Development of a Multi-Hazard Platform (MHP) for forecasting local level climate extremes and physical hazards for Iskandar Malaysia

Final report

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Summary

The Multi-Hazard Platform (MHP) project, commissioned by the Climate Technology Centre and Network (CTCN) under the UNFCCC and executed by Deltares, aims to enhance climate resilience in Iskandar Malaysia through the development of a localized, people-centred forecasting and decision-support system. The initiative responds to increasing climate-related risks—particularly flooding—exacerbated by rapid urbanization, sea level rise, and extreme weather events in the region.

The project's overarching goals are:
- To develop technical specifications for integrating local climate and hazard risk data into a forecasting platform.
- To build a prototype MHP tailored to Iskandar Malaysia and outline the financial and operational requirements for full deployment.
- To strengthen local capacities through training, stakeholder engagement, and knowledge products.

The platform focuses on five local authorities within Iskandar Malaysia, a rapidly developing coastal economic region in southern Johor, Malaysia. The MHP is designed to support early warning and risk-informed decision-making for flood hazards, but can in the future be extended to include other hazards such as droughts, and heat stress.

The project was structured into four phases:
- **Phase 1: Inception** – Development of a detailed work plan and initiation of data collection.
- **Phase 2: Functional and Technical Design** – Definition of platform functionalities and technical requirements through stakeholder workshops, literature review, and analysis of existing systems.
- **Phase 3: Prototype Development** – Construction of a working prototype using Delft-FEWS, integration of hydrological and hazard models, and estimation of costs for scaling.
- **Phase 4: Capacity Building** – Training, development of early action protocols, and dissemination of knowledge products.

The methodology included stakeholder consultations, data acquisition from local and global sources, statistical analysis, and model development. Key models integrated into the platform include:
1. **Wflow** for hydrological simulations,
2. **SFINCS** for flood hazard mapping,
3. **FIAT** for flood risk assessment.

Key Results and Findings
- **Functional and Technical Design**: The MHP was built on the Delft-FEWS platform, enabling integration of diverse datasets and models. It supports real-time monitoring, forecasting, and automated reporting tailored to different user groups.
- **Flood Risk Assessment**: Using historical and forecasted data, probabilistic hazard maps were generated for various return periods. The FIAT model calculated Expected Annual Damage (EAD) and population impact across administrative zones, identifying high-risk areas such as Plentong and Pulai.
- **Prototype Capabilities**: The system can simulate and visualize flood scenarios, estimate economic and social impacts, and generate early warnings. It includes features for heat stress and drought indicators, demonstrating its multi-hazard potential.

- **Stakeholder Engagement**: Workshops helped define user requirements and align the platform with Malaysia's NADMA Directive No. 1, ensuring institutional compatibility and operational relevance. Throughout the engagement series, stakeholders acknowledged the value of MHP in supporting the integration aspect both before and during disaster events. However, concerns were consistently raised regarding data integration and data sharing, particularly on issues of data ownership, accessibility, and interoperability across different agencies and platforms.
- **Financing and Sustainability**: A phased implementation strategy was proposed, with estimated costs ranging from USD 1.0 to 2.1 million for Phase 1. Recommendations include securing long-term funding, establishing institutional arrangements, and investing in human resources and IT infrastructure.
- **Capacity Building and Early Action Protocols**: Training needs assessments revealed gaps in technical expertise and gender representation. Early Action Protocols were developed to guide anticipatory responses based on forecast triggers, ensuring timely and coordinated disaster management.

Conclusion

The MHP prototype represents a significant step toward climate resilience in Iskandar Malaysia. It integrates hazard data, forecasting models, and stakeholder input into a unified platform that supports both planning and operational decision-making. The system's scalability and modularity make it a blueprint for broader application across Malaysia. Future phases will focus on operationalization, expansion to other hazards, and embedding the platform within institutional frameworks to ensure sustainability and impact.

By strengthening early warning systems and risk-informed planning, the MHP directly advances climate adaptation by reducing vulnerabilities to extreme weather and climate-related hazards. The platform's integrated datasets also provide insights that can guide sustainable land-use, low-carbon infrastructure, and energy-efficient development, indirectly supporting mitigation efforts. Together, these functions position MHP as both a disaster risk management tool and a catalyst for broader climate action in Iskandar Malaysia.

Contents

List of acronyms

Acronym	Full Form
APM	Angkatan Pertahanan Awam Malaysia
BBWS	Balai Besar Wilayah Sungai (River Basin Authority - Indonesia)
BMKG	Meteorological, Climatological, and Geophysical Agency (Indonesia)
BNPB	National Disaster Management Agency (Indonesia)
BPBD	Regional Disaster Management Agency
CCM	Construction Cost Malaysia
CTCN	Climate Technology Centre and Network
DID	Department of Irrigation and Drainage
DMG	Department of Minerals and Geoscience
DOSM	Department of Statistics Malaysia
DPU-DKI	Department of Public Works - Jakarta
DTAP	Development, Testing, Acceptance, and Production
EAD	Expected Annual Damage
ERA5	ECMWF Reanalysis 5th Generation
EWS	Early Warning System
FIAT	Flood Impact Assessment Tool
FTE	Full-Time Equivalent
GFS	Global Forecast System
GLOFFIS	Global Flood Forecasting Information System
GPM	Global Precipitation Measurement
GTSM	Global Tide and Surge Model
IAO	Interdepartmental Coordination Meeting
ICCb	Interdepartmental Crisis Management Committee
IM	Iskandar Malaysia
IPO	Association of Provinces
IRDA	Iskandar Regional Development Authority
JPBD	District Disaster Management Committee
JPBN	State Disaster Management Committee
JPBP	Central Disaster Management Committee

Acronym	Full Form
JRC	Joint Research Centre (European Commission)
JUPEM	Department of Survey and Mapping Malaysia
LCW	National Coordination Committee on Water Distribution
MCCb	Ministerial Crisis Management Committee
MET	Malaysian Meteorological Department
MHP	Multi-Hazard Platform
MKN	Majlis Keselamatan Negara (National Security Council)
MTW	Water Shortages Management Team
MYSA	Malaysian Space Agency
NADMA	National Disaster Management Agency
NCC	National Crisis Centre
OSM	OpenStreetMap
PSF	Python Software Foundation
PUSAIR	Research and Development Center of Water Resources (Indonesia)
QGIS	Quantum Geographic Information System
RDO	Regional Drought Coordination Meeting
SFINCS	Super-Fast INundation of CoastS
SLA	Service Level Agreement
SOP	Standard Operating Procedure
SPI	Standardized Precipitation Index
UNFCCC	United Nations Framework Convention on Climate Change
UvW	Association of Regional Water Authorities
Vewin	Drinking Water Association
Wflow	Grid-based hydrological model developed by Deltares
WMCN	Water Management Centre Netherlands
WMO	World Meteorological Organization
WSF	World Settlement Footprint

1 Introduction

South-East Asia is one of the regions that is affected strongest by climate related hazards, from extreme floods to extreme droughts. High population density amplifies the impact of these climate hazards. Climate change, including the effects of sea level rise, will further increase the risks. Figure 1-1 for example shows the low lying areas in the regions that are below 5 meters above mean sea level in 2020 (left panel) and when mean sea level would be 1 meter higher due to sea level rise (right panel). Large areas in heavily populated (delta) regions will become more vulnerable to coastal flooding.

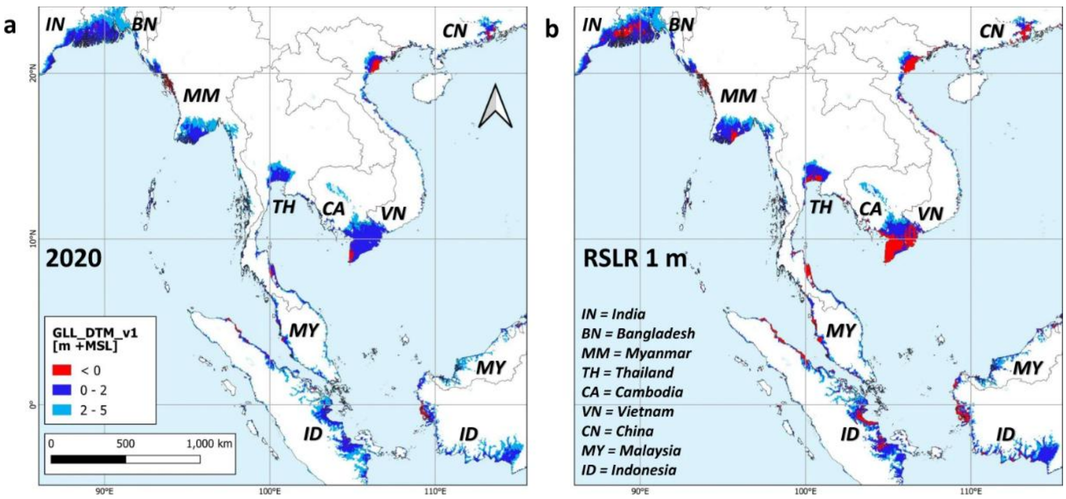


Figure 1-1 Land in South-East Asia below 5m above mean sea level (source: Hooijer et al., 2021).

This example shows there is a need for countries and regions to adapt to the new situation. To support action, local risk-based information is of critical importance to make plans for the future and to enhance early warning. This is also recognized by WMO in their “Early Warning for All” initiative, that identified 4 pillars for successful early warning systems as shown in Figure 1-2.

The first pillar is about **disaster risk knowledge**, which comprises the collection and generation of critical information that can be used for planning and to inform actions in time of occurrence of a specific hazard. This step includes the generation of risk maps and understanding where are the high risk areas, now and in the future.

The second pillar is about **collecting and sharing data** and information. Combining data from a variety of sources enhances insight into the situation. Data integration and making it accessible and interoperable are critical components of a successful early warning system.

Pillar three focusses on **preparedness and response**. Knowing what to do prior to when a disaster happens will improve the success rate of the actions taken. In times of disasters, every minute won could make a difference. Having early warning protocols in place, and train people on how to use them, is a key-factor for successful early warning and response.

The last pillar is about **communication** of hazards. In the end, information that is not shared or shared in terms and language that cannot be understood by the people that receive the information, is useless. Therefore, preparing knowledge products and bulletins that are well understood by the receivers of the information is very important. Finally also the end-to-end delivery of the information needs to be well designed and be operational also in times that, for example, telecommunication systems are down.

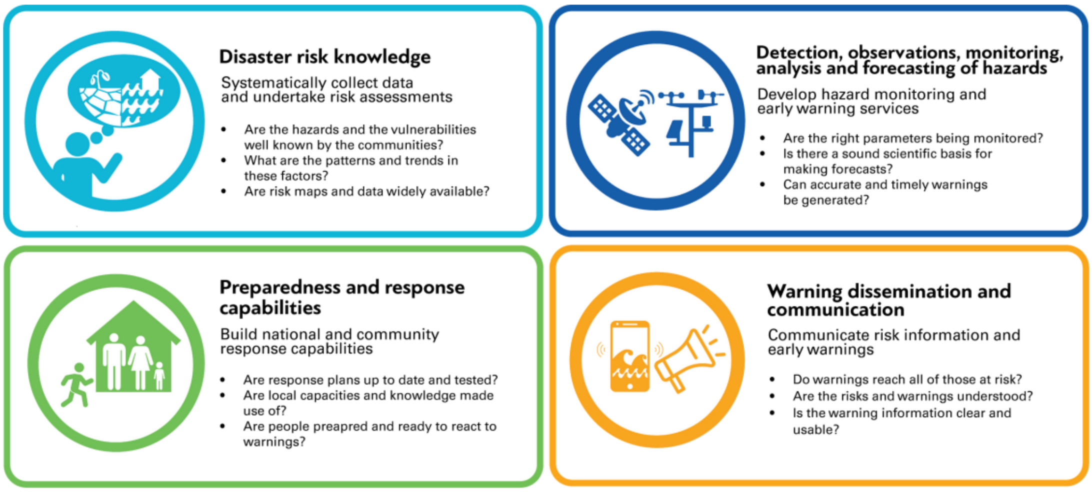


Figure 1-2 The four components of an early warning system (WMO, 2022).

The Climate Technology Centre and Network (CTCN), being the operational arm of the United Nations Framework Convention on Climate Change (UNFCCC), received and awarded a request from Malaysia to provide Technical Assistance (TA) on Development of a Multi-Hazard Platform for forecasting Local level climate extremes and physical hazards for Iskandar Malaysia. The objective of the TA is to enable Iskandar Malaysia to take early actions to mitigate climate risk through a decision support system designed in an inclusive manner and based on the understanding of the local level climate extremes and their impacts by integrating them into a prototype Multi-Hazard Platform (MHP) focusing on coastal hazards.

Coastal areas in Malaysia are largely affected by various hazards (floods, droughts, erosion, etc.) affecting its growing population and increasing number of assets. Combined with climate change and sea level rise, these hazards threaten the fast-growing coastal developments in Malaysia.

The TA delivered a prototype decision support tool which demonstrates how a multi-hazard platform for five local authorities of Iskandar Malaysia can help address growing climate change risks of this important coastal economic zone.

The overall goal of the project was to (1) develop technical specifications to design and integrate information on local climate extremes and hazard risks in a multi-hazard platform (MHP) for Iskandar Malaysia (IM), (2) develop a prototype and establish the financing requirements to operationalize the MHP for IM, and (3) improve local capacities in implementing a people-centered forecasting system using social innovation.

The project, commissioned to Deltares, aimed to capacitate the Iskandar Regional Development Authority in the development of a prototype of the multi-hazard platform. There were basically 4 main tasks in the project, preceded by an inception phase:

1 Task 1: Inception phase to deliver a detailed workplan.
2 Task 2: The functional and technical design of a multi-hazard platform.
3 Task 3: The development of a prototype of the multi-hazard platform.
4 Task 4: Improve local capacities in implementing a people-centered forecasting system.

In the inception phase the team has worked out in more detail the workplan and established the form of communication between our team and IRDA. A start was made with the data collection process, which includes the collection of relevant reports and information on data portals.

After approval of the workplan delivered in the inception phase work, Task 2 to develop a functional design of the multi-hazard platform was started. A functional design describes the functionalities that should be included in a multi-hazard platform. This task was a joint effort between our team, IRDA and potential other stakeholders. Based on a literature review and the information collected from key stakeholders, an overview of the current situation and the desired situation was made. Based on the functional design, a technical design is made. The technical design covers more details, for example on data requirements, hydrodynamic and hydrological modelling, etc.

In Task 3 a prototype of the multi-hazard platform has been developed. The functional and technical design were used as input for the prototype, but the prototype does not fully cover all elements from the functional and technical design. An implementation plan, including a rough cost estimate for the development of a fully functioning prototype was developed in parallel to demonstrate how the prototype can be upscaled.

Task 4 focused on improving local capacities through a workshop, training sessions and the development of knowledge products. These knowledge products were designed in close collaboration with key stakeholders and were made fit to local conditions. The prototype developed in Task 3 was used as input for the capacity building and knowledge product development.

This document describes the results of the project. The functional and technical design of a Multi-Hazard Platform for Iskandar Malaysia and the prototype development. The design shows how risk information is collected and can be shared via the platform. An overview of relevant datasets is presented, as well as how the data is used for e.g. the model setup, statistical analysis and generation of risk information. The document also contains an overview of the technical implementation of the multi-hazard platform in the Delft-FEWS software. Finaly the document also explains the financing requirements for implementing an operational MHP.

The report also described how the project contributed to the strengthening of local capacity in providing early warning. This includes assessing capacity needs, conducting targeted training programs, developing early warning protocols, and creating risk information and knowledge products to enhance decision-making and preparedness.

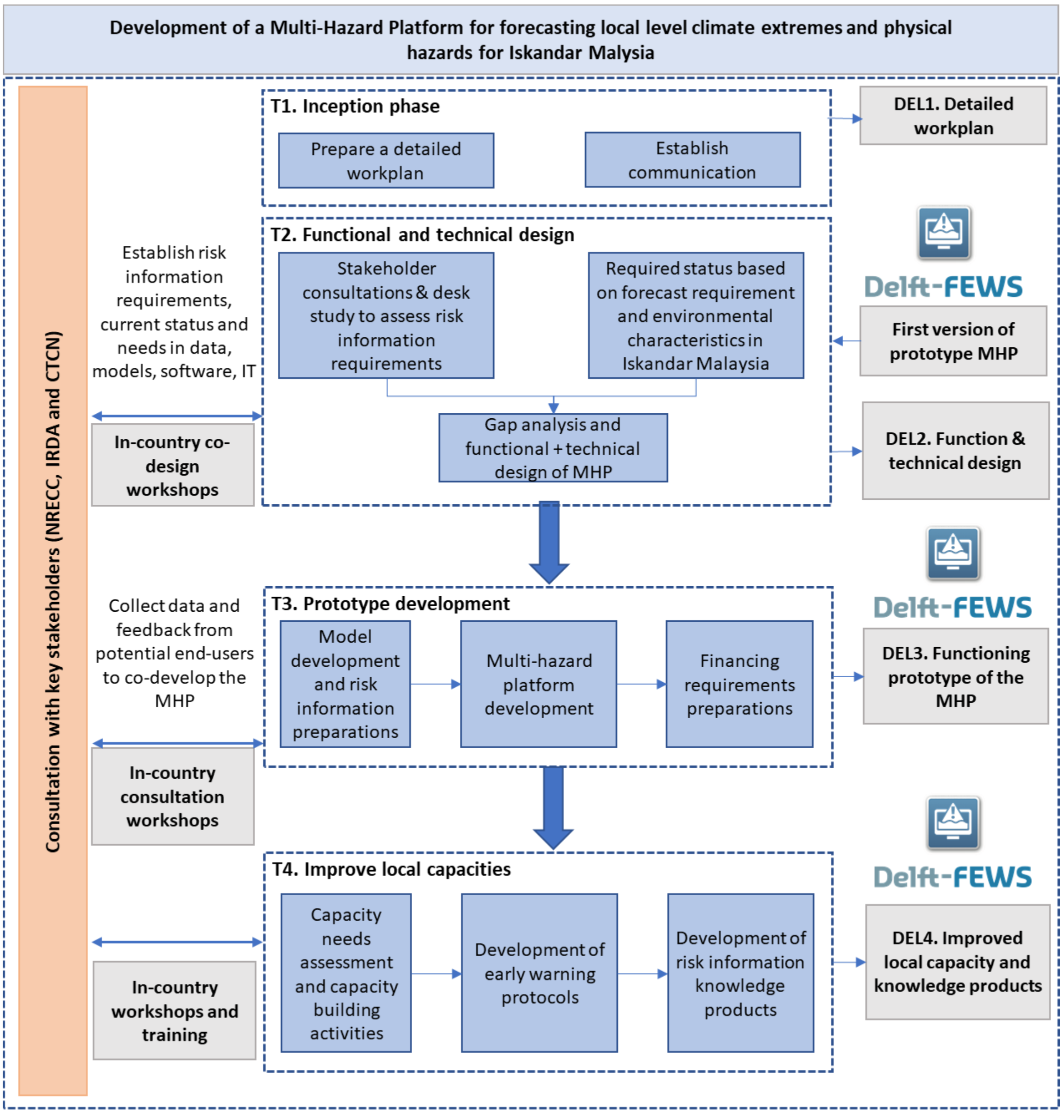


Figure 1-3 Project outline with in red the phase corresponding to this report.

2 Study area

The development of a Multi Hazard Platform (MHP) was piloted for Iskandar Malaysia (IM) area. It is a special economic development zone located in the southern region of Johor, in the southernmost part of Peninsular Malaysia. Established in 2006, it is part of the Malaysian government's strategic initiative to boost regional economic growth and attract investment. Covering approximately 2,217 km^2, it is nearly three times the size of Singapore. Figure 2-1 presents the study area for this projects. IM has a strategic connectivity to Singapore. With a mix of coastal areas, riverine systems, and mangrove forests, its population is around 2.3 million and is mainly concentrated in Johor Bahru. IM also has several important areas of manufacturing industries and tourism.

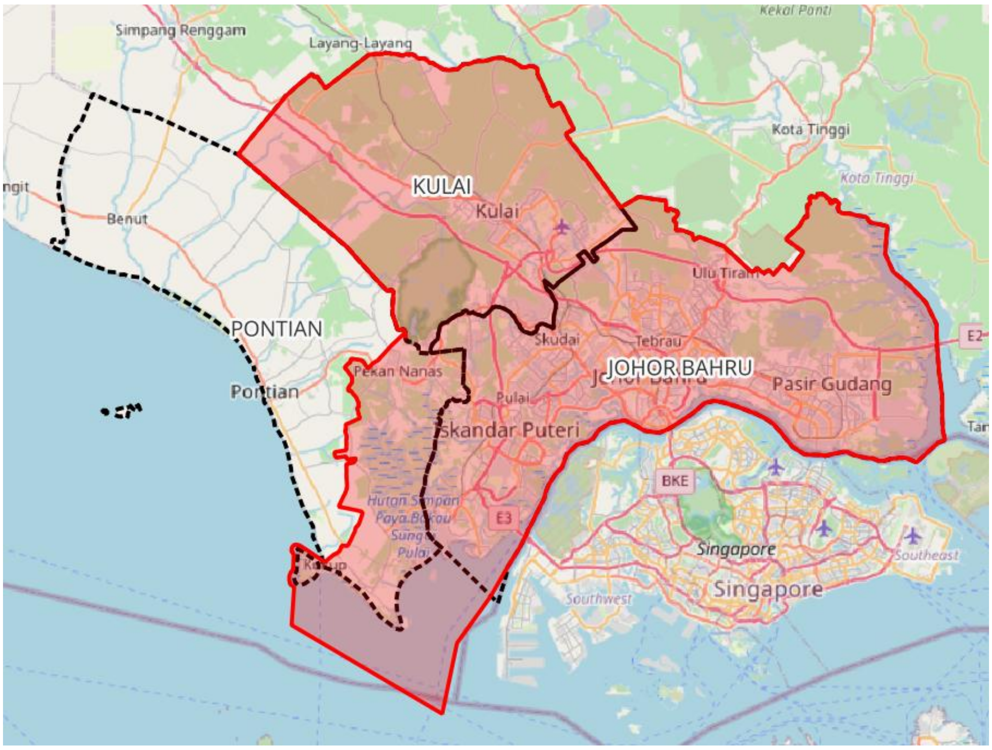


Figure 2-1 Study area indicated by the red area.

The area is characterized by a hilly central region with steep slopes and flat areas with low elevation near the coast. Heavy rainfall in the higher parts runs off quickly towards the river valleys and flatter parts. Population and economic activities are mostly located in the lower parts of the catchments, as can be seen in Figure 2-2. Rivers like Sungai Skudai and Sungai Tebrau are heavily polluted and experience sedimentation, reducing their capacity to handle large volumes of water during episodes of extreme rainfall (Kamal, Muhammad, & Abdullah, 2020). With the rapid expansion of urban areas, its impervious surfaces created a new challenge for the natural infiltration of rainwater. Its low-laying region also facing a challenge for the high tides, storm surges, as well as the sea level rise.

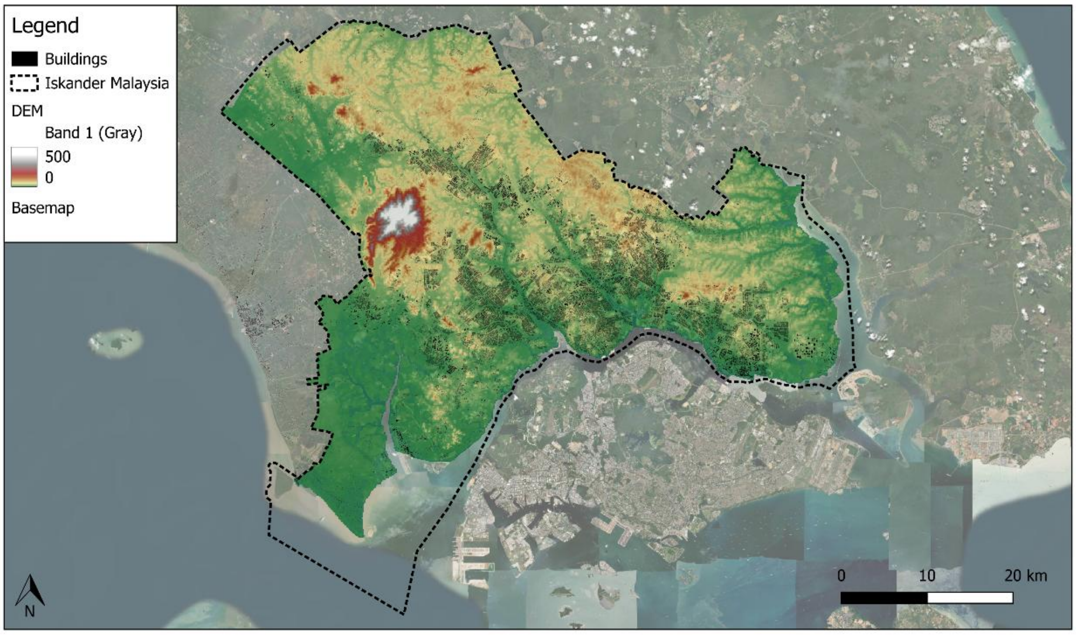


Figure 2-2 Elevation and location of buildings (both residential and economic) for the Iskandar Malaysia region.

Flooding disrupts transportation and access to services, including the movement of goods and people between Johor Bahru and Singapore. Flood-related damages to infrastructure, businesses, and homes result in significant economic costs for residents and industries. In 2021 (Figure 2-3), heavy rainfall caused severe flooding in parts of Johor Bahru and other areas in Iskandar Malaysia, displacing hundreds of residents and highlighting the urgent need for better flood management solutions. Other major events in 2022 and 2023 caused damage and forced many people to evacuate and led to the loss of their houses. Therefore, in this project, floodings are used as a pilot hazard in MHP.

Figure 2-3 Kampung Laut near Skudai flooded on January 2, 2021 (source: Bernama pic).

Figure 2-4 Flood in Johor Bahru on August 2, 2022 (source: paultan.org).

Data has been collected for this region specifically, but most of the methods can also be applied to other regions in Malaysia. The functional and technical design therefore can be seen as a blue print for applications across Malaysia.

3 Methodology

3.1 General approach

The multi hazard platform is used for different purposes, but a lot of the base data and information can be utilised for these different purposes. The two main use cases for the platform are:

- Baseline for flood risk assessment
- Preparing real-time flood risk information and warnings

At the basis of it all is the basic hydrometeorological data and information. As the focus of the prototype is on flooding, the main inputs are rainfall, discharges and (coastal) water levels. The data is collected from local, regional and national data providers. The platform is also able to integrate global datasets to complement the local information. The platform is used to streamline the data collection process and provide common access to the data.

Delft-FEWS is used as the engine for the platform. Delft-FEWS is an open platform for data and workflow management. Data from different providers and with different formats can be ingested into the central database and visualized with the different data displays. Both scalar time series data and spatial (gridded) data can be stored and visualized. Delft-FEWS can also be used to standardize the data, or do data quality checks.

One of the model components in the system is a hydrological model to translate the rainfall into runoff. In the prototype, the Wflow model was used, which is an open-source grid-based and physics-based hydrological model. The outputs of the model include discharge estimates at any location within the model domain.

The discharge estimates are used as input for the flood inundation model, SFINCS. With the SFINCS model, detailed flood maps can be generated. SFINCS also takes input from downstream boundaries, such as the coastal water levels. The SFINCS model is used to derive flood hazard maps for all relevant combinations of boundary conditions.

Using real-time weather data, actual flood hazard maps can be generated, using the model workflow, and be visualized in the platform. The same model workflow can also be used to translate historical rainfall or coastal events into flood hazard maps corresponding to specific return periods. This will provide information to planners to optimize their flood defenses of flood mitigation strategies.

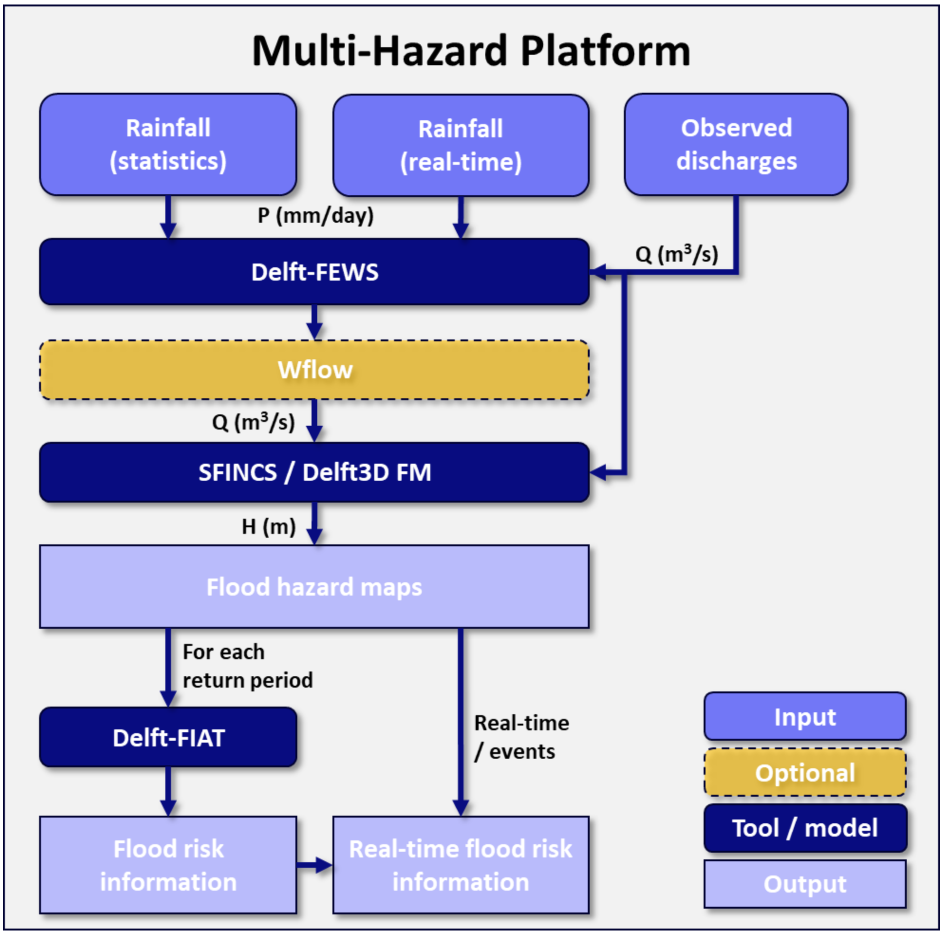


Figure 3-1 Schematic overview of the MHP components and their connections.

3.1.1 Stakeholder Consultation Workshops for data collection

The consultant conducted several workshops to gather information about the stakeholder needs, where to find the data for the development of MHP IM and the existing platforms that can be connected to MHP IM.

The first workshop was conducted in-person on 11th March 2024 at Johor Bahru Malaysia and was attended by the relevant stakeholders who might provide data to MHP IM, co-develop the MHP IM, operate the system and make use of the MHP IM.

In the workshop, there were three breakout sessions that were used to gather information from the stakeholders. The topic for each breakout session was as follows:

1 Data requirements (see Annex A for an overview of collected information)
2 Existing system/platforms (see Annex B for an overview of collected information)
3 User requirements and user perspectives

For each breakout session, the consultant has prepared several questions to be answered by the workshop participants. These questions are meant for triggering the thinking process and to help the consultant to get valuable information for the functional and technical design of the platform. The following table summarizes the results of the workshop.

Figure 3-2 Group picture after the morning session of the 11 March workshop.

On 24th of June, 2024, a second technical workshop was conducted. The purpose of the workshop was to go into more detail about data requirements and support the data collection process. During the workshop the team shared initial functional and technical design and demonstrated how data can be used in the system.

3.1.2 Data collection

To build the Multi-Hazard Platform Iskandar Malaysia (MHP-IM), various types of data are required. The quantity of data needed depends on the number of hazards intended to be monitored within the MHP-IM. Based on the results of the first workshop and discussions with IRDA, the consultant recommended that the prototype MHP-IM Iskandar Malaysia should focus on hydro-meteorological hazards such as floods, heat stress, and drought, as these disasters often have the most significant impact on the region. Therefore, for this project, the consultant will focus exclusively on gathering data related to hydro-meteorological hazards.

In this project, the approach used by the consultants to acquire data for issuing flood, heat stress, and drought warnings involves requesting sample data from authorized institutions in Iskandar Malaysia, utilizing available satellite imagery to address data limitations, and developing models to better assess the potential damage of a hazard. approach that is used by the consultant to acquire data for issuing flood, heat stress, and drought warnings involves requesting sample data from authorized institutions in Iskandar Malaysia, utilizing available satellite imagery to address data limitations, and developing models to better assess the potential damage of a hazard.

Some uses of the collected data include:

1 Providing an overview of the areas covered by the MHP-IM for Iskandar Malaysia;
2 Supplying information on available measurement data in the Iskandar Malaysia region;
3 Serving as inputs for modelling, as well as for model calibration and validation;
4 Offering additional information on the impacts of hazard events;
5 Acting as a trigger for issuing early warnings.

Based on its type, the data required can be categorized as follows:

- **Static data**
  a Administration Data
  Administration data such as administration boundary, is needed to aggregate the result. For decision-makers, it is advantageous to present both the results and their visualizations at the aggregated administrative level. This approach facilitates a

comprehensive understanding of the situation within specific administrative areas, thereby enabling informed decision-making regarding necessary actions.
For the decision maker, it would be helpful to present the result as well as the visualization as the aggregated result in the administrative level. This would help them to easily grasp what is happening in a certain administrative area, therefore they can decide what should be done there.

b Topographic & Bathymetric Data
Accurate elevation data is essential for generating a reliable model. Additionally, a reliable vertical reference is necessary to simulate water flow effectively.

c Building Vulnerability Data
Risk calculation are based on the infrastructure damage. Therefore, building footprint is used as the basis. Other information such as building function, valuation, and building vulnerability data are needed to translate the damage based on the flood depth to flood risk.
Building vulnerabilities data is needed to calculate the risk of a hazard.

- **Dynamic data**

a Meteorological Data
Meteorological data is a crucial foundational dataset for the MHP-IM in Iskandar Malaysia, because the hazards being monitored are hydro-meteorological in nature. Examples of meteorological data used for issuing a warning or modelling include rainfall, temperature, relative humidity, and radiation data. This data is generally obtainable from authorized agencies, but if availability or quality is insufficient, external sources, such as satellite imagery, can be utilized.
For early warning in areas where the rainfall-runoff response is slow, historical and near-real-time meteorological data is typically adequate. However, in regions with steep slopes where the runoff response is relatively rapid, weather forecasts for the next few hours or days are often integrated into the EWS to increase lead time. If a country does not have its own weather forecasting model, numerous free weather forecast models are available globally.

b Hydrological Data
Hydrological data is essential for issuing warnings about potential hydro-meteorological disasters. Some commonly used hydrological data for this purpose includes river water level data, tidal data, and river flow discharge measurements. This data is typically collected by authorized agencies. However, the availability of water level gauges is relatively limited and fewer in number compared to rainfall stations.
To accommodate this data limitation, hydrological and hydraulic models are often developed to estimate water levels and discharge rates in areas where water level gauges are available. Inputs for these (hydraulic) flood models include rainfall data, discharge data from hydrological models, and sea level data. In regions with relatively quick rainfall-runoff responses, weather forecast data and sea level forecasts are also necessary so that operators have additional time to disseminate warnings and determine appropriate actions to mitigate the impacts of disaster events. Of course, these models must be calibrated with measurement data to ensure that the estimated discharge, water levels, and inundation areas are accurate and reliable.

c Demographic & Socio-Economic Data
Demographic data, including population distribution, number of households, age, gender, disability status, education level, and income/poverty level, are essential for mapping vulnerable populations. Data can be aggregated in an administration boundary level 4 (village/kampong). Historical statistical data can help in forecasting the population and economic growth. Detailed information on these vulnerabilities will assist decision-makers in prioritizing measures for these groups.

A more detailed description of each type of data required for the prototype MHP-IM Iskandar Malaysia, including how it is obtained and the sources of how these data are collected can be found in **Annex A**.

3.1.3 Flood risk assessment

As part of the project, a flood risk information is performed. Each of the different tasks, as presented in the terms of reference, contribute to the flood risk assessment. Task 2.1 focusses on the collection of relevant data and information. The data is us as input to hazard assessment, which consist of two sub-task:

- **Statistical analysis:** Deriving return periods for drivers of flooding in Iskandar Malaysia based on historical data.
- **Coastal flood model development:** Static data, such as a high-resolution digital elevation model, is used to setup the different components of the flood model.

The statistical analysis in combination with the developed flood model is used to prepare the coastal hazard and risk assessment.

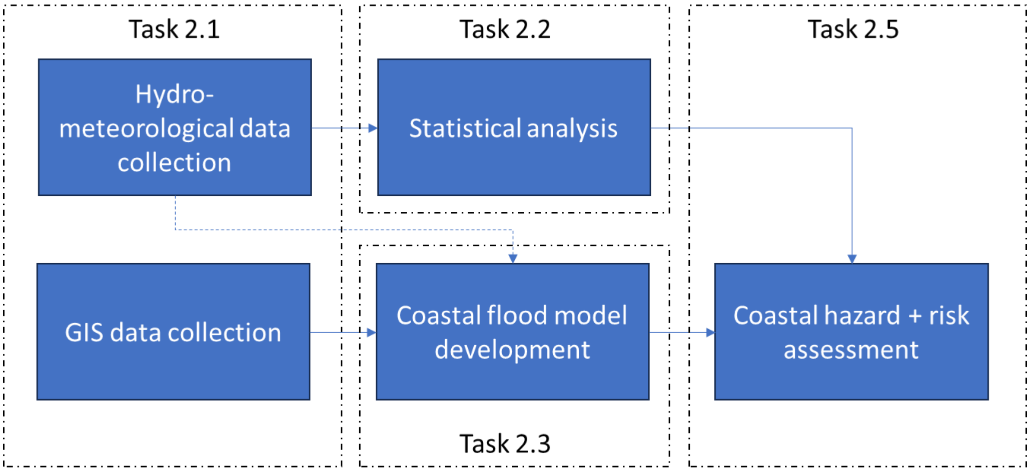


Figure 3-3 Schematic of how the data and models are used for the flood risk assessment and how the different tasks contribute to the flood risk assessment.

Flood risk (see Figure 3-1) is a function of the probability and the damages of a flood event. Damages to buildings are computed following the procedure as depicted in Figure 3-4 using damages associated with flood depth maps of different return periods. The damages for each flood map are weighted by the likelihood of a hazard map and integrated to compute the Expected Annual Damage (EAD), which is a key indicator for the flood risk for that area that is also used in the present study. The EAD is expressed in MYR per year and shown in the form of a gridded map or as a total number for the entire city or part of the city (e.g., village, ward). In this report, the term normalized EAD is used, where the total damage in a specific perimeter (a village or *mukim* boundary) was divided by the areal surface of that perimeter to avoid the EAD reflecting the differences in areal surface.

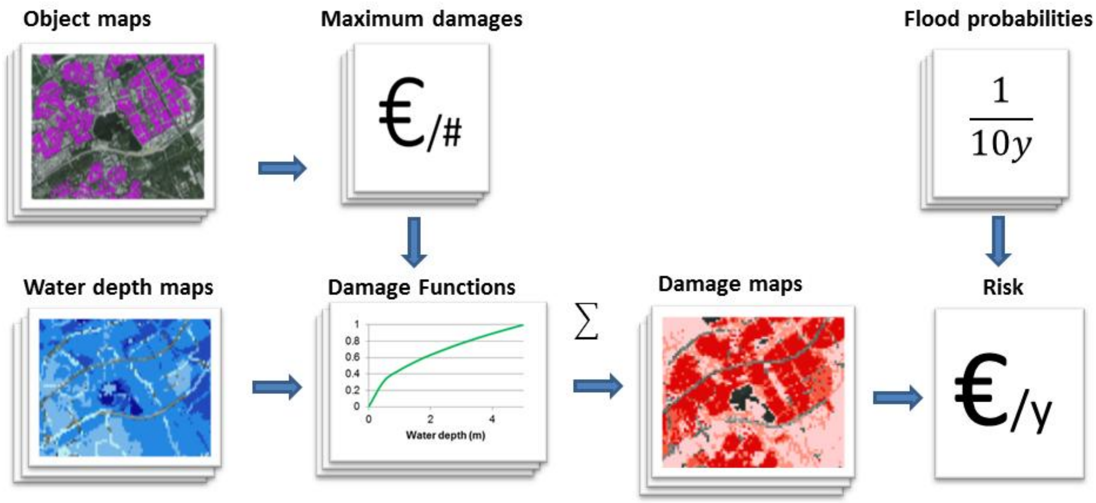


Figure 3-4 Overview of the procedure to compute flood risk in Delft-FIAT. The exposure overlay with the hazard map resulted in a damage maps.

As part of the computations described throughout this report, several technical terms are used as follows:

- **Exposure** refers to buildings (or building assets) and population. Buildings are defined here in three categories: residential, commercial, and industrial. Population is calculated based on the total population of one village and projected to each residential building.
- **Structural damage** and **content damage** are two damage components of building assets. These are also known as the **replacement cost** of the building asset. The value is calculated in USD/m^2. Different building categories have different values for structural damage and content damage.
- **Maximum structural damage** and **maximum content damage** for each building are calculated by multiplying the structural and content damage value with its footprint area.
- **Total damage** is calculated as the total of structural and content damage for each hazard map, following the procedure as depicted in Figure 3-4. It can be a result from a flood event or designed flood in a certain return period.
- **Risk** is in this report represented by the **Estimated Annual Damage (EAD)** and is calculated as the result of the probability and total damage for a set of different return periods.
- **Population impacted** is calculated based on the impacted residential building which is inundated multiplied by the total population for each impacted building.

Risk is the consequence of the interaction between a hazard and the characteristics that make people and places vulnerable and exposed. It is usually expressed as a single comparable indicator (i.e. money). In this case, risk is estimated as the integration of the interpolated damage value from different return period and represented as Estimated Annual Damage (EAD). Deltares developed a Flood Impact Assessment Tool (D-FIAT), a tool to model and calculate damage and risk.

D-FIAT produces damage maps by combining three components as listed and pictured in Figure 3-6:

1 Exposure

Exposure is defined by 'object' maps, where each object relates to assets (i.e. buildings, roads) or population at risk. Attributes of each building such as type/function of the buildings, its area, valuation, and location, are all kept in a large matrix in a csv file in FIAT. Below is the figure of how the exposure file is stored in FIAT with each row representing a building.

	A	B	C	D
1	Object ID	Object Name	Primary Object Type	Secondary Object Type
2	1	fp_1	COM4	Average Prof/Tech Services
3	2	fp_2	COM1	Average Retail, structure only
4	3	fp_3	COM8	Average Entertainment/Recreation
5	4	fp_4	COM8	Average Entertainment/Recreation
6	5	fp_5	RES1-1SNB	Res 1, 1 Story no Basement
7	6	fp_6	RES1-1SNB	Res 1, 1 Story no Basement

K	L	M	N
First Floor Elevation	Ground Elevation	Max Potential Damage: Structure	Max Potential Damage: Content
1	9.0056334	1689400.125	1689400.125
1	7.304069	2231525.75	2231525.75
1	5.6169128	1614931.375	1614931.375
1	5.3062549	3992259	3992259
1	6.5468163	734123.8125	367061.9063
1	6.7399354	636780.5625	318390.2813

P	Q	R	S
Object-Location Shapefile Path	Object-Location Join ID	Join Attribute Field	Aggregation Label: Subba
..\database\Exposure\C9\C9_Spatial.shp	1	Object_ID	C9-S-33
..\database\Exposure\C9\C9_Spatial.shp	2	Object_ID	CCB-C-2
..\database\Exposure\C9\C9_Spatial.shp	3	Object_ID	C9-S-34
..\database\Exposure\C9\C9_Spatial.shp	4	Object_ID	C9-S-34
..\database\Exposure\C9\C9_Spatial.shp	5	Object_ID	C9-N-4
..\database\Exposure\C9\C9_Spatial.shp	6	Object_ID	C9-N-4

Figure 3-5 Example of the exposure file.

2 Vulnerability

Vulnerability is a function of impact in relation to the severity of the hazard (i.e. flood depth) and the characteristics of exposed assets (i.e. building materials). It describes how the value of an asset decreases by the impact of flooding. In FIAT, it is stored in different csv table for each building category.

3 Hazard

In the prototype, flood was the main hazard which was generated through hydrodynamic modelling, including coastal flood, fluvial, and pluvial flood, as described in the previous section. Further explanation of the generation of hazard maps is described in the Section 4.2.

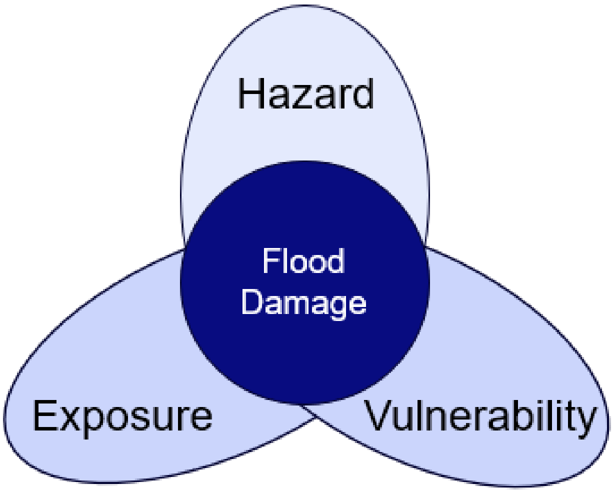


Figure 3-6 Overview of Delft-FIAT concept which combines hazard, vulnerability, and exposure data.

D-FIAT calculates damages for each exposure in the object map by referencing the maximum flood depth at that location against the corresponding depth in the damage function, which provides the fraction of the asset that is damaged. This fraction is then multiplied by the maximum potential damage for the asset. Figure 3-7 illustrates how the FIAT system identifies the maximum flood depth based on its geo-location, with the overlaid exposures, and translates it into the percentage of damage using the vulnerability curve. In this case, the building was used as the basis for the exposure. Consequently, damages for each building were calculated by converting the flood depth at each building location into the potential cost of the damage.

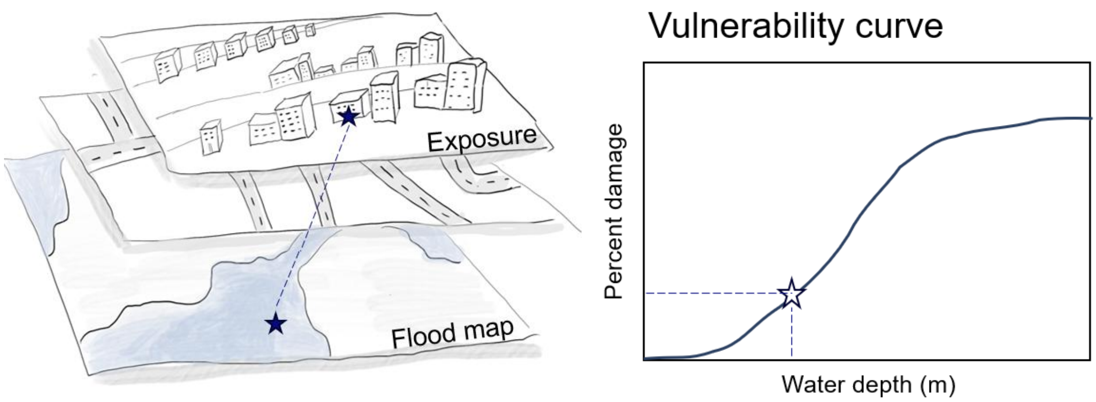


Figure 3-7 Vulnerability curve to translate the flood depth to the exposure damage.

The final maps should show risk aggregated at the administration level 4 for each type of flooding hazard and for the combined flooding scenario. The damage data from FIAT is summarized in an MS Excel database, but the object-based damage is also available in an MS Excel database and a GIS Shapefile. Results were also provided as normalized values (USD/hectare and USD/m^2), whereby the damage in a given administration level is divided by the total flooded area, thus highlighting any specific locations where high-value assets are at risk.

Figure 3-8 Result of FIAT.

3.1.4 Development of a prototype

The data and the results of the flood risk assessment shall be integrated into the Multi-Hazard Platform Iskandar Malaysia (MHP-IM) prototype. The prototype shall demonstrate the possibilities of the MHP-IM to support Iskandar Malaysia agencies and key stakeholders monitoring and forecasting climate-related hazards and risks. Building damage and population impact were calculated directly after the flood forecasting.

Raster-based calculation was done in 2 separate steps to calculate the building damage and population impact. The forecasted flood depth was converted into a damage factor layer using the vulnerability curves, and then it was multiplied with the exposure maps. Calculating the economic damage was based on the overlaying layers of the building (structure and content) cost with the damage factor layer. For the population impacted, the calculation was based on the layer of population spreading which is multiplied by the damage factor layer. End result are shown as a table to show the % flooding area, time to flood from the given warning, maximum flood duration, and its projected damages in money and number of people impacted as illustrated in Table 3-1 below.

Table of Flood Early Warning Impact per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 10 Feb 2025

Mukim	Flooded Area [%]	Number of Population Affected [People]	Estimated Damage to Buildings [10^3 MYR]
API-API	0.5	60	0
AYER BALOI	0.4	30	0
AYER MASIN	2.1	135	1,691
BANDAR BENUT	0.0	0	0
BANDAR JOHOR BAHRU	0.1	70	635
BANDAR KULAI	8.3	520	20,482
BANDAR PONTIAN KECHIL	3.9	60	0
BANDAR TEBRAU	0.0	0	0
BENUT	0.3	10	0
BUKIT BATU	0.6	195	0
JELUTONG	4.8	355	903
JERAM BATU	3.7	125	924
KULAI	0.5	3,545	54,790
PEKAN JERAM BATU	0.0	0	0
PENGKALAN RAJA	0.0	0	0
PLENTONG	1.1	1,215	320,278
PONTIAN	0.3	190	0
PULAI	1.1	2,005	30,317
RIMBA TERJUN	0.3	115	0
SEDENAK	0.2	225	0
SENAI	0.4	2,260	44,059
SERKAT	9.0	420	302,798
SUNGAI KARANG	9.6	10	70
SUNGAI PINGGAN	0.4	30	0
SUNGAI TIRAM	16.2	360	22,562
TANJONG KUPANG	12.8	750	186,955
TEBRAU	0.1	210	3,180

Table 3-1 Example of the warning on projected damages based on the forecasted floods on prototype.

3.2 Selection of hydrometeorological and hazard models

The multi-hazard platform will provide key insights in climate related hazards and risks for Iskandar Malysia. Based on several discussions with key stakeholders a list of relevant climate hazards and risks has been prepared. An overview of relevant climate hazards is shown in Figure 3-9.

Figure 3-9 Non-exhaustive overview of hazards that are currently experiences in Iskandar Malaysia.

The multi-hazard platform will cover different climate related hazards, such a flood and drought related hazards. For each hazard, real-time data, statistical information, and computational models shall be used. The first step is the identification of relevant hazards. This was discussed during the first stakeholder meeting. A list of relevant hazards is presented below:

- ***River floods***
- ***Coastal floods***
- ***Flash floods***
- Landslides
- Coastal erosion
- Heat stress
- Drought
- Water quality
- Air quality

Although the multi-hazard platform can in principle cover all climate related hazards, for this project and the prototype development the focus is on the flood hazards, including river floods, flash floods, coastal floods and the compound flood events triggered by a combination of these 3 types. Purely for demonstration purposes, hydrological drought and heat stress indicators are included in the prototype to demonstrate the capability of the platform as a multi-hazard platform.

For the coastal hazards, a more detailed assessment, including data collection, data analysis, model development and risk assessment is done, see the next sections.

3.3 Establish threshold values

To establish threshold values the following steps are taken:

- Data collection
- Statistical processing

3.3.1 Data collection

The starting point is the collection of relevant data. This includes climate variables, such as rainfall, temperature, and wind, as well as hydrological data such as water levels (coastal and inland), discharges (rivers) and existing threshold values defined by the relevant agencies. Thresholds values are typically based on either historical events, or on statistical relevant return periods (e.g. the 1/2-, 1/5-, 1/25- or 1/100-year event). To accurately derive these statistical properties, sufficiently long timeseries of the relevant parameters need to be available. To this end, timeseries with a length of 20 years or longer are required.

3.3.2 Statistical analysis

Based on the available data, the statistical analysis can be done. An example of such analysis is shown in Figure 3-10 and Figure 3-11, where 30 years of discharge data is analyzed and processed into discharge statistics. In the MHP-IM, this analysis can be done for all stations and threshold values can be set for each station separately, based on the output of the statistical analysis. For example, threshold values can be setup for specific location based on the 1-per-2, 1-per-5 and 1-per-25 year threshold for the minor, major and severe flood thresholds. In this way, local relevant thresholds are defined, which can be used by emergency response teams to give warning to the public or decide on specific measures like evacuation.

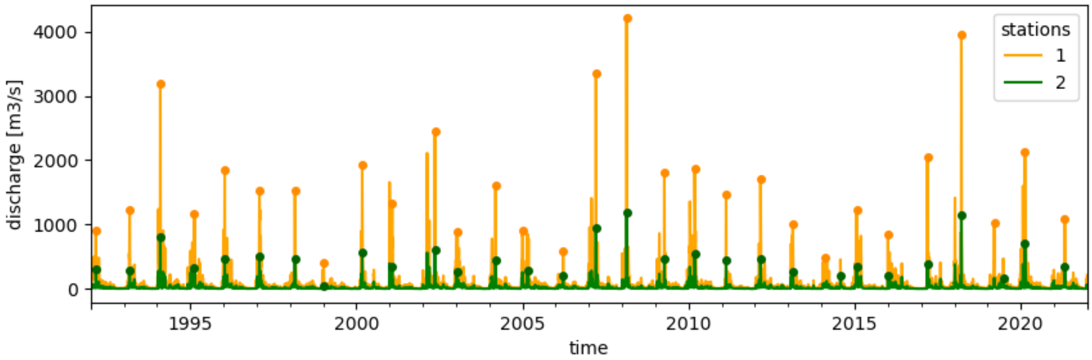


Figure 3-10 Discharge timeseries for 2 hydrological stations for the period 1992 – 2022 (30 years).

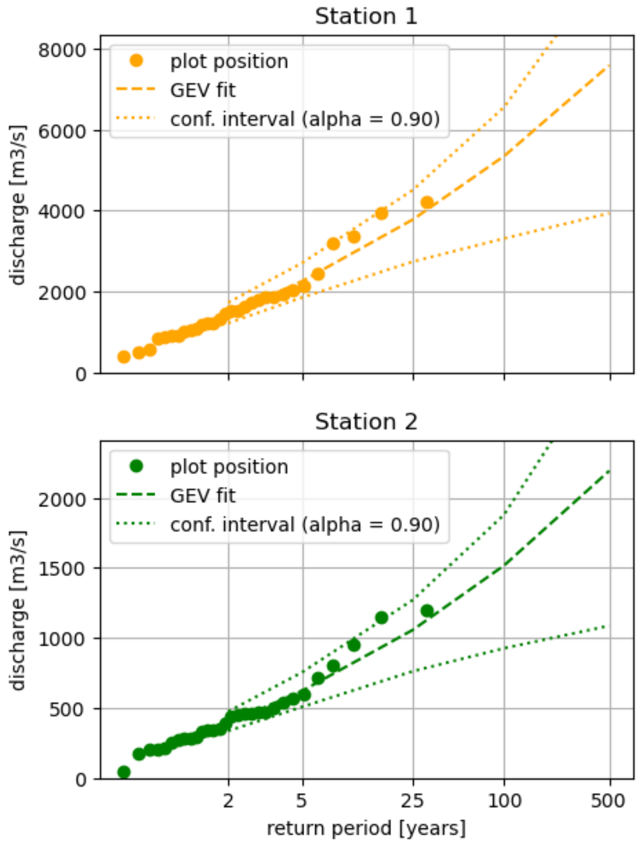


Figure 3-11 Statistics for 2 hydrological stations based on 30 years of data.

3.4 Generate probabilistic hazard maps

The next step is to translate the statistical information into hazard maps. The goal is to generate hazard maps for different return periods. For this, models are required that translate the climate information into hazard maps. Within this project, the focus is on (coastal) flooding. In this case, hydrological and hydrodynamic models were used.

For the hydrology, the Wflow-SBM distributed model is used. The model will be run for a long period (e.g. 20 years) to derive the hydrological outputs, such as land runoff, river discharge, soil moisture, and drought related parameters such as depth to the groundwater table. The maps with 20 years of model output can be used to perform statistical analysis to derive the probabilistic hazard maps. This information can later be used in combination with real-time forecast information. In that case, the current (or forecasted) conditions can, for every grid cell, be compared to the statistical values and classified based on predefined threshold values to assess the severity of potential flooding or other hydrological impacts. An example of the European EFAS system is shown in Figure 3-12. The same can also be done in the MHP-IM and for different variables.

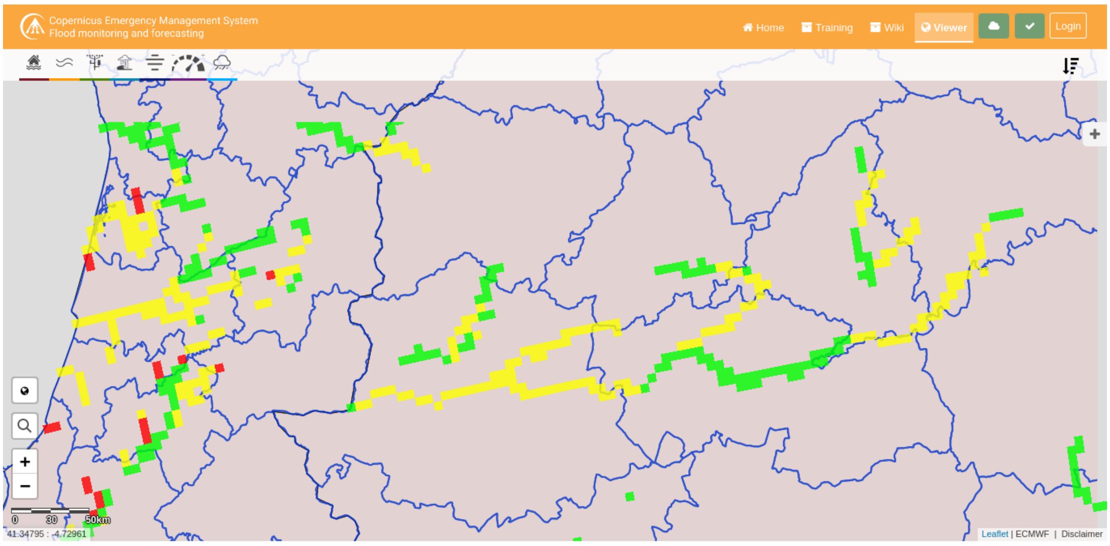


Figure 3-12 Example of the use of spatial statistical information in real-time situations from the European Flood Awareness System (EFAS).

For flood inundation, the SFINCS models was used. The SFINCS model is a fast inundation model that can be used for compound flood analysis and real-time flood forecasting. SFINCS is a 2D flood model, meaning that detailed urban drainage systems are not included explicitly in the model. Especially for coastal and river flooding, this limitation is negligible as the processes of flooding are not strongly influenced by such a drainage system.

To create the probabilistic flood maps, the model was run for a set of pre-defined statistical (compound) events. These events are derived from the data collected (activity 2.1) and the derived statistical properties (activity 2.2). A more detailed explanation of how the probabilistic flood hazard maps for Iskandar Malaysia are generated is provided in sections 6.1 - 6.3.

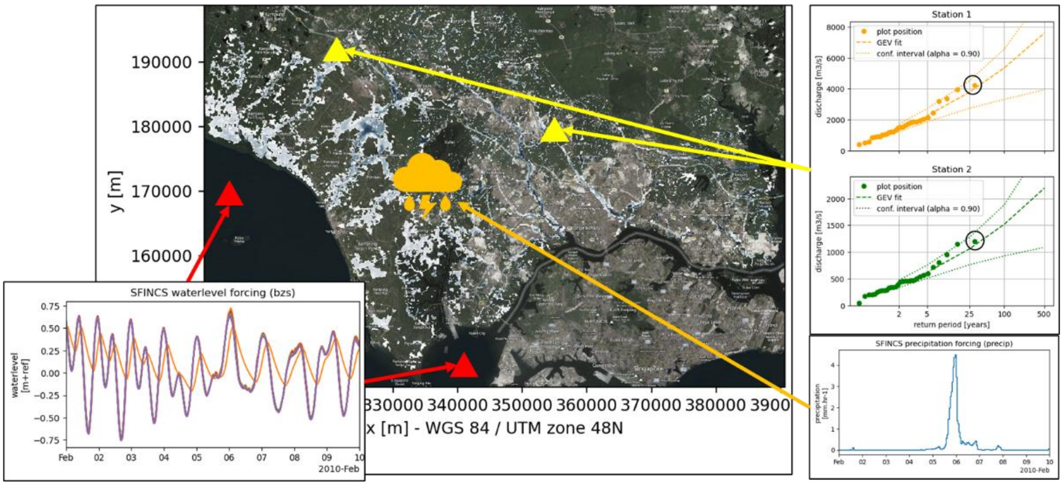


Figure 3-13 Schematic showing how to generate probabilistic flood hazard maps.

3.5 Update / develop vulnerability curves

This activity is strongly linked to activity 2.3 where the probabilistic hazard maps are generated. In this activity, the hazard maps are combined with exposure and vulnerability to come at risk indicators, as illustrated in Figure 3-14 below.

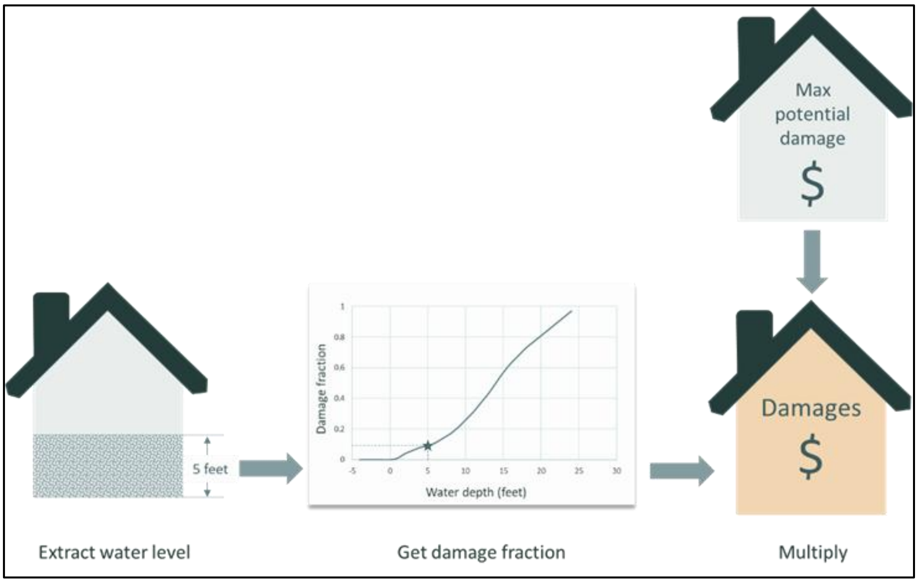


Figure 3-14 Delft-FIAT damage calculation procedure for each asset.

Vulnerability curve presents the translation of the flood depth to the damage severity of the exposure (i.e., building). Ideally, it is generated for different building materials as it will define the strength of the building. Generalizations to the available database such as the regional damage curves for building types in Asia (JRC, 2017) will be used when the local reference is not available.

3.6 Design localized hazard forecasting

The goal of this activity is to develop the MHP-IM into a forecasting system of localized hazards. The risk information from activities 2.1 – 2.3 and 2.5 shall be integrated into the platform. The models that are used for the hazard assessment can be operationalized by using real-time and forecast weather and climate information. By comparing current and forecasted situations with the hazard and risk information for specific return periods, users of the MHP-IM can easily understand the severity of an event. This comparison can be done in a visual manner such as using background colors in graphs for specific threshold crossings (Figure 3-15).

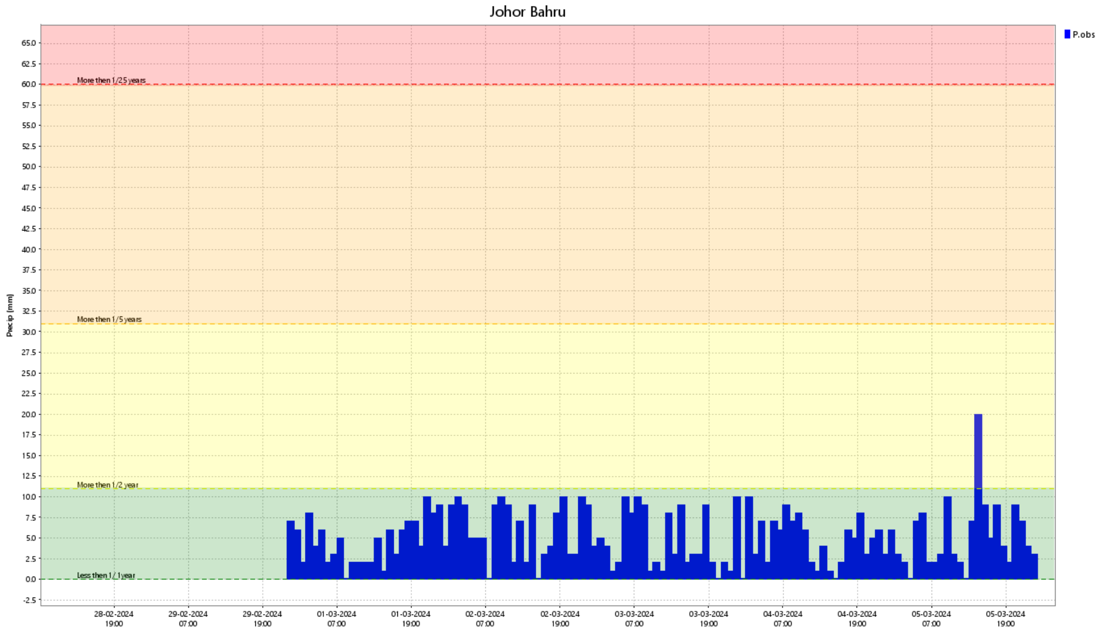


Figure 3-15 Warning levels based on statistical analysis.

Based on the severity, specific warnings can be automatically generated. For this it is important to understand the full warning and response cycle to derive the lead time for each hazard (Figure 3-16). Based on the lead time, a Standard Operating Procedure (SOP) can be setup to produce localized hazard forecasting.

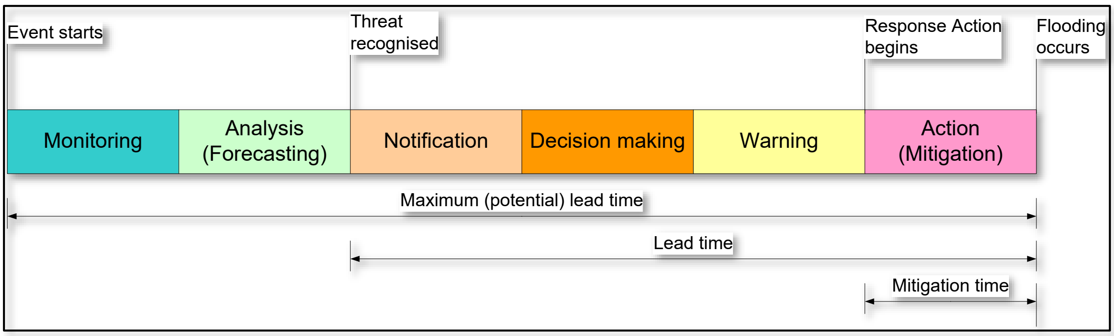


Figure 3-16 Schematic overview for deriving the required lead time for action.

As part of the project, a prototype has been developed that includes the functionality to develop localized hazard forecasts. The prototype is part of the deliverables of the project and includes a user manual.

4 Stakeholders

The goal of the development of a Multi-Hazard Platform is to support key stakeholders in their decision-making process regarding hazards and risks related to climate impacts. The first step is to understand who the key stakeholders are and how to group them based on their (shared) roles and responsibilities. For these user groups, understanding their standard operating procedures is required to understand how the platform can best support their (daily) operations.

Based on these inputs key functional requirements of the systems were defined, such as the key outputs of the platform, which will form the basis for the functional design of the system.

The stakeholders have been identified and consultant in several workshops and technical committee meetings:

- Workshop 1: Inception workshop, conducted on 11 March 2024
- Workshop 2: Discussion session with data providers conducted on 24 June 2024
- Workshop 3: Discussion with stakeholders on Functional and Technical design, conducted on 10 December 2024
- Workshop 4: Stakeholder meeting on information products and capacity building, conducted on 26 August 2025

A comprehensive list of stakeholders and their respective roles is presented in Annex C.

4.1 Overview of relevant stakeholders

In addition to the desk study and literature review, workshops were also organized to gather more information about IRDA’s needs. The workshops helped identify where to find the data necessary for developing the MHP IM and which existing platforms can be integrated with it. The first stakeholder workshop itself was conducted fully offline on 11th March, 2024 at Johor Bahru Malaysia and was attended by the relevant stakeholders who might provide data to MHP IM, develop the MHP IM, operate the system and make use of the MHP IM.

Apart from the workshop, Malaysia outlined the protocols for managing natural disasters such as floods through the NADMA Directive No. 1. The Policy and Mechanism for Disaster Management was launched on 1 August 2024, replacing MKN Directive No. 20 (Revised) issued on 30 March 2012[1]. This directive applies to all government agencies, statutory bodies, private entities, volunteer organizations, and individuals. The directive aims to guide disaster preparedness, response, and recovery. It defines the responsibilities of various government bodies, including federal, state, and district disaster management committees, in coordinating multi-agency efforts. This amends several points of the policy and mechanism for disaster management and relief. This includes an update on the role and responsibilities of different agencies, an update on procedures in information management, and a highlight on the disaster risk reduction to be taken thoroughly and inclusively. NADMA emphasizes the importance of community awareness, NGO involvement, and multi-agency coordination to improve disaster response, enhance mitigation efforts, and foster a culture of preparedness across all sectors. Therefore, the implementation of MHP IP will align with the key aspects of NADMA Directive No. 1.

[1] NADMA emphasizes that MKN Directive No. 20 is no longer applicable, and may only be mentioned as background if necessary

In the MKN 20, there is already a list of the roles and responsibilities of different agencies in terms of disaster management, which also includes the use of the early warning system (EWS). NADMA Directive No. 1 updates the roles of the agencies. Same as MKN 20, disaster management in the Directive No.1 shall be conducted based on the three levels of management:

- Central Disaster Management Committee (JPBP), which is led by NADMA;
- State Disaster Management Committee (JPBN), led by the State Civil Defense Force (APM Negeri);
- District Disaster Management Committee (JPBD), led by the District Civil Defense Force (APM Daerah).

This directive creates zoning in terms of disaster location, including the agencies and its responsibility for each zone. In the procedure of disaster management, this directive updated several responsibilities of government agencies. Regarding floods, the Department of Irrigation and Drainage (DID) is playing a crucial role. DID is responsible for sharing the information regarding flood management and risk reduction, drought, and coastal erosion. DID is also responsible for conducting damage assessments on flood mitigation infrastructure, including repairing works. Department of Minerals and Geoscience (DMG), besides providing information on geological disasters, is also responsible for action in the recovery and mitigation of floods. DMG should provide a groundwater supply to disaster-affected areas. Other agencies mentioned in NADMA Directive No. 1 are also Malaysian Space Agency (MYSA), which responsible to provide online access to District/State Disaster Management Committees (JPBD/JPBN), and related agencies to obtain information on disaster-affected areas, such as satellite images of flood-affected regions, the extent of flooded areas, locations of evacuation centers, submerged roads, available logistics facilities at evacuation centers, forward bases, and areas prone to disasters.

4.2 Stakeholder groups & requirements

The involvement of multiple stakeholders is essential for the success of a multi-hazard platform system. By integrating the knowledge, resources, and efforts of diverse stakeholders, MHP-IM can achieve greater effectiveness, inclusivity, and sustainability, ultimately saving lives and reducing the adverse impacts of disasters. Based on the findings from the initial workshop, it is recommended that the system incorporates at least three distinct groups: data providers, advanced users, and end users. Figure 4-1 illustrates the typical agencies involved in each phase of the Early Warning System (EWS) and their respective groups. Additionally, Figure 4-2 lists the stakeholders identified during the first workshop.

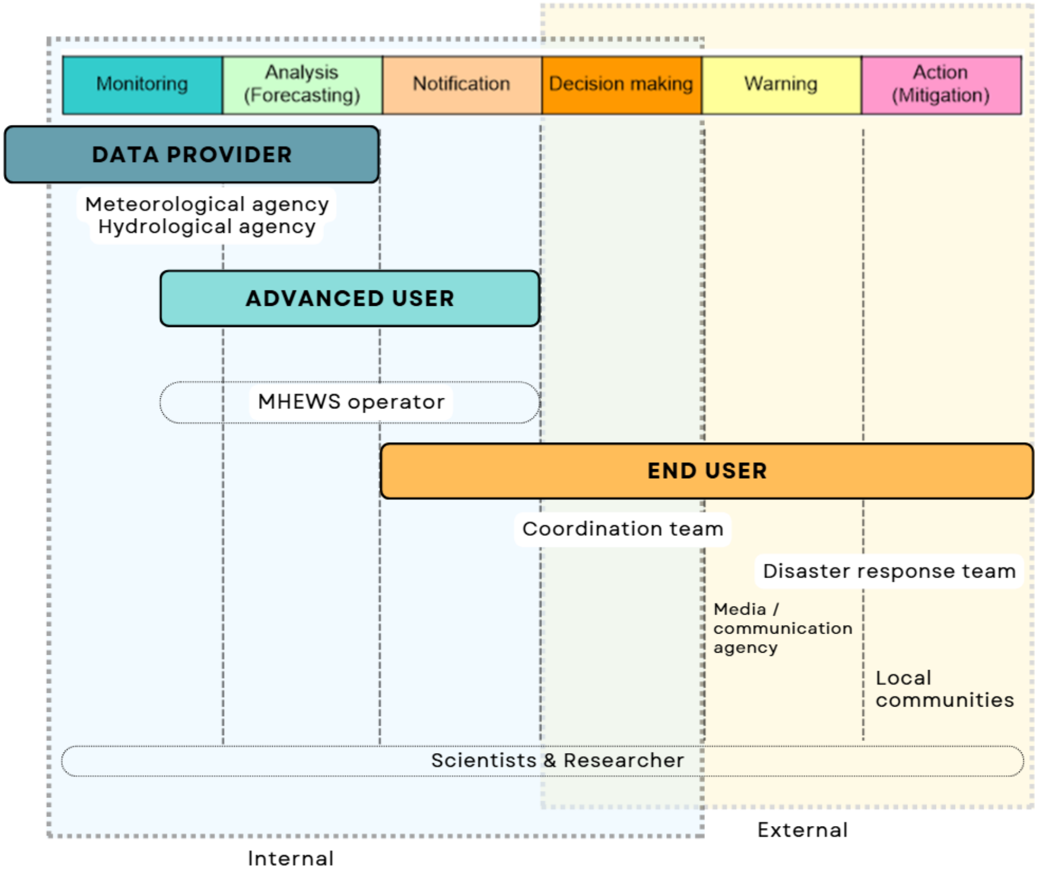


Figure 4-1 Stakeholders on a multi-hazard early warning systems. Top bars showing the phase of a disaster event where each user should play a role. Blue box indicates the internal system which mainly regulates the role of the data providers and advanced users, while the yellow box indicates the external system of MHP-IM.

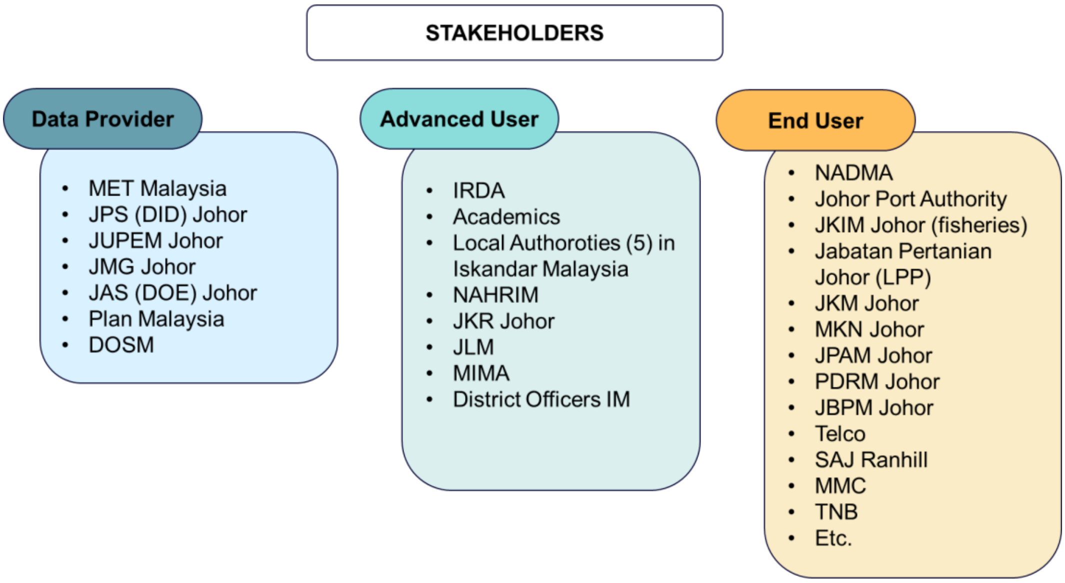


Figure 4-2 Stakeholder groups of the designed early warning system for Iskandar Malaysia.

Data providers play a crucial role in the monitoring and analysis phases of forecasting within the Multi-Hazard Platform (MHP-IM). During the monitoring phase, key stakeholders typically include meteorological and hydrological agencies. Specifically, MET Malaysia and JPS (DID) Johor were identified as primary data providers. These agencies will be responsible not only for supplying hydrological and meteorological data, but also for conducting analysis and forecasting tasks. In addition to these agencies, analysis and forecasting activities can be undertaken by scientists, non-governmental organizations (NGOs), and specialized teams. The collaborative efforts of these diverse stakeholders ensure comprehensive monitoring and accurate forecasting, which are essential for the effectiveness of MHP-IM.

Agencies categorized as advanced users are responsible for operating and analysing data collected within the platform. Typically, stakeholders in this group include decision-makers, who often establish specialized teams to manage and interpret the results. This group is the first to receive notifications from the system and is responsible for issuing warnings to other decision-makers. In addition to decision-makers, scientists, researchers, and non-governmental organizations (NGOs) frequently collaborate within this group. Their combined efforts ensure that the data is accurately analysed and that timely and effective warnings are issued.

While decision-makers are categorized as end users, the term essentially refers to those who must take action based on the warnings. Typically, following instructions from decision-makers, coordination teams, assisted by media and communication agencies, disseminate warnings more broadly. These teams and agencies play a crucial role in ensuring that warnings reach flood-threatened communities and are acted upon by disaster response teams, field coordination teams, or non-governmental organizations (NGOs). In addition to these stakeholders, private sector entities responsible for vital assets, such as telecommunications, electricity, and water providers, as well as local communities, are also considered end users. These groups need to be prepared to mitigate the impacts of hazards effectively. Responsibility for each group are defined in the Figure 4-3.

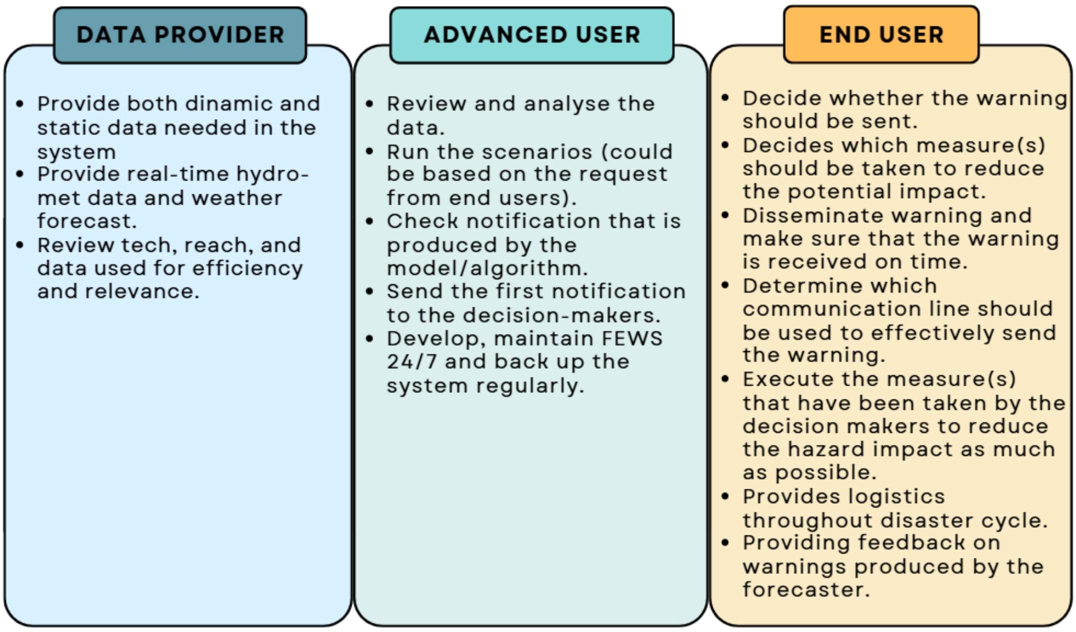


Figure 4-3 Responsibility of each group of the multi-hazard early warning system.

5 Functional and technical design

5.1 Delft-FEWS platform

The prototype was developed using the Delft-FEWS platform. Delft-FEWS is used globally and by many national and regional authorities for the development of flood or multi-hazard forecasting platforms. Delft-FEWS is open and freely available software package. Its architecture allows of connecting to many different data format and hydrological and hydrodynamic models.

Delft-FEWS can be seen as a data and workflow management system. Delft-FEWS is highly configurable, making it possible to design a tailor-made system for Iskandar Malaysia. Delft-FEWS can be used stand-alone and in a fully operational client server architecture. As client-server system, workflows can be automatically schedules and a central database allows data to be shared with all relevant stakeholders.

Figure 5-1 presents a schematic overview of the Delft-FEWS platform. Natively, Delft-FEWS can import data from field measurements, telemetry, radar, and national and global forecasting systems. The import module can read over 100 different file-formats, including most commonly used formats like GRIB and NetCDF. Data can be scalar formats (i.e. timeseries for specific locations), or gridded (e.g. radar or NWP data).

As data comes in many different formats and different levels of quality, Delft-FEWS can also automatically process incoming data. Such processing includes data validation, interpolation and transformation of the data. This means, in principle, no pre- or post-processing of the data is required at the data provider, making it relatively easy to connect to these external data sources.

One of the roles of the MHP-IM is to also provide hazard and risk forecasts. To this end, models are typically used to translate climate data into hazard and risk information. Examples are hydrological models translating rainfall into runoff, and flood models translating runoff into flood inundation maps. Delft-FEWS can connect to such models by making use of the so-called general adapter module. The general adapter module takes care of the communication between the Delft-FEWS database and the external model(s) by translating the data in the model native formats and vice-versa. The model results can be imported back into the Delft-FEWS database for processing and/or visualization.

Finally, Delft-FEWS comes with many different export options. The most commonly export of data is through the Operator Client, which is the Graphical User Interface (GUI) of the MHP-IM. User can visualize spatial and timeseries data, perform on the fly statistical analysis and can start new simulations. The Operator Client is typically used by the operators of the system to check system health and to create the forecast. Data can also be shared through via the Delft-FEWS webservice, which allows for external applications to tap directly from the central database for visualization in tailor-made dashboards or web-applications.

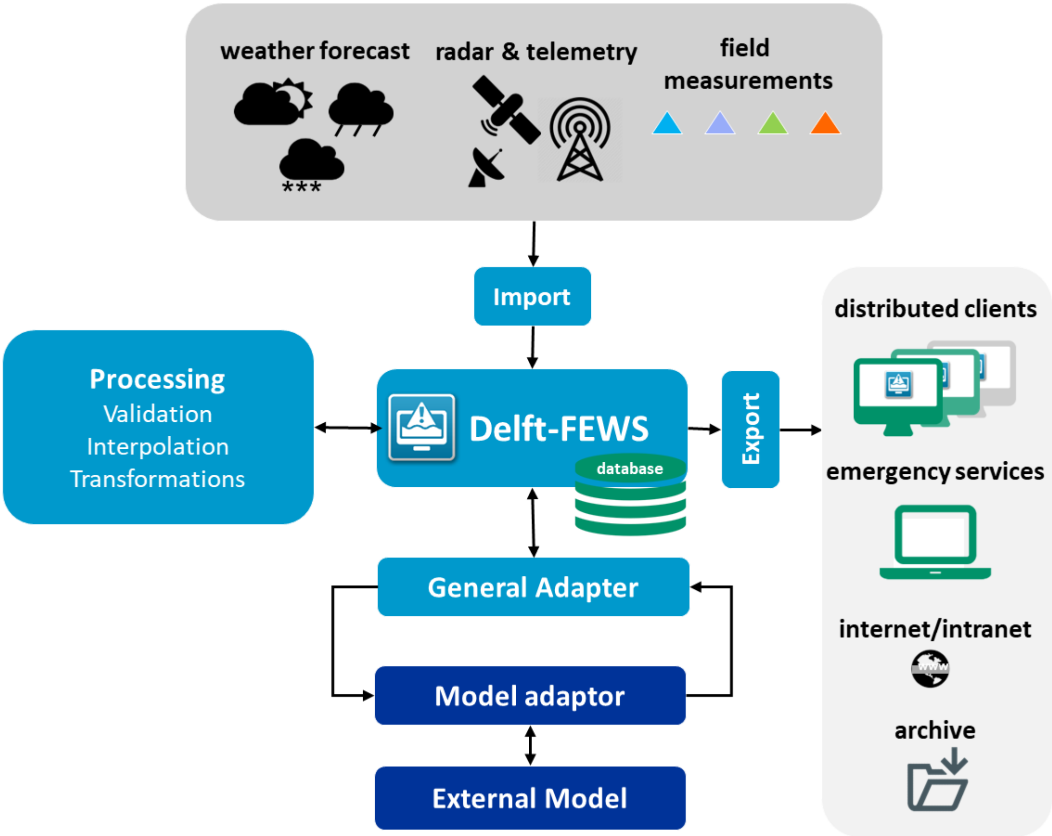


Figure 5-1 Schematic overview of the Delft-FEWS platform.

As stated, the prototype MHP-IM was setup using Delft-FEWS. The prototype was configured to specific needs for Iskandar Malaysia. The start-up screen of the system is shown in Figure 5-2. After successfully starting up the MHP-IM, the map view shall open, displaying Iskandar Malaysia centrally on the map (Figure 5-3). The map display can also be used to show important locations and link specific data to these locations, such as meteorological stations, or hydrological forecast locations.

Figure 5-2 Start-up screen MHP-IM Iskandar Malaysia (IM).

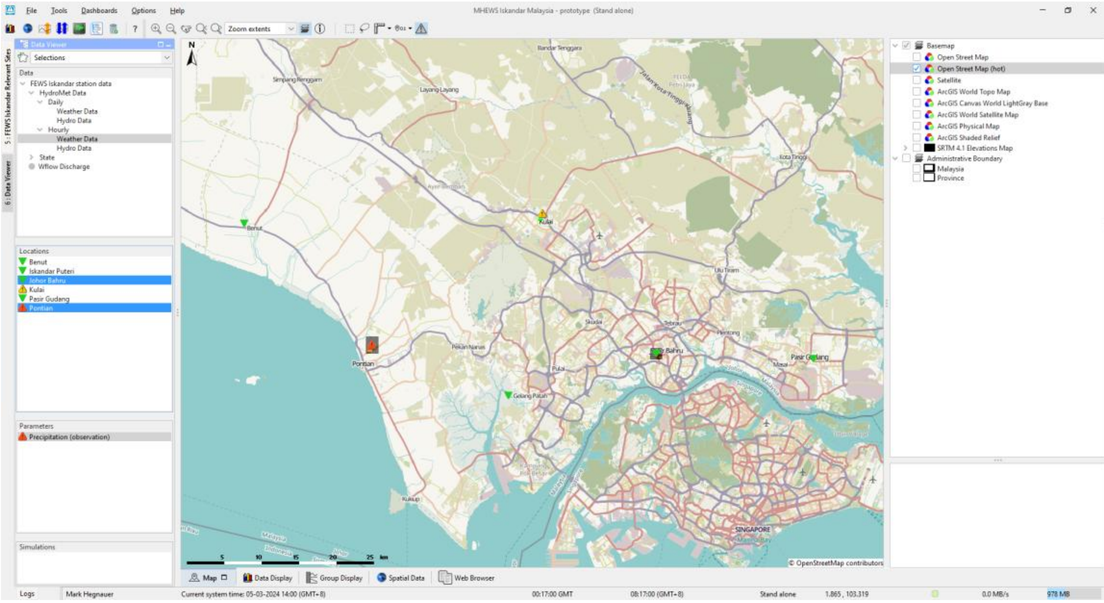


Figure 5-3 Opening screen of the MHP-IM Iskandar Malaysia (IM), showing the map display.

In addition to the map display, FEWS provides several tabs/display/features that are frequently used by operators to monitor and execute a workflow. Some of these tabs include the Spatial Data Display, System Monitor Display, Manual Forecast Display and Database Lister displays. Explanations for each of these tabs can be found in the section below.

Spatial Data Display
Similar to the map display, Spatial Data Display is used to display time series of any kind: scalar, polygon, or grid. The data is shown on a map background. The time on the display is set using a ruler that can be moved by hand or set to move on its own.

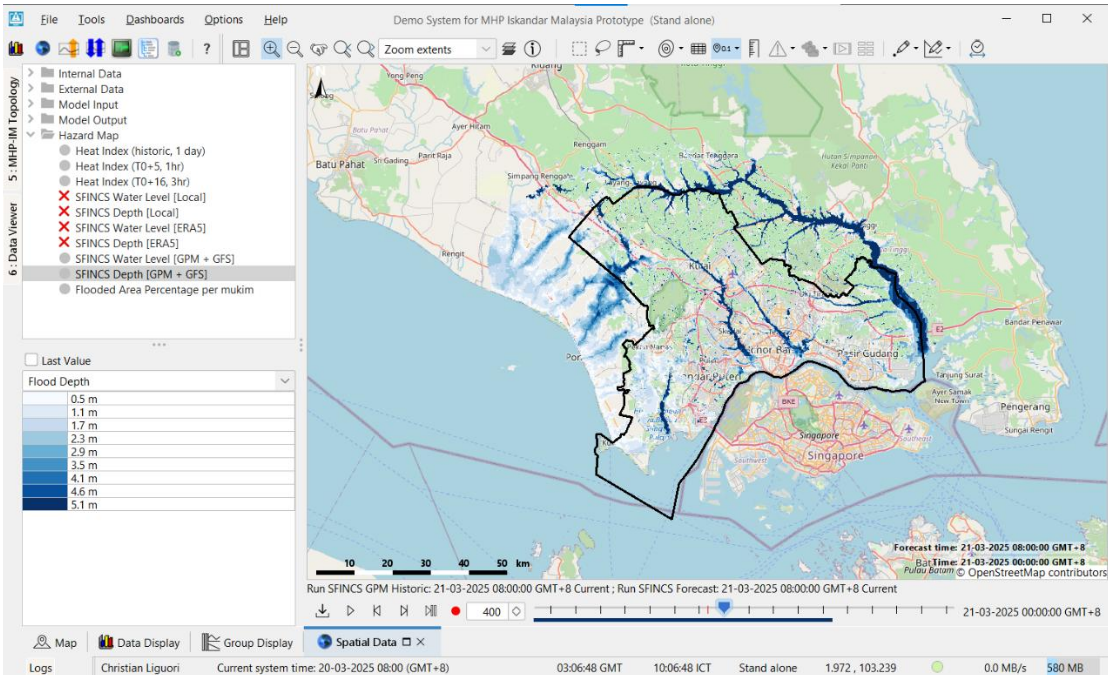


Figure 5-4 MHP-IM Iskandar Malaysia Spatial Data Display.

The spatial display is made up of the following parts:

- A spatial, grid, or map display with layers that user can change
- A Control Toolbar with general options for:
  - Zooming in and out and moving around
  - Turning map layers or metadata on and off, like labels, values, flags, thresholds, etc.
- A Time Slider Toolbar with general options:
  - Buttons for play, pause, stop, step forward, step backward, and record
  - A time slider with a time slice indicator
  - An indicator for data availability and maximum value
- Filters for selecting what to show in the Spatial Display
- A table or bar legend
- Options for exporting or recording data and time series

System Monitor Display

The System Monitor display allows for viewing the status of the system. The behaviour of the System Monitor is different depending on the use of the system, i.e. whether you are using the system in Stand Alone mode or as an Operator Client.

In the Standalone mode the System Monitor will display the Log Browser, Running Forecasts tab and Batch Forecasts tab. An overview of the tabs available in the System Monitor of a Standalone system is illustrated below.

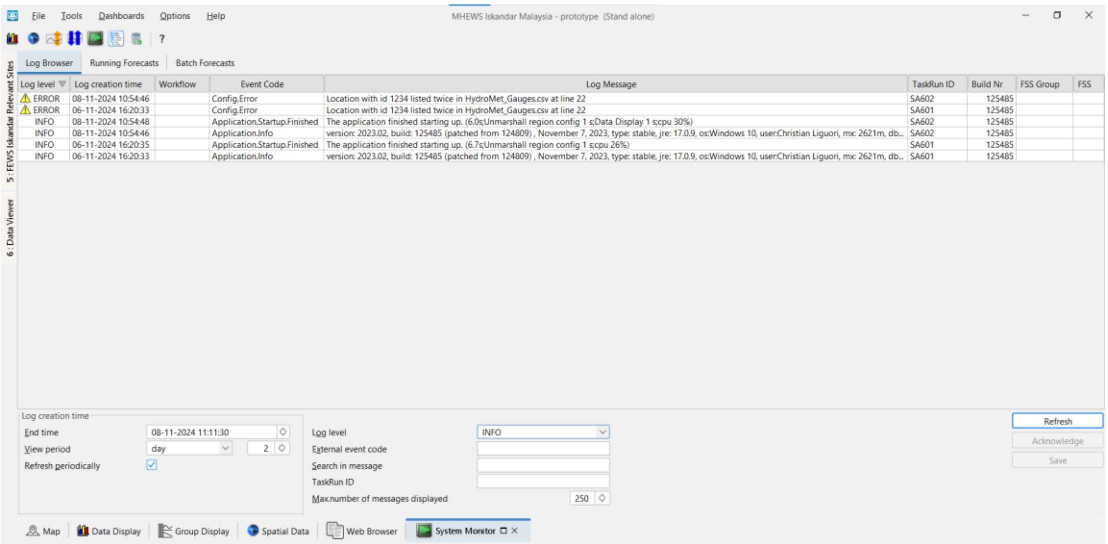


Figure 5-5 MHP-IM Iskandar Malaysia System Monitor.

In an Operator Client the System Monitor will show a number of tabs for monitoring various aspects of the live system. An example of the tabs available in a Delft-FEWS Operator Client, when logged into a live system, is illustrated below.

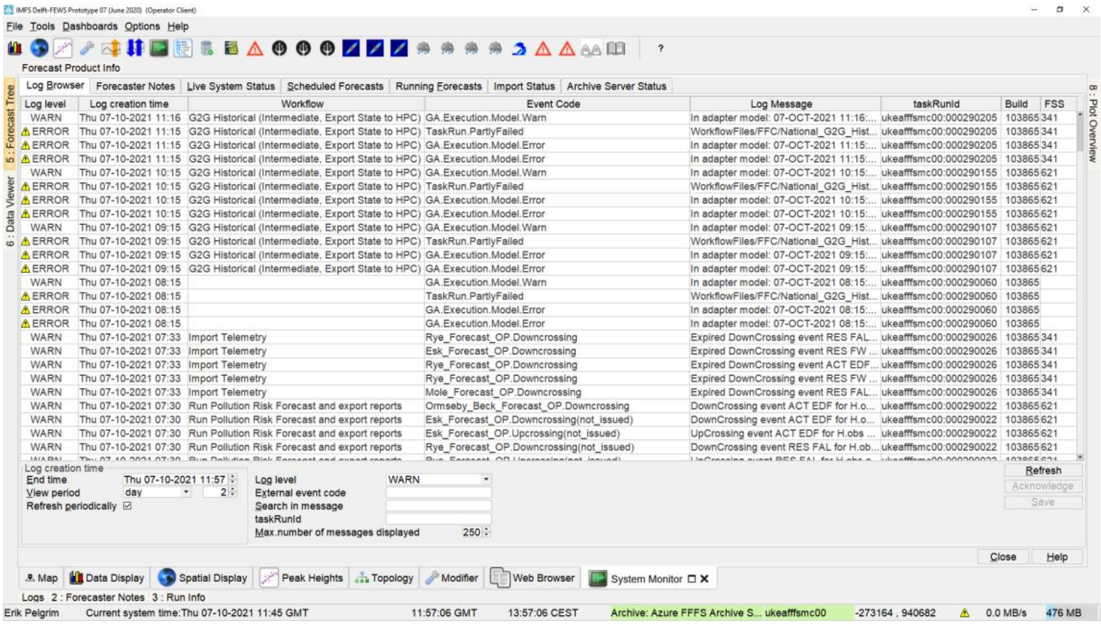


Figure 5-6 Example of the System Monitor display in Delft-FEWS OC.

Manual Forecast Display

The Manual Forecast Display shows all the workflows that have been configured by the developers. This Manual Forecast window allows user to define which workflow should be run. In the prototype of MHP-IM Iskandar Malaysia SA, the Manual Forecast display is used by users each time they want to run a workflow. In an operational context, the Manual Forecast display is used occasionally because most workflows can be scheduled to run automatically by the server via the Task Scheduler. Operators only need to run the workflow manually if there is a delay in data arriving to the system or if the workflow fails to execute.

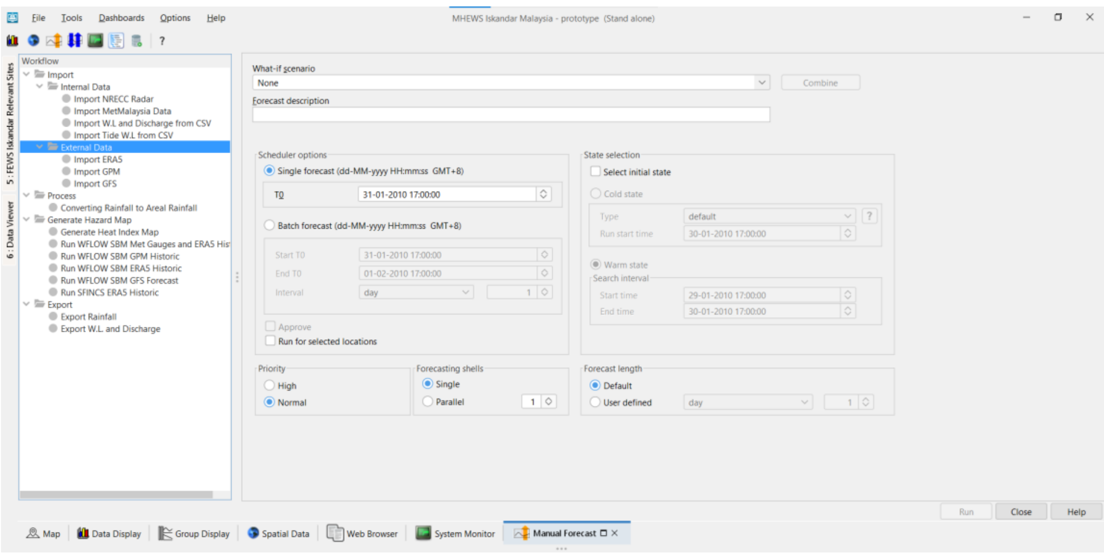


Figure 5-7 MHP-IM Iskandar Malaysia Manual Forecast Display.

Database Lister Display

The Database Lister Display is used to verify and inspect time series written to the database by any workflow. Additionally, it helps to check whether a model run was successful and if new data has been added to the system. When a workflow runs successfully, a new row with the workflow name is added to the top section of the database lister. By selecting a row in the top section, users can view detailed information about the data added to the system for each workflow run. Figure 4.8 illustrates the Database Lister of MHP-IM Iskandar Malaysia.

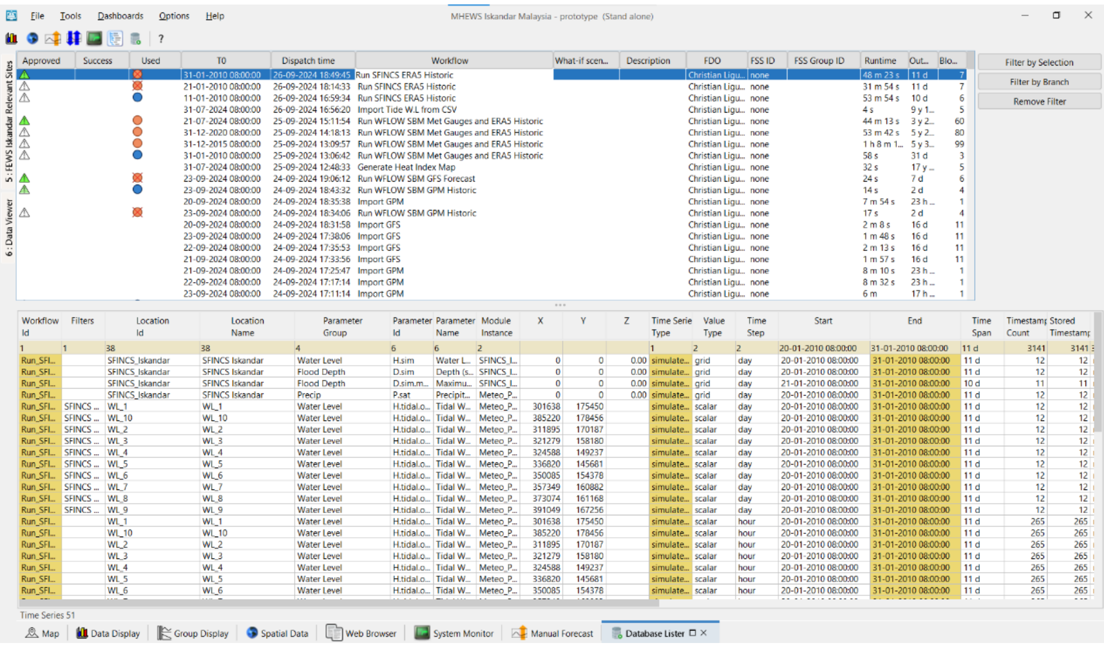


Figure 5-8 MHP-IM Iskandar Malaysia Database Lister Display.

5.2 Importing & Integrating Data

The first step in the design and setup of the MHP-IM is to configure the import of external data.
This platform is designed as a modular and extensible platform for real-time water management and forecasting, allows for customization to meet specific organizational needs. Its architecture facilitates integration with various external systems, including radar data, sensor data, CCTV data, and other web services or with Command and Control Centres for data dissemination, automated control, and interoperability. More description on the available data types and documented imports are provided in https://publicwiki.deltares.nl/spaces/FEWSDOC/pages/8683880/Available+data+types.

To this end, several workflows shall be configured that import local (i.e. Malaysian sources) and global meteorological data, as well as workflows for importing hydrological data. A user can select and run a workflow to start the process of downloading and importing data into the database. An overview of the required type of data, primary and alternative sources for the data is presented in Annex A.

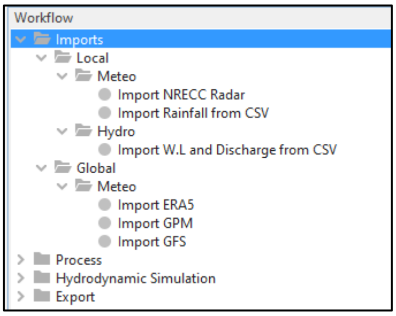


Figure 5-9 Example workflow structure.

Table 5-1 Overview of required timeseries data to be included in the MHP-IM.

Dataset	Preferred file-format	Primary source	Received	Alternative source
Historical rainfall data (grids)	NetCDF	MET	No	GPM / ERA5
Forecasted rainfall data (grids)	GRIB, NetCDF	MET	Yes	GFS
Historical rainfall data (stations)	CSV	MET	Yes	-
Historical temperature data (grids)	NetCDF	MET	No	ERA5
Forecasted temperature data (grids)	GRIB, NetCDF	MET	Yes	GFS
Historical temperature data (stations)	CSV	MET	Yes	-
Historical hydrological data (stations)	CSV	JPS (DID)	Yes	-
Forecasted hydrological data (stations)	CSV, telemetry	JPS (DID)	No	GLOFFIS
Historical sea water level data	CSV	JUPEM	Yes	GTSM
Forecasted sea water level data	CSV, telemetry	JUPEM	No	GTSM

For the prototype, global data sources have already been configured for importing data into the MHP-IM, including GPM rainfall data and GFS forecast data (rainfall, temperature, and wind). Examples of the data, visualized in the prototype are shown in Figure 5-10 (GPM rainfall over the whole of Malaysia), Figure 5-11 (GPM data zoomed in to the Iskandar Malaysia region) and Figure 5-12 (GFS wind forecast).

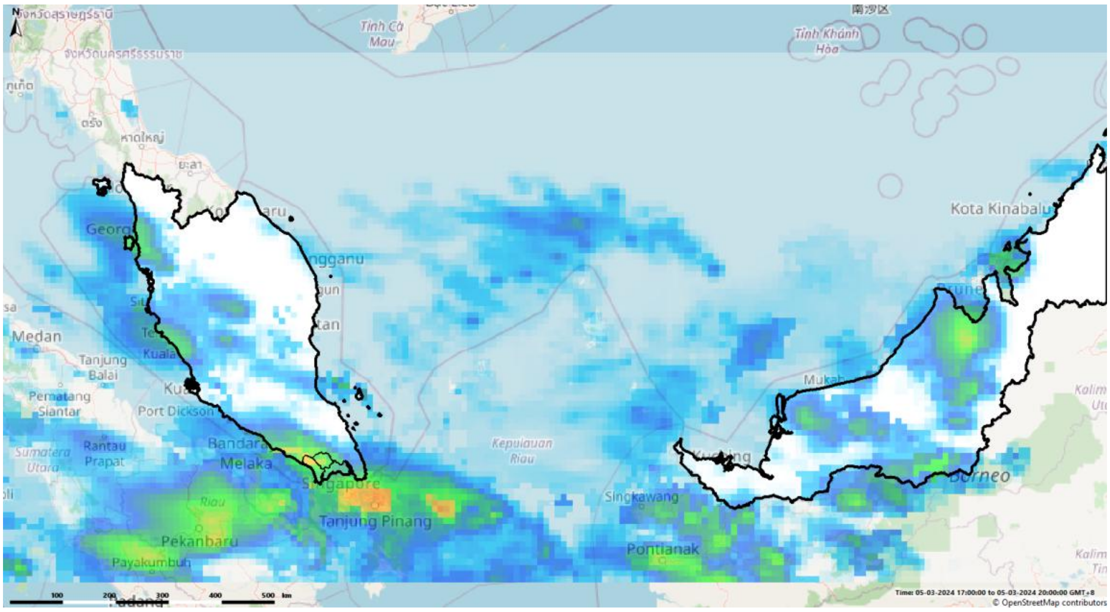


Figure 5-10 Screenshot of the GPM global rainfall historical dataset imported into MHP-IM IM.

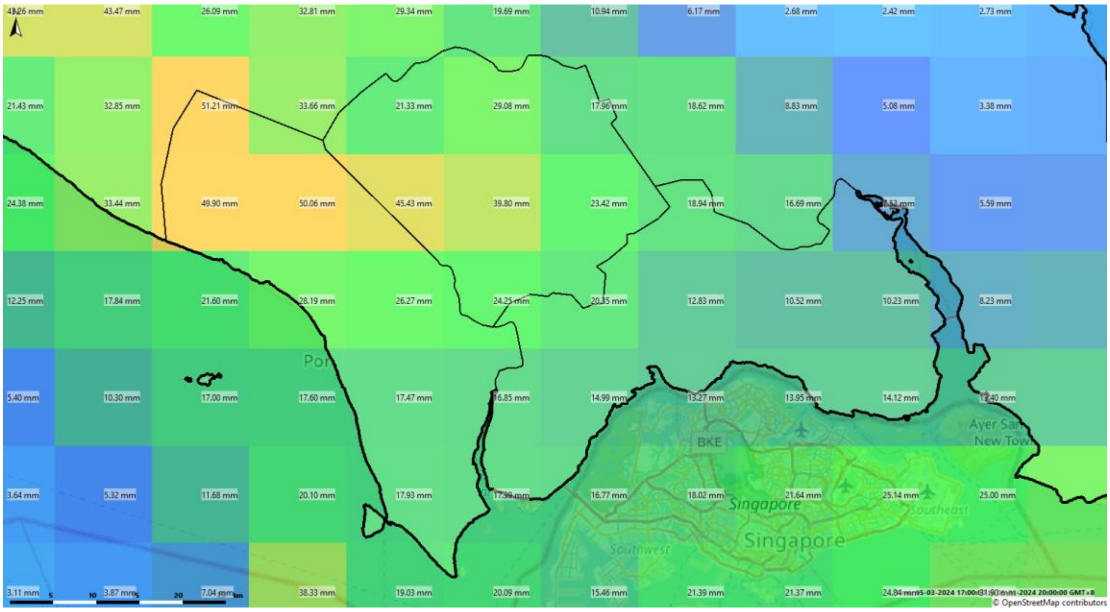


Figure 5-11 Screenshot of the GPM global rainfall historical dataset imported into MHP-IM IM, zoomed into Iskandar Malaysia.

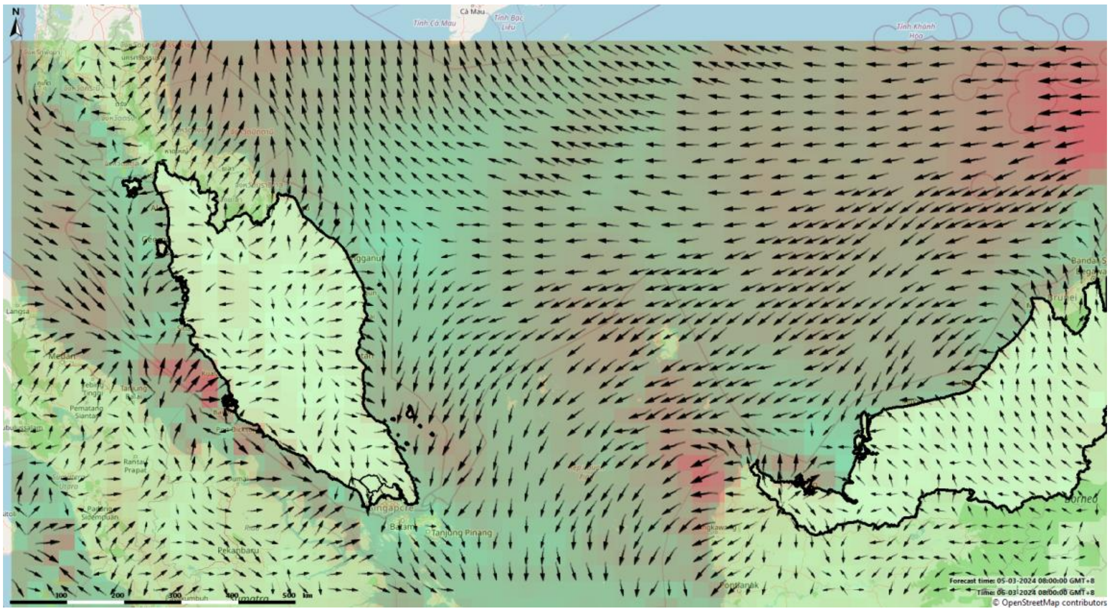


Figure 5-12 Screenshot of the GFS global wind forecast dataset import into MHP-IM IM.

The data can also be presented as timeseries, as is shown in Figure 5-13. For each location, threshold values can be configured and displayed. This helps the user of the system to quickly analyse the data compared to previous or statistical events. The threshold values can be set to different values for each parameter and for each location. This allows for creating location specific warning values based on local conditions. Threshold values can be calculated from long (>10 years) historical data and can be updated regularly if new data comes in (e.g., once very year or once every 5 years). Threshold applied in Figure 5-13 is based on the rainfall threshold from the Public Info Banjir DID website.

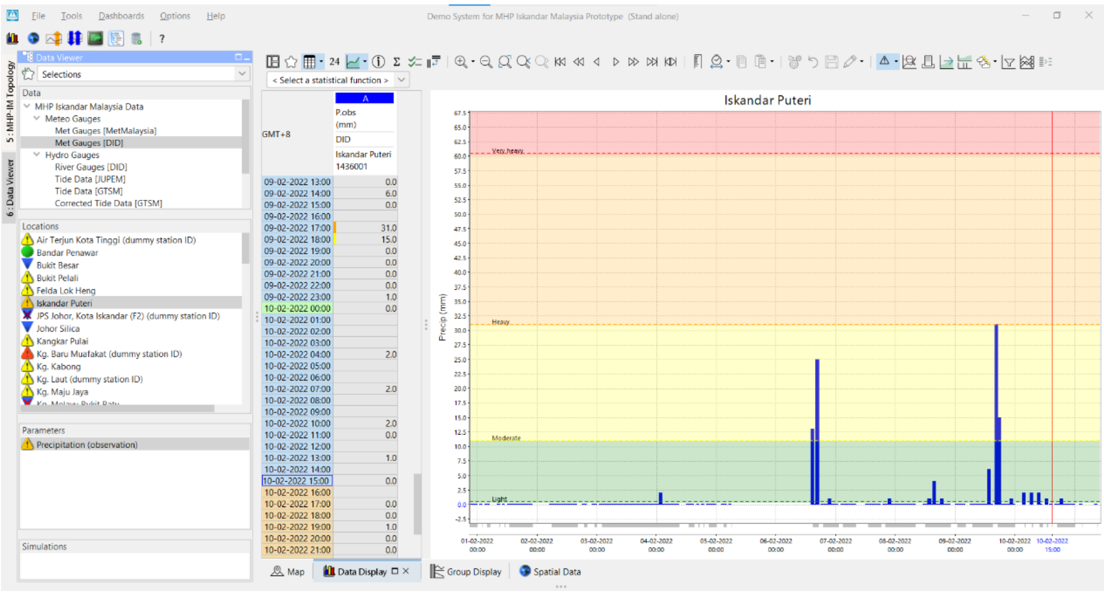


Figure 5-13 Timeseries of rainfall visualized in the MHP-IM IM, including the visualization of thresholds values.

5.3 Models

The next component of the MHP-IM is the modelling component. As mentioned previously, models can be used to translate climate data into hazard and risk information. As the focus of the prototype is on (coastal) flooding, first the hydrological model and the flood hazard model are introduced, but other hazard models can be added to the system later as well.

Within the MHP-IM, several models can be included to setup a modelling cascade. An example of such a modelling cascade is shown in Figure 5-14. The MHP-IM is setup to arrange all data flows between the models and to run the models in the right order and at predefined times during the day to provide the forecasters with the right information at the right moment. More detailed information on the models used for the MHP-IM is presented in Annex D.

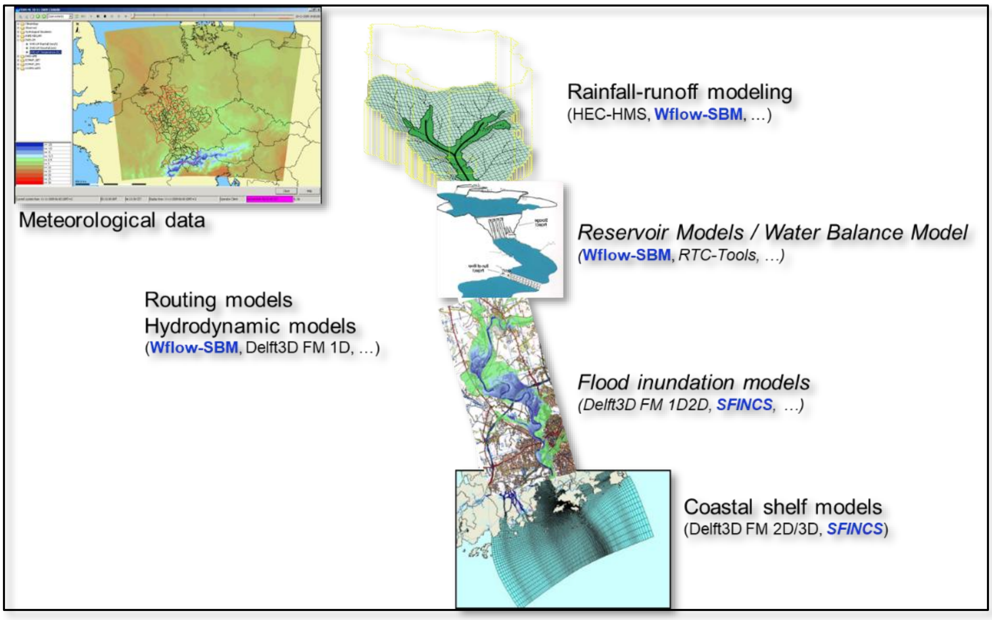


*Figure 5-14 Example of a modelling cascade. In **blue**, the models that are selected to be integrated into the prototype.*

5.3.1 Hydrological model: Wflow

The hydrological model is used to translate rainfall data into surface runoff and river streamflow information. Typically, such models included processes like interception, soil water accounting and lateral (sub)surface routing. There are many different types of rainfall-runoff models, from conceptual lumped models to physics based gridded models. Each type of model has pros and cons, as shown in Table 5-2.

Table 5-2 Overview of types of hydrological models.

Spatial representation	Physics	Example	Pros	Cons
Lumped	Conceptual	HBV, HEC-HMS	• Fast • Can be calibrated well for specific purpose.	• Difficult to calibrate for multi-purpose. • Poor spatial representation • Can be difficult to setup • Poor connection with real observable physical processes
Lumped	Physics based	SWAT	• Fast • Can be calibrated well for multi-purpose. • Good connection with real observable physical processes	• Poor spatial representation • Can be difficult to setup
Grid-based	Conceptual	Spatial-HBV	• Good spatial representation • Easy to setup	• Relatively slow • Poor connection with real observable physical processes
Grid-based	Physics based	Wflow-SBM, MIKE-SHE	• Good spatial representation • Easy to setup • Good connection with real observable physical processes	• Relatively slow

For the prototype, use is made of the fully open-source Wflow-SBM model (Van Verseveld et al., 2024). The reason to do this, is that Wflow-SBM can well represent different physical processes, which makes it suitable for both flood and drought situations. Furthermore, the spatial representation also allows it to be used as input for landslide and flash flood assessments, for example by simulating soil moisture conditions.

The Wflow-SBM model is setup for the complete river basins of the rivers flowing through and into Iskandar Malaysia. The key inputs for the model setup are the hydrographic data (elevation, river network, etc.), land use data and soil data. Making use of the open-source Hydro Model Tools package (Eilander et al., 2023), the models can quickly be setup using readily available datasets.
The Wflow-SBM model is setup with a resolution of 500x500 meter, providing sufficient spatial details while maintaining short runtimes. The latter is relevant if the model is being used for forecasting, as results need to be quickly available to provide input to other models (e.g. the flood hazard model).

The Wflow-SBM model can simulate both land surface runoff and river discharge. The land runoff is the result of the soil balance model: water that cannot infiltrate goes directly to the surface runoff component; the infiltrated water follows the sub-surface route. In Figure 5-15 a screenshot is shown, displaying the results of the Wflow-SBM model for the Iskandar Malaysia region. The screenshot shows both the spatial information, as well as the output for a few selected locations.

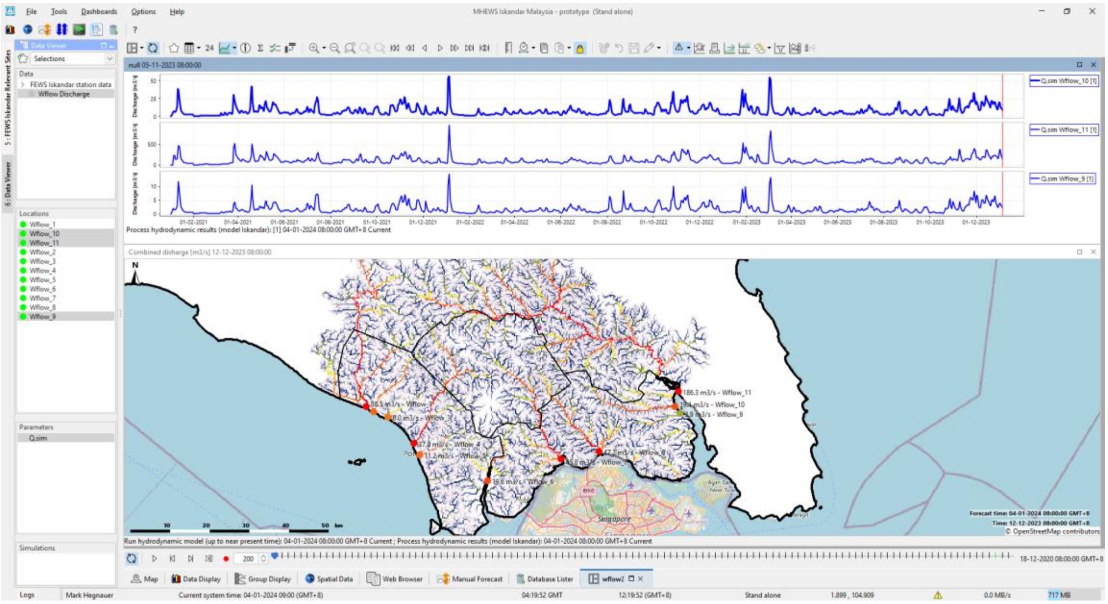


Figure 5-15 Screenshot of the MHP-IM showing the Wflow-SBM model results.

As said, the MHP-IM can also be used to perform basic statistical analysis. In Figure 5-16 an example of on-the-fly calculation of flow duration curves for selected stations is shown. The flow duration curve is a common hydrological analysis to assess both low and high flow statistics for long discharge timeseries. The results of this analysis can be used to derive location specific threshold values, for example based on the 5%, 25%, 50%, 75% and 95% non-exceedance probabilities.

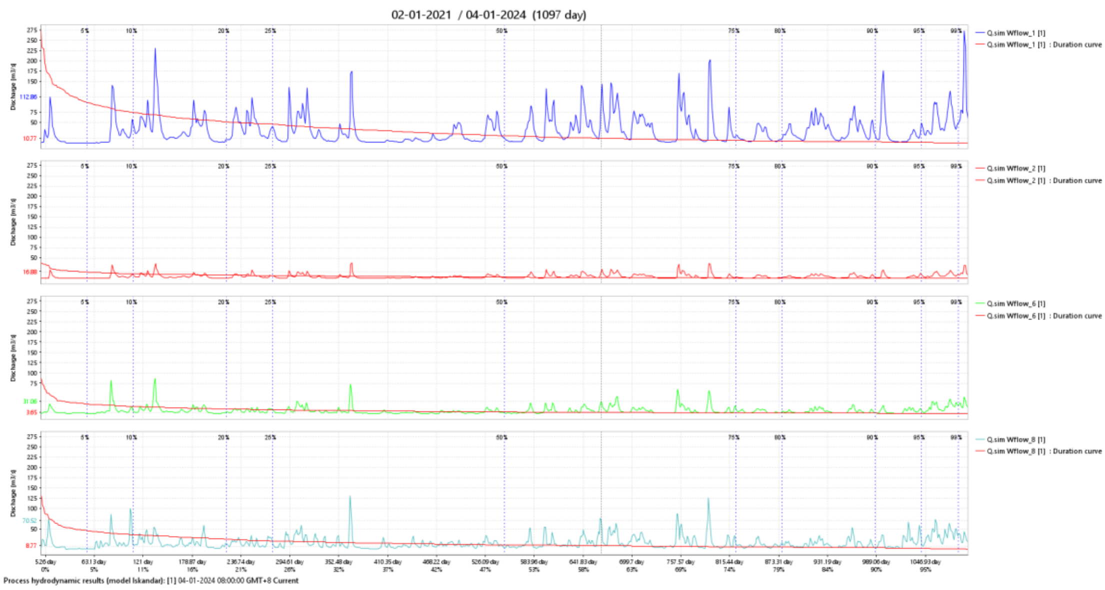


Figure 5-16 Example of on-the-fly flow duration curve calculations.

The hydrological model outputs can be used for several applications:
- Upstream boundary conditions for the flood hazard model (next section);
- Simulation and forecasting of hydrological drought conditions;
- Input for calculation of flood discharge with various return periods;
- Input for the simulation and forecasting of landslides and flash floods;
- Input for the simulation and forecasting of water quality.

Due to the multi-purpose usage of the hydrological model, it is recommended to include such a model in the MHP-IM.

5.3.2 Flood hazard model: SFINCS

A hydrodynamic model can be used to set up a flood hazard model. Hydrodynamic models can simulate water in 1D, 1D2D and 2D. For flood hazard simulations, typically 1D2D or fully 2D models are used. The disadvantage of 2D (and in some extend 1D2D) models is that they typically are slow compared to 1D models or compared to hydrological models.

Therefore, for the prototype a reduced complexity 2D model, SFINCS, was used. The SFINCS model (Super-Fast INundation of CoastS) is a new reduced-complexity engine that is capable of simulating compound flooding including a high computational efficiency balanced with good accuracy (Leijnse et al., 2022). The SFINCS model is a 2D flood model that is typically used for coastal and compound flood hazard simulations. The SFINCS model is setup for the Iskandar Malaysia region. The data sources that have been used to setup the model are listed in Table 5-3.

Table 5-3 Data input.

Data type	Source	Spatial resolution
Digital elevation data	MERIT Hydro	~ 90x90 m
Landuse / land cover	ESA World Cover	~ 10x10 m
Rainfall data (forcing)	ERA5	~ 25x25 km
Coastal water levels (forcing)	Corrected GTSM	N/A
River geometry / bathymetry	MERIT Hydro + Local bathymetry data	~ 100x100 m

The initial model domain is shown in Figure 5-17, which shows the elevation of the terrain. No 1D elements have been included into the model. The model requires the following boundary conditions:
- Downstream water levels;
- Upstream river discharge;
- Optional: local rainfall on the grid.

The upstream discharge boundary conditions come from the hydrological model. The downstream boundary conditions can be taken from a coastal model, or directly from observations.

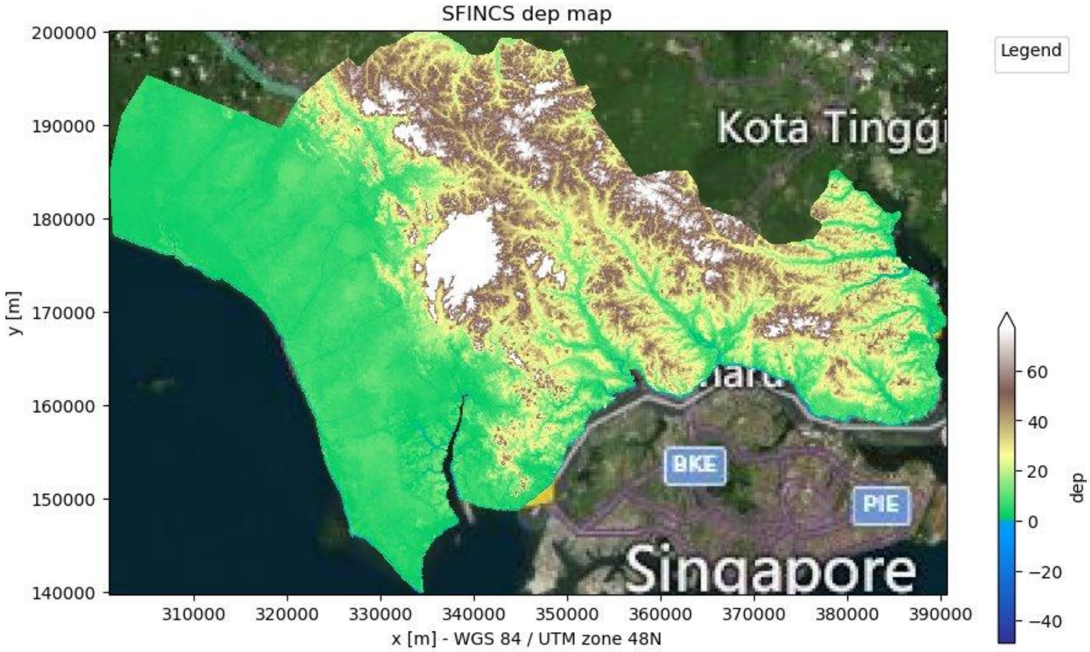


Figure 5-17 The digital elevation model used for the SFINCS model.

Next to the land elevation, the land use is a critical part of the model schematization, as the land surface roughness and the infiltration rates are determined based on the land use. Figure 5-18 shows the infiltration rates (left) and Mannings roughness values (right) derived from the ESA World Cover land use map.

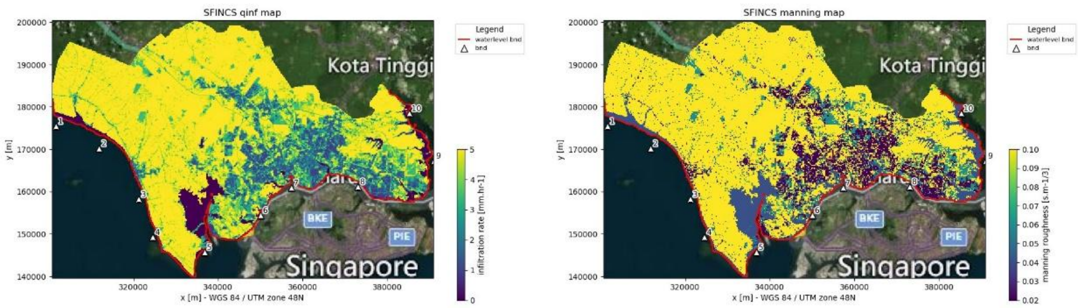


Figure 5-18 Infiltration (left) and Mannings roughness (right) grids as part of the SFINCS model.

A preliminary run, using only globally available data, was done and results for 2 events (July 2020 (left) and January 2023 (right)) are shown in Figure 5-19.

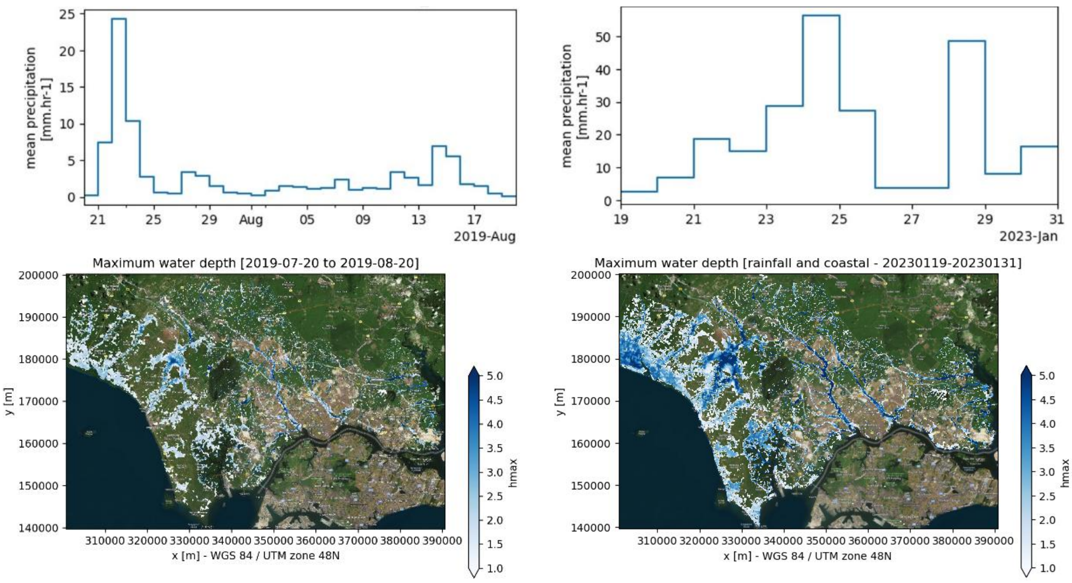


Figure 5-19 Preliminary results of a SFINCS simulation for an event in July 2020 (left panel) and January 2023 (right panel). From these results it could be concluded that the January 2023 event caused more widespread flooding.

As SFINCS is a fast model, it is suitable for flood hazard forecasting as well as for doing flood risk assessments. As part of a flood risk assessment, the relative contribution of different drivers can be investigated, and compound flood hazards and statistics can be derived. As an example, Figure 5-20 presents the results for the January 2023 event for the case only local rainfall is used, compared to only downstream boundary conditions (right). This kind of assessment can provide insight into where which process are relevant or dominant and how these processes could potentially interact with each other.

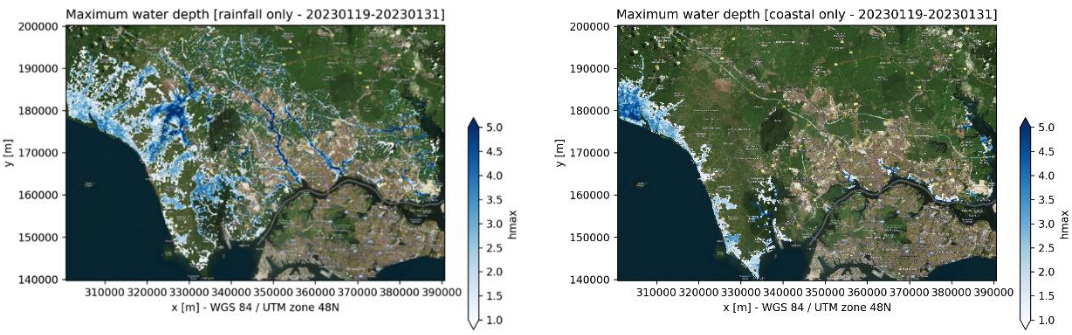


Figure 5-20 SFINCS results for different drivers. The left panel shows the maximum flood depth for only rainfall flooding, and the right panel shows the maximum flood depth for only coastal flooding.

Figure 5-21 shows in red the difference between the compound event (i.e. rainfall and downstream water level), compared to only downstream water levels (left) and only rainfall (right) drivers. The red colour indicates ≥0,5 meter difference between the two simulations. From these simulations is becomes clear that it is important to analyse these drivers together.

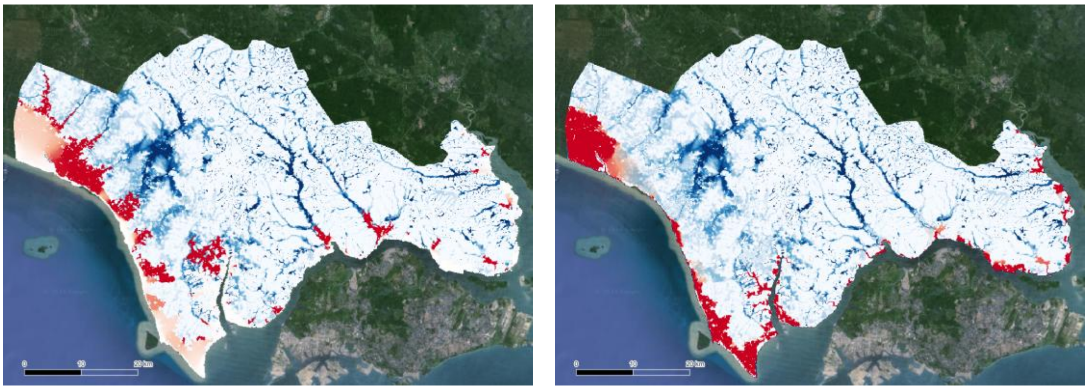


Figure 5-21 In red the difference between the compound event (i.e. rainfall and downstream water level), compared to only downstream water levels (left) and only rainfall (right) drivers.

A calibrated SFINCS model can also be used to derive probabilistic hazard maps. The probabilistic map referred to here represents flood-prone areas along with inundation depths for various return periods in the Iskandar Malaysia region. To generate the probabilistic map, the SFINCS model requires upstream boundary condition data in the form of flood hydrographs for different return periods, as well as downstream boundary condition data in the form of sea water levels. Both boundary conditions are derived through statistical analysis of river discharge and sea water level data.

An example of the probabilistic flood hazard map for the 10-year and 25-year return periods can be seen in Figure 5-22. Probabilistic flood hazard maps for other return periods can be found in sub-chapter 6.2.

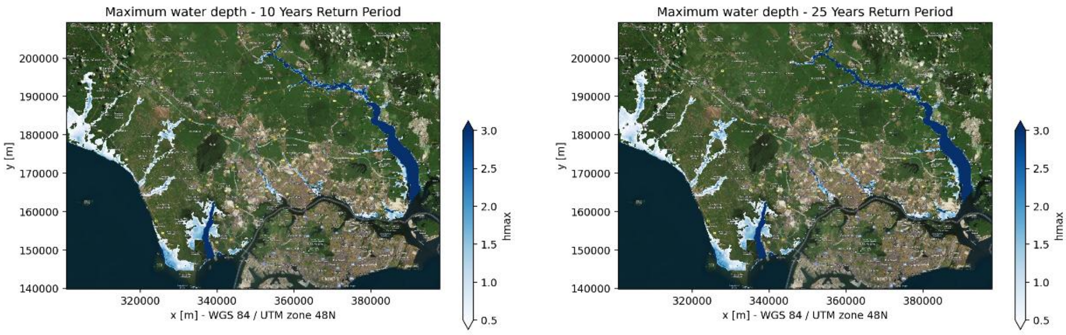


Figure 5-22 Probabilistic Flood Hazard Maps for 10-Year and 25-Year Return Periods in Iskandar Malaysia.

5.3.3 Flood risk model: FIAT

As stated in the methodology, flood risk is represented by Expected Annual Damage (EAD). It is a crucial metric representing the average yearly economic loss due to flooding. Calculation of EAD integrates potential damages across various flood events each characterized by different return periods. In this case, flood scenarios were made from 1-year, 2-year, 5-year, 10-year, 25-year, and 100-year return periods.

A risk model was set up using Delft-FIAT to quantify damages per return period and integrated into EAD. Delft-FIAT (Flood Impact Assessment Tool) is a tool developed by Deltares that takes three components as inputs, as described in Section 4.1.3 (Slager et al., 2017). List of the components and the collected data are in Table 5-4. Buildings were used as the basis object of the exposure.

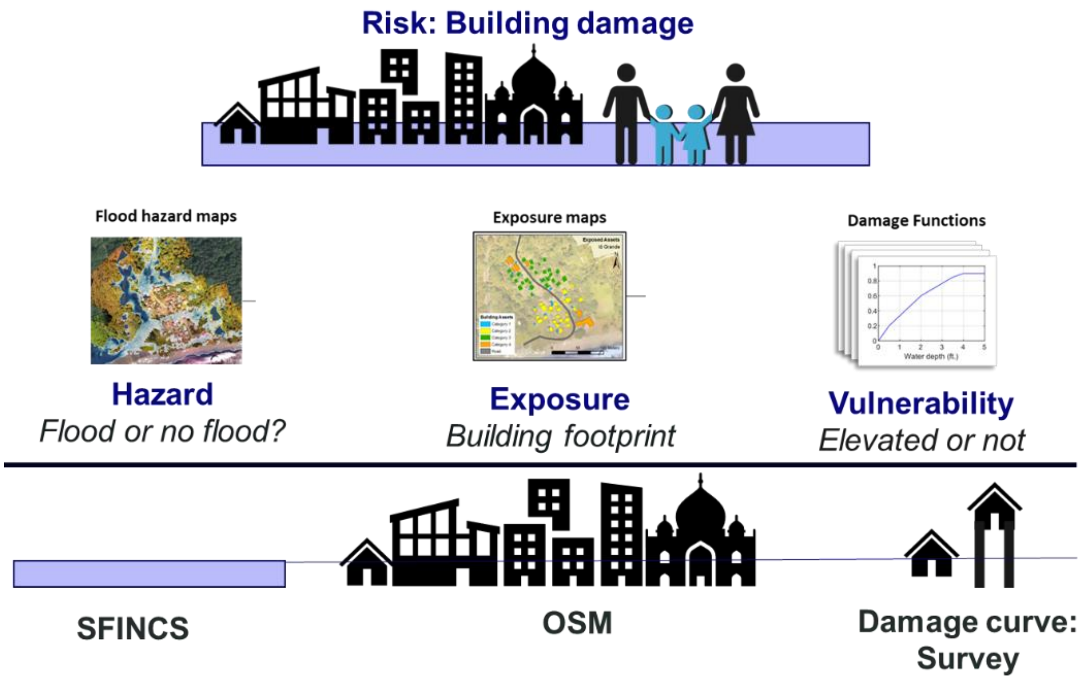


Figure 5-23 Building-based risk assessment in FIAT.

Table 5-4 Input data for risk assessment.

Category	Required data input	Source	
		Local	Global
Exposure	Building footprint	-	Open Buildings (Google)
	Building function (i.e. residential, commercial, industrial)	-	OSM
	Building damage cost	Construction Cost Malaysia Report 2022 (Arcadis & JUBM)	JRC 2017
	Plinth height of building	(assumption) 15 cm	
	POIs		Google derived
Vulnerability	Flood damage function		JRC 2017
Socio-economic	Demography status (total population, gender distribution, age distribution)	DOSM, 2020 in mukim level	WSF 2019
	Economic status (Poverty & Gini index)	DOSM, 2022 in District level	
Hazard	Flood depth map	Deltares SFINC model	
Geographic	Administration boundary	Level 3 (District) and Level 4 Johor Adm. Boundary (mukim)	

Exposure
In this case, building footprints from Open buildings (Google) served as the basis for information (Figure 4-17). Due to the absence of attributes in the provided building footprint data, land use data from OpenStreetMap (OSM) was utilized to categorize the building footprints. The building categories align with those used in the vulnerability function (residential, commercial, and industrial). Additional information, such as area, plinth height, and administrative area, was subsequently added to the building footprint attributes.

Labelling the building function, whether it is residential, commercial, or industrial, is required to estimate the value of the structure and its contents. Estimation of the building function was based on the information from OSM and the POIs from Google Earth. Building damage for structure costs were calculated based on the report on Construction Cost Handbook Malaysia 2022 (JUBM & Arcadis, 2022) for Johor Bahru. Valuation of the building is the construction cost for specific classes under 3 building categories (Residential, Commercial, and Industrial). However, in this project, building damage costs were calculated considering the depreciation value of the building from the average of the lowest range in 3 building categories. For calculating the damaged content costs, rules from JRC were followed. Table 5-5 shows the value of the structure and content damage cost for each building function in Johor.

Table 5-5 Damage structure and content cost for Johor based on the reference from CCM (2022) with adjustment for the depreciation construction cost and content following the JRC rules.

Building function	Structure				Content			
	MYR/m^2 (CCM 2022)	depreciated value factor	Max damage cost MYR/m^2	Max damage cost USD/m^2	factor	MYR/m^2	Max damage cost MYR/m^2	Max damage cost USD/m^2
Residential	995	0.6	597	134	0.5	497.5	248.75	134
Commercial	1802.5	0.6	1081.5	242	1	1802.5	1802.5	242
Industrial	1005	0.6	603	135	1.5	1507.5	2261.25	135

Population were projected for each residential building based on the total population for each *mukim*/village (Administration Level 4, as pictured in Figure 5-24) with the assumption that the average occupation area per person is similar for each village (details of the data can be found in the appendix). Therefore, based on the calculation on the building footprint, damages were then calculated for the building cost and population impacted. Figure 5-25 shows the exposure coverage from OpenBuilding data.

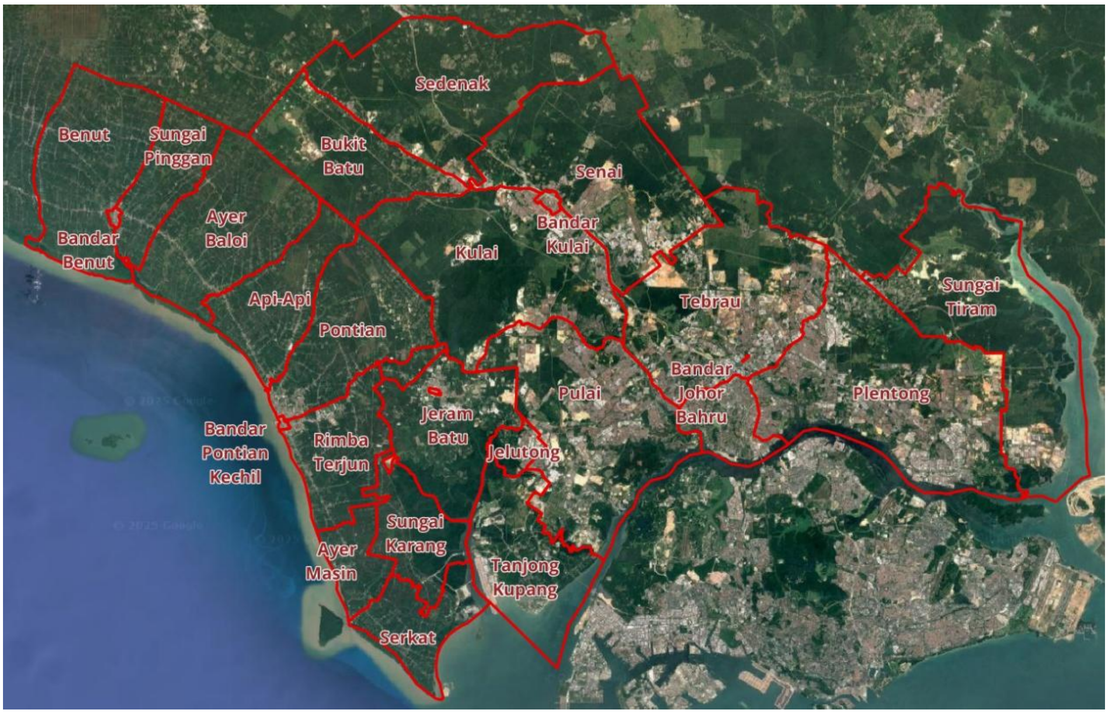


Figure 5-24 Area of interest in with the Administration boundaries at level 4 (Mukim/Village area).

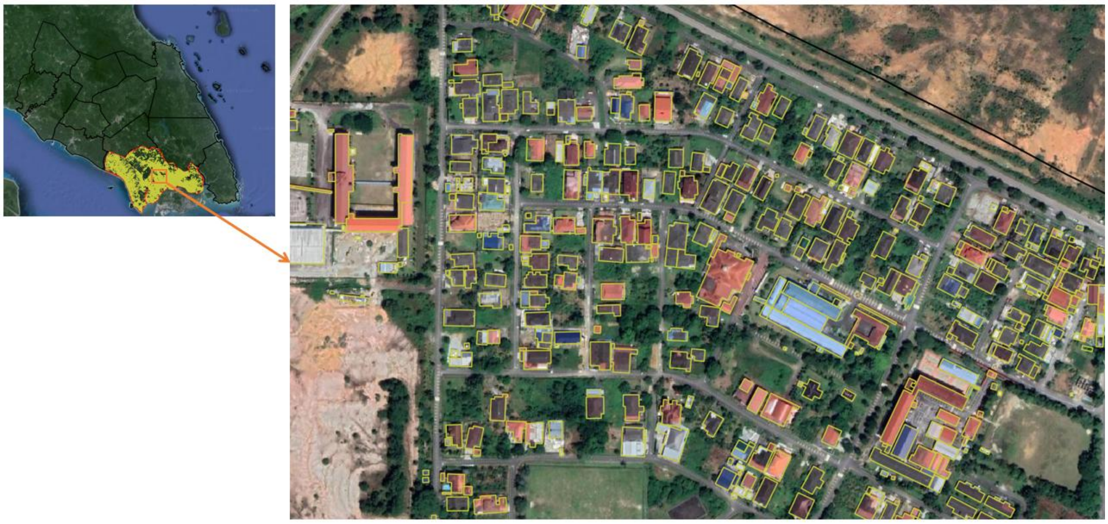


Figure 5-25 Building footprint from OpenBuilding data extent for Iskandar Malaysia.

Vulnerability

Vulnerability functions (many times called damage curves) are a critical component in estimating damages and risk. In this case, vulnerability is based on the damage curves published by JRC. There is no data available specifically for Iskandar Malaysia, or for Malaysia. Therefore, JRC database for Asia countries was used as the basis of the calculation of the damage as shown in Table 5-6 and Figure 5-26. This was made by the assumption that all buildings were made by concrete and each function had the same quality.

Table 5-6 Damage factor from the vulnerability functions published by JRC for the Asian countries.

Flood depth (m)	Damage factor		
	Residential	Commercial	Industrial
0	0.00	0.00	0.00
0.5	0.33	0.38	0.28
1	0.49	0.54	0.48
1.5	0.62	0.66	0.63
2	0.72	0.76	0.72
3	0.87	0.88	0.86
4	0.93	0.94	0.91
5	0.98	0.98	0.96
6	1.00	1.00	1.00

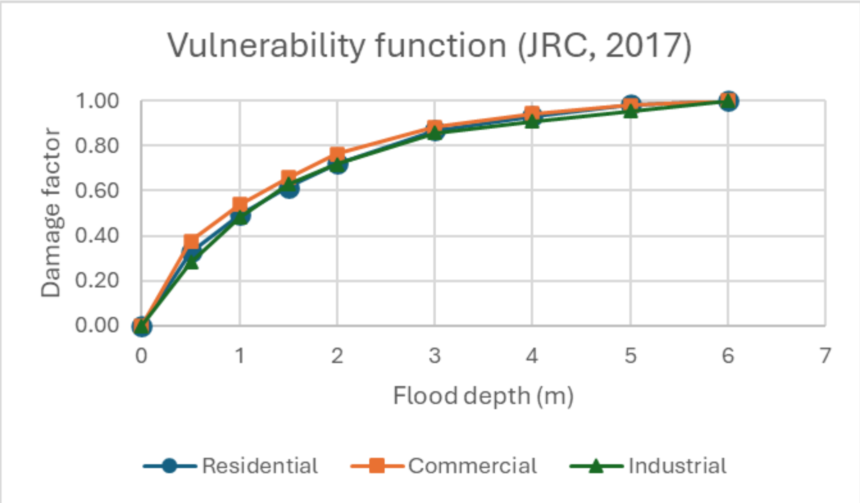


Figure 5-26 Vulnerability functions for residential, commercial, and industrial building based on JRC database for Asian countries. The X-axis shows the flood depth in meters and Y-axis shows the damage factor.

5.3.4 Other hazards

The MHP-IM ultimately shall also include other hazards than flood hazards. Examples are drought risk, heat stress indicators and air quality. These hazards are not formally part of the prototype as the focus of the MHP is on (coastal) flooding, but they are included as means of showing examples of how data can be used to create hazard and risk information.

5.3.4.1 Heat stress

In the figures below, an example of the heat stress index is shown as it has been implemented in the prototype. The heat stress index is calculated based on the Ersatz version of the Heat Index equation formula[2]. In order to calculate Heat Index, temperature and relative humidity data is required. At the time this document was created, the temperature and relative humidity data being used still came from the GFS forecast dataset. This dataset enables the calculation of the current Heat Stress Index, as well as forecasts for the next 5 days at 1-hour intervals and for the next 16 days at 3-hour intervals.

[2] Lans P. Rothfusz. "The Heat Index 'Equation' (or, More Than You Ever Wanted to Know About Heat Index)", Scientific Services Division (NWS Southern Region Headquarters), 1 July 1990

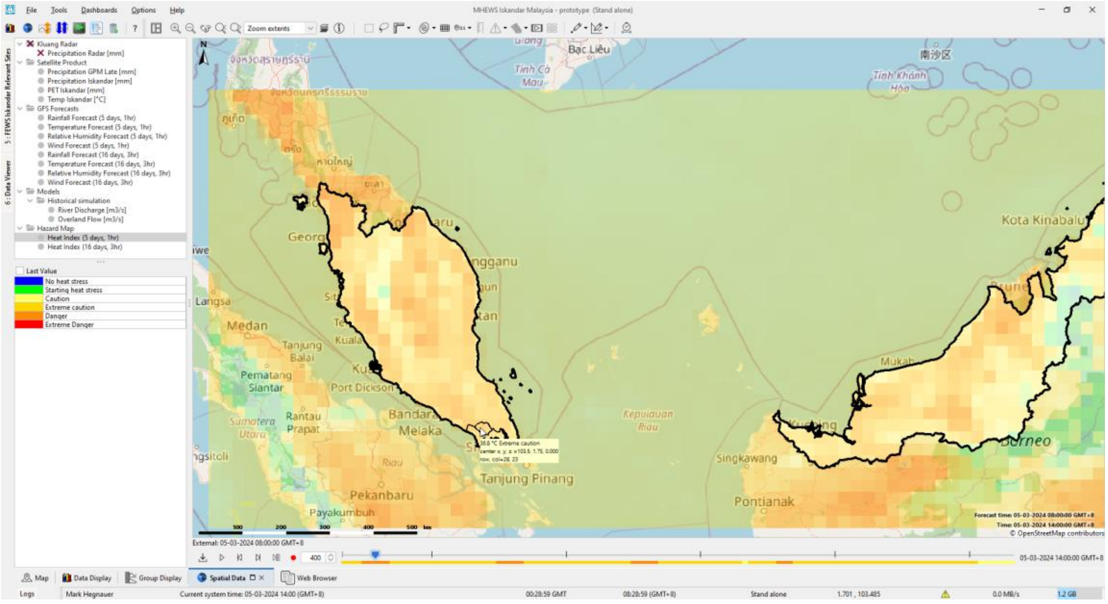


Figure 5-27 Heat stress indicator integrated into the MHP-IM-IM.

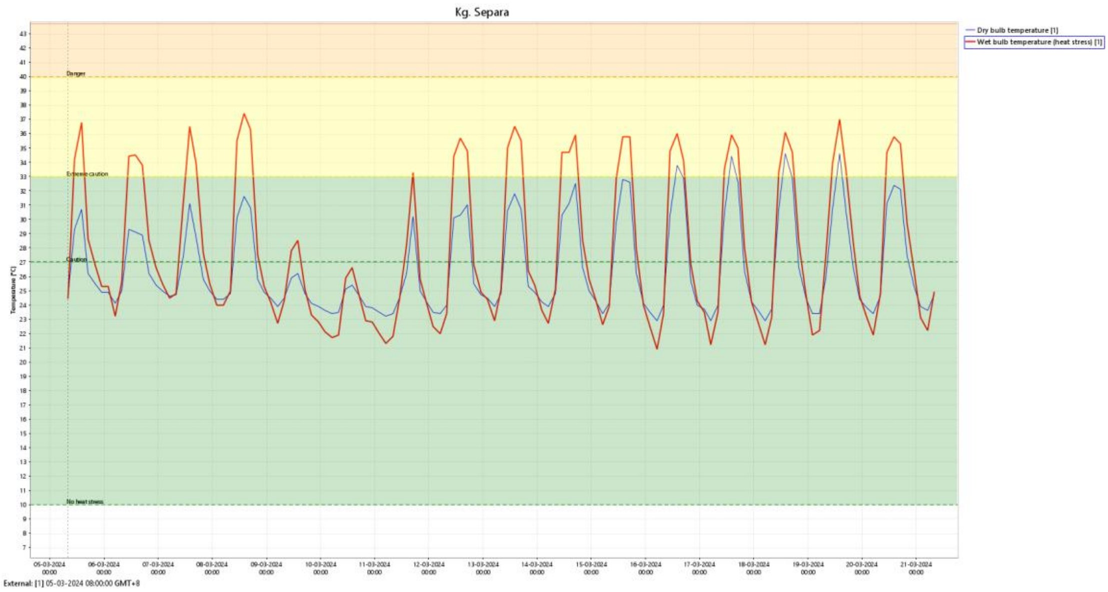


Figure 5-28 Heat stress information is made available for each location of interest.

5.3.4.2 Drought

There is no single definition of drought. Drought depends strongly on the type of application. For farmers typically the amount of water in the soil and the water available for irrigation are important drought indicators. For inland shipping, the amount of water in the rivers is a more relevant indicator. And for reservoir operations the inflow, which can be directly coupled to the amount of rainfall, is an important indicator.

Depending on which models are included in the MHP-IM, the platform can calculate the following drought indicators:

- Standardized Precipitation Index (SPI)
  This is a way of presenting meteorological drought indicators.
- Hydrological drought indicators
  Using the Wflow-SBM model, the water availability in lakes, reservoirs and rivers can be simulated and forecasted.

- Agricultural drought indicators
  Using the Wflow-SBM model, the soil water balance as well as the water availability in lakes, reservoirs and rivers can be simulated and forecasted.

It must be noted that drought indicators are very domain and application specific, so setting up a drought forecast, or early warning system requires a flexible system and good interactions with the different sectors depending on the drought information.

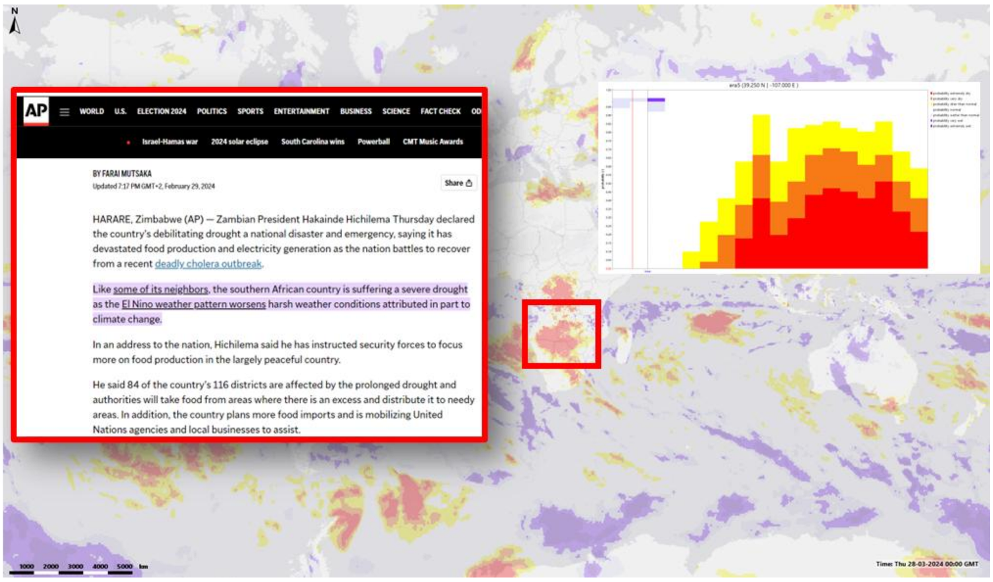


Figure 5-29 Example of the operational Standardized Precipitation Index (SPI) based on ensemble precipitation forecast data.

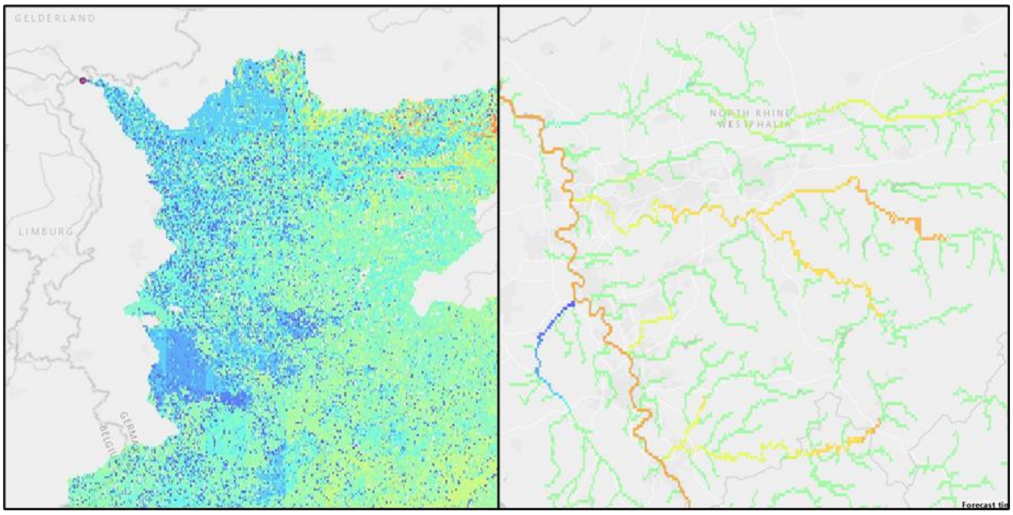


Figure 5-30 Example of agricultural drought indicators (left) based on Wflow model output for the unsaturated zone of the soil layer, and the hydrological drought indicators (right) based on the Wflow streamflow simulations. Blue colour means low probability of drought conditions, red means high probability of drought conditions.

5.4 Reporting and early warning

5.4.1 Automatic reporting

Delft-FEWS is also used to process information and generate automatic reports. The content of the report is determined by the end-user requirements. This means that for different end-users, different types of report can be automatically generated using the latest available information.

The level of detail contained in these reports might differ from user to user. In the final stage of the project, example reports for different (type of) users have been developed to demonstrate the capacity of the MHP to deliver these reports.

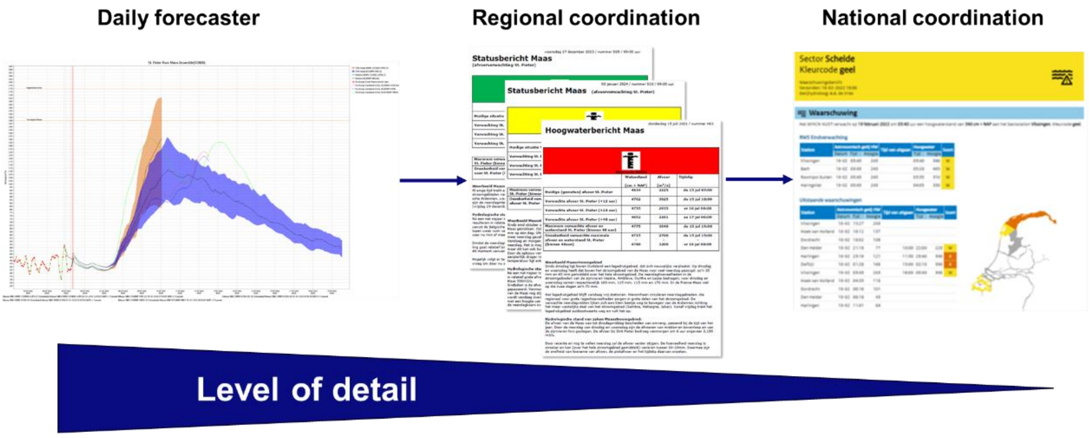


Figure 5-31 Example of automatic reports at different levels of detail.

The reports are typically designed to follow a standard operating procedure (SOP) for each user.

Title: Implementation of forecast and warning options			
SOP ID: A323	**Date:** 27/08/2019	**Version Nr.:** 1.0	
Division: National Centre for Hydromet Forecasting			
SOP preparation	Mr. X	Signature:	Date: 01/06/2019
SOP approval	Mr/Mrs Y	Signature:	Date:
Description of procedure:	This SOP describes the implementation of forecast and warning options.		
Reference docs.:	-		
Links to other SOPs:	• SOP ID A320 – Forecasting Procedure 3.2.0: Start forecasting duty • SOP ID A321 – Forecasting Procedure 3.2.1: Collection and processing of information and data • SOP ID A322 – Forecasting Procedure 3.2.2: Analysis and assessment of current situation		
Frequency of SOP:	Depending on the organizational schedule		
Update SOP:	Depending on change in Circulars or change in software		
List of definitions / acronyms	Not applicable		

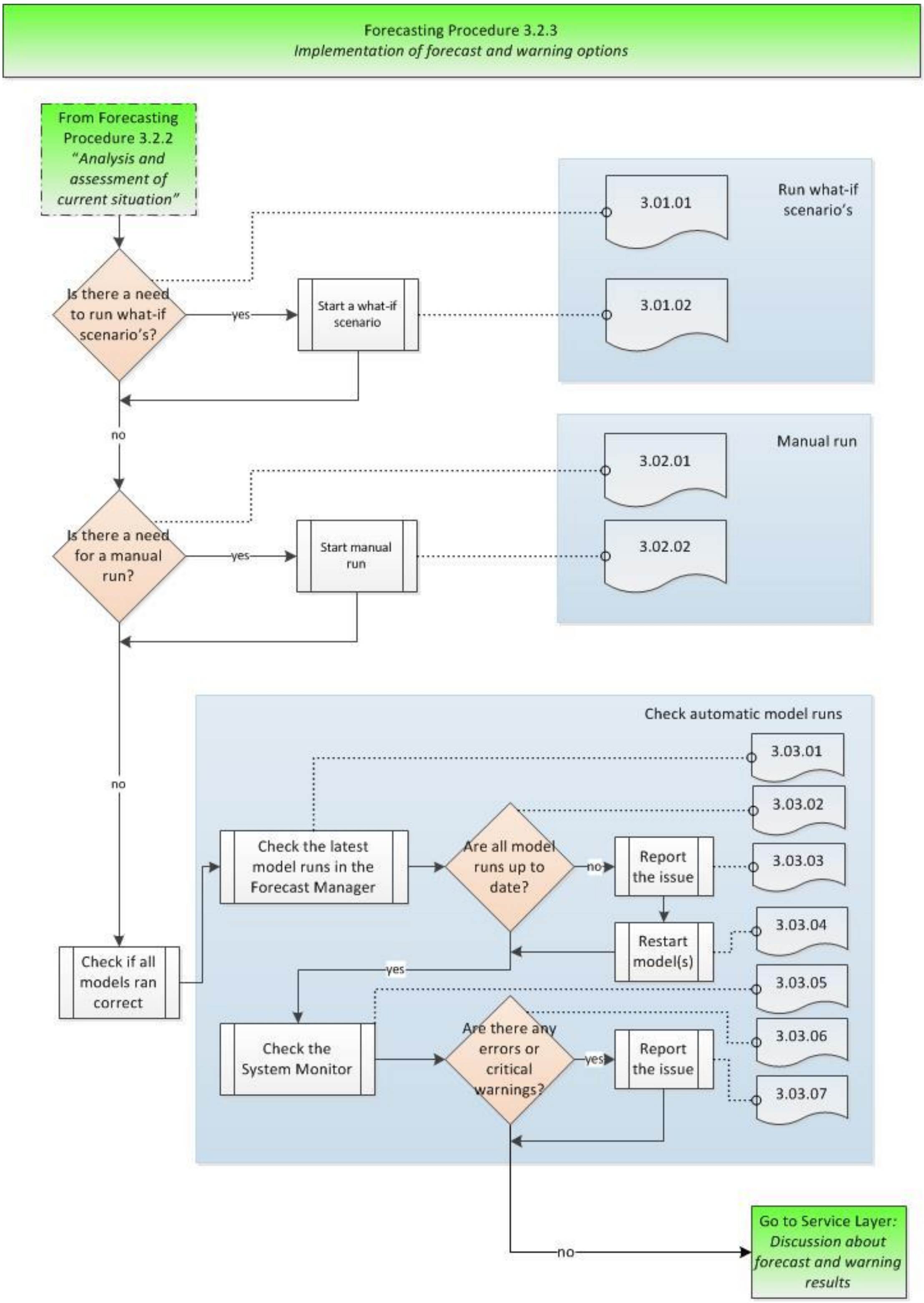


Figure 5-32 Example of a standard operating procedure (SOP) for forecast and warning options.

5.4.2 Early warning

An important aspect of the MHP is to provide early warning to (end) users to take action. The warnings can be derived and sent automatically, based on specific threshold crossings. However, in many cases, warnings are generated and sent by forecasters that check and assess the situation first. Delft-FEWS has functionality to prepare the warnings and after approving the forecasts by the forecaster, automatically sent the early warning to relevant organizations.

Early warning display has been implemented in the prototype, based on the thresholds that were derived based on collected data and information.

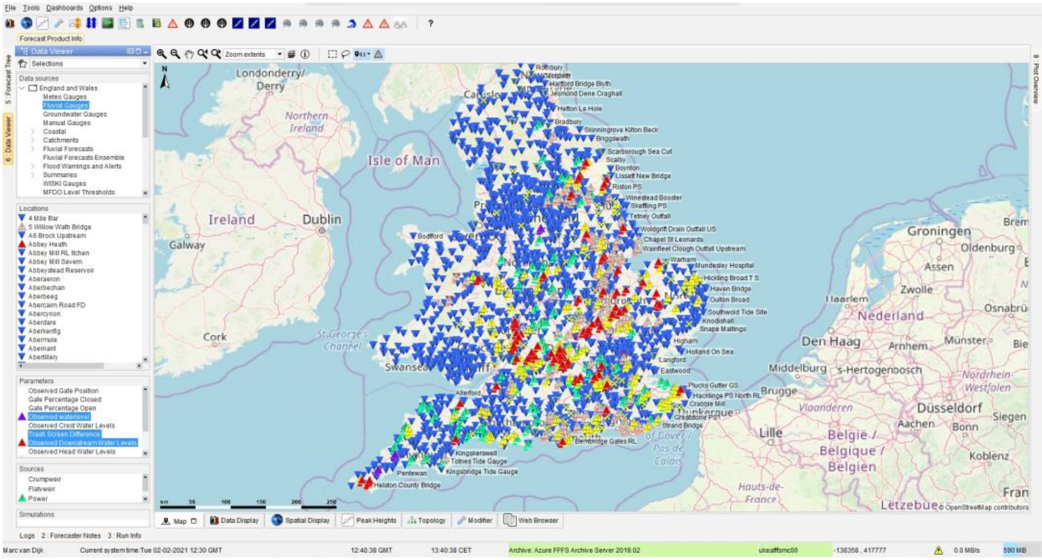


Figure 5-33 Example of thresholds crossings displayed on the map for the UK. Green means minor flood warning, orange means moderate flood warning and red means severe flood warning.

6 Results of the risk assessment

In this chapter, the results of the statistical analysis and flood risk assessment are presented. The flood risk assessment follows the framework as demonstrated in Figure 6-1. Section 6.1 presents the results of the statistical analysis and flood probabilities. Section 6.2 shows the flood hazard maps and finally and in Section 6.3 the damage and risk assessment is presented.

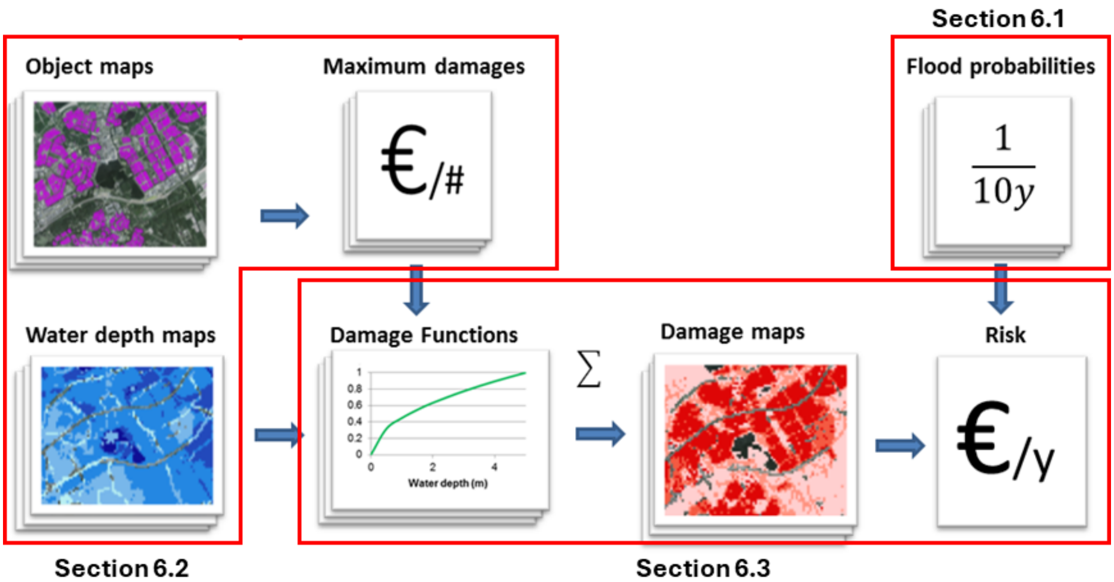


Figure 6-1 Overview of the procedure to compute flood risk in Delft-FIAT. The exposure overlay with the hazard map resulted in a damage maps.

The activities of statistical analysis, hazard mapping, and flood damage and risk assessment can be used to:

1. Provide flow discharge and sea water level information for various return periods, which are essential for flood early warning, post-event analysis, and flood protection design;
2. Provide map layers showing estimated flood-affected areas, flood depths, and potential flood damages (in MYR) for various return periods based on model results;
3. Provide flood risk information (Estimated Annual Damage in MYR) for the Iskandar Malaysia region, presented as a map layer considering different return periods.

The results of the statistical analysis and flood hazard assessment are based on local and global data sources. A comparison between the different data sources is also made for the statistical analysis.

6.1 Statistical analysis

This section contains the statistical processing results of river discharge and sea water levels for the development of probabilistic hazard maps.

Flood design (upstream boundary conditions)
To enable the SFINCS flood model to generate probabilistic hazard maps, upstream boundary conditions in the form of flood hydrographs for various return periods must be prepared. In the MHP-IM prototype, these flood hydrographs are derived from the outputs of the wflow hydrological model, which provides river discharge data for all rivers in Iskandar Malaysia. The locations of the upstream boundary conditions are shown in Figure 6-2. These locations are the upstream starting point of the flood model. The flood model requires input (discharge) to simulate how the water propagates through the river and (potentially) causes flooding downstream.

For this project, the data period used for flood design calculation spans from 1 April 2016, to 30 September 2024, as this is the period for which local rainfall data is available[3]. This data is processed using the block maxima (BM) method to determine the best-fitting distribution, either Gumbel or Generalized Extreme Value (GEV). The selected distribution is then used to generate peak design discharge for 27 upstream boundary conditions across the predefined return periods. The peak design discharge is then converted into a hydrograph by scaling it with the average hydrograph shape of the four largest historical events.

This method is used to derive 1/2, 1/5, 1/10, 1/25 and 1/100- year return values. These values are the input to produce the corresponding flood maps. In Table 6-1 the derived values are presented for the different boundary conditions. The values are derived for both local rainfall and global rainfall data. An example for the visual comparison for a single location can be seen in Figure 6-3. As can be seen in the figure and the table, discharge values based on local data are generally higher than for the global data. This has two possible explanations:

- Local rainfall data is only available for a limited number of stations. To get a spatial coverage of the rainfall, the data is spatially interpolated using the Kriging method. With low density network, local extreme rainfall events such a originating from convective cells are “blown up” to a much larger area. In this case the extreme rainfall might be overestimated for a large part of the area.
- Global data underestimates the rainfall extremes. Hydrological processes are nonlinear. Fast runoff is typically generated if certain thresholds (e.g. the infiltration capacity) are exceeded. Global datasets, such as ERA5 are very coarse and smooth out the total rainfall volume of larger areas. Therefore, rainfall intensities are typically lower than observed in reality.

This example shows the need to have reliable rainfall data, and what the impact is on the derived extreme values. For future applications, it is recommended to base the analysis on longer records, to more accurately derive the values for higher return periods.

[3] It must be noted here that this period is generally too short to accurately derive values for higher return periods.

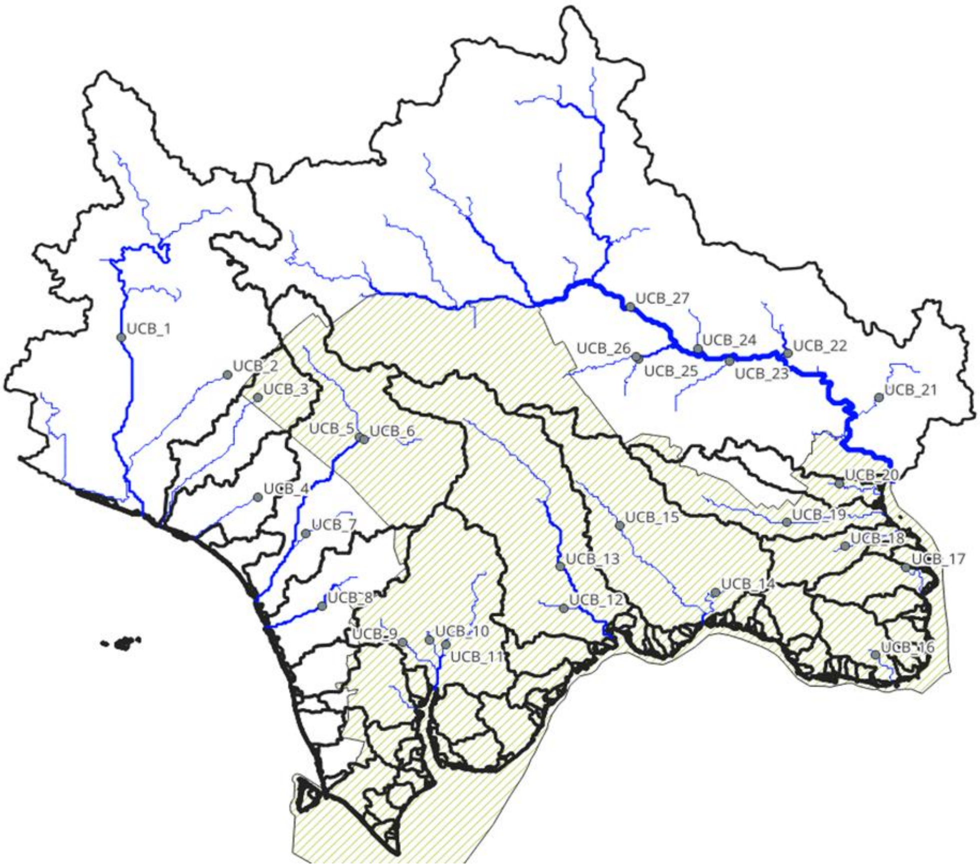


Figure 6-2 Overview of boundary locations of the flood model.

Table 6-1 Overview of derived values per location and per return period for local rainfall and ERA5 global rainfall.

Return Period	Based on local rainfall data					Based on global (ERA5) rainfall data				
	2	5	10	25	100	2	5	10	25	100
UBC_1	25.9	73.2	125.6	232.2	537.9	111.3	151.8	178.8	213.1	263.9
UBC_2	1.5	4.4	7.8	15.7	41.6	6.0	7.8	9.0	10.5	12.7
UBC_3	3.9	8.2	12.4	20.0	38.5	7.8	10.5	12.3	14.7	18.1
UBC_4	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.2
UBC_5	8.9	21.0	34.7	63.3	148.0	29.1	38.4	44.6	52.5	64.1
UBC_6	14.4	24.7	35.6	56.7	113.1	22.0	28.6	33.1	38.7	47.0
UBC_7	15.0	18.8	20.4	21.7	22.9	14.3	18.2	20.9	24.2	29.2
UBC_8	47.5	66.4	79.1	95.1	118.9	32.1	42.4	49.3	57.9	70.8
UBC_9	22.5	31.2	37.1	44.5	55.5	16.6	21.7	25.2	29.5	36.0
UBC_10	10.6	13.9	16.2	19.0	23.1	9.4	12.3	14.2	16.6	20.2
UBC_11	6.9	19.3	33.3	62.2	146.9	27.6	36.2	42.0	49.3	60.2
UBC_12	11.6	23.9	36.1	58.4	113.1	16.8	21.4	24.5	28.4	34.2
UBC_13	77.7	143.2	208.2	327.0	620.5	70.1	91.0	105.0	122.7	148.9
UBC_14	17.8	29.9	38.0	48.2	63.4	22.0	27.0	30.3	34.6	40.8
UBC_15	37.4	61.9	85.3	126.9	225.0	33.3	44.2	51.5	60.8	74.4
UBC_16	7.1	17.9	30.3	56.1	133.2	17.2	20.3	21.4	22.3	22.9

Return Period	Based on local rainfall data					Based on global (ERA5) rainfall data				
	2	5	10	25	100	2	5	10	25	100
UBC_17	1.8	5.5	10.0	19.9	52.2	6.3	8.1	9.3	10.8	13.1
UBC_18	1.1	2.7	4.8	9.5	25.4	7.6	9.7	11.1	12.9	15.5
UBC_19	18.9	37.4	54.3	82.8	145.9	26.4	33.8	38.7	44.9	54.2
UBC_20	5.4	11.9	18.4	30.2	59.2	11.0	15.1	17.9	21.3	26.5
UBC_21	59.5	116.7	154.9	203.3	275.0	36.2	56.2	69.6	86.5	111.6
UBC_22	57.8	104.0	134.9	174.1	232.1	31.9	45.1	53.9	65.1	81.6
UBC_23	34.4	63.3	82.6	107.1	143.4	26.2	35.3	41.4	49.1	60.6
UBC_24	30.4	58.8	77.8	101.9	137.6	22.8	30.9	36.4	43.2	53.4
UBC_25	24.4	44.7	62.6	91.9	154.0	22.9	30.9	36.2	42.9	52.9
UBC_26	37.1	71.5	102.9	155.8	272.4	39.0	52.4	61.4	72.8	89.7
UBC_27	131.6	397.0	692.4	1294.3	3028.2	361.1	482.9	564.5	667.8	820.7

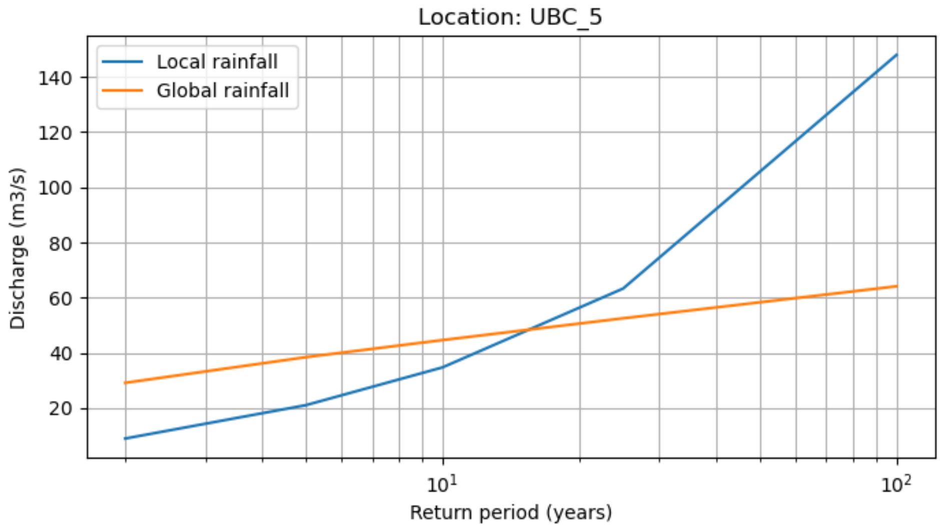


Figure 6-3 Example of the comparison between the derived flood peak values based on local rainfall data (blue line) and global rainfall data (orange line).

Sea water level design (downstream boundary conditions)
The extreme water level values were derived from the GTSM-ERA5 time series data for the period 1950–2024. It is important to note that, due to the relatively sheltered nature of the station locations and the complexity of the coastline, the accuracy of GTSM at these locations is subject to limitations. The extreme value analysis (EVA) was conducted using the Peak-Over-Threshold (POT) method with a Generalized Pareto Distribution (GPD).

Figure 6-4 Connection between GTSM Index and SFINCS Downstream Boundary Conditions.

Table 6-2 Sea Water Level Design (in Meters) for Several Downstream Locations.

Return Period	GTSM Index											
	16759		16758		39718		16757		38762		41778	
	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat
	103.28	1.56	103.40	1.42	103.43	1.30	103.55	1.33	103.93	1.42	104.04	1.39
2	1.81		1.85		1.84		1.85		1.72		1.57	
5	1.83		1.88		1.87		1.89		1.76		1.6	
10	1.86		1.91		1.9		1.91		1.79		1.63	
25	1.89		1.94		1.94		1.95		1.82		1.66	
100	1.94		1.98		1.99		2.00		1.87		1.71	

6.2 Hazard maps

This section contains probabilistic flood hazard maps for various return periods, along with their integration as additional layers in the MHP-IM platform. It is important to note that the probabilistic flood hazard maps are the results of hydrodynamic simulations utilizing flood design discharge from hydrological modeling with input from local rainfall data, as well as sea water levels design derived from the corrected GTSM data. It should be noted that the length and completeness of local rainfall data may influence the resulting flood extent and flood depth.

In terms of the results of the probabilistic flood hazard maps:

- No validation has been done, as there was no data to compare the flood maps against;
- Especially the simulated flooded area in the North-West, in the Pontian district, would require validation of the input data, especially regarding the sea water level relative to the land elevation.

The flood maps, presented in Figure 6-5 to Figure 6-11 show the flooded areas for different extreme events, as a results of the flood model. Dark blue colours indicate larger flood depth. As can be seen in the map, the most impacted areas in terms of flooded area include the Western areas around Pontian and the areas around the two main rivers in Johor Bahru city center.

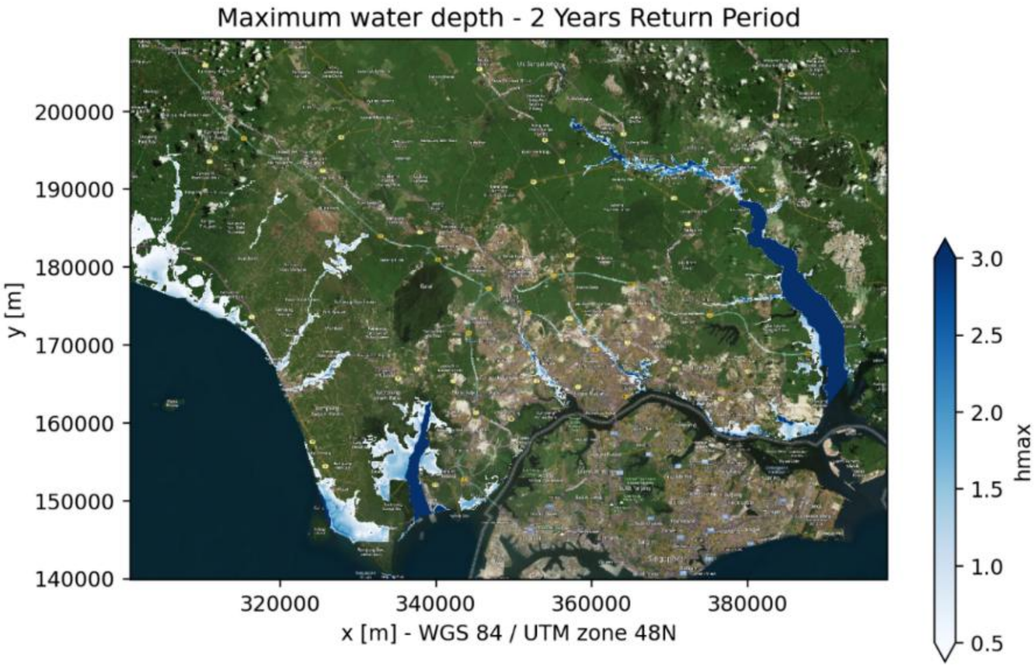


Figure 6-5 Probabilistic Flood Hazard Map for 2-Year Return Period.

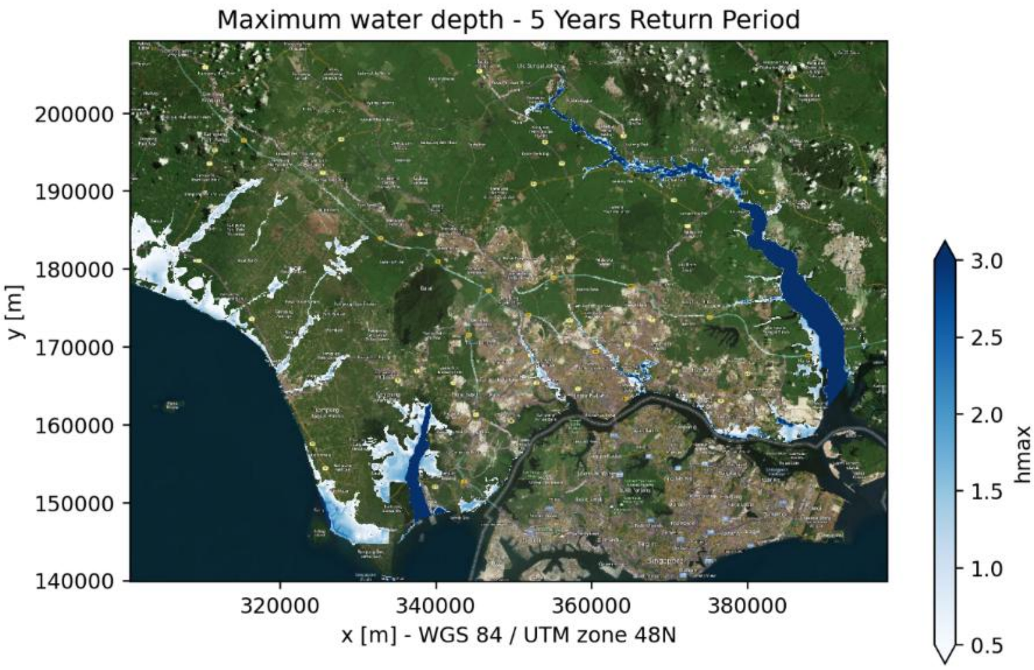


Figure 6-6 Probabilistic Flood Hazard Map for 5-Year Return Period.

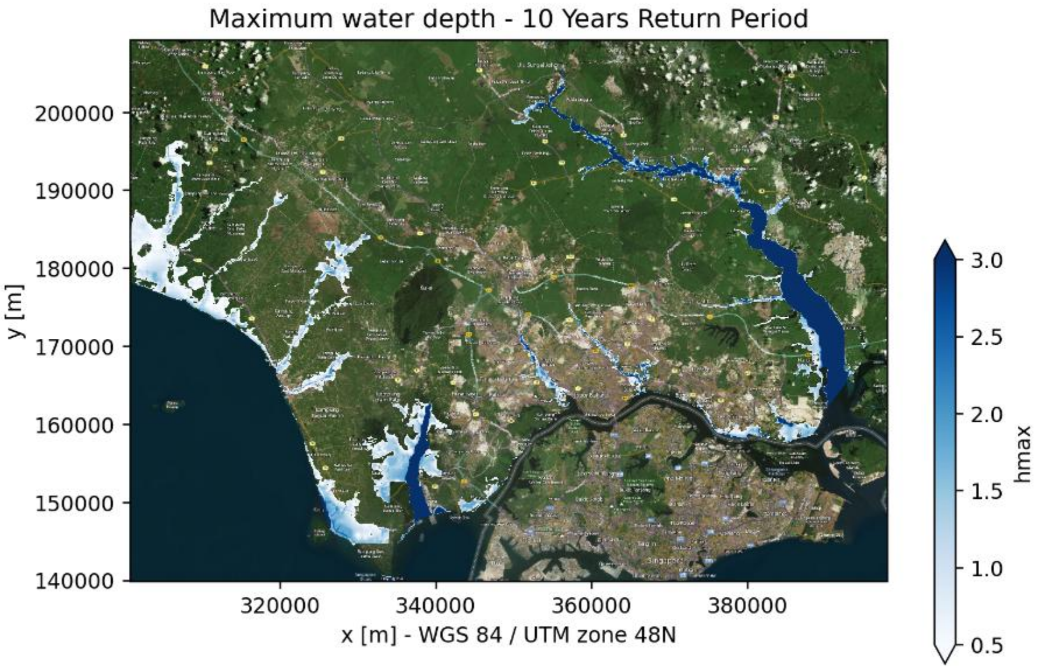


Figure 6-7 Probabilistic Flood Hazard Map for 10-Year Return Period.

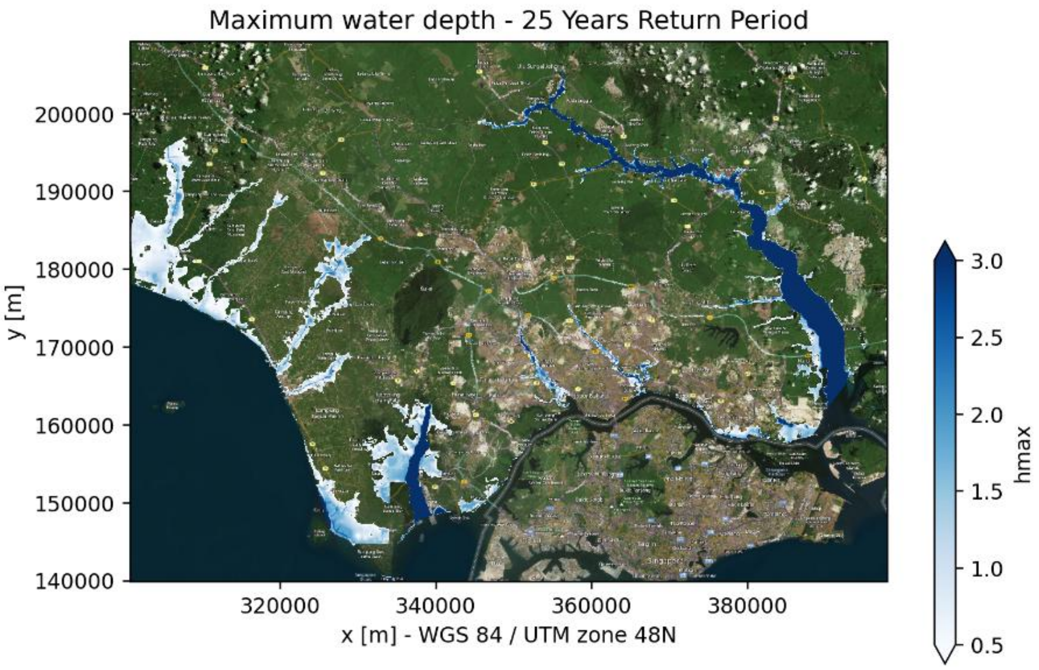


Figure 6-8 Probabilistic Flood Hazard Map for 25-Year Return Period.

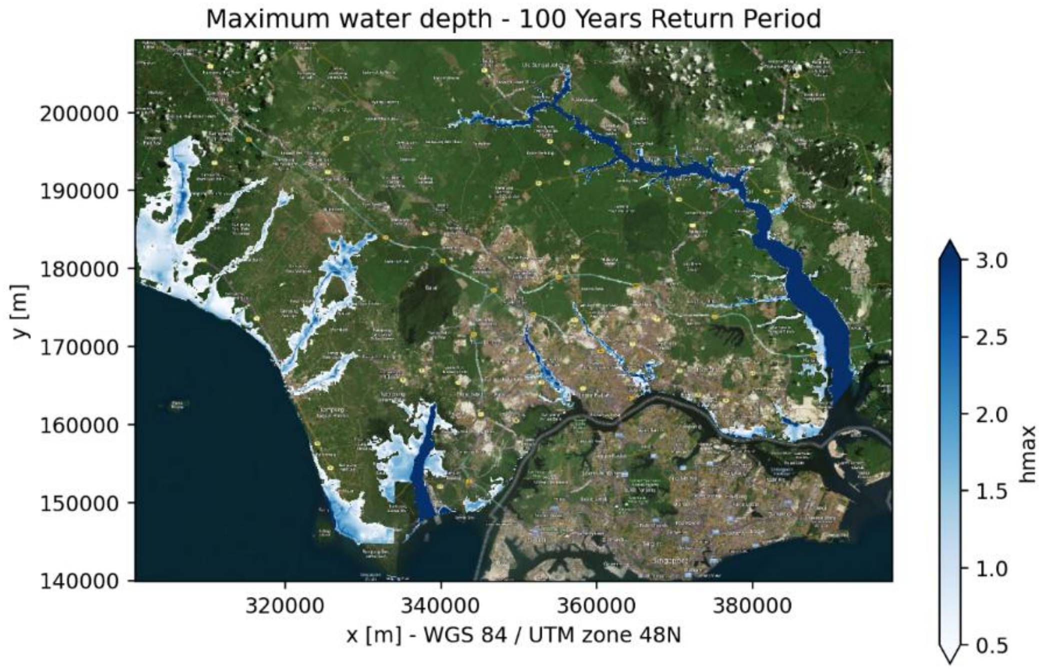


Figure 6-9 Probabilistic Flood Hazard Map for 100-Year Return Period.

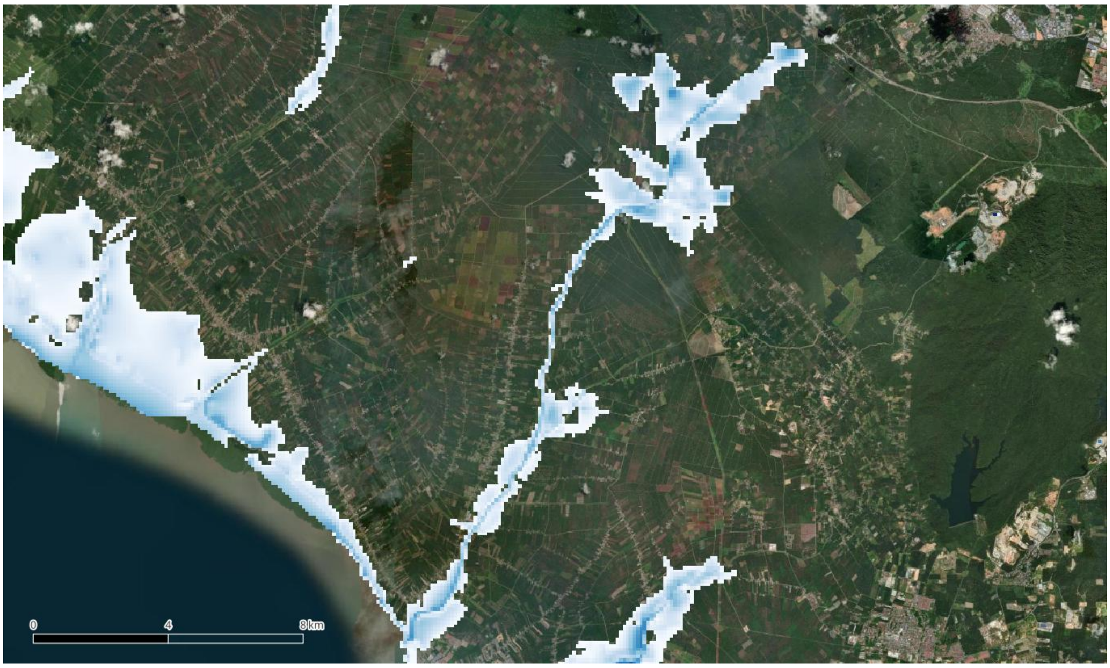


Figure 6-10 Detailed of the flood map for 2-Year Return Period for the area around Kayu Ara Pasong as an example of how the model can be used for localized hazard assessments.

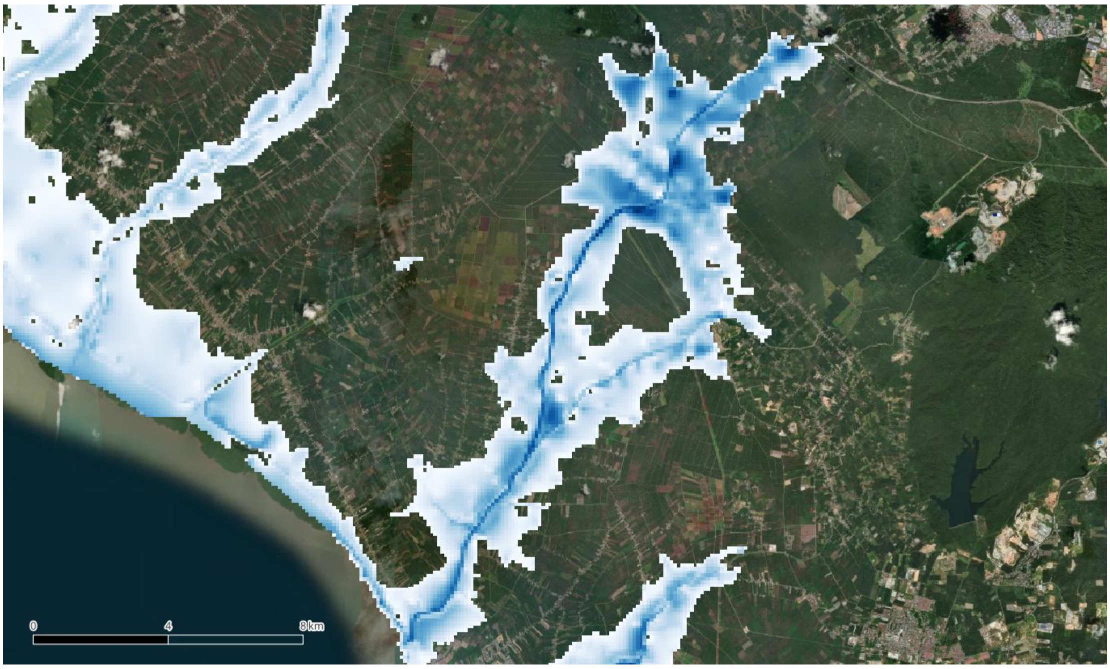


Figure 6-11 Detailed of the flood map for 100-Year Return Period for the area around Kayu Ara Pasong.

Figure 6-12 shows how the hazard maps have been integrated into the MHP-IM. These maps provide essential information for the operators of the MHP-IM and can be used as a reference dataset to compare current or forecasted situation with the pre-defined and pre-calculated hazard maps. This allows the users to quickly assess severity level of the ongoing or forecasted events.

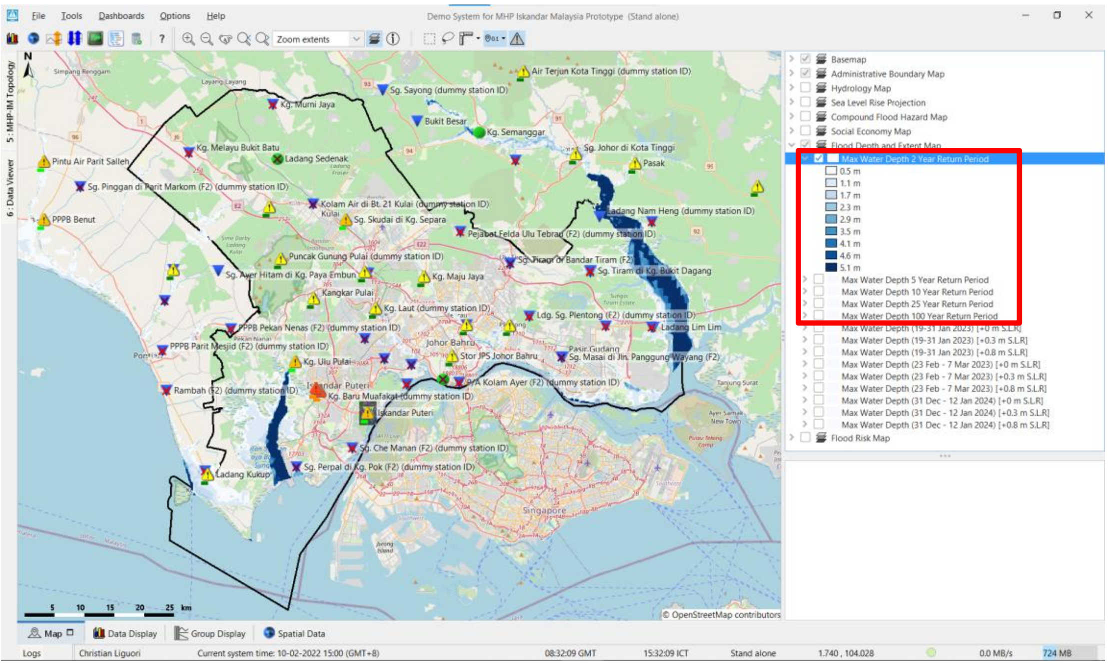


Figure 6-12 Probabilistic Flood Hazard Maps are integrated into MHP IM as reference layer for the end-user during operational usage of the MHP-IM.

6.3 Damage and risk calculations

Hazard maps for various return periods were generated for the 2-year, 5-year, 10-year, 25-year, and 100-year intervals. Using the method that has been described in Section 3.1.3, damage estimates for each return period were calculated, and the Expected Annual Damage (EAD) was then determined by integrating these results to estimate the annual loss from the floods. Calculations for both economic and population impacts were done separately. Results were then aggregated into *mukim*/village level.

In the prototype of MHP-IM, damages are automatically calculated for each flood forecasting using the explained method in Section 3.1.43.1.3 for the damage calculation. Report will also be automatically generate to show the potential damage in economic and population in mukim/village level.

Table 6-3 presents the results of the building damage assessment based on the designed flood maps from different return periods. The risk calculation resulted in individual building damage (Figure 6-13), and aggregated at the administrative level 4 (*mukim* level) as shown in Figure 6-14. These results facilitate the planning of mitigation and adaptation measures, including early warning responses, by prioritizing areas accordingly.

Table 6-3 Damage simulation based on the current flood maps. The results show for each region and for each return period the expected damages. Based on all return periods, the expected annual damages are calculated, as well as the number of people affected.

Mukim	Total Damages (million Ringgit)					EAD (million Ringgit)	Annual Population Impacted
	RP2	RP5	RP10	RP25	RP100		
Api-Api	21.1	33.2	38.6	60.2	152.8	18.7	18
Ayer Baloi	7.9	14.8	21.4	28.8	39.5	7.9	0
Ayer Masin	155.9	160.4	164.5	169.1	176.3	80.5	238
Bandar Benut	60.4	76.2	79.5	108.0	139.9	38.4	169
Bandar Johor Bahru	23.7	4.4	67.2	83.2	111.4	16.3	44
Bandar Kulai	-	-	-	-	-	-	0
Bandar Pontian Kechil	20.4	18.4	22.1	33.2	35.8	10.9	16
Bandar Tebrau	1.3	1.2	1.6	1.7	1.9	0.7	0
Benut	66.9	65.2	109.9	151.6	246.1	44.1	123
Bukit Batu	0.0	0.0	0.1	0.1	0.2	0.0	0
Jelutong	-	0.0	0.0	0.0	0.0	0.0	0
Jeram Batu	11.7	21.2	15.7	17.6	20.0	8.3	19
Kulai	0.4	0.4	0.6	0.8	1.3	0.2	0
Pekan Jeram Batu	-	-	-	-	-	-	0
Pengkalan Raja	-	-	-	-	-	-	0
Plentong	1,264.2	1,465.6	1,456.3	1,580.6	1,736.6	708.2	2491
Pontian	72.8	64.5	116.1	148.7	204.7	44.5	109
Pulai	558.1	454.8	753.5	883.7	1,090.0	301.3	2558
Rimba Terjun	89.8	44.7	144.9	179.8	231.6	48.0	177
Sedenak	-	-	-	-	0.2	0.0	0
Senai	-	-	-	-	-	-	0
Serkat	387.0	392.4	395.9	402.6	408.7	196.4	380
Sungai Karang	2.1	2.3	2.3	2.5	3.6	1.2	3

Mukim	Total Damages (million Ringgit)					EAD (million Ringgit)	Annual Population Impacted
	RP2	RP5	RP10	RP25	RP100		
Sungai Pinggan	9.7	33.0	15.7	23.5	51.8	11.1	4
Sungai Tiram	96.9	100.9	116.7	134.7	156.3	53.7	129
Tanjong Kupang	437.3	445.3	452.1	459.4	468.4	222.9	437
Tebrau	255.1	234.4	351.7	409.1	518.3	143.8	859

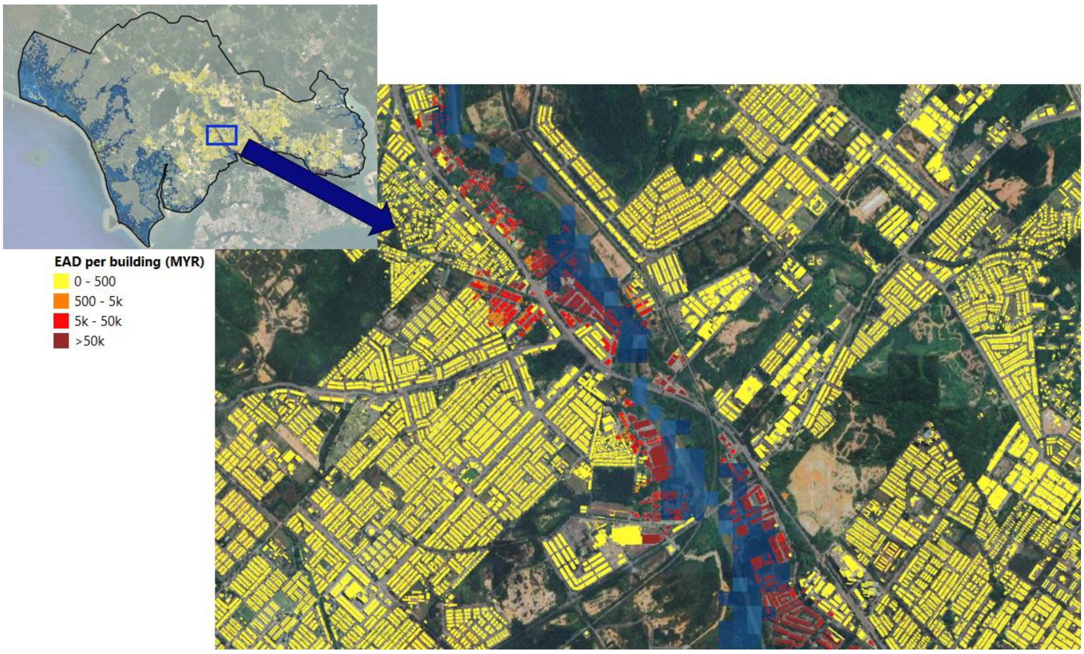


Figure 6-13 Result of EAD for each building. Deeper red colour indicates more damage as shown in the legend (valuation on MYR).

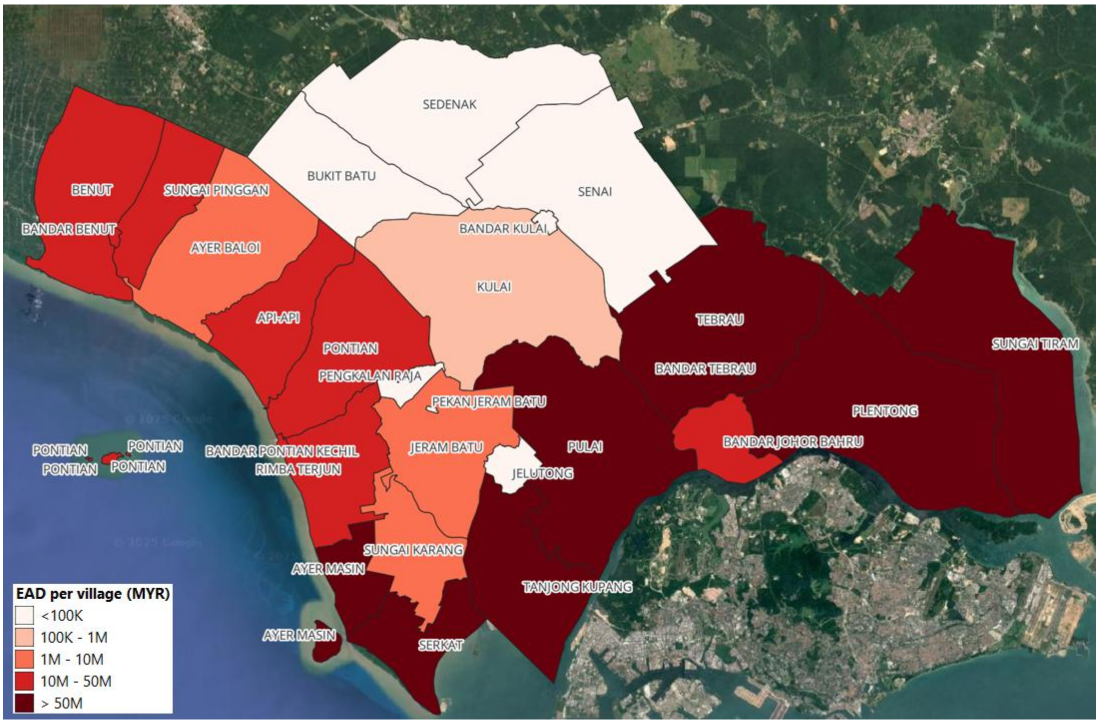


Figure 6-14 Result from building EAD in mukim aggregation. Deeper red colour indicates more damage as shown in the legend (valuation on MYR).

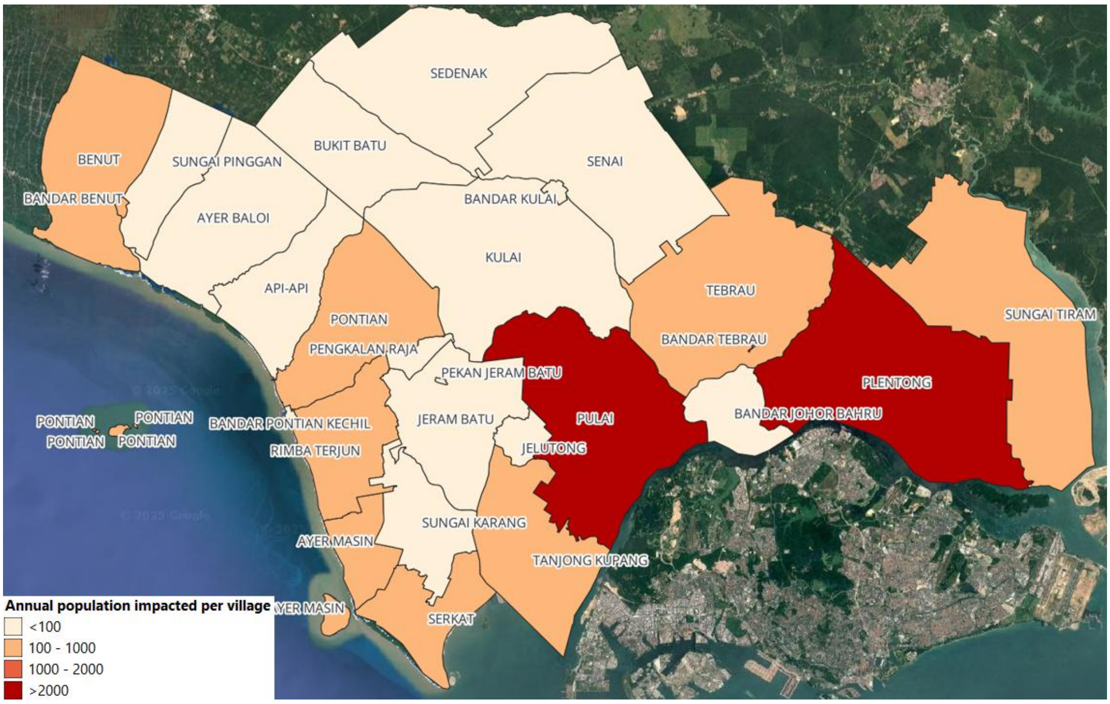


Figure 6-15 Annual population impacted per mukim/village based on the integration of different return periods flood projection.

Information of the flood risks of both economic and population impact can help the government to prioritize measures in specific areas. In figure below, risks in economic and population were plotted into a graph where we analysis can be made which mukim/village are the most impacted. Therefore, conclusion can be made that Plentong and Pulai can become two prioritise areas. Plentong is having a risk to loss about RM 700 million each year with 2500 people are most likely to be impacted. While Pulai has less potential economic loss than Plentong, but has more population in risk.

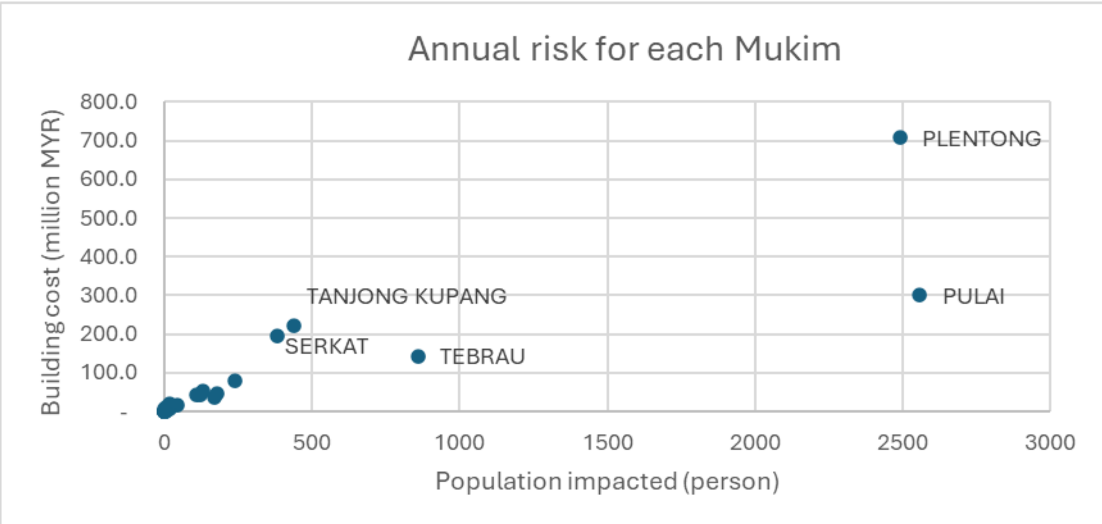


Figure 6-16 Annual risk for each mukim/village. Y-axis shows the potential economic loss based on the building damage (in million ringgit), while the X-axis shows the potential population impacted.

In the risk analysis, other socio-economic detail data should be considered. In this case, not all detailed data is available in the mukim/village level. Socio-economic indicators such as poverty absolute rate and Gini index are only available in district data. Detail data such as number of household and dependency numbers can be used to help the stakeholders mitigating the risk. Figure below visualize the current data status for socio-economic. Based on this background data, conclusion can be made that Plentong can be highlighted as a vulnerable area since the dependency number is high.

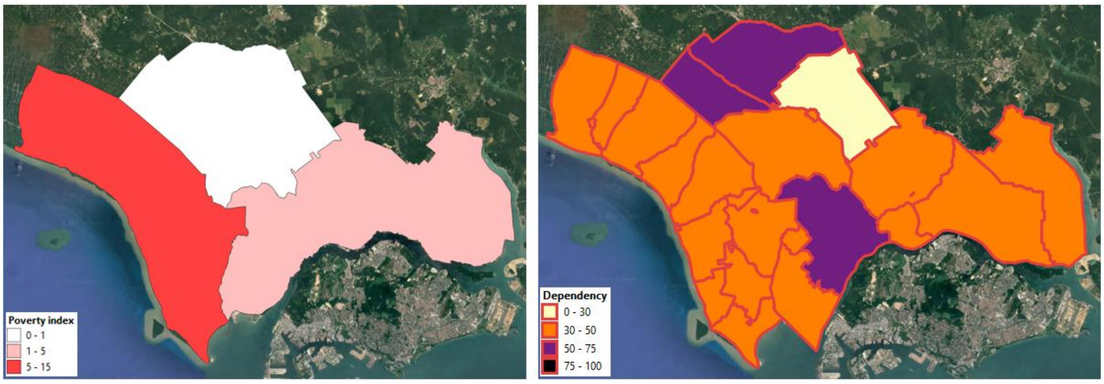
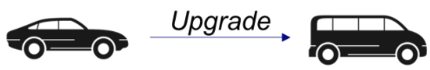


Figure 6-17 Socio-economic data based on DOSM data. Left: Poverty absolute index which is available only for district area. Red colour indicates more poor people in the area. Right: Number of dependency population, which was calculated by the ratio of children, elderly, and disabled people from the total population. Purple colour indicates more dependent people is living in the area.

7 Operating requirements

The development of the platform is only step 1 of the deployment of an operational multi-hazard platform. Other operating requirements are often just as important and sometimes forgotten, resulting in system failure and insufficient uptake of the system. There is a strong analogy between this and buying of a new car, which is explained in the textbox below. Some specific items are addressed in more detail in the following sections.

Procurement of operational system The setup of an operational early warning system starts with the initial procurement and development of the system, can be compared to buying a car. Often a big investment, so important to make an informed decision.	
Regular maintenance Once operational, the system requires regular maintenance. This includes e.g. installing updates to comply to IT security standards, or update the system following external changes (e.g. data connection updates). Very similar to the regular (annual) maintenance of a car.	
New developments Over time, there might be different or new user requirements that requirement to upgrade (components of) the system. In the analogy with the car, expending of the family might require to upgrade the car to a bigger, or safer (more robust) car.	
Support Although the system is designed to robustly run operational 24/7, components of the system can fail and would require support for fixing. In terms of a car, this could be comparable to having a flat tire, which needs immediate fixing.	
Training User, developers and system administrators need to be well trained. Training is a continuous activity to ensure system understanding at all levels in the organization is sufficient. Comparable to the need of having a driver license.	

7.1 Data connections

In the prototype stage, sample data was collected to test data imports and showcase the capabilities of the platform. To operationalize the platform, operational data feeds need to be setup. These include the following data streams:

- Real-time weather station data
- Real-time hydrological station data
- Real-time radar data
- Real-time tide gauge data
- Real-time weather forecast data

The platform, based on Delft-FEWS, is well suited for this task, but it requires the configuration of data imports reading directly from e.g. SFTP or THREDDS data servers. This requires the data providers to provide access to their operational data streams. During implementation, this typically requires some interaction between the data providers and the MHP development team.

Available data types

Documented Imports

ⓘ Please note the new types are added regularly. Most of the imports are Custom made for specific file formats.

Type String	Description	Data Type
ADCON - Telemetrie	ADCON Webservice import (Austria)	scalar
AHD	Austrian Hydro Data (Austria)	scalar
AifsML	Specific ContentReviewer XML type (Australia)	scalar
AifsMLArea	Specific ContentReviewer XML type (Australia)	scalar
AifsMLObservations	Specific ContentReviewer XML type (Australia)	scalar

Figure 7-1 Screenshot from the online documentation on available data types that can be imported into Delft-FEWS. Information can be found via this link: https://publicwiki.deltares.nl/display/FEWSDOC/Available+data+types

7.2 Support & maintenance

Running an operational early warning system requires regular support and maintenance. Depending on the architecture (e.g. on premise or in the cloud), the maintenance might include regular updates to the operating system to ensure IT security, updates to the data connections, frequent updates to the underlying software and database management. The maintenance does not result in new functionality, but is needed to ensure a stable system. For example, if the database is maintained properly, the database might become corrupt over time, resulting in poor performance or in worst case, loss of data.

Maintenance requires sound understanding of the system and its components. Although the system, based on Delft-FEWS, is relatively low-maintenance, it requires frequent monitoring.

In case of unforeseen events (e.g. power failure, or broken data connection), support needs to be available to troubleshoot the system. In many cases, there is a 1st line support for rapid response and easy support questions and a 2nd line of support for more complex issues with the system and underlying software.

7.3 IT infrastructure

As stated earlier, Delft-FEWS can be running stand-along on a single laptop, or as a client server system. The latter is highly recommended for any operational early warning system.

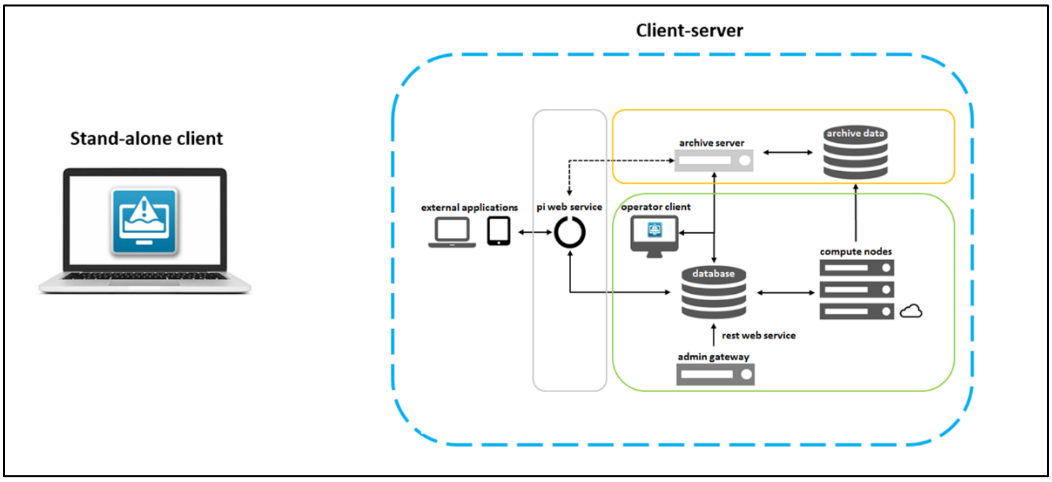
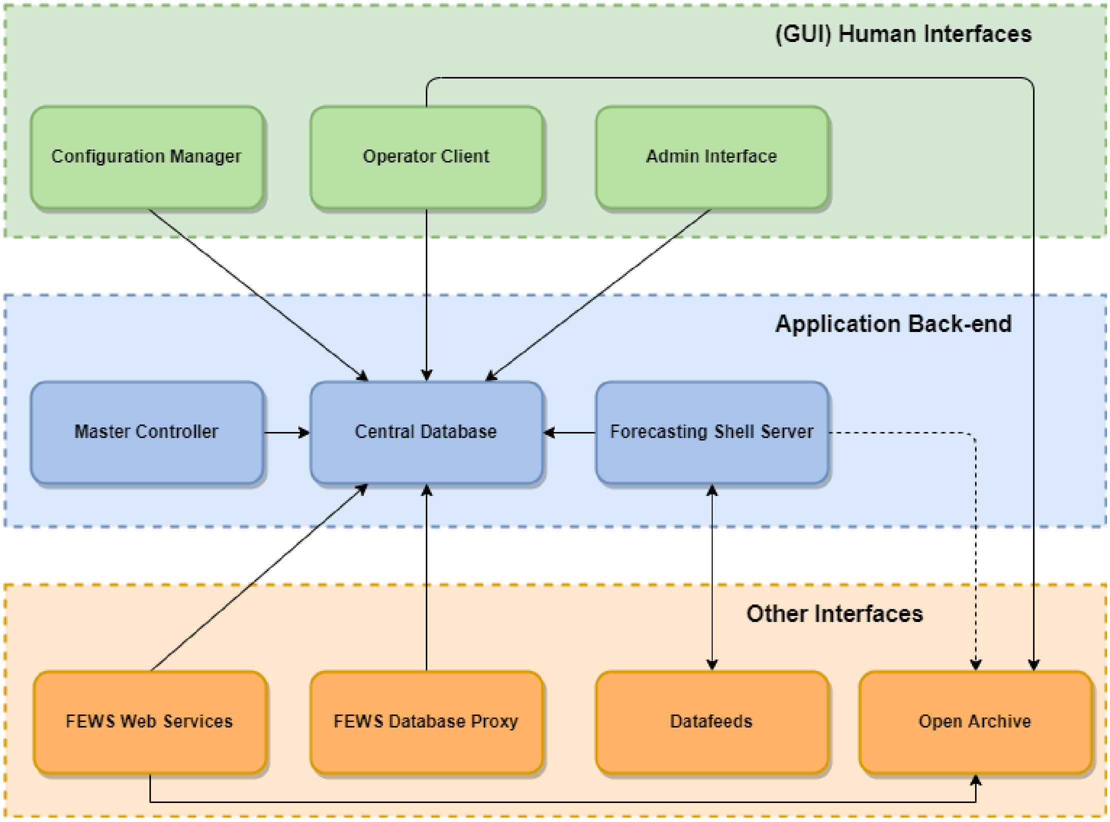


Figure 7-2 IT architecture for two types of Delft-FEWS system: Stand-Alone (left) and Client-Server (right).

Setting up and maintaining a Client-Server system requires basic to advanced IT skills, depending on the complexity of the system. As Delft-FEWS is highly flexible and highly scalable, systems can range from simple (e.g. single compute node) to very complex (>100 compute node, with dual database configuration). The complexity of the system depends strongly on the user requirements, such as:

- **Run time requirements**
  Forecasting of rapid events, such as (flash) floods require fast runtimes. This means independent simulations cannot wait until the previous run is finished. In this case, doing many simulations in parallel could be the solution. This requires multiple compute nodes to be included in the design.
- **High availability requirements**
  For some systems, that are part of the critical infrastructure, downtime of the system is basically not an option. To achieve high availability, the Delft-FEWS system can be setup in a so-called dual MC mode where the core components of Delft-FEWS are setup double in case one of the components breaks down. With recent developments in the cloud, different high availability options can also be provided by the cloud providers. Downside of any dual- or high availability configuration is the additional costs for operating.
- **Spatial domain of the application**
  The current prototype covers Iskander Malaysia, which is a relatively small region. If for example in the future the system is expended to other regions, this will increase the workload of the system.
- **Level of detail**
  For data processing and especially for modelling, the higher the resolution, the more compute power is required. Therefore, for operational forecasting, the level of details should always be a balance between runtime and available compute resources. Maintaining reasonable runtimes is often either decreasing the level of detail in the models or increasing the number of compute nodes. In any case it is always advice to balance the level of detail with the available data (for validation) and the (type of) decisions that will be made based on the information.

In recent years, the cloud has become a valuable resource of compute resources. Delft-FEWS has been designed to also run in the cloud. The cloud has advantages and disadvantages. One of the key advantages is the scalability. In terms of Delft-FEWS, the cloud provides endless compute resources. In some cases, the cloud might also be the economic best option, without the investment into expensive hardware and the training of staff to maintain such hardware. The cost structure of the cloud, however, again depends strongly on the design of the system. In systems with high data exchange (especially downloading), the costs of the cloud infrastructure might very high.



7.4 Tools & Models

A range of tools and models were utilized to support the development of MHP-IM, including hydrological and hydrodynamic models, data visualization platforms, and flood risk mapping tools. The tools and models used to develop MHP-IM need to be well understood, as they play an important role in supporting the future operations and development of MHP-IM.

Table 7-1 provides a summary of the tools and models used to develop MHP-IM, along with their respective functions. In Table 7-2 a short list of tools for other hazard is presented. It must be noted that there are many other tools available for the different hazards and an assessment on suitability should be done prior to implementation.

Table 7-1 Summary of Tools and Models Used in the Development of MHP-IM.

Tools & Models	Usage	License Type	Developed by
Delft-FEWS	User interface of MHP-IM, storing database, adapter between data and model.	Free to use	Deltares
Wflow	Performing hydrological analysis. Translating rainfall data into river streamflow that will be used for flood analysis.	Open source	Deltares
SFINCS	Making use of the Wflow output to produce flood map.	Open source	Deltares
Delft-FIAT	Producing flood risk map by making use of flood map generated from SFINCS, vulnerability map and exposure map.	Open source	Deltares
Python Script	Used to calculate the return period of flood discharge and sea water level.	Open source	Python Software Foundation (PSF).
QGIS	Mostly used for visualization purposes. In the development of MHP-IM, it is often used to plot flood maps, risk maps, and other types of maps in both vector and raster formats.	Open source	QGIS Project Steering Committee (PSC)

Table 7-2 Summary of Tools and Models that can be used for other hazards.

Hazard	Tools & Models
Sea Level Rise	Hydrodynamic model (e.g., Delft3D-FM, SFINCS)
Coastal Erosion	Hydrodynamic model (e.g., Delft3D-FM, X-Beach)
Heat Stress	Post-processing of weather data
Meteorological drought	Post-processing of rainfall data (e.g. SPI Index)
Hydrological drought	Hydrological model (e.g. Wflow or HEC-HMS)
Landslide	Hydrological model (e.g., LISEM or Wflow)
River Water Quality	Hydrodynamic model (e.g., Delft3D-FM, HEC-RAS)
Groundwater Quality	Groundwater model (e.g. MODFLOW or iMOD)
Coastal and Marine Water Quality	Water quality model (e.g. Delft3D-FM + DelWaq)
Air Quality	Air Quality dispersion model (e.g. LOTOS-EUROS, CAMX)

7.5 Capacity building

Developing, maintaining and running an operational multi-hazard platform requires training. It is important to train the team working with the system on all aspects. Training can consist of formal training or on-the-job training and typically it takes several years to develop all skills required. Collaboration with knowledge institutes or universities can help strengthen the knowledge base.

8 Financing requirements to operationalize the MHP IM

This chapter describes in more detail the financing requirements to operationalize the Multi-Hazard Platform (MHP) for Iskandar Malaysia (IM), into an ‘Integrated Multi-Hazard Platform’ (IMHP). The financing requirements can support IRDA and other stakeholders to search for and plan for development budget for the coming years.

The overall goal of the current project[4] is to (1) develop technical specifications to design and integrate information on local climate extremes and hazard risks in a MHP for IM, (2) develop a prototype and establish the financing requirements to operationalize the MHP for IM, and (3) improve local capacities in implementing a people-centred forecasting system using social innovation.

To go from protype to a fully functional and operational platform, additional developments, commitments and investments are needed, and – most important – they need to be maintained.

This chapter starts by introducing a recommended approach, followed by outlining key factors that determine a sustainable IMHP. References are made to successful operating systems and a cost range is provided. In the conclusion the findings are summarized, and recommendations are given.

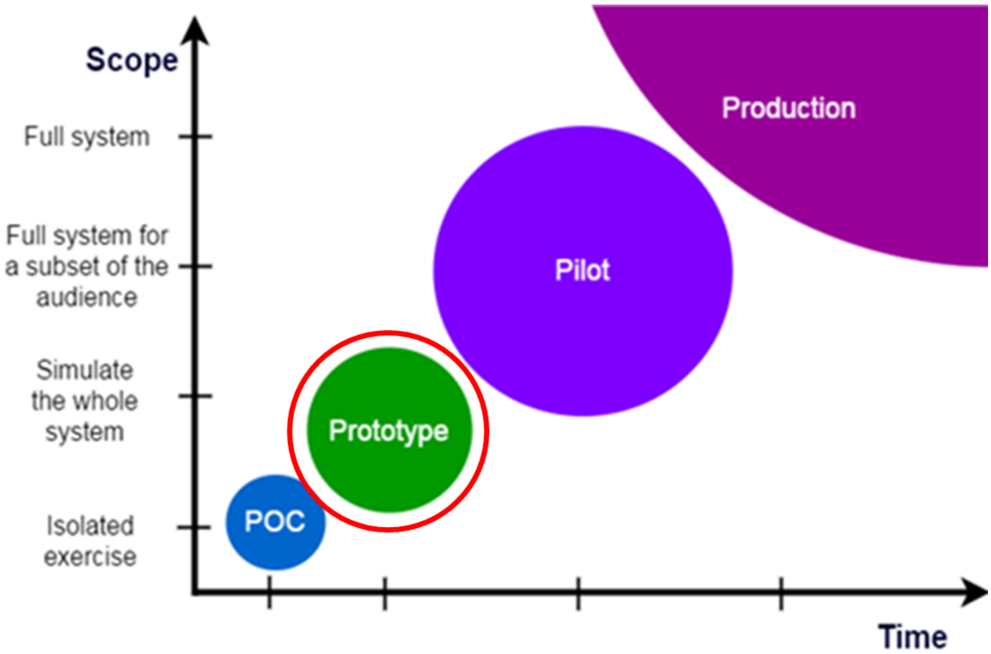


Figure 8-1 Proof of Concept to Production pipeline.

[4] Development of a Multi-Hazard Platform (MHP) for forecasting local level climate extremes and physical hazards for Iskandar Malaysia

8.1 Components of the MHP

A functional and technical description of the MHP is outlined in the previous chapters. In summary, the MHP can be defined as a platform within IM that enables seamless data flow through the 4 basic fields of operation, namely Observations, Data management, Forecasting and Dissemination (see Figure 8-2).

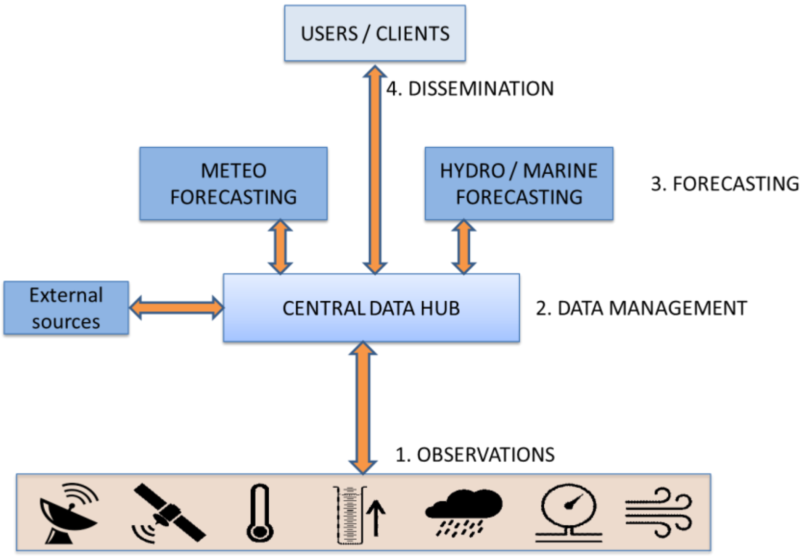


Figure 8-2 Simplified IMHP at IM.

The MHP runs workflows scheduled and automatically, such that there is always near real-time forecast information available, without requiring manual interventions. In addition to being able to automate and schedule modelling workflows, the MHP can support additional components, such as data import, validation, and processing, data visualization, dissemination, and archiving, integration with web clients, ability to analyse hypothetical ("what-if") scenarios, and decision making. The MHP should seamlessly handle the unique nuances of forecasting data.

To realise this, the MHP should be i) flexible to connect any type of data, ii) robust and reliable, iii) it should be easily scalable and iv) modular to customize to specific user needs, v) it should be easy to understand and open to create autonomy and ownership by end users, vi) web- and cloud-compatible for easy dissemination of information, and last-but-not-least, the MHP should be vii) community-based to exchange knowledge, experiences and development costs. Examples of similar systems is provided in Annex E.

8.2 Recommended approach

This chapter recommends an approach for setting up an operational storm surge forecasting system for IM. The approach is presented in phases, the benefits of which are discussed in Section 0. Section 8.2.2 describes the scope of Phase 1, including a rough time schedule and cost estimate. Finally, Section 8.2.3 lists additional improvements that could be made in subsequent phases, based on lessons learned and user requirements identified during Phase 1.

8.2.1 Phased implementation

Currently the MHP-prototype is developed as a so-called Stand-Alone system. This means that all MHP components are installed on a single machine. This could work well for small tasks and small data volumes, but for real operational usage of a Stand-Alone system is insufficient.

Most successful operational forecasting systems, including the systems in the Netherlands, USA, Australia, and Mauritius (presented in Appendix E), are developed in a stepwise way and in continuous development. This section briefly summarizes the benefits of phased implementation and describes activities that would occur in all phases.

8.2.1.1 Benefits of phased implementation

Implementing a forecasting system in phases, rather than attempting to achieve all goals in a single large project has several benefits:

- The **lessons learned** in one phase determine the scope and approach to subsequent phases.
- Developing and expanding the system functionality over time gives users **time to develop capabilities and knowledge** base, increasing ownership over and use of the system.
- As users (operators/forecasters and end-users) become more familiar with the system, they can **provide feedback** which can be addressed in subsequent phases.
- **Costs are spread out more evenly** over time, consistent with the operational nature of the system.
- **Model development is iterative**. The more experience forecasters gain using models in real-time, the more will be known about how the models perform in different (extreme) situations. The models can be improved in each subsequent phase.
- The system can evolve and grow over time to **address additional information needs**. For IM, this might include identifying critical infrastructure potentially affected by multi-hazards or producing water quality forecast information.

The phasing presented in this chapter is designed to avoid “lockouts”. In other words, functionality and components developed in previous phases will continue to be used in subsequent phases, and each phase builds on the previous one.

8.2.1.2 Activities that should occur in every phase

While each phase would likely include something new compared to previous phases, there are some activities which should occur in every phase:

1. **System maintenance and support**: On-going maintenance required to keep the system running smoothly. This includes e.g., updating the system when external data feeds change, addressing IT issues as they arise.
2. **Improve or add forecasting products**: Make changes or additions to forecasting products based on user feedback during the previous phase.
3. **Improve models**: Incorporate new/improved data and adjust models based on performance during the previous phase.
4. **Staff training**: Train new team members, provide opportunities for existing team members to learn new skills.
5. **Detailed scoping for the next phase**: Identify lessons learned and evolving user requirements to define the scope for the next phase.

8.2.2 Proposed activities phase 1

8.2.2.1 Scope

The objective of Phase 1 is to operationalize the prototype. At this stage, the focus should be on getting the system technically up and running and establishing the real-time data feeds. It is recommended to not take too big steps at once, to be able to learn while doing and to make sure the system is implemented in a robust manner.

Setting up the operational data streams will likely take some time to establish, as this requires agreements between the different organizations and data providers. Furthermore, technical this would also require IT departments from both sides (MHP side and data provider side) to closely work together to develop the best way of operational data sharing.
Regarding hazards, it is also recommended to start simple and focus on the currently implemented hazard: floods. Once the team has experience with the system, the scope of the MHP can be extended to other hazards also.

However, the technical development of such a system is only a small part of the process of improving flood resilience, as also indicated in Figure 8-3.

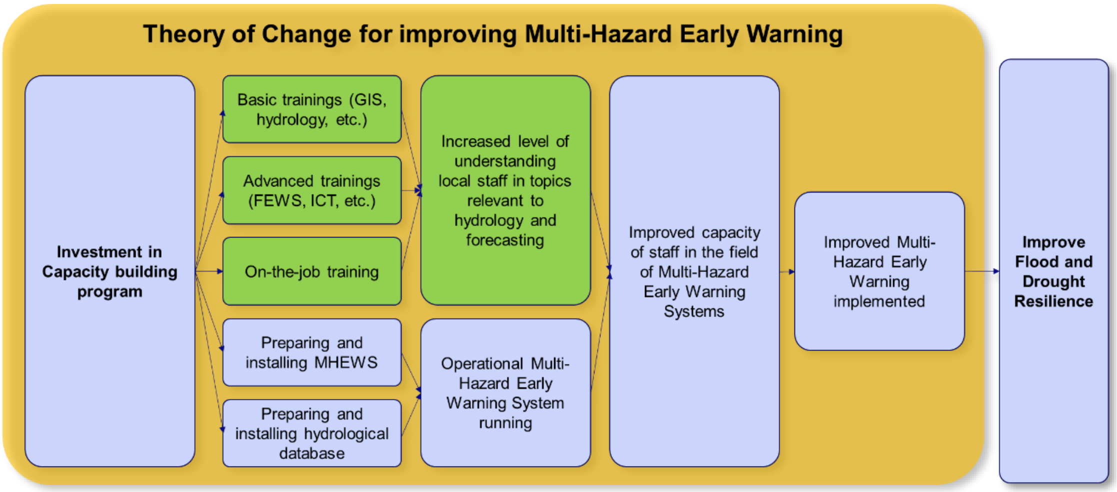


Figure 8-3 Example theory of change for improving flood and drought resilience through the development of a multi-hazard early warning platform and capacity building.

8.2.2.2 Costs

This section presents approximate cost ranges over phase 1, split in phase 1A (Table 8-1) and phase 1B (Table 8-2). In Phase 1A, the initial system would be set-up, while Phase 1B would allow for improvements to the models, products, and other system components, based on findings during Phase 1A. The total timeframe of such (typical) activities defined under phase 1 (excluding contracting) is approximately five years, with three years for Phase 1A and two years for Phase 1B.

The tables reflect the cost of designing, developing, installing, capacity building and supporting a software system for operational forecasting. However, these cost estimates **exclude the following costs**, which are associated with (and in some cases essential for) setting up an operational forecasting system:

1 IT infrastructure, such as the cost of purchasing and installing hardware on premises, or the costs associated with hosting such a system in the cloud. These costs can vary significantly depending on the provider, market fluctuations, data storage/transfer volumes, and computing requirements. The hardware for a simple desktop computer may cost on the order of 5,000 to 10,000 USD, while a client-server system might cost 30,000 to 100,000 USD, depending on whether it includes e.g., redundancy (back-up systems), shared storage, data archive, licensing, or cost of installation and typically lasts 3 to 5 years. The costs for cloud hosting, which include redundancy, shared storage, data archive, licensing, and installation, might be on the order of 50,000 to 150,000 USD for 5 years.

2 Costs associated with expanding the operational forecasting team at (e.g.) IM (salaries, other human resource expenses). Section 8.3.2 discusses personnel requirements and estimates the number of trained professionals that an established MHP team might involve.

3 Costs associated with setting up dissemination of real-time multi-hazard information from IM.

4 Costs associated with making remote sensing data available in real-time.

5 Installation, maintenance, or modifications of remote sensing sensors. This may not be necessary in Phase 1, assuming real-time rainfall and discharge measurements from several existing stations are already available. During Phase 1B, once the MHP has been tested during multi-hazard events, the information requirements related to field observations should be re-assessed as part of the scoping exercise for Phase 2. The cost of installation and maintenance of remote sensing sensors depends on many factors related not only to the equipment, such as the type of sensor and installing party, but also on the local context, like accessibility of the location, and likelihood of theft or vandalism. For these reasons, cost estimates for other regions or countries might not be representative for Malaysia[5,6].

6 Collection or costs associated with producing and acquiring new, high-resolution topographic data. The first version of an improved MHP (Phase 1A) can be developed without any additional topographic data, as the current prototype has already make uses bathymetric data and local topographic data provided by the relevant agencies. However, the need for better topographic data should be evaluated during Phase 1A (e.g., dike elevations) and Phase 1B (e.g., better topography in the polders, for flood mapping).

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[5] In the Netherlands, it costs between 50,000 and 500,000 EUR to purchase and install a new permanent water level monitoring station, depending on the type of instrument (floater, radar, ADCP, etc.) and accessibility (onshore or offshore) (Deltares, 2017). These instruments are maintained once per year and have a lifetime of approximately 30 years. It was not possible to obtain estimates of maintenance costs for these stations. The cost and installation of sensors in Malaysia is expected to be less expensive.

[6] By comparison, one measurement network in South Africa, with approximately 150 pieces of equipment (mix of meteorological and hydrological sensors) is supported by a maintenance contract of approximately 300,000 EUR/year, including installation of new sensors.

The cost ranges were developed on the following **assumptions**:

1 Ranges are based primarily on previous Deltares project experience.

2 Most of the work is done by consultants, or closely supported and supervised by consultants. This assumption is generally true in early phases of setting up an operational forecasting system. The costs of capacity building to increase local expertise is, however, included.

Table 8-1. Total cost estimate for Phase 1A.

#	**Task**	**Approximate Cost Range**	**Remarks**	
		(k USD)	**Low end of range**	**High end of range**
Phase 1A: Design and implement MHP (3 years)				
1	Institutional framework analysis	60	*N/A*	*N/A*
2	Define user requirements for the MHP	50 - 100	*If workshops combined with Task 1, only interviews with same group of stakeholders.*	*Interviews with additional stakeholder, e.g., end users of forecast information*
3	Staff training – Phase 1A	150 - 250	*Assuming 2 instructors, 2x 1-week training per year, in person*	*Increase frequency to 3x/year, more in-depth training*
4	Develop or improve MHP for IM	70 - 250	*High quality field observations data and validated remote sensing data is available.*	*Historical analysis for past events information is available*
5	Set up operational forecasting framework	100 - 150		*Uncertainty lies in ease of access to real-time data feeds. Additional iterations, user feedback.*
6	Design and develop operational forecasting dissemination products	60 - 120	*Design sessions combined with very simple product, e.g., HTML/PDF bulletin with water levels at key locations and warning level colours.*	*Separate in-person design sessions for product design. Potentially additional (simple) bulletin(s) for separate end users, or automated text messages. No web viewers or automated emails.*
7	Install operational forecasting system	40 - 60	*No support required for installation of hardware. Local IT specialist present.*	*Additional involvement in discussions around defining hardware/cloud architecture. Limited IT knowledge available on site.*
8	Set up long term data storage	20 - 40		*Uncertainty lies in complexity of the archiving mechanism: file-based storage, database etc.*
9	Assess real-time observation network	30 - 50	*Focused primarily on water level measurements.*	*Also consider meteorological data, coastal boundaries, river discharge.*
10	System support – Phase 1A	50 - 70	*Assumes no additional visits or software upgrades required for support in Phase 1A*	
Total (Phase 1A)		**0.6 – 1.2M USD**		

Table 8-2. Cost estimate for Phase 1B and total costs of Phase 1.

#	Task	Approximate Cost Range	Remarks	
		(k USD)	Low end of range	High end of range
Phase 1B: Refine MHP based on Phase 1A (2 years)				
11	Improve modelling framework for IM	40 - 200	*Relatively minor improvements to models based on forecaster and stakeholder experiences during Phase 1A.*	*Additional model validation with new data. More extensive improvements to models (e.g., incorporating new digital elevation data).*
12	Design and develop operational forecasting dissemination products	20 - 250	*Relatively minor improvements to bulletins based on forecaster and stakeholder experiences during Phase 1A.*	*Additional design sessions/workshops. Additional mode(s) of dissemination, e.g., web dissemination of forecast data. Additional products for other end users.*
13	Improvements to operational forecasting framework	50 - 100	*Relatively minor improvements to user interface. Addition of scenario tool.*	*e.g., importing new data feeds.*
14	Update operational forecasting system	50	*Assumes 2 updates over Phase 1B.*	
15	Staff training – Phase 1B	150 - 200	*Assuming 2 instructors, 2x 1-week training per year, in person.*	
16	System support – Phase 1B	50 - 80	*Assumes no additional visits or software upgrades required for support in Phase 1.*	
17	Scoping for Phase 2	40 - 60		*Involve additional stakeholders/user groups to discuss new functionality.*
Total (Phase 1B)		**0.4 – 0.9M USD**		
TOTAL (Phase 1)		**1.0 – 2.1M USD**		

8.2.3 Scope of later phases

In later phases, the MHP could be improved or expanded in many ways. The recurring activities as described in Section 8.2.1.2 should form the basis of future phases. Additional expansions or additions to the system will depend primarily on lessons learned, needs identified, and capacity developed during Phase 1. Later phases of development often involve more stakeholders, as awareness of the system grows, and new opportunities arise. New stakeholders bring new information needs. Sometimes these needs can be addressed with small changes to the system, but sometimes they require adding new models or products. At this early stage, it is not possible to say which improvements should be prioritized in Phase 2. However, the list below provides a range of potential improvements or additions that could be made, based on evolution of similar systems in other countries and knowledge of the Malaysia context. In general, additions to the system below would also require additional training of personnel and may also require changes to the IT environment (e.g., more servers, additional network connections).

Improve system reliability:

- Install a back-up system.

Improve water level predictions by considering additional physical processes:

- Incorporate (additional) river discharges and improve model boundary (forecasts) forcings
- Incorporate more sophisticated wave models.
- Use data assimilation with real-time measurements to improve forecasts.
- Incorporate additional rainfall measurements and forecasts

Understanding uncertainty:

- Add probabilistic forecasting in water level predictions (including capacity building).

Improve situational awareness:

- Import wave measurements.
- Import near-real-time earth observation data (e.g., radar for flood extent mapping).

Dissemination of forecast data:

- Make forecast data publicly available, e.g., via web interface.

8.3 Requirements for a sustainable system operation

Besides the recommended phased implementation, there are 3 key factors that are needed to realize the IMHP and to optimise its system performance and long term continuation of this system:

1 Technical developments
2 Institutional enabling conditions
3 Funds
These key factors will be elaborated in the section below.

8.3.1 Sustainable finances of technical developments

To develop and implement an IMHP, additional technical developments are needed as described in the 'Functional and Technical Report'. To summarize:

- **Upgrading the MHP** from a Stand-Alone prototype into a full Client-Server approach:
  - Operationalizing workflows (input, pre-processing data, model runs, post-processing data, visualizing- and dissemination of output products)
  - Expanding the MHP (e.g. integrating extra field observations, connecting external forecast data, modelling other phenomena, improving post-processing, visualization and dissemination)
  - Data storage and archiving
  - System integration (e.g. embedding the MHP within the organisational network, such as coupling with other IT-platforms, databases and IT-(mobile)services).
  - Interfacing: UX / UI
  - Post-event analysis
  - Scenario analysis
  - Further adjustment based on (end-)user requirements
  - SOPs
  - Testing and deployments (i.e. according to the DTAP[7] approach)

[7] Development, Testing, Acceptance and Production (DTAP) is a phased approach to software testing and deployment.

- **IT infrastructure:** The IMHP needs to run on IT infrastructure (see Appendix A). This can either be using a (commercial) cloud solution or on on-premise hardware. In both cases, investments are needed, incl. procuring the hardware (if on premise) and licenses. This investment is not needed on an annual basis, but it should be made sure these costs are in the budgets to be able to replace hardware when reaching the end of life.
- **Operating costs:** These costs include for example electricity costs (i.e. especially when the IT infrastructure is hosted on premise), IT security (See Appendix B), hardware upgrades, upgrading software licenses, third-party O&M contracts, etc.

8.3.2 Institutional enabling conditions

8.3.2.1 Human resources and institutional arrangements

Besides the technical developments, the most important component is human resources. This links to the capacity need assessment that was conducted as part of the project (see Section 9).

Running an operational MHP will have to go hand in hand with capacity development and sometimes changes in institutional arrangements. To guarantee adequate knowledge transfer and (the desired) autonomy to sustainably operate and maintain the system, the right base level understanding and the right technical training is required. To be able to operate, maintain, setup, and manage such a system, qualified personnel is necessary in order to make the implementation of an integrated system a success. To prevent institutional memory loss (due to leaving staff, lack of innovation, etc), an attractive work environment should be created where staff is being motivated by (internal) education programs and refreshment courses. A modern system will need professional specified staff such as operator, forecaster, configurator, network administrator, database administrator, etc. Therefore, attracting and keeping qualified staff is an important issue requiring policy and incentive mechanisms as well as investment in quality scholarships. We would like to mention the following aspects to consider:

- There is a need to have incentive-driven policies and regulations to encourage and recruit qualified staff to work in the hazard, risk and early warning sector. Developing a good working environment that promotes creativity of staff and to retain qualified staff to continue working in their units is very important.
- Due to the complexity of operating an integrated system as well as maintaining an integrated system, different roles and their corresponding competencies must be identified, and service level and/or performance levels should be defined in advance. Based on these competencies, qualified personnel can be recruited while training existing personnel.

Key specialists need to be assigned, before the IMHP is deployed and operated. The size of the team strongly depends how sophisticated the IMHP is. Nevertheless, it is recommended to define couples for each task to stimulate a resilient team that is able to learn from peers and is flexible, preventing single-point-off-failures in the operation. In these teams, there should be a clear division of tasks, such that during the operational phase, optimal service level[8] can be delivered. The agreed upon servers levels also highly determine the size of the team. For example, if a 24/7 service level is to be maintained, this means for a typical daily shift minimally 3 operators are required assuming an 8-hour working day. The same might apply to the application manager or IT expert, in case any issues arise during operations. Furthermore, during the busy season, shifts shall be more demanding when many alerts or warnings need to be compiled.

[8] See Appendix C

This means that for safe and efficient operations it is advised to have a rotating team to allow for sufficient rest between the shift. Table 8-3 shows an example of the main organisational tasks and corresponding key specialists can be defined. This assumes a relatively simple system, with limited number of tasks for the team. It must be noted that not all positions necessarily are full-time positions. In many cases, during the dry season for example, the team can also work on other tasks.

Table 8-3 required key staff to operate the FEWS-AMD knowledge platform.

Key Task	Key Specialist	Minimum Number of Staff
System operation	Operational forecaster	6+2
System maintenance	IT specialist	2
System development	System developer	2
System development	Product owner	1
Team manager	Coordinating the team	1

Key specialist #1: Operational forecaster
The operational forecaster will be the daily user of the MHP. He or she will constantly monitor the operational framework, to ensure the system runs stable and results are as expected. The operational forecaster is responsible for ensuring the quality of the forecasts and the disseminated results. The operational forecaster also checks if external data feeds are imported correctly and is responsible for contacting external data providers in case of unavailable data or other related issues. He or she is also the first point of contact for external stakeholders, like specific user groups who may have questions or remarks about the disseminated results. We recommend to setup a team of (part-time) operational forecasters (say 6 at minimal) shifting duties after each week, lead and supported by say two (full-time) team managers.

Key specialist #2: IT specialist
The IT specialist will be responsible for the ‘back-end’ application and provides maintenance if needed. He or she will ensure minimal downtime of the operational framework in the event of IT-related issues.. If the operational forecaster reports IT related issues with the live system, the IT specialist assists were possible. He or she is trained to be familiar with the Delft-FEWS back-end and other IT dependencies (import/export servers) and to resolve basic IT related problems which concerns the operational framework. This can be a part-time job of say two team members.

Key specialist #3: System developer
The system developer is well trained to operate the MHP and to develop and implement specific functionality for the operational framework, if needed. He or she will work together in close collaboration with the operational forecasters to develop technical improvements, like modifying web reports, adding new monitoring stations and improving data displays. Development works are done in a separate Stand-Alone application and tested thoroughly, before they are uploaded to the live system. He or she will also keep track of a revision control management system, such that a rollback can be done to a stable version of the MHP configuration, if any bugs are detected which endanger the live system. This can be a part-time job of say two team members.

Key specialist #4: Product owner
The product owner is responsible for the long term development of the system. The product owner typically is the one talking to the end users to collect feedback and new feature requests. The product owner work closely together with the system developers to make sure new requests can be implemented in the system. The product owner has a good understanding of the system and especially in how the system is used by the end users.

A product owner is responsible for developing a vision for the medium and long term and translate these into roadmaps. The product owner also has a role in prioritizing new requests based on the capacity of the development team and the availability of budget.

Team manager
A team manager coordinates the team, and makes sure the team functions optimally. He or she coordinates development and makes strategic decisions. The team manager stimulates professionals and makes sure each individual team member is seen and contributes to the team. Also, the team manager makes sure the staff is sufficiently qualified and vital to have a positive impact (see 8.3.2.1 'Human resources and institutional arrangements'). Figure 8-4 gives an impression of key specialist and how they interact during the operational phase.

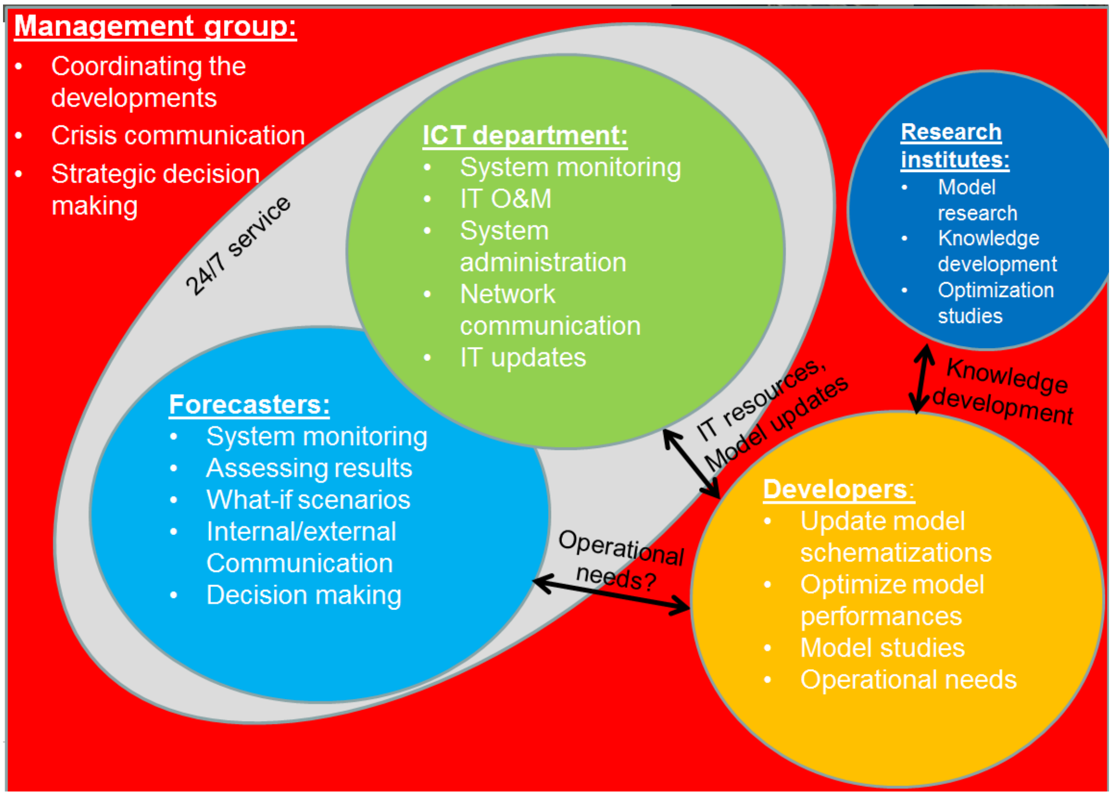


Figure 8-4 Impression of the basic tasks of different key specialists during the operational phase.

Example Netherlands (see also Appendix E.1)
Water management in The Netherlands is split into many aspects: River management, management of the large lakes, coastal zone management, drought management, shipping and managing water quality. Each aspect of the water management has different requirements in terms of early warning, depending on the nature of the hazard (fast or slow developing, how many stakeholders are involved, predictability of the hazard and duration of the hazard).

Floods in the rivers in The Netherlands are typically characterized by relatively good predictability (i.e. the flood can predicted with good accuracy a couple of days ahead) and long duration (a flood on the Rhine can take weeks to pass). For coastal hazards, the duration of a storm is much shorter (couple of hours) but predictability is also less (max. 1-2 days).

These kind of characteristics have impact on the organization. But in general terms the following applies:
- The system is operational 24/7.
- In normal conditions, several sub-systems are monitored by 1 or 2 persons 24/7.

- Each sub-system has a product owner, responsible for planning development, maintenance, and schedules.
- In case of medium alert, a team of 1 or 2 forecasters take active role during the day and maybe during the evening / night.
- In case of high alert, 2 or 3 shifts of 2 forecaster per day are formed to reduce fatigue during the high-alert situation.

In case for the River Forecasting Group in The Netherlands, the team consists of approximately:
- Team manager (0.2 FTE[9])
- Product owner (0.5 FTE)
- 1 daily forecaster (0.5 FTE)
- Team of 12 forecasters on rotation (0.2 FTE per team member)
- IT team member, shared with other systems (0.5 FTE)
- Development team (2 FTE)

This would bring the total size of the team to around 6 FTE. In times of crises, the team can be extended with other team members.

8.3.2.2 Standard Operation Procedures

Newly installed equipment and software for the IMHP will change the way staff of IM are working. Therefore, Standard Operation Procedures (SOP) need to be developed or adjusted[10] (see also section 5.4.1). Of special importance is the Live System Procedures, because for an integrated system to perform 24/7 contingency measures need to be in place at all levels. Besides guaranteeing the day-to-day operations, the system also should be kept up to date new elements are included, or new software versions become available. Before installing these new elements, the system needs to be tested so that the live system is not affected. The following SOPs are recommended for specifying standards, procedures, priority settings for critical infrastructure and responsibilities:
- Day-to-day O&M (e.g. SLA: service level agreements, see Appendix C);
- System updates according to the DTAP approach;
- Revision control system (keeping track of modifications of models and other systems);
- Long term sustainability (version management of software and testing procedures, installation of new software or models on existing systems, data management).

8.3.3 Funding sources

The development and operation of the IMHP require a stable budget. Ideally, this stable budget is paid by its stakeholders that benefit directly or indirectly from a functional and operational IMHP. Relevant stakeholders are identified and interviewed in the stakeholder workshop (see chapter 3 of the Functional and Technical Report). Typically for such systems where the IMHP aims at delivering an important public service, finances from governmental funds are most common.

The financing requirement can be split into one-off investment costs and annual costs (see also 8.3.1 and 8.3.2). One-off investments are needed to go from the MHP-protype to a fully functional and operational platform. After that, a continuous operation of the platform require annual budgets to cover (minimum) operating costs to assure uptime of the system, maintaining the team and to be able to do the required maintenance.

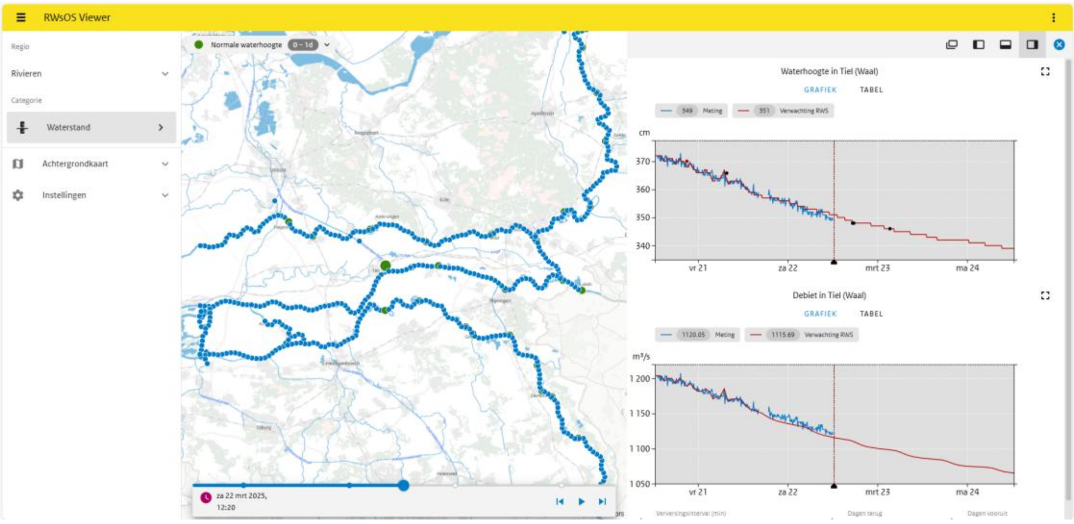
[9] FTE = Full-Time Equivalent. FTE is a unit of measurement that represents the equivalent number of full-time employees needed to perform the same amount of work.
[10] See also the 'Functional and Technical Report' from task 2 and the development of early action protocols from activity 4.3

Example Netherlands (see also Appendix E.1)
The national forecasting centre in The Netherlands is funded via Government budgets. The budget covers: Operational management, maintenance, development, and training activities. Regionalized forecasts are typically a collaboration between the regional authorities and the national government level.

Typically, regional forecasting centres have free access to the national weather and hydrological forecasts to be used as input to their regional platforms. The regional authorities each develop their own localized platforms, depending on their specific situation and typical hazards.

In some cases, regional authorities also feedback information to the national level. The main reason is that water management decisions are often taken at the regional level, but they can impact the national water management decisions. This 2-way exchange of information allows for optimal communication between national and regional authorities, something that's even more critical in times of extreme conditions.

Example (in Dutch): https://rwsos.rws.nl/viewer/map/noordzee/waterkwantiteit



Apart from governmental funds, other funding streams can be investigated. These include:

- **Developing paid services:** The system provides output that can be used by others to improve their income or develop services. These users typically require specific outputs of the system. Such outputs can be delivered as a service for which the users can pay. This will generate an additional income stream for the development and maintenance of the system. It must be noted here that the core public task to warn and alert the public should remain open and freely accessible.
- **R&D budgets:** In many countries, R&D budgets are available for developing new technologies or develop new features. Typically these R&D budgets are available for research institutes or institutes of high learning (IHLs). By working closely together with these institutions, new developments can also be tested operationally and once successful, become part of the MHP. In the MHP this can be done, for example, by integrating a new module first as pilot. R&D funds can typically provide longer term funding as projects are typically awarded for 3-4 years.

- **International funding:** For specific developments, in some countries international funding is available to develop and improve operational systems like the MHP. Providing a platform in which these developments can be integrated can be a means to attract international funds, as this means there is a high probability of successful uptake of the development.

The devastating impacts of natural hazards can be mitigated by structural as well as non-structural measures. The implementation of structural measures generally takes a long time and requires significant financial investments. Non-structural measures, such as Early Warning systems, can be very effective in reducing the impacts and can be implemented much faster. The contribution to preparedness (i.e. water safety, communication, emergency preparedness) and the disaster response (i.e. impact forecasting and response efforts) can therefore be significant as many people and sectors can benefit from a comprehensive multi-hazard platform. The implementation and operation of the MHP-IM aligns with key aspects from Malaysia’s’ protocol for managing natural disasters such as floods through the NADMA Directive No. 1. The main focus of disaster management is on comprehensive and continuous Disaster Risk Reduction through programs of Mitigation/Prevention, Preparedness, Response, and Recovery.

Figure 8-5 Disaster management cycle.

8.4 Conclusions and recommendations

To develop the MHP into a fully functional and operational platform (the IMHP), additional funding is required. Costs for operationalization can be somewhere between 250,000 and 2,500,000 USD for more complex systems, depending mainly on the scale, robustness and complexity of the platform. Therefore, a phased implementation is recommended.

The funding requirements can be categorized in different aspects:

System development
The current prototype of the MHP shall not have all required functionalities yet. This means before going operational additional developments are needed. Furthermore, along the way, new feature requests might arise. These would also require additional developments and system updates. These system developments can be seen as one-off investments. However, it is recommended to also reserve a minimal development budget in the annual budget to account for small and urgent feature requests.

Human Resources development
In the end, the success of the IMHP strongly depends on the people working with- or developing and maintaining the platform. Without well-trained staff, the IMHP is at risk of slowly deteriorating and breaking down when it is not actively being used. Well-trained and qualified staff should be seen as a vital asset of the organisation. To prevent institutional memory loss (due to leaving staff, lack of innovation, etc), an attractive work environment should be created that promotes creativity, and where staff is being motivated by (internal) education programs and refreshment courses. Also, there should be incentive-driven policies and regulations to recruit and encourage qualified staff. As not all roles are full-time positions, staff can also be used for other (similar) tasks. To keep up the level of the team, it is important to include their salary costs, training costs and costs regarding incentive-driven regulations in the annual budget.

IT infrastructure
An operational system needs to be hosted on physical servers or in the cloud. It's likely that investments are needed to procure resp. hire the necessary infrastructure. For on premise servers, this investment can be seen as a one-off investment. If the system is hosted in the cloud, a monthly budget is required that should be included in the annual budget.

Operational maintenance
A system, simple or complex, always requires maintenance. Preventive maintenance can typically be well planned. For ad-hoc maintenance, for example due to an accident or power failure, require flexibility. These costs mainly relate to staffing and incidental upgrading of hardware and software. When hosted on premise, costs on the power consumption (i.e. running servers, AC-cooling, etc.) and the IT asset depreciation (i.e. the need for renewal every 5-8 years) should not be forgotten. It is therefore important to have regular maintenance included in the annual budget, but to also reserve an emergency budget for ad-hoc activities.

Operational data feeds
The IMHP requires (near) real time data to feed into the system to be able to forecast any hazards. The data is mostly coming from other Malaysian government agencies or institutes. Setting up an operational data feed with accompanying Service Level Agreement involves costs. These costs should be part of the annual budget.

Different funding streams can be available, depending on how this is organized in Malaysia. In most countries, platforms like the IMHP are funded largely via government budgets. Additional funding streams can be explored, such as development of paid services, seeking international funding or apply for R&D budgets.

9 Improving local capacity

9.1 Capacity building needs assessment & gender aspects

As part of the project, a training needs assessment was undertaken. The goal of this assessment is linked to the human resources requirements, as presented in 8.3.2.1). In a series of questionnaires and interviews, different stakeholders and potential users were questioned on their organizations capacity to adopt the system, either as an end-user of as the maintainers of or developer of the system. The assessment process involved:

1 Collecting data from relevant staff and organizations.
2 Identifying tasks and job profiles required for MHP-IM.
3 Analysing skill levels (Basic, Fair, Advance) in relevant skill categories such as hydrology or IT to identify gaps and propose training programs.
4 Draft job description specifying knowledge and skills required
5 Suggest groups of staff to be trained by job and level.

The assessment targeted respondents are as following:

1 Department of Irrigation and Drainage HQ
2 Department of Irrigation and Drainage Johor
3 MetMalaysia HQ
4 MetMalaysia Johor
5 PLANMalaysia Johor
6 Majlis Bandaraya Johor Bahru (MBJB)
7 Majlis Bandaraya Iskandar Puteri (MBIP)
8 Majlis Perbandaran Pasir Gudang (MPPG)
9 Majlis Perbandaran Kulai (MPKu)
10 Majlis Daerah Pontian (MDP)
11 SUK Kerajaan Negeri - Bahagian Pengurusan
12 SUK Kerajaan Negeri - Bahagian KPKT
13 SUK Kerajaan Negeri - ICT Johor

The targeted respondents are the organizations identified as having potential in hosting and managing the MHP-IM. The organizations are chosen based on the feedback obtained from the previous Stakeholder Engagement sessions. All the respondents were contacted through emails and phone, and were officially invited to participate in the survey. Eight organizations responded and have given feedback by answering the survey questionnaires and through interview sessions. The 8 organizations which responded to the survey are:

1 Department of Irrigation and Drainage HQ (PRABN)
2 Department of Irrigation and Drainage Johor
3 MetMalaysia Johor (representing MetMalaysia HQ)
4 PLANMalaysia Johor
5 Majlis Bandaraya Johor Bahru (MBJB)
6 Majlis Bandaraya Pasir Gudang (MBPG)
7 Pejabat Daerah Johor Bahru
8 SUK Kerajaan Negeri - ICT Johor

Representatives of the organization were interviewed and helped in the distribution of the questionnaire surveys to a selection of targeted members of the organizations. A total of 7 respondents contributed to the survey for the Capacity and organizational Needs Questionnaire, 5 for the Q(1) Organization Division Capacity Questionnaire, 12 for the Q(2) All Divisions Staff's Capacities (except IT) Questionnaire and 1 for the Q(3) IT Staffs' Capacities Questionnaire. A total of 25 responds were collected during the survey. A breakdown of the assessment is provided in a further section in the report.

The Training Needs Assessment (TNA) for the Multi-Hazard Platform – Iskandar Malaysia (MHP-IM) provides a comprehensive understanding of current institutional and human resource capacities across key stakeholder agencies. The assessment identified significant strengths in meteorology and hydrology within MetMalaysia and JPS, respectively. However, it also revealed critical gaps in data engineering, IT support, instrument maintenance, and public-oriented forecasting.

Equally important are the institutional challenges that are frequent job rotations, coordination barriers, and limited technical capacities in agencies such as ICT Johor and PlanMalaysia, that may hinder the seamless implementation of MHP-IM. The findings underscore the need for a structured, inclusive, and gender-sensitive capacity-building plan that not only addresses technical training but also strengthens institutional cooperation.

Furthermore, the underrepresentation of women in technical roles highlights the importance of intentional strategies to enhance gender equity in disaster risk management. This includes targeted training, flexible delivery models, and leadership pathways for female professionals. By translating capacity needs into actionable training programs, impact-based forecasting protocols, and localized IEC materials, this report lays the foundation for sustainable MHP-IM implementation. The proposed recommendations ensure that all stakeholder groups, from national agencies to at-risk communities are equipped with the knowledge and tools to act early, reduce risk, and build resilience.

Ultimately, this assessment supports a proactive, inclusive, and integrated approach to disaster preparedness and response in Iskandar Malaysia, positioning the MHP-IM as a transformative system for climate-resilient development.

9.2 Early Action Protocols

Early Action Protocols (EAP) are structured, predefined guidelines that outline actions to be taken before a potential hazard occurs, based on forecast or risk information. These protocols aim to reduce the impacts of disasters by enabling anticipatory, rather than reactive, responses. As climate risks and extreme weather events become more frequent and intense, the importance of anticipatory action becomes increasingly evident.

9.2.1 Relevance to the Prototype System (MHP-IM)

The system currently under development MHP-IM (Multi-Hazard Prototype for Iskandar Malaysia) is designed to support early warning and decision-making processes by integrating data from different sources, forecast information and flood risk indicators. Within this context, the development and integration of an Early Action Protocol is essential. The EAP defines when and how stakeholders should respond, based on thresholds or triggers generated by the system. This ensures that information from the MHP-IM system can be translated into concrete and timely actions on the ground.

The inclusion of an EAP also provides a clear linkage between forecast-based early warning and operational preparedness. Without a predefined protocol, the potential of early warning information to reduce impacts may be underutilized or delayed due to uncertainty in decision-making chains.

Below are several examples of EAP that can serve as references for the MHP-IM system, so that the outputs of MHP-IM can truly be used to reduce the impact of hazards.

9.2.2 Reference Examples

Drought Early Action Protocol in the Netherlands

This section presents an example of an EAP related to the potential occurrence of a national-scale drought in the Netherlands. Drought events in the Netherlands are primarily driven by prolonged periods where evaporation exceeds precipitation, combined with declining water inflows from major rivers such as the Rhine and the Meuse. These conditions can lead to a series of significant challenges, including the drying up of streams, deterioration of water quality, and disruptions to inland navigation.

To mitigate such impacts, authorities may implement a range of early actions, such as introducing water withdrawal bans and applying economical lockage at water locks. In more severe cases, decisions must be made regarding the prioritization of water distribution across sectors and regions. This prioritization is guided by what is known as the displacement series, a national framework that ranks the allocation of limited water supplies during times of scarcity.

The displacement series is a core element in the national drought response, serving as a structured guideline for the fair and strategic distribution of surface water when shortages arise. In the face of such drought-related risks, crisis response partners are responsible for early warning, public communication, and for ensuring that surface water remains available as effectively as possible. This requires national-level coordination, which is governed by the National Water Distribution and Drought Manual, issued by the Ministry of Infrastructure and Water Management (Figure 9-1).

To ensure an effective and timely response to a developing or potential drought crisis, it is essential that:

1 Early warning signals are recognized and communicated promptly,
2 A clear and shared understanding of the situation is established,
3 Crisis partners are able to take coordinated and well-informed decisions.

To facilitate this, Dutch water management institutions have established national agreements among key actors concerning:

1 Mutual exchange of information,
2 Coordination of drought response measures, and
3 Alignment of public and media communication.

Figure 9-1 National Water Distribution and Drought Manual issued by the Ministry of Infrastructure and Water Management (source: link).

1 Organization for water management and crisis management water shortage and drought. This is formed by:

A. The drought column for water management in normal and exceptional circumstances:

i. **Water managers (water boards, Rijkswaterstaat and provinces), including:**
   - Water boards: Regional water authorities responsible for water levels, flood protection, and water quality in their areas.
   - Rijkswaterstaat: The national agency under the Ministry of Infrastructure and Water Management that manages main waterways, highways, and flood defences.
   - Provinces: Provincial governments that coordinate and supervise regional water policy and planning.

Water boards, Rijkswaterstaat and provinces each have their own structures, responsibilities and decision-making. They are leading in the implementation of water management and crisis management in their management area. If the situation requires it, they maintain contact with the safety regions (veiligheidsregio's) via their crisis teams.

ii. **Regional Drought Coordination meeting (RDO):** A platform where regional stakeholders such as water authorities and provincial governments coordinate their response to drought conditions. The six Regional Drought Consultations (RDOs) are the regional platform for monitoring and coordination between Rijkswaterstaat, water boards and provinces in the event of (threatened) regional water shortages. If necessary, they also maintain contacts with stakeholders in the region, such as representatives of shipping, nature organizations and the agricultural sector. If there is reason to do so, a representative of the drinking water sector participates in the RDO. The RDOs inform and advise WMCN-LCW.

iii. **National Coordination Committee on Water Distribution, part of the Water Management Centre Netherlands (WMCN-LCW):** This committee coordinates national-level decisions on how water should be distributed across regions during droughts or shortages, ensuring fair and effective allocation. WMCN-LCW monitors river discharges and other relevant indicators throughout the year, and is alert to impending water shortages. WMCN-LCW coordinates within the drought column and advises, if necessary, on measures to the RDOs, the parties within the RDOs, the national network manager of Rijkswaterstaat (LNM), the Director-General of Rijkswaterstaat and the MTW. In a situation of limited or incipient water shortage and drought, not all members will actively participate in the LCW. During the drought season, WMCN-LCW publishes the so-called drought monitor online, which provides a national overview of the situation. This can be found from April 2021 on https://waterberichtgeving.rws.nl/droogtemonitor.

iv. **Water Shortages Management Team (MTW):** A national-level team activated during water scarcity situations. It assesses the current water supply conditions and provides strategic advice on water distribution and usage restrictions. At Level 2 (Actual Water Shortage), the Water Shortage Management Team (MTW) becomes active. The MTW is chaired by the Director-General of Rijkswaterstaat, who also acts as the crisis management lead for all policy areas under the Ministry of Infrastructure and Water Management (IenW). The MTW is supported by DCC-IenW (the Directorate for Crisis Coordination within IenW). Within the MTW, coordination takes place between:

- The Ministry of IenW (at the director/management level),
- The Ministries of Economic Affairs and Climate Policy (EZK) and Agriculture, Nature and Food Quality (LNV),
- The Association of Regional Water Authorities (UvW),
- The Association of Provinces (IPO), and
- The Drinking Water Association (Vewin).

The MTW aligns measures and communication strategies when standard agreements are no longer sufficient. Each MTW member translates the agreed measures into decisions within their own governance structure, taking into account any prioritization rules (known as the displacement series) that may apply. As chair, the Director-General of Rijkswaterstaat is responsible for making decisions on the allocation of national water resources. In all other matters, the MTW provides advice to its network partners, and to national crisis coordination bodies ICCb (Interdepartmental Crisis Management Committee) and MCCb (Ministerial Crisis Management Committee).
The MTW receives input and recommendations on:

- Water management from the National Coordination Committee on Water Distribution (LCW), and
- Other IenW policy areas from the IenW Preparatory Group (VG).

B. The generic crisis column

i. **Safety regions:** These are regional public safety bodies that coordinate emergency response services (fire, police, health, etc.) during crises, including climate-related disasters like droughts or floods.

ii. **Interdepartmental Coordination Consultation (IAO), the Interdepartmental Crisis Management Committee (ICCb) and the Ministerial Crisis Management Committee (MCCb)**

- IAO (Interdepartmental Coordination Meeting): A working-level meeting between ministries to align policies and share information during emerging or ongoing crises. It supports preparation and coordination across departments.
- ICCb (Interdepartmental Crisis Management Committee): A strategic-level committee of senior officials (usually Director-Generals) from multiple ministries. It coordinates crisis response at the inter-ministerial level and advises the MCCb.
- MCCb (Ministerial Crisis Management Committee): The highest political decision-making body during a national crisis, led by the Prime Minister or a designated minister. It takes formal decisions on national crisis response and strategy.

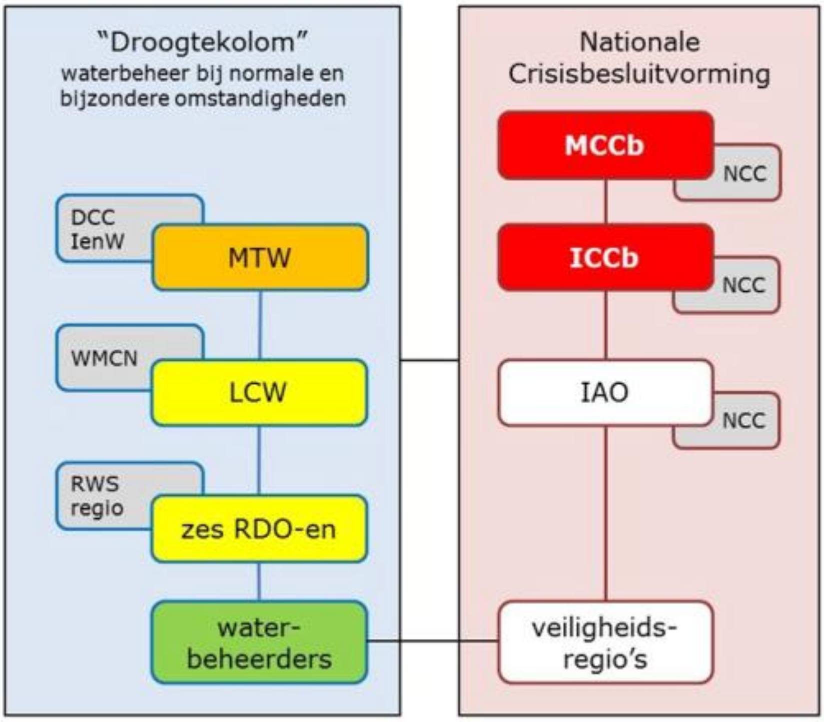


Figure 9-2 Organizational Structure for Water and Crisis Management during Water Shortage and Drought.

The step from level 2 to level 3 means that nationally, in addition to the drought column, the national generic interdepartmental crisis management will also become active. The drought column will then be an advisor to the national crisis teams and will continue to fulfil its own role. DCC-IenW will facilitate this process.

If the situation becomes very serious, there may be a (possible) national crisis. In that situation, in addition to the drought column, the national crisis structure is also activated, under the responsibility of the Ministry of Justice and Security. Decision-making then also takes place at the highest official or even ministerial level: the IAO, the ICCb or the MCCb. The drought column provides substantive advice via WMCN-LCW and the MTW. The National Crisis Centre (NCC) facilitates the IAO and ICCb/MCCb in consultation with DCC-IenW. In addition to the competent authorities in the drought column, the NCC/LOCC also forms a connection with the safety regions.

Table 9-1Summary of Roles and Tasks.

Active in				Committee, role, organization	Summary of duties and powers
			3	Minister of IenW, Ministerial Commission Crisis Management (MCCb)	Minister of Infrastructure and Water Management decides on scaling up level 2->3. Chairman of the highest active body decides on scaling down 3-> 2. Interdepartmental decision-making at ministerial level (MCCb) including on measures. NKC has control over national communication.
			3	Interdepartmental coordination meeting (IAO), Interdepartmental mental commission Crisis Management (ICCb)	Interdepartmental coordination and alignment at the highest official level (ILO, ICCb). Press and public communication as with MTW or - if scaled up and after ICCb decision - national coordination by National Core Team Crisis Communication (NKC).
Generic interdepartmental crisis column becomes active, drought column remains active.					
		2	3	Management team Water shortages (MTW)	Coordination and coordination, departmental and with partners (directorate/management level). Advises IAO, ICCb, MCCb and the Minister of IenW. Coordinates national press and public communication. MTW members translate MTW results into decisions in their own administrative column. The DG Rijkswaterstaat is chairman of the MTW, as portfolio holder crisis management IenW, and decides on open scaling down level 1-2. DG RWS decides on level 2 on measures for national waters.
	1	2	3	National Network Manager Rijkswaterstaat (LNM)	Decide on scaling up level 0->1 and downscaling 1->0 (see paragraph 3.6). If necessary, coordinates level 1 measures for national waters. Advises the DG RWS. Participates in the MTW on behalf of RWS.
0	1	2	3	National Coordination Committee Water distribution (WMCN-(LCW)	Monitoring, coordination, coordination and advice nationally. Creates a national picture of the situation. Provides national information for press and public communication and coordinates where necessary with the relevant RDOs (or RWS regions) and with other interested authorities. Participates in the MTW via a liaison if requested. Advises LNM, DG RWS, MTW and via these also IAO and ICCb/MCCb.
0	1	2	3	Regional drought-consultation (RDO)	Monitoring, coordination and advice regionally. Creates the regional image, contributes to the national image. Members inform each other and coordinate (where necessary also nationally) on press and public communication. Participates in the LCW meeting via a liaison. Advises WMCN-LCW and via this also MTW, IAO and ICCb/MCCb.
regular management				Rijkswaterstaat, water boards and provinces	Responsible for the implementation of water management in normal and exceptional circumstances within the own management area.

1 The displacement series

The displacement series provides a priority order of social and economic needs that determine the distribution of available surface water in the event of water shortages or impending water shortages. The principle is laid down in the Water Act and elaborated in the Water Decree. From the moment that the Environmental Act comes into effect, expected on 1 January 2021, the displacement series will be included in the Environmental Quality Decree. On www.helpdeskwater.nl. An extensive manual for the Displacement Series is available.

Category 1 Safety and prevent from irreversible damage	**Category 2** Utilities	**Category 3** Small scale high quality use	**Category 4** Other interests (Economic consideration, also for nature)
1. Stability of water barriers 2. Prevention of sound and setting 3. Nature *prevent irreversible damage, otherwise cat. 4*	1. Drinking water-facility (for guarantees delivery-certainty, otherwise cat. 4) 2. Energy supply (only in case of danger for delivery-certainty, otherwise cat. 4)	- Temporary irrigation capital-intensive crops - Process water	- Shipping - Agriculture - Nature (unless irreversible damage occurs) - Industry - Water recreation - Inland fishing - Drinking water supply (other than cat. 2) - Energy supply (other than cat. 2) - Other interests
Goes for 2 -	*Goes for 3 -*	*Goes for 4 -*	

Figure 9-3 The Displacement Series.

- Within categories 1 and 2 there is a priority order. Within categories 3 and 4 mutual prioritization takes place on the basis of minimizing the economic social damage. WMCN-LCW advises on this at national level, the RDO at regional level.
- A provincial regulation may determine further priorities within categories 3 and 4 (Water Decree, art. 2.2).
- Application of the displacement series may have implications, such as agreements to use additional water supply only for the benefit for which it is allocated.

2 The escalation scheme (scaling-up levels and criteria)

At each level, starting from level 0 (green), a number of relevant indicators are monitored. If one or more criteria for the next level are at risk of being exceeded (for example: Rhine discharge becomes too low, or there is significant public concern about the effects on agriculture and nature), the level of information exchange increases; this is referred to as informative scaling. Based on that information, a decision is made regarding operational scaling. The reverse process applies when scaling down.

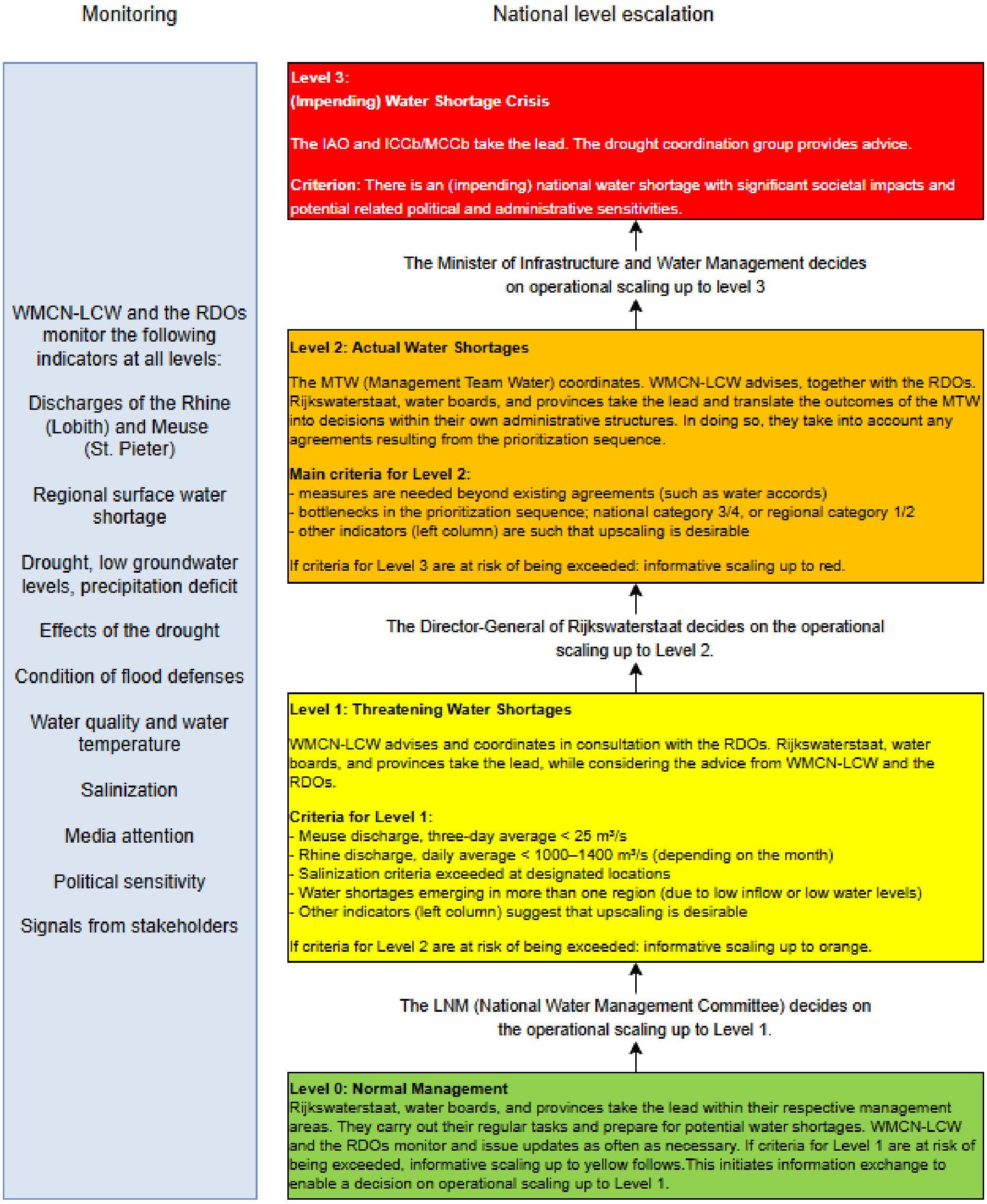


Figure 9-4 Scaling-up Levels and Criteria.

3 **The network scheme**
This diagram shows the bodies that are active in the drought column. It also shows which parties and bodies maintain contact with each other and exchange information. The network diagram also makes clear from which scaling-up level a body is active. Green stands for level 0 (normal management), yellow for level 1, orange for level 2 and red for level 3. The RDOs and WMCN-LCW act in both level 0 and 1, hence the diagonal green-yellow division. A number of parties outside the drought column are also shown.

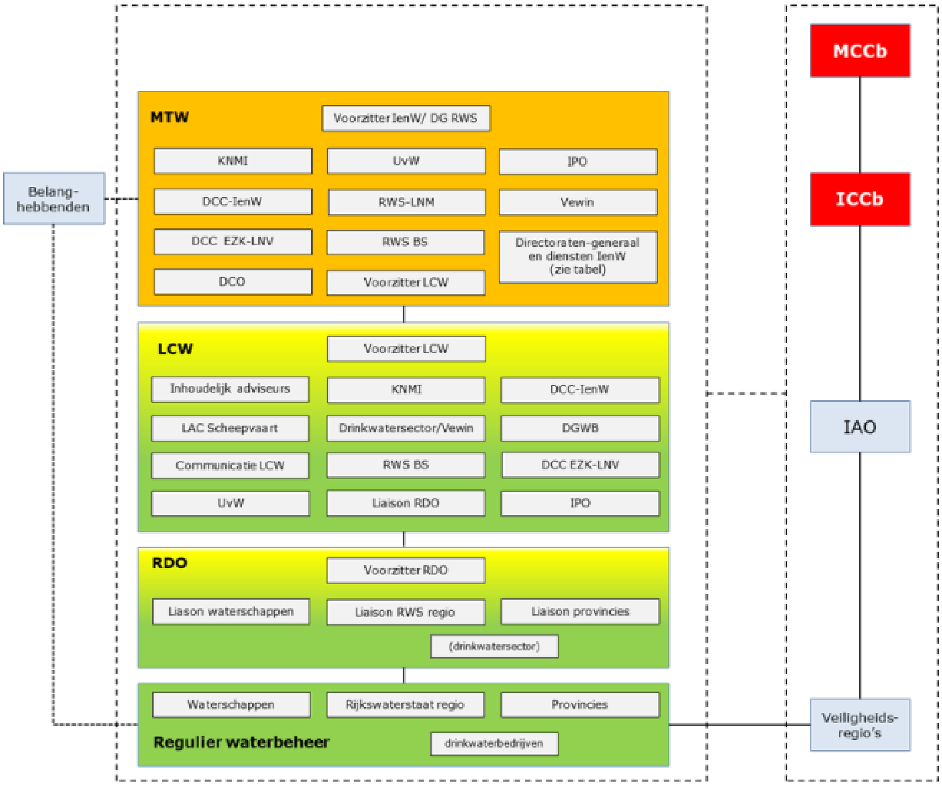


Figure 9-5 Network Diagram of Bodies and Organizations for Water Distribution and Drought.

Flood Early Action Protocol in Jakarta
To provide a more suitable illustration of the Early Action Protocol for the MHP-IM prototype, this section includes key elements that are considered important and have previously been proposed during the development of the Early Action Protocol for the Jakarta Flood Early Warning System (J-FEWS).

The context of flood management in Jakarta
Jakarta possesses a complex system of drainage canals, main rivers, water gates and pumping stations. Also the institutional context is complex, since the management of the operation and maintenance of the system is divided between two institutions that is Ciliwung Cisadane River Basin Organization (BBWS Cilicis) and DSDA DKI. Moreover many other institutions are involved in flood (disaster) management and in processes of planning and decision making in which information on flood management is crucial.

There are roughly 1.900 kilometers of canals and about 60 pumping stations in DKI Jakarta. At first the provincial public works office (DPU–DKI Jakarta) is responsible for the cities drainage canals and smaller rivers. DPU-DKI is supported by several sub-division at the municipal level. Secondly the Ministry of Public Works - through the Balai Besar for the Ciliwung and Cisadane river basins (BBWS Cilicis) – is responsible for the main river basins.

Through the Directorate PLP for urban drainage and sanitation the Ministry of Public Works also has a responsibility in the cities flood management. Figure 9-6 below gives an overview of the shared responsibilities in the Jakarta water system.

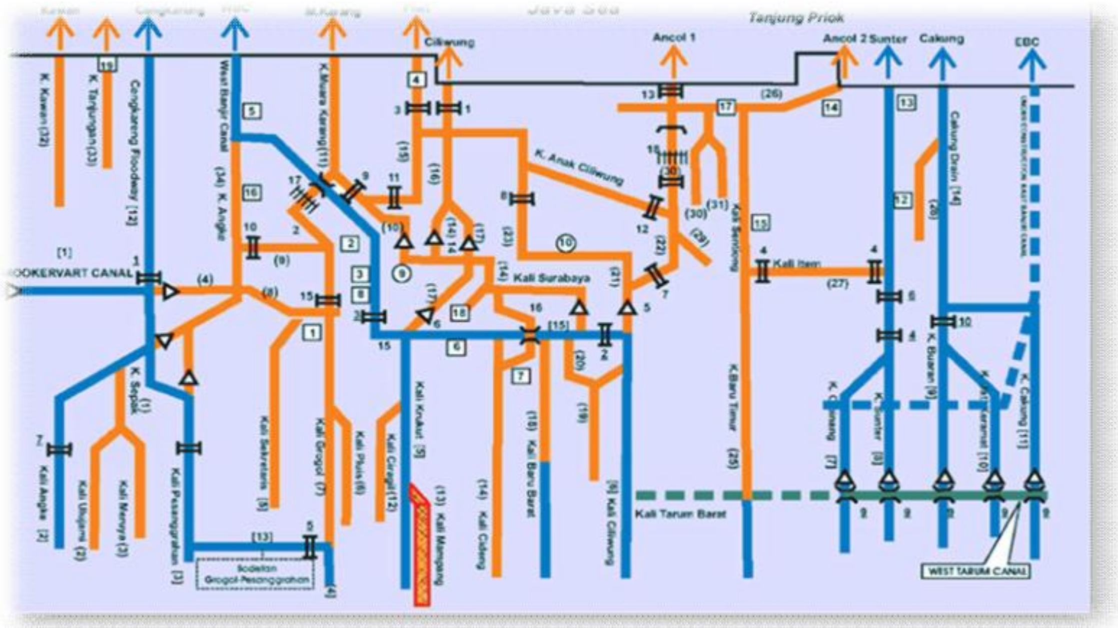


Figure 9-6 Shared Responsibilities in the Water System of Jakarta; in Orange Under Responsibility of DPU-DKI Jakarta and in Blue Under Responsibility of the Ministry of Public Works through the BBWS.

Both DPU-DKI and BBWS divided the responsibilities for the management of the water system in two divisions; a water resources management and planning division and an operations and maintenance division. In general the water resources management and planning divisions are responsible for the overall management of the water system, including data analysis, the programming and planning of flood management activities, the preparation of guidelines and technical standards, supervision and public awareness.

Whereas the operations and maintenance divisions both at DPU-DKI and BBWS are responsible for the more technical operations and maintenance of the system and infrastructure in the field. Also the management and implementation of hydrological measure systems and flood early warning systems are among the tasks of the operation and maintenance divisions.

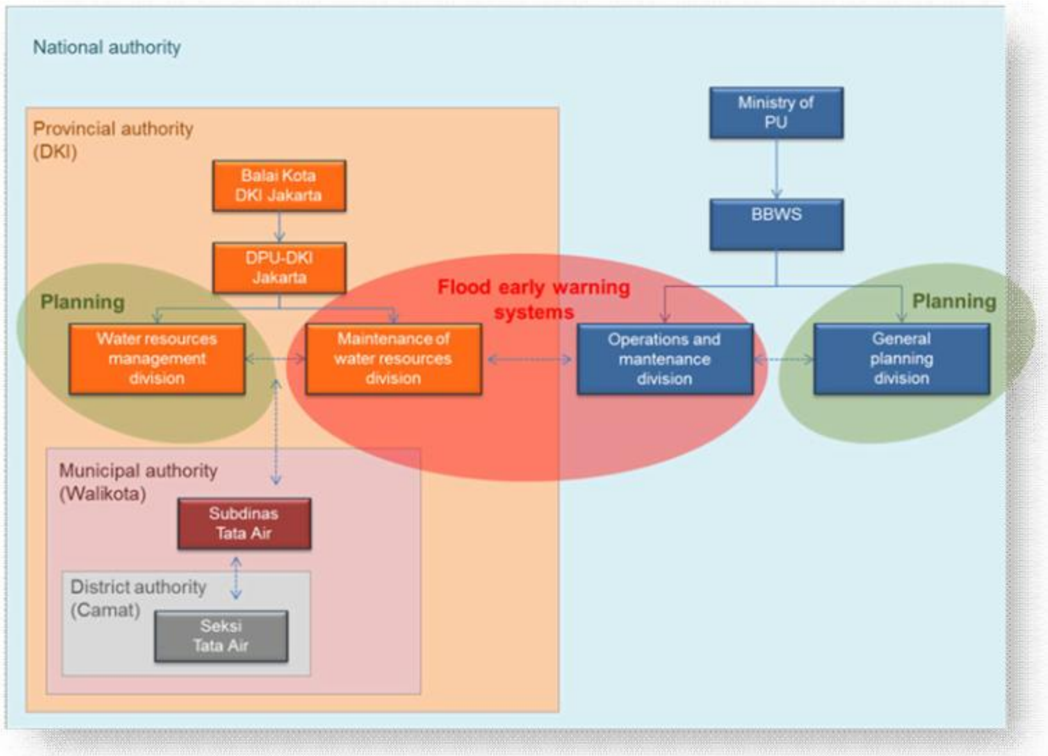


Figure 9-7 Divided Responsibilities for General Planning / Water Resource Management and Operations and Maintenance (Including Flood Early Warning) of the Water System of Jakarta.

1 Institutions involved in the management of flood information for Jakarta

In the management of flood data and information for flood disaster management and planning many government and non-government agencies and institutes are involved on national, provincial and local level. Hereafter the most relevant institutions for a flood management information system for Jakarta are described.

A. National authority

At the national level, six ministries are involved in water resources management: Public Works, Forestry, Environment, Bappenas (National Development Planning Agency), Agriculture, and Home Affairs. For a flood management information system (FMIS) in Jakarta, the Ministry of Public Works (MinPU) is the most relevant, as it is responsible for integrated water resources development and river basin management through the River Basin Management Authorities (BBWS). Other key institutions include the national water resources research center (PUSAIR), the meteorological and climate agency (BMKG), and the national survey and mapping agency (BAKOSURTANAL). The National Disaster Management Agency (BNPB) is a primary end-user of the FMIS at the national level.

•	MinPU	Ministry of Public Works (Pekerjaan Umum)	The ministry of public works is split into several directorate generals. Water resources are managed through the Directorate General of Water Resources Development. Through several directorates and the regional river basin management agencies this DG is responsible to alleviate floods and manage rivers, to develop, conserve and manage water resources and to meet with increasing demands for drinking water and water for industry and agriculture. Besides also the DG of Human Settlements (Cipta Karya) is relevant because flood management information is needed for its tasks in resettlement and sanitation.
•	BBWS	River basin authority (Balai Besar Wilayah Sungai)	Under the authority of the Ministry of Public Works these organizations function under national government. The BBWS are in charge of river basins considered as “category A” as denoted in the water law. In Greater Jakarta the BBCilCis is responsible for the water resources management for the Ciliwung and Cisidane river basins (further referred as BBWS). This agency is responsible for planning, construction, operation and maintenance of lakes, reservoirs, rivers and beaches under national responsibility.
•	PUSAIR	Research and Development Center of Water Resources (Puslitbang Sumber Daya Air)	Pusair is a non-departmental government agency under responsibility of the Ministry of Public Works. Its mandate covers research and development related to water resources, and therefore is a focus center for flood management information.

B. Provincial authority

The provincial government is led by the governor, supported by five assistant governors with specific portfolios and a secretary, all based in the ‘Balai Kota’ (Governor’s Office). Several departments (‘Dinas’) operate under this structure, two of which are responsible for water resource management: Dinas SDA (Sumber Daya Air) and Dinas PU (Pekerjaan Umum). Their roles are not always uniformly defined; however, in general, Dinas SDA manages sanitation, while Dinas PU oversees integrated water resources and flood management. Dinas PU is also responsible for providing flood management information to support disaster management and planning.

•	DPU-DKI	Department of Public Works of Jakarta Province (Dinas Pekerjaan Umum DKI	DPU-DKI is responsible for the planning, implementation, supervision, operational management, maintenance and monitoring of provincial infrastructure and utilities and for provincial water resource management.

		Jakarta)	Specifically for flood management DPU-DKI is responsible for: • The preparation of guidelines and technical standards, planning and implementation of provincial flood management activities and projects. • The operational management and maintenance of the provincial hydrological systems and early warning system. • Related research and information management.
•	BPBD	Regional board for disaster management (Badan Penanggulangan Bencana Daerah)	BPBD, a non-departmental government agency, is the regional board for disaster management in Jakarta. BPBD will implement disaster response activities after the governor declared red alert in the early warning system. In case of such flood event in Jakarta flood management information is needed.

C. Local authority

Jakarta is divided into five municipalities, each headed by a Walikota (Mayor). Similar to the provincial structure, each municipality has several departments (Dinas). At the municipal level, the Dinas PU, through the sub-Dinas Tata Air, is responsible for implementing local water resource management activities. However, overall water resource and disaster management planning are coordinated at the provincial level (DKI Jakarta).
At the district level (Kecamatan), practical water resource management activities are handled by the Seksi Tata Air, under the leadership of a Camat (district head). Districts are further divided into Kelurahan, led by a Lurah, who plays a key role in disseminating flood early warning information and providing practical support for disaster management at the community level.

2 The escalation scheme for flood early action in Jakarta

The figure below illustrates the alert levels and the authorities responsible for decision-making when river water levels exceed predetermined thresholds. It is important to note that the alert levels indicate which authority is responsible for each condition, starting from Alert Level IV, Alert Level III, Alert Level II, up to Alert Level I.

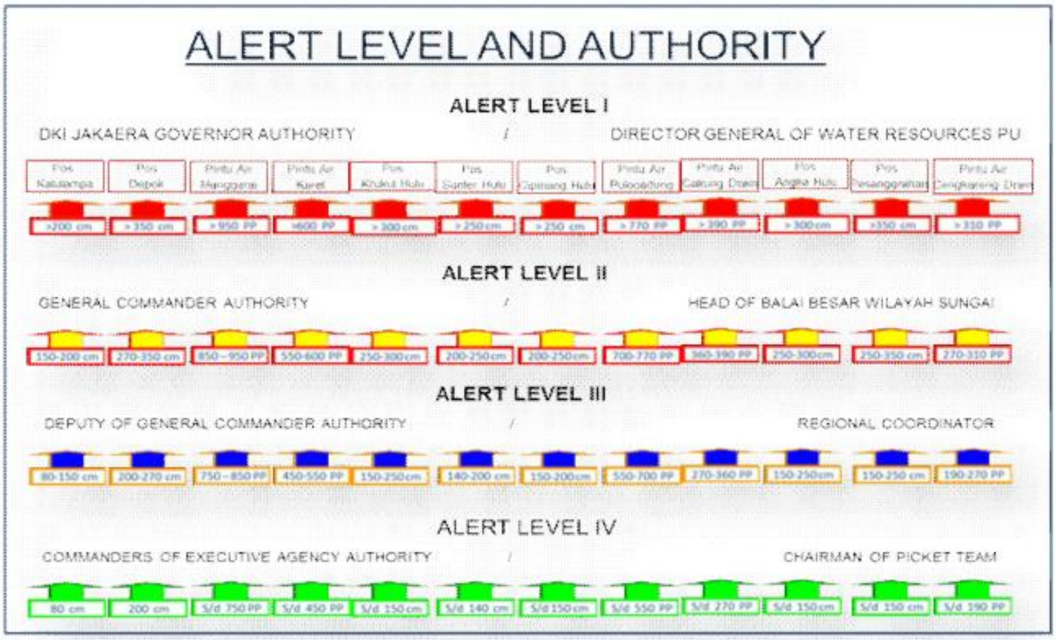


Figure 9-8 Alert Levels and Authorities in Case of Potential Flood Threat.

Below figure shows the information flow of flood early warning system in DKI province and also authorization in every alert conditions.

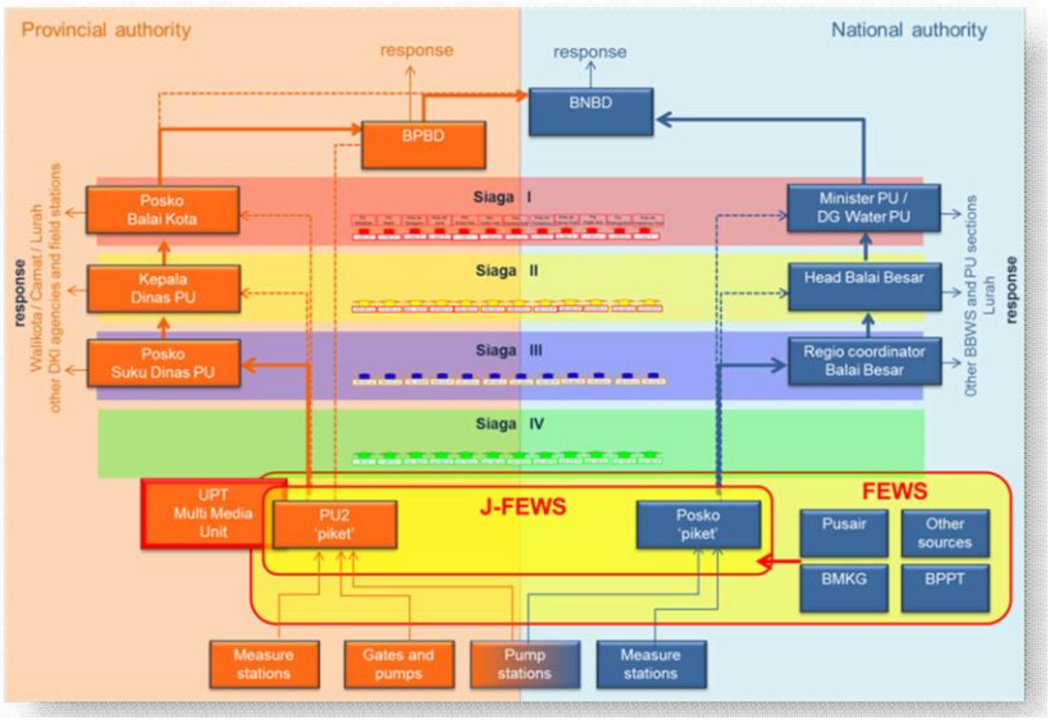


Figure 9-9 Information flow and authorization process for flood early warning system in DKI Jakarta.

The following section provides a detailed description of the tasks and responsibilities of BBWSCC, PU DKI, Pemda DKI, BPBD, and BNPB before, during and after the flood event.

A. **BBWSCC and Dinas PU3**

In term of flood mitigation PU DKI and BBWSCC have similar task and responsibilities, but for different areas. At many water gates in DKI province, staff from DPU DKI and BBWSCC work side by side. According to Task Force Guidelines DPUDKI (2009) and Flood mitigation taskforce (Satgas Banjir DKI) procedure BBWS 2011, BBWSCC and PU DKI are responsible for:

Before the event
- Checking condition of the flood control infrastructure, basin, water gate, water channel.
- Checking the hardware of communication and hydrological instrument.
- Checking the heavy equipment (bulldozer, excavator, etc.).
- Calculation the flood forecast.
- Monitoring the weather forecast from BMKG.
- Prepared the flood reduction guidance.
- Monitoring water level and dissemination to related agencies and competence person.

During the event (local rain and rain in the upstream before flood occur + during the flood)
- Walkthrough (patrol and observation) together with community. The person in charge of the walkthrough activities are officials from BBWS and DPUDKI who stay (on duty) at flood control infrastructure (water gates, pumping stations).
- Monitoring water level and dissemination to related agencies.
- Warning information (water level or a certain level of danger) based on alert status.
- Interim Reporting the flood which comprise time, inundation area , the wide, location and the damage to competent person

After the event
- Emergency repair to facing another flood.
- Stock taking of damage buildings and infrastructure, reporting to related agencies.
- Collecting data and information for future flood mitigation.

B. **BPBD**

Since 2008 Bakornas PB as disaster management organization does not longer exist and is replaced by Badan Nasional Penanggulangan Bencana and also Satkorlak as disaster management organization in provincial level is replaced by Badan Penanggulangan Bencana Daerah (BPBD). BPBD DKI is a new organization (established in 2011) with large responsibilities regarding disaster management in DKI Province, not only in preparedness and emergency response phase such as Satkorlak DKI, but also involved in all phases of disaster cycle. The BPBD is directly responsible to the Governor of DKI Jakarta.

Before the event
- Coordination with related agencies in term of flood prevention.
- Monitoring the weather forecast from BMKG.

During the event
- Warning dissemination (water level or a certain level of danger) to the public.
- Send out water level information to the heads of Kecamatan, Lurah, Army, Police, Satpol PP.
- Using social media (twitter and facebook) to inform public for emergency status.
- Coordination with related agencies (TNI, SAR, PU, Social ministry, POLRI etc) regarding emergencies response.

- Based on City hall at Ruang Pola (POSKO BANJIR DKI) with all provincial SKPD (Satpol PP, army, police, Dinkes, Dishub, etc) to coordination, controlling and monitoring all activity during the flood. BPBD also have authority to order water gates to be opened or closed, sending the mobile pumps etc.
- Coordination with all SKPD for emergencies repair and prepare for flood subsequent in another location.

After the event
- Coordination with related agencies in term of rehabilitation and reconstrcution phase (if necessary)
- Preparing for the next event (next flood)
- Rapid Assessment

C. BNPB

BNPB works on national level, with task and responsible according to Perpres No. 8 year 2008 TUPOKSI. The activities of BNPB related to flood and disaster management are:
- Dissemination all information to the public regarding disaster activity in Indonesia.
- Provide guidance and direction for disaster management efforts that include disaster prevention, emergency response, rehabilitation and reconstruction in a fair and equitable.
- Coordinating of implementing disaster management activity in a planned, integrated and comprehensive. For Jakarta this means coordination with BPBD, PU and all related agencies.
- If the disaster status raises into national level, BNPB will take a lead for emergencies response, rehabilitation and reconstruction phase (if necessary).
- Funding.

D. Pemda DKI

As the Administrator of the province of DKI Jakarta, Pemda DKI has the task and responsibility to protect their citizens, one of which is to protect the citizens from the flood.

The activities of Pemda DKI related to flood and disaster management are:

Before the event
To supported community participation through kelurahan and kecamatan, encourage community to involved walkthrough activity together with DPU DKI and BBWSCC. Public awareness for maintenance the drainage in term of preparing for the next possible flooding.

During the event
Pemda DKI (with all SKPD in charge) under coordination of BPBD (as the leader of emergency response team) to involve in emergency response activity.

After the event
Under coordination with BPBD to take care refugee (provide the food, temporary space for refugee).

9.2.3 Input for MHP-IM Early Action Protocol

The followings are key elements of an Early Action Protocol that can be adopted by MHP-IM.

9.2.3.1 Risk Monitoring and Trigger Mechanisms

Continuous monitoring of rainfall and river water levels is essential. Forecast models help predict flood timing and extent, while predefined trigger thresholds, such as danger-level river heights or heavy rainfall amounts, determine when early actions should begin.

Risk monitoring is conducted daily by advanced users through the MHP-IM platform. Several features of the platform provide information on potential risks, including alert icons displayed at water level and rainfall stations, rainfall reports, and flood reports generated from flood forecasting activities. These rainfall and flood reports offer a comprehensive overview of disaster risks, serving as indicators of the severity of potential events and functioning as trigger mechanisms to guide necessary actions.

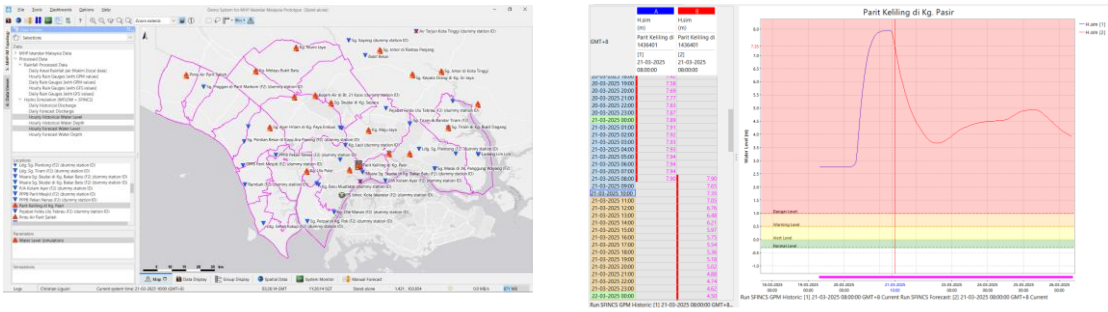
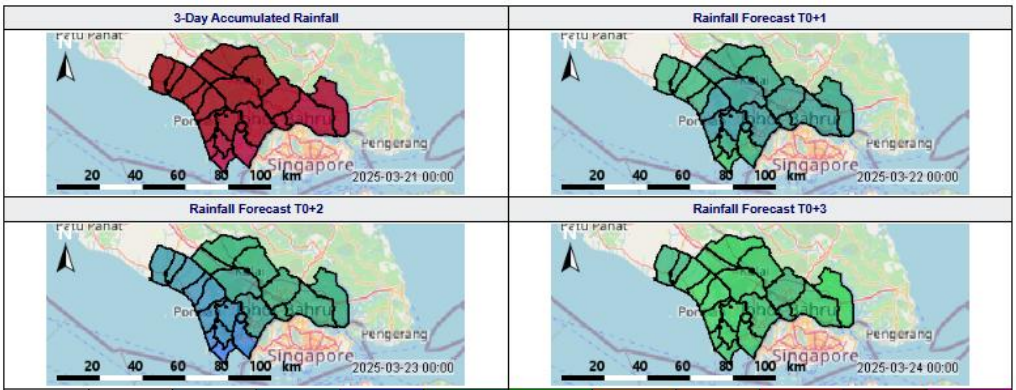


Figure 9-10 Flood forecast and warning at river gauge locations.

Rainfall Warning Report (17 Mar 2025)



Rainfall Classification											
	0 mm	0.2 mm	1 mm	5 mm	10 mm	25 mm	50 mm	75 mm	100 mm	200 mm	400 mm

Table of Rainfall per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 17 Mar 2025

Mukim	3-Day Accumulated Rainfall [mm]	Rainfall Forecast T0+1 [mm]	Rainfall Forecast T0+2 [mm]	Rainfall Forecast T0+3 [mm]
API-API	49.2	15.0	5.8	56.1
AYER BALOI	30.8	13.2	5.2	56.1
AYER MASIN	34.9	15.5	11.5	60.8
BANDAR BENUT	41.0	10.6	3.5	54.5
BANDAR JOHOR BAHRU	6.8	11.8	1.9	58.7
BANDAR KULAI	3.1	11.1	2.7	51.6
BANDAR PONTIAN KECHIL	51.5	14.2	4.7	54.4
BANDAR TEBRAU	7.7	11.8	1.9	58.7
BENUT	41.5	11.4	4.1	55.2
BUKIT BATU	8.6	11.1	2.7	51.7
JELUTONG	11.7	14.2	4.7	54.4
JERAM BATU	13.9	14.2	4.7	54.4
KULAI	4.4	12.8	3.7	53.9
PEKAN JERAM BATU	4.4	14.2	4.7	54.4
PENGKALAN RAJA	17.7	14.2	4.7	54.4
PLENTONG	8.0	9.5	2.4	62.4
PONTIAN	23.8	14.2	4.7	54.4
PULAI	4.5	12.9	3.2	56.7
RIMBA TERJUN	30.6	14.2	4.7	54.4
SEDENAK	2.8	10.9	2.7	51.5
SENAI	2.6	8.9	2.7	51.4
SERKAT	25.3	16.8	17.8	66.7
SUNGAI KARANG	25.7	14.7	7.3	56.9
SUNGAI PINGGAN	31.5	11.0	3.8	54.9
SUNGAI TIRAM	10.3	6.6	3.2	65.0
TANJONG KUPANG	13.5	15.6	11.3	61.0
TEBRAU	6.1	11.1	2.0	57.5

Note:

Rainfall Classification		
	Light	< 41 mm
	Moderate	41 - 60.9 mm
	Heavy	61 - 80.4 mm
	Very Heavy	> 80.5 mm

Figure 9-11 Example of rainfall warning report produced on 17 Mar 2025 by MHP-IM.

Flood Warning Report (17 Mar 2025)

Maximum Flood Depth

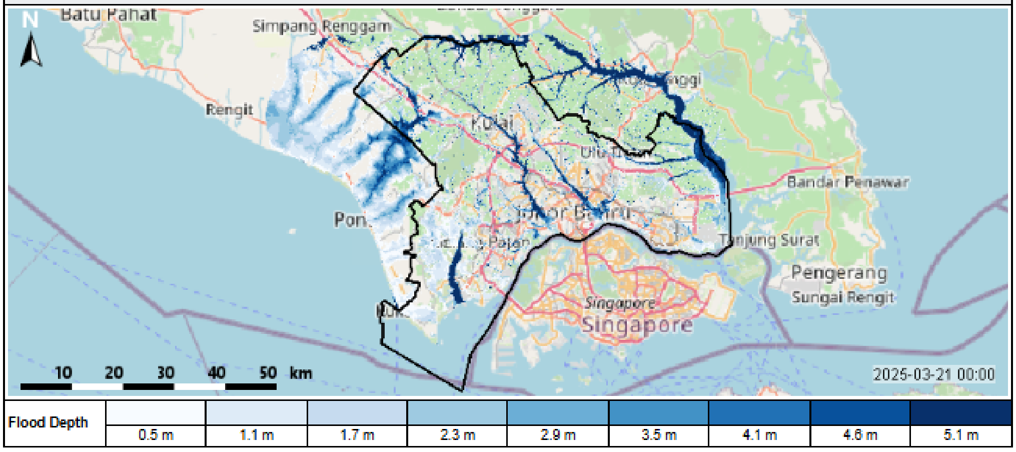


Table of Flood Early Warning Impact per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 17 Mar 2025

Mukim	Flooded Area [%]	Number of Population Affected [People]	Estimated Damage to Buildings [10^3 MYR]
API-API	12.9	2,650	135,594
AYER BALOI	11.3	1,125	23,410
AYER MASIN	8.3	350	2,661
BANDAR BENUT	96.9	3,840	46,044
BANDAR JOHOR BAHRU	3.4	5,745	223,538
BANDAR KULAI	7.6	465	14,256
BANDAR PONTIAN KECHIL	24.1	340	48,604
BANDAR TEBRAU	58.0	35	2,725
BENUT	36.7	3,565	32,834
BUKIT BATU	3.5	105	720
JELUTONG	7.4	1,690	44,113
JERAM BATU	11.6	785	14,768
KULAI	0.7	3,110	62,685
PEKAN JERAM BATU	0.0	0	0
PENGKALAN RAJA	1.6	10	0
PLENTONG	5.4	22,520	1,020,245
PONTIAN	13.0	4,420	235,209
PULAI	1.9	7,655	123,029
RIMBA TERJUN	12.4	6,495	157,434
SEDENAK	3.1	415	9,679
SENAI	3.0	3,820	324,997
SERKAT	13.6	825	306,140
SUNGAI KARANG	19.8	320	105
SUNGAI PINGGAN	16.1	1,145	7,589
SUNGAI TIRAM	19.4	560	117,871
TANJONG KUPANG	17.4	4,485	342,409
TEBRAU	3.3	12,935	876,017

Figure 9-12 Example of flood warning report produced on 17 Mar 2025 by MHP-IM.

9.2.3.2 Pre-agreed early actions and pre-agreed priority sectors

To be addressed during a disaster. Actions are planned in advance to reduce impacts once triggers are met. These include issuing flood alerts, evacuating high-risk areas, moving livestock and assets to higher ground, pre-positioning rescue equipment and relief supplies, and mobilizing medical and emergency teams. For flood events in Iskandar Malaysia, the prioritization, from highest to lowest could be as follows:

- a Human safety and protection of lives
- b Vital infrastructure and public utilities (hospitals, water supply and electricity systems, major roads, airports, bridges, and train stations)
- c Densely populated residential areas

d Educational and government facilities

Based on the pre-agreed priority sectors and the risk maps generated by the MHP-IM, early actions can be determined in advance. For example, municipalities can install signs indicating designated evacuation routes to guide residents in the event of flooding.

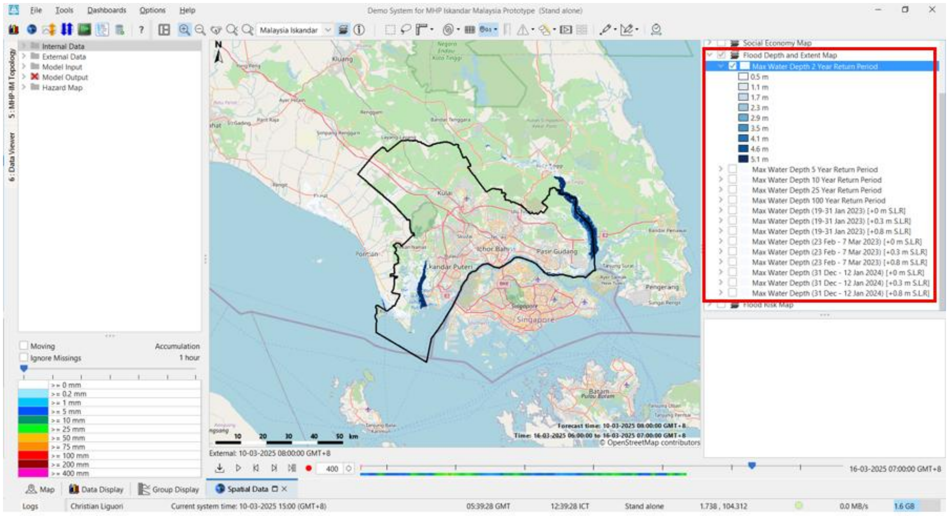


Figure 9-13 Flood extent and depth layers for various return periods.

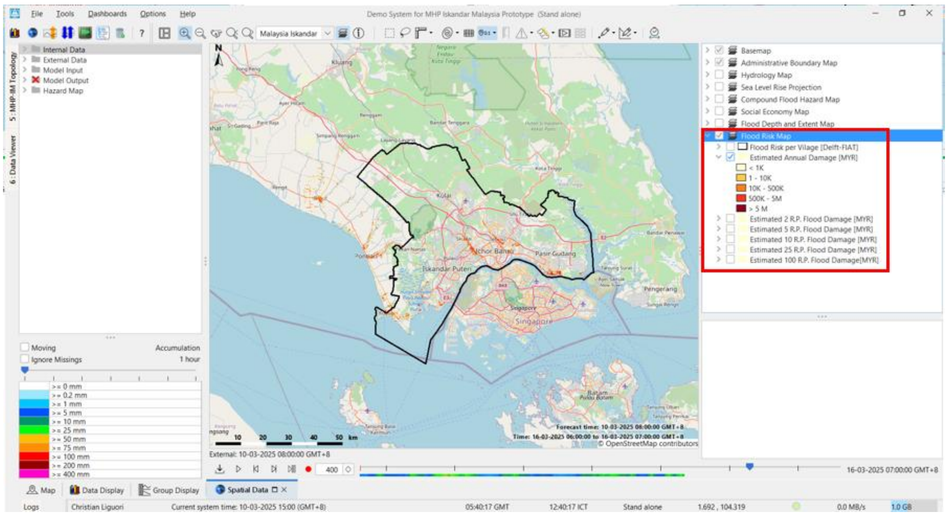


Figure 9-14 Flood risk and damage layers for various return periods.

9.2.3.3 Description of the organizations involved in disaster management.

Each institution involved in disaster management should have clear roles and responsibilities.

Based on the findings from the initial workshop, it is recommended that the system incorporates at least three distinct groups: data providers, advanced users, and end users. Figure 9-15 below illustrates the typical agencies involved in each phase of the Early Warning System (EWS) and their respective groups. Additionally, Figure 9-16 lists the stakeholders identified during the first workshop.

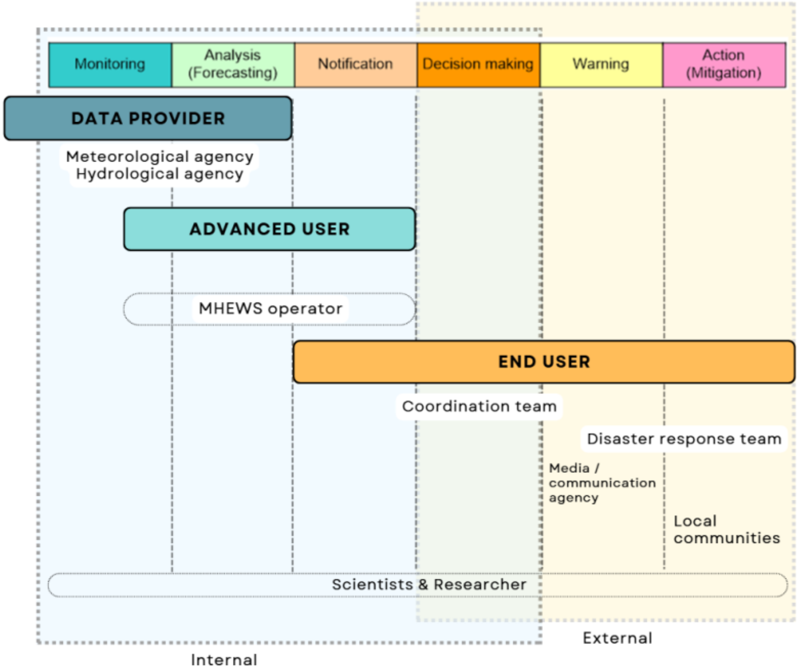


Figure 9-15 Stakeholders on a multi-hazard early warning systems.

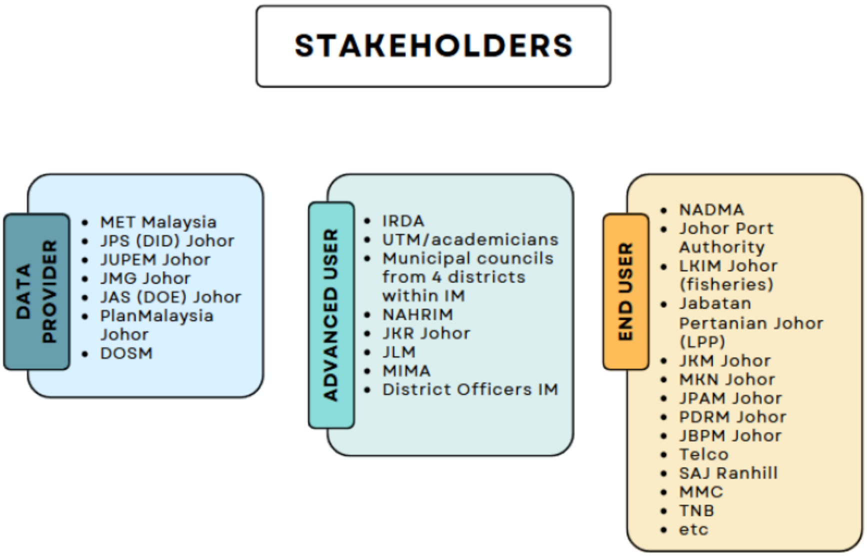


Figure 9-16 Stakeholder groups of the designed early warning system for Iskandar Malaysia.

Data providers are key to monitoring and forecasting in the Multi-Hazard Platform (MHP-IM). In the monitoring phase, MET Malaysia and JPS (DID) Johor are the main sources of meteorological and hydrological data. They also conduct analyses and forecasting. Other contributors, such as scientists, NGOs, and specialized teams, may support these activities. Collaboration among these stakeholders is essential for reliable monitoring and accurate forecasts.

Advanced users operate the platform and analyse collected data. This group includes decision-makers, scientists, researchers, and NGOs. Decision-makers often form specialized teams to interpret results and are the first to receive alerts, ensuring timely warnings are issued.

End users are those who act based on these warnings. Decision-makers coordinate with media, communication agencies, and response teams to share information with at-risk communities. End users also include private companies managing critical infrastructure (telecommunications, electricity, and water) and local communities, who must be prepared to reduce hazard impacts. Roles and responsibilities of each group are shown in Figure 9-17.

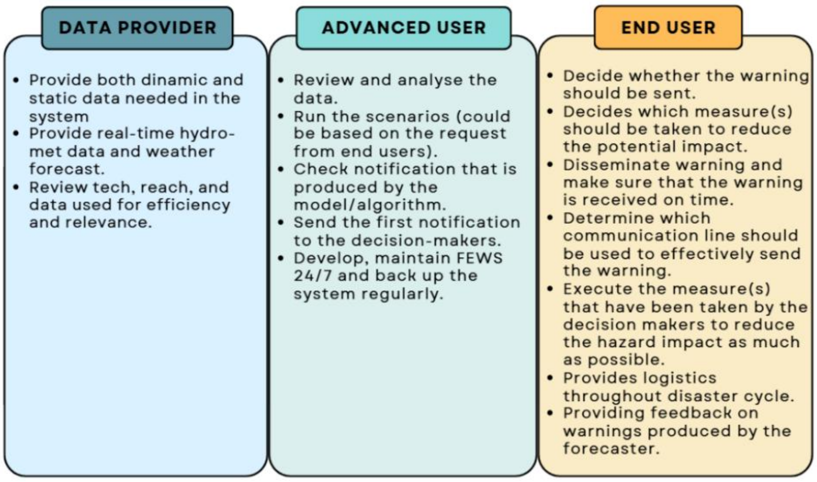


Figure 9-17 Responsibility of each group of multi-hazard early warning system.

9.2.3.4 Pre-Allocated Financing

Funds are secured in advance through forecast-based financing, enabling immediate action once triggers are reached. This ensures resources are available for evacuation, shelter setup, and emergency supplies before floodwaters peak.

Using information from the MHP-IM, particularly the flood report (Figure 9-12), operators can estimate the potential economic losses that may occur. This information is crucial as the estimated figures can serve as a reference when requesting funds for disaster relief. Additionally, the projected loss values presented in the flood report can be used as a basis for determining the required allocation in the disaster reserve fund.

9.2.3.5 Community Engagement and Communication

Communities are involved in flood risk mapping, evacuation planning, and decision-making. Warning messages are communicated in local languages using trusted channels to ensure they are clear and actionable.

MHP-IM products displayed through WebOC enable warnings to reach a wider audience more quickly. Furthermore, the warnings can be customized in local languages, ensuring that the messages are clearly understood and appropriately acted upon by the targeted communities.

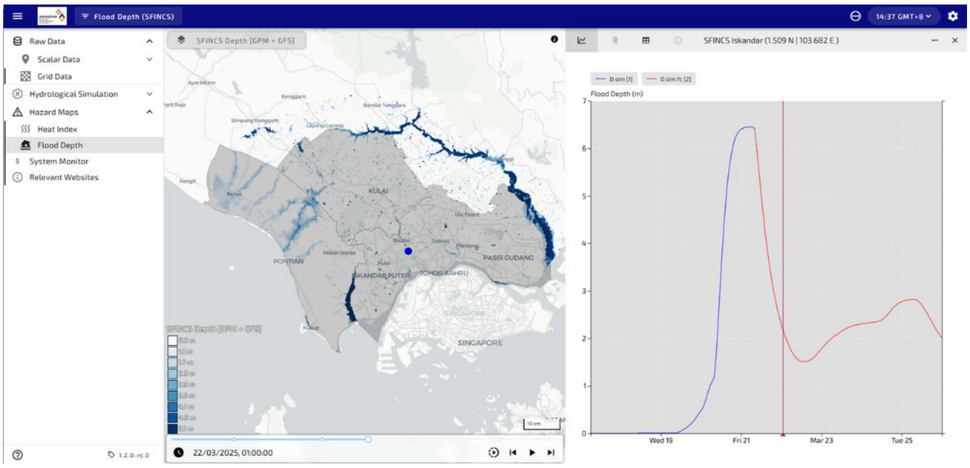


Figure 9-18 Website version of MHP-IM (WebOC).

9.2.3.6 Standard Operating Procedures (SOPs)

Step-by-step guidelines specify what actions should be taken, by whom, and when. Timelines are aligned with forecast lead times, such as preparing evacuation 72 hours in advance and executing evacuation 24 hours before expected flooding.

The following table presents an example of an Early Action SOP based on triggers, warnings, and reports issued by MHP-IM. This SOP outlines the different alert levels, the triggers used for escalation between alert levels, the required actions, the lead and supporting agencies, and the estimated lead time available to respond to potential disasters. Several actions related to the utilization of MHP-IM are further described in the MHP-IM User Manual.

Table 9-2 Example of early action SOP based on triggers/warnings issued by MHP-IM.

Alert Level	Trigger Indicators (if one or more is checked)	Action (SOP)	Lead Agency & Supporting Agencies	Timeline (Lead Time)
Alert 1 – Preparedness / Monitoring Phase	• 3-day historical cumulative rainfall: >50 mm but <100 mm • 1-day forecast rainfall: >50 mm (MHP-IM forecast) • Flooded area (model forecast): <5% per mukim • Population at risk: <500 people • Estimated damage to buildings: <RM 100,000	• MHP-IM **automatically generates early** notification to JPS Johor & District Disaster Management Committee (DDMC). • Start intensified monitoring by JPS and MET Malaysia. • Prepare **logistics and communication lines**; verify contact list of community leaders. • No evacuation yet.	• Lead: JPS Johor (DID) • Support: MET Malaysia, DDMC, Local Council	**T-72 to T-48 hours before peak rainfall**
Alert 2 – Early Warning Phase	• **3**-day historical cumulative rainfall: ≥100 mm • 1-day forecast rainfall: ≥80 mm • 2-day forecast rainfall: >50 mm - Flooded area	• Early warning message issued to IRDA, local councils in Iskandar Malaysia and community leaders.	• Lead: DDMC & District Officer • Support: JPS Johor, MET Malaysia, Police, Local Council	**T-48 to T-36 hours before forecasted flood peak**

Alert Level	Trigger Indicators (if one or more is checked)	Action (SOP)	Lead Agency & Supporting Agencies	Timeline (Lead Time)
	(forecast): 5–15% per mukim • Population at risk: 500–2,000 people • Estimated damage to buildings: RM 100,000–500,000	• Pre-position logistics (boats, relief packs) in high-risk mukims. • Activate community volunteers for preparedness drills. • Prepare temporary shelters.		
Alert 3 – Pre-Evacuation / Response Readiness Phase	• **3-day** historical **cumulative rainfall**: ≥150 mm • **1-day forecast rainfall**: ≥100 mm • **2-day** forecast **rainfall**: ≥80 mm • **Flooded area (forecast)**: 15–30% per mukim • Population **at risk**: 2,000–5,000 people • **Estimated damage to buildings**: RM 500,000–1,000,000	• Early warning message issued to IRDA, local councils in Iskandar Malaysia and community leaders. • **Public** evacuation **advisory issued** via (TV, website, radio and social media). • **Open** temporary **shelters** and prepare registration desk. • **Mobilize** rescue **teams** (Fire & Rescue Department, Police). • **Coordinate with Health Department** to prepare mobile medical units.	• **Lead**[11]: JPBP (chaired by the Prime Minister or appointed Minister, with NADMA as the secretariat), or; JPBN (chaired by the State Secretary, with APM as the secretariat), or; JPBD (chaired by the District Officer, also with APM as the secretariat) • Support: JPS Johor, Police, Fire & Rescue, Health Department	**T-36 to T-24 hours before flood peak**
Alert 4 – Emergency Response / Evacuation Phase	• 3-day historical cumulative rainfall: ≥200 mm • 1-day forecast rainfall: ≥120 mm • 3-day forecast rainfall: remains high (>80 mm) • Flooded area (forecast): >30% per mukim • Population affected: >5,000 people • Estimated damage to buildings: >RM 1,000,000	• Early warning message issued to IRDA, local councils in Iskandar Malaysia and community leaders. • Mandatory evacuation orders issued to high-risk areas. • Full deployment of rescue & relief operations. • Distribute emergency relief packs (food, water, medicine). • Continuous situation reporting through MHP-IM every 3 hours. • Request additional resources from state/national level if required.	• **Lead**[11]: JPBP (chaired by the Prime Minister or appointed Minister, with NADMA as the secretariat), or; JPBN (chaired by the State Secretary, with APM as the secretariat), or; JPBD (chaired by the District Officer, also with APM as the secretariat) • **Support: DDMC, Police, Army, JPS Johor, NGOs**	**T-24 hours to during flood event**

[11] For further understanding of disaster management implementation at the state or district level, you are encouraged to directly contact the relevant JPBN or JPBD

9.2.3.7 Capacity Building and Training

Regular drills, simulations, and training sessions strengthen preparedness. Local volunteers, emergency teams, and community members are trained to respond quickly and effectively when warnings are issued.

The following section elaborates on the early action protocol components developed based on the MHP-IM, which are particularly aimed to reduce the impact of floods in Iskandar Malaysia.

Regular drills, simulations, and training sessions enhance preparedness. Local volunteers, emergency teams, and community members are trained to respond quickly and effectively when warnings are issued by MHP-IM.

9.3 Knowledge products and information

Communicating risk information is a crucial component of the Multi-Hazard Early Warning System. The are several levels of user or stakeholders that work with the MHEWS or use the outputs of the system. Information requirements can be tailored to each type of user.

9.3.1 Information for forecasters

Although the system can run fully automatic once the system is operationalized, forecasters are still required to check and interpret the results. Typically, forecasters do:

- **Check** is the system is functioning without problems (see for example Figure 9-19 and Figure 9-20)
- **Validate** the results of the models
- **Interpret** the results and warnings generated by the system
- **Correct** the forecasts, for example to account for specific situations that are not accounted for in the models.

Forecasters therefore require detailed information, both on the technical details of the forecasts as well as on the status of the system. The technical details of the prototype are presented in the User Manual.

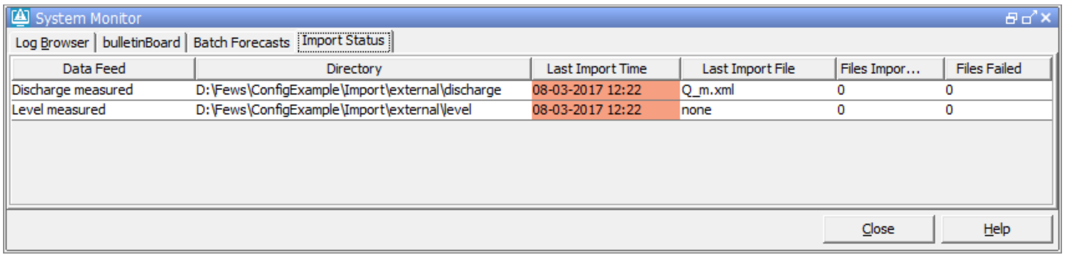


Figure 9-19 System monitor can be used to track import status and check if required data is coming in.

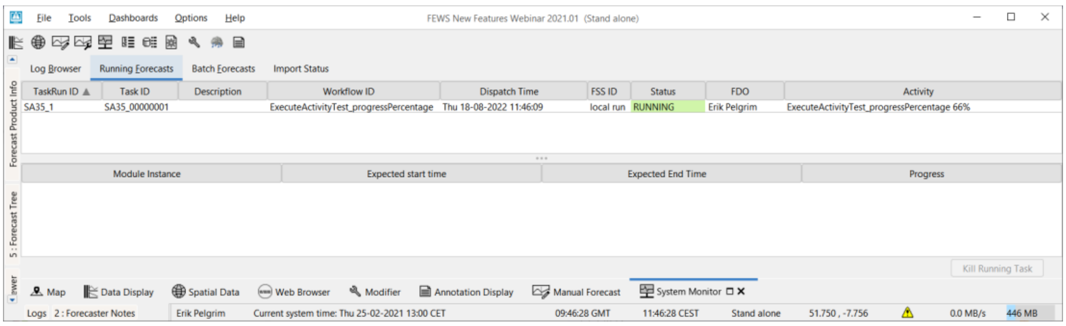


Figure 9-20 System monitor can be used to track status of model runs and forecasts and track if any errors occur during a forecast.

9.3.2 Information for decision making

Typically, decision makers require condensed and easy to understand information with sufficient detail to make the right decision. Based on experience from other systems from around the world, 2 examples of reports have been developed:

1 Rainfall Report
   Provides a summary of the past 3 days of rainfall and a 3-day daily forecast at the mukim level, presented in both table and map formats. This helps operators and decision-makers identify areas at risk of heavy rainfall.

2 Flood Report
   Summarizes potential flood extent, including the percentage of inundated area per mukim, estimated number of affected people, and potential building damage (in MYR).

Together, these reports support timely decision-making and disaster impact reduction. Once operational, both reports can be updated every 12 hours following the import of new weather forecasts into MHP-IM.

In Annex F, an example is shown of how these reports look like during a real event, in this case the Monsoon Surge event that caused widespread flooding in Johor in March, 2025.

Rainfall Warning Report (18 Mar 2025)

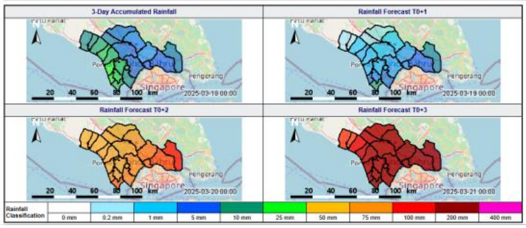


Table of Rainfall per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 18 Mar 2025

Mukim	3-Day Accumulated Rainfall [mm]	Rainfall Forecast T0+1 [mm]	Rainfall Forecast T0+2 [mm]	Rainfall Forecast T0+3 [mm]
API-API	17.1	1.9	72.9	152.3
AYER BALOI	11.5	1.1	68.1	113.9
AYER MASIN	24.4	6.6	79.2	189.0
BANDAR BENUT	10.5	0.1	62.1	89.4
BANDAR JOHOR BAHRU	4.5	2.8	82.1	201.7
BANDAR KULAI	4.3	0.4	69.0	163.9
BANDAR PONTIAN KECHIL	33.5	1.8	72.1	173.2
BANDAR TEBRAU	2.7	2.8	82.1	201.7
BENUT	8.9	0.4	63.7	92.7
BUKIT BATU	7.9	0.4	68.9	162.3
JELUTONG	14.9	1.8	72.1	173.2
JERAM BATU	14.9	1.8	72.1	173.2
KULAI	6.0	1.4	72.2	173.2
PEKAN JERAM BATU	7.3	1.8	72.1	173.2
PENGKALAN RAJA	11.3	1.8	72.1	173.2
PLENTONG	5.5	5.4	89.3	210.1
PONTIAN	13.2	1.8	72.1	173.1
PULAI	6.2	2.3	77.5	188.5
RIMBA TERJUN	25.0	1.8	72.1	173.2
SEDENAK	6.0	0.4	69.5	165.3
SENAI	3.8	1.0	76.8	185.2
SERKAT	15.5	11.0	85.7	203.6
SUNGAI KARANG	19.1	3.7	74.8	179.3
SUNGAI PINGGAN	9.3	0.3	62.9	91.1
SUNGAI TIRAM	7.4	8.2	96.6	213.7
TANJONG KUPANG	9.1	6.6	79.5	190.3
TEBRAU	2.9	2.6	82.0	201.0

Note:

Rainfall Classification		
	Light	< 41 mm
	Moderate	41 - 60.9 mm
	Heavy	61 - 80.4 mm
	Very Heavy	> 80.5 mm

Flood Warning Report (18 Mar 2025)

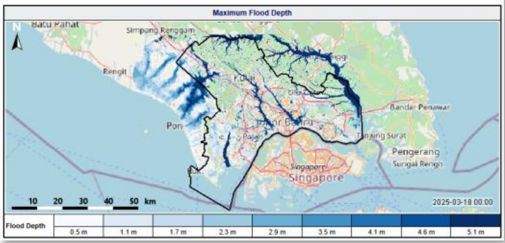


Table of Flood Early Warning Impact per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 21 Mar 2025

Mukim	Flooded Area [%]	Number of Population Affected [People]	Estimated Damage to Buildings [10^3 MYR]
API-API	79.6	13,170	1,764,278
AYER BALOI	69.3	10,075	954,773
AYER MASIN	45.6	2,630	62,670
BANDAR BENUT	100.0	4,060	320,921
BANDAR JOHOR BAHRU	14.1	14,805	1,142,602
BANDAR KULAI	39.9	3,210	247,335
BANDAR PONTIAN KECHIL	89.7	2,035	378,046
BANDAR TEBRAU	94.5	115	11,788
BENUT	84.6	9,745	808,576
BUKIT BATU	49.0	5,010	974,119
JELUTONG	48.3	5,575	218,429
JERAM BATU	52.2	14,640	1,550,556
KULAI	20.3	38,920	2,208,953
PEKAN JERAM BATU	0.0	0	0
PENGKALAN RAJA	55.5	680	31,035
PLENTONG	21.5	102,010	7,261,783
PONTIAN	74.6	32,990	2,197,954
PULAI	24.7	108,930	7,956,520
RIMBA TERJUN	64.6	24,835	2,983,769
SEDENAK	22.9	4,875	419,589
SENAI	19.1	21,915	6,583,963
SERKAT	42.9	4,465	450,193
SUNGAI KARANG	45.4	670	35,084
SUNGAI PINGGAN	80.8	7,560	672,249
SUNGAI TIRAM	37.5	3,650	462,269
TANJONG KUPANG	40.1	11,370	783,457
TEBRAU	18.9	70,130	7,050,391

Figure 9-21 Example reports for the Monsoon Surge event of March 2025.

9.3.3 General information on MHEWS

As the MHEWS is a new platform for Iskandar Malaysia, general information on the platform in the form of a fact sheet was generated. The fact sheet can be easily shared with key stakeholders to introduce the platform and highlight its functionalities. Such information can help support the rapid uptake of the platform. The example fact sheet is presented in Annex G. Such factsheets proof valuable for outreach to the user community should be frequently updated, based on for example latest developments or interesting use cases. In some cases, such information and fact sheets are combined or integrated with a frequent newsletter, such as for Rijkswaterstaat (The Netherlands), the European Centre for Medium Range Weather Forecasting (ECMWF) and the UK MET Office (see Figure 9-22).

Figure 9-22 Example newsletters of early warning systems around the world.

10 Conclusions

Climate related hazards pose a growing risk to society. With growing population and climate changing, risk is likely to increase in the near future. Reports published by IPCC indicate that people and society need to adapt, as mitigation of the impact of climate change and socio-economic change in many cases shall not be possible or insufficient.

The multi-hazard platform has an important role in the climate adaptation plans. The platform, once fully developed and operational, addresses both planning and operational aspects of climate adaptation.

The planning aspects are about generating risk information and knowledge that can be used for planning purposes. For example for the development or upgrading of infrastructure or urban planning, such risk information is crucial. Decision makers need to understand where they can build safely, or where additional measures need to be taken to keep people safe and protect infrastructure from disasters.

Especially with climate changing, keeping the risk information up-to-date is becoming increasingly important. Around the world, events are being observed that do not fall within current standards or statistics. Examples are the floods in Europe in the summer of 2021 and the extreme floods in Pakistan in 2022. This means that risk information needs to be updated rapidly and more frequently. The MHEWS can play a vital role by collecting and storing relevant data and information and for example updating flood hazard maps that form the basis for spatial planning.

The platform plays a vital role by bringing data from different data providers and stakeholders together. Often information is scattered across many different agencies or platforms, making it difficult to effectively and efficiently bringing together all relevant information. The MHEWS as a data integration platform can support better decision making and improves the overall disaster risk reduction efforts and helps identifying data and knowledge gaps.
The MHEWS also plays an important role in the operational aspects of disaster risk reduction. As presented in the Early Warning for All framework (Figure 10-1).

Figure 10-1 Early Warning for All framework for disaster risk reduction.

This framework is based on four pillars:

- **Disaster risk knowledge**
  This includes risk mapping, including knowing and understanding the location and vulnerability of critical infrastructures, such as hospitals, energy infrastructure, roads & railways, and schools. The MHEWS can be used to generate hazard and risk maps and overlay this information with relevant socio-economic data. By integrating the information into the platform, relevant information is grouped together for more efficient decision making.
- **Observation, monitoring, analysis and forecasting**
  The MHEWS, once fully operational, is able to integrate data from several data providers into a single platform. The platform is able to integrate many types of data and can combine global, regional and local data to generate valuable information and feed into decision making processes. By combining observations with forecasted information, risk information can be provided accurately and in a timely manner. This is crucial, as during disasters, every minute counts to reduce loss-of-life or to prevent unnecessary damages to buildings or infrastructure.
- **Warning, dissemination and communication**
  By combining real-time information with disaster risk knowledge, the system can generate accurate warning. One fully operational, the system can be used to automatically disseminate warnings to stakeholders for quick and effective decision making. Automatic reports and other knowledge products can be used for effective communication.
- **Preparedness and response**
  Disaster risk knowledge available in the MHEWS can support improving preparedness and response. Early Action Protocols can be developed and integrated directly in the MHEWS. The Early Action Protocols help improving the effectiveness of disaster risk reduction as user and decision makers know better what to do and when to do it. Triggers for taking actions can be build into the MHEWS, reducing response times, increasing lead-time for taking action.

The current prototype of the MHEWS focusses on floods only. Climate risks, however, come in many forms. Drought or other environmental issues can also have substantial impact and need to be addressed. In the future, the MHEWS can be extended into these other domains. By bringing together floods and droughts into a single platform, for example, resources for development and maintenance of data and tools can be optimized.

In conclusion, the MHEWS can be an excellent tool for data integration to support different stakeholders and organizations to improve decision-making, both for planning and operational real-time requirements. By doing this, the MHEWS can further contribute to disaster risk reduction efforts and climate adaptation.

11 Recommendations

To move forward towards to the implementation and operationalization of the MHP, there are several steps to be taken. It is important that these steps are integrated with ongoing activities in Iskandar Malaysia. The proposed next steps are summarised below.

Centralised Access and Integration
The Iskandar Malaysia Analytics Centre (IMAC) will integrate modelling outputs from the Resilient Environment/Multi-Hazard Platform (MHP) team into its secure analytics portal, providing government agencies, developers, and academic institutions with consistent, validated, and up-to-date hazard information. IMAC will handle integration, dissemination, and cross-sector analytics, while the MHP team ensures technical accuracy and scientific validation of hazard models. The combined system will link hazard forecasts with socio-economic, demographic, and infrastructure datasets, enabling comprehensive risk and impact assessments to support resource allocation, investment planning, and resilience strategies.

Collaboration, Refinement, and Outreach
Ongoing collaboration will see IMAC managing continuous data collection and model updates, with the MHP team refining outputs using the latest scientific methodologies. These insights will inform evidence-based policymaking, strengthening urban planning, infrastructure design, and zoning regulations. Joint capacity-building initiatives will equip stakeholders with the skills to interpret and apply hazard modelling data, while targeted public awareness campaigns will translate technical findings into actionable preparedness measures for at-risk communities.

Alignment with Johor–Singapore Special Economic Zone (JS SEZ)
The Multi-Hazard Platform (MHP) can serve as a strategic tool for climate resilience planning within the JS SEZ, providing investors with credible, location-specific risk assessments to safeguard infrastructure and operations. By integrating hazard forecasts with socio-economic and infrastructure data, MHP supports informed decision-making, reducing potential climate-related disruptions and protecting long-term asset value. This capability positions the JS SEZ as a “climate-ready” economic hub, enhancing its attractiveness to investors seeking stable, future-proofed environments for growth.

References

Bogaard, T. (2021, January 13). Delft-FEWS applications. Retrieved from Early Warning System for the Republic of Mauritius: https://oss.deltares.nl/web/delft-fews/-/mauritius-early-warning-system

Deltares. (2017). Kosten efficiente meetopstellingen en sensoren: Een verkenning voor de casus NZK en ARK. Author: M. Schroevers. Prepared for Rijkwaterstaat CIV. Report number: 11200887-002-BGS-0001.

EPA. (2023, July 13). SHOM - L'océan en réference. Retrieved from https://www.shom.fr/en

Government of Spain. (2023, July 13). Ministry of Transport, Mobility and Urban Agenda. Retrieved from National Ports: https://www.puertos.es/en-us

GSO, NSF and University of Rhode Island. (2020). Hurricanes: Science and Society. Retrieved from National Hurricane Center Forecast Process: http://hurricanescience.org/science/forecast/forecasting/forecastprocess/#:~:text=Forecasters%20use%20satellite%20data%20to,from%20their%20formation%20to%20dissipation

Huizinga, J., De Moel, H., & Szewczyk, W. (2017). Global flood depth-damage functions: Methodology and the database with guidelines.

India Meteorological Department. (2023, July 13). Regional Specialized Meteorological Centre for Tropical Cyclones Over North Indian Ocean. Retrieved from Storm Surge Guidance: https://rsmcnewdelhi.imd.gov.in/archive-information.php?internal_menu=Nw==&menu_id=NQ==

JUBM, & Arcadis. (2022). Construction Cost Handbook. JUBM & Arcadis.

Kamal, N. A., Muhammad, N. S., & Abdullah, J. (2020). Scenario-based pollution discharge simulations and mapping using integrated QUAL2K-GIS. Environmental Pollution, 259, 113909.

Leijnse, T., de Goede, R., van Ormondt, M., Lemans, M., Hegnauer, M., Eilander, D., Maguire, S. (2022). Developing large scale and fast compound flood models for Australian coastlines. International Conference on Coastal Engineering 2022. Sydney.

Met Office. (2023, July 13). Government : Envrionmental Agency. Retrieved from Flood Forecasting: https://www.metoffice.gov.uk/services/government/environmental-hazard-resilience/floodforecasting

NOAA. (2023, July 13). National Hurricane Center and Central Pacific Hurricane Center. Retrieved from NHC Active Tropical Cyclones: https://www.nhc.noaa.gov/cyclones/

NOPP. (2023, July 13). NOPP Event Viewer. Retrieved from FHICS: Successful forecast of Hurricane Ian impacts: https://nopphurricane.sofarocean.com/updates/fhics-successful-forecast-of-hurricane-ian-impacts

Rijkswaterstaat. (2023, July 13). Waterberichtgeving. Retrieved from Kust en benedenrivieren: https://waterberichtgeving.rws.nl/owb/waterveiligheid/hoogwater-kust-benedenrivieren

Rijkswaterstaat. (2023, October 3). Watermanagementcentrum Nederland. Retrieved from Rijkswaterstaat: https://www.rijkswaterstaat.nl/water/waterbeheer/watermanagementcentrum-nederland

US Navy. (2023, July 13). Naval Oceanography Portal. Retrieved from Joint Typhoon Warning Center: https://www.metoc.navy.mil/jtwc/jtwc.html

Van Verseveld, W. J., Weerts, A. H., Visser, M., Buitink, J., Imhoff, R. O., Boisgontier, H., Russell, B. (2024). Wflow_sbm v0.7.3, a spatially distributed hydrological model: From global data to local applications. Geoscientific Model Development, 17, 3199–3234. doi:https://doi.org/10.5194/gmd-17-3199-2024

Yan, K. (2019, June 6). Ocean modelling and Early-Warning System for the Gulf of Thailand. Delft-FEWS applications. Deltares. Retrieved July 14, 2023, from https://oss.deltares.nl/web/delft-fews/-/ocean-modelling-and-early-warning-system-for-the-gulf-of-thailand

Zijl, F., Sumihar, J., & Verlaan, M. (2015). Application of data assimilation for improved operational water level forecasting on the northwest European shelf and North Sea. OCean Dynamics, 65, 1699-1716.

Zijl, F., Verlaan, M., & Gerritsen, H. (2013). Improved water-level forecasting for the Northwest European Shelf and North Sea through direct modelling of tide, surge and non-linear interaction. Ocean Dynamics, 63.

List of annexes

A Data requirements

In the first workshop, there was a breakout session where participants from various agencies were asked several questions related to the MHP-IM Iskandar Malaysia prototype that is to be developed. These questions were prepared by the consultant to gather more information on the existing data and platforms, what data is currently available, which types of hazards are to be integrated into the MHP-IM Iskandar Malaysia, and the expectations that different agencies have for MHP-IM Iskandar Malaysia. Examples of questions asked during the breakout session can be seen in the Figure A-1 to Figure A-7.

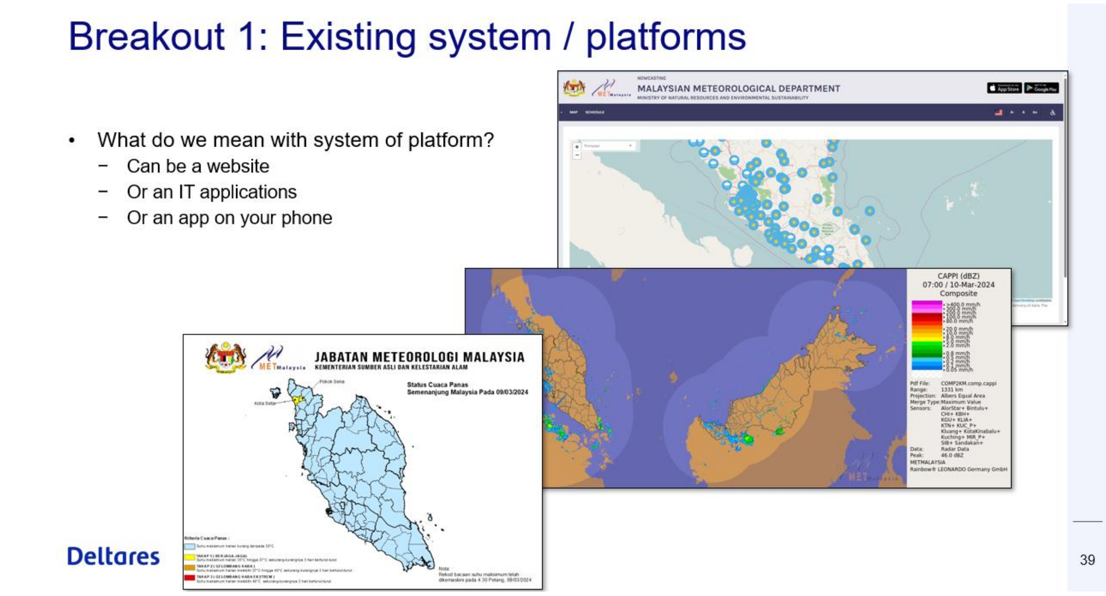


Figure A-1 Identifying existing platforms in Iskandar Malaysia region, the consultants first compiled.

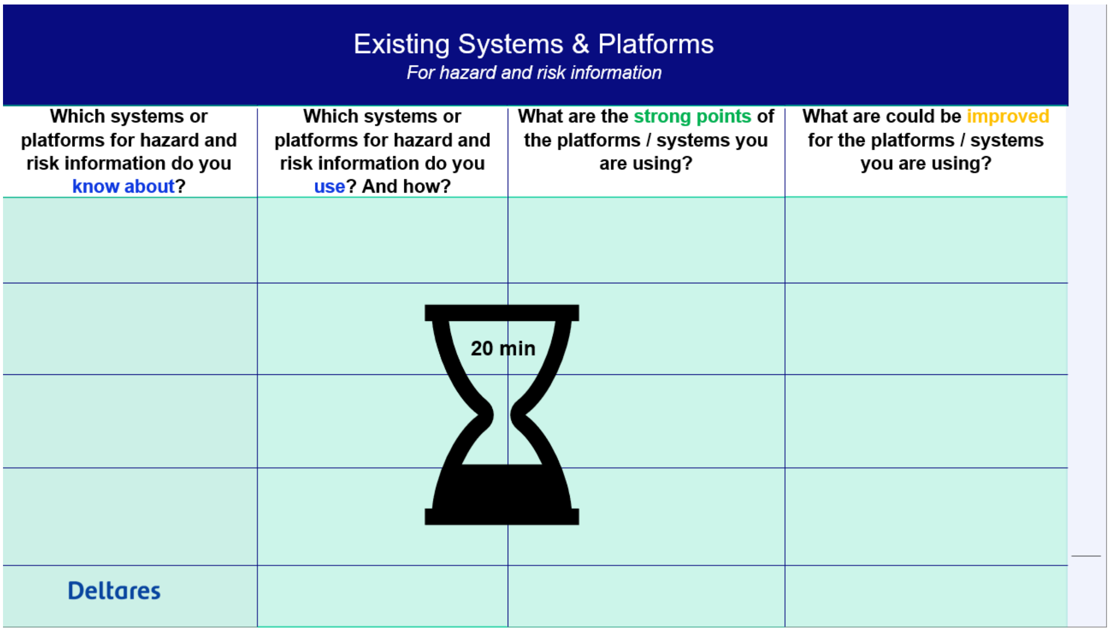


Figure A-2 Identifying existing platforms in Iskandar Malaysia region.

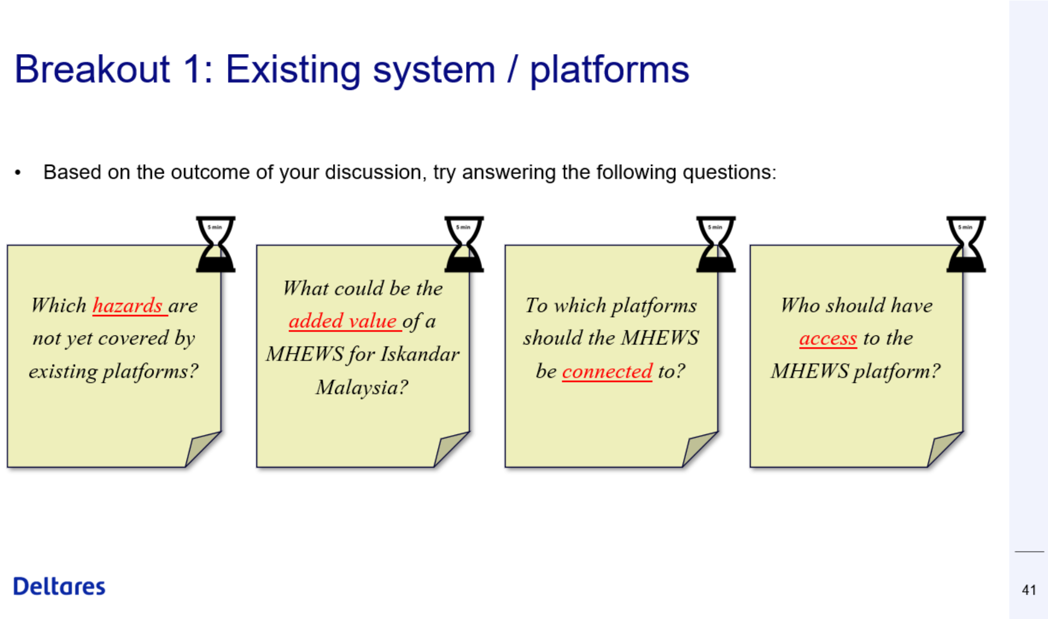


Figure A-3 Identifying existing platforms in Iskandar Malaysia region.

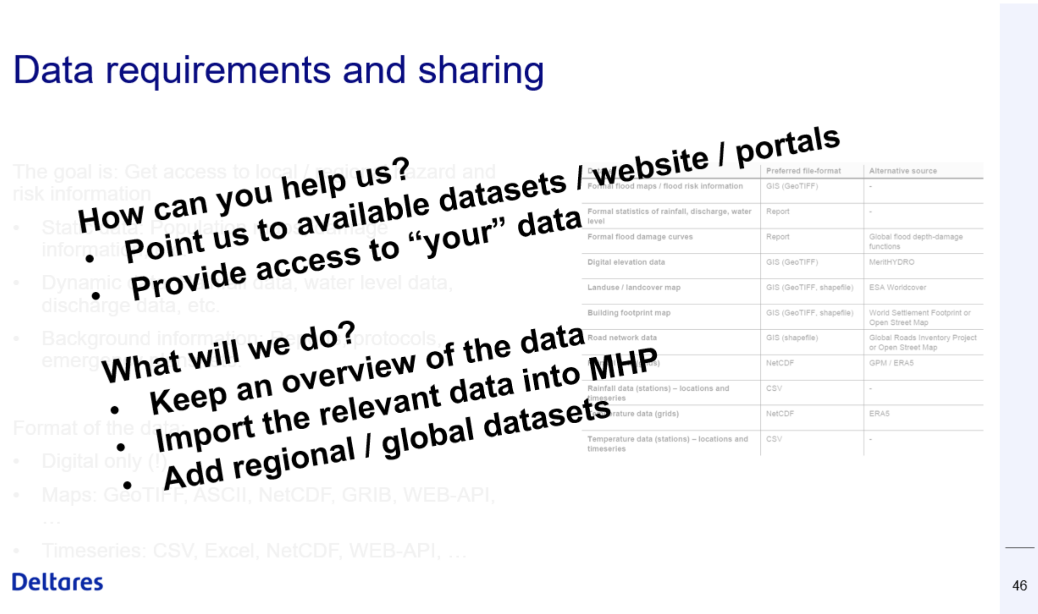


Figure A-4 Identifying existing data to be used for developing prototype of MHP-IM Iskandar Malaysia.

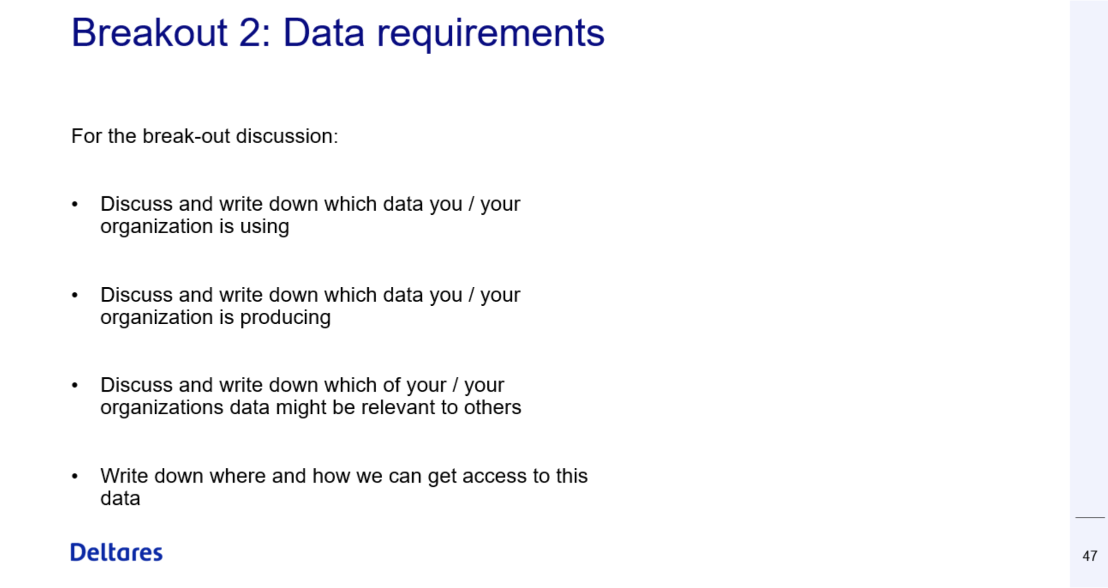


Figure A-5 Identifying existing data to be used for developing prototype of MHP-IM Iskandar Malaysia.

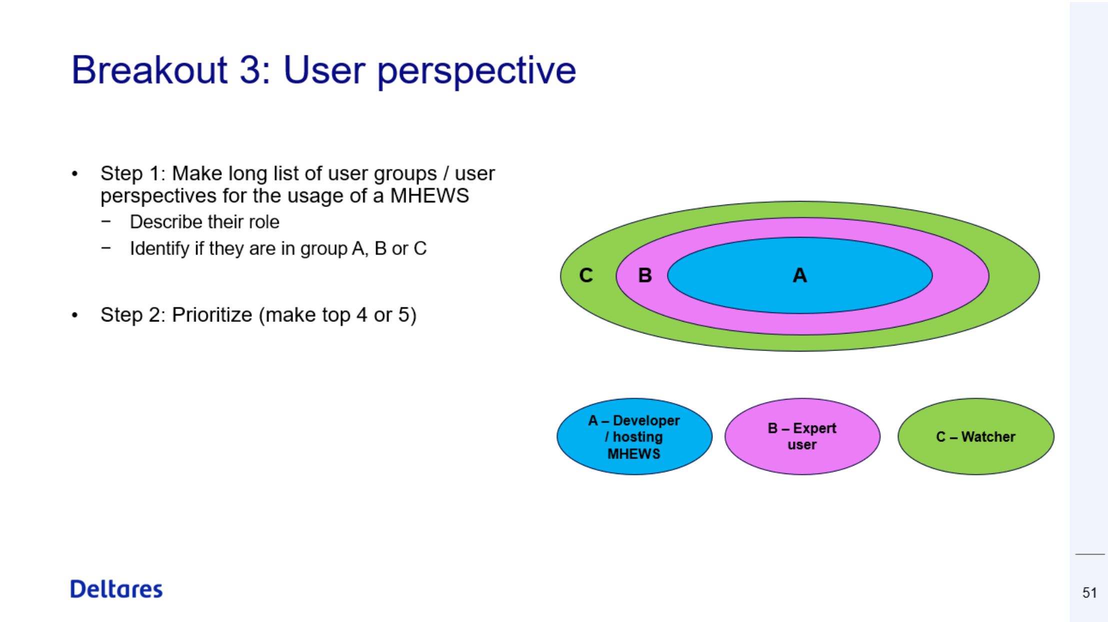


Figure A-6 Identifying the potential user of MHP-IM Iskandar Malaysia.

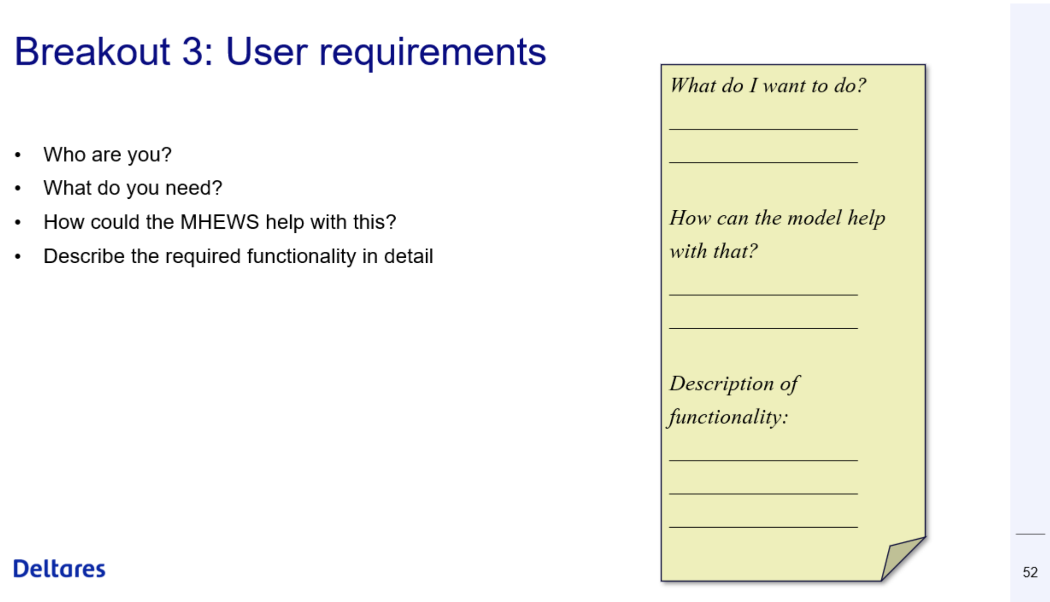


Figure A-7 Identifying the user requirement for MHP-IM Iskandar Malaysia.

The result of the breakout session is then used by the consultant to make a list of data required data, mapped potential sources, and prepared a draft data request letter. This letter was sent to IRDA, which then forwarded it to relevant agencies holding the data.

The following are the draft letters prepared by the consultant to request data from agencies holding relevant data in the Iskandar Malaysia region.

- **Data Request to MetMalaysia**
  The United Nations Framework Convention on Climate Change received and approved a request from Malaysia for Technical Assistance (TA) concerning the development of a Multi-Hazard Platform to forecast local-level climate extremes and physical hazards for Iskandar Malaysia. The aim of the TA is to facilitate early action in mitigating climate risks in Iskandar Malaysia through the creation of an inclusive decision support system. This system will be based on an understanding of local-level climate extremes and their impacts, integrated into a prototype Multi-Hazard Platform (MHP) focusing on coastal hazards.

  One of the outputs of this TA is to develop a prototype multi-hazard platform using the Delft-FEWS platform. To demonstrate the potential benefits of this prototype to local authorities in the Iskandar Malaysia region and illustrate how the Iskandar Malaysia MHP operates, sample data related to coastal hazards is required.

  The following table describes the most important parameters that the team needs to get from Met Malaysia for the development of Multi Hazard Early Warning System for Iskandar Malaysia (MHP-IM IM). The focus area of this project is Iskandar Malaysia which cover four districts in Johor (Johor Bahru, Kulai Jaya, Pontian and Kota Tinggi) and therefore, only data in this area is requested from Met Malaysia. These parameters will be used together with other datasets collected from other agencies and institutions to produce hazard maps and risks for Iskandar Malaysia.

In the operational context of early warning system, only real time data and forecast data will be used. Therefore, it is preferable to obtain the samples of data that is coming from telemetry devices and operational forecasting system that have 1 hourly timestep or even shorter timestep.

No	Parameter	Data Format	Source	Time Horizon	Note
1	Rainfall	• *.csv for point data • *.netCDF for raster data	• Meteorological gauges • Radar • Numerical weather forecast (both deterministic and probabilistic)	• Historical • Nowcast • Medium range forecast • Seasonal forecast	Will be used as an input for several hazard analysis i.e. flood (pluvial flood, fluvial and coastal flooding) & drought
2	Temperature	• *.csv for point data • *.netCDF for raster data	• Meteorological gauges • Numerical weather forecast (both deterministic and probabilistic)		Together with relative humidity data, heat stress index can be produced
3	Relative humidity	• *.csv for point data • *.netCDF for raster data	• Meteorological gauges • Numerical weather forecast (both deterministic and probabilistic)		Together with temperature data, heat stress index can be produced
4	Wind speed	• *.csv for point data • *.netCDF for raster data	• Meteorological gauges • Numerical weather forecast (both deterministic and probabilistic)		Will be used as an input for coastal flooding analysis
5	Wind direction	• *.csv for point data • *.netCDF for raster data	• Meteorological gauges • Numerical weather forecast (both deterministic and probabilistic)		Will be used as an input for coastal flooding analysis

Note:
- For all point data, the unit and the coordinates of the measurement location are required.
- For all raster data, the unit, extent, and grid size are required.

The following period is selected by the team to show how MHP-IM IM could show the flood hazard and risk map for Iskandar Malaysia:
- Historical data = 26 Dec 2021 until 4 Jan 2024
- Two or six hour nowcast data on 4 January 2024
- Medium range forecast = forecast of 4 Jan 2024 for the coming 1 week or 2 weeks
- Seasonal forecast = forecast of 4 Jan 2024 for the coming 4 months up to 12 months

In addition, it is imperative to emphasize the importance of establishing a clear point of contact within your institution for seamless communication throughout the data acquisition process. This designated individual will serve as a crucial liaison, facilitating any necessary clarifications and expediting the exchange of information. Your cooperation in appointing a point of contact is greatly appreciated.

- **Data Request to JPS (DID)**
  The United Nations Framework Convention on Climate Change received and approved a request from Malaysia for Technical Assistance (TA) concerning the development of a Multi-Hazard Platform to forecast local-level climate extremes and physical hazards for Iskandar Malaysia. The aim of the TA is to facilitate early action in mitigating climate risks in Iskandar Malaysia through the creation of an inclusive decision support system. This system will be based on an understanding of local-level climate extremes and their impacts, integrated into a prototype Multi-Hazard Platform (MHP) focusing on coastal hazards.

  One of the outputs of this TA is to develop a prototype multi-hazard platform using the Delft-FEWS platform. To demonstrate the potential benefits of this prototype to local authorities in the Iskandar Malaysia region and illustrate how the Iskandar Malaysia MHP operates, sample data related to coastal hazards is required.

  The following table describes the most important parameters that the team needs to get from Met Malaysia for the development of Multi Hazard Early Warning System for Iskandar Malaysia (MHP-IM IM). The focus area of this project is Iskandar Malaysia which cover four districts in Johor (Johor Bahru, Kulai Jaya, Pontian and Kota Tinggi) and therefore, only data in this area is requested from Met Malaysia. These parameters will be used together with other datasets collected from other agencies and institutions to produce hazard maps and risks for Iskandar Malaysia.

  In the operational context of early warning system, only real time data and forecast data will be used. Therefore, it is preferable to obtain the samples of data that is coming from telemetry devices and operational forecasting system that have 1 hourly timestep or even shorter timestep.

No	Parameter	Data Format	Note
1	Water Level	*.csv/.shp table	Dynamic data, with time and coordinate location. Min. timestep: hourly
2	River discharge	*.csv	Dynamic data, with time and coordinate location. Min. timestep: hourly
3	River networks	*.shp	Vector data
4	Existing flood maps	raster file	• Historical flood maps with time and location • Flood map derived from analysis for several return periods (Q2, Q5, Q10, Q25, Q50 and Q100)

Note:
- For all point data, the unit and the coordinates of the measurement location are required.
- For all raster data, the unit, extent, and grid size are required.

The following period is selected by the team to show how MHP-IM IM could show the flood hazard and risk map for Iskandar Malaysia.
- Historical data = 26 Dec 2021 until 4 Jan 2024
- Forecast data = forecast of 4 Jan 2024 for the coming 1 week or 2 weeks

In addition, it is imperative to emphasize the importance of establishing a clear point of contact within your institution for seamless communication throughout the data acquisition process. This designated individual will serve as a crucial liaison, facilitating any necessary clarifications and expediting the exchange of information. Your cooperation in appointing a point of contact is greatly appreciated.

- Data request to JUPEM

The United Nations Framework Convention on Climate Change received and approved a request from Malaysia for Technical Assistance (TA) concerning the development of a Multi-Hazard Platform to forecast local-level climate extremes and physical hazards for Iskandar Malaysia. The aim of the TA is to facilitate early action in mitigating climate risks in Iskandar Malaysia through the creation of an inclusive decision support system. This system will be based on an understanding of local-level climate extremes and their impacts, integrated into a prototype Multi-Hazard Platform (MHP) focusing on coastal hazards.

One of the outputs of this TA is to develop a prototype multi-hazard platform using the Delft-FEWS platform. To demonstrate the potential benefits of this prototype to local authorities in the Iskandar Malaysia region and illustrate how the Iskandar Malaysia MHP operates, sample data related to coastal hazards is required.

The following table describes the most important parameters that the team needs to get from Met Malaysia for the development of Multi Hazard Early Warning System for Iskandar Malaysia (MHP-IM IM). The focus area of this project is Iskandar Malaysia which cover four districts in Johor (Johor Bahru, Kulai Jaya, Pontian and Kota Tinggi) and therefore, only data in this area is requested from Met Malaysia. These parameters will be used together with other datasets collected from other agencies and institutions to produce hazard maps and risks for Iskandar Malaysia.

In the operational context of early warning system, only real time data and forecast data will be used. Therefore, it is preferable to obtain the samples of data that is coming from telemetry devices and operational forecasting system that have 1 hourly timestep or even shorter timestep.

No	Parameter	Data Format	Note
1	Administration boundary	*.shp	Static data, in administration level 2 and 3
2	River basin boundary	*.shp	Static data in vector
3	Elevation data	raster file	Static data
4	Tidal data	*.csv or raster file	Dynamic data, with time and coordinate location. Min. timestep: hourly

Note:
– For all point data, the unit and the coordinates of the measurement location are required.
– For all raster data, the unit, extent, and grid size are required.

The following period is selected by the team to show how MHP-IM IM could show the flood hazard and risk map for Iskandar Malaysia:
– Historical data = 26 Dec 2021 until 4 Jan 2024
– Forecast data = forecast of 4 Jan 2024 for the coming 1 week or 2 weeks

In addition, it is imperative to emphasize the importance of establishing a clear point of contact within your institution for seamless communication throughout the data acquisition process. This designated individual will serve as a crucial liaison, facilitating any necessary clarifications and expediting the exchange of information. Your cooperation in appointing a point of contact is greatly appreciated.

- **Data request to NAHRIM**
  The United Nations Framework Convention on Climate Change received and approved a request from Malaysia for Technical Assistance (TA) concerning the development of a Multi-Hazard Platform to forecast local-level climate extremes and physical hazards for Iskandar Malaysia. The aim of the TA is to facilitate early action in mitigating climate risks in Iskandar Malaysia through the creation of an inclusive decision support system. This system will be based on an understanding of local-level climate extremes and their impacts, integrated into a prototype Multi-Hazard Platform (MHP) focusing on coastal hazards.

One of the outputs of this TA is to develop a prototype multi-hazard platform using the Delft-FEWS platform. To demonstrate the potential benefits of this prototype to local authorities in the Iskandar Malaysia region and illustrate how the Iskandar Malaysia MHP operates, sample data related to coastal hazards is required.

The following table describes the most important parameters that the team needs to get from Met Malaysia for the development of Multi Hazard Early Warning System for Iskandar Malaysia (MHP-IM IM). The focus area of this project is Iskandar Malaysia which cover four districts in Johor (Johor Bahru, Kulai Jaya, Pontian and Kota Tinggi) and therefore, only data in this area is requested from Met Malaysia. These parameters will be used together with other datasets collected from other agencies and institutions to produce hazard maps and risks for Iskandar Malaysia.

In the operational context of early warning system, only real time data and forecast data will be used. Therefore, it is preferable to obtain the samples of data that is coming from telemetry devices and operational forecasting system that have 1 hourly timestep or even shorter timestep.

No	Parameter	Data Format	Note
1	Sea level rise projection	*.shp or raster file	Sea level rise projection in (2030 until 2100, per 10 years)

Note:
– For all point data, the unit and the coordinates of the measurement location are required.
– For all raster data, the unit, extent, and grid size are required.

In addition, it is imperative to emphasize the importance of establishing a clear point of contact within your institution for seamless communication throughout the data acquisition process. This designated individual will serve as a crucial liaison, facilitating any necessary clarifications and expediting the exchange of information. Your cooperation in appointing a point of contact is greatly appreciated.

From the distributed data request letter, the consultant has obtained various types of data for the development of the MHP-IM Iskandar Malaysia prototype. The following table shows the requested data, its source, acquisition status, and its specific role in the MHP-IM Iskandar Malaysia.

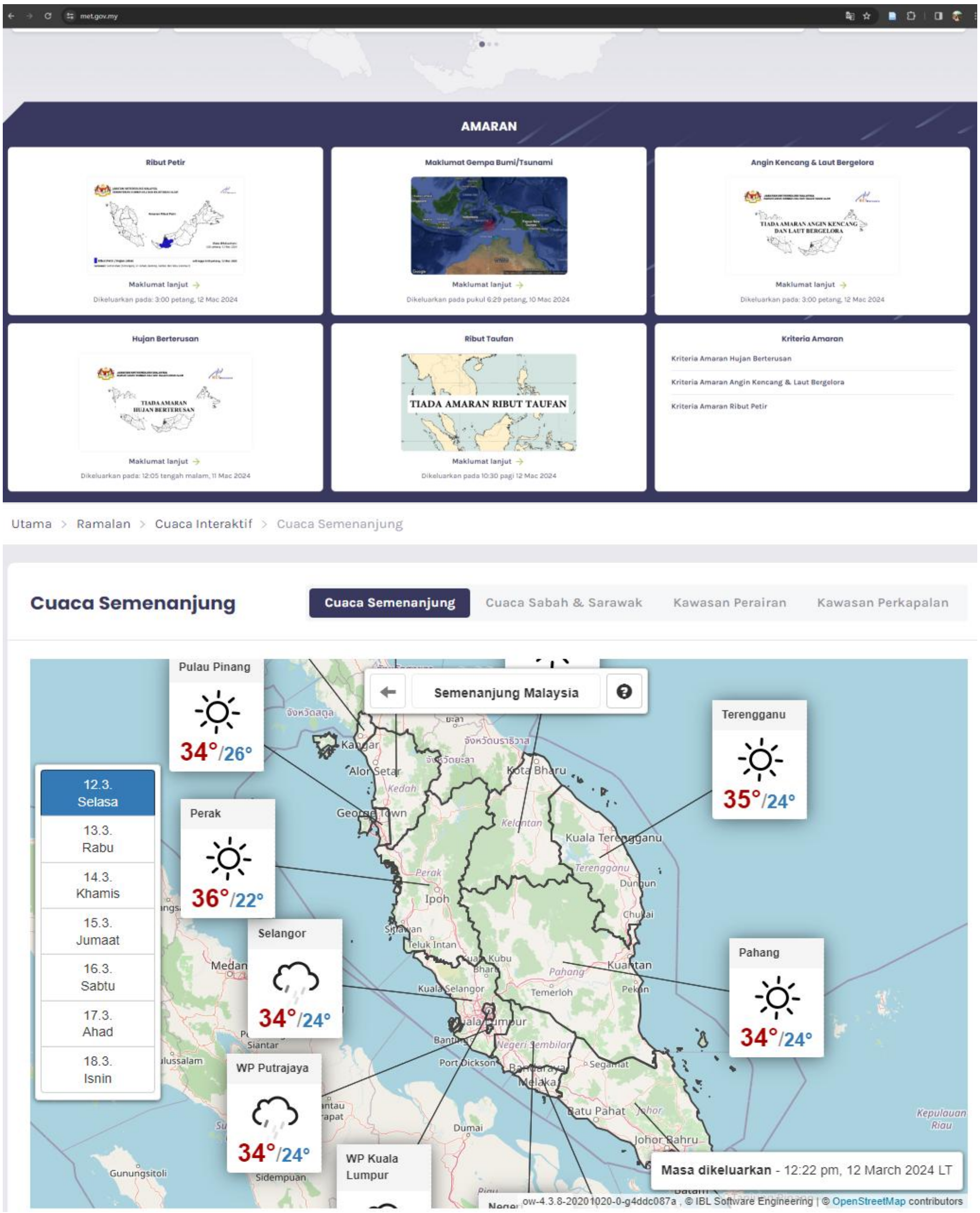
Data	Data Provider	Acquisition Status	Serves As
Administration data			
Administration boundary	IRDA	Collected	Base map at Map Display and Spatial Data Display
Topographic data			
Bathymetry for Pulai and Johor River	NAHRIM	Collected	Used to refine flood model
Digital Terrain Model	JUPEM	Collected	Used to build flood model
Meteorological data			
Rainfall data (from rain gauge)	MetMalaysia	Collected	Input for flood model
Rainfall estimate from radar	MetMalaysia	Not yet collected	Input for flood model
Rainfall estimate from satellite imagery	GPM+	Collected	Input for flood model
Forecast rainfall data	MetMalaysia	Collected	Input for flood model
Forecast rainfall data	GFS+	Collected	Input for flood model
Temperature data	GFS+	Collected	Input for producing heat stress early warning
Hydrological data			
River basin boundary	JUPEM	Collected	Base map at Map Display and Spatial Data Display
Water level data	DID	Collected	Calibrating and validating flood model
Discharge data	DID	Not available	Calibrating and validating hydrological model
River networks	DID	Collected	Base map at Map Display and Spatial Data Display
Tidal data (measurement)	JUPEM	Collected, historical 1. Kukup (1986-2022) 2. Johor Bahru (1984-2014)	Boundary condition for running flood model
Historical tidal data	GTSM+	Collected	Boundary condition for running flood model
Forecast tidal data	GTSM+	Collected	Boundary condition for running flood model
Flood maps	DID	Collected, hotspot flood map from 2000-2010	Base map at Map Display and Spatial Data Display

Data	Data Provider	Acquisition Status	Serves As
Sea level rise projection	NAHRIM	Collected	Showing which area is prone to flooding due to sea level rise
Building Data Demographical & building vulnerability data			
Building footprint	OSM+Open Buildings	Collected	Basic data for risk calculation
Building function	OSM	Collected. Support from local data will improve the risk assessment.	Determining building damage function
Critical Infrastructure (Schools, Hospitals, etc)	Google Earth	Collected. Support from local data will improve the risk assessment.	Determining vulnerability
Building damage function	JRC report (Huizinga, De Moel, & Szewczyk, 2017)	Collected. Support from local data will improve the risk assessment.	Determining building damage function
Building valuation	Construction cost report for Malaysia 2022	Collected	Calculating damage and risk
Demographic & Socio-economic data			
Population distribution per village (mukim level)	DOSM	Collected for 2010 & 2020 (mukim level)	Basic data to estimate impacted population
Number of households	DOSM	Collected for 2010 & 2020 (mukim level)	Basic data to estimate impacted household
Gender distribution	DOSM	Collected for 2010 & 2020 (mukim level)	Determining vulnerability
Age distribution	DOSM	Collected for 2010 & 2020 (mukim level)	Determining vulnerability
Disabled people	DOSM	Not available	Determining vulnerability
Income level	DOSM	Not available	Determining vulnerability
Poverty rate	DOSM	Collected for 2019 & 2022 (district level)	Determining vulnerability
Gini Index	DOSM	Collected for 2019 & 2022 (district level)	Determining vulnerability
Health status (aggregated per village)	DOSM	Not available	Determining vulnerability to health

B Comparison of Existing platforms and MHP-IM prototype

The following are some existing platforms covering the Iskandar Malaysia area and containing various data that can be utilized for the MHP-IM prototype.

1 METMalaysia (https://www.met.gov.my/)

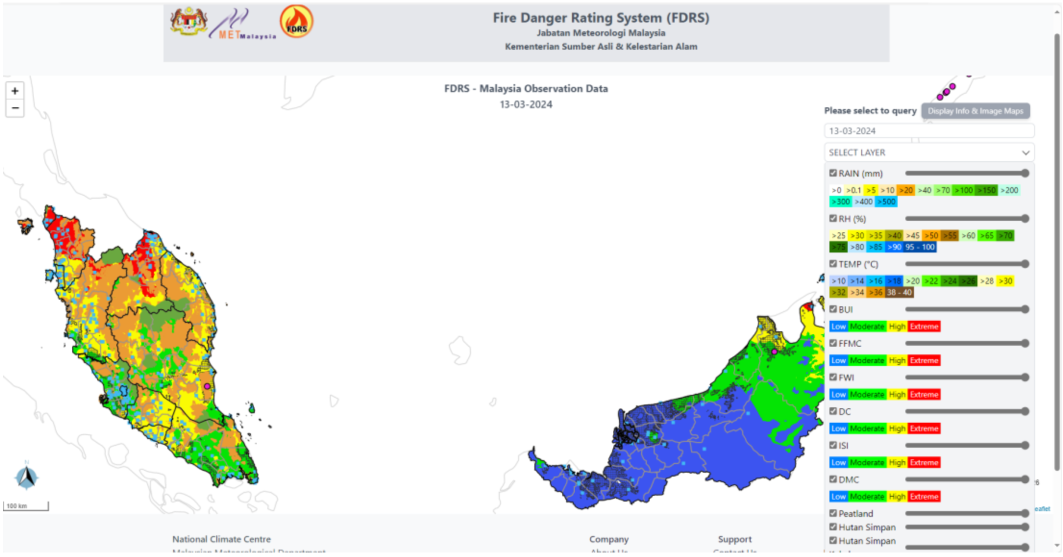


This webpage is maintained by MetMalaysia and serves for:

– Providing weather forecasts to the public in a spatial map display

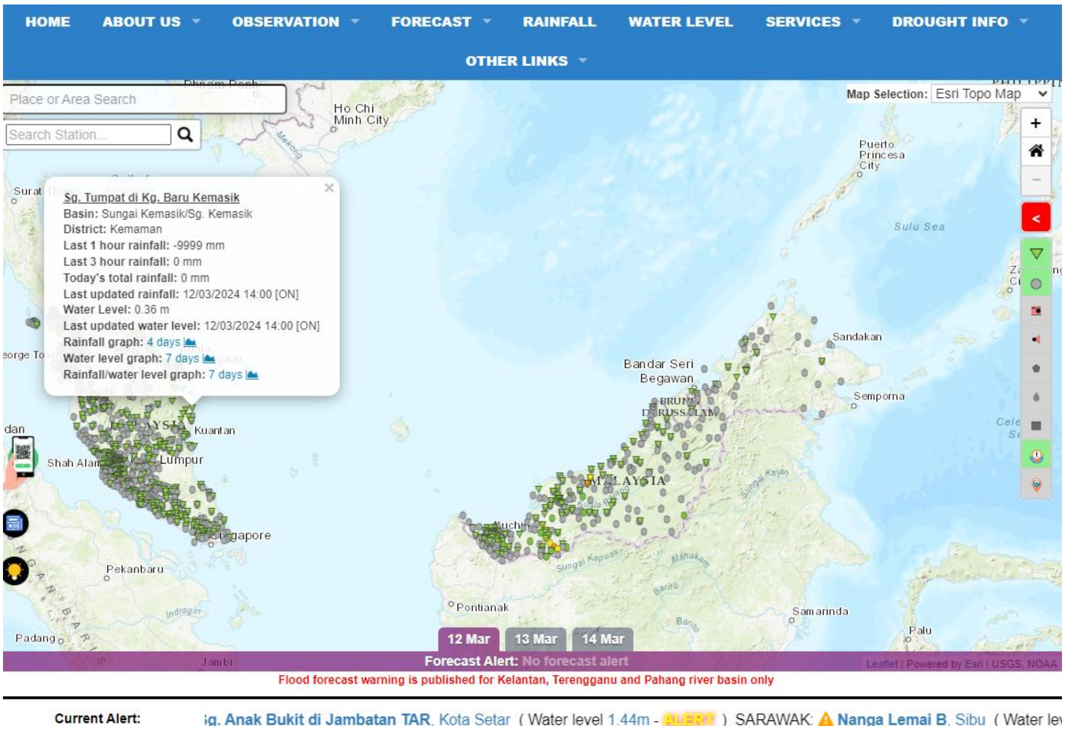
– Providing forecast in table format for the following parameters: rain, temperature, humidity, UV index, and seasonal weather
– Providing warnings in table format for the following hazard: earthquake, thunder, tsunami & typhoon.
– Meteorological data aggregator for both cities and states.

2 FDRS by METMalaysia
(https://myclimate.met.gov.my/fdrsWmsObsMsiaMetPortal)



This webpage ***is maintained by MetMalaysia and*** is a system that monitors the risk of forest/vegetation fires and provides information for fire management. Some important data available in this system that can be utilized by MHP-IM Iskandar Malaysia include: rainfall, temperature and humidity.

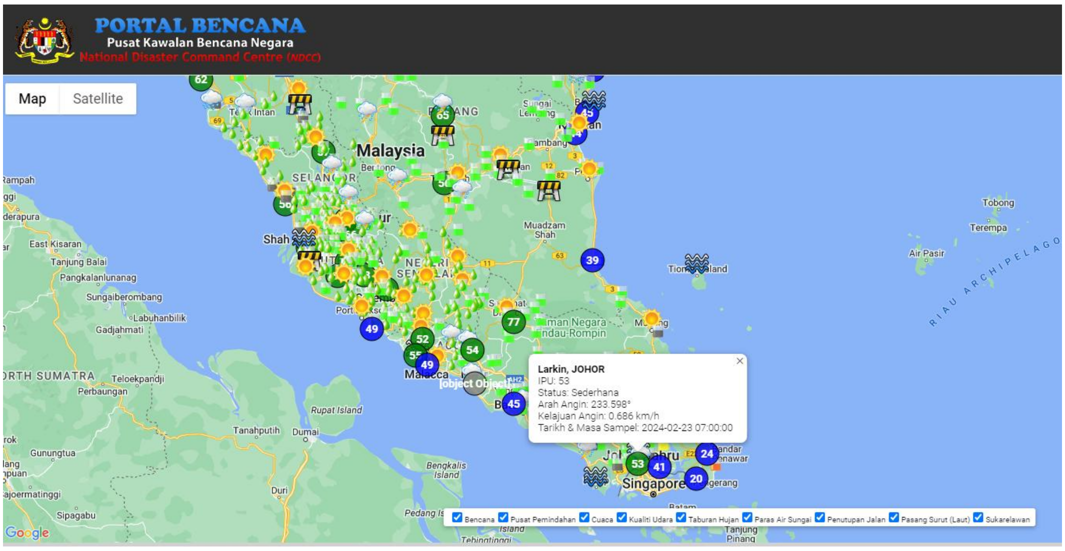
3 Public Info Banjir - DID (https://publicinfobanjir.water.gov.my/)



This webpage is maintained by DID and provides:

- Rainfall and water level measurement data from telemetry stations for the past few days.
- Classification of rainfall types based on intensity over a 1-hour period.
- Provision of flood potential warnings when water levels exceed predetermined thresholds.

4 National Disaster Command Center (NDCC) - NADMA (*https://portalbencana.nadma.gov.my/ms/*)

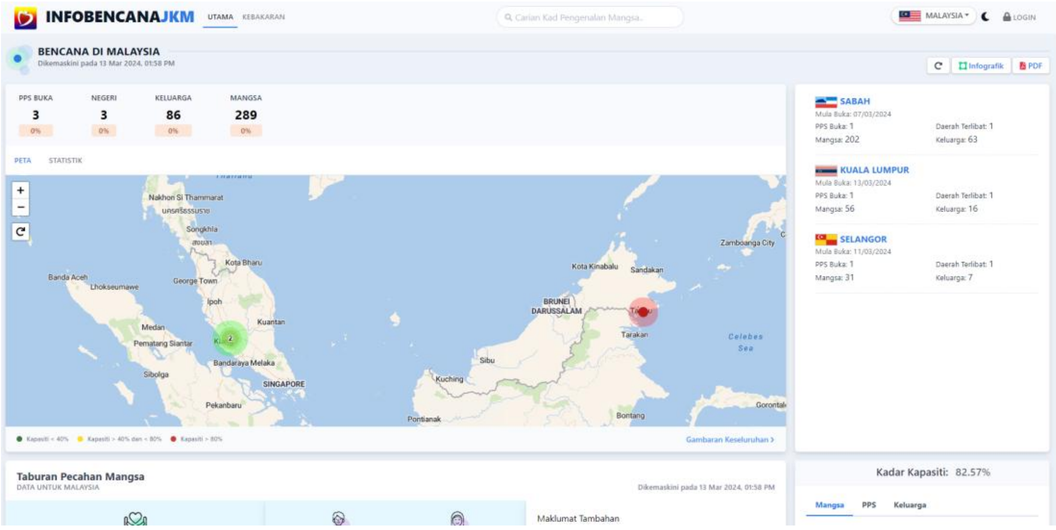


This webpage connects to the data from different servers from METMalaysia, JPS (DID), JAS (DOE), JKR, JUPEM, and JKM.

This webpage offers the following information:

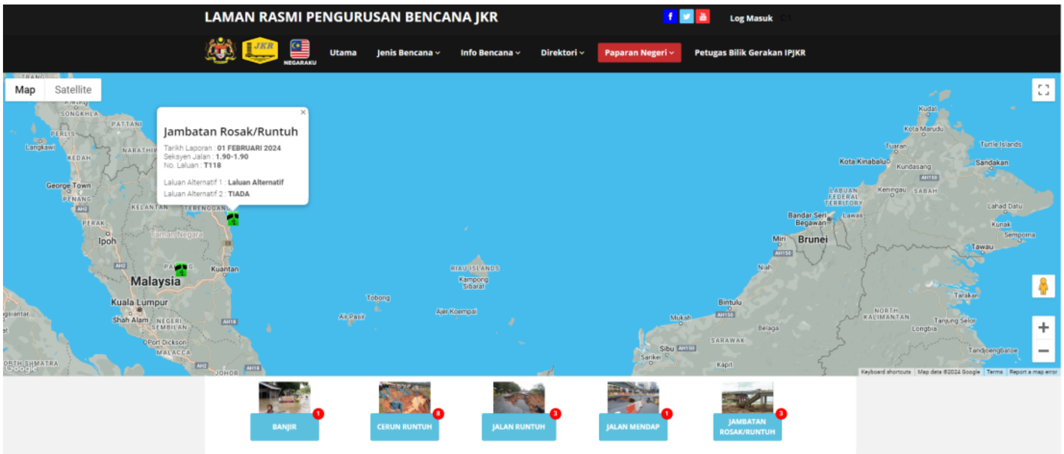
- Observational data on weather, air quality, rainfall, wind, and tidal conditions.
- Disaster information related to fires, floods, air pollution, and road closures.

5 Info Bencana - JKM (https://infobencanajkmv2.jkm.gov.my/landing/)



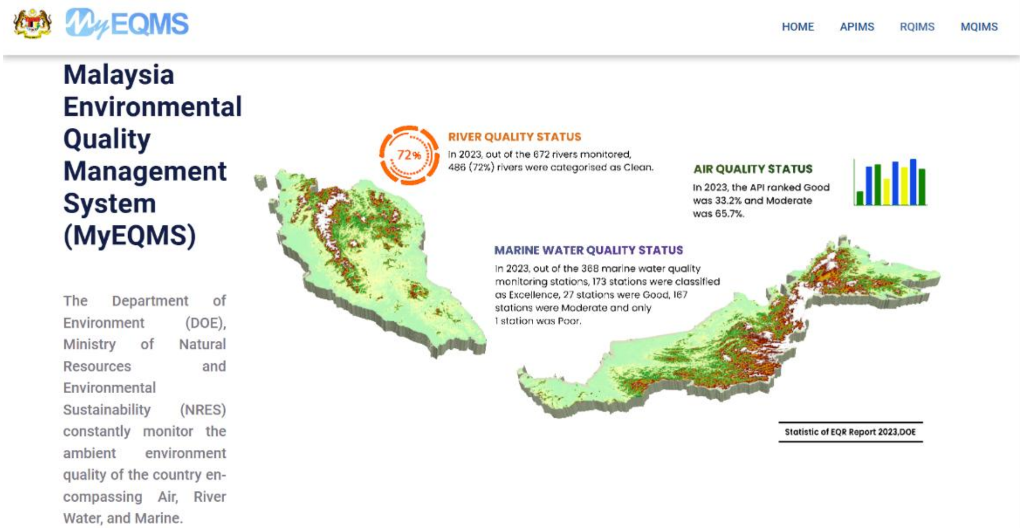
This webpage provides disaster information categorized by location. It also includes details about the number of victims affected. Users can easily access relevant data based on specific disaster events.

6 Bencana Alam - JKR (http://bencanaalam.jkr.gov.my/)



This webpage serves information on the infrastructure failures such as road and bridges failure caused by floods and landslide.

7 MyEQMS - DOE (https://eqms.doe.gov.my/)



The MyEQMS website by the Department of Environment (DOE), under the Ministry of Natural Resources and Environmental Sustainability (NRES), offers comprehensive data on the country's ambient environmental quality. It provides real-time information from monitoring stations nationwide, covering air quality, river water quality, and marine water quality indices.

The figure below illustrates a summary of various existing platforms and their capabilities in Early Warning Systems (EWS). Compared to other identified platforms, the MHP-IM prototype has integrated all four key elements of a flood-related EWS, indicating that it provides added value beyond the existing systems.

Furthermore, the MHP-IM prototype has demonstrated the ability to provide EWS for more than one type of hazard. In this case, it is capable of forecasting, issuing warnings, and enabling preparedness for potential heat wave events.

From the diagram, several platforms are shown to offer flood monitoring, forecasting, and warning capabilities. However, the MHP-IM prototype can be considered more advanced and informative because:

1. It can generate flood inundation maps for various time intervals based on hydrodynamic model simulations, using near real-time meteorological data and weather forecasts.
2. It provides flow discharge and sea water level information for multiple return periods, which are critical for flood early warning, post-event analysis, and flood mitigation design.
3. It produces map layers showing estimated flood-affected areas, flood depths, and potential flood damages (in MYR) for different return periods, based on model outputs.
4. It delivers flood risk information in the form of Estimated Annual Damage (in MYR) for the Iskandar Malaysia region, presented as map layers considering various return periods.

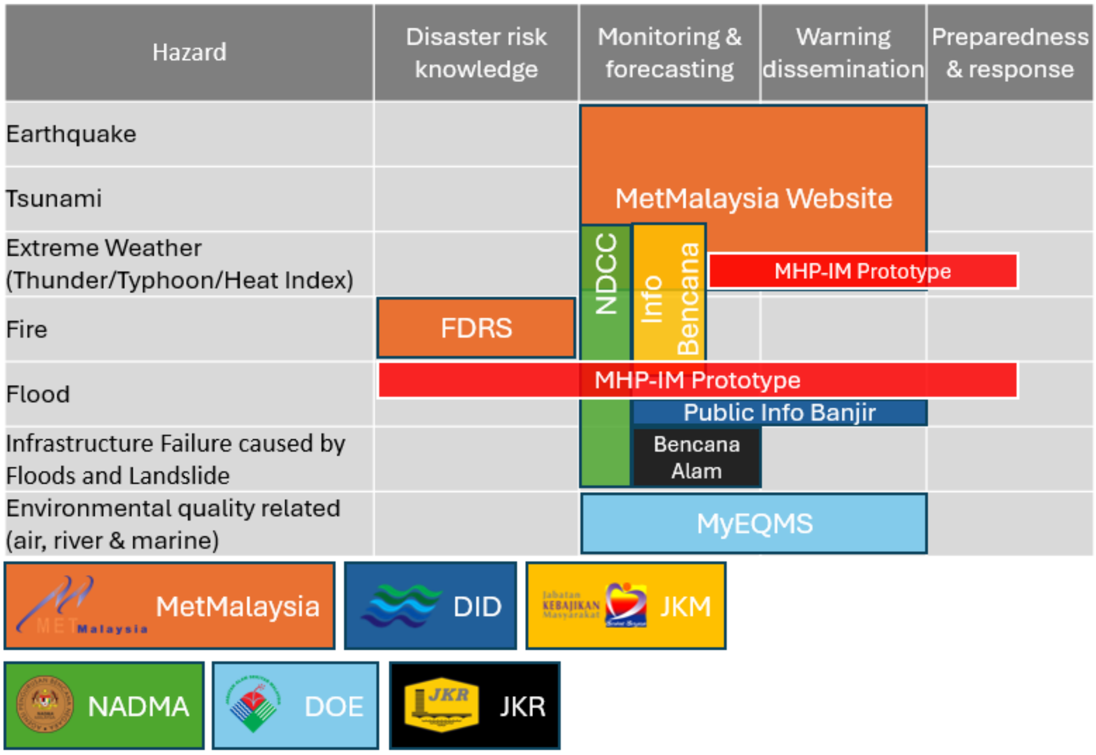


Figure B-1 Categorization of existing platforms according to the four key elements of a good practice Multi Hazard Early Warning System: disaster knowledge, monitoring and forecasting, warning and dissemination, and preparedness and response.

C List of stakeholders

In below table, organisations and its tasks are listed. Different colours show different.

Organization	Task	Level	Type of Hazard	User profile in platform
Malaysian Meteorological Department (MET) Malaysia	Provide hydro-met data	National level	Flood, Drought, Typhoon, Storm-surge, Thunder	Data provider
Jabatan Pengairan dan Saliran (JPS/DID) Johor	Provide river data, flood and drought information	State level	Flood, Drought	Data provider
Jabatan Ukur dan Pemetaan Malaysia (JUPEM) Johor	Provide basic maps (elevation, admin boundary)	State level	(Base Information)	Data provider
Jabatan Mineral dan Geosains (JMG) Johor	Provide geological maps	State level	Land slide, Drought	Data provider
Jabatan Alam Sekitar (JAS/(DOE) Johor	Provide environmental data	State level	Air pollution, Water Quality,	Data provider
PlanMalaysia Johor	Provide spatial planning data	State level	(Base Information, Risk)	Data provider
Department of Statistics Malaysia (DOSM)	Provide statistical data on demography, socio-economic.	National level	(Base Information, Risk)	Data provider, Advanced user
Iskandar Regional Development Authority (IRDA)		Regional IM	All hazards	Advanced user
Municipal councils JB		Regional JB	Flood, typhoon, storm-surge	Advanced user
Institut Penyelidikan Air Kebangsaan Malaysia (NAHRIM)	Research on Water	National Level	Flood, drought, Water Quality, storm-surge	Advanced user
Jabatan Kerja Raya (JKR Johor)	Managing construction works for public. Provide information on critical infrastructure. Extract risk information	State level	Flood, Typhoon, Land slide, Storm-surge, Water Quality	Advanced user
Jabatan Laut Malaysia (JLM)	Regulating operational on maritime sector	National level	Storm-surge, Typhoon	Advanced user
Maritime Institute of Malaysia (MIMA)	Research on maritime	National level	Storm-surge	Advanced user
District officer - Johor	Command system	State level	Flood, Typhoon, Land slide, Storm-surge, Water Quality	Advanced user
Agensi Pengurusan Bencana Negara (NADMA)	Focal point for disaster management	National level	All hazards	User

Organization	Task	Level	Type of Hazard	User profile in platform
Johor Port Authority	Authorization on port area	State level	Storm-surge, Typhoon	User
Lembaga Kemajuan Ikan Malaysia (LKIM) Johor	Regulate fisheries affairs	State level	Flood, Typhoon, Storm-surge, Water Quality	User
Jabatan Pertanian Johor (LPP)	Regulate agriculture production	State level	Flood, Land slide, Drought, Storm-surge, Water Quality	User
Jabatan Kebajikan Masyarakat (JKM) Johor	Regulate health facilities. Extract information on flood, drought, weather. Part of ERP	State level	All hazards	User
Majlis Keselamatan Negara (MKN) & Jabatan Kebajikan Masyarakat (JKM) Johor	ERP (safety and emergency scheme)	State level	All hazards	User
Malaysian Communications and Multimedia Commission (MCMC) Johor	Disseminating warning (communication)	State level	All hazards	User
Jabatan Pertahanan Awam Malaysia (JPAM) Johor	ERP (Civil defense)	State level	All hazards	User
Polis Diraja Malaysia (PDRM) Johor	ERP	State level	All hazards	User
Jabatan Bomba dan Penyelamat Malaysia (JBPM)	ERP	State level	All hazards	User
Telco (private)	Telecommunication company	National level	Flood, Typhoon, Land slide	User
Syarikat Air Johor (SAJ) Ranhill	Drinking water company	State level	Flood, Land slide, Drought	User
Majlis Perbandaran (MMC)	Airport service, Port, Trains	National level	Flood, Typhoon, Land slide	User
Tenaga Nasional Berhad (TNB)	Serve electricity	State level	Flood, Typhoon, Land slide	User

D Background on the models

D.1 WFLOW

This distributed hydrological modelling software, WFLOW, is a free and open-source platform developed by Deltares, designed to conduct hydrological simulations using GIS raster data, often based on global datasets (Van Verseveld, et al., 2024). It incorporates major hydrological processes, such as interception, soil moisture percolation, evapotranspiration, and runoff generation (Figure D-1).

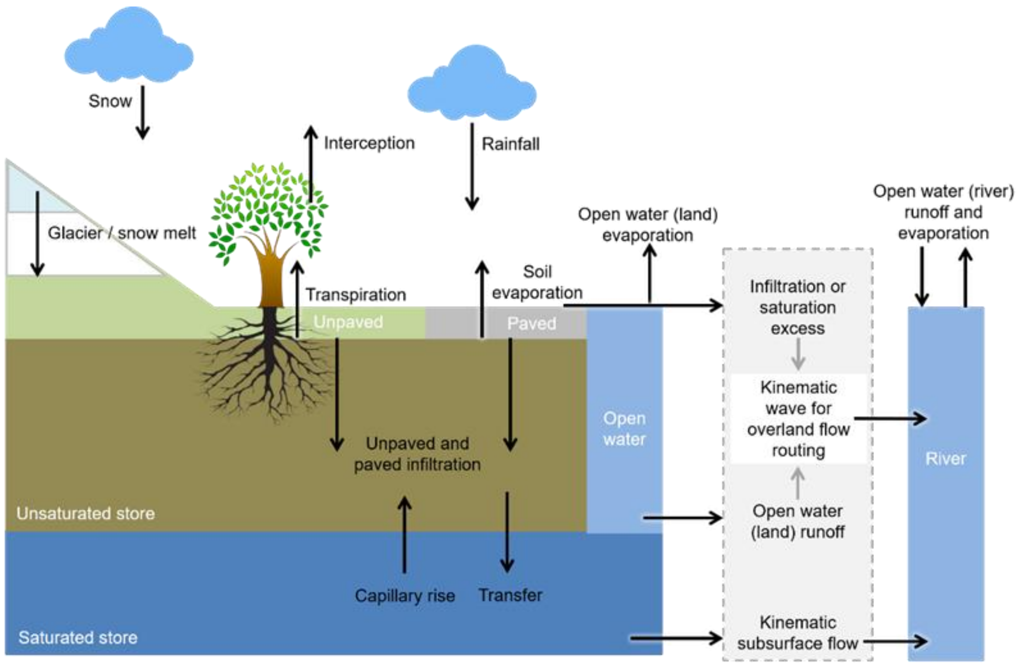


Figure D-1 Overview of the main hydrological processes in the Wflow SBM cell.

WFLOW offers many advantages. It is an open source and freely available model. As it is a distributed (gridded) model, results can be obtained for any locations/cells in the studied catchment and can then easily be connected to both the water resources and the hydrodynamic model and provides information such as river or lateral inflows (Figure D-2).

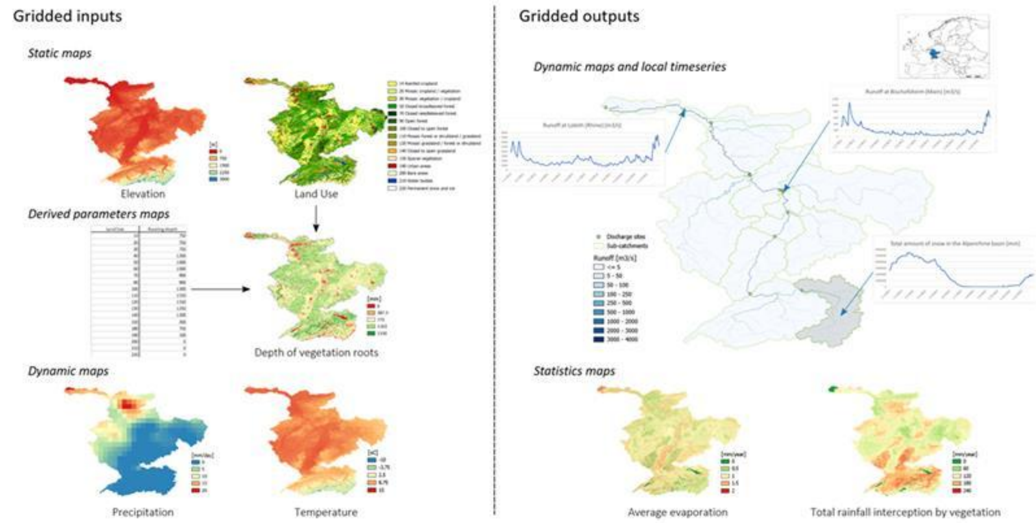


Figure D-2 Distributed inputs and outputs of the wflow_sbm model.

Model setup and datasets
A WFLOW hydrological model requires three main types of inputs (Figure D-2):

- Model construction dataset, such as a Digital Elevation Model (DEM), soil type, land use or stream network and the parameters derived from them (such as soil hydraulic conductivity, rooting depth or surface roughness).
- Model forcing dataset, such as precipitation, potential evapotranspiration or temperature.
- Model calibration and validation dataset such as discharge or rainfall timeseries.

Online WFLOW model documentation can be found at https://deltares.github.io/Wflow.jl/stable/.

D.2 SFINCS

D.2.1 What is SFINCS

SFINCS (Super-Fast INundation of CoastS) is a reduced-physics model capable of simulating compound flooding with a high computational efficiency balanced with an adequate accuracy. In SFINCS a set of momentum and continuity equations are solved with a first order explicit scheme based on Bates et al. (2010). Traditionally SFINCS neglects the advection term (SFINCS-LIE) which generally justified for sub-critical flow conditions. For super-critical flow conditions or when modelling waves, the advection term likely needs to be solved. For this purpose, the SFINCS-SSWE version can be used (including advection).

D.2.2 Why SFINCS

Compound flooding during tropical cyclones and other extreme events result in tremendous amounts of property damage and loss of life. Early warning systems and multi-hazard risk analysis can reduce these impacts. However, large numbers of computations need to be run in a probabilistic approach and in a short time due to uncertainties in the meteorological forcing. Current modelling approaches are either fast but too simple (bathtub approach) or models are very accurate but too slow (e.g. Delft3D, XBeach). SFINCS balances a high computational efficiency with good accuracy and is therefore perfectly equipped for compound flooding in operational forecasting systems. To simulate compound flooding events, a model needs to be able to model all these types of forcing. Therefore, SFINCS includes fluvial, pluvial, tidal, wind- and wave-driven processes.

D.2.3 Subgrid features

To make the results of SFINCS even more accurate when calculating on relatively course model grid sizes, the option to add subgrid features have been developed (Leijnse et al. 2020). Subgrid features are a method in which flux computations are performed on a coarser grid than the update of the water levels, which is done on a much finer grid. In this way computations can be speeded up, while still using high resolution information of an available DEM. This makes it possible to compute on a coarser grid resolution (improvement of efficiency) while still detailed information about the local elevation is incorporated when determining corresponding water levels leading to accurate results.

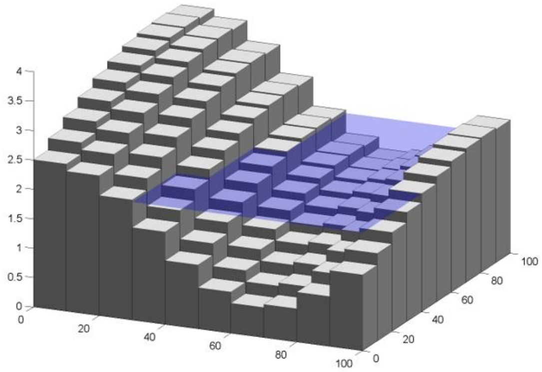


Figure D-3 Example of a cell with SFINCS subgrid features included in the local elevation (https://sfincs.readthedocs.io/)

D.3 Delft-FIAT (FIAT)

Risk being the consequence of the interaction between a hazard and the characteristics that make people and places vulnerable and exposed. It is usually expressed as a single comparable indicator (i.e. money). To calculate risk, Deltares developed Delft-FIAT (Flood Impact Assessment Tool. It is designed to run quick, consistent, and well-founded flood damage and risk calculations. This tool supports decisions on appropriate courses of action and helps underpin the benefits of flood mitigation and adaptation measures when recommending and prioritizing infrastructure investments. It allows users to evaluate the damage and risk-reduction benefits of flood mitigation and adaptation measures once the hydrodynamic modelling of these scenarios is completed. It evaluates and outputs damages per building and/or road segment and/or utility, and aggregates to user-specified aggregation scales.

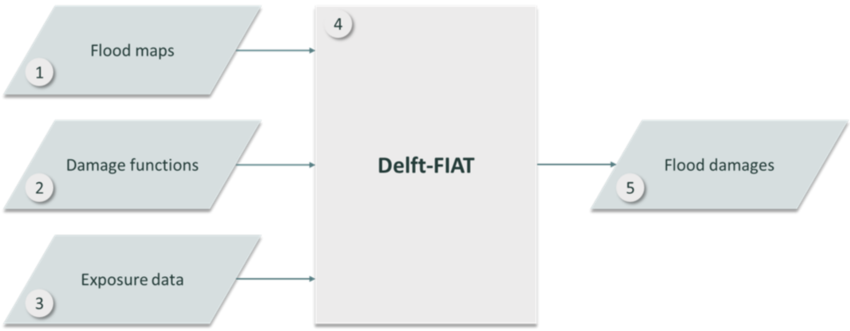
Delft-FIAT is a free, Python-based tool developed by Deltares for calculating flood impacts, with a run time of about one minute per flood scenario. This manual describes the use of Delft-FIAT together with a user interface. Delft-FIAT can also be run via scripts or command line, for users who are familiar with programming. This allows the most flexibility, but the user interface makes the software accessible to a wider audience. The user interface enables the user to easily select and run flood damage and risk calculations for an individual event or multiple flood inundation scenarios.

It is designed to rapidly assess the direct economic impacts of flooding on buildings, utilities, and roads using user-input flood maps. Several key features on FIAT:

- Speed and Automation: Delft-FIAT can perform simulations quickly. It can be run in batch mode to automatically iterate over multiple scenarios, making it possible to evaluate future risks and the effectiveness of various interventions.

- Flexibility: The tool has a flexible architecture, allowing users to customize it according to their needs. Users can modify exposure data, hazard data, and even the types of damage analysed. This flexibility makes it suitable for a wide range of applications.
- Customization: Delft-FIAT can be connected to tailored user interfaces, custom-designed viewers, or existing tools like PowerBI or ArcGIS Online. It can also integrate with other software, such as flood modelling tools, to provide comprehensive analysis.
- Global Application: Delft-FIAT has been used worldwide, including in data-rich and data-scarce communities. It supports projects in various regions, including the U.S., Australia, Asia, Africa, Europe, and the Caribbean.
- Open-Source Development: The tool is continuously improved and is set to be released as open-source software, enhancing its accessibility and adaptability for different users.

Delft-FIAT produces damage maps by combining the exposure object maps and the damage functions with the hazard maps (Figure D-4). More information about FIAT could be found in https://www.deltares.nl/en/software-and-data/products/delft-fiat-flood-impact-assessment-tool



1	Flood maps	Selected per damage simulation in user interface
2	Damage functions	Prepared in set-up phase, coupled to exposure types
3	Exposure data	Prepared in set-up phase, developed per area of interest
4	Delft-FIAT	User interface and underlying Delft-FIAT damage assessment executable
5	Flood damages	Object-level + aggregated tables and (optional) shapefiles of damages

Figure D-4 Overview of how Delft-FIAT combines hazard, damage functions and exposure data.

E International practices for storm surge forecasting

This section briefly describes four national storm surge and/or flood forecasting systems, in the Netherlands, the USA, Australia, and Mauritius. The four systems were selected because they demonstrate varying levels of technical complexity, are at different stages of development, and are familiar to Deltares. However, many countries (and regions within countries) host multi hazard forecasting and/or storm surge forecasting systems. Some additional examples include:

- **The Indian Meteorological Department** publishes cyclone tracks, and the Regional Specialised Meteorological Centre (RSMC) for Tropical Cyclones Over North Indian Ocean publishes daily "Storm Surge Guidance" bulletins (India Meteorological Department, 2023), containing maps and tables of storm surge and expected inundation extents.
- **French Naval Hydrographic and Ocean Service** (SHOM) (EPA, 2023)
- **Joint Typhoon Warning Centre** (JTWC) in Japan (US Navy, 2023)
- **UK Met Office, UK Environment Agency, and Scottish Environment Protection Agency** (SEPA) provide a range of flood forecasting services (Met Office, 2023)
- **Puertos del Estado (National Ports) in Spain** hosts an operational coastal forecasting system, primarily for maritime safety but also other end users (Government of Spain, 2023)
- **Hydro and Agro-Informatics Institute** (HAII) in Thailand (Yan, 2019)

E.1 Example 1: Netherlands – Rijkswaterstaat Operational Systems (RWsOS)

Rijkswaterstaat (RWS) is part of the Dutch Ministry of Infrastructure and Water Management and responsible for the design, construction, management, and maintenance of the main infrastructure facilities in the Netherlands, including water monitoring, forecasting, warning, and management. RWsOS (RWs = Rijkswaterstaat, OS = Operational System) is the overarching name for the operational water forecasting systems in the Netherlands. It consists of five different systems, for (1) the North Sea, (2) large inland lakes (Ijsselmeer and Markermeer), (3) large rivers (Rhine and Meuse), (4) river deltas, and (5) inland canals. Two of the operational systems (North Sea and large inland lakes) are described later in this section.

The Water Management Center of the Netherlands (WMCN) is the main information center for the Dutch water system. The WMCN is responsible for disseminating national water-related warnings and bulletins, providing advice during crisis situations, and knowledge sharing. The WMCN works closely with the national meteorological agency, water boards, provinces, and knowledge institutes. The "Waterkamer" (translates to "water room") of the WMCN is the operational centre monitoring the national water situation on a 24-hour basis, every day of the year. While the overall WMCN is much larger, the team responsible for daily monitoring and forecasting water levels and waves *along the Dutch coast* is approximately 8 full time employees (pers. comm. Rijkswaterstaat, Oct 4, 2023). During storm events, this increases by approximately 4-5 people, whose main role is communication of warnings by phone. The overall pool of people on call is larger, to allow forecasters to alternate in 12-hour shifts and to account for absences.

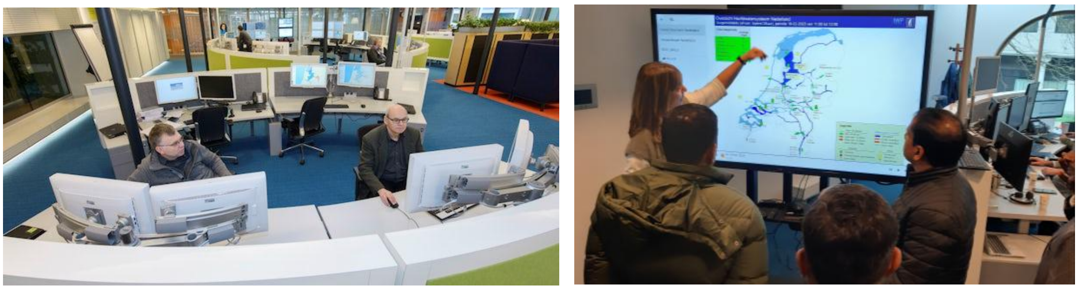


Figure E-1 Photos at the WMCN. Source: Left: ((Rijkwaterstaat, 2023). Right: M. Van Ledden.

RWsOS North Sea is the state-of-the-art coastal forecasting system for water levels and waves on the North Sea and the Dutch coastal waters (Zijl, Verlaan, & Gerritsen, 2013). This system produces water level, flow velocities, and wave forecasts. Several sophisticated hydrodynamic (WAQUA, Delft3D-FM) and wave (SWAN) models run at regular intervals (e.g., 3 hours, with a 2-day forecast period, course versions of the models provide up-to 10-day forecasts) using meteorological forecasting from the Royal Netherlands Meteorological Institute, ECMWF, and tidal forcing at the open sea boundaries.

RWsOS North Sea is also equipped with a data assimilation component (Kalman filter) to improve the accuracy of the water level forecasts (Zijl, Sumihar, & Verlaan, 2015). The Kalman filter assimilates observed water level data from 32 observing stations (provided at 10-minute intervals) along the British and Dutch coasts and a few offshore locations. Ensemble forecasts are generated every 12 hours using a coarser version of the models using ECMWF-ENS meteorological forecasts as input.

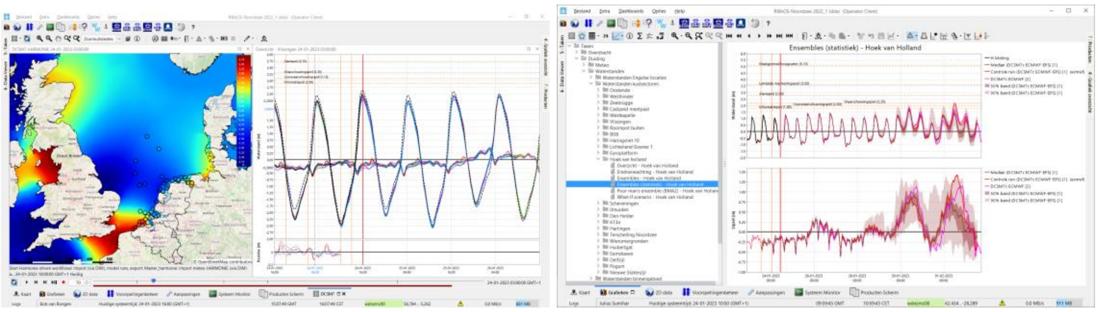
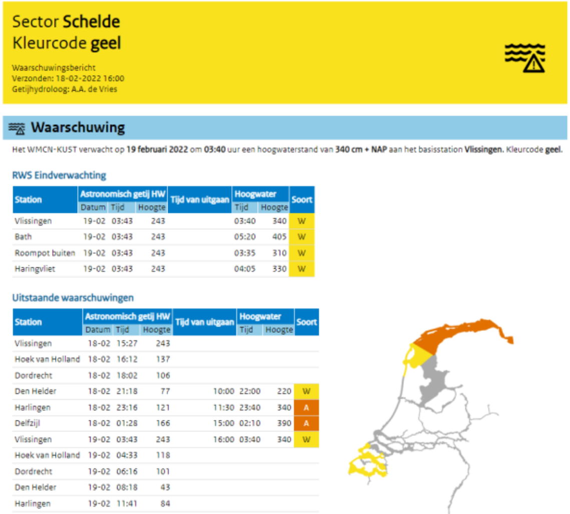


Figure E-2 (Left) water level and storm surge forecasts and (right) ensemble forecast statistics along the Dutch coast, depicted in the Delft-FEWS desktop client. Source: RWsOS North Sea.

In daily operations, RWsOS North Sea is used for water management of Dutch coastal waters, such as ensuring maritime safety on busy shipping routes towards the seaports of Antwerp, Rotterdam, Amsterdam, and Ems area. During storm surge events, a team of forecasters use the system to issue warnings, based on which measures can be taken to prevent flooding. Warning information is published on a publicly accessible website (Rijkswaterstaat, 2023). Figure E-3 shows an example of a warning bulletin for the North Sea.


Sector **Schelde**
Kleurcode **geel**

Waarschuwingsbericht
Verzonden: 18-02-2022 16:00
Getijhydroloog: A.A. de Vries

Waarschuwing

Het WMCN-KUST verwacht op **19 februari 2022** om **03:40** uur een hoogwaterstand van **340 cm + NAP** aan het basisstation **Vlissingen**. Kleurcode **geel**.

RWS Eindverwachting

Station	Astronomisch getij HW			Tijd van uitgaan	Hoogwater		Soort
	Datum	Tijd	Hoogte		Tijd	Hoogte	
Vlissingen	19-02	03:43	243		03:40	340	W
Bath	19-02	03:43	243		05:20	405	W
Roompot buiten	19-02	03:43	243		03:35	310	W
Haringvliet	19-02	03:43	243		04:05	330	W

Uitstaande waarschuwingen

Station	Astronomisch getij HW			Tijd van uitgaan	Hoogwater		Soort
	Datum	Tijd	Hoogte		Tijd	Hoogte	
Vlissingen	18-02	15:27	243				
Hoek van Holland	18-02	16:12	137				
Dordrecht	18-02	18:02	106				
Den Helder	18-02	21:18	77	10:00	22:00	220	W
Harlingen	18-02	23:16	121	11:30	23:40	340	A
Delfzijl	18-02	01:28	166	15:00	02:10	390	A
Vlissingen	19-02	03:43	243	16:00	03:40	340	W
Hoek van Holland	19-02	04:33	118				
Dordrecht	19-02	06:16	101				
Den Helder	19-02	08:18	43				
Harlingen	19-02	11:41	84				

Figure E-3 Example of a new coastal bulletin warning of storm surge along specific sections of the coast. Source: Rijkswaterstaat (2023).

RWsOS-Meren (RWsOS-Lakes) is a forecasting system for two of the large, low-lying, diked lakes in the Netherlands (Ijsselmeer and Markermeer). This system produces water level and wave forecasts along the dikes and combines them with detailed and regularly updated dike cross-section information to forecast wave run-up and overtopping. This detailed information is used during storm events to decide when to start monitoring specific sections of dikes or implement additional mitigation measures.

E.2 Example 2: United States of America – National Hurricane Center

The United States National Hurricane Center (NHC) in Miami, Florida is part of the National Atmospheric and Oceanographic Administration (NOAA). The centre provides official 2-day and 7-day graphical tropical weather outlooks for the Atlantic, Caribbean, and Gulf of Mexico Basins as well as for the Central Pacific (Hawaii) and Eastern Pacific (Mexico, Southern California) (NOAA, 2023). Once a cyclone forms, the NHC produces and disseminates a set of forecast products every 6 hours[12]. The forecast system use satellite, aircraft, buoy, and radar observations to assimilate with numerical prediction models to produce a forecast of hurricane track and intensity.

The maps show the storm (disturbance) location, forecasted track, and classification on the Samson-Saffir scale. Forecast products include surface (10 m) wind speeds, wind gusts, sea level pressure, significant wave heights/periods and direction, and marine hazards. Text forecasts and low-bandwidth displays are also provided.

Regarding Tropical Cyclones, the NHC provides a Public Advisory indicating hurricane "watches and warnings," a forecast discussion, and a description of potential hazards (such as storm surge, wind, tornadoes, etc.). More detail is provided in the "Tropical Cyclone Forecast/Advisory" product. Experimental products include probability maps of surge, and overland flood maps.

[12] (GSO, NSF and University of Rhode Island, 2020).

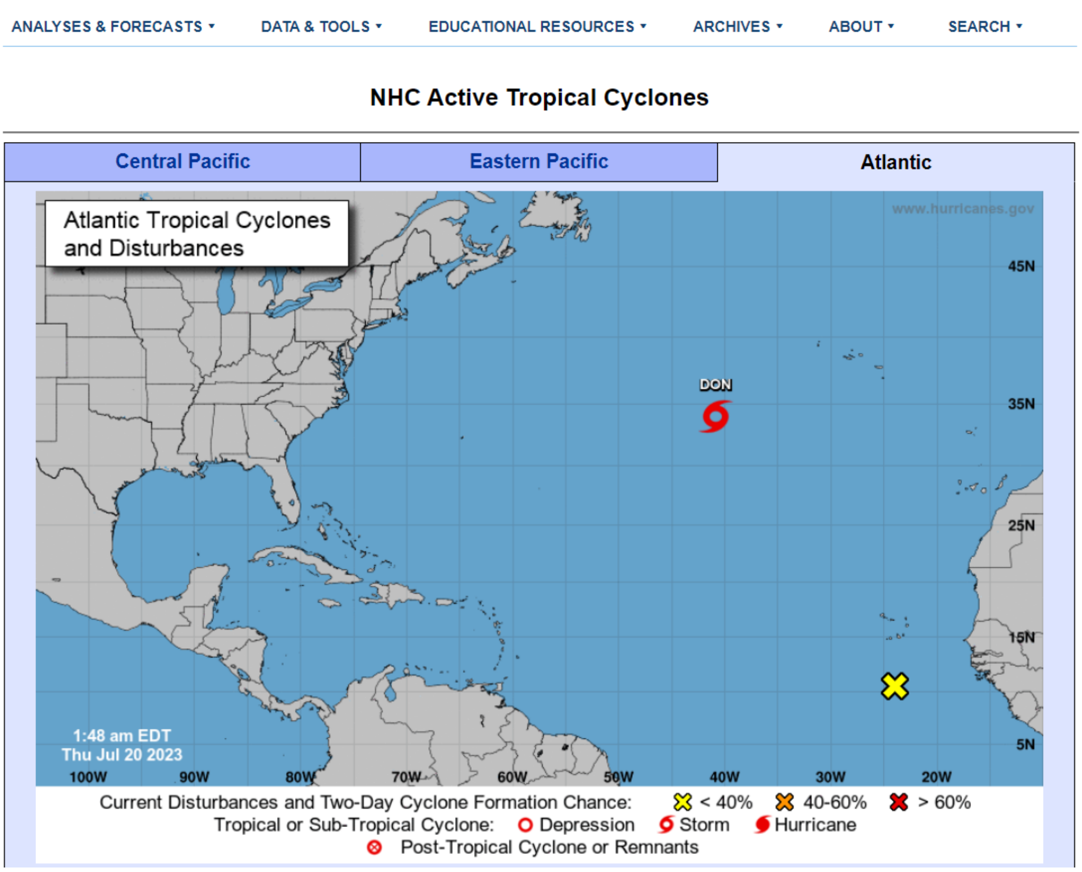


Figure E-4 Example of a hurricane forecast by NHC, NOAA (USA). Source: (NOAA, 2023)

There are several other institutes that produce unofficial hurricane storm surge forecasts in the U.S. for various purposes and end users. These are unaffiliated with the official National Weather Service forecasts described above. One example is the Coastal Emergency Risks Assessment (CERA) project, hosted by Louisiana State University and sponsored by several Southeastern US institutes, which provides real time storm surge information[13] using the ADCIRC model. Similarly, Deltares and the United States Geological Survey (USGS) operate the Coastal Storm Modelling System (CoSMoS) system[14], which provides information on waves, storm surge, tides, flooding, and coastal erosion.

E.3 Example 3: Australia Flood Impact Forecasting System

In Australia, the impact of flooding from both tropical cyclones (e.g., TC Debbie, 2017) and extratropical storms have shown the vulnerability of low-lying areas in floodplains and along the coast to flooding. Particularly when flooding from rainfall, rivers, and the sea converge, it can cause significant damage to infrastructure and even loss of life. A national Flood Intelligence Forecasting System (FliFS), currently in the Proof-of-Concept phase, has been developed to help reduce these impacts in Australia. The goal is to provide end users with flood inundation forecasts, real-time inundation analysis, and post-event flood maps to support decision-making before, during, and after events (Figure E-5).

[13] Forecast information can be viewed at: https://cera.coastalrisk.live/
[14] Forecast information can be viewed at https://opendap.deltares.nl/static/deltares/cosmos/nopp_event_viewer/index.html

FliFS leverages the Bureau of Meteorology's national flood forecasting system, with Delft-FEWS as its operational framework. It is hosted in an Azure cloud and consists of a flood modelling framework covering the entire coast of New South Wales, Queensland, and Northern Territory, a data archive, and a connection to ArcGIS Online (Figure E-6). Flood extent shapefiles produced by the system are used by disaster managers in their existing GIS workflows as input to impact models that calculate potential damages to people and property.

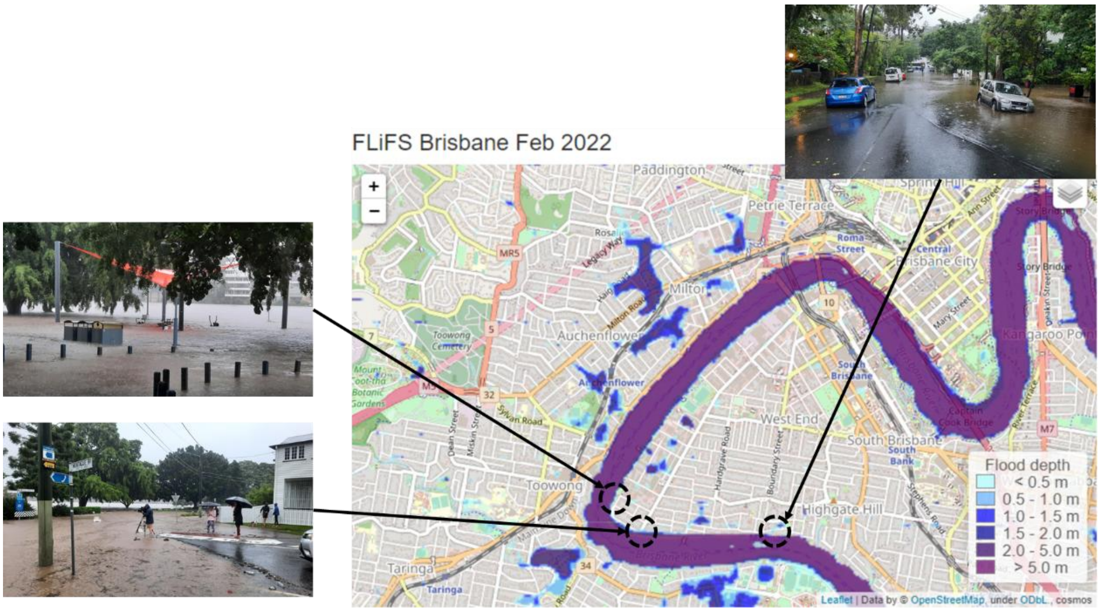


Figure E-5 Flooding predictions by FliFS in Australia, Brisbane during February 2022 event. Including pictures of local situation. Source: (Leijnse, et al., 2022).

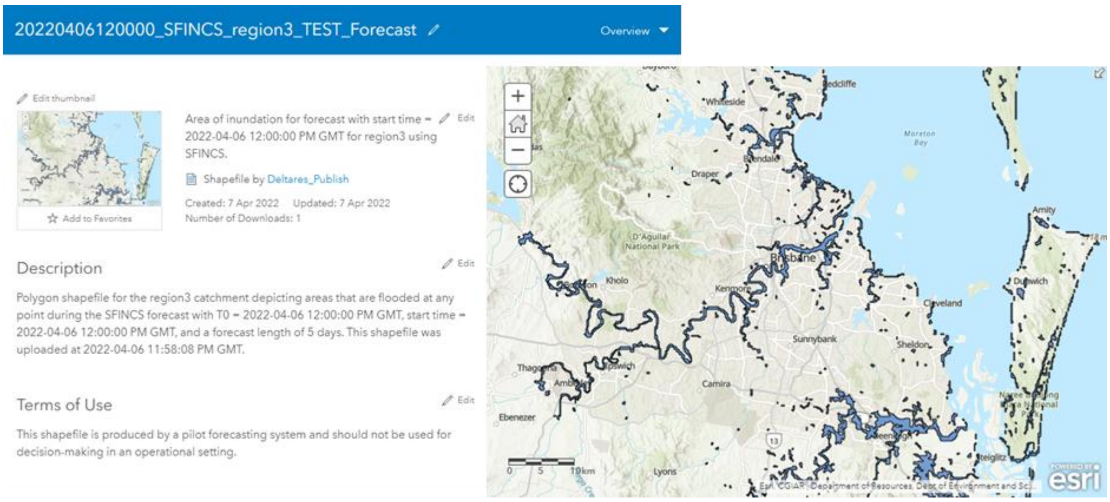


Figure E-6 Shapefile depicting maximum forecasted flood extent automatically uploaded in the ArcGIS Online environment.

E.4 Example 4: Mauritius Storm Surge Forecasting System

Mauritius experiences the effects of tropical cyclones almost yearly, and the associated storm surge and flooding can occasionally cause significant damage to coastal communities. The Mauritius Meteorological Services (MMS), hosts, manages, and maintains an operational storm surge and inundation forecasting system.

The main purpose of the system is to provide the information needed to inform coastal communities of a high-water event with enough time to evacuate safely. When an event is expected, MMS sends warnings to various government agencies, who disseminate the information further. It relies on freely available modelling and forecasting software and publicly available global datasets. Five sets of tide, storm surge, and wave models were developed using coupled Delft3D-FLOW and SWAN models. Meteorological forcing for two regional models is provided by the 0.25° NOAA Global Forecast System, while 2D spectral wave boundary conditions, including the swell component, are derived from 0.5° Global WAVEWATCH III Production Multigrid forecasts. Locally generated tropical cyclone winds based on cyclone track information, when available, are blended with numerical weather predictions. Forecasters can manually adjust the cyclone tracks using their best judgement before each 6-hourly modelling cycle begins. Water levels are translated to simple flood depth maps using a GIS-based flood mapping algorithm (Bogaard, 2021).

The system runs on two dedicated desktop computers (one production and one back-up), both with a back-up power supply.

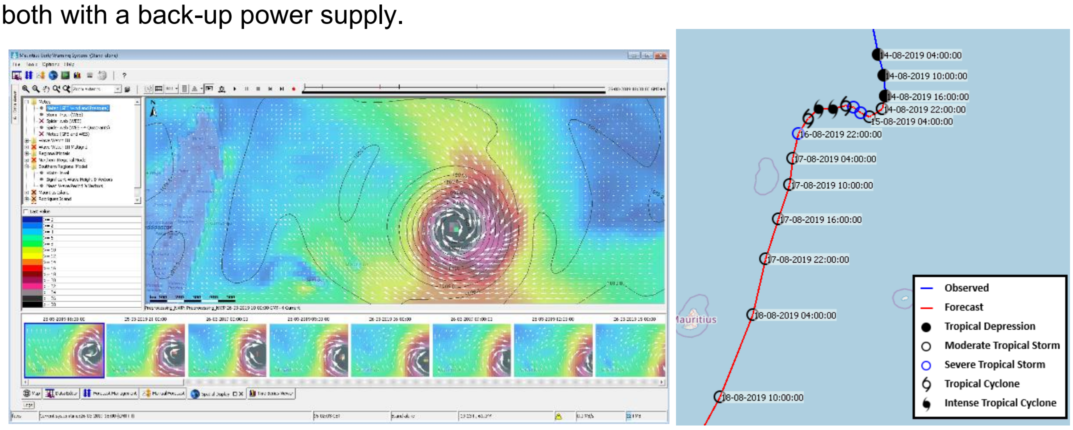
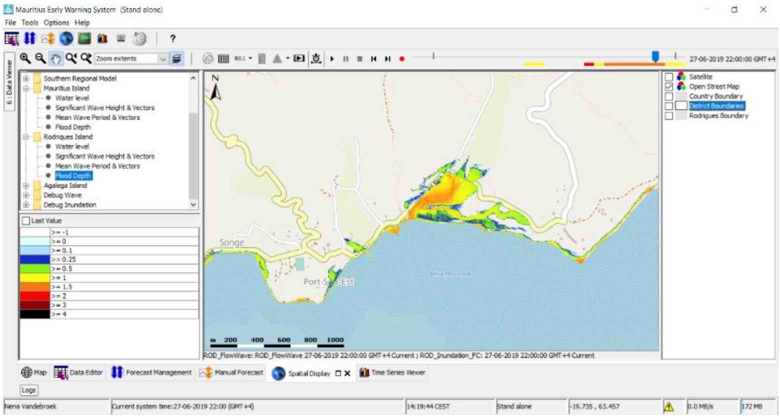


Figure E-7 Screenshots from the Mauritius storm surge forecasting system. Left: pressure, wind speed, and wind direction for a tropical cyclone. Right: Cyclone track forecast, with icons reflecting storm category. Source: (Bogaard, 2021)



Location	0-6h	6-12h	12-18h	18-24h	24-30h	30-36h	36-42h	42-48h	48-54h	54-60h	60-66h	66-72h
Port Louis	-0.28	0.88	0.90	0.80	0.83	0.74	0.77	0.70	0.76	0.59	0.66	0.55
Albion	-0.28	0.79	0.80	0.67	0.70	0.63	0.67	0.62	0.68	0.50	0.58	0.47
Canal Dayot	-0.28	1.05	0.97	0.82	0.85	0.72	0.75	0.66	0.72	0.53	0.61	0.49
Port Louis Harbour	-0.28	0.88	0.90	0.80	0.83	0.74	0.77	0.70	0.76	0.59	0.66	0.55
Port Louis Harbour Entrance	-0.27	0.87	0.90	0.82	0.85	0.76	0.79	0.72	0.78	0.60	0.68	0.56
Pointe aux Piments	-0.28	0.82	0.83	0.81	0.84	0.78	0.82	0.74	0.81	0.62	0.69	0.58
Mon Choisy	-0.28	0.91	0.88	0.74	0.77	0.66	0.69	0.63	0.69	0.52	0.61	0.48
Pointe aux Canonniers												
Grand Baie	-0.30	1.22	1.04	0.88	0.92	0.74	0.77	0.62	0.68	0.45	0.53	0.39
Pereybere	-0.29	0.87	0.87	0.83	0.87	0.77	0.81	0.71	0.77	0.57	0.65	0.52
Poudre d'Or	-0.38	1.21	1.21	1.45	1.46	1.49	1.50	1.40	1.43	1.20	1.25	1.10
Pointe des Lascars	-0.39	1.17	1.18	1.30	1.30	1.27	1.28	1.18	1.21	0.98	1.03	0.89

Figure E-8 Top: flood depth map produced by GIS-based algorithm. Bottom: automatically generated water level forecast bulletin, showing expected water levels and thresholds for different locations and lead times. Source: (Bogaard, 2021)

F Example Monsoon Surge, March 2025

In the days of 20 and 21 March, 2025, a Monsoon Surge hit Johor and Singapore region, resulting in extremely large and high-intensity rainfall amounts. This caused widespread flooding in the Johor region.

Asia

Over 10,700 people evacuated in Johor due to severe floods; major roads in JB city centre affected

As of 8am on Friday (Mar 21), 10,763 people have been sent to temporary flood relief centres, more than double the number recorded on Thursday night.

21 Mar 2025 01:34PM
(Updated: 21 Mar 2025 01:46PM)

The flood situation at Bandar Dato Onn (left) and Tampoi (right) in Johor Bahru on Thursday (Mar 20, 2025).
(Sources: Facebook/Polis Dato Onn, Facebook/Balai Polis Tampoi)

Figure F-1 Headlines in CNA showing the floods in Johor caused by the March 2025 Monsson Surge (source: https://www.channelnewsasia.com/asia/malaysia-johor-bahru-severe-floods-tebrau-pandan-roads-5015281)

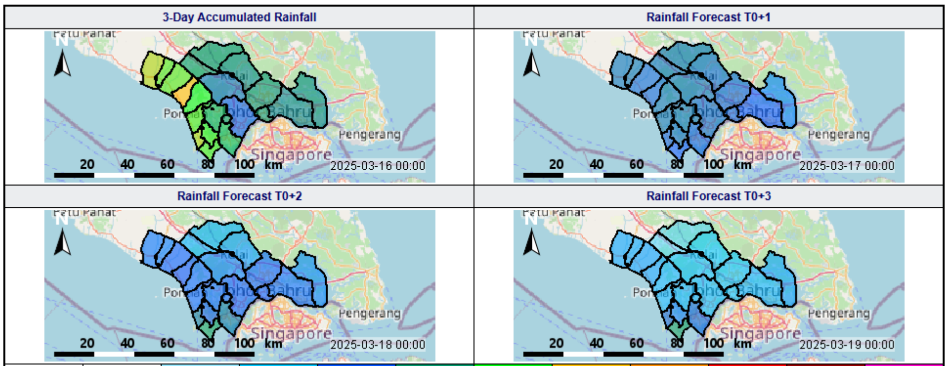
The prototype of the MHEWS was used to test its functionality for a real case. To mimic the situation, the hindcast started on 16th of March, 4 days prior to the real event. In Figure F-2 the rainfall report for 16th of March is shown. As can be seen, only limited rainfall was forecast for the next 3 days and no warnings were generated by the MHEWS.

One day later, on 17th of March, the forecast started to show indications that substantial rainfall was coming, indicated by the orange warning colours in the map and tables in the report shown in Figure F-3. One day later, all signals turn to red, meaning extreme rainfall is to be expected. This is clearly shown in the reports shown in Figure F-4 and Figure F-5.

By combining the rainfall forecast with the flood models, the MHEWS also produced flood maps and flood impact assessments. These are shown in Figure F-6.

ISKANDAR REGIONAL DEVELOPMENT AUTHORITY

Rainfall Warning Report (16 Mar 2025)



Rainfall Classification										
0 mm	0.2 mm	1 mm	5 mm	10 mm	25 mm	50 mm	75 mm	100 mm	200 mm	400 mm

Table of Rainfall per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 16 Mar 2025

Mukim	3-Day Accumulated Rainfall [mm]	Rainfall Forecast T0+1 [mm]	Rainfall Forecast T0+2 [mm]	Rainfall Forecast T0+3 [mm]
API-API	51.1	6.3	5.1	2.4
AYER BALOI	32.3	6.4	4.6	2.5
AYER MASIN	40.5	6.1	7.9	6.3
BANDAR BENUT	41.6	7.7	3.4	2.1
BANDAR JOHOR BAHRU	10.2	6.1	4.7	1.2
BANDAR KULAI	7.9	7.4	1.8	0.7
BANDAR PONTIAN KECHIL	51.8	7.5	4.3	1.8
BANDAR TEBRAU	11.2	6.1	4.7	1.2
BENUT	41.7	7.3	3.9	2.3
BUKIT BATU	11.0	7.4	1.8	0.7
JELUTONG	11.5	7.5	4.3	1.8
JERAM BATU	14.2	7.5	4.3	1.8
KULAI	7.4	7.3	3.4	1.3
PEKAN JERAM BATU	6.3	7.5	4.3	1.8
PENGKALAN RAJA	19.2	7.5	4.3	1.8
PLENTONG	8.9	4.8	4.1	1.7
PONTIAN	25.3	7.5	4.3	1.8
PULAI	5.8	6.7	4.5	1.5
RIMBA TERJUN	30.1	7.5	4.3	1.8
SEDENAK	9.8	7.4	1.8	0.7
SENAI	9.2	6.8	2.5	1.0
SERKAT	29.6	4.8	11.2	10.5
SUNGAI KARANG	27.7	7.0	5.7	3.6
SUNGAI PINGGAN	32.2	7.5	3.7	2.2
SUNGAI TIRAM	9.2	3.4	3.2	2.3
TANJONG KUPANG	15.6	6.1	7.9	6.2
TEBRAU	9.8	6.2	4.4	1.2

Note:

Rainfall Classification		
	Light	< 41 mm
(yellow)	Moderate	41 - 60.9 mm
(orange)	Heavy	61 - 80.4 mm
(red)	Very Heavy	> 80.5 mm

Figure F-2 Rainfall report, based on the GFS forecast of 16th of March 2025.

ISKANDAR REGIONAL DEVELOPMENT AUTHORITY

Rainfall Warning Report (17 Mar 2025)

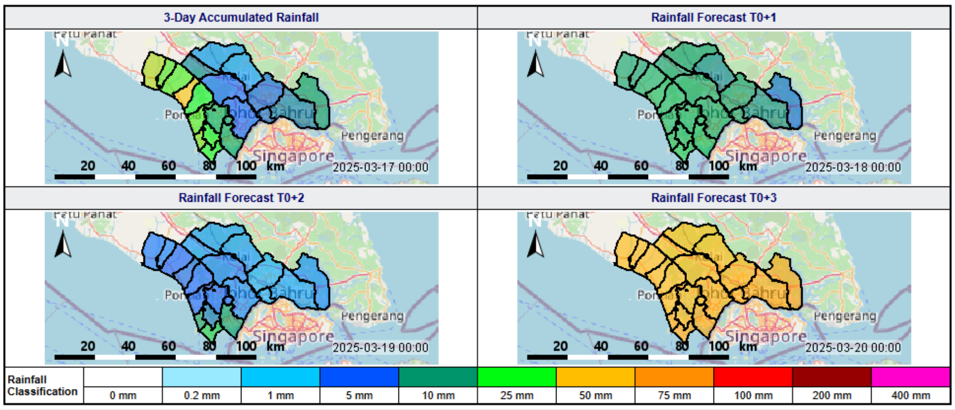


Table of Rainfall per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 17 Mar 2025

Mukim	3-Day Accumulated Rainfall [mm]	Rainfall Forecast T0+1 [mm]	Rainfall Forecast T0+2 [mm]	Rainfall Forecast T0+3 [mm]
API-API	49.2	15.0	5.8	56.1
AYER BALOI	30.8	13.2	5.2	56.1
AYER MASIN	34.9	15.5	11.5	60.8
BANDAR BENUT	41.0	10.6	3.5	54.5
BANDAR JOHOR BAHRU	6.8	11.8	1.9	58.7
BANDAR KULAI	3.1	11.1	2.7	51.6
BANDAR PONTIAN KECHIL	51.5	14.2	4.7	54.4
BANDAR TEBRAU	7.7	11.8	1.9	58.7
BENUT	41.5	11.4	4.1	55.2
BUKIT BATU	8.6	11.1	2.7	51.7
JELUTONG	11.7	14.2	4.7	54.4
JERAM BATU	13.9	14.2	4.7	54.4
KULAI	4.4	12.8	3.7	53.9
PEKAN JERAM BATU	4.4	14.2	4.7	54.4
PENGKALAN RAJA	17.7	14.2	4.7	54.4
PLENTONG	8.0	9.5	2.4	62.4
PONTIAN	23.8	14.2	4.7	54.4
PULAI	4.5	12.9	3.2	56.7
RIMBA TERJUN	30.6	14.2	4.7	54.4
SEDENAK	2.8	10.9	2.7	51.5
SENAI	2.6	8.9	2.7	51.4
SERKAT	25.3	16.8	17.8	66.7
SUNGAI KARANG	25.7	14.7	7.3	56.9
SUNGAI PINGGAN	31.5	11.0	3.8	54.9
SUNGAI TIRAM	10.3	6.6	3.2	65.0
TANJONG KUPANG	13.5	15.6	11.3	61.0
TEBRAU	6.1	11.1	2.0	57.5

Note:

Rainfall Classification		
	Light	< 41 mm
(yellow)	Moderate	41 - 60.9 mm
(orange)	Heavy	61 - 80.4 mm
(red)	Very Heavy	> 80.5 mm

Figure F-3 Rainfall report, based on the GFS forecast of 17th of March 2025.

Rainfall Warning Report (18 Mar 2025)

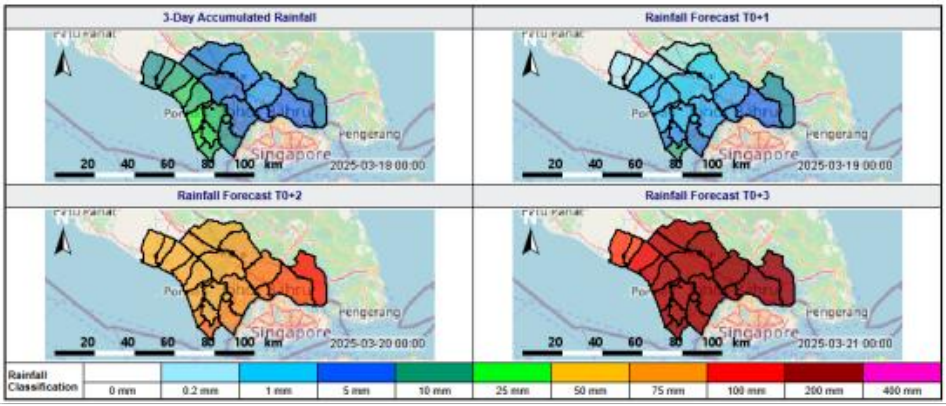


Table of Rainfall per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 18 Mar 2025

Mukim	3-Day Accumulated Rainfall [mm]	Rainfall Forecast T0+1 [mm]	Rainfall Forecast T0+2 [mm]	Rainfall Forecast T0+3 [mm]
API-API	17.1	1.9	72.9	152.3
AYER BALOI	11.5	1.1	68.1	113.9
AYER MASIN	24.4	6.6	79.2	189.0
BANDAR BENUT	10.5	0.1	62.1	89.4
BANDAR JOHOR BAHRU	4.5	2.8	82.1	201.7
BANDAR KULAI	4.3	0.4	69.0	163.9
BANDAR PONTIAN KECHIL	33.5	1.8	72.1	173.2
BANDAR TEBRAU	2.7	2.8	82.1	201.7
BENUT	8.9	0.4	63.7	92.7
BUKIT BATU	7.9	0.4	68.9	162.3
JELUTONG	14.9	1.8	72.1	173.2
JERAM BATU	14.9	1.8	72.1	173.2
KULAI	6.0	1.4	72.2	173.2
PEKAN JERAM BATU	7.3	1.8	72.1	173.2
PENGKALAN RAJA	11.3	1.8	72.1	173.2
PLENTONG	5.5	5.4	89.3	210.1
PONTIAN	13.2	1.8	72.1	173.1
PULAI	6.2	2.3	77.5	188.5
RIMBA TERJUN	25.0	1.8	72.1	173.2
SEDENAK	6.0	0.4	69.5	165.3
SENAI	3.8	1.0	76.8	185.2
SERKAT	15.5	11.0	85.7	203.6
SUNGAI KARANG	19.1	3.7	74.8	179.3
SUNGAI PINGGAN	9.3	0.3	62.9	91.1
SUNGAI TIRAM	7.4	8.2	96.6	213.7
TANJONG KUPANG	9.1	6.6	79.5	190.3
TEBRAU	2.9	2.6	82.0	201.0

Note:

Rainfall Classification		
	Light	< 41 mm
	Moderate	41 - 60.9 mm
	Heavy	61 - 80.4 mm
	Very Heavy	> 80.5 mm

Figure F-4 Rainfall report, based on the GFS forecast of 18th of March 2025.

Rainfall Warning Report (19 Mar 2025)

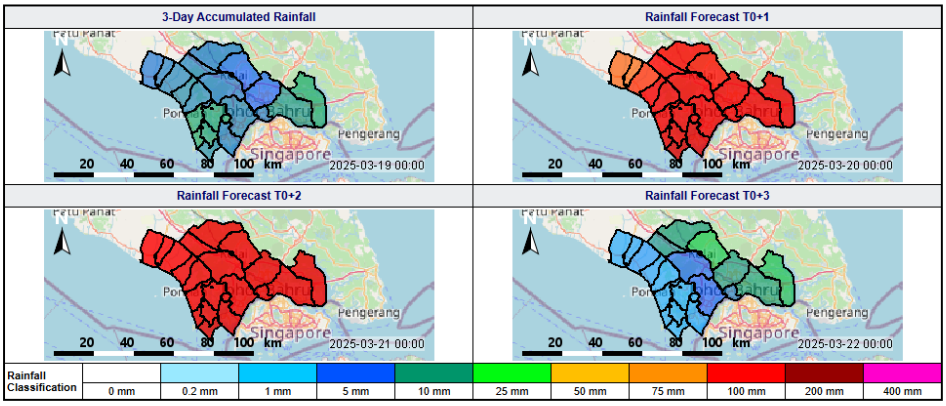


Table of Rainfall per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 19 Mar 2025

Mukim	3-Day Accumulated Rainfall [mm]	Rainfall Forecast T0+1 [mm]	Rainfall Forecast T0+2 [mm]	Rainfall Forecast T0+3 [mm]
API-API	8.1	108.0	112.7	2.7
AYER BALOI	7.5	92.7	106.3	3.1
AYER MASIN	11.9	127.6	124.3	2.3
BANDAR BENUT	7.5	81.9	99.4	2.7
BANDAR JOHOR BAHRU	7.1	115.0	123.8	7.3
BANDAR KULAI	5.2	99.9	111.2	9.1
BANDAR PONTIAN KECHIL	14.5	114.3	113.2	2.3
BANDAR TEBRAU	4.9	115.0	123.8	7.3
BENUT	6.5	84.3	101.0	2.5
BUKIT BATU	7.3	99.5	111.0	9.0
JELUTONG	11.8	114.3	113.2	2.3
JERAM BATU	10.5	114.3	113.2	2.3
KULAI	6.7	109.1	113.7	5.4
PEKAN JERAM BATU	7.3	114.3	113.2	2.3
PENGKALAN RAJA	7.4	114.3	113.2	2.3
PLENTONG	9.4	114.0	120.6	10.6
PONTIAN	7.7	114.2	113.2	2.4
PULAI	7.6	114.7	118.9	5.0
RIMBA TERJUN	11.6	114.3	113.2	2.3
SEDENAK	6.5	99.7	111.4	9.7
SENAI	4.9	97.8	114.5	17.1
SERKAT	8.3	140.0	134.6	2.3
SUNGAI KARANG	10.0	119.5	117.5	2.3
SUNGAI PINGGAN	7.1	83.2	100.2	2.6
SUNGAI TIRAM	11.8	111.3	119.2	15.5
TANJONG KUPANG	7.2	127.4	124.6	2.5
TEBRAU	5.0	112.0	122.6	9.6

Note:

Rainfall Classification		
	Light	< 41 mm
	Moderate	41 - 60.9 mm
	Heavy	61 - 80.4 mm
	Very Heavy	> 80.5 mm

Figure F-5 Rainfall report, based on the GFS forecast of 19th of March 2025.

ISKANDAR REGIONAL DEVELOPMENT AUTHORITY

Flood Warning Report (18 Mar 2025)

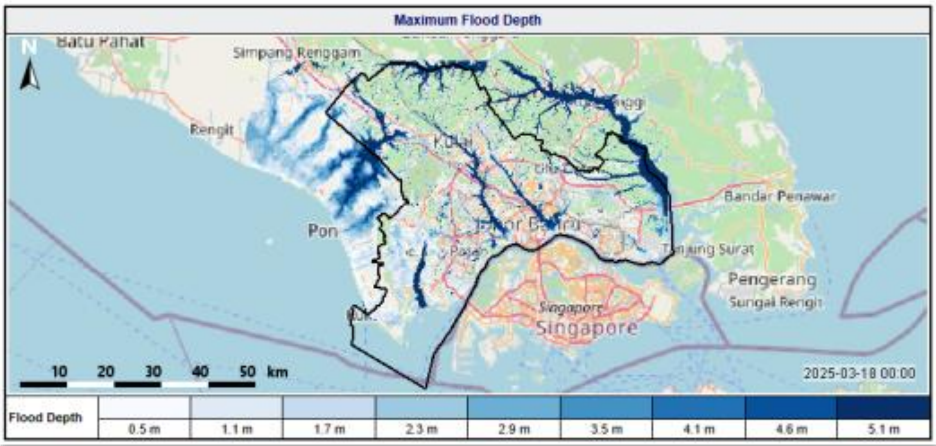


Table of Flood Early Warning Impact per Mukim for the Iskandar Malaysia Region

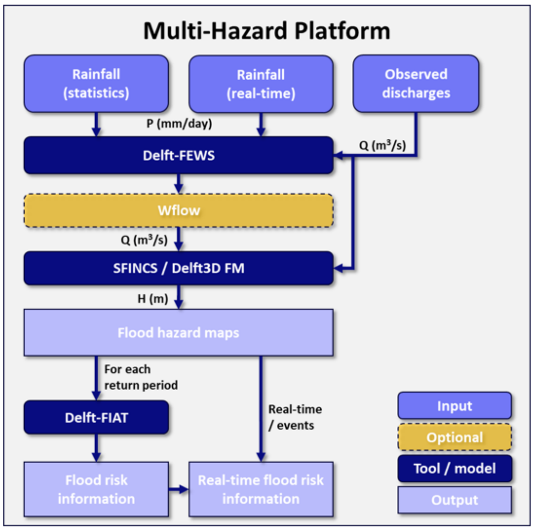
Based on forecast with T0 = 21 Mar 2025

Mukim	Flooded Area [%]	Number of Population Affected [People]	Estimated Damage to Buildings [10^3 MYR]
API-API	79.6	13,170	1,764,278
AYER BALOI	69.3	10,075	954,773
AYER MASIN	45.6	2,630	62,670
BANDAR BENUT	100.0	4,060	320,921
BANDAR JOHOR BAHRU	14.1	14,805	1,142,602
BANDAR KULAI	39.9	3,210	247,335
BANDAR PONTIAN KECHIL	89.7	2,035	378,046
BANDAR TEBRAU	94.5	115	11,788
BENUT	84.6	9,745	808,576
BUKIT BATU	49.0	5,010	974,119
JELUTONG	48.3	5,575	218,429
JERAM BATU	52.2	14,640	1,550,556
KULAI	20.3	38,920	2,208,953
PEKAN JERAM BATU	0.0	0	0
PENGKALAN RAJA	55.5	680	31,035
PLENTONG	21.5	102,010	7,261,783
PONTIAN	74.6	32,990	2,197,954
PULAI	24.7	108,930	7,956,520
RIMBA TERJUN	64.6	24,835	2,983,769
SEDENAK	22.9	4,875	419,589
SENAI	19.1	21,915	6,583,963
SERKAT	42.9	4,465	450,193
SUNGAI KARANG	45.4	670	35,084
SUNGAI PINGGAN	80.8	7,560	672,249
SUNGAI TIRAM	37.5	3,650	462,269
TANJONG KUPANG	40.1	11,370	783,457
TEBRAU	18.9	70,130	7,050,391

Figure F-6 Flood map, produced by the MHEWS, based on the forecast on 18th of March 2025, at least 24 hours prior to the floods happening.

G Factsheet: Multi-Hazard Platform – Iskandar Malaysia (MHP-IM) - Prototype Version

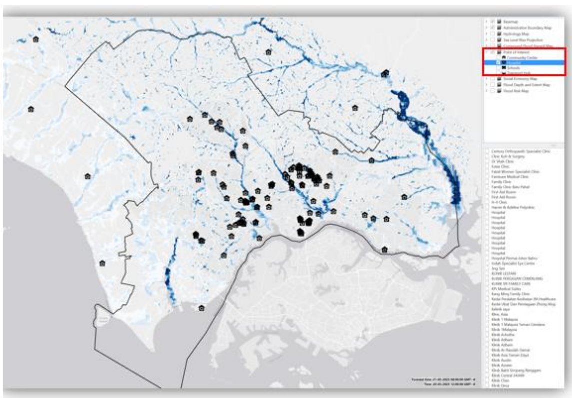
The Multi-Hazard Platform – Iskandar Malaysia (MHP-IM) is a prototype platform developed under a Technical Assistance (TA) request by the Government of Malaysia to the Climate Technology Centre and Network (CTCN). The TA, implemented by Deltares, aims to support the Iskandar Regional Development Authority (IRDA) in taking early actions to mitigate climate-related risks. The platform is designed as a decision support system that incorporates local climate extremes and physical hazard data, with an initial focus on flood risk.



MHP-IM is built using Delft-FEWS, an open-source software developed by Deltares for data integration and workflow management. It allows ingestion and visualization of time series and spatial (gridded) data from multiple providers. Delft-FEWS is selected as the core engine due to its flexibility and model integration capabilities. The prototype integrates two open-source models: wflow (hydrological model) & SFINCS (hydrodynamic model). Additionally, Delft-FIAT is used to assess flood risk impacts in the Iskandar Malaysia region.
The MHP-IM was developed through stakeholder consultations and utilizes existing institutional data sources. While still in its prototype phase, the platform enables IRDA to gain a clearer and more comprehensive understanding of disaster risks, identify flood-prone areas, and support early warning and decision-making. It is also important to note that MHP-IM incorporates modeling tools to provide flood forecasts for the Iskandar Malaysia region.

The following basemaps have been integrated and are available within the MHP-IM application

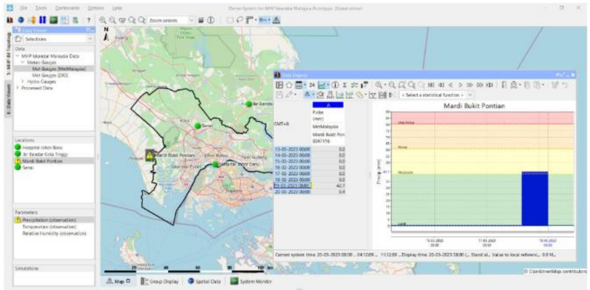
1. Administrative boundary maps (from IRDA)
2. Hydrology maps (from DID, JUPEM and derived wflow model)
3. Sea level rise projection maps (for year 2050 and 2100 from NAHRIM)
4. Compound flood hazard maps (from DID)
5. Point of Interest (PoI) maps (from OpenStreetMap)
6. Social economy maps (from DOSM)
7. Flood depth and extent maps for various return periods (from SFINCS simulation)
8. Flood risk and damage maps (calculation results using Delft-FIAT)



Point of interest maps

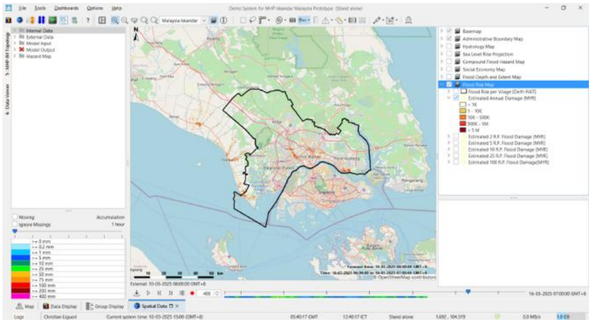
Key Features of the MHP-IM Prototype

1 Data Management & Integration
   a Validation rules and data flagging for quality control
   b Centralized data hub for historical and forecast data from:
   c Local sources: MetMalaysia, DID, JUPEM
   d Global sources: ERA5, GPM, GFS, GTSM
   e Import and export of rainfall, water level, and river discharge data
   f Extraction of global rainfall data for local meteorological stations
   g Processing of historical rainfall into areal rainfall per mukim



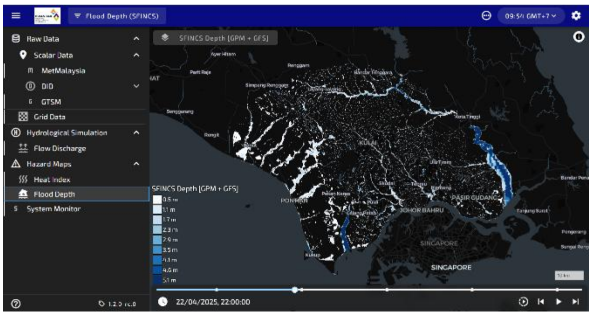
Map display and data viewer

2 Modelling & Forecasting
   a Model-based estimation of river discharge, flood depth, extent, and duration
   b Flood modeling for historical and forecasted events
   c Flood impact estimation (e.g., area affected, population impacted, potential damage)
   d Provides flood risk information based on hazard, exposure, and vulnerability
   e Generation of heat index forecasts (Demonstrates Delft-FEWS's potential for application in hazards beyond flooding)



Flood risk information

3 Information Access & Visualization
   a Integrated situational awareness
   b Visual flood warnings via reports and changing map icons
   c Provision of flood risk maps and other relevant map layers to support decision-making
   d Multi-hazard information (including sea level rise)
   e Provides information on areas impacted by sea level rise.
   f User-friendly web interface (WebOC, a light version of MHP-IM)



MHP-IM WebOC
(light version of MHP-IM)

Key Outputs of MHP-IM

1 Rainfall Report
Provides a summary of the past 3 days of rainfall and a 3-day daily forecast at the mukim level, presented in both table and map formats. This helps operators and decision-makers identify areas at risk of heavy rainfall.

2 Flood Report
Summarizes potential flood extent, including the percentage of inundated area per mukim, estimated number of affected people, and potential building damage (in MYR).

Together, these reports support timely decision-making and disaster impact reduction. Once operational, both reports can be updated every 12 hours following the import of new weather forecasts into MHP-IM.

Rainfall Warning Report (19 Mar 2025)

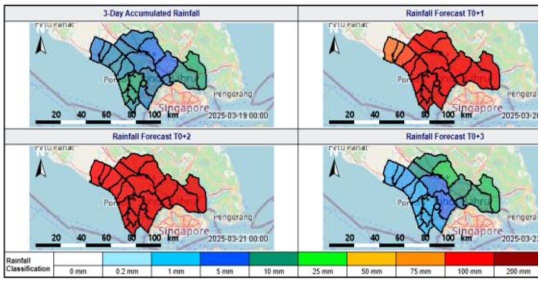


Table of Rainfall per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 19 Mar 2025

Mukim	3-Day Accumulated Rainfall [mm]	Rainfall Forecast T0+1 [mm]	Rainfall Forecast T0+2 [mm]	Rainfall Forecast T0+3 [mm]
API-API	8.1	108.0	112.7	2.7
AYER BALOI	7.5	92.7	106.3	3.1
AYER MASIN	11.9	127.6	124.3	2.3
BANDAR BENUT	7.5	81.9	99.4	2.7
BANDAR JOHOR BAHRU	7.1	115.0	123.8	7.3
BANDAR KULAI	5.2	99.9	111.2	9.1
BANDAR PONTIAN KECHIL	14.5	114.3	113.2	2.3
BANDAR TEBRAU	4.9	115.0	123.8	7.3
BENUT	6.5	84.3	101.0	2.5
BUKIT BATU	7.3	99.5	111.0	9.0
JELUTONG	11.8	114.3	113.2	2.3
JERAM BATU	10.5	114.3	113.2	2.3
KULAI	6.7	109.1	113.7	5.4
PEKAN JERAM BATU	7.3	114.3	113.2	2.3
PENGKALAN RAJA	7.4	114.3	113.2	2.3
PLENTONG	9.4	114.0	120.6	10.6
PONTIAN	7.7	114.2	113.2	2.4
PULAI	7.6	114.7	118.9	5.0
RIMBA TERJUN	11.6	114.3	113.2	2.3
SEDENAK	6.5	99.7	111.4	9.7
SENAI	4.9	97.8	114.5	17.1
SERKAT	8.3	140.0	134.6	2.3
SUNGAI KARANG	10.0	119.5	117.5	2.3
SUNGAI PINGGAN	7.1	83.2	100.2	2.6
SUNGAI TIRAM	11.8	111.3	119.2	15.5
TANJONG KUPANG	7.2	127.4	124.6	2.5
TEBRAU	5.0	112.0	122.6	9.6

Note:

Rainfall Classification		
	Light	< 41 mm
	Moderate	41 - 60.9 mm
	Heavy	61 - 80.4 mm
	Very Heavy	> 80.5 mm

Rainfall report report produced by MHP-IM

Flood Warning Report (19 Mar 2025)

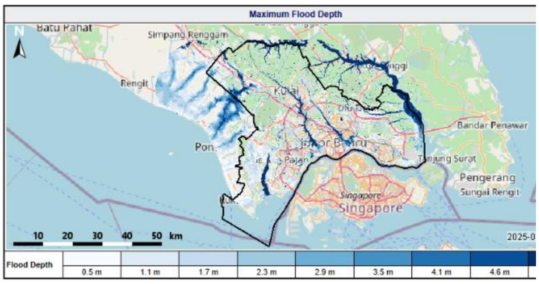


Table of Flood Early Warning Impact per Mukim for the Iskandar Malaysia Region

Based on forecast with T0 = 19 Mar 2025

Mukim	Flooded Area [%]	Number of Population Affected [People]	Estimated Damage to Buildings [10^3 MYR]
API-API	83.5	13,375	1,831,905
AYER BALOI	73.3	10,265	1,039,984
AYER MASIN	46.7	2,735	70,587
BANDAR BENUT	100.0	4,060	320,921
BANDAR JOHOR BAHRU	15.1	16,470	1,227,929
BANDAR KULAI	43.2	3,500	262,520
BANDAR PONTIAN KECHIL	89.8	2,040	424,199
BANDAR TEBRAU	100.0	125	11,788
BENUT	87.2	9,925	834,830
BUKIT BATU	51.8	5,565	992,918
JELUTONG	49.3	5,640	222,916
JERAM BATU	53.2	15,595	1,639,148
KULAI	21.7	42,980	2,306,170
PEKAN JERAM BATU	0.0	0	0
PENGKALAN RAJA	57.6	690	34,527
PLENTONG	22.3	108,355	7,763,961
PONTIAN	77.5	33,635	2,363,516
PULAI	25.4	112,420	8,313,512
RIMBA TERJUN	66.6	25,130	3,091,486
SEDENAK	25.2	6,335	533,341
SENAI	20.1	23,665	6,960,145
SERKAT	44.1	4,540	492,157
SUNGAI KARANG	46.1	710	35,199
SUNGAI PINGGAN	83.2	7,640	688,435
SUNGAI TIRAM	38.3	3,765	476,632
TANJONG KUPANG	41.2	11,750	937,834
TEBRAU	19.9	73,985	7,609,622

Flood report produced by MHP-IM

H Capacity needs and gender assessment

DEVELOPMENT OF A MULTI-HAZARD PLATFORM (MHP) FOR FORECASTING LOCAL LEVEL CLIMATE EXTREMES AND PHYSICAL HAZARDS FOR ISKANDAR MALAYSIA

Report for task 4.1 and 4.2

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