

REPORT

Captains Flat Total Flood Warning System Design

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Executive Summary

Captains Flat, located in the Southern Tablelands of New South Wales, Australia, is vulnerable to flooding due to its proximity to the Molonglo River and other watercourses. Historical flood events, particularly in 2010, have caused substantial damage. The town's topography and existing infrastructure, including the Captains Flat Dam, play crucial roles in flood dynamics.

A TFWS design has been developed which is based on principles from the Australian Emergency Management Institute's guidelines and involves multiple components:

- **Data Sources:** Incorporation of water level sensors, rain sensors, rainfall radar, and weather forecasts.
- **Data Processing:** Utilization of both resilience triggers (based on measured values) and forecast triggers (based on predicted rainfall).
- **Data Storage:** Structured databases for efficient storage and retrieval of time-series and gridded data.
- **Data Dissemination:** Automated sharing of data with external applications and stakeholders.
- **Visualization and Communication:** An expert dashboard, public website, automated alarming system, and manual dissemination channels for community alerts.

The execution of the TFWS implementation has been divided into two phases. The necessity of the second phase is intended to be assessed once the Phase 1 system is in place. Also, the added value of the Phase 2 implementation is limited until the high-resolution weather nowcasting product is released for the Captains Flat area by the Bureau of Meteorology (timing for this is currently unknown). The two phases are:

1. **Phase 1:** Initial system development focusing on sensor measurements and weather forecasts.
2. **Phase 2:** Expansion to include a hydrologic / hydrodynamic model for high-resolution flood forecasts.

Indicative costs for system development and maintenance are provided, with Phase 1 focusing on sensor installation and telemetry infrastructure, and Phase 2 on model development and calibration. The total estimated costs range from \$182,500 to \$215,000 for Phase 1 and between \$75,000 to \$145,000 for Phase 2.

The TFWS will significantly enhance flood preparedness in Captains Flat by providing timely and accurate warnings. The phased implementation allows for initial deployment and subsequent expansion, based on additional information becoming available and operational experience. Key recommendations include developing standard operating procedures and engaging with the community and emergency services to ensure effective use of the system.

1 Introduction

Riverine flooding and overland flows at Captains Flat can pose a significant risk to residents and properties in the Township, especially those that live near water courses. Regular floods have affected the town over the years, with notable events in 1978, 1988, 1991, 2010 and 2012. The 2010 flood event was the most severe event on record, in which over a dozen properties experienced above floor flooding, some with depths over 1 metre.¹

To mitigate the risk that flooding poses to Captains Flat, Queanbeyan-Palerang Regional Council has engaged Royal HaskoningDHV (RHDHV) to undertake the design of a Total Flood Warning System (TFWS) for the Captains Flat Township. The purpose of the project is to provide advance warning to the Captains Flat community of impending flood events. Design and installation of a TFWS is one of the emergency response modifications proposed in the Captains Flat Floodplain Risk Management Study and Plan (FRMSP), 2016. Installation of a TFWS was also strongly supported by the community in workshops held during development of the Captains Flat FRMSP, and subsequently as part of this study.

This report summarises the design of the preferred total flood warning system setup for Captains Flat. The report is set up as follows:

1. Site analysis
2. System design
3. Implementation plan
4. Cost analysis
5. Summary and Conclusions.

¹ QPRC (2016): *Captains Flat Floodplain Risk Management Study & Plan*

2 Site analysis

Captains Flat, shown in **Figure 2-1**, is an historic mining town located in the Southern Tablelands of rural New South Wales, Australia, within the Queanbeyan-Palerang Regional Council area. Situated 64 km southeast of Canberra, the town stands at an elevation of more than 800 meters above sea level.

Captains Flat is nestled in a valley surrounded by hills that were once heavily mined. The town's setting is characterised by its proximity to the upper reaches of the Molonglo River, with the surrounding area featuring forests, waterways, and reserves.

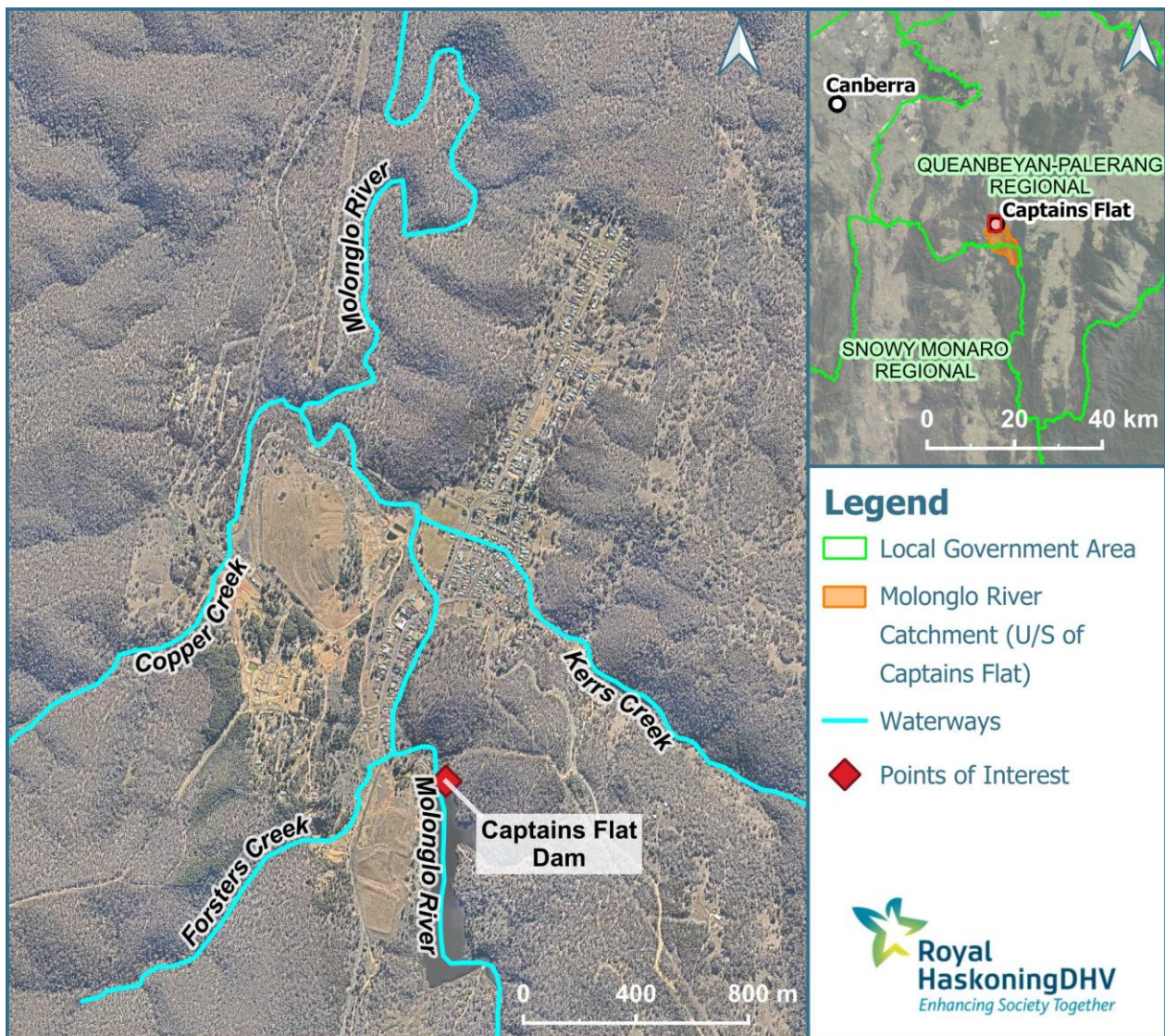


Figure 2-1 Captains Flat locality

Just upstream of the town on the Molonglo River is the Captains Flat Dam; built originally to supply water for mining operations, and still utilised to supply raw water to the water treatment plant for the towns potable water supply. The Dam was constructed in 1939 and was upgraded in the early 1990s. The dam is operational and has a gate valve installed on a low-level outlet pipe (approximately DN900mm), which appears to have the ability to drain the base of the dam, but is not utilised to regulate water levels. This

gate valve would not be utilised by the Council to regulate or attenuate flooding. Any decision to significantly lower the operating water level of the dam would require a review of the operational requirements for water supply of the dam and potential environmental impacts relating to water release and changes to lake levels. **Figure 2-2** shows images of the dam under sunny day conditions (2014) and with spillway overtopping during flood conditions (2020).



Figure 2-2: Images of Captains Flat dam in dry (2014) and overtopping (2020) conditions,

Source: <https://theflatproject.wordpress.com/2014/06/11/the-dam/>

Flooding drivers in Captains Flat

To understand which type of TFWS is most suitable for Captains Flat, it is important to properly understand how floods develop and affect the town. In 2013, a Flood Study was conducted for the Captains Flat Township². There are four main sources of flooding in the area: the Molonglo River, Kerrs Creek, Keatings Collapse, and “Town Creek”. An extract from that study for the December 2010 flood shows inundation is most pronounced near Foxlow St bridge, Kurrajong St and Jerangle Rd (refer **Figure 2-3**~~Error! Reference source not found.~~).

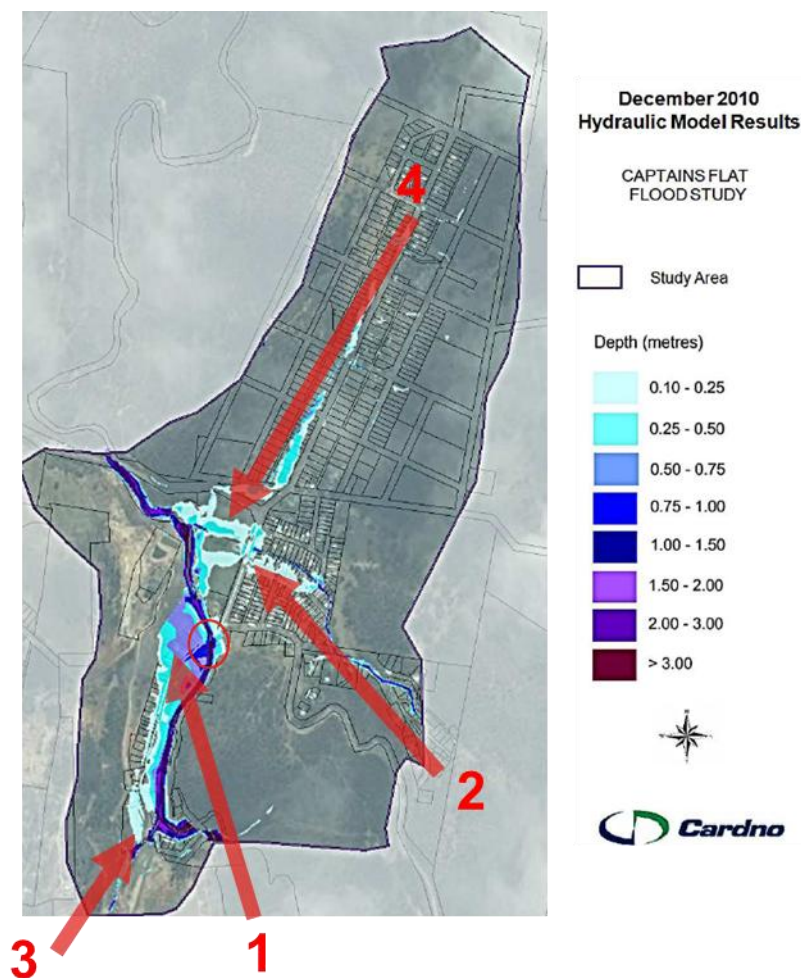


Figure 2-3 Modelled 2010 flood event. 1 is the Molonglo River, 2 is Kerrs Creek, 3 is Keatings Collapse and 4 is Town Creek

Molonglo River

The largest flood risk occurs from the Molonglo River. The Molonglo River discharges via the Captains Flat dam. The Captains Flat Flood study showed the dam's storage capacity is insufficient to provide significant attenuation of peak flood events. The frequency of uncontrolled spills correlates well with anecdotal records of flooding experienced within the town of Captains Flat.

The Molonglo River catchment is the largest of the three main contributing catchments to the town, being approximately 40km². It has a typical flooding lead time of 4 to 7 hours from the onset of rainfall, but exact timing depends on the severity of the event and antecedent conditions. If the reservoir is already fully

² Captains Flat Flood Study – Flood Study Report FINAL – August 2013

filled, and the catchment is wet, the flood will occur faster than when the catchment is dry and the reservoir of the dam is relatively low. If the Molonglo River channel overflows in the township, the majority of this inundation occurs on its west bank. The flooding occurs from the 20% Annual Exceedance Probability (AEP) events onwards (**Figure 2-4**).



Figure 2-4 Inundation on the west bank of the Molonglo River near Captains Flat Dam (20% AEP event shown)

Kerrs Creek

Kerrs Creek is a smaller catchment to the east of Captains Flat with a catchment area of 6km². Catchment response times are generally within 2 to 4 hours after the rainfall starts, with observed catchment response times as fast as 30 minutes. If a flood occurs from Kerrs Creek, it is likely to overtop Kurrajong Street, exposing both the road and surrounding houses (refer **Figure 2-5**). This flooding occurs at a 20% AEP rainfall event onwards.



Figure 2-5 Flooding along Kerrs Creek (20% AEP event shown)

Keatings Collapse

Keatings Collapse has a catchment area of 2.5 km² and is positioned to the south-west of the town. Only in rare situations (e.g., 1 in 50 AEP events and rarer) will it cause overtopping of Foxlow Street and/or Jerangle Road. Because this is quite a small catchment, it has a typical response time of 1 to 2 hours. The inundation due to flooding from Keatings Collapse is, however, minimal compared to the Molonglo River or Kerrs Creek.

Town Creek

Next to the main sources of flooding mentioned in the Flood Study, residents also identified Town Creek as a source of flooding which originates from the North of Captains Flat. Its catchment consists mostly of the town of Captains Flat to the north of Montgomery Street, with a limited catchment area of approximately 0.7km².

Flooding is primarily attributed to blockage of the Montgomery Street culvert (approximately 300mm diameter) due to debris transport during flash flooding. The creek causes regular flooding, up to and above floor levels for those living along Montgomery street. Because the catchment is so small and relatively urbanised, the response time is approximately 1 hour (or less). Processes like blocked culverts cannot be accounted for in a TFWS. However, if the BOM Nowcast product comes available, it will be possible to warn of the potential risk based on forecasted heavy rainfall.

3 Total Flood Warning System Design

In this section we will outline the proposed Total Flood Warning System design for Captains Flat. We propose a two phased implementation of a TFWS for the area (refer **Section 3.2**). In **Section 4**, the implementation plan is presented with the rationale for the phasing.

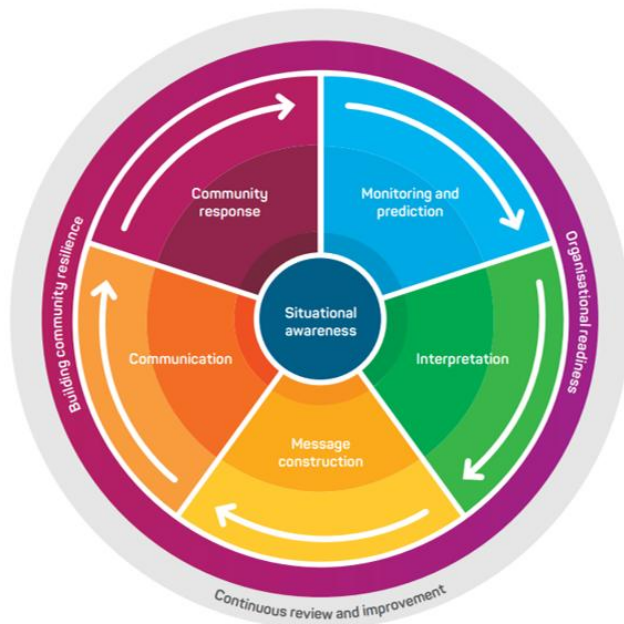
Below we first outline the key design principles and criteria, followed by the components of the system and the data processing and analysis tools.

3.1 Design Principles and Criteria

In 1995, the Australian Emergency Management Institute (AEMI) published a best-practice manual titled 'Flood Warning: an Australian Guide' following a national review of flood warning practices after severe flooding in the eastern states in 1990. This manual introduced the concept of the Total Flood Warning System (TFWS) and emphasized the importance of flood warning as an effective flood mitigation measure. It highlighted the need for a balanced approach, integrating various elements such as risk communication and community education about flood risks and appropriate responses.

The TFWS concept is built on the principles of effective early warning, as documented in the UN's 1997 guidelines. The updated Manual 21 of the Australian Emergency Manuals Series (EMA, 2009) continues to promote these principles, advocating for a consultative approach that involves community input in defining flood warning issues and solutions. The manual is intended for use by flood forecasters, emergency management practitioners, local council personnel, government departments, and members of flood-prone communities.

A fully effective TFWS requires the cooperation of multiple agencies, each with specialized roles, working together through all stages of system development and operation. The system must facilitate clear communication among these agencies and with local stakeholders, ensuring that everyone understands their roles and the actions they need to take.



Key Design Criteria

1. **Facilitate Communication Among Agencies:** The TFWS should enable seamless communication between different agencies involved in flood warning and response, ensuring coordinated efforts.
2. **Engage Local Stakeholders:** The system should effectively communicate with local stakeholders, providing clear instructions on the actions they should take in response to flood warnings.
3. **Reliable Communication Technology:** The system should utilize communication technology that works reliably in the Captains Flat area, ensuring that warnings are received promptly.
4. **Continuous Data Analysis:** Given the short lead-time for flood events, the system should continuously analyse historical data to provide timely and accurate warnings.
5. **Specific Flood Warnings:** The system should be capable of warning about flooding from the Molonglo River and Kerrs Creek, and ideally also from Keatings Collapse and Town Creek.
6. **Consider Dam Conditions:** The system should take into account the initial conditions of the Captains Flat dam when issuing flood warnings.
7. **Adhere to SES Standards:** The system should comply with the flood risk standards set by the State Emergency Service (SES).

Infrastructure Standards

The Flood Warning Infrastructure Standard outlines the performance requirements for infrastructure used in flood forecasting and warning. This includes field instruments, communications equipment, and data ingest software for real-time flood data. While satellite and radar data contribute to flood forecasting, they are not within the scope of this standard. The standard focuses on the 'what' and is independent of technology, while the National Industry Guidelines for Hydrometric Monitoring (NIGL) provide detailed guidelines on the 'how' and are technology-dependent.

The NIGL offers best practices for site and sensor setup, maintenance, and measurement actions, ensuring that the infrastructure meets the performance requirements of the Flood Warning Infrastructure Standard.

Water Level Sensors

1. **Accuracy and Precision:** Water level sensors should provide accurate and precise measurements to ensure reliable flood forecasting. Non-contact sensors such as radar and ultrasonic, are recommended for their accuracy and low maintenance
2. **Durability and Reliability:** Sensors must be robust and capable of withstanding harsh environmental conditions, including extreme weather events

3. **Real-Time Data Transmission:** Sensors should be capable of transmitting data in real-time to ensure timely flood warnings
4. **Calibration and Maintenance:** Regular calibration and maintenance are essential to ensure the sensors continue to provide accurate data

Rainfall Sensors

1. **Measurement Range:** Rain sensors should be capable of measuring a wide range of rainfall intensities, from light showers to heavy downpours
2. **Rainfall resolution:** Rain sensors should be capable of measuring units of a minimum of 1mm.
3. **Response Time:** Sensors should have a fast response time to detect sudden changes in rainfall intensity
4. **Reliability:** Sensors must be reliable and able to operate continuously without frequent failures

Telemetry Network

1. **Coverage and Connectivity:** The telemetry network should provide extensive coverage and reliable connectivity, especially in remote areas like Captains Flat. It is foreseen that mobile network (4G) communication may not be sufficient. The lack of mobile reception is a known issue in Captains Flat and there are no known plans to improve mobile communication in this area. Low Power Wide Area Networks (LoRaWAN) could provide an alternative here.
2. **Data Transmission Speed:** The network should support high-speed data transmission to ensure real-time monitoring and timely flood warnings
3. **Redundancy and Backup:** The network should have redundancy and backup systems in place to ensure continuous operation even if some components fail

3.2 Components of the System

A two phased implementation of the TFWS is envisioned for Captains Flat:

- **Phase 1:** Provides forecasts based on water level and rainfall measurements and forecasted rainfall
- **Phase 2:** Continuous hydrologic / hydrodynamic simulations are added to the system to create spatially varying inundation predictions.

A phased approach is proposed because: Phase 1 may provide sufficient information for Council and comes at a lower operational cost. Also, Phase 2 becomes more advantageous with higher quality rainfall data and Nowcast data, which is yet to be provided for the Captains Flat area by the Bureau of Meteorology. Staging the approach allows for the second phase to only be implemented once the more detailed rainfall data is available.

The envisioned Phase 1 TFWS for Captains Flat combines (gauged) measurements of rainfall and water levels with predicted rainfall. The combination with predicted rainfall is a necessity to create forecasts well in advance, given the short lead-time of the catchments. The gauges then provide timely information about current conditions in the system while the weather forecast gives an outlook of whether the situation will worsen. In Phase 2, the measured and predicted rainfall are also used to run a hydrologic / hydrodynamic models and create a spatially varying forecast of the potential inundation.

The system should be easily accessible, understandable by the end-users and made available to different types of stakeholders including the local council and SES. To connect the TFWS to external applications, it should make use of generic data exchange protocols. This enables the system to provide information to the SES but also to incorporate external data sources like the gauge at the reservoir and the Bureau of Meteorology products.

The system should also be able to provide internal warnings (e.g., actively reach out to SES or Council via SMS/WhatsApp/email). Automated communication to the local communities is currently unwanted as there is a preference to manually validate the warnings before community outreach takes place.

Additionally, the SES should be the single source of warning dissemination to the community to avoid confusion.

Technically, the system can be divided into multiple components:

- Data sources
- Data transfer
- Data storage
- Data Processing & Simulation
- Data dissemination
- Visualisation & communication

A schematic overview of the TFWS setup is provided in **Figure 3-1. Section 3.2.1 to Section 3.2.5** describe the 6 different components in terms of required specifications.

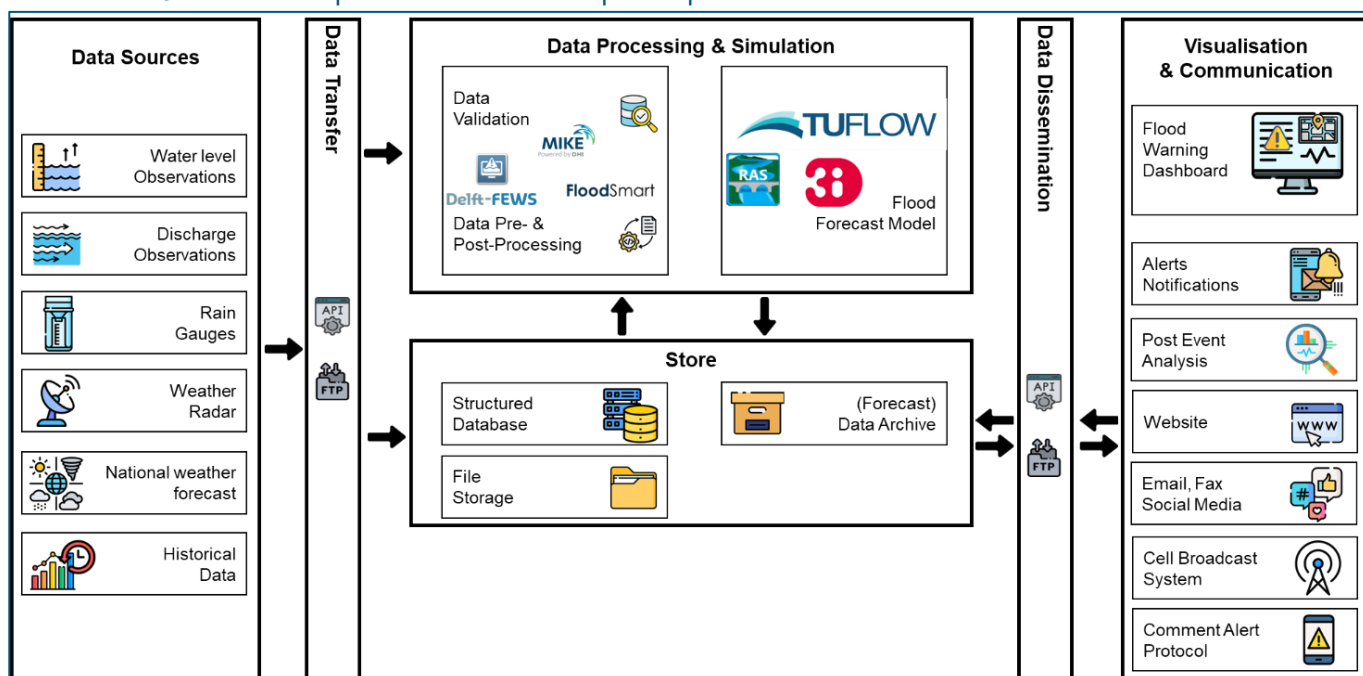


Figure 3-1 TFWS setup and different components

3.2.1 Data sources and transfer to the system

For the TFWS, RHDHV foresee the incorporation of 4 (or 5) different (external) data sources:

- Water level sensors (existing and new)
- Dam discharge measurements (based on rating curve and water level sensor)
- Rainfall sensors
- Rainfall radar
- National weather forecast (Bureau of Meteorology)

If possible, historical data of these sources could also be collected in the system to allow for comparison of situations. Additionally, the radar Nowcast product could also be included, once available. The Bureau of Meteorology is currently working on implementation of a Nowcast product (Rainfields) for all their radar stations. However, this is not yet available for Captains Flat. No timeline is available from the Bureau of Meteorology for when Nowcast will be implemented in this location.

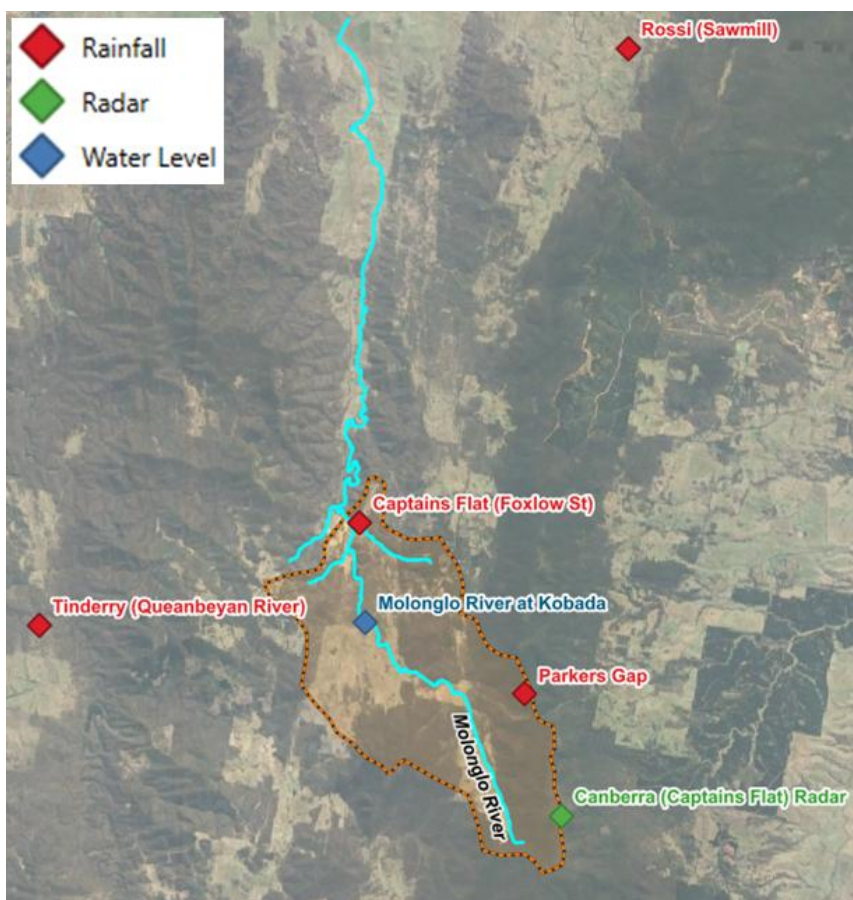


Figure 3-2: Existing gauge infrastructure around Captains Flat. The brown outlined area is the catchment of the four contributing rivers/creeks

There are five existing relevant sensors in the catchment and its vicinity and 1 radar. These should all be imported into the system. The data can be imported as follows:

Table 3-1: Existing Sensors

Source	Owner	Exchange
Parkers Gap	Bureau of Meteorology	FTP: Text files
Tinderry	Bureau of Meteorology	FTP: Text files
Rossi	Bureau of Meteorology	FTP: Text files
Captains Flat	Bureau of Meteorology	FTP: Text files
Molonglo River at Kobada	Council	SCADA REST API or ODBC
Canberra	Bureau of Meteorology	FTP: Netcdf

These measurements are all available as real-time data and can be included in the system from their external source. Several new gauges should be installed to complement the existing sensor network (**Figure 3-3**). A total of four gauges are proposed to be installed; three rainfall gauges and one water level sensor.

Firstly, two gauges should be installed in the Kerrs Creek catchment. One water level and one rainfall sensor. The proposed location is $149.458^{\circ}, -35.597^{\circ}$, which is the confluence of Kerrs Creek's two upper branches. The area is relatively accessible as there is no (dense) forest between the Captains Flat Road and the proposed sensor location. The absence of forest also helps in the transmissivity of the measurement data to the central server and is a prerequisite for rainfall gauges.

The second new rainfall gauge should be installed near the Captains Flat radar ($149.512^{\circ}, -35.661^{\circ}$). This is roughly the upper end of the Molonglo river catchment. The location was chosen to spatially supplement the existing Captains Flat gauge (Foxlow street) and the two new gauges it gives a good understanding of what happens over the catchment. The Captains Flat radar location was selected as well because it is easy to reach (for maintenance) and likely has good existing telemetry connectivity.

The third rainfall gauge should be installed in the Keatings Collapse catchment around $149.438^{\circ}, -35.600^{\circ}$. Since the catchment is small, and without permanent creek flow, a rainfall gauge is more suitable than a water level sensor. The rainfall gauge will detect potential floods earlier and is less likely to be disturbed by vegetation affecting the sensor.

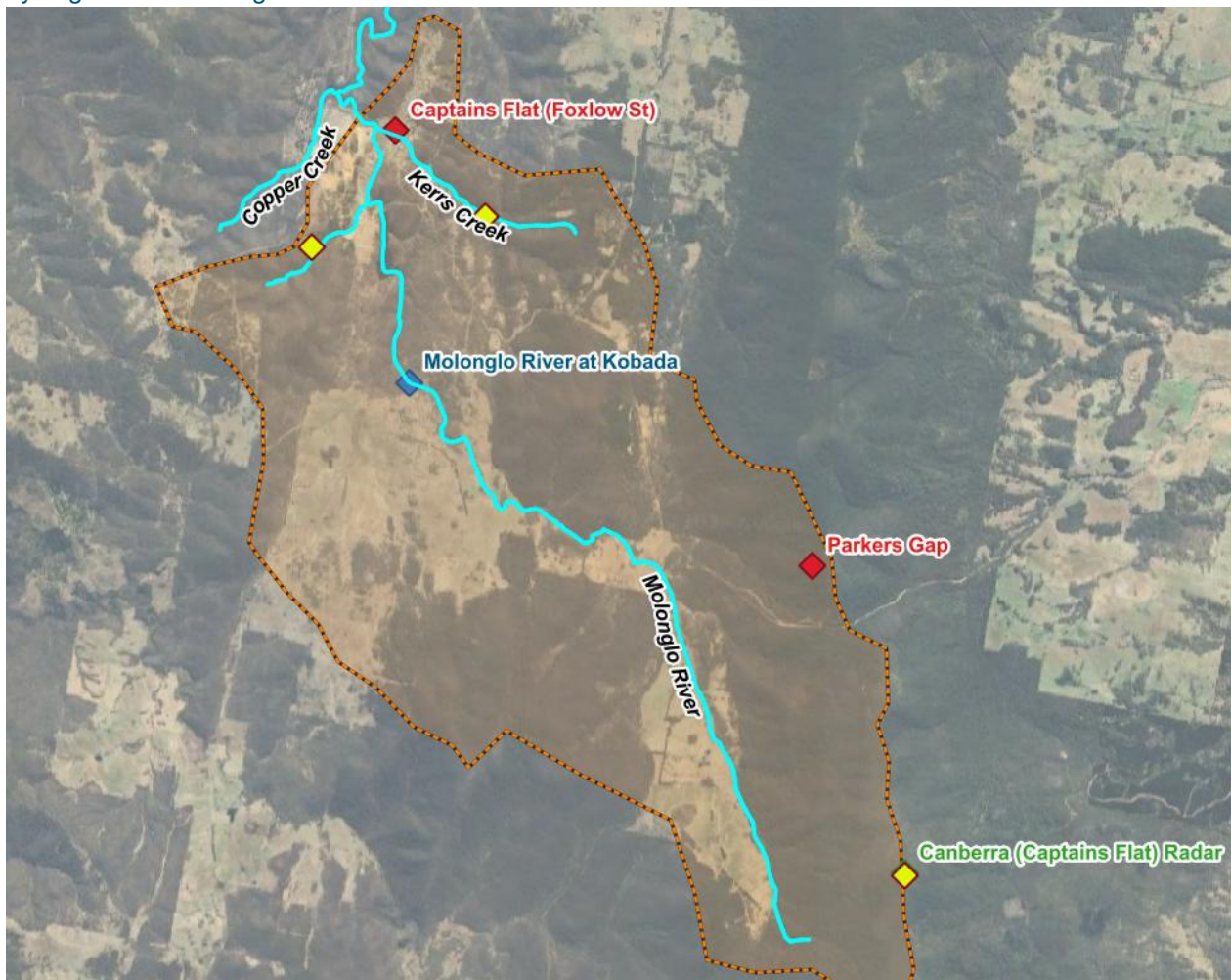


Figure 3-3 Existing rainfall gauges (Red), existing water level gauge (blue) and proposed new gauges (yellow). The new gauge at Kerrs Creek is both a water level and rain gauge while the other new gauges are only rainfall.

Sensor network specifications

The sensors should meet at least the following specifications which are in line with the requirements of the Flood Warning Infrastructure Standard (2019) available from <http://www.bom.gov.au/water/standards/floodwarning.shtml>:

Rainfall

- Measurement accuracy at least 1 mm
- Data sampling interval of 5 minutes or less. Alternatively, transmission once 1mm of water is collected (as is common practice with tipping buckets).
- Data transmission every 5 minutes, at least during rainfall conditions.
- Powered by solar panel and with sufficiently large battery to ensure measurement continuation during multiple day cloudy conditions.

Rainfall gauges are to meet the standards required for Bureau of Meteorology, examples include:

- The TB3 Tipping Bucket Rain Gauge ([Tipping Bucket Rain Gauge | TB3 | KISTERS](#)); and
- The RIMCO 7499 Tipping Bucket Rain Gauge [RIMCO-7499-BOM Tipping Bucket Rain Gauge \(0.2mm\)](#)

Water level:

- Non contact sensor type (radar/ultrasonic) opposed to pressure sensors
- Measurement frequency of 5 minutes
- Transmission frequency of 5 minutes
- The sensor should have a measurement filter (for example moving average or standard deviation). By measuring short time periods and applying a filter (opposed to a single measurement), noise is substantially reduced.
- Powered by solar panel and with sufficiently large battery to ensure measurement continuation during multiple day cloudy conditions.

Due to the remote locations, solar and battery power is the only feasible option to power the proposed sensors. The required battery and solar panel for the non-contact water level sensor will have to be substantially larger than for the rain gauge (though exact capacities depend on sensor manufacturer). Ideally both sensor types can be connected to the same logger type for easy maintenance and configuration.

Water Level Sensors are to meet the standards required for Bureau of Meteorology, examples include:

- The HS40 water level sensor. [Compact bubble sensor | HS40AFC/3100 Compact | KISTERS](#)

Telemetry network

A number of telemetry systems are available, but the chosen option must meet the minimum performance requirements to perform the desired flood warning function, examples include:

- **Radio telemetry** is considered the most reliable system due to its ability to keep working when mobile or satellite systems may drop out at a critical time during a storm event, but this approach would require a repeater station nearby so additional research is required at subsequent design stages to determine the exact requirements.
- **Satellite** is a more standard and less costly option. However, it has a tendency to drop out during extreme weather (which is exactly when you need it to operate). It is common to receive data packets every 15 minutes for 6 months then lose coverage right when it is most needed for flood warning.
- **4G/5G Mobile** is another more standard and less costly option. However, this also has a tendency to drop out during extreme weather (which is exactly when you need it to operate). It is common to

receive data packets every 15 minutes for 6 months then lose coverage right when it is most needed for flood warning.

There are 5 common data transmission methods to transmit data from the sensors to the central data storage system: cellular network, Radio Frequency, Satellite, Internet and wired connections. The cellular network (and hence internet as well) in Captains Flat is fairly unreliable and should therefore not be utilised for the data transmission. Transmission via Satellite comes with a high operational (monthly) cost and wired connections are expensive during the initial installation. Radio Frequency data transmission is the preferred option for Captains Flat as it is fast, reliable, and affordable. LoRaWAN is a widely used radio frequency technology for sensor applications like the one considered for Captains Flat.

To ensure reliability and redundancy of the system, it should ideally be developed as a high-availability setup with geographical redundancy (e.g., distributing the operating system over two geographical locations), and critical components should be installed in a clustered setup where one process takes over if the other fails.

System Ownership

In terms of the ongoing ownership and operation of the equipment, the Bureau of Meteorology (BoM) is in the process of 'acquiring' flood warning systems around the State of NSW. Depending on the relative flood risk in the area, it is possible that BoM would look to acquire the site(s). However, many systems are also owned and maintained by the local Councils, and the data is still fed into the BoM systems. It is our understanding that the BoM would lean towards that model, meaning that for BoM to acquire the site the Councils would need to prove that they have funding for ongoing maintenance. There is a Form provided in **Appendix A**. Once the system design has been completed, the form should to be returned to water_information_fwn@bom.gov.au but also include FWIN@bom.gov.au, and make a note that you want these gauges considered for FWIN acquisition.

3.2.2 Data storage

The data will mostly consist of (temporal) gridded data and timeseries data. For efficient storage, scalability, and exposure of the data to external services (like a website of SES), the timeseries data should be stored in a structured relational database (e.g. PostgreSQL or MYSQL database). Similar databases are utilized in the backend of Delft-FEWS, Mike Operations and FLASH. PostgreSQL is the most common solution as it is open source and therefore free. The measurement timeseries data should be stored long term for a better understanding of the system and future model calibration and validation.

The gridded data (radar rainfall, water depth maps) should be stored either in a file storage or the relational database. There is no preferred solution as long as the storage allows for publishing the data as a (temporal) Web Map Service ((T)WMS) layer. The (T)WMS publishing is particularly important to allow expansion potential for Phase 2 implementation of the system, such as production of temporal water depth results. In Phase 1, this functionality would only be utilized to visualize weather forecasts.

The system should support the possibility to save a copy of a forecast under specific conditions (for example if a warning is issued). These copies are required to perform a post event analysis. Without a copy functionality the weather forecast would, for example, be overwritten by later forecasts. Overwriting these snapshots removes the ability to compare system performance between scenarios and/or updates. Keeping the water level records would also benefit model calibration and validation when the flood study/ Floodplain Risk Management Study Plan is revisited in the future.

The following indicative data volumes should be supported (**Table 3-2**). The number of events to be stored is assumed to be 20, however, storage of more (historical) events may assist in calibrating the system and

flood model. No request for this was noted in any of the stakeholder engagement meetings and the need for additional events to be stored is dependent on the consultant developing the TFWS.

Table 3-2 Foreseen data storage quantity and types

Data type	Quantity
Measurement timeseries	10 stations, 20 years, 5 minutes data
Radar imagery	1 set of grids, 10 years, 5 minutes data
Weather forecast	1 set of grids, 10 days, 3 hourly data
Flood maps	10 per saved event, 20 events
Historic weather forecast	56 grids per event, 20 events

The total volume of data is thus limited but should be structured in such a way that it can be exposed to web interfaces.

3.2.3 Data processing and simulation

Phase 1

To create warnings for imminent flooding, two types of triggers should be developed:

1. Triggers based on measured water level and rainfall values (**resilience triggers**)
2. Triggers based on a combination of measured water level and (cumulative) rainfall forecast (**forecast triggers**).

These triggers should be bound to flood warning zones in the township (**Figure 3-4**). Four flood warning zones are proposed, one for each source of flooding with their extent based on flood modelling results:

1. Molonglo River zone
2. Kerrs Creek zone
3. Keatings Collapse zone
4. Town Creek zone

Zone 1 (Molonglo River zone): This is the zone which floods due to discharge through the Molonglo River. The river mostly overflows its west bank Where it inundates houses along Foxlow Street (both sides). The river also affects Wilkins Park, but impact here is less severe.

Zone 2 (Kerrs Creek): This is the zone which floods due to discharge through Kerrs Creek. The creek mostly overflows its southern bank and affects mostly Kurajong Steet and Willow Street, and to a lesser extent Foxlow Lane and Wilga Street. The creek then potentially overflows Foxlow Street and inundates the War Memorial Zone.

Zone 3 (Keatings Collapse): This is the zone which floods due to discharge through Forsters Creek. During high flow conditions the creek may overflow Jerangle Road and the Rural Fire Brigade west of Foxlow Street.

Zone 4 (Town Creek): This is the zone which floods due to runoff in Town Creek. The affected zone is the back-side of the houses along the northern part of Foxlow Street, and some buildings along Montgomery Street.

By specifying triggers for the different flood warning zones, it becomes easier to set up communication and response protocols. Defining those areas will lead to a shared understanding of what a warning means and what area may be affected for a certain alarm level

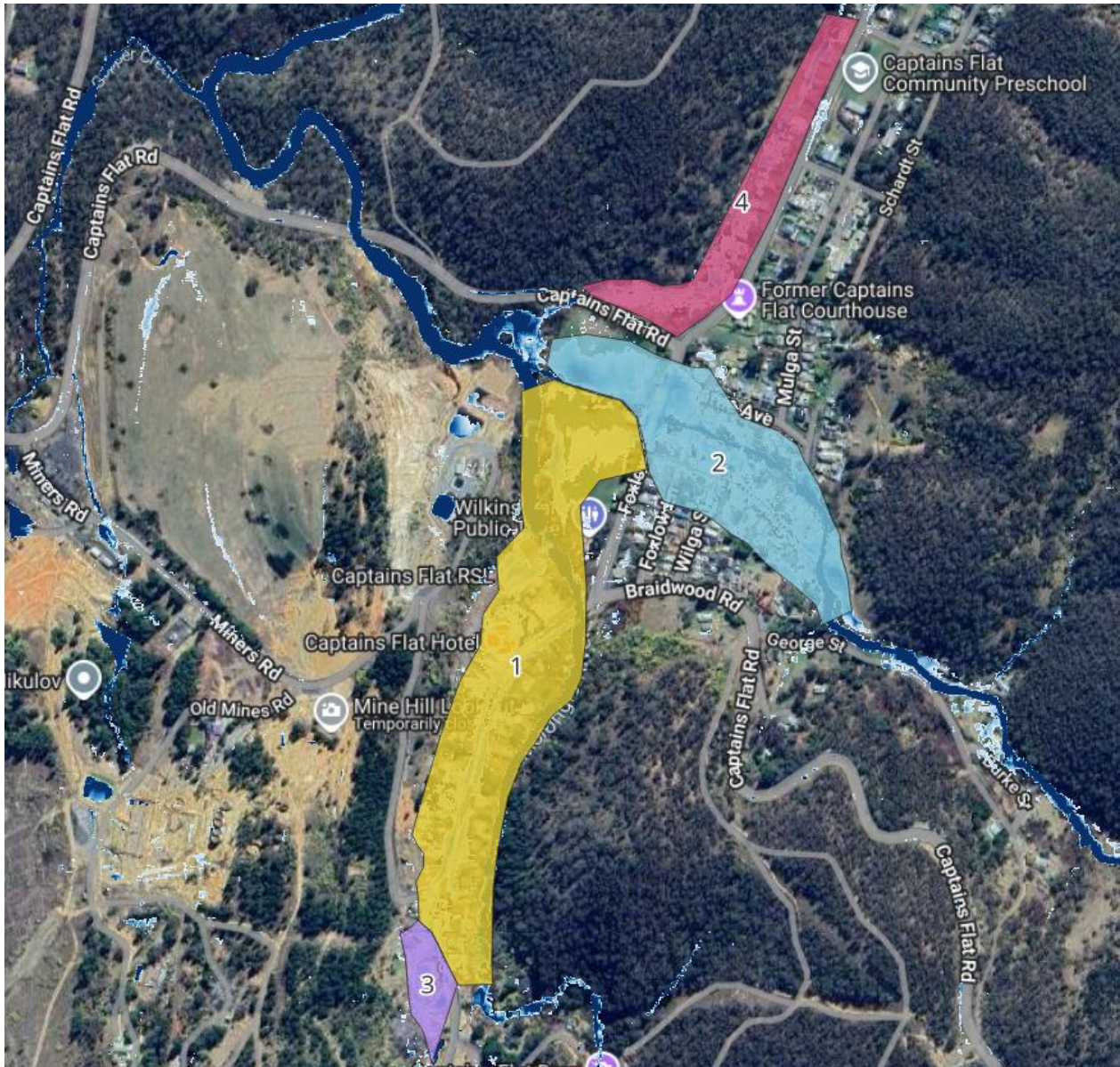


Figure 3-4 Flood warning areas

Triggers

To send out warnings for the four flood warning areas defined above, thresholds are defined for cumulative rainfall volumes and measured water levels. Depending on the catchment size, the aggregation period for the cumulative rainfall differs **Table 3-3**. It should be noted that these are necessarily draft values until the flood model is accurately refined during system set up.

Table 3-3 Aggregation period for the cumulative rainfall specified per area and gauge

Warning area	Gauge	Aggregation period (rain only)
Area 1	Molonglo River (water level) New, Parkers Gap, gauge (rainfall)	3 – 5 hours
Area 2	New, Kerrs Creek, gauge (water level & rainfall)	1 – 3 hours

Warning area	Gauge	Aggregation period (rain only)
Area 3	New, Keatings Collapse, gauge (rainfall)	1 – 3 hours
Area 4	Captains Flat (rainfall)	1 – 3 hours

To distinguish between event severity, a minor, moderate, and major trigger can be defined. We propose to use the following events (<https://knowledge.aidr.org.au/resources/ajem-october-2023-accurate-flood-classifications-are-critical-to-keep-our-communities-safe/>) in line with industry standards and noting that flooding starts to occur in the 20% AEP in most locations.

- Minor: 20%AEP
- Moderate: 5%AEP
- Major: 1%AEP

This corresponds to the following rainfall for each area (<http://www.bom.gov.au/water/designRainfalls/revised-ifd>).

Table 3-4 Proposed rainfall triggers for flood warning areas

Area	Minor rain trigger	Moderate rain trigger	Major rain trigger
Molonglo River	43.5 mm in 4.5 hours	58.4 mm in 4.5 hours	77.3 mm in 4.5 hours
Kerrs Creek	32.5 mm in 2 hours	43.3 mm in 2 hours	56.2 mm in 2 hours
Keatings Collapse	25.9 mm in 1 hour	34.8 mm in 1 hour	45.4 mm in 1 hour
Town Creek	25.9 mm in 1 hour	34.8 mm in 1 hour	45.4 mm in 1 hour

The water levels triggers are based on the Annual Exceedance Probability analysis of discharge in the Molonglo River and the rating curve of the reservoir. The values for the Kerrs Creek catchment are based on initial hydrodynamic modelling to reproduce the Minor, Moderate and Major floods in the entire catchment.

Table 3-5 Proposed water level triggers

Area	Minor water level trigger	Moderate water level trigger	Major water level trigger
Molonglo River	865.7 mMSL	865.9 mMSL	866.1 mMSL
Kerrs Creek	889.5 mMSL	890 mMSL	890.5 mMSL

The thresholds above correspond to the level where the floodings occur. These thresholds can be utilized for both resilience and forecast triggers. A forecast trigger uses the actual thresholds, while a resilience trigger uses a slightly lower value to generate additional lead time (see below).

Resilience triggers

Resilience triggers are the backup of the system, they are alarms bound to the exceedance of a certain water level at the gauge. These levels should be defined at a slightly lower level than the actual alarm level. For example, if a water level of 865.7 m, at the gauge in the Captains Flat reservoir causes flooding of Foxlow Street, the resilience trigger would be set at 865.5 m, AHD. In this way the rising water level is

ideally detected some time before peak flood wave arrives; potentially also accounting for a level of uncertainty.

Forecast triggers

For forecast triggers the cumulative forecasted rainfall will be utilized. The national weather forecast Australian Digital Forecast Database (ADFD) and later Rainfields (radar-based rainfall forecast, when available from BoM) will be aggregated to create cumulative rainfall forecast estimates. It should be noted that the ADFD has reasonably coarse resolution (5 km x 5 km grid) that it is likely to predict reasonably uniform rainfall throughout the Captains Flat catchment (e.g. refer **Figure 3-5**). Therefore, it is advisable to incorporate the Rainfields product (which is more accurate, and typically has a 1 km x 1km grid) as soon as it becomes available.

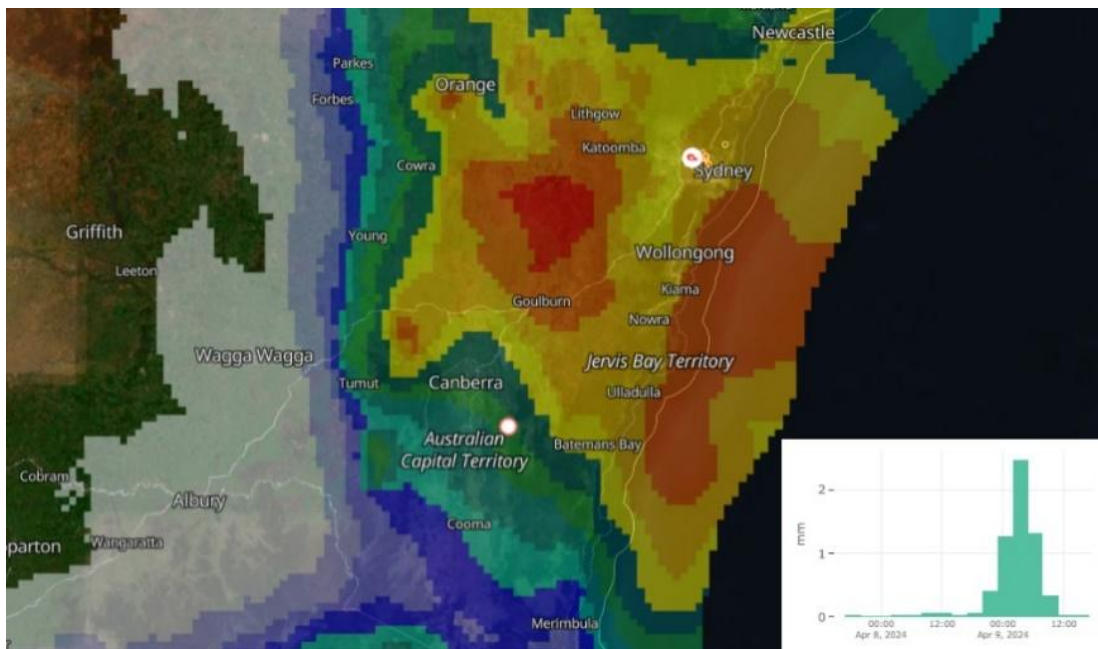


Figure 3-5 Screenshot of the ADFD weather forecast with the temporal pattern for captains flat in the lower right corner. The dot south-east of Canberra is where Captains Flat is located. The Molonglo River catchment may be made up out of, say two (2) times 5km x 5km grid pixels, but the majority of the town gets the same predicted rainfall.

To improve forecast reliability, the rainfall forecast should be combined with latest water level sensor measurements (i.e. antecedent conditions). The dam sensor is of significant importance as the (initial) lake levels determines how much storage and attenuation is available. The exact combination of the two data sources will have to be worked out during the system development but a correction between rainfall volume and rainfall excess volume is foreseen for the Molonglo River (e.g., subtract the remaining storage volume) while considering the rating curve for uncontrolled release to inform AEP. An illustrative example is presented in **Figure 3-6**.

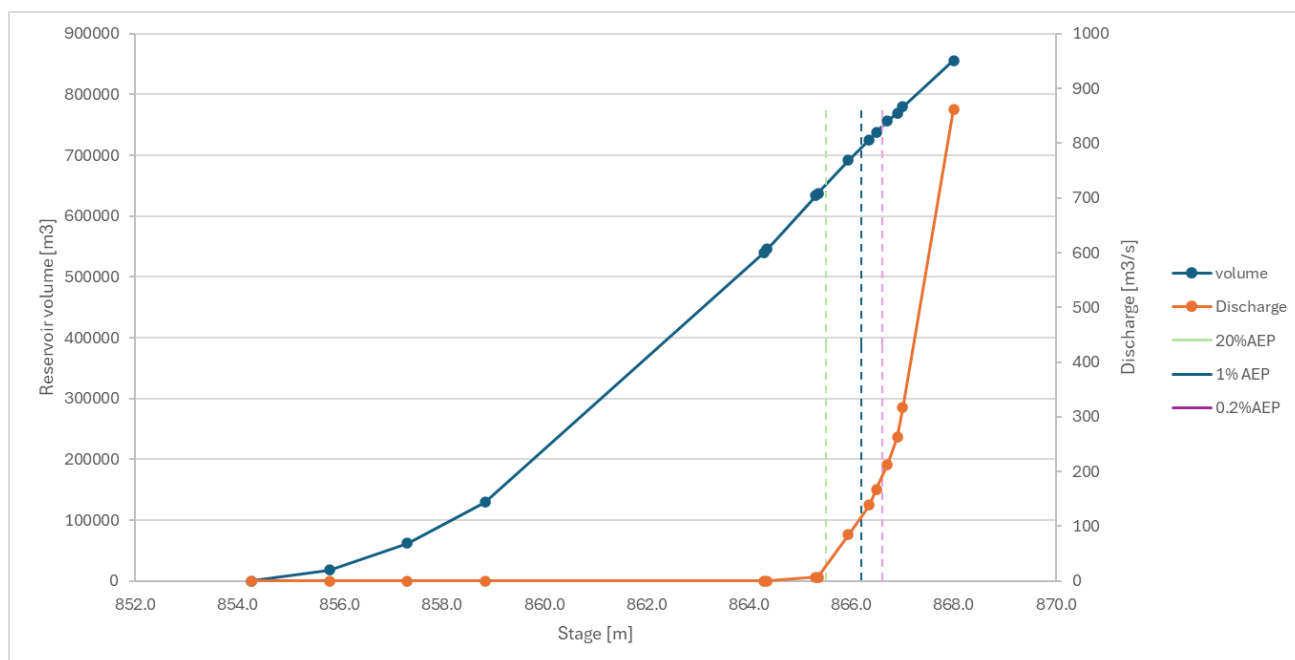


Figure 3-6 - Example reservoir volume and discharge in relation to water level at the dam gauge

Model simulation (Phase 2)

In Phase 2, the data processing is extended with an operational hydrologic / hydrodynamic model. The hydrodynamic model will run continuous simulations to create spatially varying predictions of potential flooding. This has added value to the system because it could provide more precise information when flooding will start, which streets will be affected and what water depths can be expected. These forecasts are heavily reliant on the weather forecasts which is why we propose to implement this in Phase 2 after experience has been obtained from Phase 1 and the Nowcast product has become available. The Phase 2 system does function without the Nowcast product, but due to the limited accuracy of the ADFD the added value would be less.

The model could be developed in a Hydrologic Model combined with TufLOW (which allows for building on the existing models) or could be developed from scratch in an alternative software package. Building on the existing models is preferred and RHDHV believe that we, or a similarly experience consultant can refine the models to be sufficiently fast to meet the system's requirements.

The modelling software adopted will need to meet the following minimum requirements:

- Possibility to run hydrologic model
- Possibility to run 1D / 2D simulations
- Possibility to include 1D structures (culverts)
- Possibility to include rainfall on grid (although unlikely to be preferred method)
- Possibility to provide (upstream discharge) boundary conditions
- Possibility to include the Dam either via initial conditions, state, or boundary conditions

Because the catchment is small and the lead-time relatively short, it is important that the model has a limited runtime to ensure sufficient time is available for review and notification of impending flooding before the predicted flood occurs. The forecast should run up to **12 to 24** hours into the future, beyond that, the weather forecast is too unreliable for the scale of the catchment. The model should run every **30** minutes to **1 hour** to include the rainfall forecasts, latest radar measurements and Nowcasts. The model should then be used to extract water level timeseries at key locations and send automatic alarms to

Stakeholders if a threshold is predicted to be exceeded. The water depth forecast should also be published to the TFWS dashboard (**Section 3.2.4**).

3.2.4 Data dissemination

The data in the system should be sharable automatically with external applications and stakeholders. This holds for timeseries (actual data), gridded products (web map), and we would advise to create the possibility to share (future) automated reports (files). Any secure data transfer protocol would suffice but the following are preferred in the first instance:

- Representational State Transfer Application Programming Interface (REST API) is preferred for the timeseries, and
- TWMS for the gridded data and (Secure) File Transfer Protocol ((S)FTP) for the reports/files

This is a data dissemination setup which can be utilized by all modern external applications and has the possibility to limit and authenticate connections/interactions with the TFWS database. Therefore, the setup is easy to approach and yet the TFWS will not be at risk from external connections.

3.2.5 Visualization and communication

The visualization and communication options of the TFWS are the most important component towards the end-user as this is where the different stakeholders get their warnings and information from. The visualization and communication should consist of multiple platforms:

- An expert (online) dashboard with all relevant information tailored towards the stakeholders
- A public website for communication to the local community
- An automated alarming system which draws the expert stakeholders to the dashboard (WhatsApp/email/SMS)
- A dissemination channel to alert the local community

The dashboard is the key information source for the different stakeholders. It comes with multiple requirements:

- The dashboard should be hosted online (e.g., approachable as a website and not on a specific server)
- The dashboard should be protected with a login to ensure that it is not open to local communities
- The dashboard should provide insight in the latest measurement values to obtain an understanding of the current conditions in the town
- The dashboard should have an easily understandable interface which highlights the alarm level in a single glance.
- The alarm thresholds should be configurable by Council/SES as this will likely require some finetuning during the first years that the system is operational.
- In Phase 2: a map viewer which shows the potentially inundating areas
- Optionally: Ideally the dashboard comes with a (user) management interface where Council can modify who has access to the system and configure the interface.

The public website should ideally be part of existing SES or Council websites. This would need to be agreed with the hosting party as part of building Phase 1 of the system. For findability and platform credibility reasons, it would be beneficial for the portal to be integrated with, or directly linked from website(s) the local community is already familiar with (e.g. existing Hazards-Near-Me App and Council website). If the data dissemination setup is configured correctly (**Section 3.2.4**) it is possible to integrate information in any external website. However, the future supplier of the system should support the people developing/maintaining the external website to streamline the integration.

The automated alarming system should send messages to the mobile phones of selected persons (SES, Council). The messages should be automated and provide sufficient specifics to understand the severity of the event.

A dissemination channel towards the local community should be arranged. This dissemination should be triggered manually (opposed to the automated alarming towards SES/Council). By having a manual dissemination to the local community, a check can be performed by the system operators to assess the reliability of the alarm. Using the cell broadcast system would be the ideal solution as this is a reliable means of communication which can target specific areas without the necessity of installing (mobile) apps on people's cell phones. An audible warning (siren) is not preferred as it would be triggered too infrequently to be effective.

3.3 Non-functional requirements

In addition to the functional requirements describe above, there are several non-functional requirements:

1. **Reliability:** The system must provide accurate and timely warnings with a high degree of reliability to ensure that users can trust the alerts and take appropriate actions.
2. **Scalability:** The system should be able to handle an increasing number of users and data sources without a significant drop in performance.
3. **Performance:** The system must process and disseminate warnings quickly, ensuring minimal latency from data collection to alert issuance.
4. **Availability:** The system should be operational 24/7, with minimal downtime, to ensure continuous monitoring and alerting.
5. **Usability:** The user interface should be intuitive and easy to use for both technical and non-technical users, ensuring that warnings are easily understandable and actionable.
6. **Interoperability:** The system should be able to integrate with other systems and data sources, such as weather stations, river gauges, and emergency services, to provide comprehensive and coordinated warnings.
7. **Security:** The system must ensure the confidentiality, integrity, and availability of data, protecting it from unauthorized access and cyber threats.
8. **Maintainability:** The system should be designed for easy maintenance and updates, allowing for quick fixes and improvements without significant downtime.
9. **Resilience:** The system should be able to withstand and recover from hardware failures, network issues, and other disruptions to ensure continuous operation.
10. **Compliance:** The system must adhere to relevant standards and regulations, ensuring that it meets legal and organizational requirements.

4 Implementation Plan

The implementation plan consists of two phases corresponding to the two versions of the system described above. Initially only Phase 1 will be implemented. However, several things should be considered during the development of Phase 1 to ensure that Phase 2 can be implemented later.

Phase 1: Initial System Development

1. **Objective:** Develop an initial flood warning system utilizing rainfall forecasts and gauged measurements.
2. **Components:**
 - **Rain and Water Level gauges:** Select reliable gauges which transmit information in a standard data format enabling integration into different TFWS software.
 - **Data Operation Platform:** Select a scalable and flexible platform that supports future expansion.
 - **Server Specifications:** Ensure servers are capable of handling increased data loads and model running requirements for Phase 2.
 - **Technology:** Use generic technology to facilitate supplier switching if needed.
3. **Steps:**
 - **Requirement Analysis:** Identify and document system requirements based on rainfall forecasts and gauged measurements.
 - **Platform Selection:** Choose a data operation platform that supports scalability and flexibility.
 - **Server Setup:** Configure servers with specifications that allow for future scaling.
 - **System Development:** Develop the initial flood warning system using selected technologies.
 - **Testing and Validation:** Conduct testing to ensure system accuracy and reliability.
 - **Deployment:** Deploy the system and provide training to relevant personnel.

Phase 2: System Expansion (Conditional)

1. **Objective:** Expand the system to run a hydrodynamic model continuously and create high-resolution forecasts.
2. **Components:**
 - **Hydrologic / Hydrodynamic Model:** Develop and integrate a hydrologic / hydrodynamic model for continuous operation.
 - **High-Resolution Forecasts:** Develop capabilities for generating high-resolution flood forecasts.
3. **Steps:**
 - **Requirement Analysis:** Reassess system requirements for hydrodynamic modelling and high-resolution forecasting.
 - **Platform and Server Upgrade:** Upgrade the data operation platform and servers as needed to support the expanded system.
 - **System Development:** Develop and integrate the hydrodynamic model into the existing system.
 - **Testing and Validation:** Conduct extensive testing to ensure the accuracy and reliability of high-resolution forecasts.
 - **Deployment:** Deploy the expanded system and provide additional training to relevant personnel.

5 Cost Analysis

Below we provide indicative cost information for the two phases (**Table 5-1**). These numbers can be used as internal estimates when preparing for tendering. It should be noted that we have specified a range of costs (low and high scenario). The Phase 2 costs are in addition to Phase 1 costs, assuming Phase 1 has been implemented. The development costs are dominated by the installation of sensors and telemetry infrastructure and for Phase 2 the model development and calibration. In case the gauges can be implemented as an extension of the existing telemetry system a substantial cost reduction may be realized.

Table 5-1 Indicative costs for the system development and maintenance

Item	Phase 1		Phase 2	
	Low	High	Low	High
CAPEX (Development Cost)				
Installation rainfall gauges	\$30,000.00	\$30,000.00	\$0.00	\$0.00
Installation gauges (1 Water Level Gauges)	\$20,000.00	\$20,000.00	\$0.00	\$0.00
Telemetry - Repeater Stations, integration etc (approximate estimate)	\$100,000.00	\$100,000.00	\$0.00	\$0.00
Model Infrastructure (Hardware and Software)	\$20,000.00	\$25,000.00	\$10,000.00	\$15,000.00
Model Development and Calibration	\$0.00	\$5,000.00	\$50,000.00	\$100,000.00
EWS	\$5,000.00	\$20,000.00	\$5,000.00	\$15,000.00
Other Consultancy and Management	\$7,500.00	\$15,000.00	\$10,000.00	\$15,000.00
	\$182,500.00	\$215,000.00	\$75,000.00	\$145,000.00
OPEX (Annual Operational Cost)				
Operational modelling	\$-	\$1,000.00	\$-	\$10,000.00
EWS platform	\$2,500.00	\$5,000.00	\$0.00	\$15,000.00
BOM subscription	\$2,000.00	\$2,500.00	\$0.00	\$0.00
Gauge maintenance	\$1,500.00	\$2,500.00	\$1,500.00	\$2,500.00
Help and support	\$1,000.00	\$2,500.00	\$0.00	\$5,000.00
	\$7,000.00	\$13,500.00	\$1,500.00	\$32,500.00
<i>Additional Gauges</i>				
Rainfall	3	3	3	3
Water Level	1	1	1	1

6 Conclusions & Recommendations

6.1 Conclusions

Captains Flat is susceptible to flooding from four different catchments. The development of a TFWS can support to provide timely warnings to communities and inform emergency services on where to take actions. A two phased implementation is proposed. Initially a system based on sensor measurements and weather forecast can be implemented. This system is relatively affordable, especially in operational costs.

Later, in phase 2, the system can be expanded to include an operational hydrodynamic model and create spatially varying inundation forecasts if the additional information is desirable. By taking the potential phase 2 into account during the implementation of phase 1, additional costs are limited to some additional consultancy and project management hours.

The system will ingest existing measurement and weather forecast data and this will be complemented with one additional water level sensor and three additional rainfall gauges to obtain information at key locations. The system will combine the measurement values with the weather forecast to create predictions and warnings. The system should have a web interface and API to ensure all stakeholders can access the information and, if desired, include it in their own information systems.

Sensors should be connected to a reliable telemetry system for the Captains Flat area. This implies that communication could take place either through a direct satellite connection or probably LoRaWAN as cell networks are unreliable in the area. The same holds for the final communication from the SES to the local community. This could, for example, take place via mobile phone, the siren at the old fire station or maybe the cell broadcasting service if it functions reliably (to be investigated). The most likely solution is for the sensors to be connected using LoRaWAN with final communication being via multiple methods allowing residents to receive warnings as text alerts and warnings over a Wi-Fi network.

To ensure that the forecasts are easily understandable, their naming conventions and levels should be defined in close collaboration with the SES. The system should be flexible in its alarming terminology. Depending on local preferences, the terminology of the warnings should be aligned or differentiated from SES and BOM.

6.2 Recommendations

This design of the TFWS focussed predominantly on the technical setup and requirements to come to an effective system for Captains Flat. However, in the implementation of the system, some organisational and communication aspects should be further developed. For example, there will be both regional (Bureau of Meteorology) and local (Captains Flat) warnings in place. Who will be responsible to act (and coordinate) on the new warnings, what measures can the community and local emergency services take and when will they start to mobilize. The new TFWS should come with standard operating procedures to utilize it to its full potential, where possible these should be integrated into current plans and measures.

Next to that, we recommend starting using the system as soon as possible and not directly move to Phase 2. A TFWS requires time to fully understand the information it provides, which situations does it perform well and when does it create erroneous predictions. Through “learning by doing”, Council and SES will gain progressively more experience with the system and will learn what eventual functionalities are missing and should be added or improved in the future.

Appendix A

Application for Station ID Number Form

APPLICATION FOR FLOOD STATION NUMBER

Completed forms should be sent to: water_information_FWN@bom.gov.au

Applicant details			
Name		Organisation	
Phone number		Email	
Station owner			
Technical point of contact - name		Technical point of contact – phone number / email	
Maintenance service provider		Maintenance frequency	
Installation service provider			
Reason for installation	☐	Improved flood forecasting	
	☐	Situational awareness of riverine flooding	
	☐	Data to support local or flash flooding system (requires Flood study or equivalent documentation to be attached)	
	☐	Supports / Improves Alert2 Network	
	☐	Other - provide further information below:	
Will the site be established and maintained according to the National Industry Guidelines for hydrometric monitoring (bom.gov.au) ?	☐	Yes	
	☐	No – provide further details below:	

Location details

☐	New station (proposed)	☐	Existing station
☐	Private land access	☐	Public land access
Local Government Agency / Authority:			
Latitude (5 decimals)		Longitude	
Elevation (m AHD)		Catchment	
River basin ID		Catchment area (km ²) (if available)	

Equipment and data details

Site name (First name - Locality (town suburb etc.) Second name - more localised feature, such as the property or river name)		Site function (e.g. rain, rain/repeater, rain/water level)	
Infrastructure	☐ Raised platform ☐ Alert Tree ☐ Short rain gauge housing ☐ Cabinet ☐ Other – Details below: 	Frequency (MHz / modem bands)	
Equipment (e.g. gas bubbler unit and 0.2 mm TB RG)		Communication type	☐ 4G / 5G cellular ☐ ALERT / 2 VHF ☐ Satellite ☐ Other
Data logging frequency	☐ 5-minute ☐ 15-minute ☐ 1-hour ☐ 3-hour ☐ Event based	Station data transmit frequency	
Provider data export to Bureau frequency (FTP)		Sensor Range and increment (if applicable)	

Communications details (radio network only)

**Data transmission steps
from site to user ingest**
e.g.

Identify Repeater and Base
Station Sites required to support
data transfer/ingest.

Agency to agency transfer method
if not directly ingested by Bureau.

Fade Margin results

Field results from fade margin
testing

FTP (incoming):
Agency ID:
Agency Station ID
(River ID / AWRC):

If ALERT ID required
Tick all that are relevant

- ☐ Rain
- ☐ River
- ☐ Battery
- ☐ Alert 2
- ☐ Other (provide details below)

Metadata (if installed)

Gauge zero (AHD/LGH)		Orifice level offset	
Measurement increment (Water Level)		Rating date and version	
Water level sensor range		Site installation photos provided	☐ Yes ☐ No
ACMA License Number (Only applicable to repeaters)		Maintenance frequency: service record provided	☐ Yes ☐ No

Site map

BUREAU OF METEOROLOGY USE ONLY (DSS to update)		
Gauge benefits		
Inclusions	☐	SLS
	☐	WEB
	☐	FDS Standard product suit
	☐	FDS Agency specific product
	☐	Sensitivity (Data Sharing)
	☐	WET
Outgoing UDP	☐	No
	☐	Yes. Provide agency name below: