

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

Functional and Technical Design Report



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# 1 Introduction

The Climate Technology Centre and Network (CTCN), being the operational arm of the United Nations Framework Convention on Climate Change, 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 will deliver a prototype decision support tool which will demonstrate how a multi-hazard platform for five zones of Iskandar Malaysia can help address growing climate change risks of this important coastal economic zone.

The overall goal of the project is 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-centred forecasting system using social innovation.

The project, commissioned to Deltares, aims to capacitate the Iskandar Regional Development Authority in the development of a prototype of the multi-hazard platform. There are 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-centred 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 on 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 will be 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 will be 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 will be developed. The functional and technical design are used as input for the prototype, but the prototype shall not be fully covering

all elements from the functional and technical design. An implementation plan, including a rough cost estimate for the development of a fully functioning prototype will be developed in parallel to demonstrate how the prototype can be upscaled.

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

This document describes the results of phase 2 of the project: The functional and technical design of a Multi-Hazard Platform for Iskandar Malaysia. The designs are the basis for the further development of the prototype, which will be delivered in the next phase of the project.

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.

Next steps in the project include the actual development of the prototype using local data, and the design and development of the early warning protocols and associated knowledge products.

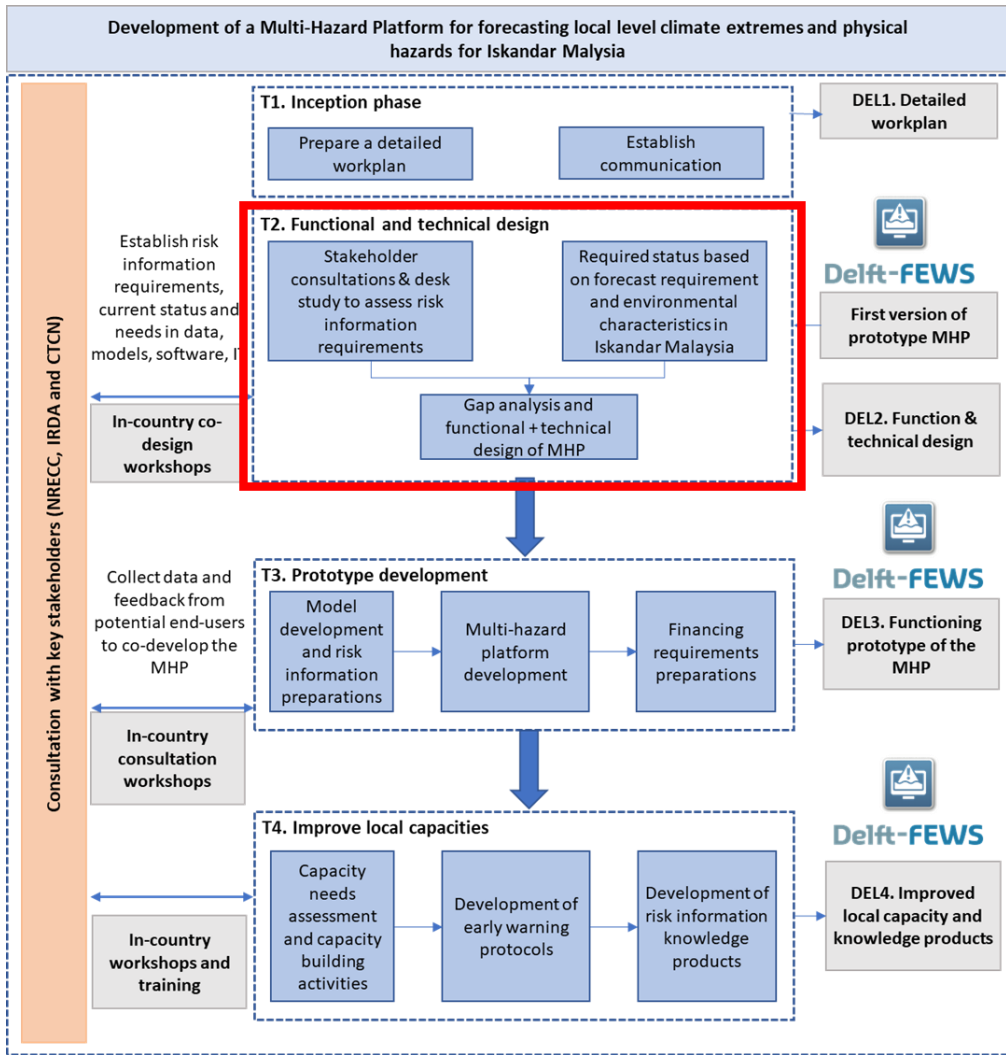


Figure 1-1 Project outline with in red the phase corresponding to this report.

## 2 Study area

This project will be 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<sup>2</sup>, 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 mainly concentrated in Johor Bahru. IM also has several important areas of manufacturing industries and tourism.

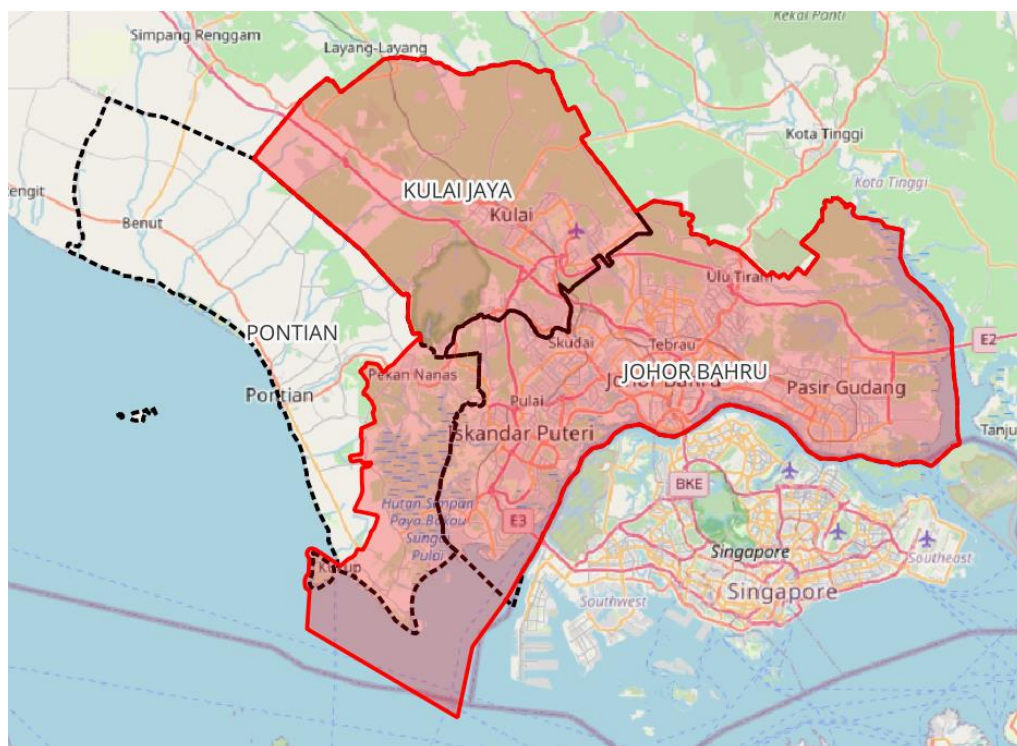


Figure 2-1 Study area indicated by the red area.

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 et al., 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.

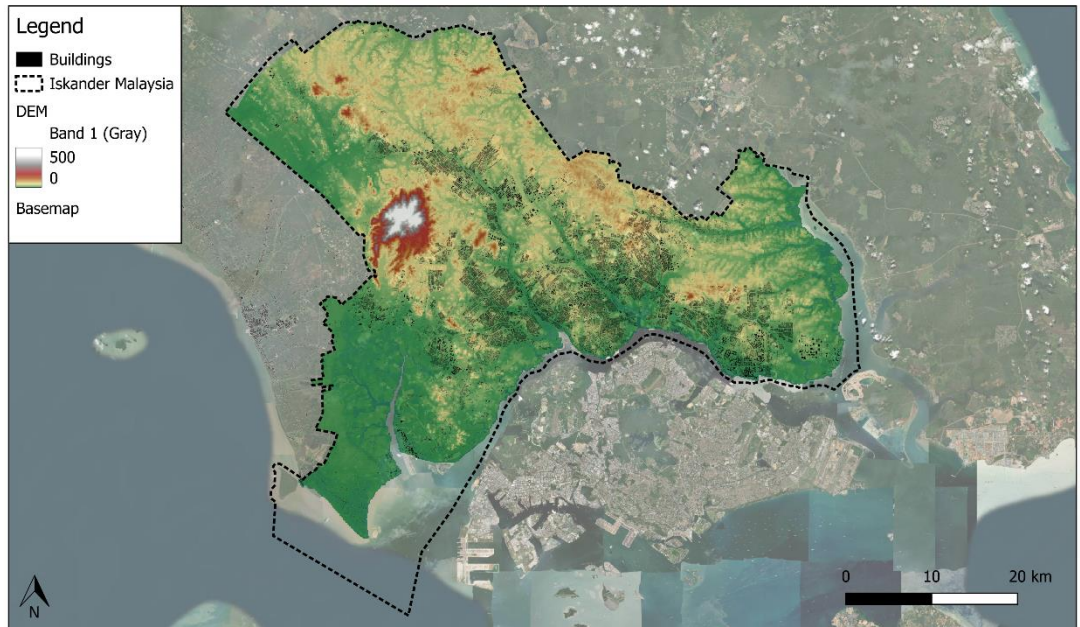


Figure 2-2 Elevation and location of buildings (both residential and economic) for the Iskandar Malaysia region.

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 loss their houses. Therefore, in this project, floodings will be used as a pilot for the 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 for other regions in Malaysia. The functional and technical design therefore can be seen as a blue print for applications across Malaysia.

# 3 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 it will be grouped 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 can be defined, such as the key outputs of the platform, which will form the basis for the functional design of the system.

## 3.1 Overview of relevant stakeholders

Apart from the desk-study and literature review, in this project the consultant also conducts a workshop to gather more information about the client needs, where to find the data for the development of MHP IM and the existing platforms that can be connected to MHP IM. The workshop itself was conducted fully offline on 11 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.

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

1. Existing system/platforms
2. Data requirements
3. User requirements and user perspectives

For each breakout session, the consultant has prepared several questions to be answered by the workshop participants (Appendix A). These questions are meant for triggering your thinking process and to help the consultant to get valuable information for the functional and technical design of the platform.

Apart from the workshop, Malaysia outlined the protocols for managing natural disasters such as floods through the National Security Council Directive No. 20 (MKN 20). It consists of the policy and mechanism for disaster management and relief. It includes the use of early warning systems (EWS) for floods. Therefore, the implementation of MHP IP will align with the key aspects of MKN 20.

MKN 20 already listed the incidents which are considered as disasters. Through this directive, disaster management is controlled in accordance with disaster level (Figure 3-1). MKN 20 emphasizes the establishment of effective early warning systems and timely dissemination of warnings to the public. Role of the involved agencies were defined. Agencies like the Malaysian Meteorological Department (MetMalaysia), the Department of Irrigation and Drainage (DID), and the Malaysian National Disaster Management Agency (NADMA) are key players.

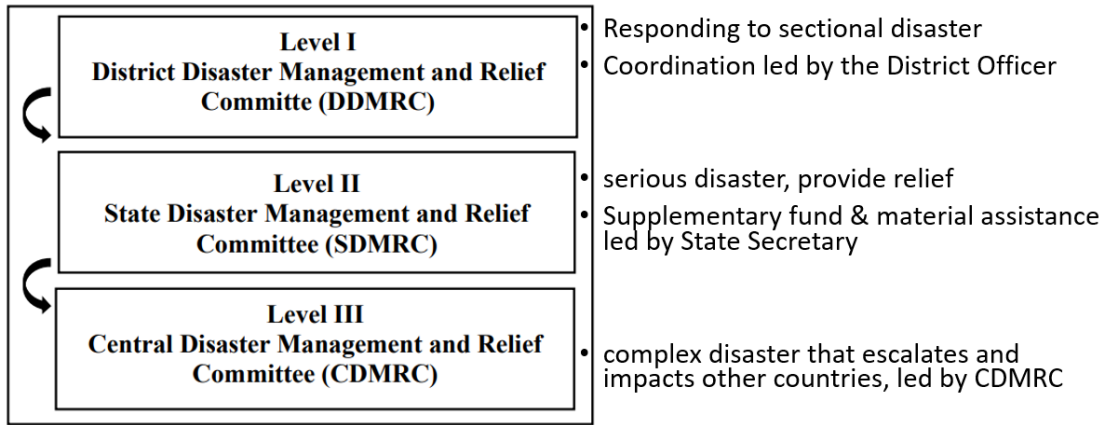


Figure 3-1 Level of disasters based on MKN 20.

### 3.2 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-IP 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 3-2 illustrates the typical agencies involved in each phase of the Early Warning System (EWS) and their respective groups. Additionally, Figure 3-3 lists the stakeholders identified during the first workshop.

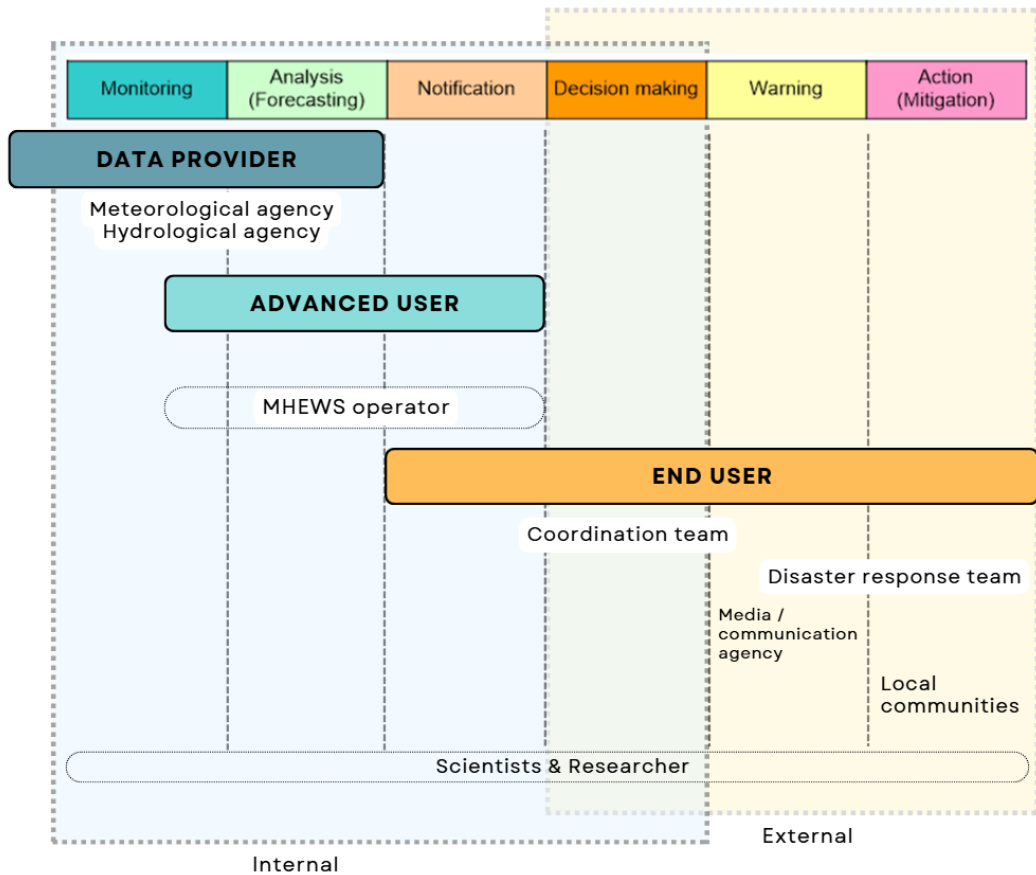


Figure 3-2 Stakeholders on a multi-hazard early warning systems. Top bars showing the phase of a disaster event where each user should play a role. Blue box indicates the internal system which mainly regulates the role of the data providers and advanced users, while the yellow box indicates the external system of MHP-IP.

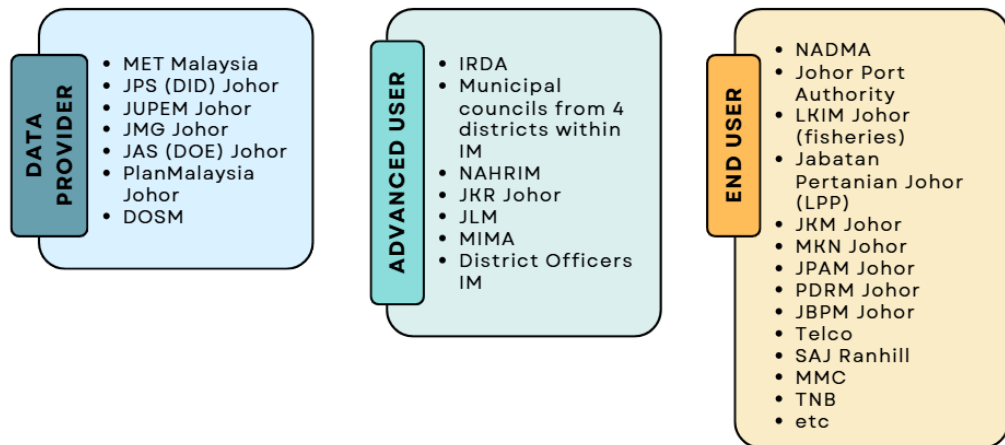


Figure 3-3 Stakeholder groups of the designed early warning system for Iskandar Malaysia

Data providers play a crucial role in the monitoring and analysis phases of forecasting within Multi-Hazard Platform (MHP-IP). 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-IP.

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 3-4.

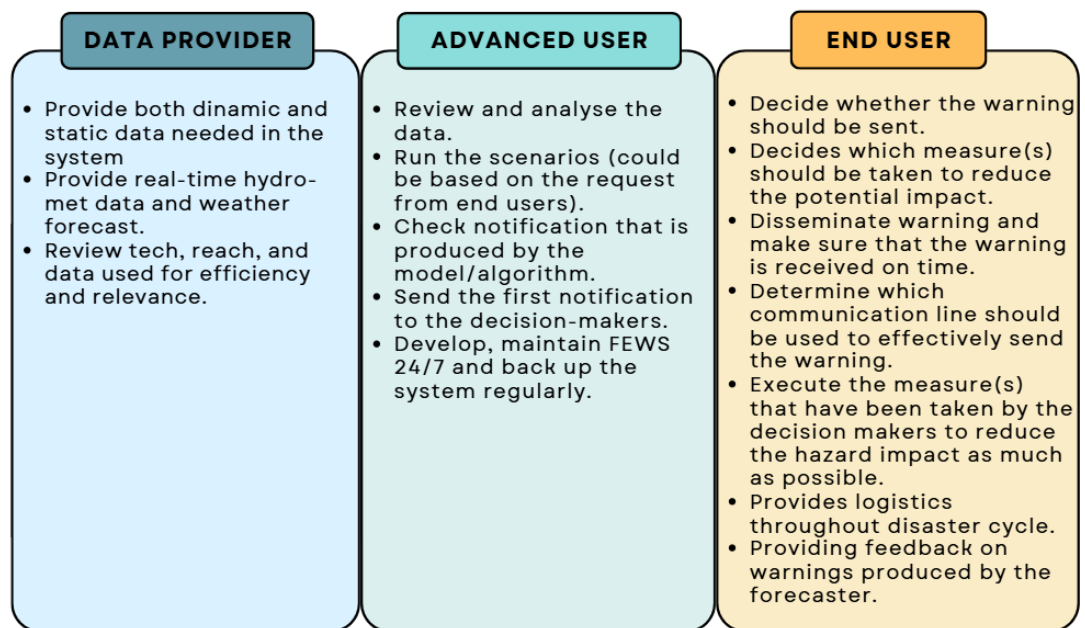


Figure 3-4 Responsibility of each group of multi-hazard early warning system

# 4 Methodology

## 4.1 General approach

The multi-hazard platform is used for different purposes, but a lot of the base data and information can be shared 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, wflow model was use the open-source, which is a 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 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, real-time flood hazard maps can be generated using the model workflow and 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 defences of flood mitigation strategies.

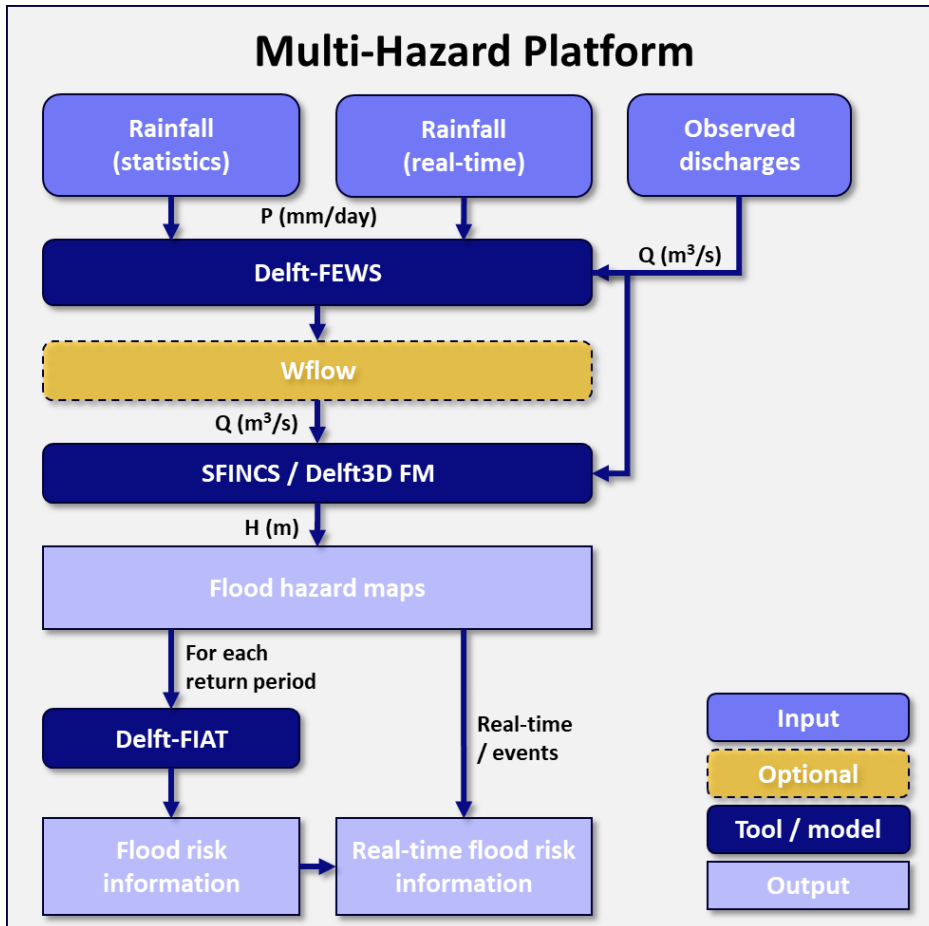


Figure 4-1 Schematic overview of the MHP components and their connections.

#### 4.1.1 Stakeholder Consultation Workshops

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 11 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) Existing system/platforms
- 2) Data requirements
- 3) User requirements and user perspectives

For each breakout session, the consultant has prepared several questions to be answered by the workshop participants (Appendix A). 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 4-2 Group picture after the morning session of the 11 March workshop.

On the 24<sup>th</sup> of June 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.

#### 4.1.2 Data collection

To build the Multi-Hazard Platform Iskandar Malaysia (MHP-IP), various types of data are required. The quantity of data needed depends on the number of hazards intended to be monitored within the MHP-IP. Based on the results of the first workshop and discussions with the client, the consultant recommended that the prototype MHP-IP 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-IP 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 into two categories, namely:

- **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 will be based on the infrastructure damage. Therefore, building footprint will be 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.

Used for calculating flood risk. Includes building vulnerabilities data. 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-IP 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 MHP to increase lead time. If a country does not have its own weather forecasting model, numerous free weather forecast models are available globally for MHP purposes.

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 flood (hydraulic) 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 prioritising measures for these groups.

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

#### 4.1.3 Flood risk assessment

As part of the project, a flood risk information assessment 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 task 2.2, 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 will be used to prepare the coastal hazard and risk assessment.

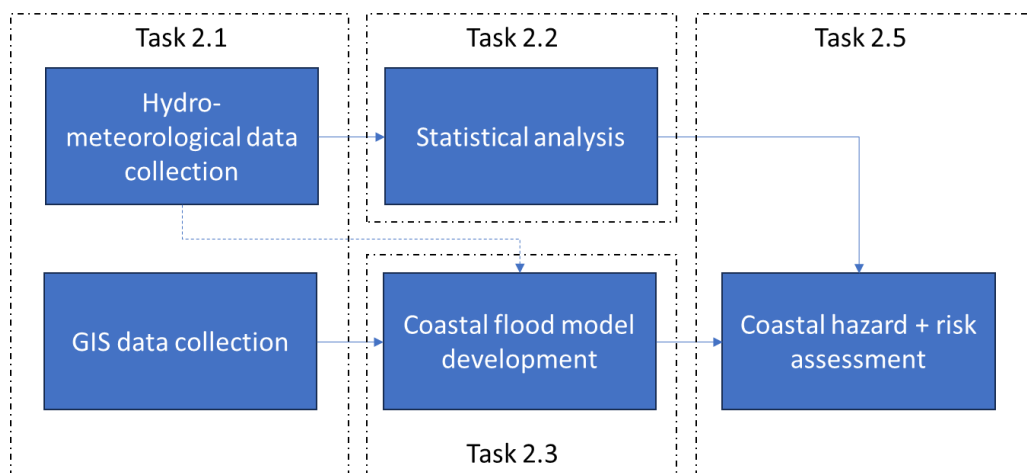


Figure 4-3 Schematic of how the data and models are used for the flood risk assessment and how the different tasks contribute to the flood risk assessment.

Flood risk, which will be done using Delft-FIAT (see Figure 4-1), 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 4-4 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 normalised 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.

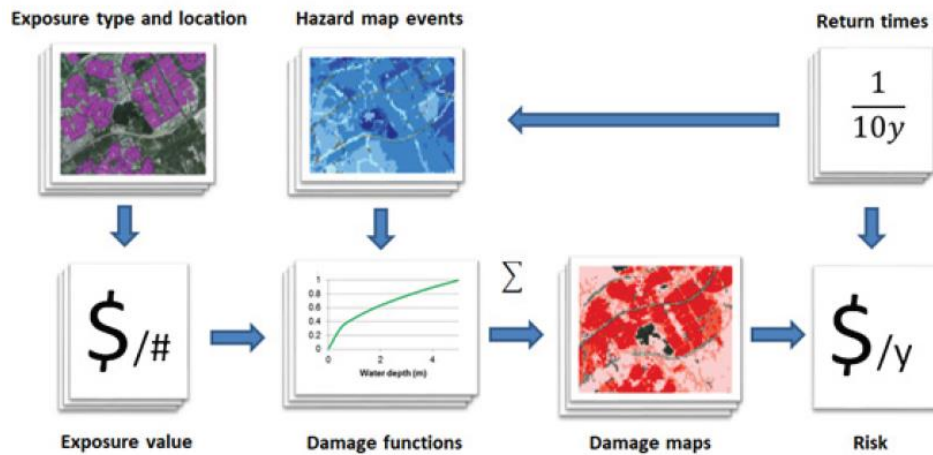


Figure 4-4 Overview of the procedure to compute flood risk in Delft-FIAT. The exposure overlay with the hazard map resulted in a damage maps.

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

- **Assets** refer to buildings (or building assets) which are defined here in three categories: residential, commercial, and industrial.
- **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<sup>2</sup>. 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 4-4.
- **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 flood events.

#### 4.1.4 Development of a prototype

The data and the results of the flood risk assessment shall be integrated into the MHP-IP prototype. The prototype shall demonstrate the possibilities of the MHP-IP to support Iskandar Malaysia agencies and key stakeholders monitoring and forecasting climate related hazards and risks.

## 4.2 Selection of hydrometeorological and hazard models (activity 2.1)

The multi-hazard platform will provide key insights in climate related hazards and risks for Iskandar Malaysia. 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 4-5.



Figure 4-5 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 will be on the flood hazards, including river floods, flash floods, coastal floods, pluvial 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.

### 4.3 Establish threshold values (activity 2.2)

To establish threshold values the following steps are taken:

- Data collection
- Statistical processing
- Development of a risk matrix

### 4.3.1 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) and discharges (rivers). Threshold 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.

### 4.3.2 Statistical analysis

Based on the available data, the statistical analysis can be done. An example, currently based on dummy data, of such analysis is shown in Figure 4-6 and Figure 4-7, where 30 years of discharge data is analysed and processed into discharge statistics. In the MHP-IP, 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.

***The statistical analysis presented in the figures below shall be updated using local meteorological and hydrological data as part of Phase 3 of the project. The current figures are meant for demonstration purpose.***

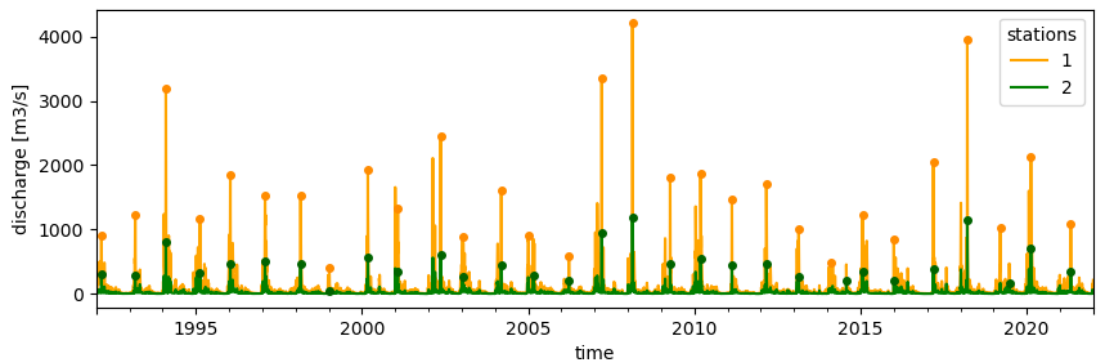


Figure 4-6 Discharge timeseries for 2 hydrological stations for the period 1992 – 2022 (30 years).

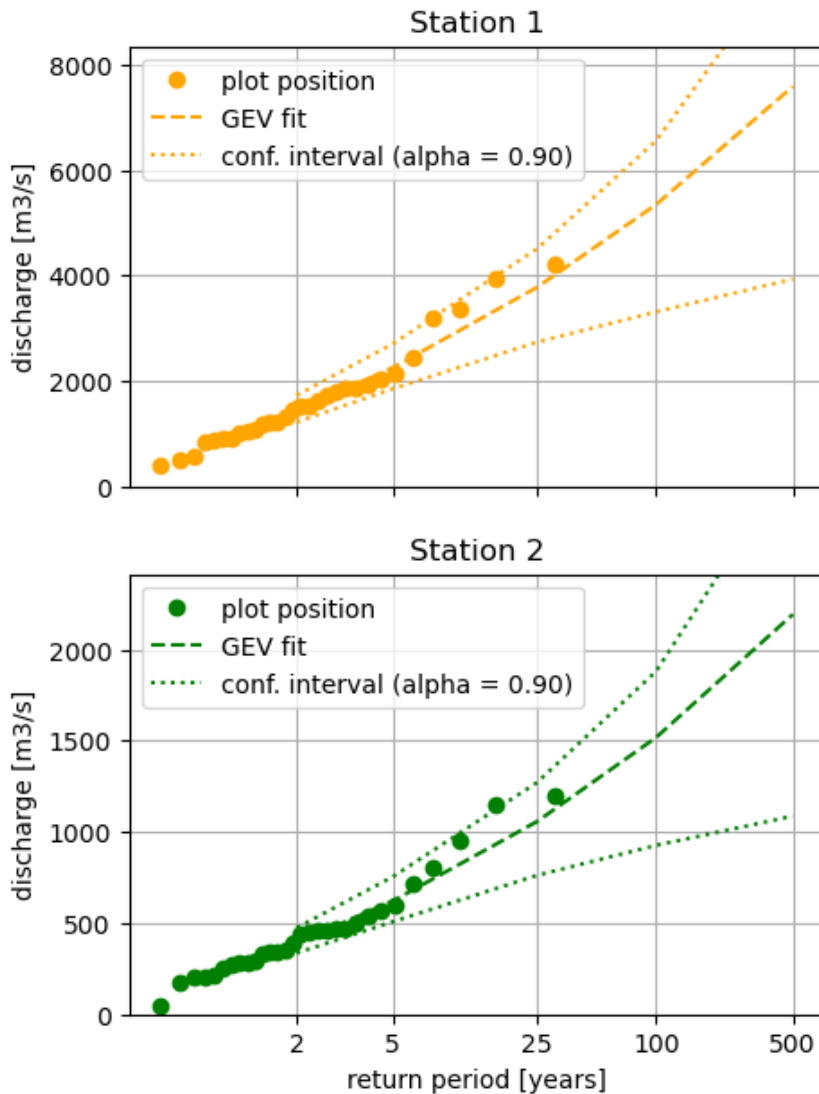


Figure 4-7 Statistics for 2 hydrological stations based on 30 years of data.

#### 4.4 Generate probabilistic hazard maps (activity 2.3)

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, Wflow-SBM model was used as the grid-based. 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 based on thresholds value be classified. An example of the European EFAS system is shown in Figure 4-8. The same can also be done in the MHP-IP and for different variables.

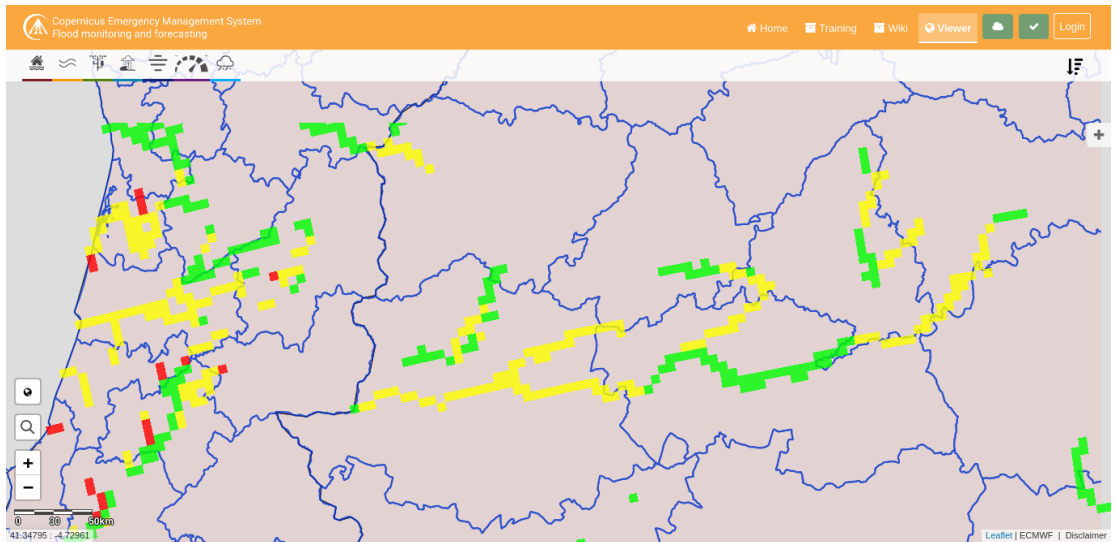


Figure 4-8 Example of the use of spatial statistical information in real-time situations from the European Flood Awareness System (EFAS).

For flood induction, the SFINCS models will be 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 will be 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).

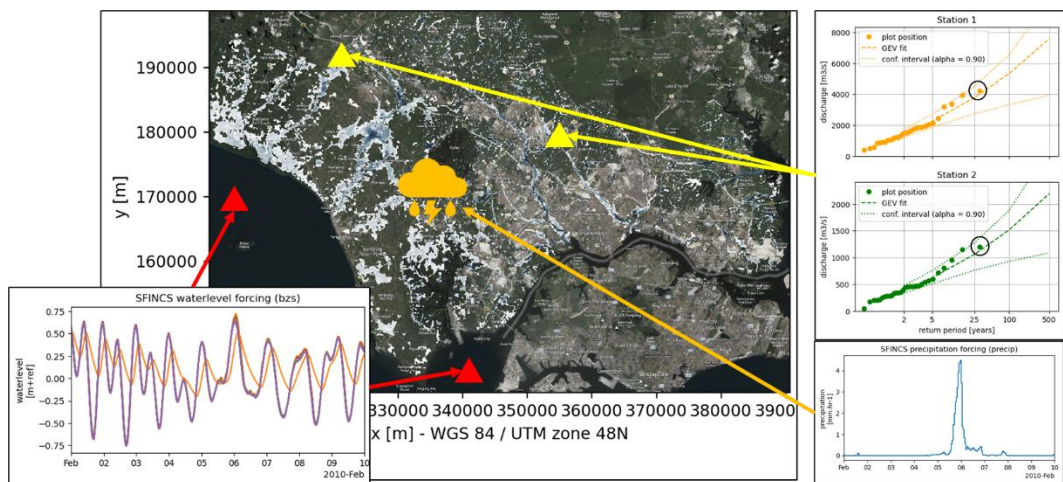


Figure 4-9 Schematic showing how to generate probabilistic flood hazard maps.

#### 4.5 Update / develop vulnerability curves (activity 2.5)

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.

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 4-10:

**1. Exposure**

Exposure is defined by 'object' maps, where each object relates to assets (i.e. buildings, roads) or population at risk.

**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.

**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.

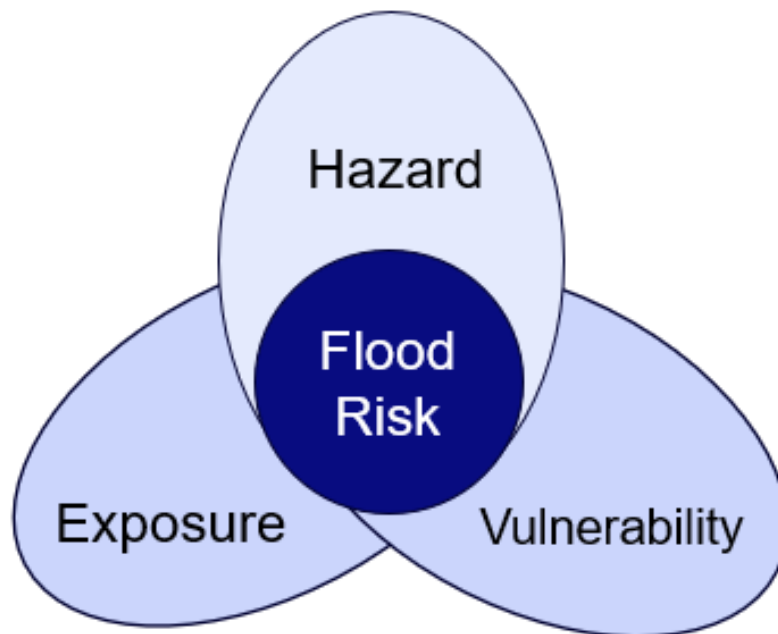


Figure 4-10 Overview of Delft-FIAT concept which combines hazard, vulnerability, and exposure data.

D-FIAT calculates damage for each asset in the object map (Figure 4-11) by referencing the maximum flood depth at that location, to the corresponding depth (or wind speed) in the damage function providing the fraction of the asset damaged, which is then multiplied by the maximum potential damage for the asset. The final maps showing 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 as a MS Excel database and a GIS Shapefile. Results were also provided as normalized values (USD/hectare and USD/m<sup>2</sup>), 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.

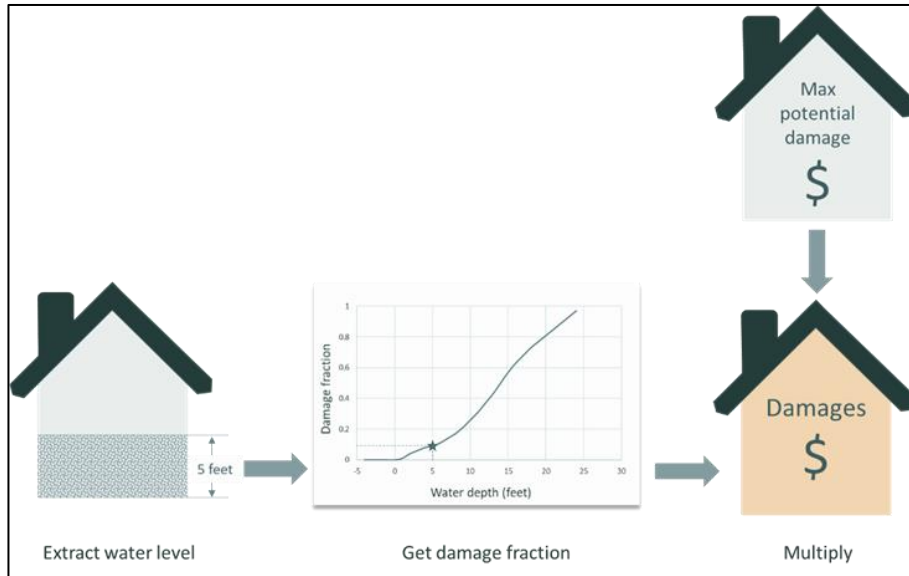


Figure 4-11 Delft-FIAT damage calculation procedure for each asset

#### 4.6 Design localized hazard forecasting (activity 2.4)

The goal of this activity is to develop the MHP-IP 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 will 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-IP can easily understand the severity of an event. This comparison can be done in a visual manner such as using background colours in graphs for specific threshold crossings (Figure 4-12).

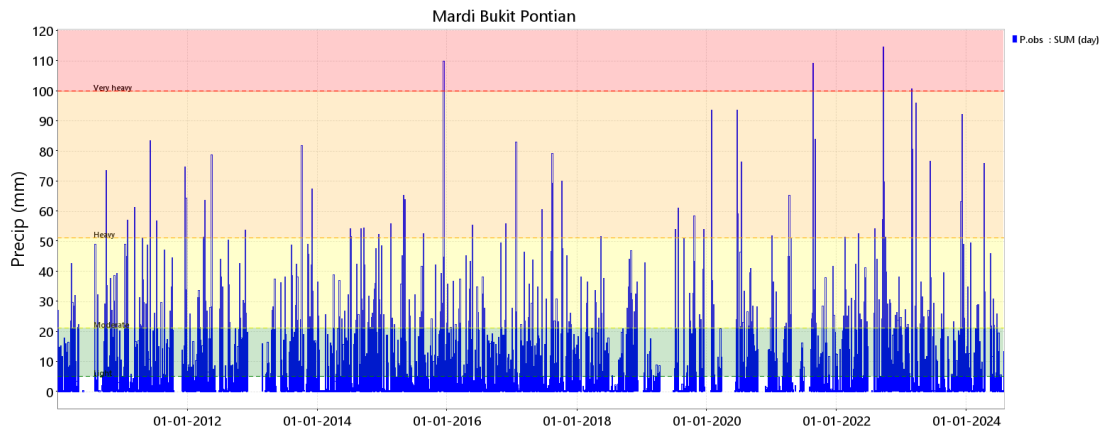


Figure 4-12 Warning levels based on statistical analysis.

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 4-13). Based on the lead time, a Standard Operating Procedure (SOP) can be setup to produce localized hazard forecasting.

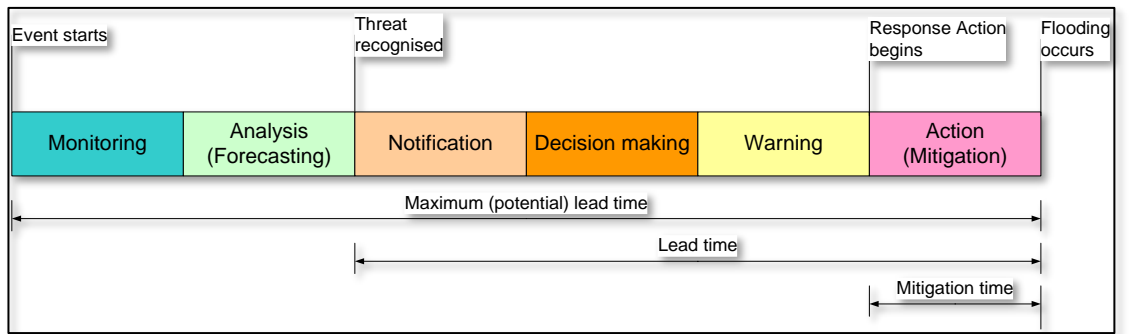


Figure 4-13 Schematic overview for deriving the required lead time for action

# 5 Functional and technical design

## 5.1 Delft-FEWS platform

The prototype will be 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 formats 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. 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-IP 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-IP. 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.

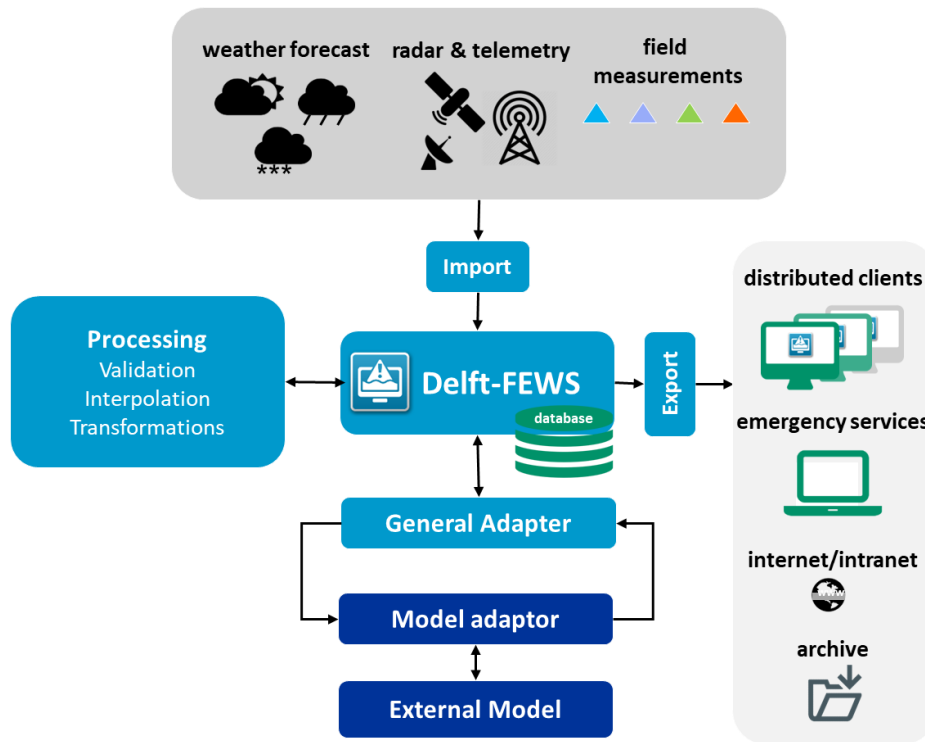


Figure 5-1 Schematic overview of the Delft-FEWS platform.

As stated, the prototype MHP-IP will be setup using Delft-FEWS. The prototype will be 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-IP, 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-IP Iskandar Malaysia (IM).

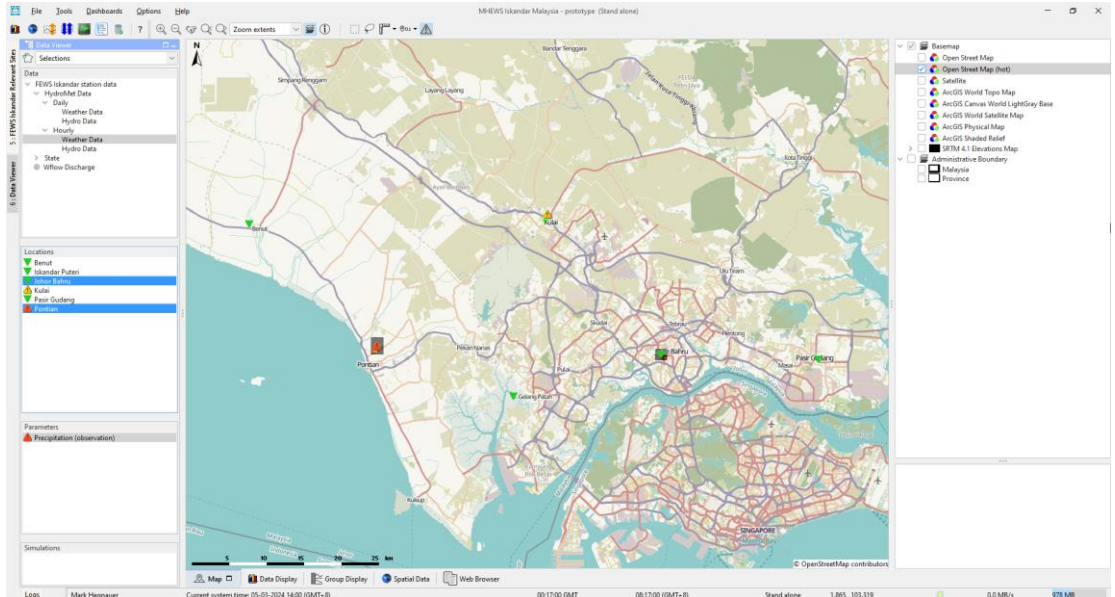


Figure 5-3 Opening screen of the MHP-IP Iskandar Malaysia (IM), showing the map display.

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.

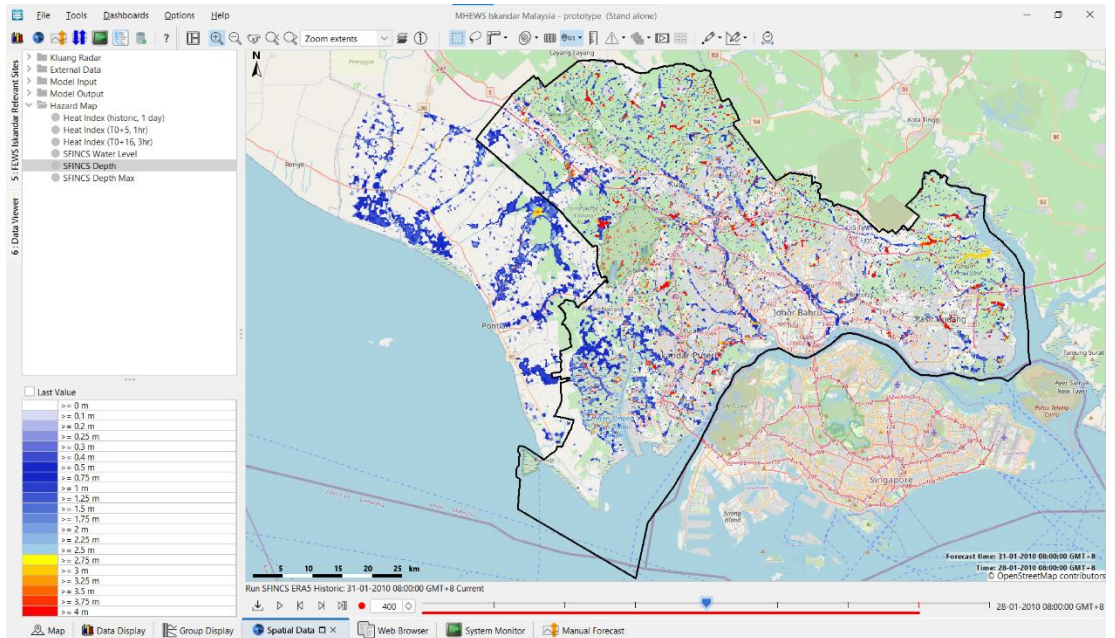


Figure 5-4 MHP-IP Iskandar Malaysia Spatial Data Display.

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. On overview of the tabs available in the System Monitor of a Standalone system is illustrated below.

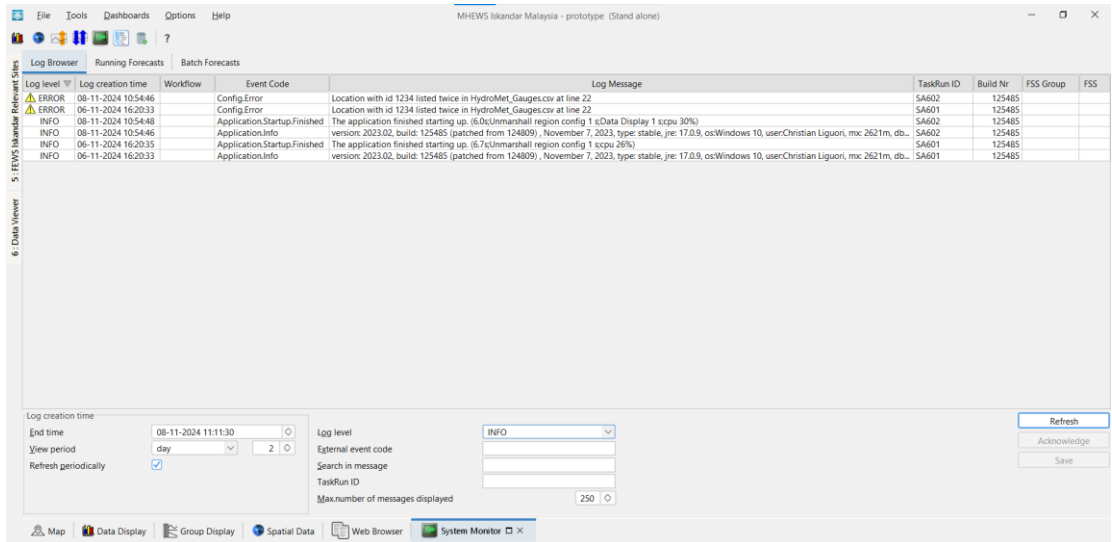


Figure 5-5 MHP-IP Iskandar Malaysia System Monitor

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.

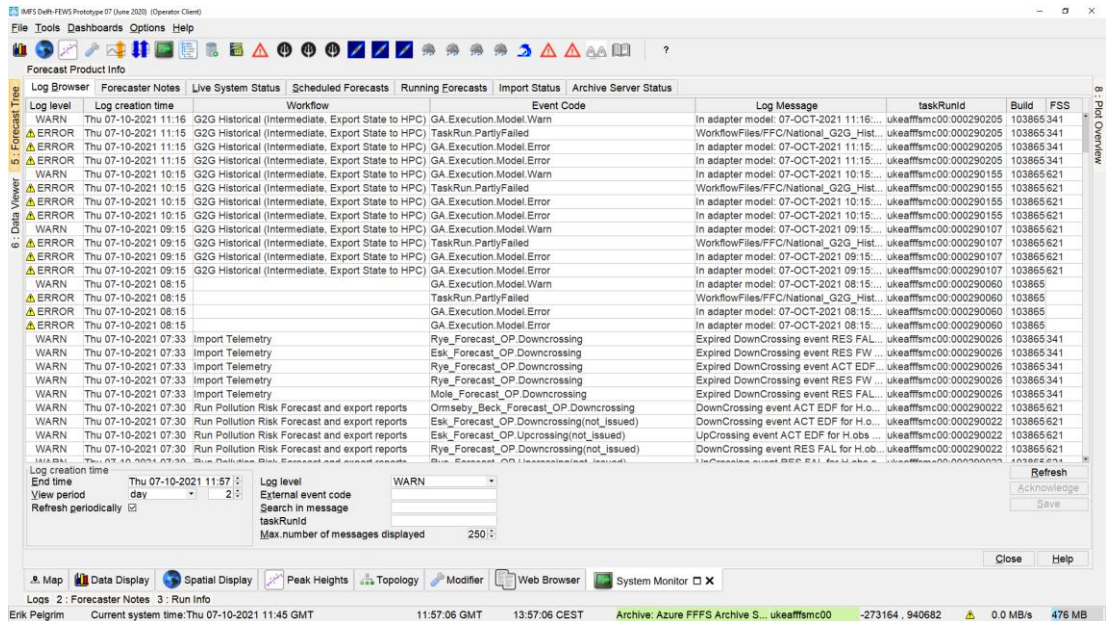


Figure 5-6 Example of the System Monitor display in Delft-FEWS OC

## Manual Forecast Display

The Manual Forecast Display displays 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-IP 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.

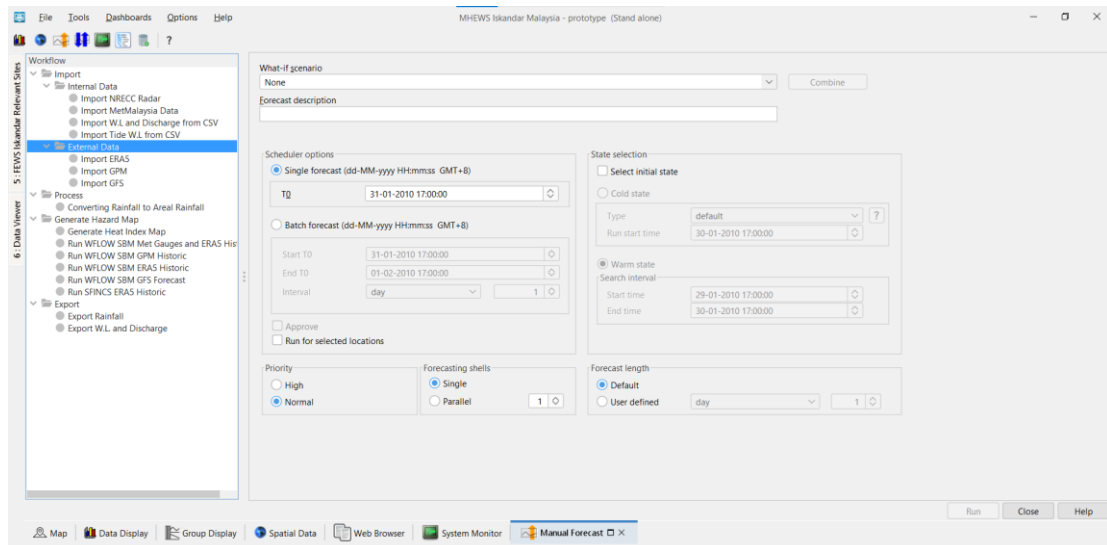


Figure 5-7 MHP-IP Iskandar Malaysia Manual Forecast Display

## 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 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-IP Iskandar Malaysia.

Approved	Success	Used	ID	Dispatch time	Workflow	What-if scen.	Description	FDO	FSS ID	FSS Group ID	Runtime	Out..	Blo..
			31-01-2010 08:00:00	24-09-2024 15:49:45	Run SFNCS ERA5 Historic	Christian Ligu	none	45 m 3 s	11 d				
			21-01-2010 08:00:00	26-09-2024 18:14:33	Run SFNCS ERA5 Historic	Christian Ligu	none	31 m 54 s	11 d				
			11-01-2010 08:00:00	26-09-2024 16:59:34	Run SFNCS ERA5 Historic	Christian Ligu	none	53 m 54 s	10 d				
			31-07-2024 08:00:00	26-09-2024 16:56:20	Import Tide W.L from CSV	Christian Ligu	none	4 s	9 y 1..				
			21-07-2024 08:00:00	25-09-2024 15:11:54	Run WFLOW SBM Met Gauges and ERA5 Historic	Christian Ligu	none	44 m 13 s	3 y 2..				
			31-12-2020 08:00:00	25-09-2024 14:18:13	Run WFLOW SBM Met Gauges and ERA5 Historic	Christian Ligu	none	53 m 42 s	5 y 2..				
			31-12-2015 08:00:00	25-09-2024 13:09:57	Run WFLOW SBM Met Gauges and ERA5 Historic	Christian Ligu	none	1 h 8 m 1..	5 y 3..				
			31-01-2010 08:00:00	25-09-2024 13:06:02	Run WFLOW SBM Met Gauges and ERA5 Historic	Christian Ligu	none	55 s	31 d				
			31-07-2024 08:00:00	25-09-2024 12:46:33	Generate Heat Index Map	Christian Ligu	none	32 s	17 y..				
			23-09-2024 08:00:00	24-09-2024 19:06:12	Run WFLOW SBM GFS Forecast	Christian Ligu	none	24 s	7 d				
			23-09-2024 08:00:00	24-09-2024 18:43:32	Run WFLOW SBM GPM Historic	Christian Ligu	none	14 s	2 d				
			20-09-2024 08:00:00	24-09-2024 18:35:58	Import GPM	Christian Ligu	none	7 m 54 s	23 h..				
			23-09-2024 08:00:00	24-09-2024 18:34:05	Run WFLOW SBM GPM Historic	Christian Ligu	none	17 s	2 d				
			20-09-2024 08:00:00	24-09-2024 18:31:58	Import GFS	Christian Ligu	none	2 m 8 s	16 d				
			23-09-2024 08:00:00	24-09-2024 17:38:05	Import GFS	Christian Ligu	none	1 m 48 s	16 d				
			22-09-2024 08:00:00	24-09-2024 17:35:53	Import GFS	Christian Ligu	none	2 m 37 s	16 d				
			21-09-2024 08:00:00	24-09-2024 17:33:56	Import GFS	Christian Ligu	none	1 m 57 s	16 d				
			21-09-2024 08:00:00	24-09-2024 17:25:47	Import GPM	Christian Ligu	none	8 m 10 s	23 h..				
			22-09-2024 08:00:00	24-09-2024 17:17:14	Import GPM	Christian Ligu	none	8 m 32 s	23 h..				
			23-09-2024 08:00:00	24-09-2024 17:11:14	Import GPM	Christian Ligu	none	6 m	17 h..				

Workflow Id	Filters	Location Id	Location Name	Parameter Group	Parameter Name	Parameter Instance	Module	X	Y	Z	Time Series Type	Value	Time Step	Start	End	Time Span	Time Count	Time Stamp	Stored		
1		38	38	4	6	2					1	2		20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		3141	31418		
Run_SF1..	SFNCS..	Iskandar	SFNCS..	Iskandar	Water Level	Hsrm	Water_L..	SFNCS..	L..	0	0	0.00	simulate..	grid	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12
Run_SF1..	SFNCS..	Iskandar	SFNCS..	Iskandar	Flood Depth	D.sirm	Depth (s..	SFNCS..	L..	0	0	0.00	simulate..	grid	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12
Run_SF1..	SFNCS..	Iskandar	SFNCS..	Iskandar	Flood Depth	Maximu..	SFNCS..	L..	0	0	0.00	simulate..	grid	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		11	11	
Run_SF1..	SFNCS..	Iskandar	SFNCS..	Iskandar	Precip	Precip..	Meteco..	P..	0	0	0.00	simulate..	grid	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_1	WL_1	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	301638	175450		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_10	WL_10	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	365220	178456		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_2	WL_2	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	311895	170187		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_3	WL_3	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	512379	158180		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_4	WL_4	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	324588	149237		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_5	WL_5	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	336820	145681		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_6	WL_6	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	350085	154378		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_7	WL_7	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	357349	160882		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_8	WL_8	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	373074	161168		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_9	WL_9	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	391649	167256		simulate..	scalar	day	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		12	12	
Run_SF1..	SFNCS..	WL_1	WL_1	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	301638	175450		simulate..	scalar	hour	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		265	265	
Run_SF1..	SFNCS..	WL_10	WL_10	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	365220	178456		simulate..	scalar	hour	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		265	265	
Run_SF1..	SFNCS..	WL_2	WL_2	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	311895	170187		simulate..	scalar	hour	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		265	265	
Run_SF1..	SFNCS..	WL_3	WL_3	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	512379	158180		simulate..	scalar	hour	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		265	265	
Run_SF1..	SFNCS..	WL_4	WL_4	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	324588	149237		simulate..	scalar	hour	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		265	265	
Run_SF1..	SFNCS..	WL_5	WL_5	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	336820	145681		simulate..	scalar	hour	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		265	265	
Run_SF1..	SFNCS..	WL_6	WL_6	Water Level	H.tidal.o..	Tidal W..	Meteco..	P..	350085	154378		simulate..	scalar	hour	20-01-2010 08:00:00	31-01-2010 08:00:00	11 d		265	265	

Figure 5-8 MHP-IP Iskandar Malaysia Database Lister Display

## 5.2 Importing of data

The first step in the design and setup of the MHP-IP is to configure the import of external data. 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 required type of data, primary and alternative source for the data is presented in Table 5-1.

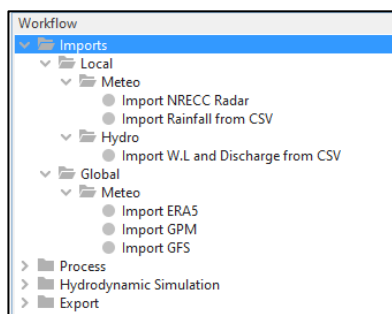


Figure 5-9 Example workflow structure.

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

Dataset	Preferred format	file-	Primary source	Alternative source
Historical rainfall data (grids)	NetCDF		MET	GPM / ERA5
Forecasted rainfall data (grids)	GRIB, NetCDF		MET	GFS
Historical rainfall data (stations)	CSV		MET	-
Forecasted rainfall data (stations)	CSV, telemetry		MET	-
Historical temperature data (grids)	NetCDF		MET	ERA5
Forecasted temperature data (grids)	GRIB, NetCDF		MET	GFS
Historical temperature data (stations)	CSV		MET	-
Forecasted temperature data (stations)	CSV, telemetry		MET	-
Historical hydrological data (stations)	CSV		JPS (DID)	-
Forecasted hydrological data (stations)	CSV, telemetry		JPS (DID)	GLOFFIS
Historical sea water level data	CSV		JUPEM	-
Forecasted sea water level data	CSV, telemetry		JUPEM	GTSM

For the prototype, global data sources have already been configured for importing data into the MHP-IP, 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).

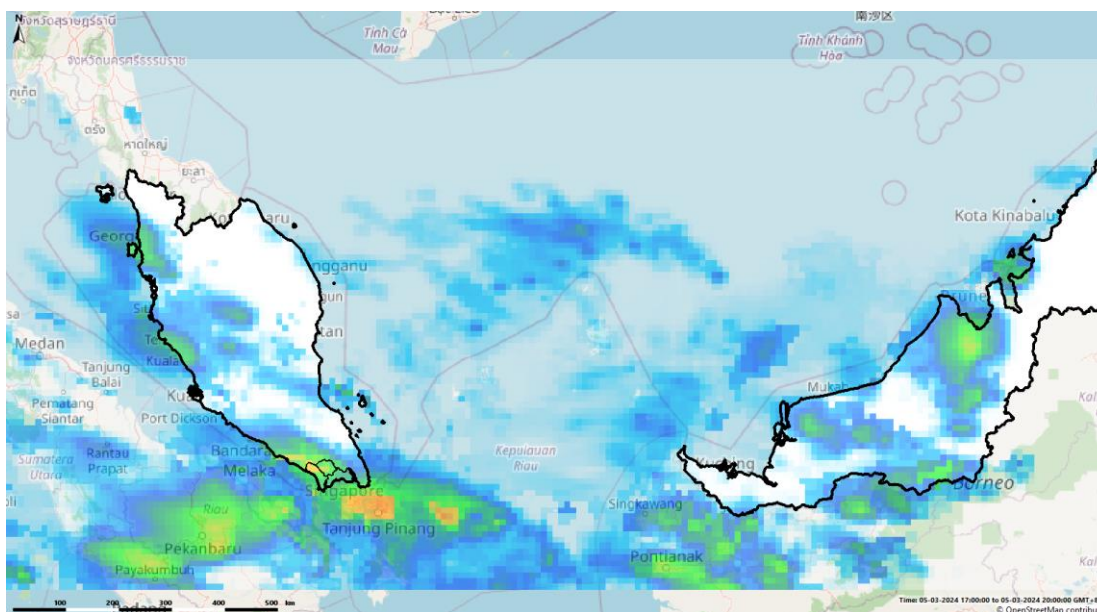


Figure 5-10 Screenshot of the GPM global rainfall historical dataset imported into MHP-IP IM.

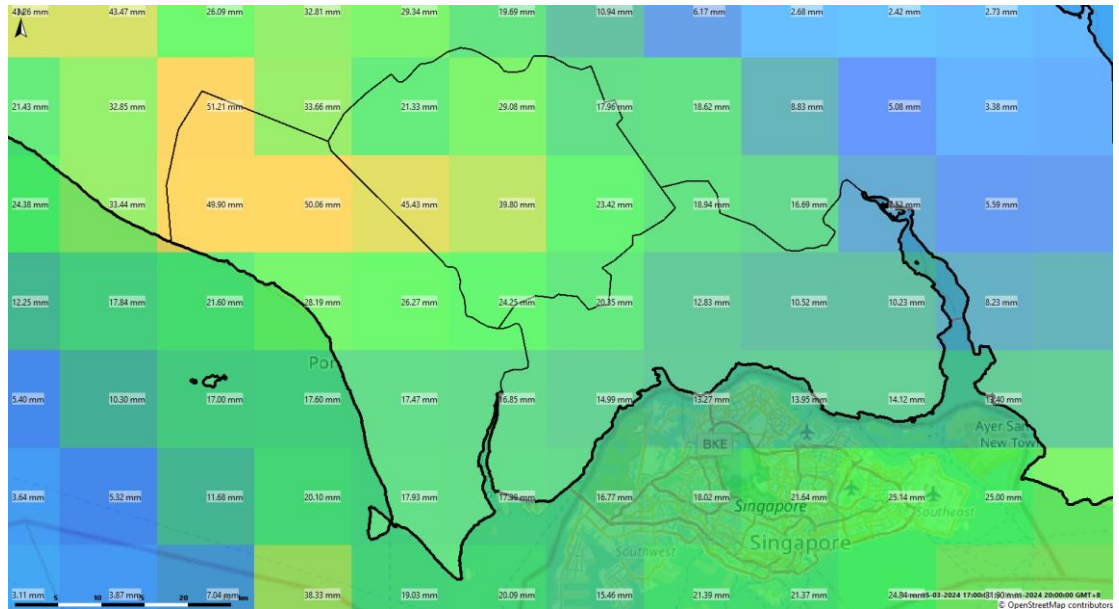


Figure 5-11 Screenshot of the GPM global rainfall historical dataset imported into MHP-IP IM, zoomed into Iskandar Malaysia.

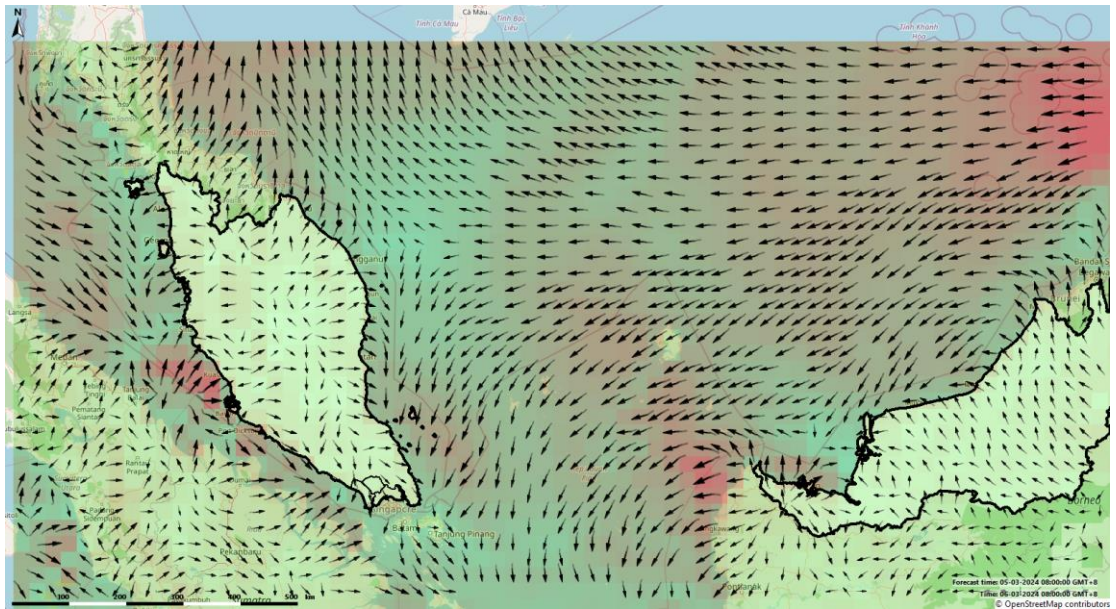


Figure 5-12 Screenshot of the GFS global wind forecast dataset imported into MHP-IP IM.

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 every year or once every 5 years).

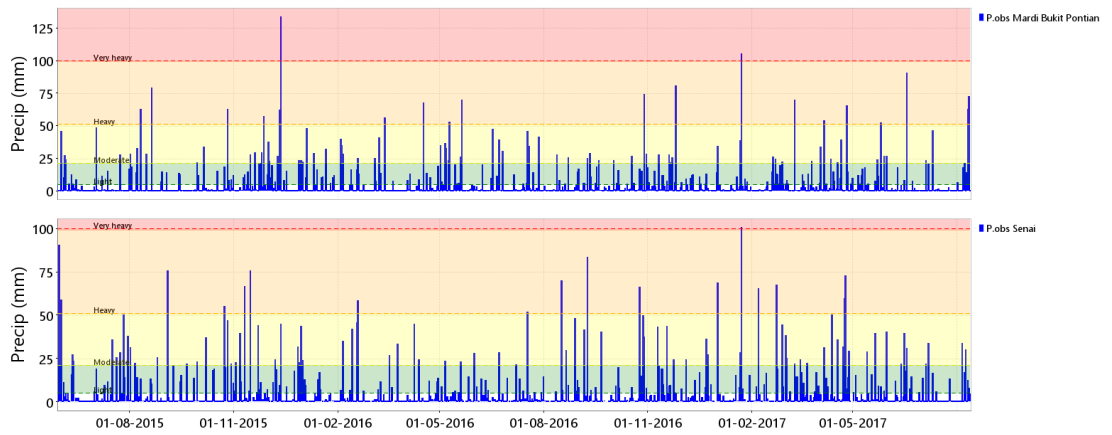


Figure 5-13 Timeseries of rainfall visualized in the MHP-IP IM, including the visualization of thresholds values.

### 5.3 Models

The next component of the MHP-IP 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-IP, 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-IP 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.

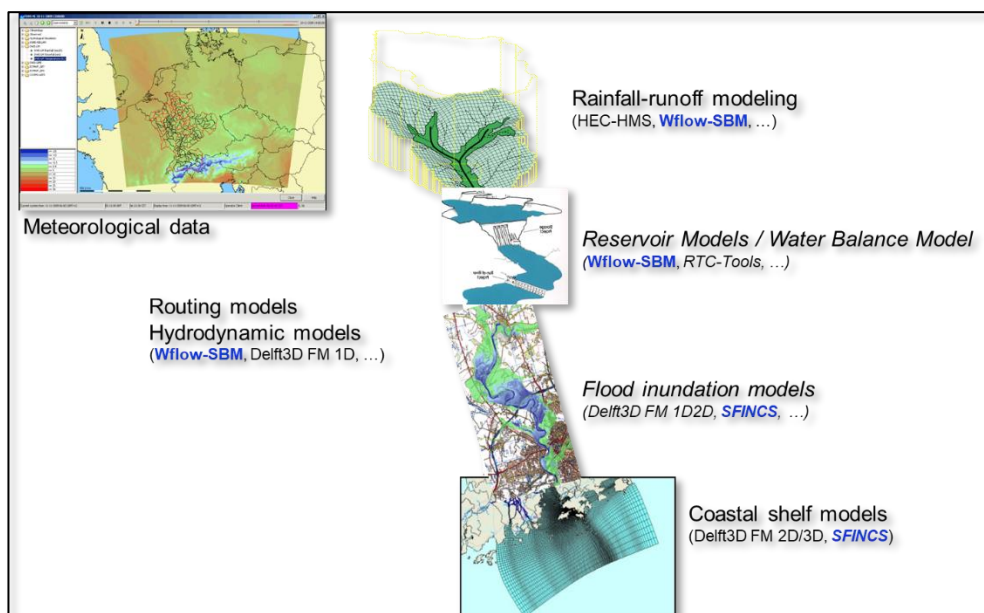


Figure 5-14 Example of a modelling cascade. In blue, the models that are selected to be integrated into the prototype.

#### 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	<ul style="list-style-type: none"> <li>• Fast</li> <li>• Can be calibrated well for specific purpose.</li> </ul>	<ul style="list-style-type: none"> <li>• Difficult to calibrate for multi-purpose.</li> <li>• Poor spatial representation</li> <li>• Can be difficult to setup</li> <li>• Poor connection with real observable physical processes</li> </ul>
Lumped	Physics based	SWAT	<ul style="list-style-type: none"> <li>• Fast</li> <li>• Can be calibrated well for multi-purpose.</li> <li>• Good connection with real observable physical processes</li> </ul>	<ul style="list-style-type: none"> <li>• Poor spatial representation</li> <li>• Can be difficult to setup</li> </ul>
Grid-based	Conceptual	Spatial-HBV	<ul style="list-style-type: none"> <li>• Good spatial representation</li> <li>• Easy to setup</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively slow</li> <li>• Poor connection with real observable physical processes</li> </ul>
Grid-based	Physics based	Wflow-SBM, MIKE-SHE	<ul style="list-style-type: none"> <li>• Good spatial representation</li> <li>• Easy to setup</li> <li>• Good connection with real observable physical processes</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively slow</li> </ul>

For the prototype, use is made of the fully open-source Wflow-SBM model<sup>1</sup>. 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.), landuse data and soil data. Making use of the open-source Hydro Model Tools package<sup>2</sup>, 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.

<sup>1</sup> <https://deltares.github.io/Wflow.jl/stable/>

<sup>2</sup> <https://deltares.github.io/hydromt/stable/>

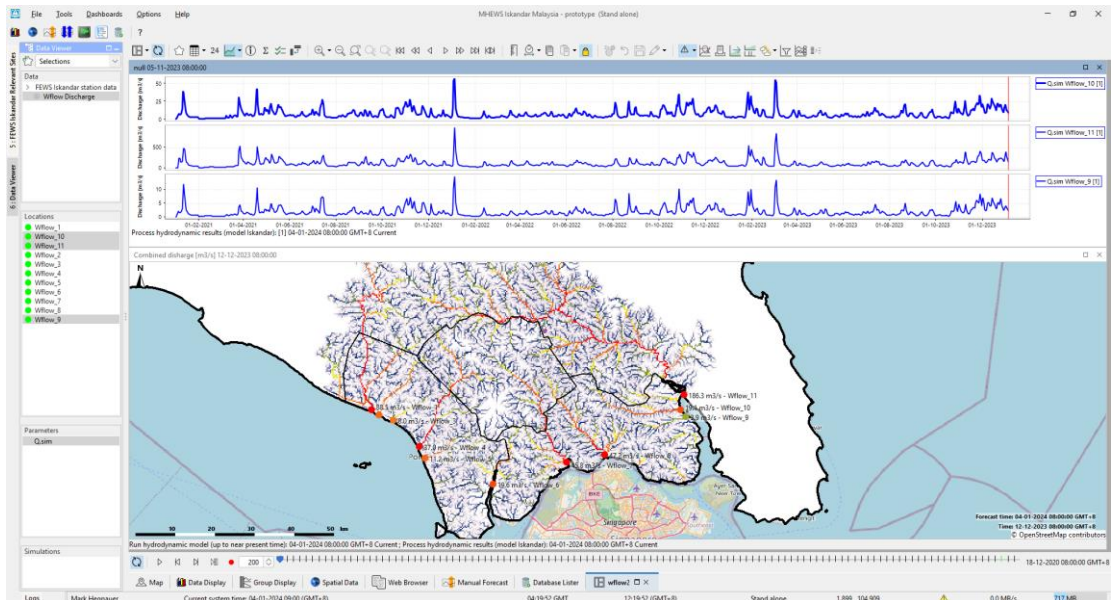


Figure 5-15 Screenshot of the MHP-IP showing the Wflow-SBM model results.

As said, the MHP-IP 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.

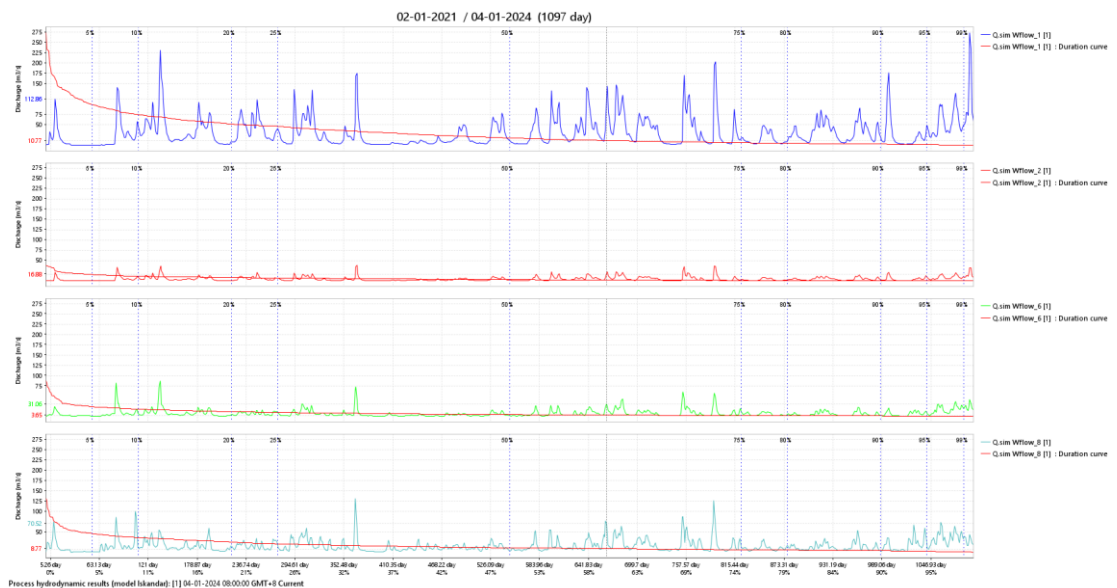


Figure 5-16 Example of on-the-fly flow duration curve calculations.

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 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 model in the MHP-IP.

### 5.3.2 Flood hazard model: SFINCS

A hydrodynamic model can be used to setup 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, will be used. 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. As of now, no local information or data could be collected, but it is highly recommended to update the models with higher resolution and better-quality data. In terms of priorities, the digital elevation data and the forcing datasets have highest priority.

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)	Dummy	N/A
River geometry / bathymetry	MERIT Hydro	N/A

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.

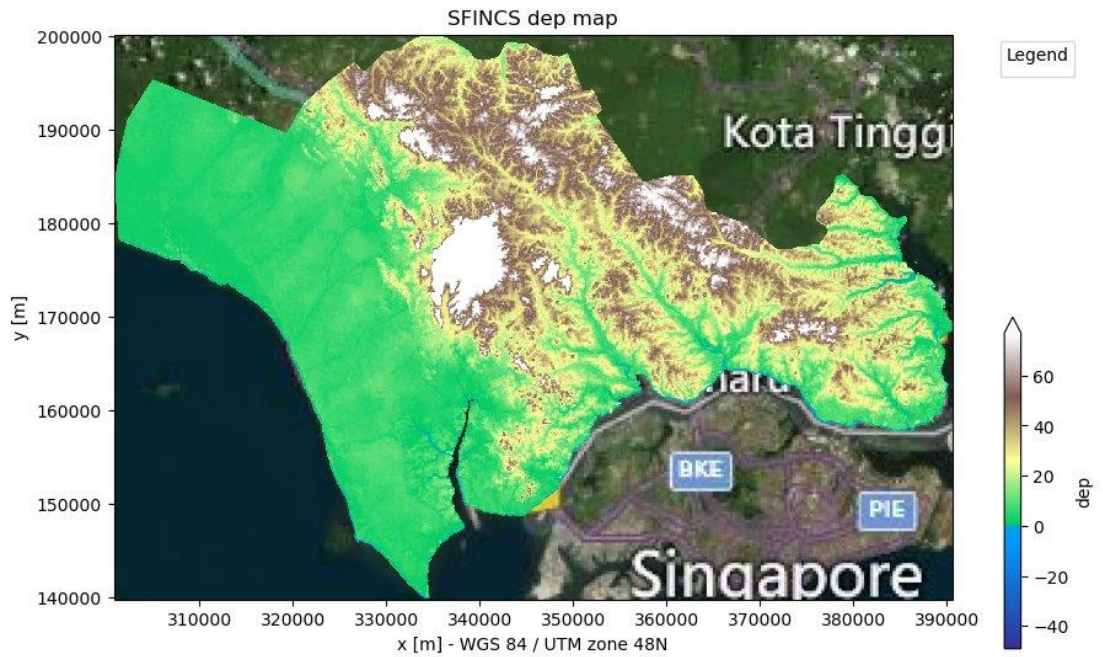


Figure 5-17 The digital elevation model used for the SFINCS model.

Next to the land elevation, the landuse 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.

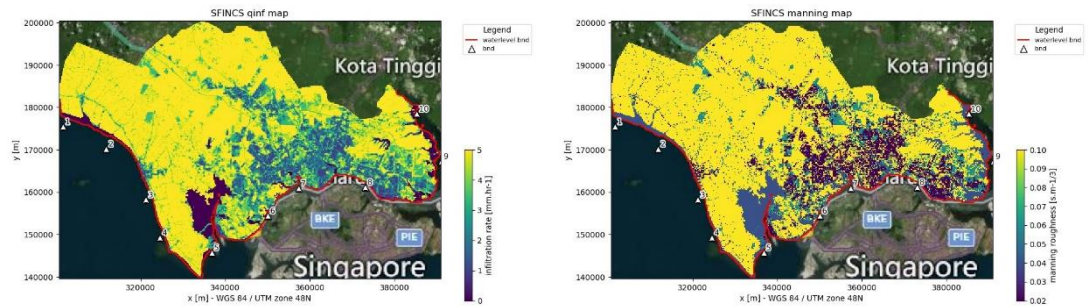


Figure 5-18 Infiltration (left) and Mannings roughness (right) grids as part of the SFINCS model.

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.

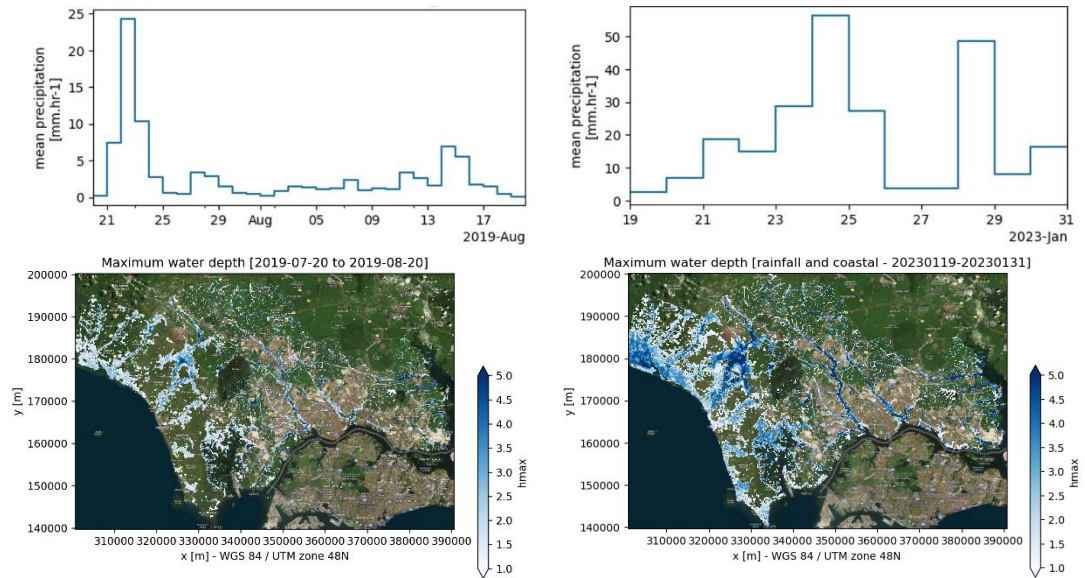


Figure 5-19 Preliminary results of a SFINCS simulation for an event in July 2020 (left panel) and January 2023 (right panel).

As SFINCS is relatively 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 processes are relevant or dominant and how these processes could potentially interact with each other.

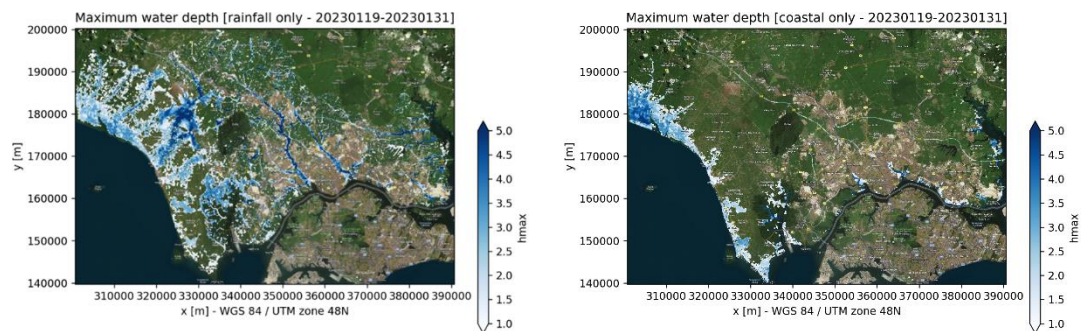


Figure 5-20 SFINCS results for different drivers. The left panel shows the maximum flood depth for only rainfall flooding, and the right panel shows the maximum flood depth for only coastal flooding.

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  $\geq 0,5$  meter difference between the two simulations. From these simulations it becomes clear that it is important to analyse these drivers together.

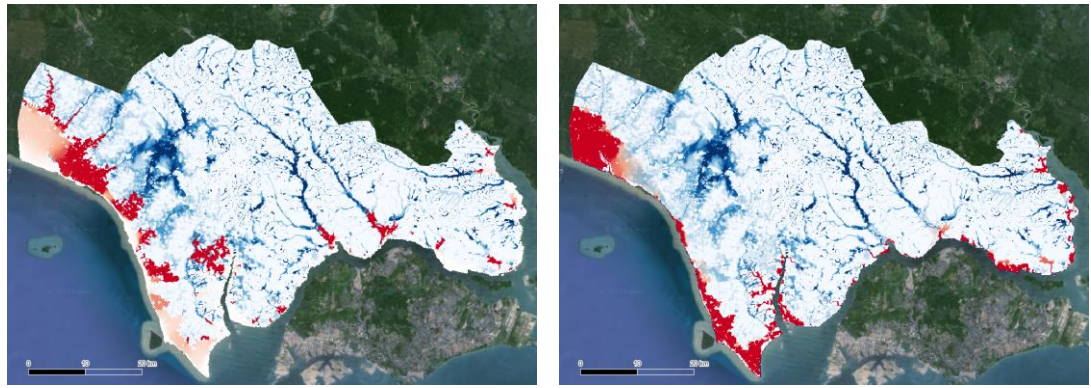


Figure 5-21 In red the difference between the compound event (i.e. rainfall and downstream water level), compared to only downstream water levels (left) and only rainfall (right) drivers.

### 5.3.3 Flood risk model: FIAT

In the prototype, global data was used to simulate the flood risk. When local data is available, data will be replaced and updated. A risk model was set up using Delft-FIAT to quantify risk. Delft-FIAT (Flood Impact Assessment Tool) is a tool developed by Deltares that takes three components as inputs, as described in Section 2.1.3.

Buildings will be used as the basis object of the exposure. In this case, building footprints from Open buildings (Google) will serve as the basis 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. Additional information, such as area, plinth height, and the number of occupants, was subsequently added to the building footprint attributes. Table 5-4 below is the list of input data used in the risk assessment:

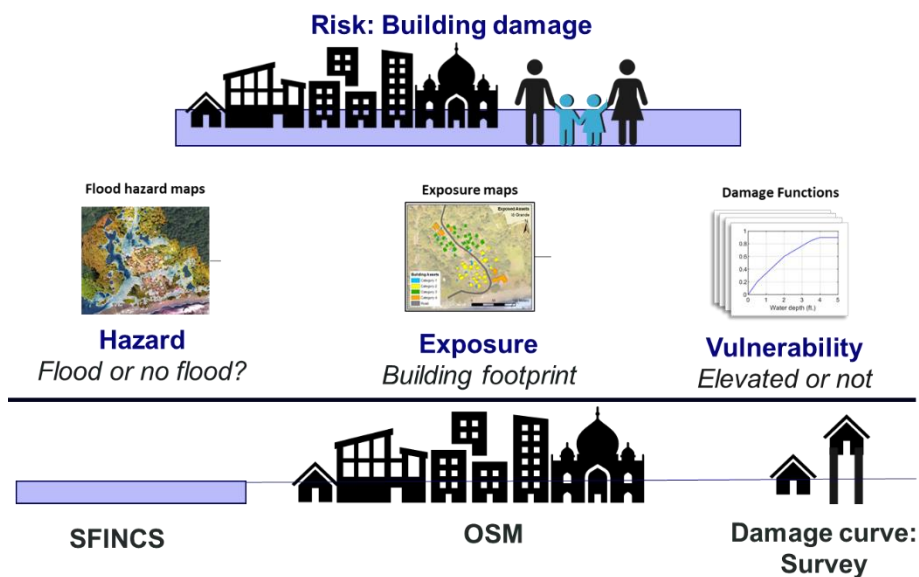


Figure 5-22 Building-based risk assessment in FIAT

Table 5-4 Input data for risk assessment

Category	Required data input	Source	
		Local	Global
<b>Exposure</b>	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
<b>Vulnerability</b>	Flood damage function		JRC 2017
<b>Socio-economic</b>	Demography status (total population, gender distribution, age distribution, income level)		WSF 2019
<b>Hazard</b>	Flood depth map	Deltares SFINC model	
<b>Geographic</b>	Administration boundary	Level 4 Johor Adm. Boundary (mukim)	

### Exposure

In the prototype, building footprint from the OpenBuilding data represented the object map of the exposure. Based on the calculation on the building footprint, damages were then calculated for the building cost and population impacted. Figure 5-23 shows the coverage of the exposure from OpenBuilding data.



Figure 5-23 Building footprint from OpenBuilding data extent for Iskandar Malaysia

Labelling the building function whether it is a residential, commercial, or industrial is required to estimate the value of the structure and its content. (At the moment) no local data is available to define the building function, 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 2002 (Arcadis & JUBM, 2022) for Johor Bahru. Valuation of the building are the construction cost for specific classes under 4 building categories (Residential, Commercial, Industrial, and Hotels). However, in this project, building damage costs were calculated considering the depreciation value of the building from the average of the lowest range in each building category. 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.

Table 5-5 Damage structure and content cost

Building function	Structure				Content			
	MYR/m2 (CCM 2022)	depreciated value factor	Max damage cost MYR/m2	Max damage cost USD/m2	factor	MYR/m2	Max damage cost MYR/m2	Max damage cost USD/m2
<b>Residential</b>	995	0.6	597	134	0.5	497.5	248.75	134
<b>Commercial</b>	1802.5	0.6	1081.5	242	1	1802.5	1802.5	242
<b>Industrial</b>	1005	0.6	603	135	1.5	1507.5	2261.25	135

### Vulnerability

Vulnerability functions (many times called damage curves) are a sensitive 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 5-24. This was made by assumption that all buildings were made by concrete and each function has 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
<b>0</b>	0.00	0.00	0.00
<b>0.5</b>	0.33	0.38	0.28
<b>1</b>	0.49	0.54	0.48
<b>1.5</b>	0.62	0.66	0.63
<b>2</b>	0.72	0.76	0.72
<b>3</b>	0.87	0.88	0.86
<b>4</b>	0.93	0.94	0.91
<b>5</b>	0.98	0.98	0.96
<b>6</b>	1.00	1.00	1.00

### Vulnerability function (JRC, 2017)

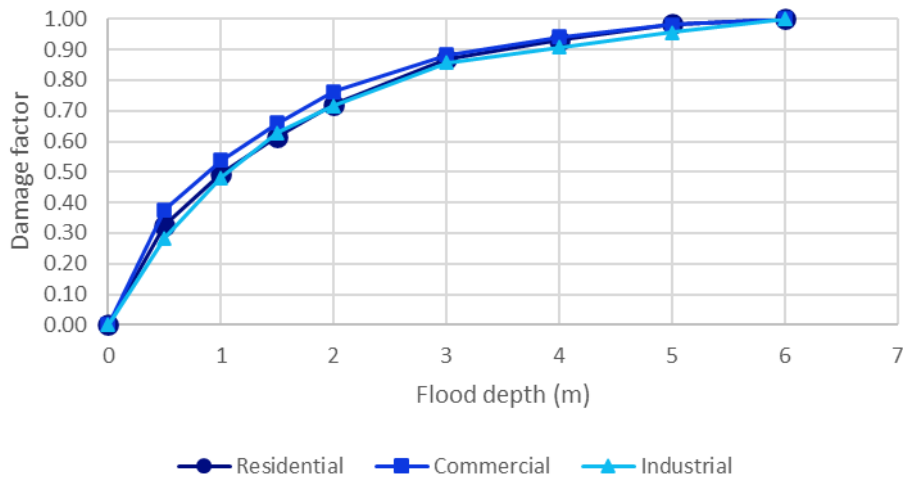


Figure 5-24 Vulnerability functions for residential, commercial, and industrial building based on JRC database for Asian countries. X-axis shows the flood depth in meter and Y-axis shows the damage factor.

### Damage Result

Table 5-7 presents the results of the building damage assessment based on the current flood hazard. The risk calculation results can be visualized by individual building damage (Figure 5-25), and aggregated at the administrative level 4 (mukim level) as shown in Figure 5-26. These results facilitate the planning of mitigation and adaptation measures, including early warning responses, by prioritizing areas accordingly.

Table 5-7 Damage simulation based on the current flood map

Building function	Area (ha)	% of area AOI	Max potential damage (1E9 MYR)	Actual damage (1E9 MYR)	% damage
Residential	10450	76,12	134,5	23,2	17,24
Commercial	589	4,29	42,7	6,2	14,49
Industrial	2689	19,59	11,0	1,0	9,30
<b>Total</b>	<b>13728</b>	<b>100,00</b>	<b>188,2</b>	<b>30,4</b>	<b>16,16</b>

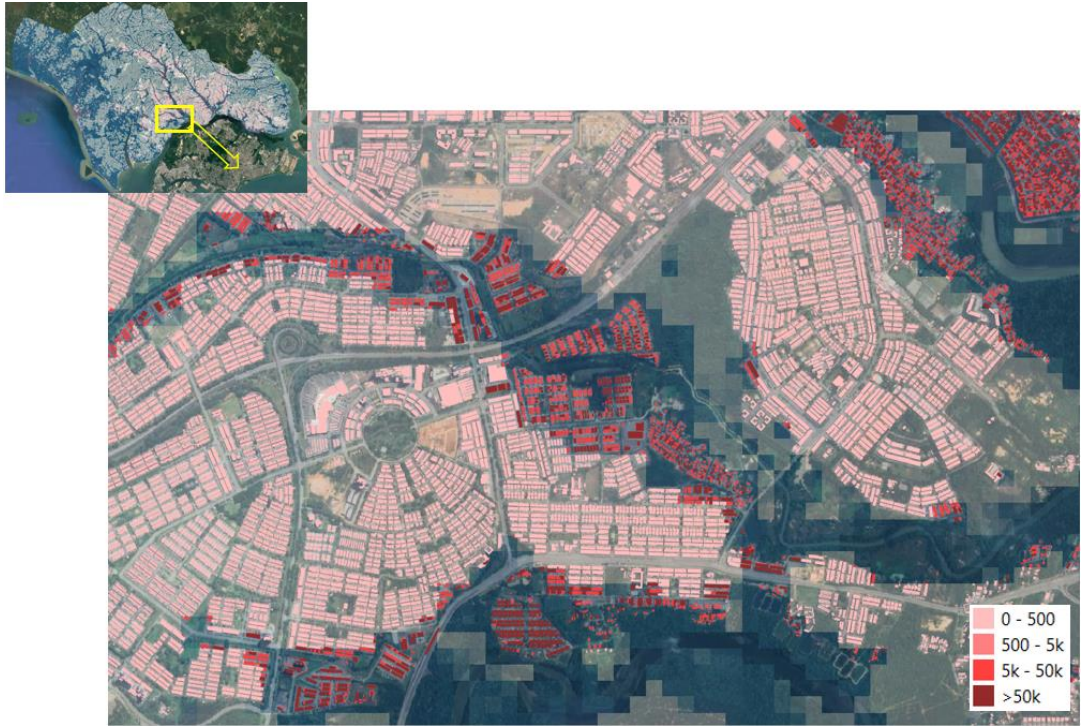


Figure 5-25 Result from building damage. Deeper red colour indicate more damage as shown in the legend (valuation on MYR)

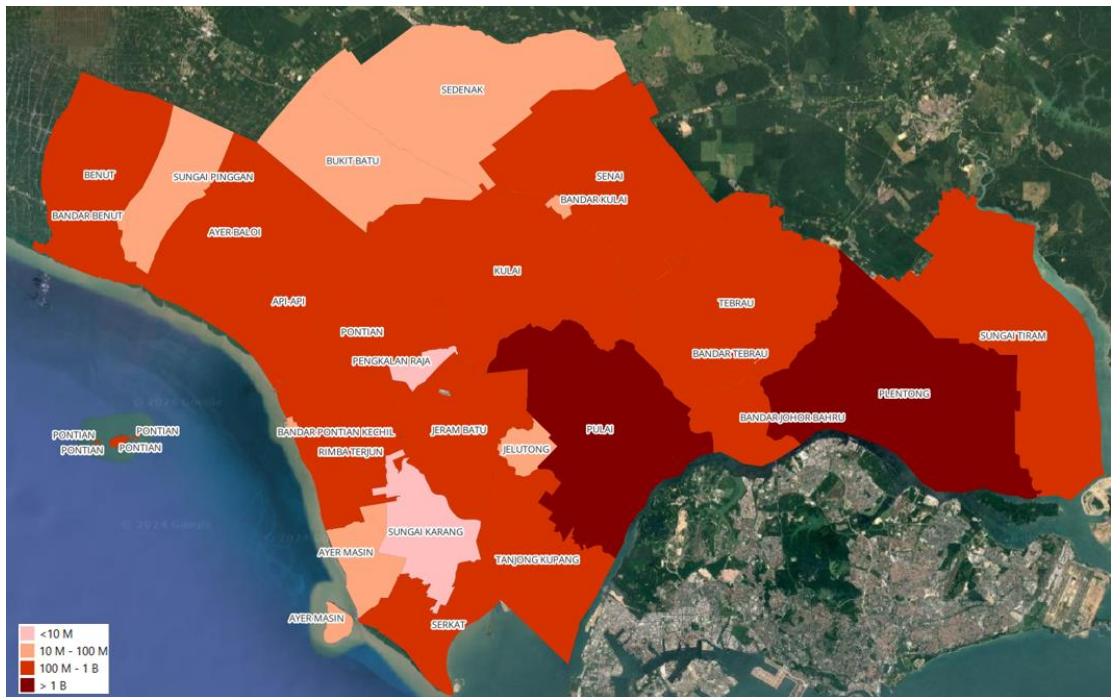


Figure 5-26 Result from building damage in mukim aggregation. Deeper red colour indicate more damage as shown in the legend (valuation on MYR)

#### 5.3.4 Other hazards

The MHP-IP 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<sup>3</sup>. 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.

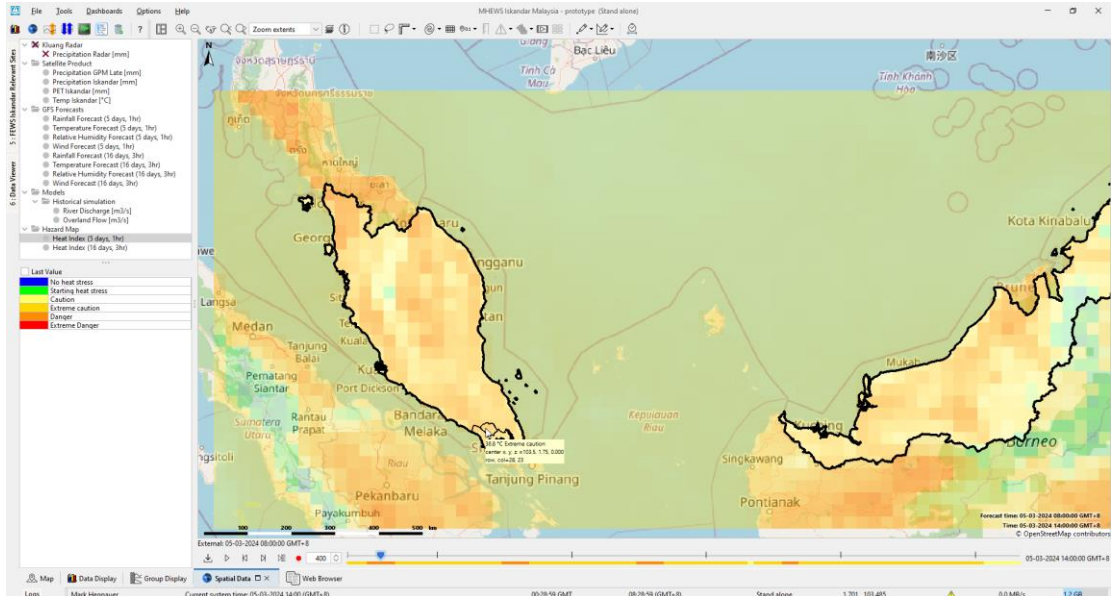


Figure 5-27 Heat stress indicator integrated into the MHP-IP-IM

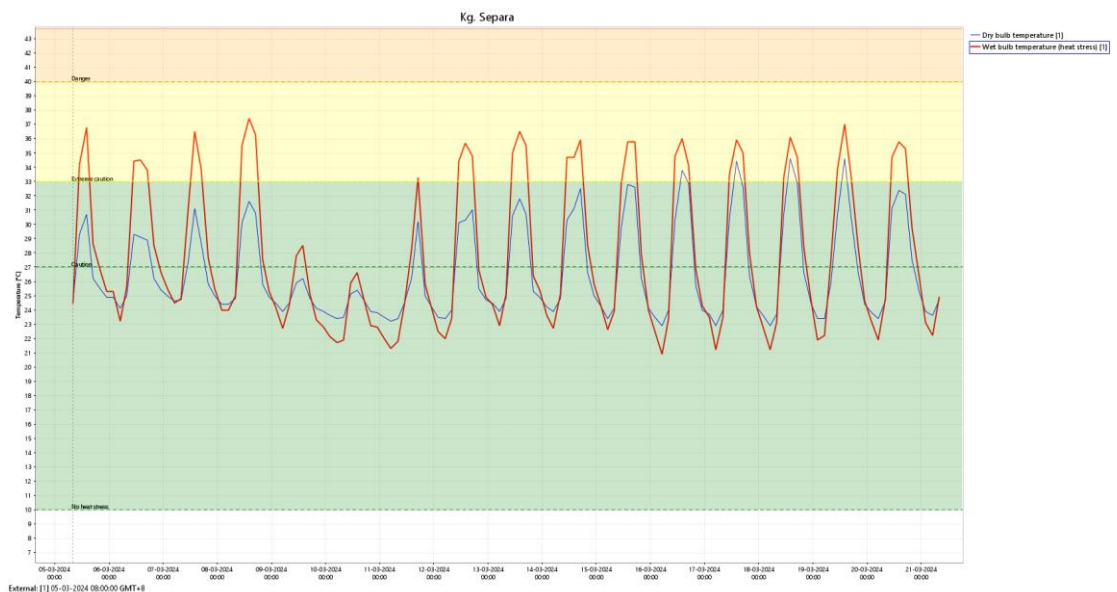


Figure 5-28 Heat stress information is made available for each location of interest

<sup>3</sup> Lans P. Rothfus. "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

### 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 amount of inflow, which can be directly coupled to the amount of rainfall, is an important indicator.

Depending on which models are included in the MHP-IP, 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.

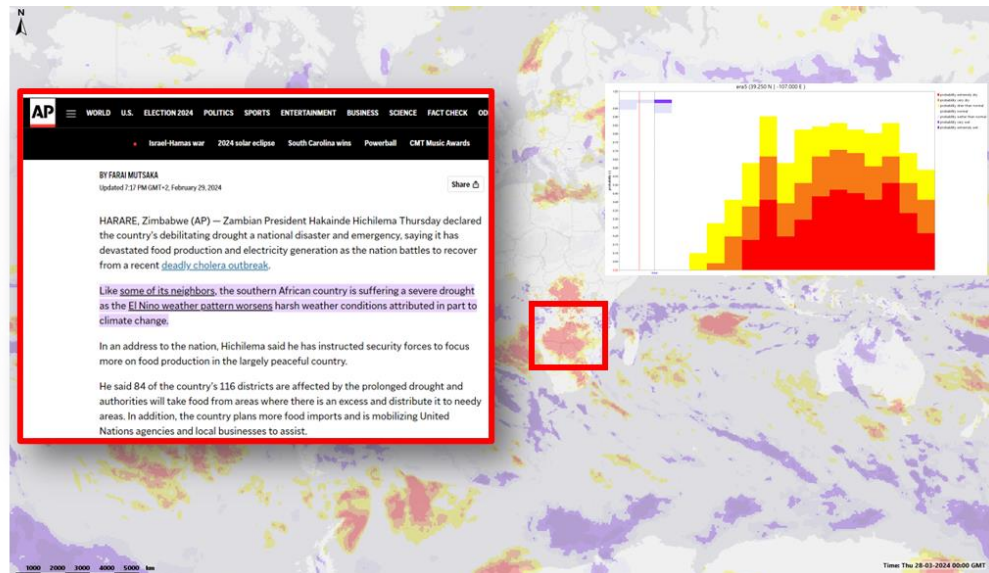


Figure 5-29 Example of the operational Standardized Precipitation Index (SPI) based on ensemble precipitation forecast data.

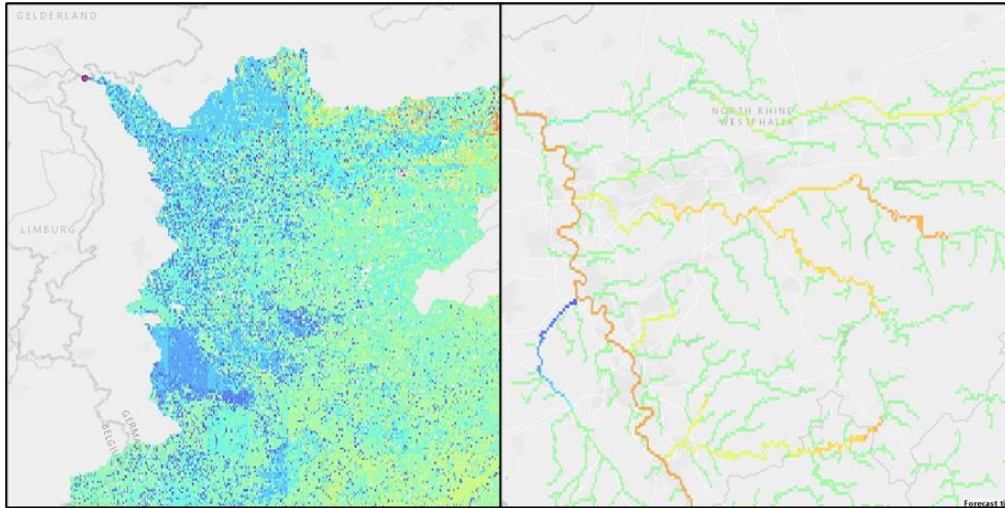


Figure 5-30 Example of agricultural drought indicators (left) based on wflow model output for the unsaturated zone of the soil layer, and the hydrological drought indicators (right) based on the wflow streamflow simulations. Blue colour means low probability of drought conditions, red means high probability 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 next stage of the project, example reports for different (type of) users will be developed to demonstrate the capacity of the MHP to deliver these reports.

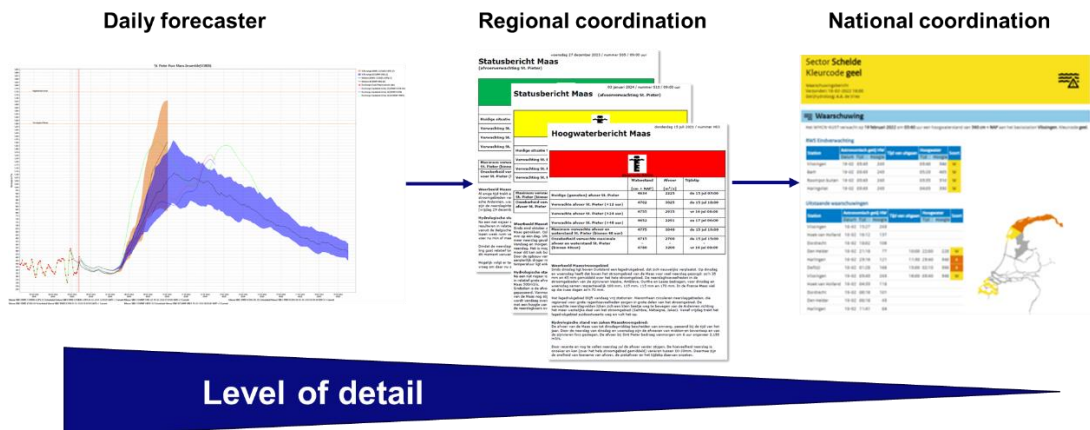


Figure 5-31 Example of automatic reports at different levels of detail.

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. B. Stengs	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:	<ul style="list-style-type: none"> <li>SOP ID A320 – Forecasting Procedure 3.2.0: Start forecasting duty</li> <li>SOP ID A321 – Forecasting Procedure 3.2.1: Collection and processing of information and data</li> <li>SOP ID A322 – Forecasting Procedure 3.2.2: Analysis and assessment of current situation</li> </ul>		
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		

Forecasting Procedure 3.2.3  
Implementation of forecast and warning options

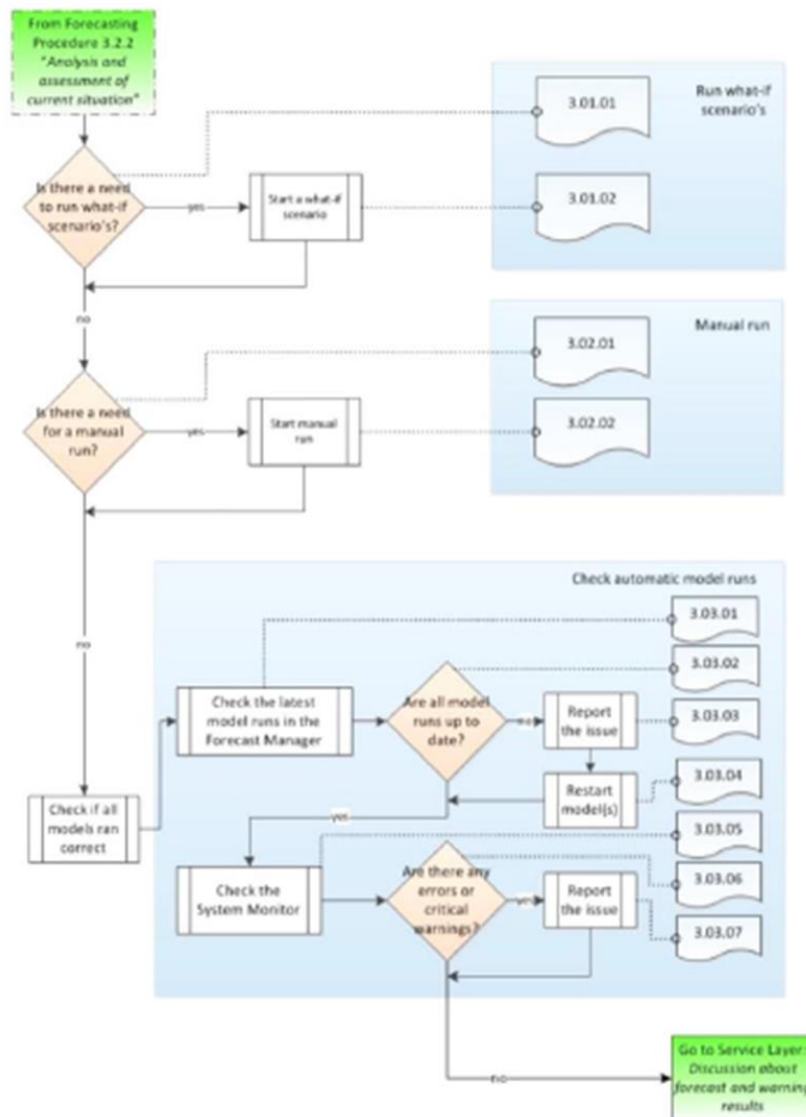


Figure 5-32 Example of a standard operating procedure (SOP) for forecast and warning options.

## 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 will be implemented in the prototype in the next phase of the project, based on the thresholds that will be derived based on collected data and information.

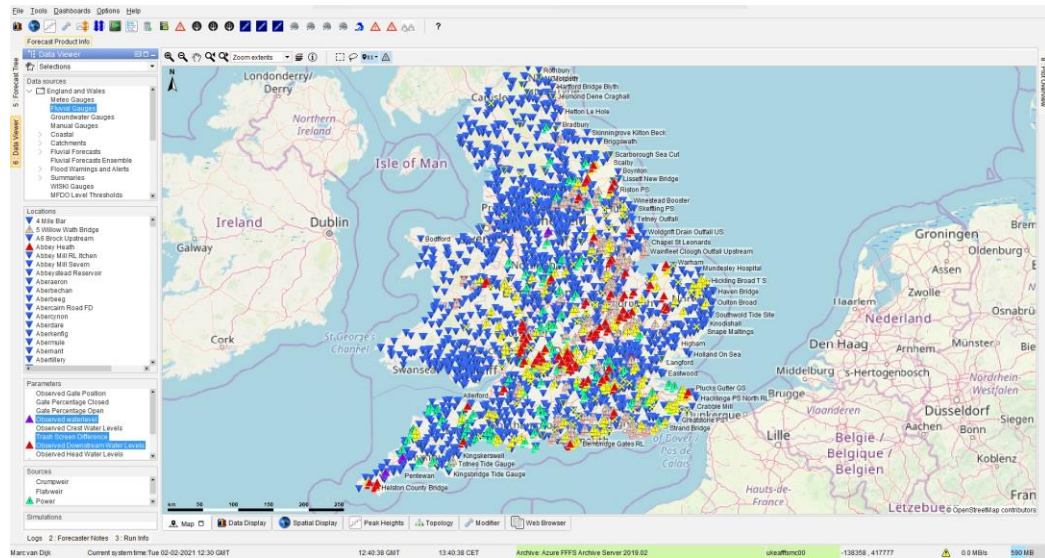


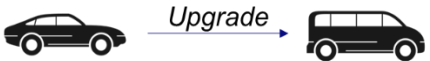




Figure 5-33 Example of thresholds crossings displayed on the map for the UK. Green means minor flood warning, orange means moderate flood warning and red means severe flood warning.

## 6 Other 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 explain in the textbox below. Some specific items are addressed in more detail in the following sections.

<p><b>Procurement of operational system</b></p> <p>The setup of an operational early warning system starts with the initial procurement and development of the system and can be compared to buying a car. Often a big investment, so important to make an informed decision.</p>	
<p><b>Regular maintenance</b></p> <p>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.</p>	
<p><b>New developments</b></p> <p>Over time, there might be different or new user requirements that requirement to upgrade (components of) the system. In the analogy with the car, expanding of the family might require to upgrade the car to a bigger, or safer (more robust) car.</p>	
<p><b>Support</b></p> <p>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.</p>	
<p><b>Training</b></p> <p>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.</p>	

## 6.1 Data connections

In the prototype stage, sample data will be 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 6-1 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>

## 6.2 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. And although the system, based on Delft-FEWS, is fairly low-maintenance, it requires frequent monitoring of the system.

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 1<sup>st</sup> line support for rapid response and easy support questions and a 2<sup>nd</sup> line of support for more complex issues with the system and underlying software.

## 6.3 IT infrastructure

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

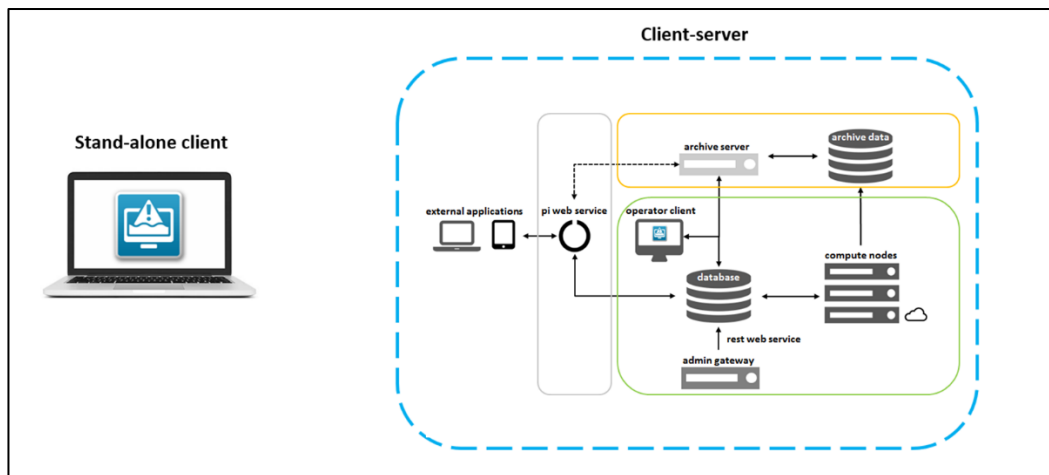


Figure 6-2 IT architecture for two types of Delft-FEWS system: Stand-Alone (left) and Client-Server (right).

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 nodes, 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.

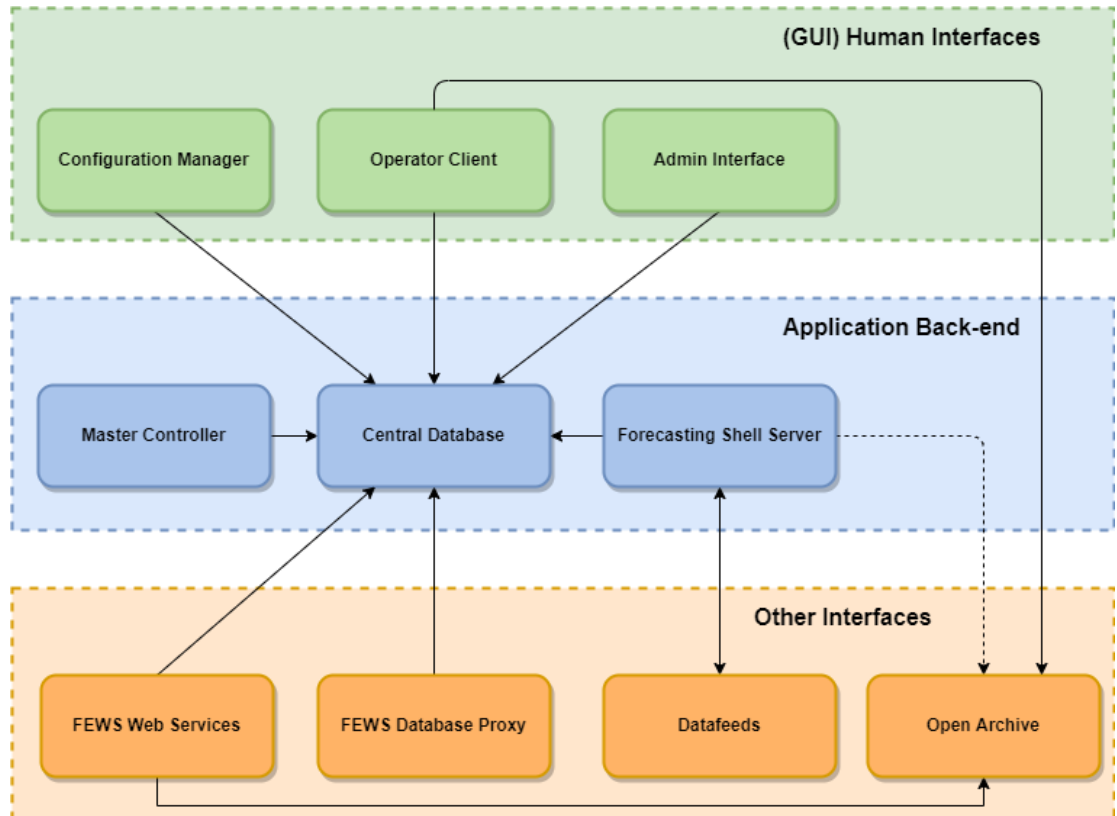


Figure 6-3 Architecture of Delft-FEWS as Operator Client system.

## 6.4 Capacity building

Developing, maintaining and running an operational multi-hazard platform requires training. In this project, the team will assess training needs and conduct basic training in the use of the prototype. The training shall help the stakeholders to get a good understanding of what the system can do, how it could be used operationally in the future and which future developments are required.

The capacity building is part of the next 2 phases of the project. This section will be updated after phase 3 and 4 of the project have been completed.

## 7 Financing requirements

The current project delivers a prototype for the Multi-Hazard Platform for Iskandar Malaysia. To understand the financing requirements to go from prototype to a fully operating system, requires additional developments and investments.

In phase 3 of this project, the financing requirements will be worked out added to this report. The financing requirements can support IRDA and other stakeholders to search for and plan for development budget for the consecutive years.

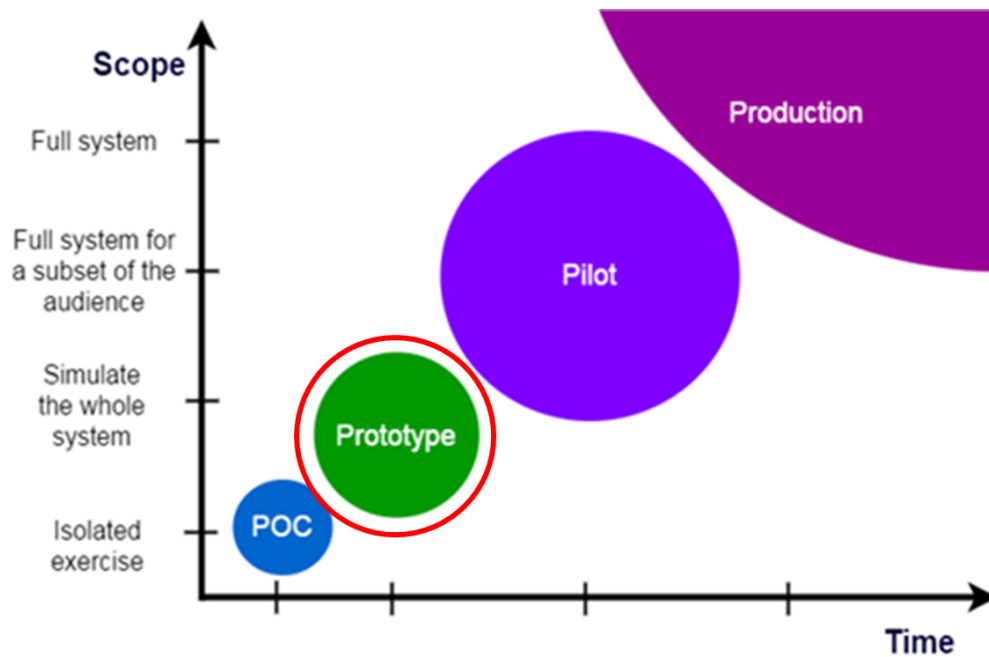


Figure 7-1 Proof of Concept to Production pipeline.



## Breakout 1: Existing system / platforms

- Based on the outcome of your discussion, try answering the following questions:

Which **hazards** are not yet covered by existing platforms?

What could be the **added value** of a MHEWS for Iskandar Malaysia?

To which platforms should the MHEWS be **connected** to?

Who should have **access** to the MHEWS platform?

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Figure 7-4 Identifying existing platforms in Iskandar Malaysia region

## Data requirements and sharing

The goal is: Get access to local level hazard and risk information

- Static information: rainfall, discharge, water level data, etc.
- Dynamic information: data, water level data, discharge data, etc.
- Background information: protocols
- Emergency information: protocols

Format of the data

- Digital only (GeoTIFF, ASCII, NetCDF, GRIB, WEB-API, ...)
- Maps: GeoTIFF, ASCII, NetCDF, GRIB, WEB-API, ...
- Timeseries: CSV, Excel, NetCDF, WEB-API, ...

**How can you help us?**

- Point us to available datasets / website / portals
- Provide access to "your" data

**What will we do?**

- Keep an overview of the data
- Import the relevant data into MHP
- Add regional / global datasets

	Preferred file-format	Alternative source
Flood risk maps / flood risk information	GIS (GeoTIFF)	-
Formal statistics of rainfall, discharge, water level	Report	-
Formal flood damage curves	Report	Global flood depth-damage functions
Digital elevation data	GIS (GeoTIFF)	MeriHYDRO
Landuse / landcover map	GIS (GeoTIFF, shapefile)	ESA Worldcover
Building footprint map	GIS (GeoTIFF, shapefile)	World Settlement Footprint or Open Street Map
Road network data	GIS (shapefile)	Global Roads Inventory Project or Open Street Map
Rainfall data (stations) - locations and timeseries	NetCDF	GPW / ERA5
Temperature data (stations) - locations and timeseries	CSV	-

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Figure 7-5 Identifying existing data to be used for developing prototype of MHP-IP Iskandar Malaysia

## Breakout 2: Data requirements

For the break-out discussion:

- Discuss and write down which data you / your organization is using
- Discuss and write down which data you / your organization is producing
- Discuss and write down which of your / your organizations data might be relevant to others
- Write down where and how we can get access to this data

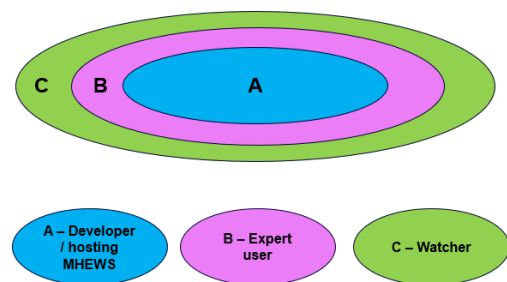
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Figure 7-6 Identifying existing data to be used for developing prototype of MHP-IP Iskandar Malaysia

## Breakout 3: User perspective

- Step 1: Make long list of user groups / user perspectives for the usage of a MHEWS
  - Describe their role
  - Identify if they are in group A, B or C
- Step 2: Prioritize (make top 4 or 5)



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Figure 7-7 Identifying the potential user of MHP-IP Iskandar Malaysia

## Breakout 3: User requirements

- Who are you?
- What do you need?
- How could the MHEWS help with this?
- Describe the required functionality in detail

*What do I want to do?*

---

---

*How can the model help with that?*

---

---

*Description of functionality:*

---

---

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Figure 7-8 Identifying the user requirement for MHP-IP 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-IP 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	<ul style="list-style-type: none"> <li>*.csv for point data</li> <li>*.netCDF for raster data</li> </ul>	<ul style="list-style-type: none"> <li>Meteorological gauges</li> <li>Radar</li> <li>Numerical weather forecast (both deterministic and probabilistic)</li> </ul>	<ul style="list-style-type: none"> <li>Historical</li> <li>Nowcast</li> <li>Medium range forecast</li> <li>Seasonal forecast</li> </ul>	Will be used as an input for several hazard analysis i.e. flood (pluvial and coastal flooding) & drought
2	Temperature	<ul style="list-style-type: none"> <li>*.csv for point data</li> <li>*.netCDF for raster data</li> </ul>	<ul style="list-style-type: none"> <li>Meteorological gauges</li> <li>Numerical weather forecast (both deterministic and probabilistic)</li> </ul>		Together with relative humidity data, heat stress index can be produced
3	Relative humidity	<ul style="list-style-type: none"> <li>*.csv for point data</li> <li>*.netCDF for raster data</li> </ul>	<ul style="list-style-type: none"> <li>Meteorological gauges</li> <li>Numerical weather forecast (both deterministic and probabilistic)</li> </ul>		Together with temperature data, heat stress index can be produced
4	Wind speed	<ul style="list-style-type: none"> <li>*.csv for point data</li> <li>*.netCDF for raster data</li> </ul>	<ul style="list-style-type: none"> <li>Meteorological gauges</li> <li>Numerical weather forecast (both deterministic and probabilistic)</li> </ul>		Will be used as an input for coastal flooding analysis
5	Wind direction	<ul style="list-style-type: none"> <li>*.csv for point data</li> <li>*.netCDF for raster data</li> </ul>	<ul style="list-style-type: none"> <li>Meteorological gauges</li> <li>Numerical weather forecast (both deterministic and probabilistic)</li> </ul>		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-IP 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-IP 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	<ul style="list-style-type: none"> <li>• Historical flood maps with time and location</li> <li>• Flood map derived from analysis for several return periods (Q2, Q5, Q10, Q25, Q50 and Q100)</li> </ul>

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-IP 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-IP 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-IP 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-IP 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-IP Iskandar Malaysia prototype. The following table shows the requested data, its source, acquisition status, and its specific role in the MHP-IP Iskandar Malaysia.

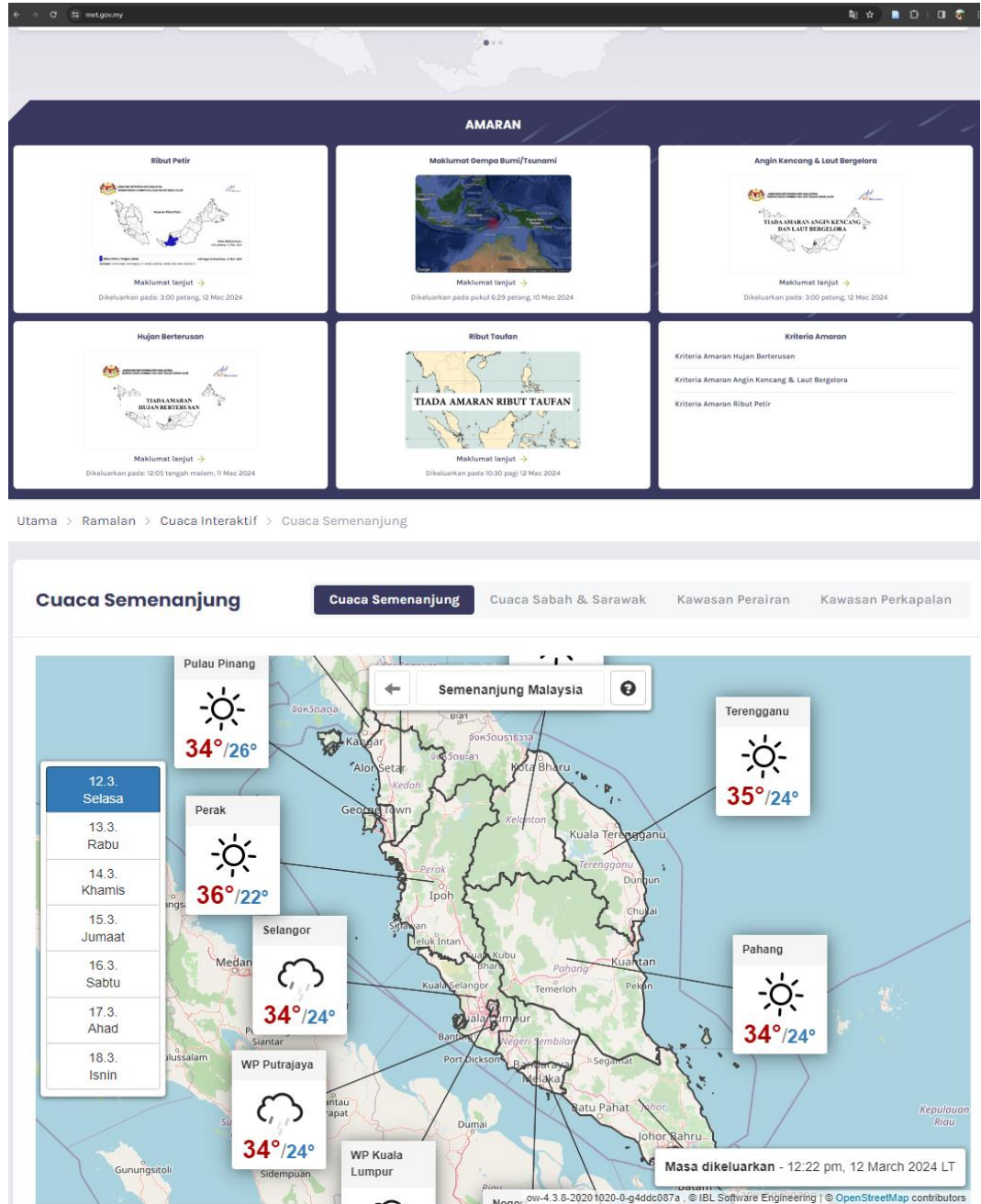
Data	Data Provider	Acquisition Status	Serves As
<b>Administration data</b>			
Administration boundary	IRDA	Collected	Base map at Map Display and Spatial Data Display
<b>Topographic data</b>			
Bathymetry for Pulau and Johor River	NAHRIM	Collected	Used to refine flood model
Digital Terrain Model	JUPEM	Collected	Used to build flood model
<b>Meteorological data</b>			
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
<b>Hydrological data</b>			
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
Sea level rise projection	NAHRIM	Collected	Showing which area is prone to flooding due to sea level rise
<b>Building Data Demographical &amp; building vulnerability data</b>			
Building footprint	OSM+Open Buildings	Collected	Basic data for risk calculation
Building function	OSM	Collected. Support from local data will improve.	Determining building damage function
Critical Infrastructure (Schools, Hospitals, etc)	Google Earth	Collected. Support from local data will improve.	Determining vulnerability

<b>Building damage function</b>	JRC report (2017)	Collected. Support from local data will improve.	Determining building damage function
<b>Building valuation</b>	Construction cost report for Malaysia 2022	Collected	Calculating damage and risk
<b>Demographic &amp; Socio-economic data</b>			
<b>Population distribution per village (mukim level)</b>	DOSM	Collected only for district, based on 2010	Basic data to estimate impacted population
<b>Number of households</b>	DOSM	Not yet collected	Basic data to estimate impacted household
<b>Gender distribution</b>	DOSM	Not yet collected	Determining vulnerability
<b>Age distribution</b>	DOSM	Not yet collected	Determining vulnerability
<b>Disabled people</b>	DOSM	Not yet collected	Determining vulnerability
<b>Income level</b>	DOSM	Not yet collected	Determining vulnerability
<b>Health status (aggregated per village)</b>	DOSM	Not yet collected	Determining vulnerability to health

## B Existing platforms

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

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

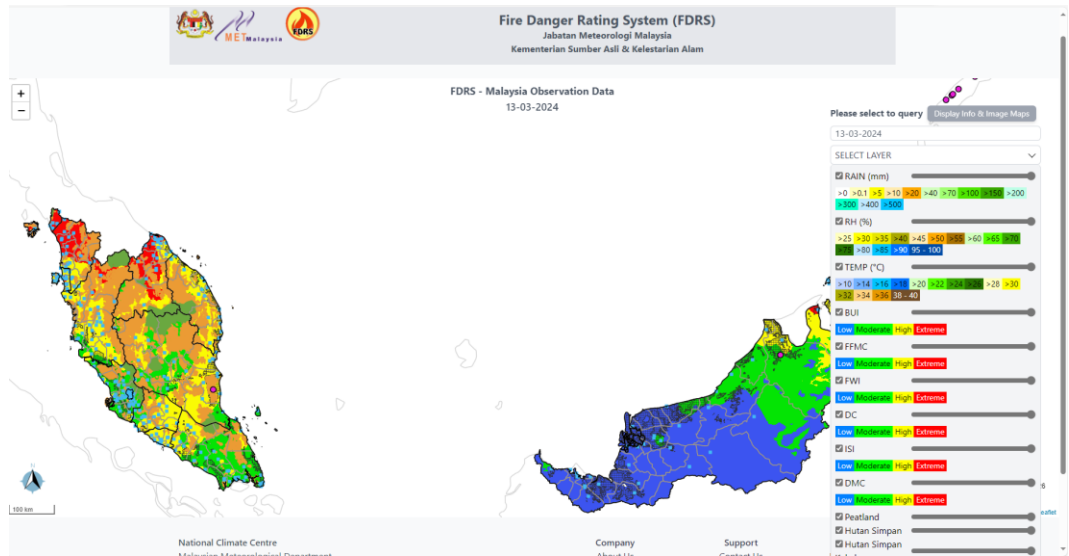


This webpage is maintained by MetMalaysia and serves for:

- 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

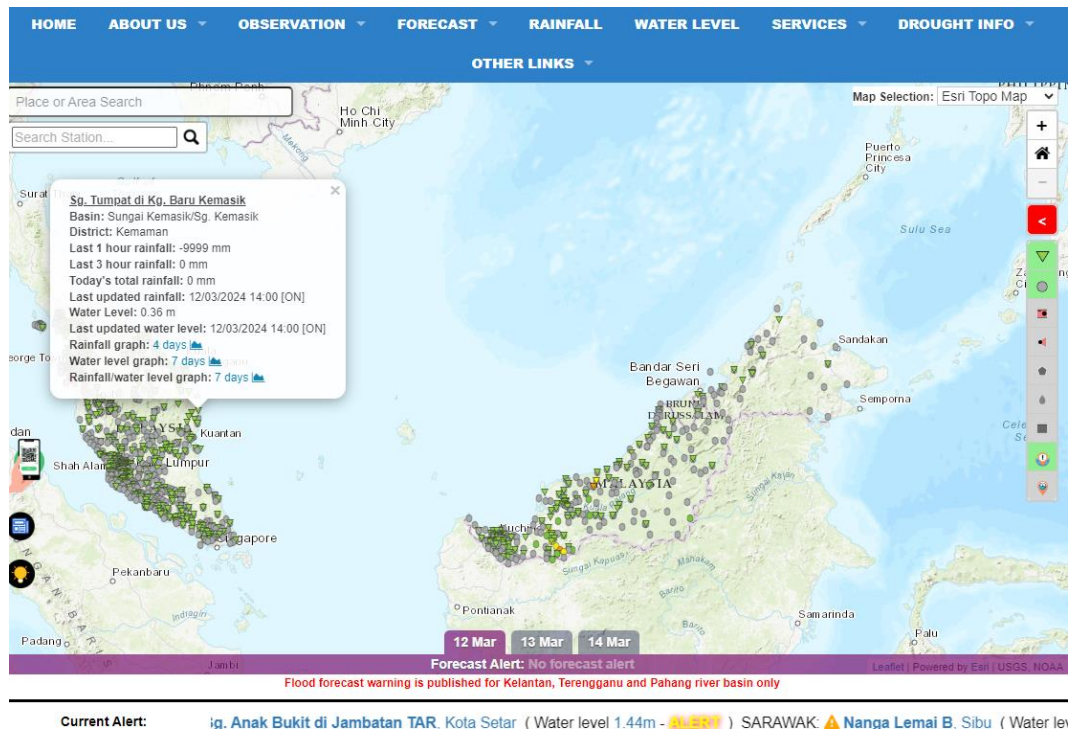
- Providing warnings in table format for the following hazard: earthquake, thunder, tsunami & typhoon.
- Meteorological data aggregator for both cities and states.

2. **FDRS** by **METMalaysia**  
[\(https://myclimate.met.gov.my/fdrsWmsObsMsiaMetPortal/\)](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-IP Iskandar Malaysia include: rainfall, temperature and humidity.

3. **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.
- Information on drought potential based on reservoir water level.

4. **NADMA** (<https://portalbencana.nadma.gov.my/ms/>)

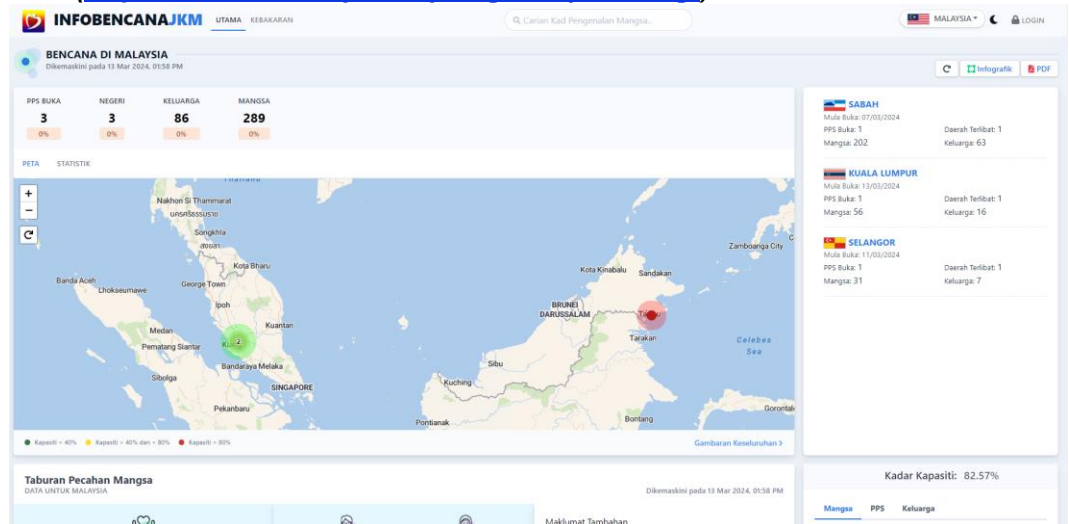


This webpage connects to the data from different servers from METMalaysia, JPS (DID), JAS (DOE), JKR, JUPEM, and JKM.

This webpage offers the following information:

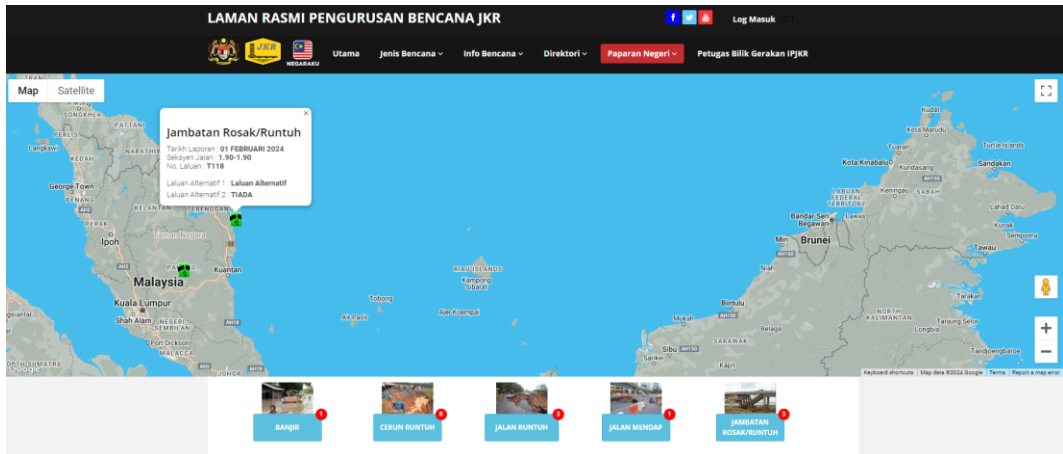
- Observational data on weather, air quality, rainfall, wind, and tidal conditions.
- Disaster information related to fires, floods, air pollution, and road closures.

5. **JKM** (<https://infobencanajkmv2.jkm.gov.my/landing/>)



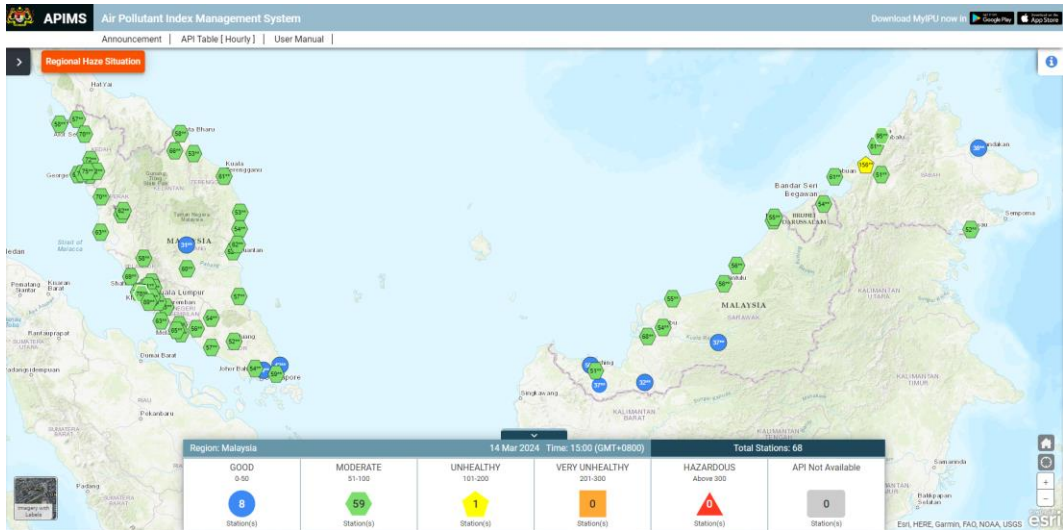
This webpage provides disaster information categorized by location. It also includes details about the number of victims affected. Users can easily access relevant data based on specific disaster events.

6. **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. **DOE** (<https://apims.doe.gov.my/home.html>)



This webpage provides information on air quality monitoring based on the station. The website also features air quality indicators ranging from good, moderate, unhealthy, very unhealthy, to hazardous. There are 68 air quality measurement stations nationwide that measure air quality every hour on this webpage.

## C List of stakeholders

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.	State level	Flood, Typhoon, Land slide, Storm-surge, Water Quality	Advanced user

Organization	Task	Level	Type of Hazard	User profile in platform
	Extract risk information			
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
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	ERP (Civil defense)	State level	All hazards	User

Organization	Task	Level	Type of Hazard	User profile in platform
Awam Malaysia (JPAM) Johor				
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, 2021). It incorporates major hydrological processes, such as interception, soil moisture percolation, evapotranspiration, and runoff generation (Figure 7-9).

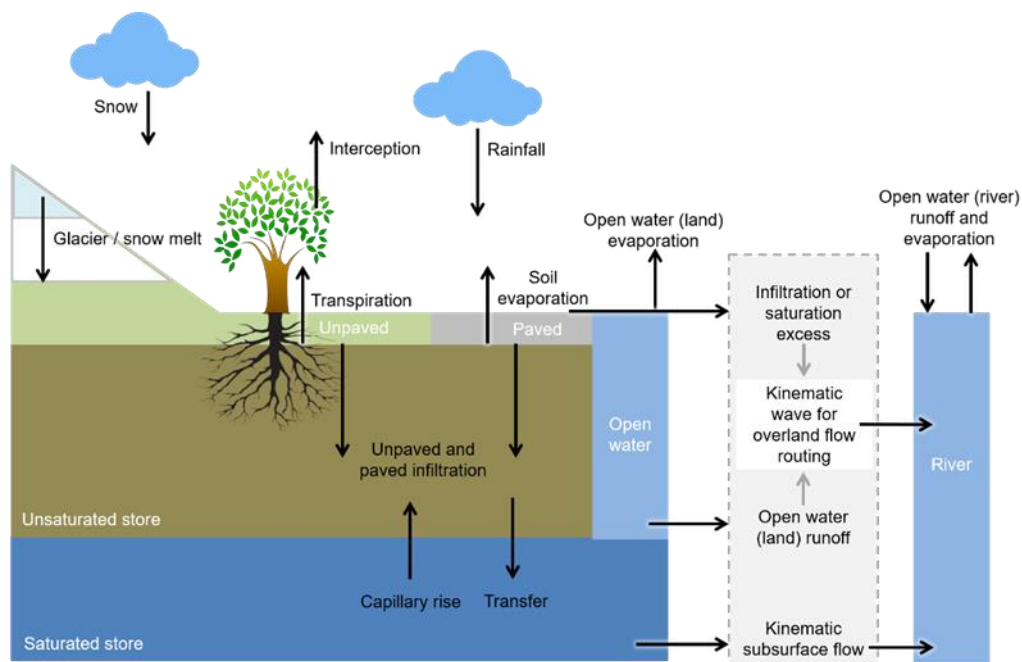


Figure 7-9 Overview of the main hydrological processes in the Wflow SBM cell

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 7-10).

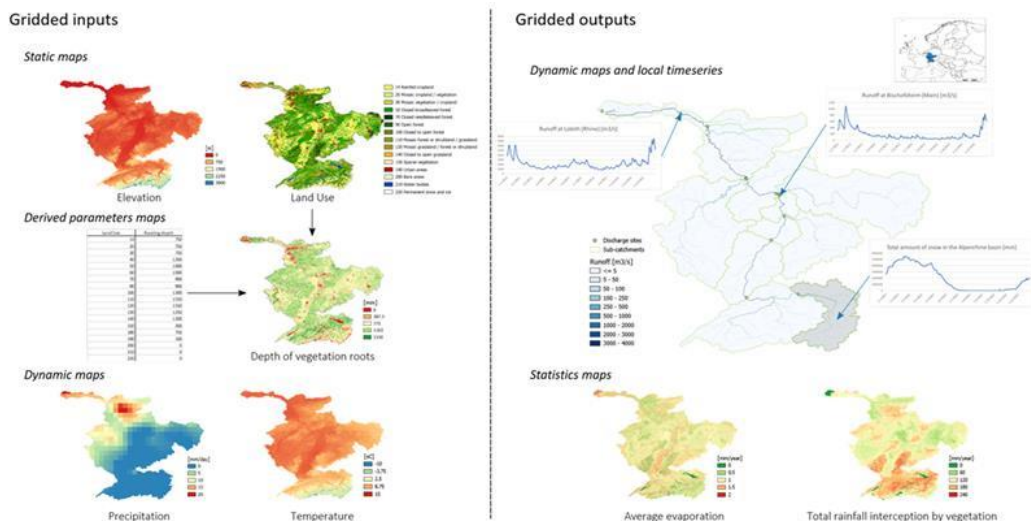


Figure 7-10 Distributed inputs and outputs of the wflow\_sbm model

## Model setup and datasets

A WFLOW hydrological model requires three main types of inputs (Figure 7-10):

- 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). For more information see Leijnse et al. (2021).

### 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 coarse 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.

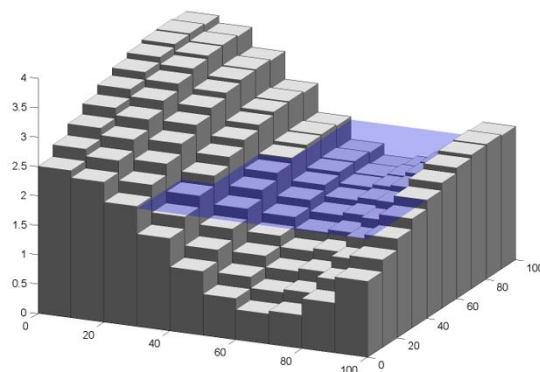


Figure 7-11 Example of a cell with SFINCS subgrid features included in the local elevation (<https://sfincs.readthedocs.io/>)

## D.3 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.

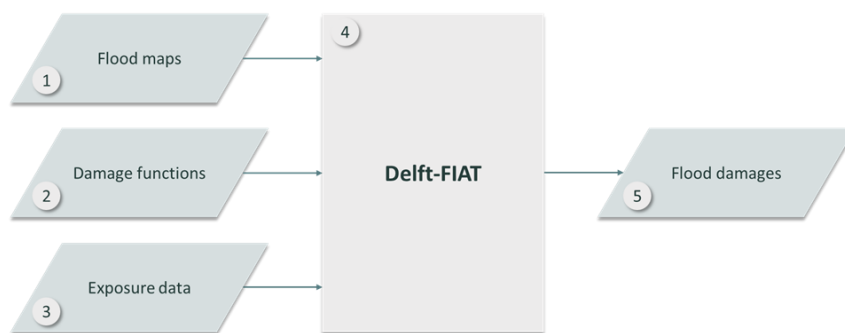
Delft-FIAT is a free, Python-based tool developed by Deltares for calculating flood impacts, with a run time of about one minute per flood scenario. This manual describes the use of Delft-FIAT together with a user interface. Delft-FIAT can also be run via scripts or command line, for users who are familiar 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 7-12). 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 7-12 Overview of how Delft-FIAT combines hazard, damage functions and exposure data.*

Deltares is an independent institute for applied research in the field of water and subsurface. Throughout the world, we work on smart solutions for people, environment and society.

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