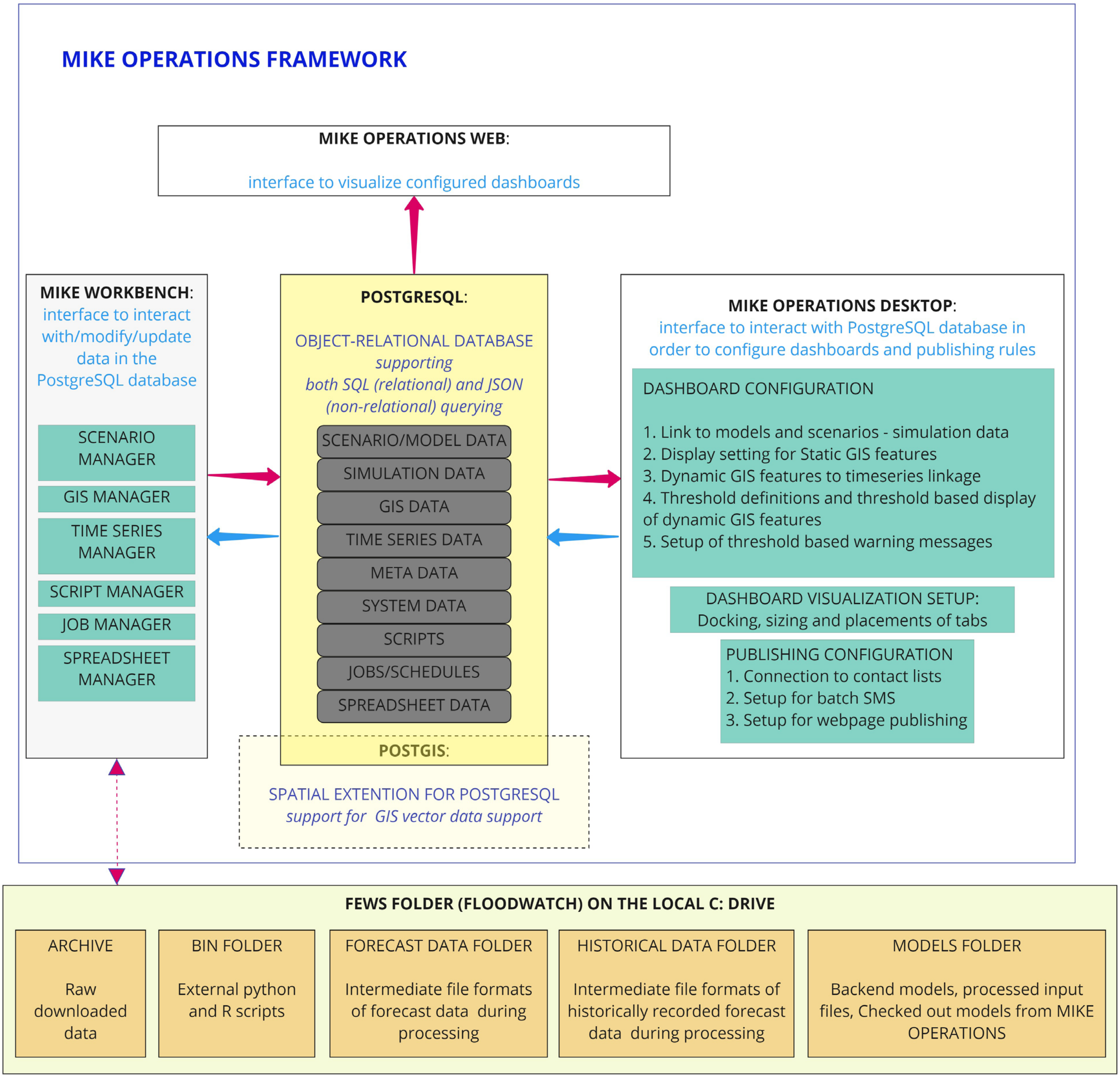


Figure 5-1 MIKE OPERATIONS Framework and 'Floodwatch' folder.
Source: Ramboll

5.1.1 BACK-END SET-UP: MIKE WORKBENCH

MIKE Workbench has multiple 'managers' for inputting the various types of data into the database. These managers also allow the editing and updating of the data in the database. Types of data stored and managed by the various managers in MIKE Workbench is summarized in Table 5-1.

The FEWS setup in MIKE Workbench includes several 'one-time' setup processes and data input into the database following which several real-time operation processes are executed. 'One-time' indicates that these steps do not get repeated during the real-time operation of the system and include mainly, the inclusion of all relevant data into the FEWS database as a first step to the FEWS setup process. The details of the 'one-time' processes are further described in Appendix C.

Table 5-1 Summary of data types stored in the database

MIKE Workbench Manager	Data type	Description
GIS Manager	GIS data	Also referred to as spatial data. The spatial data is a collection of feature classes and rasters. Examples of feature classes are City boundary, Barangays, Real-time stations etc.
Timeseries Manager	Time series data	Time series are sequences of measurements in time. Examples of time series are discharge, water level, rainfall etc.
Scenario Manager	Model data	All data associated with a model setup, i.e., the basic simulation properties, and the Hydro Objects.
Scenario Manager	Scenario data	All the data related to the definition of scenarios, i.e. definitions of linkages between a model set-up and the input and output data involved in model execution.
Scenario Manager	Simulation data	All the data related to an executed simulation (references to model and scenarios, input time series, output times series, other input and output data, initial conditions)
Scripts Manager	Scripts	All scripts written for the FEWS setup for executing processes such as downloading data from various sources, processing of downloaded data, setting up simulation data for models, processing of output data from simulations, generating logs etc.
Job Manager	Scheduling data	All rules which describe the sequence of execution of scripts written for the FEWS setup
Spreadsheet manager	Tabulated data	All tables used for the setup of the FEWS including Logs, configuration sheets, tables used to pass parameters to scripts etc.
Metadata Manager	Meta data	Variable descriptive data for different entities in the system and time-varying history information describing the life-line of these entities.
System Administration	System data	Configuration information on system installation components (e.g., computers), users, groups, studies and otherwise non-domain specific information.

Source: Ramboll

Real-time operation processes are executed by scheduling jobs (tasks) in the Job Manager where each job defines a set of ‘targets’ in a predetermined sequence which triggers different inbuilt functions or user defined scripts from the Script Manager to achieve specific goals.

The goals for achieving real time operation of the FEWS can broadly be listed as below:

- Model input preparation and model scenario running
- Real time log creation and system warning messages
- Database backup process

The steps of the ‘model input preparation’ in real-time is outlined in Figure 5-2, while the details of the other real-time processes are outlined in Appendix C. The full list of jobs and the specifications of these can be found in Appendix G.

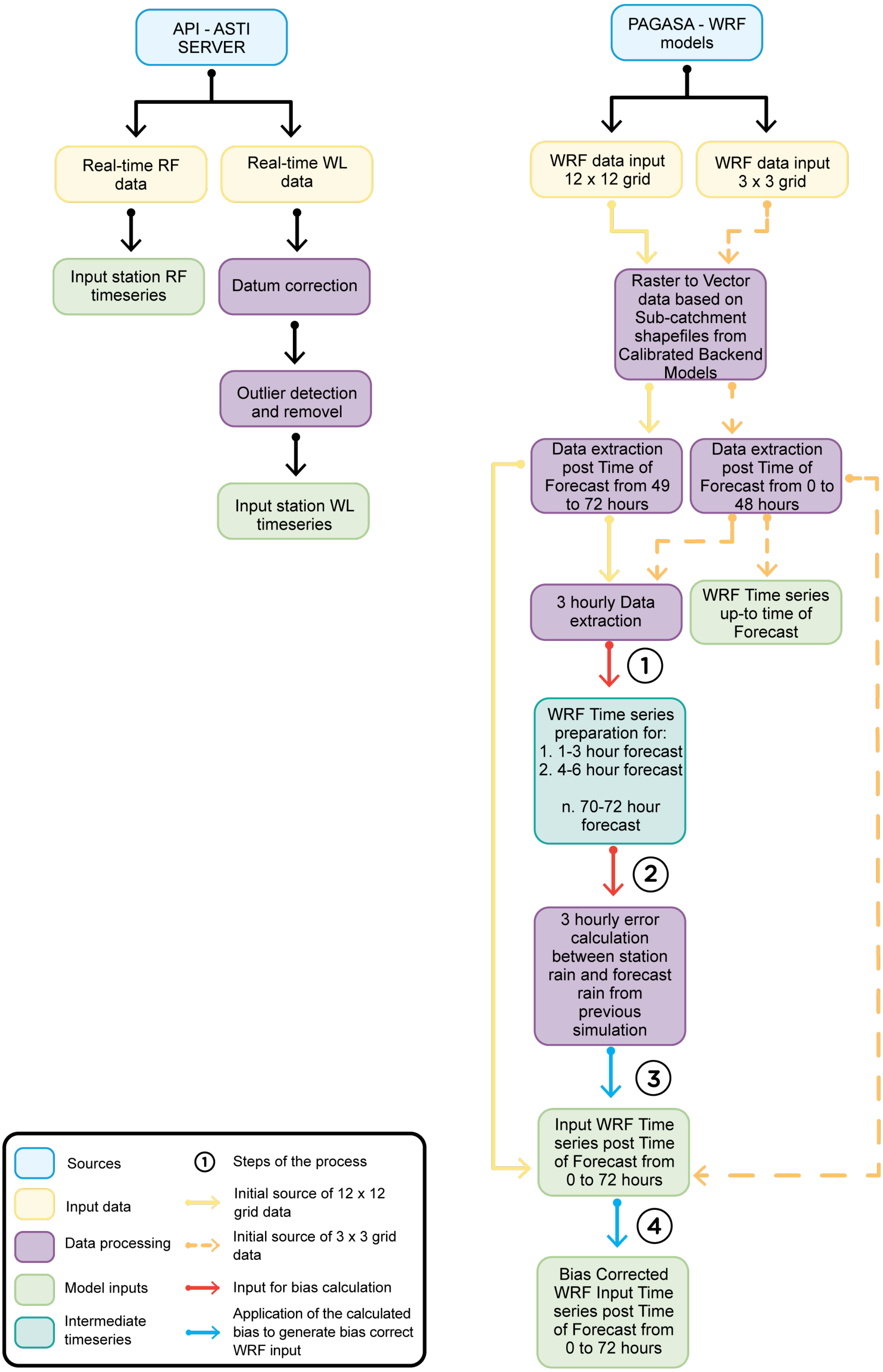


Figure 5-2 Model input preparation in real-time.
Source: Ramboll

5.1.2 FRONT-END SET-UP: MIKE OPERATIONS DESKTOP AND MIKE OPERATIONS WEB

The setup of the dashboard for the Baguio FEWS has been configured to indicate reaches along the pilot river, Balili river, which are at risk of overtopping based upon forecasted water levels from the latest model simulations. However, the areas prone to flooding due to overtopping of riverbanks is limited to a small percentage of the city. A large part of the city faces inundation during heavy rain events due to other issues such as insufficient or choked urban drainage. To accommodate this, Barangay level warnings are also considered during the dashboard setup to show Barangays at risk of flooding based upon the latest forecasted rainfall used in the models.

Configurations have been setup in MIKE OPERATIONS to access and connect data included in the PostgreSQL database such as GIS shapefiles, last updated timeseries, model objects, Scenarios' inputs-outputs from simulation runs etc.

The finalization/finetuning of the dashboard is dependent on the validation of standard operating procedures, warning messages, and the validation of the dissemination plan. The dashboard should be refined as part of the full-scale test of the FEWS.

Initially, the system is expected to run in test mode during which the internal team will operate, assess, and update the system. The warnings and access to the dashboard is therefore limited to the established FEWS O&M group.

5.1.2.1 BAGUIO FEWS DASHBOARD SETUP

A dashboard has been setup for the three models in the FEWS database. The current setup is indicated in Figure 5-3. Numbers (in red) are inserted on this figure representing the following:

1. Dropdown menu to access which Model's dashboard should be displayed. All three models are available for selection by the user.
2. Drop down menu to choose which simulation results to display on the dashboard for the selected model. By default, the last run simulation of the selected model is selected for display. Previous simulations may also be viewed if the user wishes.
3. Gallery to check map objects on or off. The selectable map objects for Models 1 and 2 currently includes, the ' At Risk Barangays' layer, the ' Water level Stations' Layer, 'Vulnerable Reaches (Right Bank)' layer and 'Vulnerable Reaches (Left Bank)' layer, which are all the layers associated with forecast inputs and outputs from the models.
   Note that currently, the vulnerable reaches are not indicated by the names of the specific regions and instead by unique IDs. Once the appropriate names are identified for the regions, the display name for these objects must be revised. For Model 3, only Water level stations has been included currently.

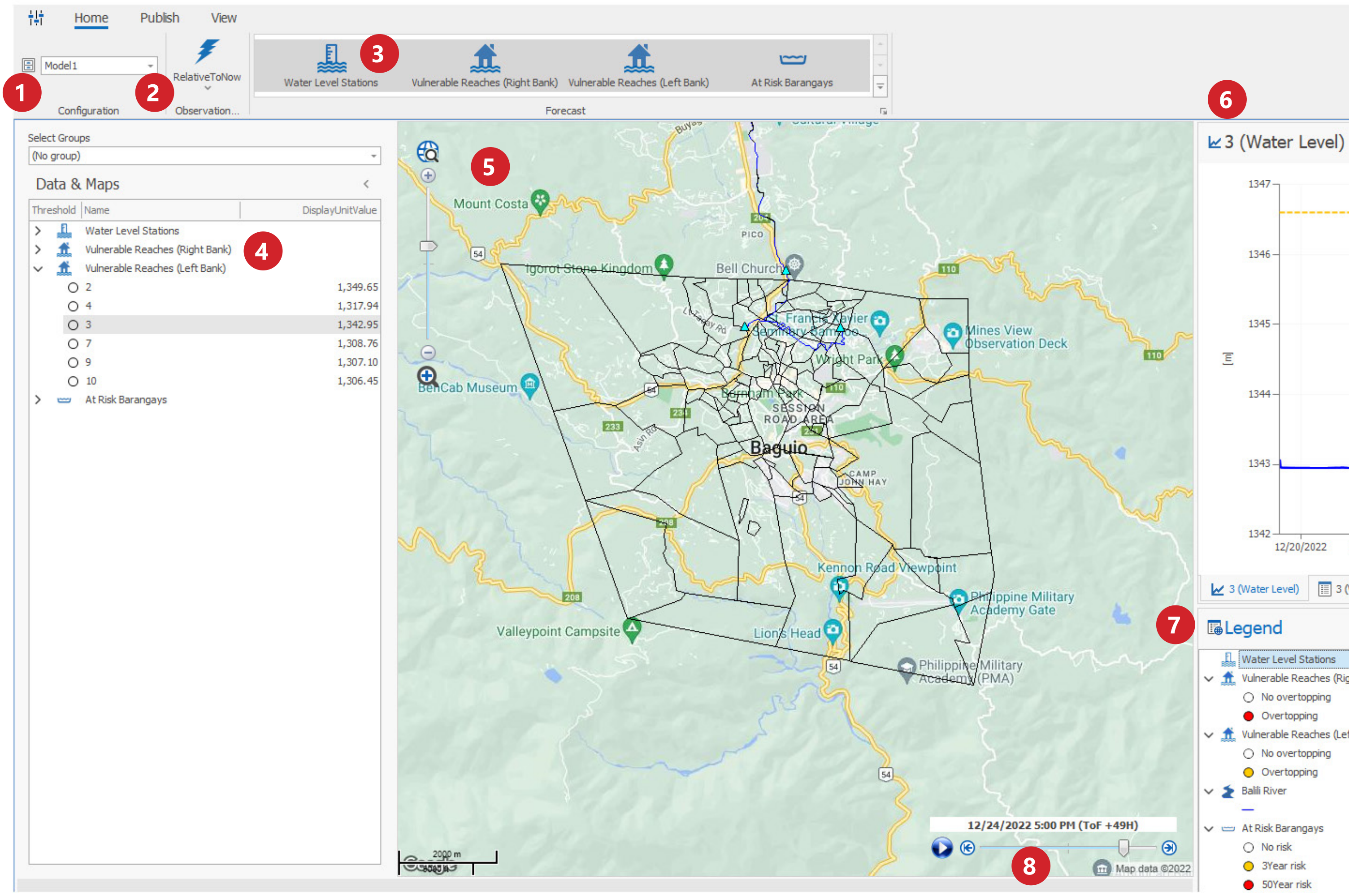
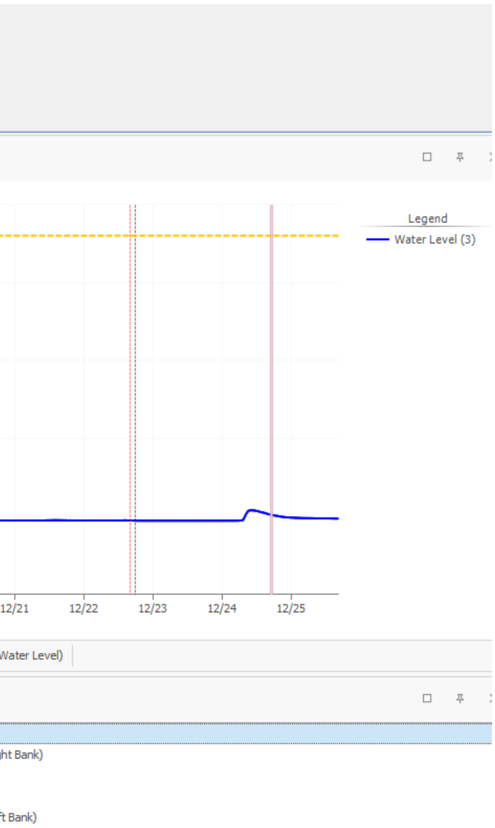


Figure 5-3 Baguio FEWS - Dashboard setup in MIKE OPERATIONS.
Source: Ramboll

Once the setup has been validated for the pilot river, the system functionalities can be expanded for the three secondary river basins.

4. Menu indicating visible items on the map, i.e. map object which are checked on in the Gallery. Note that the numbers against the objects in the menu are the values extracted from the timeseries linked to the model object for the current time.
5. Map display, displaying all the checked items in the gallery.
6. Timeseries associated with the map object selected
   - At Risk Barangays layer – Latest forecast rain input is associated with the objects in this layer. Thresholds are defined as rainfall intensities for a 3-hour event for a 3-year return period and 5-year return period.
   - Water Level Stations Layer – Simulation output timeseries for WL at the specific locations are associated with the objects in this layer. No thresholds are defined here.
   - Vulnerable Reaches (Right Bank) layer and Vulnerable Reaches (Left Bank) layer – Simulation output timeseries for WL at the specific locations are associated with the objects in this layer. Note that the defined thresholds for overtopping are visible in the timeseries plot as dashed horizontal lines.
7. Legend indicating the color coding of map objects based on defined thresholds for the features
8. Animation bar that allows to view results on the map at different times of the selected simulation.



Thus, the dashboard displays two types of warnings:

- **Riverbank overtopping**
  Color-coding is used in the dashboard to illustrate the riverbanks where overtopping is forecasted; No overtopping, no color. Overtopping is defined as the water level exceeding the identified critical water level threshold. The stretches along the river where right bank overtopping is forecasted will be indicated in 'red' and the stretches along the river where there is a risk of left bank overtopping will be indicated in 'yellow'. A detailed description of the methodology is found in Appendix C.

- **Warnings for at-risk Barangays**
  Color-coding is used in the dashboard to illustrate Barangays at-risk of flooding; No color indicates low risk of flooding, 'yellow' indicates flood risk corresponding to a 3-year rainfall, and 'orange' indicates flood risk corresponding to a 50-year rainfall. Based on the flood maps produced during the Flood Hazard and Risk Assessment (Task 2), Barangays at-risk of flooding have been identified for different intensities of rain corresponding to 3- and 50-year return periods. In the current configuration, Barangays at-risk are being identified and displayed appropriately on the dashboard by correlating rainfall forecasts for 72 hours with these rain intensities in real time. The Barangays at risk with respect to the rain intensity for a 3-year return period are being indicated

in yellow and the Barangays at risk with respect to the rain intensity for a 50-year return period are being indicated in red. It should be noted, that this is a preliminary setup. Ideally, the WRF data, bias-corrected against station rainfall data, will be compared to rain intensities for various return periods (as per existing IDF curves developed by PAGASA) and based on this comparison, flood warnings will be triggered by the FEWS for the various at-risk barangays. More details are available in Appendix C.

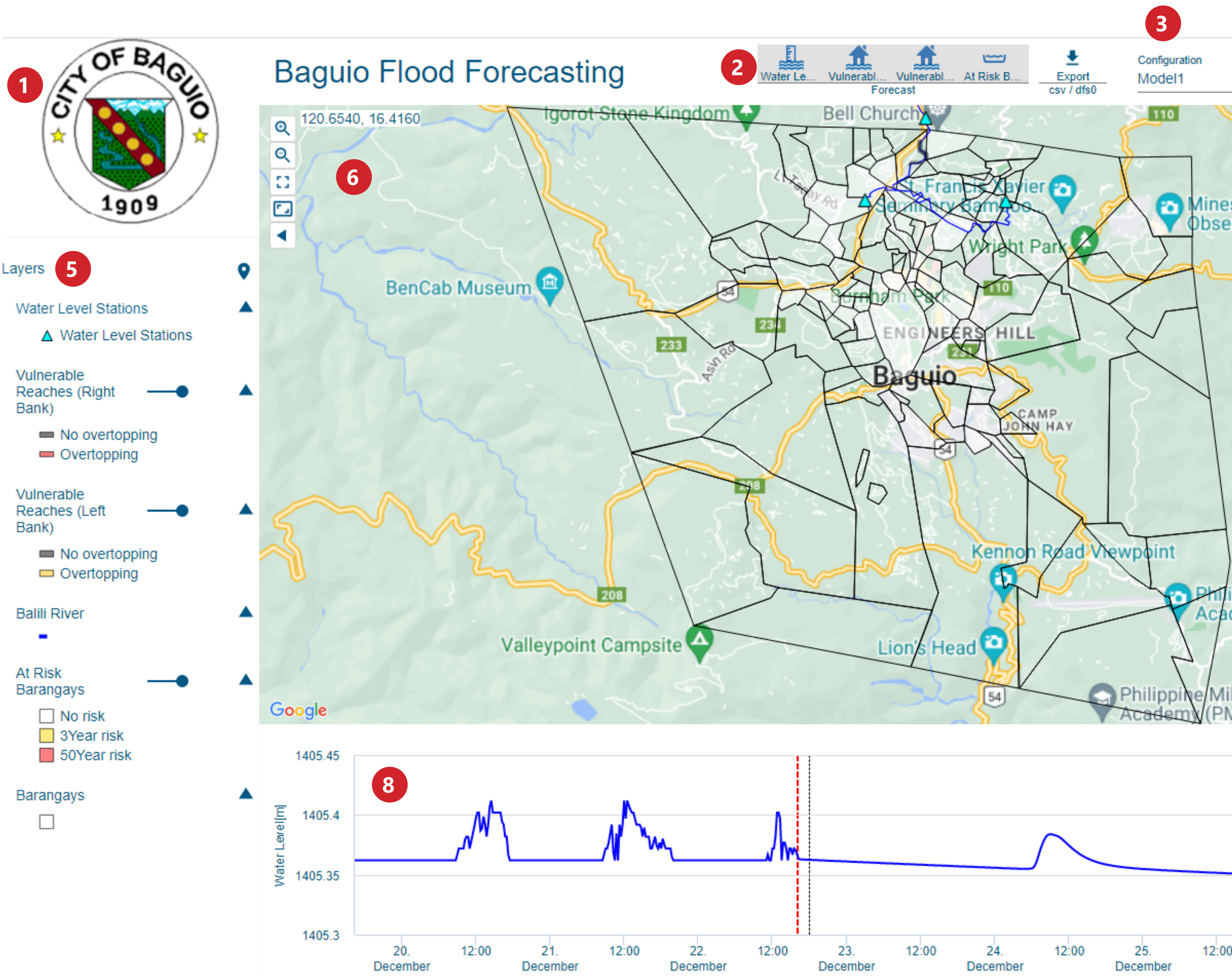


Figure 5-4 Baguio Flood forecasting webpage - currently available on internal systems.

Source: Ramboll

5.1.2.2 MIKE OPERATIONS WEB

The dashboards can be viewed and shared through the MIKE OPERATIONS Web platform. This would allow for dissemination of warnings to stakeholders. The finalization of the dashboard is dependent on the validation of on the dissemination plan and finalization of FEWS dissemination SOPs.

Currently, the system is expected to run in test mode during which the FEWS O&M team will operate, assess, and update the system.

The webpage for viewing the dashboard setup on MIKE OPERATIONS Desktop has currently been published on the localhost through MIKE OPERATIONS Web and is accessible on the internal MITD systems connected to the LAN. The setup of the web dashboard is shown in Figure 5-4.

Numbers (in red) are inserted on this figure representing the following:

1. Baguio City LGU Logo
2. Gallery to check map objects on or off
3. Drop down menu to access which of the 3 models should be displayed
4. Drop down menu to select the simulation based on which the values in the charts should be displayed
5. Legend of items in the map view. This pane in the dashboard can be switched to visualize the menu from where individual objects for chosen layers can be selected.
6. Map view
7. Animation slider bar to navigate the timeline for the period when data is available in the chosen simulation.
8. Chart/timeseries plot – the data in this view gets updated based upon which object is selected in the map view or the menu. The vertical red line indicates the time of forecast in the selected simulation. The horizontal dashed lines represent the defined thresholds.

5.2 TESTING AND VALIDATION OF THE FEWS

The FEWS has been fully installed at the LGU but it was not possible to complete online testing and operational acceptance during the 2022 monsoon. The finalized system with the calibrated models and WRF inputs was not running during the monsoon of 2022, and therefore a full-scale test of the system during real-time operation has not yet been completed. The key reasons why this was not achieved within the timeline of the pilot project relate to delays in obtaining access to crucial data from stakeholder organizations, issues with data quality and delays in construction, commissioning and installation of water level stations. Further details are provided in appendix C.

Thus, it is recommended to complete a full-scale test of the FEWS in real-time operation during the upcoming monsoon running troubleshooting and feedback loops and fine-tuning the system during a post-monsoon period. The need for testing is not limited to one single monsoon season, as any FEWS requires proper validation (several monsoons) before it's publicly launched. Launching a FEWS without proper testing and troubleshooting time can have serious consequences on the credibility of the LGU and ultimately on the confidence in the system itself. Further details on the recommendations for testing, validation and finetuning of the system and its governance to enhance long-term sustainability are outlined in Section 10.


Source: Adobe Stock

6 INSTITUTIONAL FRAMEWORK

Source: Adobe Stock

The Philippines has a long history of disaster risks, with approaches to addressing them evolving over the decades. This has created a rich institutional and legal landscape that a new FEWS needs to be aligned with in order to function effectively and make efficient use of the knowledge exchange and communication between the many stakeholders involved in DRRM activities. A thorough understanding of that landscape and anchoring the FEWS in the relevant local institutions ensures long-term sustainability of the system and allows for early identification of potential barriers and capacity gaps, but also opportunities to develop the FEWS further.

This section provides a brief overview of the institutional tissue concerning disaster risk reduction and management in Baguio City, as well as the relevant stakeholders and their responsibilities on a national, regional, and local scale. The institutional setup is further documented in the Data Dissemination and Outreach Plan for the FEWS (Task 4).

6.1 EXISTING INSTITUTIONAL TISSUE

At the local level in Baguio City, the main planning, coordination, integration, supervision, monitoring, and evaluation functions of disaster management lie with the City Disaster Risk Reduction and Management Council (CDRRMC), with the City Mayor acting as chairperson.

CDRRMC is additionally responsible for approving and monitoring the implementation of the City's DRRM Plan and its consistency with other national, regional, and local planning programs, as well as ensuring the integration of DRRM and CCA into local development programs and budgets. In emergency situations, it is the CDRRMC who recommends the implementation of forced or pre-emptive evacuation. The DRRM Act of 2010 [3] reinforces the role of CDRRMC as a key player in pursuing the mission of creating a 'sustainable and enabling environment that increases community consciousness on hazards, aims for zero casualty and reduce human suffering, decrease property damage, and protect environmental sensitive areas from all types of disasters'.

The City Disaster Risk Reduction and Management Office (CDRRMO) is the executive arm of the CDRRMC. Its responsibilities include:

- Setting the direction for development, implementation, and coordination of DRRMS programs in Baguio City, implement risk reduction measures, implement policies, plans and programs of the CDRRMC,
- Designing and coordinating DRRM activities consistent with NDRRMC's standards in collaboration with relevant local organizations,
- Facilitate risk assessment and contingency planning activities, consolidate local risk information,
- Conduct training and knowledge management, both on a broader awareness raising level, as well as training and equipping DRRM staff and local response teams,
- Operate the multi-hazard early warning system,
- Formulate and implement a local DRRM Plan,
- Continuously monitor hazards, vulnerabilities, and risks,
- Disseminate information on these hazards, vulnerabilities, and risks,
- Coordinate disaster response, carry out evacuation, recovery activities,
- Strengthen the collaboration with relevant agencies, CSOs, private sector organizations and volunteers.

The institutional structure for disaster risk management in Baguio City is outlined in Figure 6-1. The complexity of the institutional tissue is evident, with many stakeholders involved, several lines of communication established, and data and information shared between many agencies. At the heart of DRRM activities during disasters lies the Baguio City Emergency Operations Centre (OPCEN) anchored at the CDRRMO. The OPCEN serves as the central command and control facility responsible for the overview of emergency situations. It collects information from monitoring stations, partner agencies, emergency responders, and directly from the affected communities through emergency hotlines to create an overview of the situation. OPCEN's responsibility also includes the dissemination of warnings.

Baguio City CDRRMO-Operation Center (OpCen) /Emergency Operation Center (EOC) Operational Flow Chart

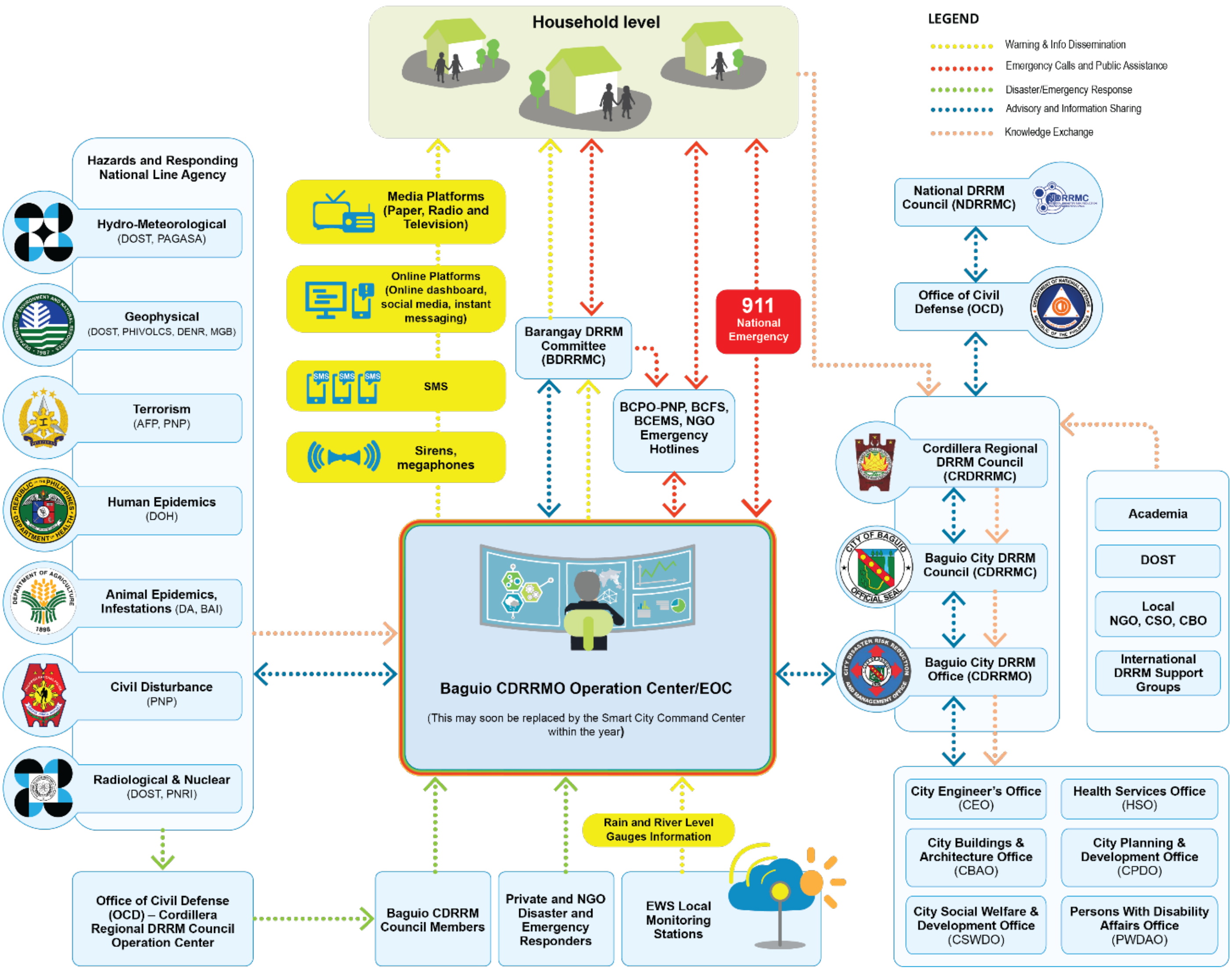


Figure 6-1 Baguio City CDRRMO OPCEN operational flowchart including local stakeholders. During disaster preparedness and response, the CDRRMO is in close coordination with the following offices: CEO, CBAO, CSWDO, HSO, PDAO, PIO, CVAO and GSO.
Source: Ramboll

Throughout the project, it has become increasingly apparent that the institutional setup in Baguio is highly complex, with local organizations not being able to clearly explain their roles and mandates, which many times are concurrent across different organizations. It has therefore been a challenge to identify which organizations to engage on specific matters and clarify the existing distribution of responsibilities and roles.

It has become apparent that there is a need to improve cooperation and communication across institutions in Baguio. This is mainly between the key organizations which the LGU is dependent for the design and implementation of the FEWS in Baguio: DOST-CAR, DOST-ASTI and PAGASA. Clear communication is key to efficient and continuous operation of the FEWS.

6.2 INSTITUTIONAL SETUP FOR THE FEWS

The ownership of the FEWS is with the LGU. Within LGU, the system is anchored between three bodies: CDRRMO and its OPCEN, Management Information Technology Division (MITD), and Baguio Smart City Command Center (SCCC). It was essential to place the FEWS into the already established organizational structure to leverage the connections between LGU staff and peer organizations, to facilitate knowledge exchange, and ensure long-term effectiveness beyond the completion of the pilot project in December 2022. The FEWS operations and maintenance (O&M) team consists of LGU staff with support from peer organizations, such as PAGASA, DOST-CAR, DOST-ASTI, Saint Louis University, University of Cordilleras, and Baguio City District Engineering Office of the Department of Public Works and Highways (DPWH). The composition and responsibilities of the FEWS O&M Team is outlined in Section 8 and further detailed in Appendix D.

The FEWS servers are currently anchored at the MITD with the staff of the MITD and Baguio City Smart City Command Center (SCCC) working closely together and supporting each-other. Eventually, it is recommended to migrate the FEWS to the SCCC when the on-site set-up allows for it, thereby gathering smart capabilities in one location.

6.3 STAKEHOLDERS AND PARTNERSHIPS

Strong stakeholder partnerships are essential in ensuring success and sustainability of the FEWS. Through stakeholder partnerships with public and private organizations as well as academia, the LGU can gain knowledge, experience and innovation improving the overall impact and usefulness of the FEWS for the City of Baguio. These partnerships provide two-way benefits, where the partnering organizations gain access to the data and outputs from the FEWS. By partnering with the LGU on the FEWS the partnering organizations can demonstrate their support and commitment to protecting the citizens of Baguio by ensuring timely and inclusive flood warnings.

The complex institutional setup highlights the need for clearly defined roles, responsibilities and communication lines in the operation and maintenance of the FEWS. The foundation of the operation and maintenance of the FEWS is established through preparation of standard operating procedures (SOPs), but the implementation of these is highly dependent on well-established partnerships between the City of Baguio and stakeholder institutions.

6.3.1 MEMORANDUM OF AGREEMENTS FOR THE FEWS

Formalization of stakeholder partnerships through a formal agreement i.e. a Memorandum of Agreement (MoA) contributes to enhancing collaboration by describing the scope of the agreement and detailing each party’s role and responsibilities.

Important MOAs have been signed with DOST-CAR and PAGASA, outlining the key roles and responsibilities of each partner as well as the LGU. Additionally, a MOA with Saint Louis University is under preparation. The MOAs enable collaboration and formalizes working arrangements around maintenance, technical support, and data-sharing between the agencies, but it is ultimately up to the respective agencies to take the responsibility required.

- The MOA between the LGU and DOST-CAR outlines the commitment by both agencies to collaborate on the operation and maintenance of the FEWS. DOST-CAR will provide technical assistance related to the new gauging stations including training in operation and maintenance of the stations. Furthermore, DOST-CAR will communicate and coordinate with DOST-ASTI on all technical issues related to the equipment and data management concerns which are included in the services of the DOST-ASTI.
- The MOA between the LGU and PAGASA enable collaboration between the agencies and provides the foundation for data-sharing. The real-time WRF data shared by PAGASA through the agreement serves as input for the FEWS and is crucial for the operation of the system. The MOA outlines the responsibilities of both the LGU and PAGASA in the maintenance of the FEWS, and the commitment by both agencies to work together to continuously improve the FEWS.

The above MOAs took several months to get formulated and signed, and represent an important achievement as they ensure ownership, delineate expectations across organizations and set the foundation for long-term sustainability of the system, anchored at the LGU. An official signing ceremony took place in September 2022, with Mayor of Baguio and representatives from departments of the LGU, DOST-CAR and PAGASA, and highlights the importance of this partnership-oriented early warning approach, pioneered in the Philippines by Baguio LGU.

In addition to the achieved MOAs, it is recommended to establish MOAs with SLU and DOST-ASTI. The MOA with SLU will enable knowledge exchange, support through student projects to further develop the FEWS, and formalize the role of SLU staff in the FEWS organization, who has the relevant educational background to support operation and maintenance of the FEWS.

DOST-ASTI is a crucial stakeholder in Baguio FEWS project, as they oversee processing, storing, and publishing the real-time data from the monitoring stations. At the core of the functionality of the FEWS in Baguio lies the need to operate in real-time. Hence, for the proper design of the system, it is crucial to cover all potential vulnerabilities in the entire real-time data assimilation chain. This covers, among other things, both the vulnerabilities at the stations, but also the vulnerabilities in data transmission and (virtual) data access. In this regard DOST-ASTI is the key organization to establish a partnership with. DOST-ASTI has expressed their concern that any form of documentation they would provide, should not end up supporting any commercial activity. Documentation and insight knowledge provided by DOST-ASTI should only be used for research purposes or to support public authorities. Thus, there is a need to formalize an agreement that specifies that the sole beneficiary of all FEWS activities is the City of Baguio and formalizes the collaboration and data-sharing between the two agencies.

7 CAPACITY BUILDING AND TRAINING

Source: Ramboll

To ensure an effective, sustainable and resilient Baguio FEWS, it is necessary to secure establishment of the required local capacity and organizational structure for operating and utilizing the FEWS. This aspect was addressed through the implementation of the 'Targeted Capacity Building Program to Enhance Delivery of a Sustainable FEWS' with participation of staff from the LGU of Baguio City and peers from relevant stakeholder organizations. The main objective of the program was to enhance long-term sustainability of the established FEWS by enhancing the local capacity for operating and maintaining the FEWS. The targeted training and capacity building program consisted of the following key elements:

- 3-module training program: This component was led by DHI and supported by Ramboll. It focused on giving the participants in the training program a general understanding of Flood Early Warning Systems and training in the different types of DHI software used in the FEWS for Baguio. The training program was carried out as online (self-paced, instructor-led, and expert advice) modules based on the ACADEMY by DHI eLearning platform.
- On-the-job (OTJ) training: This was led by Ramboll and included specific hands-on training and support related to the Baguio flood models and the specific FEWS for Baguio developed by Ramboll in collaboration with the LGU. The OTJ training took place in-person at the Baguio City Hall in June 2022 (6-day training program) and September 2022 (5-day training program).

A total of 11 professionals were selected to participate in the training and capacity building program following nomination from the LGU. Five staff members from the LGU were selected for participation in the program, forming the 'core group', who will have the main responsibility for operation and maintenance of the FEWS. A 'peer group' consisting of six (6) persons outside of the LGU were also selected for the program. The peer group participants come from local/regional public institutions which include three (3) participants from two (2) universities, one (1) from PAGASA, and (1) from The Department of Science and Technology in Cordillera (DOST-CAR), one (1) from the District Engineering Office (BCDEO), and their main role will be to support the core group.

During the program, one (1) participant from the peer-group (from University of the Cordilleras) left the program due to added responsibilities and changed schedules and requirements in their projects. Support staff outside the core and peer group members was identified to enhance sustainability and resilience. Two (2) support staff from the MITD was identified to enhance sustainability and resilience. The two (2) staff were added to the list of trainees in June 2022, attending the following training sessions to get an understanding of the FEWS IT infrastructure. Furthermore, one (1) participant from the core-team (from MITD) was unable to participate in the program from September 2022 due to academic leave. Hence, eleven (11) trainees finalized the program.

While the scope, outcome, and effectiveness of the Capacity Building Program activities have been documented in the deliverables under Task 8, as presented in Table 1-1, the On-the-Job training activities and achievements are presented in Appendix F and briefly summarized on the next page.

7.1 SCOPE AND FACILITATION OF OTJ TRAINING

The OTJ training aims at preparing the O&M team with skills and knowledge for setting up, operating, and maintaining the FEWS. The in-person training sessions provided in-depth hands-on experience to the trainees which will build the confidence in a more efficient manner than traditional classroom trainings or online e-learning training modules. Effective OTJ training was made possible by the Capacity Building Program, which provided the trainees with a general understanding of hydrology, hydraulics, flood modelling and early warnings systems as well an understanding of the DHI software used for the FEWS. Thus, the OTJ training focused on four core elements:

- Understanding of the hydrological and hydraulic characteristics specific to Baguio
- Understanding the historical and real-time data available for Baguio
- Capability of managing annual post-monsoon management, calibration and evaluations and applying changes to the system
- Capability of troubleshooting and operating the system in real-time during monsoon

The OTJ training program was divided in two phases; a 6-day pre-monsoon training program, facilitated in June 2022, and a 5-day post-monsoon training program facilitated in September 2022. The training sessions were facilitated at the Mayor's IT Department (MITD) at Baguio City Hall.

A key focus of the first phase of the OTJ training in June 2022 was ensuring that the learnings from the online capacity building sessions, which were more theoretical due to the trainees' background, were coupled to hands-on exercises and system demonstrations. The first OTJ sessions focused on input data requirements, data processing, basics of NAM modelling and hydrodynamic modelling and the DHI software to assess the learnings on the subject covered in the capacity building program and build on these learnings. The following sessions provided in-depth discussions and demonstrations of the available data in the region, the gaps in the data, and its quality. The IT infrastructure, scripts, back-end and front-end FEWS setup was also presented and discussed. Furthermore, hands-on exercises on processing and formatting of data inputs for the model and FEWS system were completed by the participants. Finally, the FEWS O&M team organizational structure and the roles and responsibilities were discussed.

Following the OTJ training in June, online training sessions were facilitated for the trainees to stay updated on system design progress as the WRF data was being shared by PAGASA. Additionally, these sessions allowed the trainees to stay in touch with the project team and trainers.

In September, the focus of the OTJ was the Baguio FEWS design, models and data. The training sessions included a series of hands-on calibration exercises, where trainees collaborated on calibrating both NAM and hydro-dynamic model parameters. The content covered in the first OTJ phase was reviewed to ensure that all trainees were aligned. The O&M team structure, roles and responsibilities was discussed and revised following team discussions.

Figure 7-1 On-the-Job training session in September 2022 at Baguio City Hall.
Source: Ramboll

7.2 EVALUATION AND ASSESSMENT OF TRAINING EFFECTIVENESS

To conclude both phases of the OTJ training, feedback and evaluation sessions were held, which provided an opportunity for the participants to share their thoughts, concerns, needs and ideas. As part of the feedback sessions the participants completed an individual evaluation survey and contributed to round-table discussions on program effectiveness and execution. In the feedback sessions, the trainees acknowledged that the outcome of the OTJ training was strengthened due to the online Capacity Building Program activities; a sentiment that was echoed by the project team leading the OTJ training.

The OTJ training has been key to building a sense of team spirit among the staff who will form the FEWS Operation and Maintenance (O&M) Team. Gathering the participants in-person at the same location for OTJ training allowed for enhanced interaction and collaboration between participants. Furthermore, meeting the participants in-person allowed the project team to get a better understanding of their skills and potential roles in the operation and maintenance of the FEWS. The informal conversations between trainings allowed the participants to get to know each other and built relations within the team which is crucial for a successful FEWS.

To assess the improvement in understanding and confidence in the training topics, an evaluation form was circulated among the trainees before and after each of the two training sessions. In the survey, trainees were asked to assess their level of understanding of training topics before and after the two OTJ training sessions on a scale from 1 (worst) to 10 (best). A summary of the survey results for the June session (completed by 10 trainees) can be found in Figure 7-2. A summary of the survey results for the September session (completed by 9 trainees) can be found in Figure 7-3.

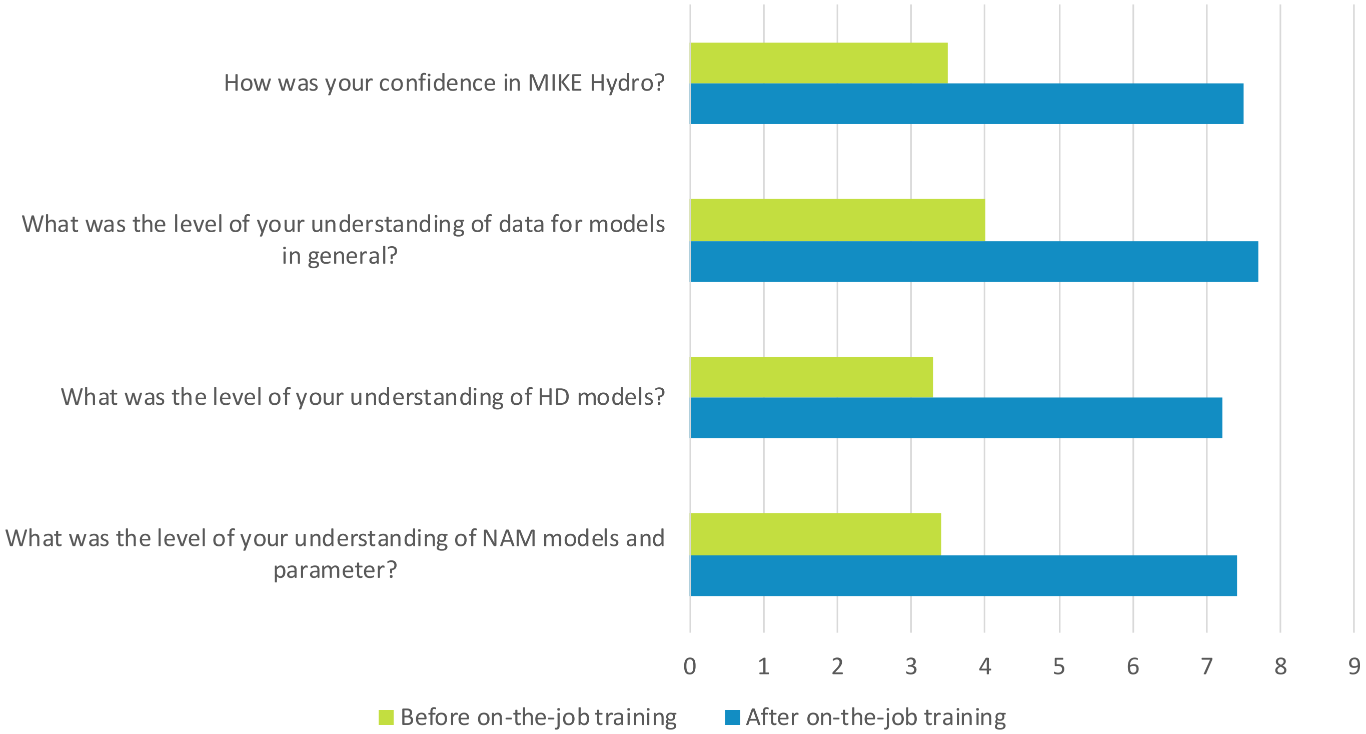


Figure 7-2 Self-reported level of confidence in training topics before and after OTJ training phase 1 in June 2022.

Source: Ramboll

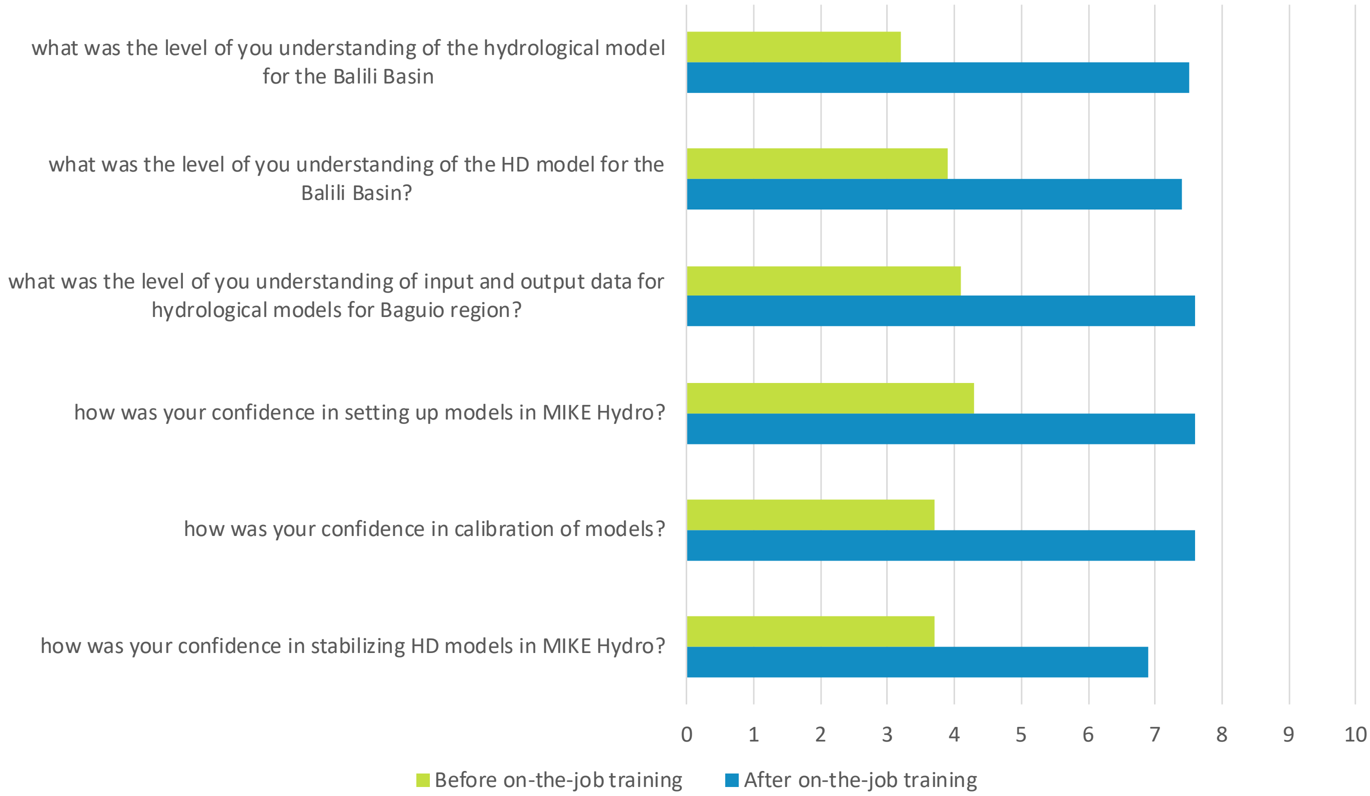


Figure 7-3 Self-reported level of confidence in training topics before and after OTJ training phase 2 in September 2022.
Source: Ramboll

The effectiveness of both OTJ training sessions is evident from Figure 7-2 and Figure 7-3. The level of understanding of the first phase (June) topics rose from an average of 3.6 to 7.5, with no question falling below 7. The understanding of the second phase (September) topics saw a similar increase, from an average of 3.8 to 7.4, with only one question falling below 7.

The survey results and direct feedback from participants indicate that the training program has successfully improved capacity within hydrology, hydraulics and modelling as all participants state that their knowledge and experience within all topics covered by the program has increased. Hence, there has been a good learning progress. However, given the starting point of the participants, it has not possible to bring them to the necessary professional level through completion of training to enable them to be fully responsible for the operation and maintenance of the FEWS system. During feedback sessions following the OTJ training, the trainees expressed concern about being unable to meet expectations and were anxious to be left without technical support. This further enhances the need for Baguio City to continue receiving technical support and expert advice on the operation and maintenance of the FEWS to ensure the long-term sustainability of the system. Recommendations for future training activities to be completed are presented in Section 10.

8 OPERATION AND MAINTENANCE FRAMEWORK

Source: Adobe Stock

The Flood Early Warning System (FEWS) for Baguio is to be operated and tested in the coming monsoon seasons and maintained henceforth. It is required that, as the network of real-time monitoring stations for the basins grow and develop and additional catchment data is collected, the system is updated accordingly to produce better forecasts and timely warnings.

To foster long-term sustainability of the Baguio FEWS, it is necessary to secure establishment of the required local capacity and organizational structure for operating and utilizing the FEWS as an active risk mitigation instrument beyond the timeframe of the pilot project. The FEWS operation and maintenance framework is introduced on the next page with further details described in Appendix D.

8.1 O&M AS THE BACKBONE OF THE FEWS

To enable effective operation and maintenance of the FEWS for Baguio, an FEWS Operation and Maintenance (O&M) Team has been formed. The ownership of the FEWS is anchored at the Local Government Unit (LGU) and thus, the O&M core team consists of LGU staff with support from a peer team of representatives from academia and selected relevant agencies (i.e. PAGASA, DOST-CAR, BCDEO). To ensure long-term sustainability of the FEWS, the LGU should continuously ensure that the O&M team members are available to perform the required tasks. It is crucial that O&M team is institutionalized and well-trained, and that team members have the mandate to prioritize the required tasks.

To secure effective operation of the FEWS, Standard Operating Procedures (SOPs) have been prepared to guide the FEWS O&M team, see Appendix E. The purpose of a SOP is to carry out operations correctly and always in the same manner. The SOPs contribute to enhancing sustainability by outlining specific activities and tasks to be undertaken by the O&M team and serving as a guide for the team throughout the different operation and maintenance phases.

The activities and tasks related to operation and maintenance of the FEWS can be divided into three phases as seen in Figure 8-1:

- **Preparation phase: Pre-monsoon period (April)**
  - This phase includes preparation of the FEWS for operation in the monsoon season. The pre monsoon system maintenance for a season will essentially be the outcome of the post-monsoon analysis of the previous monsoon.
- **Application phase: Monsoon period (May – October)**
  - This phase includes operation and maintenance of the FEWS during the monsoon.
- **Assessment phase: Post-monsoon period (November – March)**
  - This phase includes assessment and updating of the FEWS post-monsoon. In this phase the existing system needs to be assessed to evaluate its performance in the recent monsoon season; this assessment primarily is to be carried out in two areas:
    - Assessment of real-time monitoring station performance- which work well, which malfunction, which are consistent, which have very intermittent data, overpredicting underpredicting, addition of any new stations in the network etc.
    - Updating the FEWS by inclusion/removal of input data based upon above assessment and readjustment of the models to accommodate any changes.

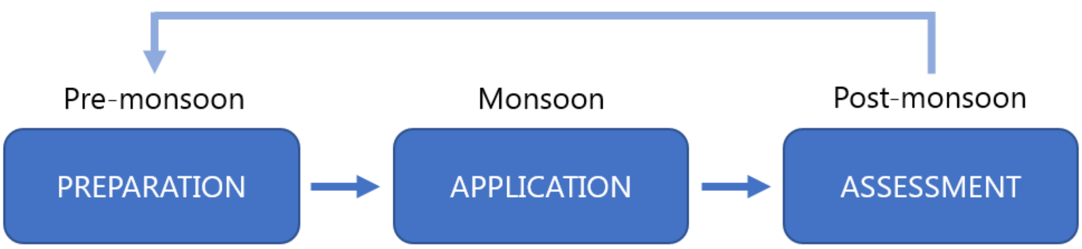


Figure 8-1 Operation and maintenance phases for the FEWS.
Source: Ramboll

8.2 O&M TEAM ORGANIZATION

A well-defined organizational structure for the O&M team provides guidance to all team members by laying out the official reporting relationships that govern the workflow of the team. A formal outline of the team's structure provides the foundation for efficient operation and communication.

The proposed organizational structure of the O&M team can be seen in Figure 8-2. Overall supervision of the FEWS O&M team will be with the head of CDRRMO who has the mandate to coordinate directly with high-ranking government officials and guide in decision-making. The O&M team is led by the Team Lead supported by the Deputy Team Lead. The team is sub-divided in three smaller teams: the modelling team, the instrument team, and the IT team. Each team has a team lead and two core team specialists from the LGU. Peer support is defined for each team. The responsibility for a defined SOP will be assigned to one of the three teams.

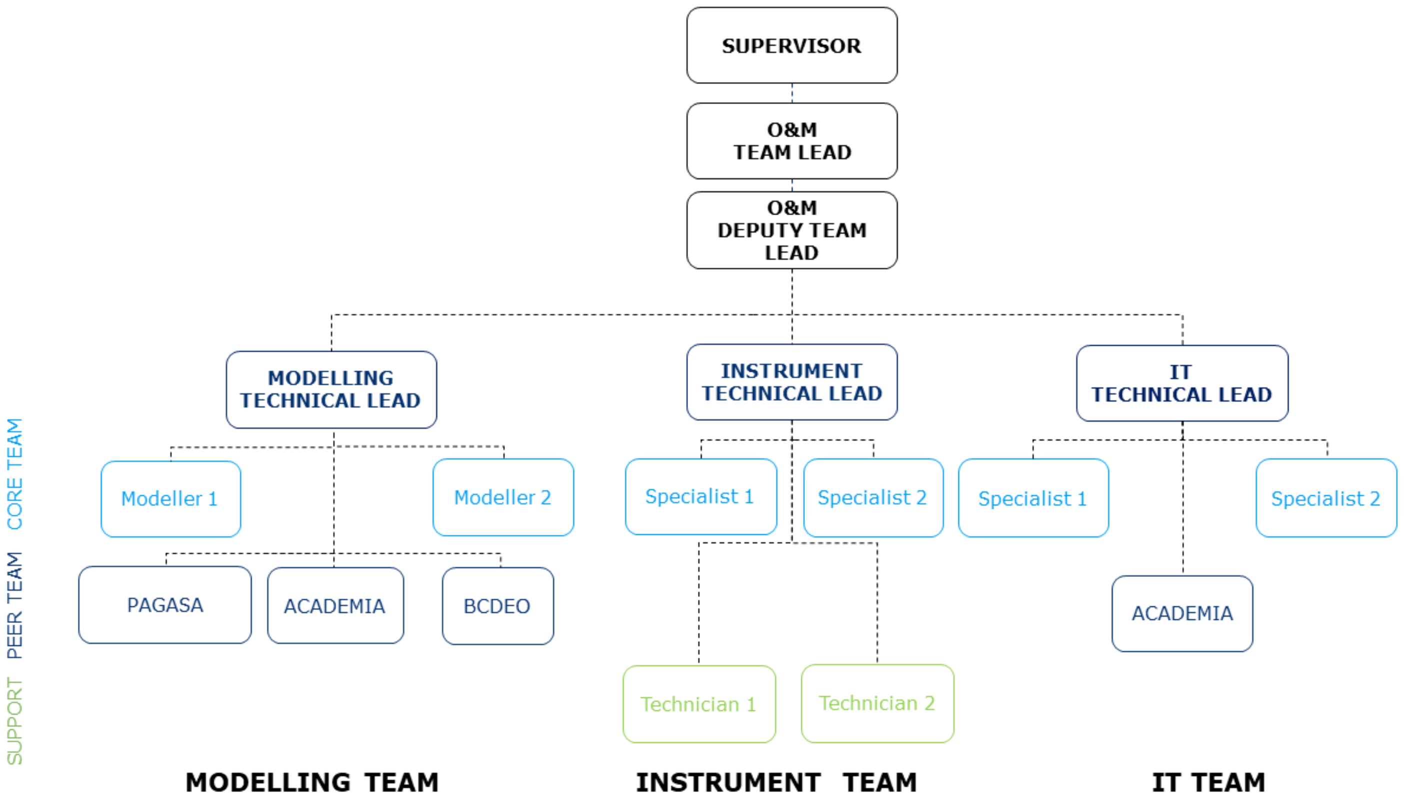


Figure 8-2 The structure of the FEWS Operation and Maintenance (O&M) team.
Source: Ramboll

The responsibilities for the operation and maintenance tasks and implementation of their respective SOPs are distributed separately between the following roles/teams:

- The **Team Lead** is responsible for operation and maintenance of the FEWS through management of team members and provision of effective guidance. The Team Lead is expected to be supervising, managing and motivating team members through all operational phases.

- The **Deputy Team Lead** is responsible for supporting the Team Lead in all day-to-day activities and will be the point of contact for any issues when the Team Lead is not available. They will provide advice, guidance, and project and task oversight for team members.

- The **Technical Lead of the Modelling Team** is responsible for managing the Modelling Team and ensuring completion of all SOPs assigned to the Modelling Team. The Technical Lead will provide guidance for members of the Modelling Team and ensure that the team has the required knowledge and skills to complete their assigned tasks. The Technical Lead will communicate directly with the Team Lead on task progress and concerns.

- The **Modelling Team** is responsible for completing the SOPs assigned to the Modelling Team with guidance from their Technical Lead. The team is responsible for maintaining all hydraulic and hydrodynamic models and undertake troubleshooting in case model failures. The team members will communicate directly with the Technical Lead of the Modelling Team on task progress and concerns.

- The **Technical Lead of the Instrument Team** is responsible for managing the Instrument Team and ensuring completion of all SOPs assigned to the Instrument Team. The Technical Lead will provide guidance for members of the Instrument Team and ensure that the team has the required knowledge and skills to complete their assigned tasks. The Technical Lead will communicate directly with the Team Lead on task progress and concerns.

- The **Instrument Team** is responsible for completing the SOPs assigned to the Instrument Team. The team is responsible for maintaining all real-time monitoring stations and undertake troubleshooting in case of any station failures. The team members will communicate directly with the Technical Lead of the Instrument Team on progress and issues.

- The **Technical Lead of the IT Team** is responsible for managing the IT Team and ensuring completion of all SOPs assigned to the IT Team. The Technical Lead will provide guidance for members of the IT Team and ensure that the team has the required knowledge and skills to complete their assigned tasks. The Technical Lead will communicate directly with the Team Lead on task progress and concerns.

- The **IT Team** is responsible for completing the SOPs assigned to the IT Team. The team is responsible for maintaining the IT infrastructure including the front-end and back-end systems of the FEWS. The team members will communicate directly with the Technical Lead of the IT Team on progress and issues.

The time and resources required to operate and maintain the FEWS will change throughout the operation phases. The resources required are expected to be highest in the application phase, where the system is actively used as a decision-making tool. Table 8-1 below outlines the expected time requirements for the staff of the O&M team. The number of hours stated are to be a guidance and may vary depending on actual system performance.

The LGU and partner organizations should ensure that all O&M team staff are available to support the operation and maintenance of the FEWS as required. In case of unforeseen circumstances, it is required that the LGU is flexible and can adapt workflows to be meet increased demands for resources to e.g. complete troubleshooting.

Table 8-1 Number of hours required for roles in the FEWS O&M team.

*Note: The (*) marks hours stated as team hours which implies the total hours that are needed from the team as a whole. Based on availability of team members for tasks, the total hours would be divided between them.

Role	Time allocation (hours/week)		
	Monsoon	Post-monsoon	Pre-monsoon
Team Lead	12	12	12
Deputy Team Lead	8	8	8
Technical Lead	12	12	12
Modelling Team (core team)	16*	12*	8*
IT Team (core team)	16*	8*	12*
Instrument Team (core team)	16*	8*	8*
Peer Staff	4	2	2
Support	2	2	2

Source: Ramboll

8.2.1 PROPOSED O&M TEAM 2022

Following the completion of the Targeted Training and Capacity Building Program, the trainees were assigned roles in the O&M team. The roles were assigned based on an assessment of knowledge, skills and capacity and in close dialogue with the trainees. The proposed structure and staff roles are seen in Figure 8-3 and represents the recommended team composition in 2022. It should be noted that it is ultimately the responsibility of the LGU to ensure that all team members are available to perform their required tasks. The team composition may change with time, if staff at the LGU or stakeholder organizations are replaced. In the case of staff replacement, it is crucial that the LGU ensures that new O&M team members have the required capacity to perform their tasks through facilitation of required OTJ training sessions and capacity building.

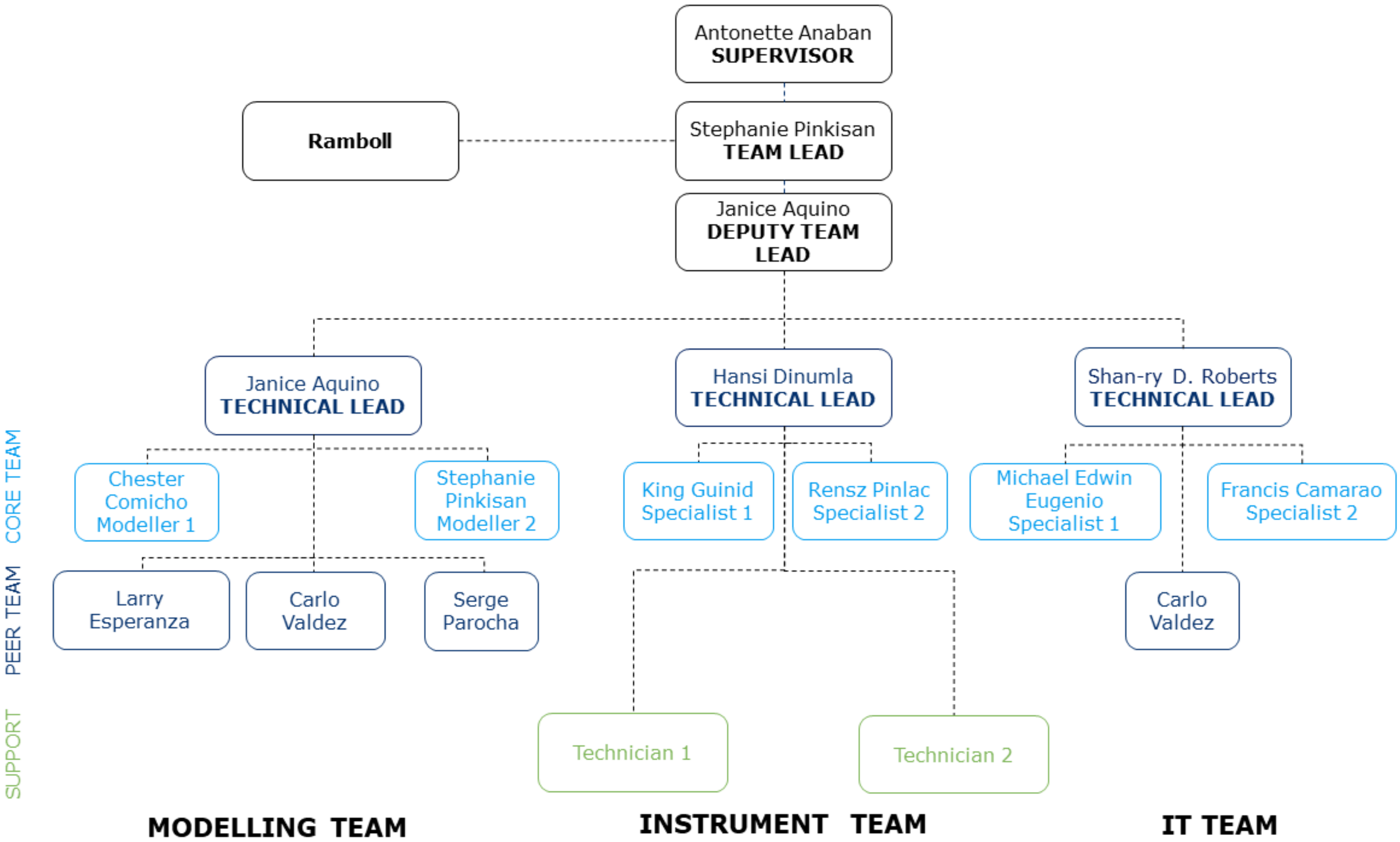


Figure 8-3 The proposed roles for staff in the FEWS O&M team 2022.
Source: Ramboll

There is a need to employ technicians for operation and maintenance of the real-time monitoring stations. Currently, the LGU does not have the knowledge and technical skills maintain the stations and needs technical support from DOST-CAR, PAGASA and DOST-ASTI to resolve all issues. It is recommended that the LGU employs technicians to be part of the Instrument Team in the O&M team, as outlined in the O&M team organizational chart. Ideally, these would be staff who are already familiar with maintenance of the equipment, but if such resources are not available, a training program facilitated by DOST-CAR is needed.

An important note to add is, that given the starting point of the trainees, it has not been possible to bring the O&M team to the necessary professional level to enable them to be fully responsible for the operation and maintenance of the FEWS system once the pilot project is completed in 2022. More training and technical support is required as the FEWS operational group needs to be able to perform a full-scale testing of the system, for which more dedicated OTJ training is needed. The team needs to gain experience in collaborating on operating and maintaining the FEWS and refining internal communication lines and work procedures as well as establishing confidence in working as a team before they can be expected to successfully operate the system on their own.

The LGU should continuously ensure that the O&M team members are available to perform the required tasks. The O&M team should be institutionalized and well-trained, and team members need to have the mandate to prioritize the required tasks. The LGU should assess the need for amendment of role descriptions or contracts of staff to ensure this is achieved.

8.3 STANDARD OPERATING PROCEDURES

Standard Operating Procedures (SOPs) have been prepared to guide the FEWS Operation and Maintenance team (O&M team). The purpose of a SOP is to carry out operations correctly and always in the same manner. SOPs can be defined as a written document with step-by-step instructions on how to perform a designated activity to obtain a desired outcome. Clearly defined SOPs are crucial to ensuring consistent operation of the FEWS. The benefits of effective SOPs for the FEWS include:

- Effective operation of the FEWS
- Consistency in operation
- Assigning responsibility and accountability of tasks to smaller teams
- Ensuring dynamic upgrades of the FEWS
- Creating a safe work environment
- Saving time and money

Thus, the SOPs contribute to enhancing long-term sustainability by outlining specific activities and tasks to be undertaken by the O&M team and serving as a guide for the team throughout the different operation and maintenance phases. At the same time the SOPs contribute to achieving efficiency, quality output and uniformity of performance, while reducing miscommunication and failure to comply with standards.

An overview of the Standard Operating Procedures for the Baguio FEWS is shown in Figure 8-4. The full SOPs can be found in Appendix F. For each SOP the following is described:

- **Phase**: The operation phase in which the SOP should be carried out
- **Frequency**: The number of times a task should be completed within a given time period.
- **Responsible**: The team responsible for performing the SOP
- **Section**: The number of the section in which the SOP described step-by-step
- **SOP**: The title of the SOP

Phase	Frequency	Responsible	Section	Standard Operating Procedure
Monsoon	Daily	IT	4.1.1	Operate system, check IT system and connectivity
	Daily	TL DL M IT IN	4.1.2	Daily review system logs and jobs
	Daily	IT	4.1.3	Daily report on job and script performance
	Daily	M	4.1.4	Daily report on model performance
	As needed/as scheduled	IN	4.1.5	Real-time station maintenance and weekly report on station performance
	Weekly	M	4.1.6	Weekly report on quality of model input data
Post-monsoon	Post-monsoon	IN	4.2.1	Station assessment
	Post-monsoon	M	4.2.2	Model input data assessment
	Post-monsoon	M	4.2.3	Catchment assessment
	Post-monsoon	M	4.2.4	NAM-model assessment
	Post-monsoon	M	4.2.5	Hydrodynamic (HD) model assessment
	Post-monsoon	M	4.2.6	Data assimilation (DA) assessment
	Post-monsoon	IT	4.2.7	Update Mike Operations (MO) back-end
	Post-monsoon	IT	4.2.8	Update Mike Operations (MO) front-end
	Post-monsoon	M	4.2.9	Update reports
	Post-monsoon	TL DL M IT IN	4.2.10	Update SOPs
Pre-monsoon	Pre-monsoon	TL	4.3.1	Ensure completion of post-monsoon SOPs
	Pre-monsoon	TL	4.3.2	Coordinate with stakeholder organizations
	Pre-monsoon	TL	4.3.3	Plan O&M activities during monsoon
	Pre-monsoon	TL	4.3.4	Assemble O&M team
	Pre-monsoon	M	4.3.5	Ensure real-time stations are operational

TL Team leader; DL Deputy team leader; M Modelling team; IT IT team; IN Instrument team

Figure 8-4 Standard Operating Procedures for the Baguio FEWS.
Source: Ramboll

Implementation of the SOPs is a responsibility shared by all members of the O&M team. To foster long-term sustainability of the FEWS, it is key to ensure continuous maintenance of the system as well as availability and capacity of resources. The City of Baguio needs to continuously prioritize physical maintenance of the system equipment and operation of the system by providing funding for required repairs, operation, and training of staff.

Proper coordination and understanding among different stakeholders are a prerequisite for sustainability of the FEWS. The SOPs provide the foundation for the operation and maintenance of the FEWS, but the implementation of these is highly dependent on well-established partnerships between the City of Baguio and stakeholder organizations. The MOAs with relevant stakeholder organizations enable collaboration, but it is ultimately up to the City of Baguio and stakeholder organizations to take the responsibility required.

Therefore, it is crucial that the LGU prioritizes:

- Allocation of adequate financial resources
- Motivated, available and trained human resources
- Well-established partnerships and proper coordination with stakeholder organizations
- Research and knowledge-sharing on FEWS
- Annual assessment of external technical support required

The FEWS is a dynamic system that should be adapted as additional data and knowledge is gained and lessons learned are utilized in the system to enhance the system's resiliency, sustainability and value for the citizens of the City of Baguio. The SOPs may need to be updated as new information becomes available and data, tasks and responsibilities for the operation and maintenance of the Baguio FEWS are validated. All procedures should be reviewed and, if necessary, adjusted or expanded to ensure lessons learned from the monsoon season are incorporated.

9 CONCLUSIONS

Source: Ramboll

This report has aimed at answering the following five questions:

- What are the main benefits and the overall design approach of the FEWS?
- What are the supporting IT infrastructure requirements?
- What are the supporting institutional requirements?
- How is the FEWS to be operated and maintained to ensure long-term sustainability?
- What efforts are required in testing and validating the FEWS?

The FEWS support Baguio City's vision of becoming a truly resilient, dynamic, and smart city. The end-goal of the Flood Early Warning System (FEWS) development for Baguio City is to improve the city's resilience to flooding by facilitating early preparedness. The value added by the FEWS is an increase in reaction lead time by way of forecasting water levels in the four main rivers, and link this to the risk of flooding in Baguio. The FEWS is developed in collaboration with the Baguio Local Government Unit (LGU) and other key stakeholders to improve community disaster preparedness, raise awareness, and ensure ownership. At the core of its design, the FEWS is an IT system, composed of back-end and front-end components. The FEWS system has successfully been configured to run automated jobs to acquire the currently available real-time data and information from external data sources, perform data checking for timeseries analysis and visualization, and run forecast models. The front-end development of the system includes a dashboard that triggers warning messages on the basis of pre-defined thresholds. The data outputs from the system are translated into flood warnings which can, following a system testing and validation phase, be disseminated to various stakeholder groups through different channels. As part of the real-time data acquisition, a total of 5 new gauging stations (4 water-level stations and 1 tandem station) have been installed on the two main river basins within Baguio: the Balili and Bued basins. The FEWS could yield significant benefits in Baguio and serve as a tool to provide timely flood warnings to Baguio's residents. The design of the inclusive people-centric FEWS is a tool to reduce the climate change-enhanced risk of flooding by providing appropriate and applicable early warning to those who might be left behind — that is, the most vulnerable and marginalized.

The FEWS is heavily data dependent; hence, reliability and quality are key to ensuring the success of the project. A highly technical, smart, and resilient IT framework to house the system has been established using MIKE OPERATIONS, a state-of-the-art software product for model-based forecasting. The deployment of the MIKE OPERATIONS platform has been completed at the LGU premises comprises three key servers: MIKE OPERATIONS Web Server Hardware Information, MIKE OPRERATIONS Platform Server Hardware Information, and Backup Server. All servers have been inspected during the site visits in June and September 2022. The FEWS IT system has initially been installed at the servers located in the Management and Information Technology Division (MITD), at the Baguio City Hall. In time, it is expected that the system will be moved to the Smart City Command Center (SCCC), which is envisioned to be the anchor for all smart city solutions/initiatives in Baguio.

The ownership of the FEWS is with the LGU. Within LGU, the system is anchored between three institutional bodies: City Disaster Risk Reduction and Management Office (CDRRMO) and its Emergency Operations Centre (OPCEN), Management Information Technology Division (MITD), and Baguio Smart City Command Center (SCCC). It was essential to place the FEWS into the already established organizational structure to leverage the connections between LGU staff and peer organizations, to facilitate knowledge exchange, and ensure long-term effectiveness beyond the completion of the pilot project in December 2022. Through stakeholder partnerships with public and private organizations as well as academia, the LGU can gain knowledge, experience and innovation improving the overall impact and usefulness of the FEWS for the City of Baguio. These partnerships provide two-way benefits, where the partnering organizations gain access to the data and outputs from the FEWS. By partnering with the LGU on the FEWS the partnering organizations can demonstrate their support and commitment to protecting the citizens of Baguio by ensuring timely and inclusive flood warnings. Important MOAs have been signed with DOST-CAR and PAGASA, outlining the key roles and responsibilities of each partner as well as the LGU. The MOAs enable collaboration and formalizes working arrangements around maintenance, technical support, and data-sharing between the agencies, but it is ultimately up to the respective agencies to take the responsibility required. In addition to the achieved MOAs, it is recommended to establish MOAs with Saint Louis University (SLU), which is under preparation, and DOST-ASTI.

To enable effective operation and maintenance of the FEWS for Baguio, a FEWS Operation and Maintenance (O&M) Team has been formed. The ownership of the FEWS is anchored at the Local Government Unit (LGU) and thus, the O&M core team consists of LGU staff with support from a peer team of representatives from academia and selected relevant agencies (i.e. PAGASA, DOST-CAR, BCDEO). The team members have completed a 'Targeted Capacity Building and Training Program', a year-long program consisting of online instructor-led and self-paced training modules and on-the-job training. To further enhance long-term sustainability of the FEWS, the LGU should continuously ensure that the O&M team members are available to perform the required tasks. It is crucial that O&M team is institutionalized and well-trained, and that team members have the mandate to prioritize the required tasks. Standard Operating Procedures have been prepared for the FEWS which contribute to enhancing sustainability by outlining specific activities and tasks to be undertaken by the FEWS O&M team and serving as a guide for the team throughout the different operation and maintenance phases (i.e. pre-monsoon, monsoon, post-monsoon).

The FEWS has been fully installed at the LGU servers but it was not possible to complete online testing and operational acceptance during the 2022 monsoon. The finalized system with the calibrated models and WRF inputs was not running during the monsoon of 2022, and therefore a full-scale test of the system during real-time operation has not yet been completed. Furthermore, given the starting point of the O&M team, it has not been possible to bring the O&M team to the necessary professional level to enable them to be fully responsible for the operation and maintenance of the FEWS system once the pilot project is completed in 2022. More training and technical support is required to the LGU as the FEWS O&M group needs to be able to perform a full-scale testing of the system, for which more dedicated OTJ training is needed. The team needs to gain experience in collaborating on operating and maintaining the FEWS and refining internal communication lines and work procedures as well as establishing confidence in working as a team before they can be expected to successfully operate the system independently. Thus, to validate and test the FEWS the LGU will continue to require technical assistance in preparing for a full-scale monsoon testing, running troubleshooting and feedback loops during the monsoon, and fine-tuning the system during a post-monsoon period. If this is not provided, it is very likely that the effort of the last couple of years will slowly start falling apart, and the competencies that are being built through the Capacity Building Program and the OTJ training sessions will become stagnant. It should be understood that the need for testing is not limited to one single monsoon season, as any FEWS requires proper validation (several monsoons) before it's publicly launched. Launching a FEWS without proper testing and troubleshooting time can have serious consequences on the credibility of the LGU and ultimately on the confidence in the system itself.

10 RECOMMENDATIONS

Source: Adobe Stock

The following activities/tasks are recommended as part of a project consolidation phase to finetune, validate, and test the FEWS for Baguio City:

10.1 UPGRADING EXISTING GAUGING STATIONS

This task entails improvement of the consistency of real-time data from existing stations. The task covers both the rainfall data captured by the rainfall gauges owned by PAGASA, and the real-time water level data captured through the water-level sensors operated by ASTI, with both data types being published at the philsensor website, to which access has been provided by ASTI via the APIs. This is a fundamental task to complete, as the existing stations have not been working consistently throughout 2022. The historical data from these stations, prior to 2022, also contains significant inconsistencies and gaps, with a few exceptions covering limited periods of time. To solve the issues, the equipment at the existing stations would likely need replacement as identified by DOST-CAR.

10.2 MODEL IMPROVEMENTS

The model will be updated, with some updates implemented pre-monsoon to be tested during the monsoon period and additional updates will be implemented post-monsoon following monsoon data capture and assessment of system performance.

10.2.1 DEVELOPMENT OF BIAS CORRECTION FACTORS FOR FORECAST RAINFALL DATA (WRF)

This task will be done using the station rainfall data (historical) referred to in the paragraph above, and also using the historical WRF data which has already been collected. The overall objective here is to improve the forecasts from the FEWS, for which the developed models are calibrated using station rainfall data. This task should take place before the monsoon so the real-time performance testing can be carried out during the monsoon.

10.2.2 IMPROVEMENTS IN MODEL DATA ASSIMILATION AND MIGRATION OF UPDATED FEWS TO THE MITD SERVER

Data Assimilation is a specific module included in the Mike HYDRO river model. The appropriate period to be considered for error calculation, which is an important part of the Data Assimilation setup at each station location, will be assessed during the real-time system operation. Assessment of the appropriate period to be considered for error calculation in real-time operation with respect to each station location will be completed ahead of the monsoon, and the updated system will be migrated to the MITD server.

On a daily basis, it will be assessed how well the data assimilation is working by sitting with the model, preferably on-site in Baguio so that this activity can also be coupled to OTJ training and O&M activities. This will then be followed-up with additional iterative offline model test runs post-monsoon.

10.2.3 IMPROVEMENTS IN STAGE DISCHARGE RELATIONSHIPS AND SUBSEQUENT UPDATES TO THE MODELS

The stage-discharge relationships currently applied to derive the calculated discharge are generated using the inbuilt tool in MIKE Hydro. These should be revised based on simultaneous measurements of water levels and flow data, but this requires further development. Measurements should be taken in the next few monsoons and non-monsoon seasons to have sufficient data to apply this system improvement.

10.2.4 EXTENDING CALIBRATION PERIOD – CAPTURING MORE DATA

Due to the inconsistencies and gaps in the station data, a limited period of 2-3 years has been identified for calibration based on historical station data. This period should be longer to ensure models are reliable and truly representing the catchment hydrology. Models need to be continuously improved every year, with addition of more and better monsoon data and with a more consolidated data assimilation.

10.2.5 INCLUSION OF DATA FROM NEW STATIONS

As the purpose in the FEWS is to continuously get better coverage of rainfall data and more water-level calibration points, the additional data collected for the new stations installed in 2022 will also be used for improvements in model calibration post-monsoon, i.e., they cannot be used for the model being run in 2023 and can first be used in the model calibrated for monsoon of 2024. It should be noted that these new stations are indeed used for water-level data assimilation and this process will indeed be tested during the upcoming monsoon seasons.

10.2.6 DEVELOPMENT OF BARANGAY-LEVEL WARNINGS BASED ON IMPROVED RAINFALL DATA INPUT AND FLOOD MAPS

This task can be postponed until the full-scale testing of the system has taken place and lessons have been drawn regarding how the system is emitting warnings on the Dashboard. WRF data, which have been bias-corrected against station rainfall data, will be compared to rain intensities for various return periods (as per existing IDF curves developed by PAGASA) and based on this comparison, flood warnings will be triggered by the FEWS for the various at-risk barangays. This will allow the FEWS to benefit areas in the city which experience flooding not just due to the riverine flooding but also due to other issues such as insufficient or blocked urban drainage infrastructure. For identifying the at-risk barangays with greater reliability, flood maps will need to be prepared for more return periods as required and the ones prepared already will need to be prepared again based upon new rain data analysis using only most appropriate station data. The same stations would be used for the bias correction of the WRF data to ensure proper correlation.

10.3 FINALIZE THE FEWS GOVERNANCE AND O&M ROUTINES

The setup of the overall FEWS O&M group is well established, but still requires improvements such as finishing its composition (i.e., the technicians still need to come on board) and getting it ready for the full-scale testing. Moreover, the overall FEWS Governance is still missing important aspects regarding the ownership of the existing stations and the necessary extra agreements with DOST-ASTI, SLU, and PAGASA.

Regarding the existing stations, more work needs to be done to fully clarify what is up and down in the existing setup. It is very likely that all data loggers in the 5 existing stations will have to be replaced, meaning that all stations will likely have to be re-installed from scratch. Although representing a cost, the benefits in the long-term outweigh these as Baguio would then be equipped with a total of 10 newly installed and modern gauging stations, which will ensure connectivity, real-time operations, and a proper data assimilation, all of which is required for a sustainable FEWS. This task should take place as soon as possible, as it affects the proper development of other tasks outlined in this section.

10.4 OTJ TRAINING SESSIONS

As outlined in this report, the LGU needs more dedicated on-the-job training sessions with a special focus on the full-scale testing of the FEWS. For this, two training phases are proposed on-site where key experts will be in Baguio and sit together with the entire O&M team, similar to the OTJ training activities completed in 2022. The training phases would take place in June and October/November. This would allow the O&M team to fully come together for testing and validating standard operating procedures of the FEWS while being supported and guided by technical experts.

10.5 PRELIMINARY ROADMAP FOR CONSOLIDATION PHASE

A preliminary consolidation phase roadmap has been prepared outlining the planned activities and deliverables (only at a very high level for 2024 & 2025), see Figure 10-1. A Final Consolidation Plan and Roadmap will be delivered in the early stage of the consolidation phase.

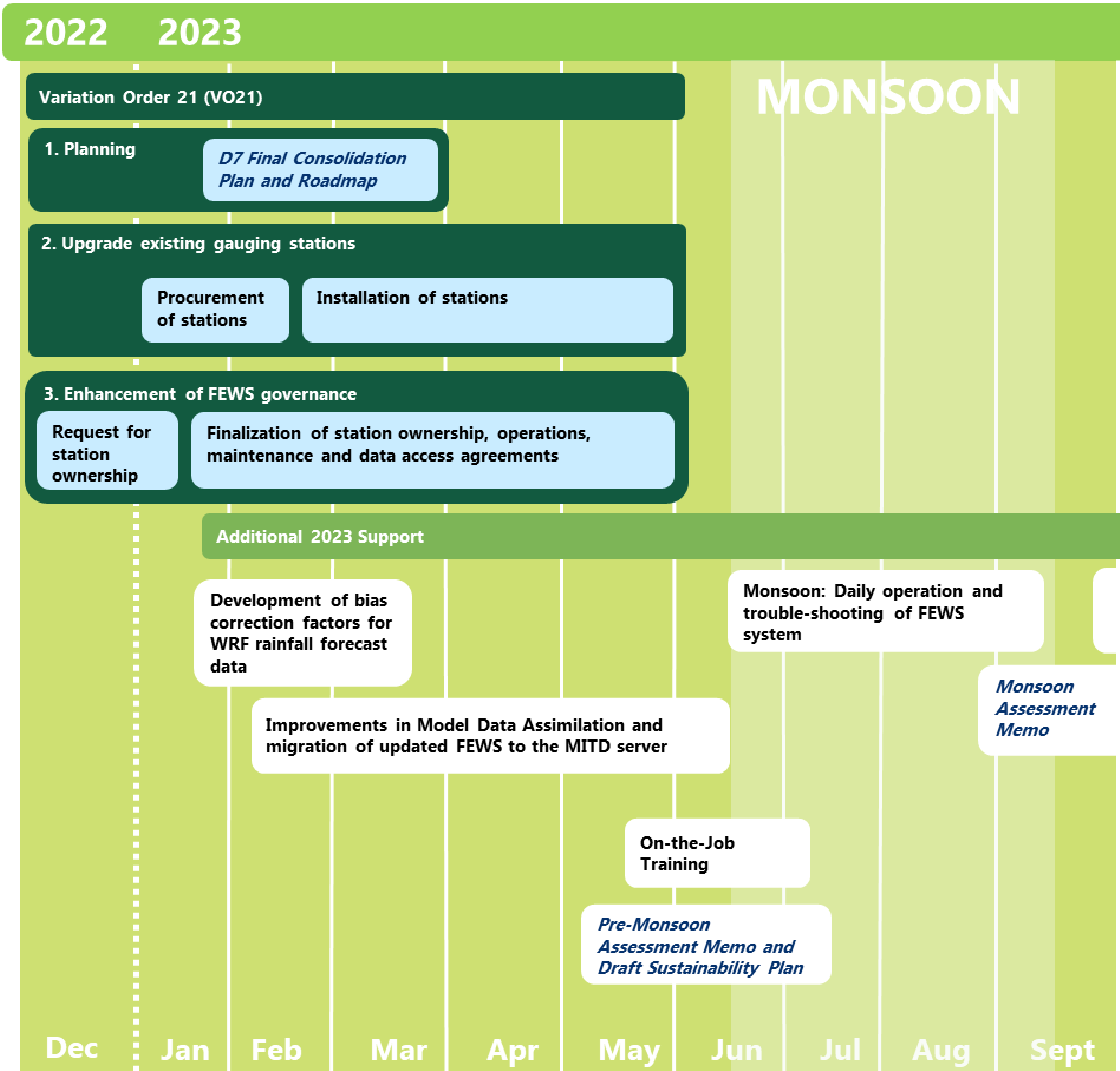


Figure 10-1 Preliminary Roadmap for the proposed Consolidation Phase
Source: Ramboll

System Performance Assessment and updates

Updates to SOPs

On-the-Job Training

Assessment of additional technical support required

Oct | Nov | Dec

2024

Technical support to LGU (*extend to be scoped in 2023*)

System Performance Assessment and updates

On-the-Job technical support

Surveys of water levels and discharges for development of stage-discharge relationship

Support for validation of data dissemination and outreach plan including integration of GESI actions

Development of Barangay-based warnings based on improved rainfall data input and flood maps

2025

Technical support to LGU (*extend to be scoped in 2024*)

System Performance Assessment and updates

On-the-Job technical support

Update model calibration based on new stage-discharge relationships

Support for validation of data dissemination and outreach plan including integration of GESI actions

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Source: Adobe Stock

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