PERFORMANCE REVIEW OF FLOOD WARNING GAUGE NETWORK IN QUEENSLAND

Findings report

Prepared for:
DEPARTMENT OF NATURAL RESOURCES AND MINES
PO Box 15216
City East Qld 4002

Prepared by:

Kellogg Brown & Root Pty Ltd
ABN 91 007 660 317
Level 11, 199 Grey Street, South Bank Qld 4101
Telephone (07) 3721 6555, Facsimile (07) 3721 6500

16 December 2015

BEW553-TD-EV-REP-0011 Rev. 2

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Revision History

Revision	Date	Comment	Signatures		
			Originated by	Checked by	Approved by
A	1/9/2015	Issued for comment	G. Ross	H. Betts	C. Gimber
0	23/10/15	Issued for use	H. Betts	C. Gimber	C. Gimber
1	2/11/2015	Comments incorporated	H. Betts	C. Gimber	C. Gimber
2	16/12/2015	Issued for use	H. Betts	C. Gimber	C. Gimber

ACRONYMS

ALERT	Automated Local Evaluation in Real-Time
BMA	Billiton Mitsubishi Alliance
AWS	All Weather Station
BoM	Bureau of Meteorology
BTE	Bureau of Transport Economics
CoA	Commonwealth of Australia
DEWS	Department of Energy and Water Supply
DILGP	Department of Infrastructure, Local Government and Planning
DNRM	Department of Natural Resources and Mines (project owner)
DPC	Department of Premier and Cabinet
DSITI	Department of Science, Information Technology and Innovation
DTMR	Department of Transport and Main Roads
EMAF	Emergency Management Assurance Framework
FRMP	Flood Risk Management Plan
FTP	File Transfer Protocol
FW	Flood Warning
FWCC	Flood Warning Consultative Committee
FWGN	Flood Warning Gauge Network
GUI	Graphical User Interface
IGEM	Inspector General of Emergency Management
KBR	Kellogg Brown & Root Pty Ltd (project consultant)
KSG	Key Stakeholder Group
LDMG	Local Disaster Management Group
LGAQ	Local Government Association of Queensland
NBN	National Broadband Network
PSBA	Public Safety Business Agency
PwC	PricewaterhouseCoopers
QFCC	Queensland Flood Consultative Committee
QFCI	Queensland Floods Commission of Inquiry
QFES	Queensland Fire and Emergency Service
QPS	Queensland Police Services
QRA	Queensland Reconstruction Authority
ROAMES	Remote Observation Automated Economic Simulation
ROT	Remote Observer Terminal
SES	State Emergency Service
SLS	Service Level Specification
TFWS	Total Flood Warning System
TM	Telemetry
VHF	Very High Frequency

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Executive Summary

ES1 INTRODUCTION

Flood warning reduces the impact of floods

Floods are one of the most expensive types of natural disaster in Australia. Queensland has been subject to a number of significant floods in recent history which have incurred large expenses. The public infrastructure costs for the 2010–2011 floods exceeded $6 billion and the repair bill for the 2013 floods has exceeded $2.5 billion. Since 2009, natural disasters have cost Queensland more than $14 billion (QRA, 2014) and unfortunately 48 lives have been lost. Accurate flood forecasts and appropriate warning allow a local area to plan, prepare for and minimise the impacts of these destructive natural disasters.

The Bureau of Meteorology (BoM) currently provides a riverine flood warning service in Queensland in line with the Queensland Service Level Specification (SLS) at 143 forecast locations across the state, providing forecasts for 123 flood-prone settlements in Queensland. Its weather forecasting also provides advice on pending severe weather events. In order to make timely, reliable and high quality flood forecasts for Queensland communities BoM hydrologists rely on information collected from a range of rainfall and stream water level monitoring gauge networks owned and operated by state and local agencies for a range of purposes.

The compelling need for the study

Previous experience has shown that, following recent events, gauges have been installed that are not always suitable for BoM use or not properly installed. Further, there have been examples of the duplication of assets in close proximity, new products entering the marketplace that may not meet BoM standards and, with the growth in gauge numbers in the last 5 years (with the primary use for flood warning), the placement of those assets has not been aligned to the priority areas across the state. Overall management and maintenance also varies quite widely.

DNRM is lead agency

The Department of Natural Resources and Mines (DNRM) was appointed as the lead agency for policy oversight of the Queensland flood warning gauge network in October 2013. This means that DNRM is responsible for ensuring that the BoM has the best data available for making flood warnings and forecasts. It does not mean that DNRM has operational responsibility for the gauging networks, owned and operated by all the other entities, upon which the BoM relies.

Study reviews the gauging stations providing data for flood warning services in Queensland

DNRM commissioned Kellogg Brown & Root Pty Ltd (KBR) to evaluate the adequacy of the hydrometric gauge networks used for flood warning in Queensland including spatial configuration, standard of equipment, and operational arrangements in order to identify and prioritise potential areas of improvement. The scope of the condition assessment component of the study was confined to state and local government owned assets, and specifically excluded BoM-owned assets.

Project oversight was provided by a Key Stakeholder Group (KSG) which was chaired by the Queensland Reconstruction Authority and study activities were based on IGEM's Emergency Management Assurance Framework.

This review included:

- Background data review
- Assessment of the configuration and technology of networks used for flood warning
- Consultation with gauge owners

- Risk-based methodology to identify gaps in the configuration of the hydrometric gauges used for flood warning
- Prioritisation of improvements to the hydrometric gauges used for flood warning.

ES2 RECOMMENDATIONS

Governance

1. That the State Government establish a cross-agency forum (modelled on the previous Queensland Flood Consultative Committee) to oversee improvements in the strategic and operational arrangements of the Queensland flood warning gauge network and the implementation of the recommendations outlined in this review.

Engagement with BoM

2. That State Government continue to work collaboratively with BoM and respective local governments to review the number of flood forecast locations in Queensland and confirm that the identified 92 settlements that have a riverine flood risk actually require a flood warning service.

Funding strategies

3. That the recommended cross-agency forum facilitate the development of an implementation plan for improvements to the hydrometric gauges used to support flood warning, including funding arrangements and investment strategy guidelines for local governments.
4. That the cross-agency forum implement a coordination program to reduce the overall burden of gauge operation, maintenance and administration expenses, for example sharing costs on a catchment basis under a sharing formula.

Capacity Building

5. That the cross-agency forum facilitate the roll-out of an education and training program and the preparation and dissemination of guidance documents to local governments to clarify their flood responsibilities and access to tools

Asset management

6. That the cross-agency forum oversee the collaborative development of an individual local government and aggregated state-wide asset management system (AMS), that will work at a local, catchment or basin basis. The AMS should serve the respective needs of local governments and overall state management needs.

   The state amalgamated asset management system should align with the BoM AMS in key database fields. The BoM and the cross-agency forum should collaborate to define the fields of the AMS.
7. That the cross-agency forum work with the BoM to share radio and telecommunications communication network information with state agencies and local governments. This will assist in identifying gaps in the overall communications network, refining potential upgrade costs and system integration for new gauges.

Operation and maintenance

8. That the cross-agency forum work with the BoM to develop an outcomes-based accreditation system for instrumentation used for flood warning purposes, based on the outcomes of the Australia New Zealand Emergency Management Committee (ANZEMC) initiatives. This would include developing implementation guidelines for new flood warning gauges to demonstrate need, determine funding sources, establish and seek budgets, assess capacity and support requirements, conduct site assessment, and plan for implementation, commissioning and certification, and operation and maintenance.
9. That the cross-agency forum and BoM develop a rating, hierarchy or assessment within the database that assigns more confidence and more importance to certain gauges than others.
10. That the cross-agency forum and BoM develop a strategy that encourages competition and the entry of new suppliers of equipment.
11. That the cross-agency forum regularly review the effective life of asset components and oversee upgrades or refurbishments as needed.

Technology

12. That BoM advise the cross-agency forum with regard to the impacts of delays for the implementation for ALERT2. (BoM's ALERT and ENVIROMON systems currently limit the number of new stations that can be incorporated into its flood warning system.)

Flash flooding

13. That the cross-agency forum develop a strategy in collaboration with the BoM to identify and publish locations that are likely to be affected by flash flooding, and identify opportunities to improve flash flood warning systems on a regional basis.
14. That the cross-agency forum develop a strategy to integrate warning services for flash flooding across multiple catchments. (This could lead to economies and efficiencies of scale, combining and consolidating management of flash flooding with potential cost sharing for gauges used for flood warning.)
15. That the cross-agency forum work with the BoM, as part of the National Flash Flood Repository project, and in recognition of related BoM supplementary services, to disseminate generalised district-scale flash flood warning services based around BoM's existing severe weather warning services.
16. That gauge owners continually examine workplace health and safety risks for the different types of installations, with a view to modification of existing sites or designs for proposed sites when possible and convenient.

Other issues

17. That the cross-agency forum facilitate an assessment of rating curves used for flood forecast locations for accuracy and require rating curves to be reviewed and updated during each relevant flood study.

Next Steps

18. That the operational recommendations and outcomes of this report be validated on the ground with the respective local governments, dam owners, QFES, BoM etc. (This will ensure the consideration of issues such as the impact of storages not considered in the state-wide GIS analysis.)
19. That the Queensland hydrometric networks used for flood warning be reviewed periodically and the findings of this report be updated.

ES3 CONTEXT

The expansion of gauges to support flood warning has evolved with little governance and there are some implications

Over time, the establishment of gauging stations in Queensland has included assets of variable standards and technical consistency. Gauges have been installed by different entities for their own core business purposes. This presents a considerable challenge for data reliability when it comes to the BoM providing a reliable flood forecasting and warning service. In addition, there is an expectation from the community to view data on demand for their location on the BoM website irrespective of its standard or quality. Hydrometric gauge stations collect, record and communicate rainfall and stream water level data to BoM which is displayed on the web site and input into hydrological forecast models.

There are no consistently applied standards for instrumentation, monitoring and data collection for gauges used for flood warning. Individual owners may have their own standards, but these vary between owners.

BoM provides hydrologic forecasts for riverine floods only

The flood forecasting and warning services provided by BoM in Queensland are directed at riverine flood events; that is, where the rain-to-flood time is greater than six hours. Forecasting and warning of more rapid flood events (flash flooding with a rain-to-flood time of less than six hours) is not occurring consistently and there is no clear allocation of responsibility within government to provide this service.

An effective flood warning system is a cooperative partnership across a range of stakeholders at different levels of government and sometimes includes organisations from the private sector. The real benefit the data provides is the ability to predict likely flood risk by estimating the flood peak and the timing of the peak.

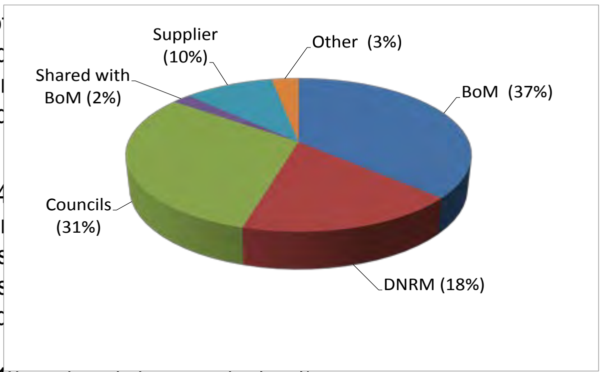
Improved warning lead-time allows for earlier evacuation, reduction of injuries from flooding, reduction in accidents, protection of property, facilitation of orderly evacuation and less stress on the affected communities.

ES4 GAUGES USED FOR FLOOD WARNING IN QUEENSLAND

54 owners of gauges used for flood warning

There are 54 owners of gauges used for flood warning purposes, comprising 38 local governments and 16 entities and/or departments. The BoM owns approximately 1/3 of the gauges and local governments own approximately 1/3 of gauges. DNRM is the other major owner. The ownership is depicted in the chart.

BoM owns around 40% o rain gauges and ar ounc 20% of the stream watei level gauges used for flooc warning.



2,924 gauges are used for flood warning purposes, usually as a secondary function

There are currently 2,924 gauges that are used fo flood warning purposes and the number of gauges reported has increasec substantially over the last 1,349 rain gauges and 1,119 combined stream water level/rain gauges.

At least 250 gauges have been identified that may be available for inclusion in the list of stations that support BoM's flood warning service. Major owners include TMR, Seqwater, some local governments and a few private organisations. These would need to be investigated as part of the on-ground validation proposed.

ES5 DATA COLLECTION AND COLLATION

At the start of the project, DNRM and BoM provided information including spreadsheets of gauge data, background information, spatial data files, DNRM asset management overview, and contact information for local governments and FloodHub. FloodHub contains information on settlements at risk and availability of flood reports.

DNRM also continued to provide recently released documents and others were discovered during the course of the review.

Gauge owners were invited to participate in the review

Additional information was sought from local governments, state agencies and BoM through a consultative stakeholder engagement process. The consultation activities undertaken included responses to questionnaires, field inspections and face-to-face meetings with key stakeholders.

The stakeholder engagement undertaken for the review was consistent with the Inspector-General Emergency Management Stakeholder Engagement Framework 2014-2018 and was designed to ensure that the views and interests of stakeholders were consistently and meaningfully considered.

Stakeholder engagement formed a key part of the data collection process

The main objectives of the plan were to:

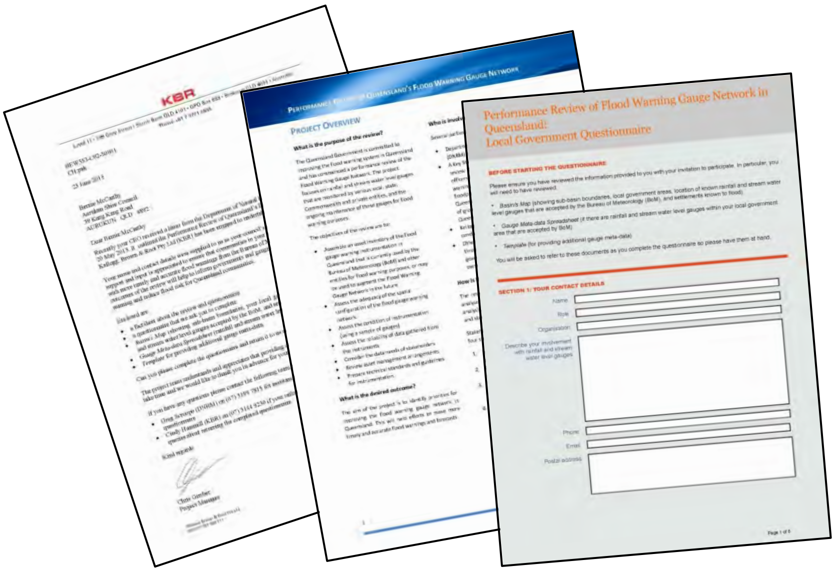
- provide stakeholders with balanced and objective information to help them understand the purpose, process and intended outcomes of the review
- obtain stakeholder input (perceptions/opinions and technical information) to enable a thorough review of the hydrometric gauges used to support flood warning in Queensland.

The adopted approach to stakeholder engagement was multilayered.

Questionnaire

A questionnaire was prepared for organisations throughout Queensland. The questionnaire was distributed via email and in hard copy to 77 local governments throughout Queensland.

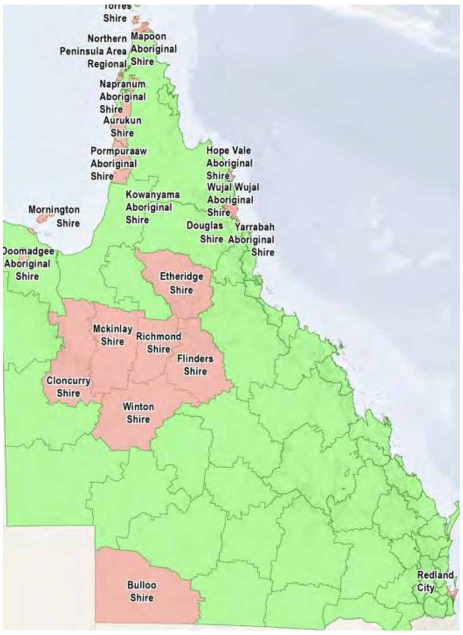
A modified questionnaire was sent to 17 government departments and agencies.



Face to face interviews were conducted

In-depth interviews at 30 local governments and government agencies were used to gain a more detailed understanding of:

- local government approaches and needs
- suggestions for improvements
- capacity
- concerns in relation to flood warning.



Questionnaire response rate was excellent

The questionnaire response rate was 68%. The map shows in green the local governments with which there was communication (e.g. meeting, survey, phone) during the project.

Coincident with the face-to-face interviews, the opportunity was taken to visit 81 gauge locations.

The data were collated into a GIS system

The GIS database provided a basis for gauge location gap analysis that was conducted through a series of specially coded routines.

Data was extracted for the development of an asset register and for further risk-based analysis.

ES6 ROLES, RESPONSIBILITIES AND CAPACITY

The warning service provides forecasts at specific locations

The National Arrangements for Flood Forecasting and Warning (http://www.bom.gov.au/water/floods/document/National-Arrangements.pdf) describe the roles and responsibilities of all three levels of government for flood warning. Specific arrangements relevant to each state and the NT are described in separate chapters with Chapter 6 describing the Queensland arrangements. However, this does not describe the detailed arrangements within the state in terms of legislation, maintenance, operation and funding.

The Commonwealth Government is ultimately responsible for Emergency Management and Incident Management through operation of the Australian Government Crisis Coordination Centre, which consolidates actions during complex national crises and manages the national capacity to respond to such a crisis.

The Commonwealth Government also provides funding and research and development support for hydrometric gauges used for flood warning through the Attorney General's Department. The Attorney General's Department is responsible for Australian Emergency Management and publishes the Emergency Management Handbooks and Manual Series.

The State Government has a range of responsibilities to assist BoM deliver a flood warning service

The roles and responsibility of the state government as defined in the National Arrangements for Flood Forecasting and Warning include to support the real-time collection of data for flood prediction, provide and coordinate emergency management and flood responsiveness activities, disseminate BoM flood predictions, provide a local understanding of the predictions, and develop and implement flood awareness programs at a local level. A number of additional and ancillary roles performed by various state departments are relevant to flood warning but are not discussed in the national arrangements.

The Flood Warning Consultative Committee (FWCC) chaired by BoM is made up of representatives from organisations that are recognised as key stakeholders for flood warning in each State.

Its role is to provide a consultation mechanism for the flood forecasting and warning services provided by BoM and was originally intended to coordinate the development and operation of flood forecasting and warning services and act as an advisory body to BoM.

Queensland Flood Consultative Committee (QFCC) is not active

The Queensland Flood Consultative Committee (QFCC), which has not been active since July 2010, provided a forum for overall coordination of flood management activities in Queensland. Following the Queensland Flood Commission of Inquiry (QFCI) and other findings, it is desirable to reactivate and clarify the role and responsibilities of the QFCC in Queensland.

Local Government is responsible for contributing gauge data for flood warning purposes

According to the national arrangements (BoM, 2015a), local governments are responsible for contributing to real-time flood warning by providing assistance in the collection of data though this does not appear to be uniformly understood across all local governments.

The majority of direct management roles during a flood event should be adopted by local governments on the basis that local issues are best dealt with locally. Key responsibilities include flood response planning, flood disaster management, promotion of local flood awareness amongst the community and interpretation of flood predictions.

Responsibilities for regular assessment and review of hydrometric gauges used for flood warning are not clearly defined in the current arrangements. Various reviews have been commissioned by state government (e.g. QRA 2012); the BoM undertakes internal reviews following major flood events and local governments are responsible for catchment specific flood study initiatives. More recently, a Working Group called the National Flood Warning Infrastructure Working Group was proposed under the Australia New Zealand Emergency Management Committee (ANZEMC) to lead improvements to flood warning infrastructure by facilitating the development of national technical standards and Strategic Flood Warning Infrastructure Plans. This Working Group will bring together key stakeholders in the gauge networks from each jurisdiction. To support this initiative one Queensland agency should have the governance responsibility to plan and collaboratively manage the priorities for the state hydrometric gauges that provide flood warning.

Flash flood warning responsibility

The responsibility for flash flood warning is not currently defined in legislation. The Inspector General Emergency Management's Assurance Framework has a warning standard that recognises all stakeholders share responsibility to ensure the outcome that "communities at risk of impact from an event, receive fit-for-purpose, consistent, accurate warnings through all phases of events".

BoM and the states/territories are currently negotiating a National Agreement that, when finalised, will clarify responsibilities. It is likely the responsibility for flash flood warning will be assigned to state government in partnership with local government, with support provided by BoM in the form of forecasts and warnings for severe weather conditions and potential heavy rainfall conducive to flash flooding.

The consequences and implications of this responsibility are not fully understood by some local governments.

There is no standard system design, guidance, documentation or policy available for local governments to outline what is necessary to provide functional and resilient flash flood warning arrangements. Further, local governments were generally unsure of what their responsibilities entailed. More recently, a National Flash Flood Information Repository was proposed to be set up by the BoM to provide a portal for technical matters on flash flood warning. This may help overcome the gaps in understanding referred to above.

O&M is the responsibility of the owner

Operation and maintenance of the gauges that support a flood warning service is currently the responsibility of the ownership agency and the resources provided for maintenance vary widely by gauge owner and maintainers. This current methodology could be a high cost model and a catchment-wide approach might be more cost-effective and efficient. The funding of new gauges that contribute a flood warning function should ideally be linked to an O&M commitment of the applicant.

Local governments do not always have the capacity to provide the ongoing maintenance required for the gauges in their area so some support has been provided by BoM. This is now changed with national agreement being reached that gauge owners will be responsible for O&M under the standardisation of Bureau Hazard Services Taskforce set up under ANZEMC.

Many local governments advised they lacked staff with the technical expertise to maintain their gauging stations and so needed to rely on external providers (e.g. contractors, BOM).

Existing budget allocations are insufficient to meet O&M needs

Based on existing budget allocations, the development of the flood warning services is unlikely to keep pace with likely future demands, primarily due to the required maintenance and replacement of assets.

Additional financial implications are presented if there is a requirement for augmentation and upgrade of existing assets to cope with changes to technology.

Feedback from some local governments reflected that they felt they were unable to meet the financial obligations of maintenance and potential upgrade of the existing flood warning assets without financial assistance.

The robustness of flood warning assets could be strengthened with improved governance including greater direction, clearer allocation of responsibilities, funding for new installations, operation and maintenance, and research into equipment with a lesser maintenance burden or improved reliability. This task should ideally be coordinated by one lead agency at the state level.

The responsible lead agency should:

- have the highest stake across all aspects of flood warning considering the quality, quantity, accuracy and reliability of information required for flood warnings: if there is a flood disaster, it would be in that department or agency's interest to minimise the impact
- have close links with Treasury and able to influence the supply of funding to other agencies
- have strong linkages to the Department of the Premier and Cabinet, and Queensland Disaster Management Committee (QDMC)
- include staff with effective and extensive personal communications with local government
- have governance, administrative, technical oversight, and access to technical support.

ES7 ASSET INVENTORY

Inconsistencies between agency databases needs further review

BoM maintains a hydrological database that contains information on some components of the hydrometric networks used for flood warning. The database is not exhaustive and gauge owners or third party providers typically hold additional information in separate databases. There needs to be one point-of-truth database to support asset management.

Feedback from the local governments (councils) and information collected during the field investigation highlight a need to confirm the data currently held in the database. There is also scope to expand the data captured to assist with asset management. For effective collaboration to occur asset owners should be able to see the status of all of the gauges in their catchment/basin. A shared and online asset management system would also contribute to ongoing collaborative arrangements.

There are no documented details regarding confidence in the data provided from individual gauges that contribute to flood warning. In general, BoM places high confidence in ALERT data and sites maintained by BoM and DNRM. Additionally, there are no documented details on the importance of certain gauges in supporting BoM's flood warning service, and therefore O&M is not targeted towards gauges with the greatest importance.

There is currently no published accreditation system for instrumentation that can be used to support a flood warning service. BoM does have an accreditation system for its gauge network, but as identified previously, BoM-owned assets comprise only around one third of the gauges that are used for flood warning purposes. Larger state agencies with gauges used for flood warning also have their own accreditation systems for their hydrometric networks.

GIS based asset database developed

The database prepared and used as part of this review combined a subset of the BoM's hydrological data base with information received from agencies and councils as well as data collected in the field. Additional fields which have been brought into the database include the gauge survey datum, gauge zero level, installation date, technical details of the equipment installed in the gauge as well as recent inspection dates.

Condition assessment indicates gauges are generally in good conditions

The physical condition and functionality were assessed for each inspected asset for the condition of the housing, pipework, staff gauge and likelihood of impact from sedimentation.

Of the 81 gauges inspected as part of this review (3% sample size) the findings were as follows:

- 41 gauges (50%) were deemed to be in good condition, with no major issues noted and no need for immediate repair
- 18 gauges (22%) were considered to be in a good condition with some issues noted. In the majority of these cases, this generally related to the absence of a staff gauge which could be easily installed. In some instances equipment was visibly aged or some corrosion was noted, or some potential blockages from algae or sedimentation. At the time of the inspection however, the gauges were in working order. Ongoing maintenance and possibly some minor repair would be of benefit.
- 11 gauges (14%) were of a reasonable condition. Generally, it was noted that one or more components were of a fair condition with signs of corrosion and blockages noted. The condition appeared likely to affect the reliability of the gauge, and repair should be considered in the near future.
- 11 gauges (14%) were identified as in need of repair. Some of the gauges showed corrosion of equipment, visible signs of aging, and/or damage. In one case fire damaged equipment was noted. The integrity of these gauges could not be relied upon, and some form of immediate repair was required.

Guidance documents

Stream water level and rain gauges are typically established by an owner for its core business activity. If the gauge adds value to the provision of a flood warning service then the data will be used by BoM. BoM only requires the data to be fit for purpose and able to be provided to BoM in in a timely manner. The BoM sets out the gauges used for informing its flood warnings and forecasts in the BoM Service Level Specification. Unless there is some certainty as to the quality of the information supplied, the quality of forecasts could be compromised. Further, the data from these gauges provide critical situation awareness to the community, emergency services and other forecasting and warning agencies. Some of the key guidance documentation that has been considered in this review to confirm the quality of information includes:

- National Industry Guidelines Hydrometric monitoring (BoM, 2013b)
- Standard Instrumentation Policy - Version 3 (DNRM, 2013)
- Water Monitoring and Data Collection Standards - Version 2.1 (DNRM, 2007)
- Transport and Main Roads Specifications - MRTS233 Provision of Roadway Flood Monitoring Systems (DTMR, 2015)
- Observation Specification No 2013.1 - Guidelines for the Siting and Exposure of Meteorological Instruments and Observing Facilities. (BoM 1997)
- BoM - Hydrometric Monitoring WISBF GL 100.00-2013. May 2013
- Australian Standards - AS3778.2.3-2009: Measurement of water flow in open channels.
- BoM standard drawings and specifications around ALERT.

Equipment performance specifications, their applications and standard drawing should be made available to councils and contractors so that the market and any future asset owners understand what is expected of gauges that support a flood warning service when new gauges are considered.

The National Flood Warning Infrastructure Working Group to be set up under ANZEMC is expected to develop standards relevant to flood warning infrastructure and publish them by using the services of a Technical Advisory Group.

ES8 NETWORK ANALYSIS

Analysis and prioritisation based on a risk-based method

The assets used for flood warning were analysed to identify improvements to the spatial coverage and the reliability of gauges. The analysis used a risk-based assessment methodology to identify and prioritise improvements that would result in the greatest benefit to communities at risk of flooding.

Analysis was peer reviewed

The risk-based assessment methodology was peer reviewed by an independent hydrology expert commissioned by DNRM and deemed suitable for use.

Flood-prone settlements were identified based on previous assessment by BoM, the previous Department of Community Safety and advice from councils. Settlements susceptible to isolation by flooding (e.g. road network cut for more than 48 hours) were also included in the analysis. Town or city populations were used as a proxy for critical infrastructure such as hospitals and airports.

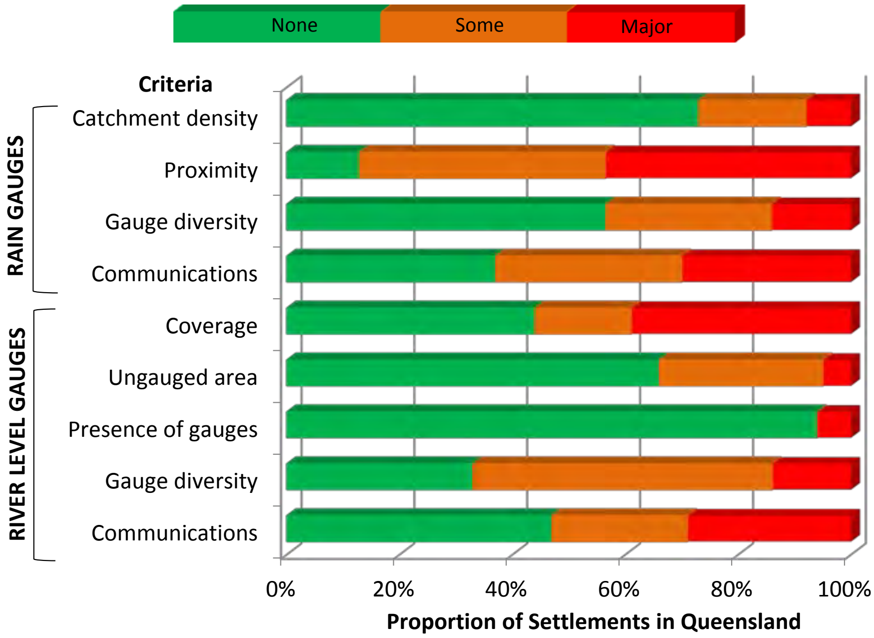
GIS routines were developed to assess the exposure and hazard of flood-prone settlements to riverine flooding, flash flooding, or both, based on travel times on a sub-basin scale and an overlay of state-wide flood mapping against developed areas.

Flood warning gauges analysed in a GIS environment

The spatial distribution and reliability of rain gauges and stream water level gauges were assessed in a GIS environment. This was used to develop a rating of the suitability of gauges above flood-prone settlements to support a flood warning service. Assessment criteria were developed to identify areas where improvements could be made. A “traffic light” system was used as depicted in the figure to show the ability of both the rain gauge and stream water level gauges above each settlement to meet a number of criteria. This shows the proportion of settlements across the state that require nil, some, or major improvements to support a reliable flood warning service.

The results will need to be validated on the ground. (The report finalised by the Banana Shire Council is response to the IGEM Callide Creek Flood Review is a good example of local validation.)

Figure ES7.1 Improvements required to support a flood warning service



Rain gauge density is generally suitable, but clustering of gauges is a problem

The density of rain gauges across catchments was acceptable upstream of 73% of settlements. There were many instances of gauges clustered together leaving large areas without rain gauges, which have now been identified. Only 13% of settlements met the proximity criteria (which identifies gaps in spatial distribution of rain gauges). Half of those that did not meet the proximity criterion, scored poorly (red).

More than half of the settlements score well (green) on rain gauge diversity (diversity is a measure of the variety of gauge types and a pr oxy for the robustness of the networks), with less than 15% scoring poorly (red).

44% of settlements scored well (green) on stream water level gauge coverage with 39% of settlements scoring poorly (red).

The gauging score was matched with the flood hazard score to determine priorities for gauge investment. Settlements with a pr iority of medium or above were considered in need of upgrades. 85 settlements received a priority of medium or above.

The analysis indicates the following spread of results:

- 21 very high priority settlements across 14 drainage basins
- 33 high priority settlements across 16 drainage basins
- 31 medium priority settlements across 16 drainage basins
- 70 low priority settlements across 27 drainage basins
- 60 very low priority settlements across 22 drainage basins.

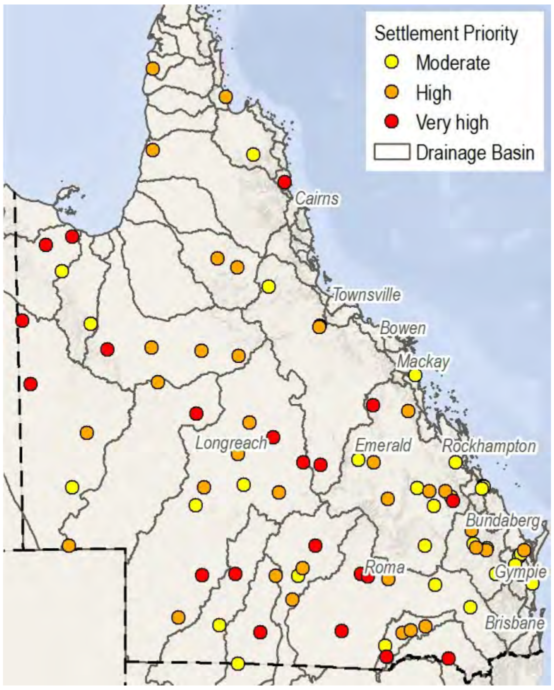
There is a dominance of one technology in particular regions.

Consistent themes that emerged through the performance metrics were a reliance on manual gauges at many locations, and vulnerability due t o the dominance of one technology in particular regions.

The vast majority of settlements have at least one stream water level gauge upstream of the settlement, although 118 flood-prone settlements do not have a manual gauge board within 2 km of the settlement.

ES9 NETWORK IMPROVEMENTS

Prioritised improvements were identified



Improvements to the flood warning system have focussed on increasing the number of forecast locations, increasing the warning time to settlements and increasing the number of rain gauges. Each of these priorities will require 'on ground' validation with local governments and the BoM. The proposed improvements do not relate to BoM-owned gauges since these are outside the scope of this study. Where upgrades of BoM-owned assets are warranted (e.g. manual gauge to ALERT), then the upgrade should be coordinated by the state/local government and involve installation of new assets at that location. BoM would likely retain and maintain its existing asset alongside the new asset as a redundancy.

184 new gauges sites are recommended

Subject to verification on the ground, recommended capital works improvements are indicated below:

Priority 1: Installation of 43 rain gauges, 12 rain/stream water level gauges and 3 water level only gauges in catchments above very high priority settlements ($1.5M)

Priority 2: Installation of 74 rain gauges, 26 rain/stream water level gauges and 1 water level only gauge in catchments above high priority settlements ($2.7M)

Priority 3: Installation of 19 rain gauges and 80 rain/stream water level gauges in catchments above medium priority settlements ($0.8M).

Various replacements and upgrades to improve resilience are suggested

Subject to verification on the ground, potential replacements/upgrades are indicated below:

Priority 4: Approximately 260 new manual water level gauges to provide a gauge in each riverine flood-prone settlement and also at those existing ALERT or TM gauges without gauge boards ($1.8M)

Priority 5: Resurvey of approximately 290 existing manual water level gauges ($0.7M)

Priority 6: Renewal of approximately 180 existing manual water level gauges ($0.9M)

Priority 7: Upgrade approximately 100 manual rain gauges to automatic gauges ($1.5M)

Priority 8: Upgrade approximately 17 manual water level gauges to automatic gauges ($1.0M)

Priority 9: Upgrade landline/satellite communications at approximately 400 stations to 3G or radio ($1M+)

Priority 10: Renewal of approximately 160 existing manual rain gauges ($0.2M).

ES10 ONGOING OPERATION, MAINTENANCE AND ASSET MANAGEMENT

There are currently no national technical standards in place that define how operation and maintenance is to be carried out on gauges used for flood warning purposes. This is expected to be significantly improved with the setting up of a Standards Technical Advisory Group within the ANZEMC National Flood Warning Infrastructure Working Group.

O&M is usually different for each gauge owner

The current O&M models used by owners of gauges that provide a flood warning function are:

- Undertake all O&M (some local governments)
- Undertake routine maintenance with BoM undertaking annual services and calibration (most local governments)
- Shared responsibility with DNRM
- Contractor engaged by local governments
- In-house O&M by infrastructure owner.

Of the 36 local governments that provided information on their maintenance practices, BoM was involved in at least some capacity with around half. Contractors were also involved in maintenance in around half of the respondents. Only 15% of respondent local governments undertook maintenance without any external assistance.

BoM currently provides annual maintenance services to >750 non-BoM-owned gauges which is higher than that provided in other states of Australia.

The level of understanding and flood experience amongst local government officers varies greatly. Some officers do not have the ability to interpret flood warnings or predicted flood levels to on-ground impacts. An appreciation of the importance of maintaining gauges that provide a flood warning function is sometimes lacking.

If external support to local governments in the form of advice or funding were reduced, this would compromise the ability of some local governments to fulfil their obligations. A carefully planned transition strategy would be required.

Additional forecast locations would require additional resources

The number of BoM forecast locations within Queensland is currently 143 but this review identified a possible 92 locations that might experience riverine flooding that could be added to that list, subject to confirmation based on local knowledge. This could have implications for BoM due to the increased load on its hydrologists who are engaged in flood forecasting.

Most local governments involved in this review identified a need for additional human and financial resources and ongoing support to maintain the minimum skill level required for the imposed flood obligations.

For the above to be successfully implemented, training would need to be provided, most likely from state resources.

ES11 FLASH FLOODING

BoM does not provide a specific flash flood warning service, however it does provide severe weather warnings of heavy rainfall that may lead to flash flooding. BoM supports local governments and emergency services in flash flooding by providing Severe Weather and Severe Thunderstorm warnings and by providing technical advice. Recently BoM has secured funding to develop a Flash Flood Warning Information Repository, to provide technical information and advice to local governments.

Local governments require assistance to fulfil their flash flood responsibilities

It is the collective responsibility of the Local Disaster Management Group (LDMG) and local governments to identify flash flooding prone areas along with the other local hazards, however additional assistance from BoM, QFES and DNRM to help evaluate the risk of flash flooding is necessary as some local governments lack the experience to perform such a t ask. Preparation for flash flooding is intrinsically linked to local knowledge, knowing the low-lying areas and understanding the local waterways and how they respond during storms.

The capacity of local governments to prepare for and deal with flash flooding varies significantly.

The nature of flash floods makes forecasting and del ivery of appropriate warnings challenging, Some local governments perform this function using rainfall predictions provided by BoM, while others have developed specialised software to assist with forecasting. Local governments that are not well-resourced however, state that flood forecasting is outside of the normal duties of a council officer.

Existing rain gauges coverage is insufficient for flash flooding

The rain gauge c overage is insufficient in many flash flood prone settlements. The preliminary GIS analysis suggests over 500 additional ALERT gauges would be required in 81 of the 94 flash flood risk settlements.

Prior to further gauge installations a more detailed understanding of flash flood risk is required

Irrespective of the rain gauge coverage, there are other fundamental problems with flash flood warning in Queensland that need t o be r esolved before such infrastructure investment would be warranted. These include:

- detailed assessment of flash flood risk locations (94 identified flash flood locations, plus the additional 320 s ettlements for which no determination of flash flood exposure has been made)
- establishing clear accountabilities for flash flood warning
- communication of those accountabilities
- establishing response plans so that effective responses can be made on w arnings that are issued (either based on forecasts or observed rainfall)
- detailed assessment of the rain gauge coverage in flash flood risk locations so that improvements can be developed that are tailored to the local conditions
- prioritisation of improvements
- consideration of emerging technologies.

Opportunities for regional cooperation should be investigated

Individual storms can often affect entire regions across multiple catchments and an opportunity exists to develop a cooperative regional flash flood management strategy. This strategy could lead to efficiencies of scale through combined and c onsolidated management of flash flooding with potential cost sharing arrangements.

The scope of regional cooperative arrangements should include opportunities to share resources (financial and human), running costs, regional warehousing of spare parts and asset management.

The potential to disseminate generalised district-scale flash flood warning services based around BoM's existing severe weather warning services should be examined.

ES12 OTHER ISSUES

OH&S

Some gauge stations that provide data for flood warning do not satisfy current Occupational Health and Safety (OHS) requirements. OHS assessment at stations should form part of the maintenance requirements.

Rating curves

Rating curves (that relate water level to stream flow) are rarely updated and there are limited requirements for reporting to BoM when floodplain changes occur that affect rating curves.

The maximum stage recorded at a gauging station is often far in excess of the maximum gauging level used to develop the rating curve for the site. This affects the calibration of hydrologic models used for flood warning. Synthetic rating curves derived from two-dimensional hydraulic models can assist rating improvements.

1 Introduction

In the past five years Queensland has experienced some of the most devastating floods in recent history. The 2010–-2011 flood events, tropical cyclones and storms since have had long lasting effects on a number of communities in Queensland. The Queensland Government is committed to improving the flood warning system in Queensland to ensure communities can adequately prepare to assist with flood damage mitigation and prevention.

The Department of Natural Resources and Mines (DNRM) has identified that the ability of the Bureau of Meteorology (BoM) to make timely, reliable and high quality flood warnings and forecasts for Queensland communities is an essential component of the flood warning system in Queensland.

The BoM relies on information collected from the monitoring gauges of 54 owners. For convenience this is referred to as the Queensland Flood Warning Gauge Network (FWGN) but it is not a physical network so much as a data network. Local governments also rely on flood warning gauge data when dealing with flash flooding.

The DNRM has commissioned Kellogg Brown & Root (KBR) to undertake a performance study and review of the FWGN in Queensland. This review is confined to the gauge installations and associated hardware and not the BoM forecasting system or its forecast methods.

The review sought to identify opportunities to rationalise and augment the network to reduce the incidence of flood risk to Queensland communities. Ultimately, the findings of this report should lead to an improvement in the robustness of the wider FWGN that includes the broader cooperation of the stakeholders involved.

The approach to the review of the FWGN is based upon four fundamental tenets:

- The existing gauge installations provide a gross warning time for each settlement
- The data from flood warning gauges must be received with sufficient warning time for evacuation
- At some time a large flood will require the total evacuation of small settlements
- The time needed for evacuation is based on the settlement population.

The review of the FWGN included:

- Examination of previous reports, reviews and recommendations made about the preparedness of Queensland for floods.
- Engagement with key stakeholders to understand their issues and concerns, and gain feedback about their impressions of the FWGN in Queensland.
- Preparation of a comprehensive asset inventory which incorporates information provided from a range of stakeholders about the current assets within the FWGN. Spatial analysis was undertaken of gauge location proximity to settlements at risk of flooding and was focused on the adequacy of installations in different warning envelopes, to identify those settlements with insufficient warning. The analysis provided prioritised recommendations for upgrades to gauging infrastructure.

The report is structured in the sequence of activities completed during the course of the review and is supported by a series of Appendices that contain more detailed information. Appendix A is a Glossary of terms used in floodplain management and flood emergency planning.

1.1 PURPOSE AND OBJECTIVES

The purpose of this study/review was to evaluate the adequacy of the State's hydrometric gauge network in Queensland used by the BoM and local governments for flood warning purposes, including its spatial configuration, standard of equipment, and operational arrangements.

The study had multiple objectives:

- Assess the current status of the spatial arrangement of the FWGN, identify gaps in the spatial distribution of gauges in the network, and develop a staged network improvement program for implementation.
- Develop a complete inventory of the assets and instruments within the FWGN, prepare a conditional assessment report and create agreed technical standards and guidelines for the instrumentation.
- Provide detail of the current operation and maintenance arrangement for assets within the FWGN, identify the capacity of asset owners to provide on-going operations and maintenance, and evaluate options for changes to the current arrangements.
- Compile information on any other ancillary issues encountered during the study including, but not limited to the flow rating curves, adequacy of survey datum for river height gauge, and the accuracy of gauge metadata and its geo-location.

The project terms of reference are included in Appendix B. Some components of the terms of reference could not be thoroughly investigated within the scope of the engagement or with the information currently available. Appendix C provides a cross reference between the terms of reference and this report, with a commentary on how the specific components of the terms of reference have been addressed.

1.2 RISK-BASED APPROACH

The study made use of a risk-based methodology and a high level hydrologic interrogation to identify network upgrade requirements, with a roadmap for implementing improvements to the spatial coverage, equipment standards, and asset management. This took into consideration flood risk, potential flood damages to communities and critical infrastructure, the adequacy of the current FWGN, and flood warning times, with the aim of providing a high standard of flood warning and flood forecasts for Queensland communities.

The review of the FWGN included an examination of previous reports, reviews and recommendations made about the preparedness of Queensland for floods, and engaging with key stakeholders to understand their issues and concerns, and gain feedback about their impressions of the FWGN. KBR has also prepared a comprehensive asset inventory which incorporates information provided from a range of stakeholders about the current assets within the FWGN.

The review included a spatial analysis of the proximity of gauges to settlements at risk of flooding and focused on the adequacy of installations in different warning envelopes to provide sufficient warning. The analysis provided a prioritised recommendation for network upgrades to take place.

1.3 PROJECT OVERSIGHT

Project oversight was provided by the Key Stakeholder Group (KSG) for this review. The KSG was chaired by the Queensland Reconstruction Authority (QRA) and included senior representatives from a number of groups including:

- Department of Natural Resources and Mines (DNRM)
- Bureau of Meteorology (BoM)
- Department of Energy and Water Supply (DEWS)
- Department of Infrastructure, Local Government and Planning (DILGP)
- Department of Premier and Cabinet (DPC)
- Department of Science, Information Technology and Innovation (DSITI)

- Inspector General of Emergency Management (IGEM – Observer)
- Local Government Association of Queensland (LGAQ)
- Public Safety Business Agency (PSBA)
- Queensland Fire and Emergency Service (QFES)
- Queensland Police Services (QPS).

The KSG was established by DNRM before the review started. The group's role in the project was to guide the review. The KSG was convened at three workshops throughout the review and was also occasionally required to provide out of session input. Table 1.1 outlines the date and purpose of each workshop.

Table 1.1 Key Stakeholder Group workshops

Workshop	Date	Purpose
Hold Point 1 Workshop	9 June 2015	Endorse the risk-based methodology and consultation plan
Hold Point 2 Workshop	10 August 2015	Review preliminary findings and discuss key issues before the draft report was finalised
Hold Point 3 Workshop	9 September 2015	KBR's presentation of draft report for comments from KSG over the following week

1.4 IGEM EMERGENCY MANAGEMENT ASSURANCE FRAMEWORK

The Inspector-General for Emergency Management (IGEM) Emergency Management Assurance Framework (EMAF) has been prepared to help guide and support the improvement of Queensland's disaster management programs in response to the increasing human-social, environmental and economic cost of natural disasters. The framework is founded on four principles: leadership, public safety, partnership and performance.

The framework outlines the practices to ensure broader community expectations are considered at all phases of disaster management. These practices reflect the attributes of an effective disaster management system:

- they can be applied to any size of event
- the system is comprehensive
- the system promotes interoperability across sectors
- the services provided represent value for money
- the system is adaptable.

The IGEM EMAF also outlines some accountabilities that should be demonstrated by all organisations involved with the disaster management system. These accountabilities cover the governance, policies, performance and capability that should be employed to integrate effectively the disaster management system within the organisation.

Some accountabilities are for shared organisational responsibilities. These shared responsibilities may relate to hazard identification, risk assessment, hazard mitigation, risk reduction, preparation and planning, emergency communications, response, relief and recovery. To be most effective, these shared responsibilities need to be an agreed part of a targeted strategy that facilitates resilience (the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events) (Brose, 2015).

The IGEM EMAF provides a list of key outcomes (with good practice indicators). In this regard, the framework is not dissimilar to the Integrated Development Application System framework used in Queensland's planning process (the *Integrated Planning Act 1997*, and *Sustainable Planning Act 2009*) and local government planning schemes, which promote adoption of the IGEM EMAF in those organisations.

This IGEM EMAF indicates that the FWGN is one requirement of disaster management within the disaster resilience spectrum. This review of Queensland's FWGN has been conducted with the IGEM EMAF in mind.

1.5 STAKEHOLDER CONSULTATION

It was recognised that stakeholders across Queensland held valuable information for the review. Collecting this information was important to:

- Answer critical questions that could not be addressed though other sources.
- Cross-check information gathered through desk-top research.
- Validate the spatial modelling undertaken.

The consultation undertaken for the review was consistent with the IGEM Stakeholder Engagement Framework 2014-2018 and was designed to ensure that the views and interests of stakeholders were consistently and meaningfully considered. It was guided by a consultation plan developed in liaison with DNRM. The main objectives of the plan were to:

- Provide stakeholders with balanced and objective information to help them understand the purpose, process and intended outcomes of the review.
- Obtain stakeholder input (perceptions/opinions and technical information) to enable a thorough review of the FWGN throughout Queensland.

The plan outlined:

- Groups of stakeholders that would be consulted.
- Methods that would be used to consult with each group including a questionnaire, face-to-face meetings, in-depth interviews, site inspections and formal request for information letters.
- Communication materials that would be used to support the consultation.
- Mechanisms that would be used to provide feedback to participants.

The plan was presented to the project's KSG for endorsement and to DNRM for approval before it was implemented.

Table 1.2 outlines the stakeholders that were invited to participate in the study.

Table 1.2 Project Stakeholders

Stakeholders
COMMONWEALTH GOVERNMENT • BoM • Department of Science, Information Technology and Innovation (DSITI)
STATE GOVERNMENT • DNRM • Queensland Rail • Department of Transport and Main Roads (DTMR) • Department of Energy and Water Supply (DEWS) • Department of Infrastructure, Local Government and Planning (DILGP) • Department of Premier and Cabinet (DPC)
LOCAL GOVERNMENT • 77 local governments throughout Queensland • Local Government Association of Queensland (LGAQ)
DISASTER MANAGEMENT GROUPS AND COMMITTEES • Queensland Reconstruction Authority (QRA) • Inspector General of Emergency Management (IGEM) • Public Safety Business Agency (PSBA) • Queensland Fire and Emergency Service (QFES) • Queensland Police Services (QPS)
GOVERNMENT-OWNED CORPORATIONS • Energex • Ergon Energy • PowerLink • Gladstone Water Board • Seqwater • SunWater
PRIVATE SECTOR BUSINESSES • Aurizon • Stanbroke Pastoral Company • Origin Energy • Glencore Coal Assets Australia • BHP Billiton • QGC • Santos

1.6 PUBLIC INTEREST

The continuation and augmentation of the FWGN is intended to extend flood warning time and to provide more accurate and focussed warnings to a greater number of settlements.

This expense is justified by it being in the public interest to provide for the safety of communities.

The benefits of a flood warning network result from improved warning times that allow for earlier evacuation, reduction of injuries from flooding, reduction in accidents, the protection of property, facilitation of more orderly evacuation, and less stress on the affected communities, first responders and those within the disaster coordination centres, and reduction in continuing impacts.

This is matched by the expectations of community members with respect to government processes and outcomes can vary in a number of ways:

- participation in government (Arnstein, 1969)
- involvement in floodplain development planning (Betts 2001)
- expectation of self-destiny in the hazard mitigation planning (Burby 2001)
- expectations of risk communication (prior to a flood) (Betts 2009)
- crisis communication (during a flood) (Reynolds and Seeger 2005).

These expectations are underpinned by the emergency management precept that people have a right to know (Emergency Management Australia, 2004).

Response to an imminent flood presents issues relating to management (and accompanying institutional arrangements), community response (acceptance and w illingness to act), and t echnical knowledge (hydrologic and hydraulic modelling, forecast accuracy, and trusting the information received).

The community expectations also require government to develop strategies for community awareness and public education programs that will hopefully prepare the community to understand warning messages and act responsibly, quickly and efficiently to minimise overall losses and the adverse impacts of flooding.

The effectiveness of the warning and c ommunication system is founded on a r obust flood warning network of gauges.

1.7 REPORT STRUCTURE

This document is structured as follows.

Section	Title	Description
1	Introduction	Outlines review's purpose and how it was conducted
2	Context	Provides more detail on the background
3	Existing FWGN	Describes the current ownership arrangements and equipment and installation types
4	Data collection and collation	Outlines the review approach and methodology
5	Roles and responsibilities	Examines how the FWGN is managed and explores options
6	Asset inventory	Outlines the development of the inventory, instrumentation, communication systems and reliability
7	Network analysis	Outlines the network analysis process and findings
8	Improvements	Outlines potential improvements to the FWGN
9	Ongoing operation, maintenance and asset management	Discusses the operation and maintenance requirements of gauges in the FWGN
10	Flash flooding	Describes flash flooding and its impacts
11	Other Issues	Outlines other issues encountered during the review.
12	Findings and recommendations	Lists report findings and recommendations
13	References	

2 Context

Findings

- Responsibility for providing a riverine flood warning service in Queensland lies with BoM, and this is generally well understood by councils. The level of service offered by BoM is detailed in the Service Level Specification (SLS)
- BoM provides flood warning at 143 forecast locations, providing forecasts at or near to 123 settlements in Queensland.
- Floods are one of the most expensive natural disasters in Queensland and Australia. In recent history there have been a number of flood events that have incurred large costs. The public infrastructure costs in Queensland for the 2010–2011 floods exceeded $6 billion and 2013 floods exceeded $2.5 billion.
- Historically riverine monitoring and rain gauges have been installed for purposes other than flood warning (e.g. water management) but the data has been shared for flood warning purposes.
- The FWGN has evolved over time with little governance. The assets that have been installed have variable technical consistency and data reliability for flood warning and modelling purposes.

There are two management frameworks in place at a national level that have been prepared to improve response to flood risk from government level to businesses and residents:

- 'flood risk management framework' (FRMF)
- 'total flood warning system' (TFWS) (CoA, 2013a).

FRMF is associated with activities that should be undertaken prior to a flood event to assist in the management of risks associated with flooding (e.g. policies in place to govern flood preparation and responsiveness). The TFWS relates to activities that occur primarily during a flood event (e.g. flood level prediction, interpretation and warning dissemination).

In Queensland, climatic conditions make the State prone to extreme weather events, particularly the heavy rainfall during summer months that can lead to river rise, flooding and inundation. Tropical cyclones and severe thunderstorms are not unusual and accordingly flooding has been the most destructive and expensive of the natural disasters to affect the State and the Nation. The direct public infrastructure cost to Queensland of the 2010–2011 flood events exceeded $6 billion, and the 2013 flood events cost Queensland in excess of $2.5 billion. Since 2009, natural disasters have cost Queensland more than $14.5 billion (QRA, 2014).

2.1 FLOOD HISTORY IN QUEENSLAND

There are a number of large historical flooding events that have significantly impacted parts of Queensland including the 1927 floods that affected Brisbane, Cairns and Townsville, the 1974 floods that impacted Brisbane and the 1998 floods in Townsville (BoM, 2015b).

In recent years, Queensland has been affected by flooding events at a notably high rate:

- The 2010–2011 flooding in South East Queensland resulted in 35 confirmed deaths and over $6 billion in public infrastructure damage (QRA, 2014). This was caused by heavy rainfall in September 2010, Tropical Cyclone Tasha in December 2010 and then Tropical Cyclone Yasi in February 2011. In February 2012, significant rainfall in inland southern Queensland resulted in major flooding throughout the region, followed by moderate flooding events later in the month in the Sunshine Coast area. In January 2013, ex-Tropical Cyclone Oswald produced extremely heavy rainfall across Queensland causing significant flooding that resulted in six deaths and impacted 54 regions across the State (DILGP, 2013). The damage bill for this flood event exceeded $2 billion (QRA, 2014).

- Between January and April 2014, various regions of the State were affected by heavy rainfall and persistent flooding, culminating in the flooding produced by Tropical Cyclone Ita in the northern tropical coast and Tablelands districts.

In response to the impacts of the 2010–2011 floods the Queensland Premier established the Queensland Floods Commission of Inquiry (QFCI) to investigate the circumstances surrounding those floods. The QFCI reviewed critical elements of the 2010–2011 floods including:

- preparation and planning of government at all levels
- adequacy of forecasts and early warning systems
- responses of emergency service
- performance of insurers in meeting their claim responsibilities.

The QFCI prepared a final report which included over 150 recommendations across seven topic areas in March 2012 (State Government of Queensland, 2012).

Since the recommendations of the QFCI were handed down in 2012, the FWGN in Queensland has been considerably advanced. Reports and reviews have been undertaken in line with the inquiry recommendations and funding has been made available for the installation of new rain and stream water level monitoring stations as well as the improvement of existing stations.

2.2 FLOOD WARNING PRINCIPLES

Flood warning is the provision of a qualitative and/or quantitative prediction about the risk of peak flood level in a given area for an upcoming time period. Flood warnings are issued for a variety of reasons, but essentially, the provision of effective flood warning allows a local area to take action to minimise the impacts of these destructive natural disasters. Effective flood warning provides time to identify which roads/rail links may be affected or closed by the impending flood, inform the public of the scale of the impeding flood so they can evacuate if necessary, and allow Local Disaster Management Groups (LDMGs) to prepare and plan to enact contingency plans for re-supply.

When discussing the flood warning system, it is presumed that a riverine flood event has a greater than six hour lag time between the causative event (heavy rainfall, dam breaks etc.) and the onset of the flood. Adverse flood impacts may result in damage to property, injury or death. Riverine floods can cause damage to buildings, roads, gravel shoulders, bridges, railways or other landscape features including soil erosion.

Flash flooding is a flood event that occurs within six hours of the causative event. Flash floods are characterised by rapidly rising water levels following short intense bursts of rainfall (commonly from thunderstorms) and rapid dam releases, and tend to occur in areas where the waterways are steep and the terrain more hilly or mountainous. Flash floods have the capacity to cause fatalities, injuries, and significant damage to property. Flash floods tend to be localised and it can be difficult to provide effective warning due to the rapid onset. Flash flooding is discussed in more detail in Section 10.

Because of the forewarning opportunity that exists with riverine flooding, the ability to plan makes flooding a highly manageable hazard compared to other natural hazards. Flood risk can be defined and appropriate emergency preparedness and mitigation strategies developed as floods tend to occur in a repeatable pattern with a certain regular seasonal rhythm (CoA 2013a). The effectiveness of a flood warning system is dependent upon the cooperative involvement of stakeholders and the development of an appropriate warning system (ibid).

The TFWS is an initiative described in Manual 21 of the Emergency Manual series (CoA, 2009) to provide appropriate flood warning to communities across Australia. The TFWS recognises the multi-faceted nature of the provision of flood warnings and the components required to deliver effective flood monitoring and prediction. The key components of the TFWS are:

- monitoring rainfall and river flows that may lead to flooding and predicting flood severity
- interpreting the prediction to determine the likely flood impacts on the community
- constructing warning messages describing what is happening, the expected impacts and w hat actions should be taken
- disseminating warning messages
- responding warnings by the agencies involved and community members
- reviewing the warning system after flood events.

These components should be integrated with constant communication and consultation with stakeholders and other agencies. The TFWS components are shown in Figure 2.1.

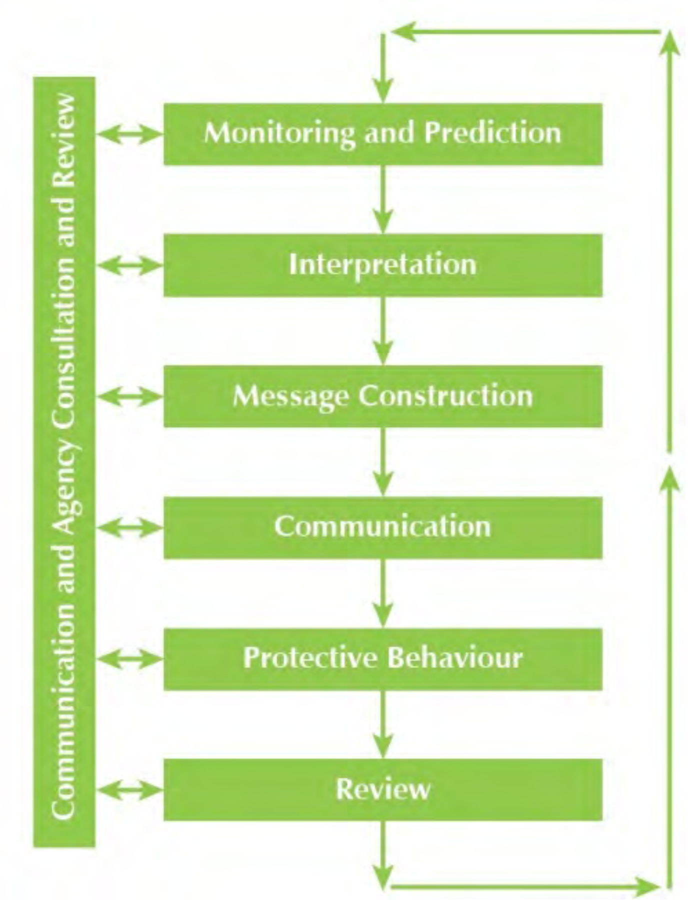


Figure 2.1
THE COMPONENTS OF THE TOTAL FLOOD WARNING SYSTEM (CoA, 2009)

The matters to consider when designing, implementing and maintaining a TFWS mimic the issues described in the IGEM EMAF. Key TFWS considerations include:

- communities with high flood risk need to be identified and accommodated in the system by ensuring the community is involved in the system design and development
- organisations and entities involved in flood management and flood response should have buy-in to floodplain and emergency management arrangements
- the system must be adaptable to cope with both ‘routine’ and severe flood events
- responsibility needs to be shared across each agency involved under cooperative arrangements.

The QFCI Final Report (State Government of Queensland, 2012) states:

"during a flood, decision-making is best informed by the use of a real-time flood model. Real-time flood models use current rainfall and river height data to predict the likely extent of flooding".

The FRMF highlights activities that should be predominantly undertaken before a flooding event, generally at a more local, or catchment-based level, to assess and prepare for the risks associated with flooding. FRMFs are often the responsibility of the council. These frameworks allow for variations in structure but should describe activities undertaken at a local level to identify and quantify flood risks and raise awareness of those risks. Guidance on the requirements of a FRMP is not provided by the State and councils generally rely on 'Managing the Floodplain' Handbook 7 (CoA 2013a) and the NSW Floodplain Development Manual.

If an effective TFWS and FRMF are in place, the ability of residents and other stakeholders to manage and respond to flood risks is greatly increased. If an effective TFWS and FRMF are supported by advanced flood warnings, the potential damage caused by the flood can be decreased significantly as depicted in Figure 2.2

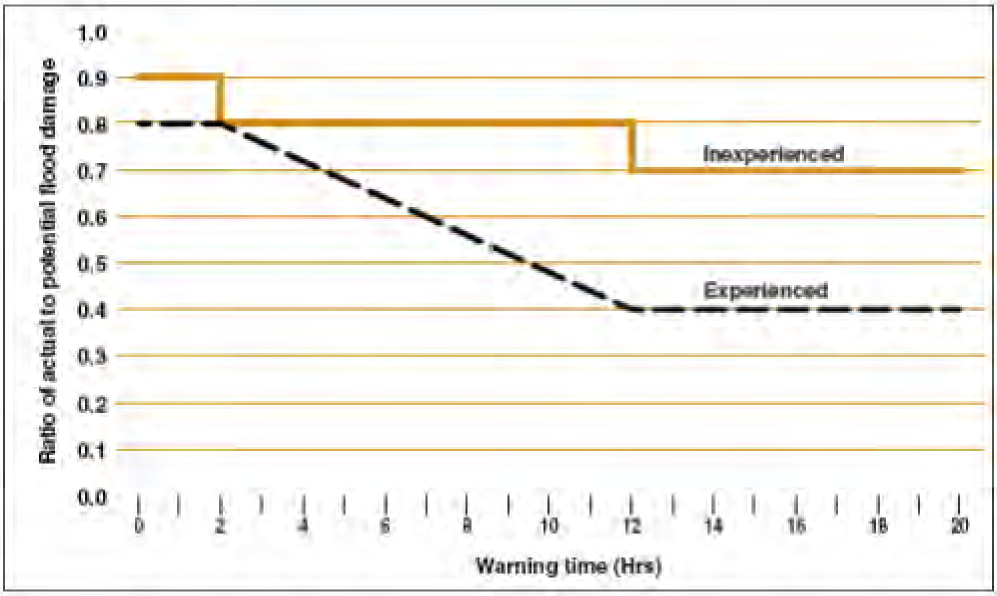


Figure 2.2
PERCEIVED REDUCTION IN POTENTIAL DAMAGE GIVEN WARNING TIME

*Reproduced from Figure 4.4 of BTE (2001).

From the figure above, it is clear that warning time can be of great benefit provided the community is properly prepared. Unfortunately the longer the lead time, the greater the degree of uncertainty in the flood forecast, so a proper balance must be achieved.

Flood forecasting and warnings are usually generated using a predictive hydrological model of a given catchment. These hydrological models require inputs such as the forecast rainfall (meteorological) and the existing stream water level. The accuracy of a prediction is limited by the quality and timeliness of data provided for input into a hydrological forecast model.

A TFWS requires buy-in and a sharing of responsibility by a range of stakeholders at different levels of government and from the private sector. The real benefits of the data provided by the FWGN for input into a hydrological model are the quantification of the flood risk, the location of the floods, the peak height and the anticipated timing of the event. BoM produces and distributes flood warning at 143 forecast locations across Queensland (as at June 2015) based on the data collected from the hydrometric gauges in the FWGN.

2.3 THE QUEENSLAND FLOOD WARNING NETWORK

The FWGN includes those hydrometric gauge stations that collect, record and communicate rainfall and stream water level data that helps inform decision makers. Measurements collected from the gauges are communicated back to gauge owners and thence to BoM. The data provided to BoM is used by hydrological forecast models that have been prepared and calibrated using historical records of previous flooding events to produce and update flood forecasts.

The models can help to estimate times and flow rates at commencement of flood rise, the rate of rise that is expected and the flood peak at pre-determined forecast locations. The flow rates are matched with rating tables or other references to give forecast peak flood heights, usually at a gauge that is used as a local reference.

Accurate flood warning predictions inform the flood risk, the implementation of evacuation plans and the need to communicate flood warnings to the public. Stream water level gauges indicate present water level, and tracking rates of rise and correlations with upstream gauges can indicate what the peak water level may reach and when road closures may occur. Rain gauges indicate the depth, extent of rain that has fallen across an area, and with other meteorological information can indicate the speed and direction of travel of the rain producing clouds, which can assist in addressing where additional rain may fall.

Hydrologic forecasting is not an exact science. More certainty can be built into hydrologic flood forecasts by quantifying other inputs such as expected run-off rates and catchment behaviour during rainfall events. Catchment behaviour will change as ground absorption and rainfall interceptions diminish, therefore it is important hydrologists receive feedback about those characteristics to inform the forecast. Comparison of forecast and observed water levels at key locations is essential to ensure ongoing forecast accuracy of the hydrologic model. By running models in hind-cast mode and adjusting parameters of the model to mimic forecasts and observed circumstances, a higher level of understanding of current catchment behaviour can be developed. For this reason it is important that stream water level and rainfall data is provided during flood events, not just in the lead up period. The FWGN needs a level of redundancy to ensure critical information is not lost during these flood events.

Data is transferred from the collection location (point of record) to a central database. This function requires communication systems. The most common communication types are VHF, 3G or satellite or land line, each with positive and negative aspects. These are discussed in Section 3.4.

For the flood warning system to work effectively, these components must all function in an integrated manner. If any one component fails, it limits the overall effectiveness of the entire system.

2.4 EARLY DEVELOPMENT OF THE FLOOD WARNING GAUGE NETWORK

The evolution of the FWGN in Queensland has been organic, with spurts of development usually following significant flood events. A natural network optimisation starts with a minimum number of stations, and increases gradually to a point where the amount of data collected and processed is economically justifiable and it meets the quality criteria of the users (Pyrce, 2004).

While the technology involved in flood warning gauges has improved considerably in the past 25 years, the components of the FWGN remain relatively unchanged. Field observations are recorded, stored and processed for input into a hydrological model for forecasting purposes. Automatic data collection for the FWGN commenced in the early 1980's when field measurements were usually collected manually and reported to regional BoM offices via telephone (Thompson, 2015).

Prior to 1987, there was no strategic focus for the design of the FWGN and gauges were installed almost exclusively for specific projects without consideration of the potential flood warning benefits. In 1987, BoM was provided with additional resources to coordinate data transfers and improve its flood warning capacity in response to the agreed sharing of responsibility for flood warning between the three levels of Government. This arrangement specified that BoM would remain the lead agency for flood warning.

Table 2.1 shows the scale of the upgrade of the FWGN in Queensland between 1987 and 1995, and the rapid change in technology with the proportion of stations using telemetry increasing from 17% to 69%.

Table 2.1 Historical number and type of gauges used for flood warning in Queensland

Year	Reporting mode		Data type	
	Manual	Telemetry	Rainfall	Stream water level
1987	360	73	146	287
1995	356 (a)	776	332	800

(a) Includes 329 Remote Observation Terminals (ROTS) to replace manual reporting

In the 1990's, BoM adopted and customised an event radio reporting telemetry system, based on USA technology developed in the 1970s known and referred to as Automated Local Evaluation in Real-Time (or ALERT). As part of the migration from a manual data collection and processing system, BoM initiated more sophisticated data processing and hydrological modelling during the mid-1990s (ibid). BoM also embarked on a pr oject to standardise the commercial aspects of the ALERT system so that field technology in those stations would not change dramatically (ibid).

The ALERT system allows field stations to transmit data over VHF radio that can be listened to by cooperating agencies. This has allowed BoM to work cooperatively with councils and the SES to provide access to real-time data from catchments across the State. However, the advanced BoM technology has proved a severe limitation to other organisations' ability to collect and utilise the data (ibid).

After the Flood Warning Consultative Committee (FWCC) was commissioned in 1996 (Section 2.5), there was greater cooperation in the operation of the FWGN. Formerly the technology changes and implementation of the ALERT systems lacked consultation with key stakeholders who up until that time had continued to install stream water level and rain gauges based on water storage facilities, or project-specific purposes.

After continued pressure from external parties, BoM reviewed the status of the ALERT system platform (based on the US model) in 1996 and decided to adopt a new system platform to cater for more users. The replacement system became known as ENVIROMON.

The ALERT protocol has been a successful initiative by BoM in Australia, however ageing technology and continued expansion of the network is pushing the system. The ALERT protocol is simple and efficient, but is not able to be easily expanded (Thompson, 2015). There is only one supplier of ALERT technology in Australia, which limits opportunity for innovation and technology development, as well as competition in the marketplace.

The FWGN has been expanded to include stations that have not been installed by BoM but pass an assessment by BoM. Once accepted a station is assigned a BoM identification number and BoM is able to access and use the data when incorporated into the ENVIROMON database. The design of ENVIROMON easily handles the other operating data without causing significant issues.

The State Government of Queensland has noted the benefit of having the State's entire flood data consolidated in a central, easy-to-access repository. The establishment of the FloodHub, an MS-Excel-based dashboard reporting system that has consolidated known flood data, is an example of one such initiative that is independent of BoM jurisdiction and provides a valuable resource for DNRM and the broader Queensland Government (MWH Global, 2014). The system has been designed to be simple and modular so that as new data becomes available this can be integrated into the system. FloodHub is able to provide a rating for each of the identified localities in terms of flood risk and preparedness based on the significant database of relevant data stored in the system.

2.5 BoM SERVICE LEVEL SPECIFICATION

It is well accepted that efficient and effective flood warning systems help to minimise the risk of loss of life and also allow community and emergency services planning and preparation time to protect key assets and property (Groppa F, 2012). A flood warning system such as that present in Queensland is comprised of multiple components that require co-ordination and effective management to return reliable and useful warnings to a community.

The scope of flood warning services that BoM provides in Queensland is outlined in the Queensland SLS (BoM, 2013a). It identifies the roles and responsibilities of BoM and other key stakeholders for issues such as data sharing. BoM has similar service level agreements with the other States and territories of Australia. The SLS was prepared in consultation with this State's FWCC.

The FWCC in Queensland was formed in 1996 to coordinate the development and operation of the State's flood forecasting and warning services. The role of the FWCC is outlined in Schedule 1 of the SLS, and includes Terms of Reference that are nationally consistent with other FWCCs. In essence, the FWCC was intended as an advisory body that reports to BoM and comprised key stakeholders across Queensland. Members of the Queensland FWCC include:

- Bureau of Meteorology [Chair/Secretariat)
- Queensland Department of Community and Safety
- Queensland Department of Natural Resources and Mines
- Queensland Department of Energy and Water Supply
- Queensland Department of Infrastructure, Local Government and Planning
- Queensland Reconstruction Authority
- Queensland Bulk Water Supply Authority (trading as Seqwater in South-East Queensland)
- SunWater
- Local Government Association of Queensland.

Additional organisations invited to participate include:

- Queensland Police
- Queensland Department of State Development
- Brisbane City Council.

Within the SLS, it is recognised that an effective flood warning service is by nature, multi-faceted and involves input from a number of agencies to maintain, develop and operate. It is essential the stakeholders involved in the FWGN maintain a close and cooperative working agreement to achieve the outcomes of effective flood warning services.

As well as issuing and publishing specific warning and data products, the SLS also includes services that BoM provides in the areas of routine catchment monitoring and stream water level prediction including:

- collection and publication of rainfall and stream water level data
- routine monitoring of flood potential
- flood modelling and prediction
- automated information and alerting
- communication of flood warnings and flood watches
- data networks, communications and storage
- operations
- publishing of data and flood information
- planning and liaison
- support for emergency management training and training exercises.

2.6 GUIDANCE DOCUMENTS

Stream water level and rain gauges and other equipment associated with the flood gauge network have to be fit for purpose and provide BoM and other users with sufficient and accurate data in a timely manner. Unless there is some certainty as to the quality of the information supplied, the quality of forecasts could be compromised. That being said, not all of the gauges installed across the State have been installed primarily for flood warning purposes, and have therefore not necessarily complied with BoM standards.

Guidance documents, drawings and technical standards are required to simplify the processes involved in establishing a new site that will report to BoM and should include:

- gauge purpose
- site selection with regard to the hydrologic imperative, convenience of access, communication choices, level of flood immunity and security
- equipment type
- power requirements
- communication system
- technical standards
- workplace health and safety
- performance requirements.

There are a number of guidance documents available which outline the technical standards or intended governance that are of relevance. Some of the key documents encountered during this review include:

- Commonwealth Government of Australia, (CoA 2009), Australian Emergency Manuals Series: Flood Warning, Manual 21, Emergency Management Australia
- Service Level Specification for Flood Forecasting and Warning Services for Queensland (BoM, 2013a)
- 'Managing the Floodplain' Emergency Handbook (CoA 2013a)
- National Arrangements for Flood Forecasting and Warning (BoM, 2015a)
- National Industry Guidelines Hydrometric monitoring (BoM, 2013b)
- Standard Instrumentation Policy - Version 3 (DNRM, 2013)
- Water Monitoring and Data Collection Standards - Version 2.1 (DNRM, 2007)
- Transport and Main Roads Specifications - MRTS233 Provision of Roadway Flood Monitoring Systems (DTMR, 2015)
- Observation Specification No 2013.1 - Guidelines for the Siting and Exposure of Meteorological Instruments and Observing Facilities. (BoM 1997)
- BoM - Hydrometric Monitoring WISBF GL 100.00-2013. May 2013.
- Australian Standards - AS3778.2.3-2009: Measurement of water flow in open channels.

The FWGN in Queensland encompasses rain and stream water level gauges originally installed for other purposes. This has resulted in differing technical standards.

2.7 PREVIOUS REVIEWS

The Queensland Floods Commission of Inquiry (State Government of Queensland, 2012)

The QFCI was established by the Queensland Premier in response to the 2010–2011 flood events. The Commission of Inquiry conducted a comprehensive review focusing on areas such as preparation and planning, adequacy of response, adequacy of forecasts and early warning systems, and land-use planning in the lead up to the 2010–2011 floods.

The findings of the QFCI were that:

- governance of the FWGN was complex involving a wide range of stakeholders with often differing priorities
- a coordinated approach to the assessment of the network risks and establishment of priorities was necessary to evaluate the competing demands.

The Review recommended investigation of alternative models for the ongoing management of the FWGN.

The final report included recommendations across a vast range of technical and governance disciplines which highlighted the complexity of flood risk management in Queensland. Included in the recommendations was the need to conduct additional flood studies and undertake further consultation with local governments to enhance the cooperative approach to flood risk management.

Munro Review (Munro, 2011)

Professor C. Munro undertook a review of BoM's capacity to respond to future extreme weather and natural disaster events and its capacity to provide forecasting services in 2011. Recommendations from the review focused on key areas such as the allocation and sharing of responsibilities and the need for nationally consistent standards for operation of flood monitoring networks. The review noted that the current governance model of shared responsibility was not sustainable for BoM and it recommended BoM's role should either be confined to data management (and the responsibility for data collection be divested) or BoM's flood management role should be expanded under a new governance structure which included a Flood Operations Centre.

Queensland Reconstruction Authority Audit of Queensland's Flood Warning Service (QRA, 2014)

In 2012, the Queensland Reconstruction Authority was commissioned to undertake an Audit of Queensland's Flood Warning Service in collaboration with BoM, DNRM and the then Department of Community Safety. The audit was commissioned in response to the recommendations of the QFCI and focussed on the State's hydrometric flood warning gauge network.

The audit found that approximately 191 towns and key locations across Queensland were historically prone to flooding. Of those towns identified 75% were deemed to lack adequate flood warning services.

The Audit identified a number of common themes that indicated a need for enhancement of the FWGN in Queensland. Overall the FWGN appeared to provide insufficient coverage of rainfall and stream water level gauging stations upstream of settlements, the technology employed within the FWGN was particularly lacking in regional areas and there was limited redundancy in the FWGN at some key forecasting locations.

Queensland Flood-prone Communities Review - Current State Review (MWH Global 2014)

In 2014, MWH Global was engaged by DNRM to undertake a review of the flood-prone communities in Queensland and a stocktake of existing flood studies to prioritise new flood studies.

Included in the findings of the report was a supporting database called the FloodHub. The FloodHub consolidated relevant flood information for known flood-prone localities in Queensland in an MS-Excel based storage system with a graphical user interface (GUI) that could be used to help prioritise future development and planning activities across the State.

The review examined flood studies undertaken at settlements/localities across the State and assessed the suitability of the studies in terms of land use planning and disaster management. The main findings were that many settlements appeared to lack auditable flood studies, and that the ones that had been reviewed were generally of low suitability for disaster management purposes. The study found that there was little common understanding of what a flood study must contain.

Queensland Flood Warning and Risk Management Arrangements (PwC, 2015)

In 2014, PricewaterhouseCoopers (PwC) was engaged by DNRM to assess the flood warning system and flood risk management arrangements in Queensland and to identify gaps that could be addressed through recently acquired functions. The review also considered the adequacy of broader flood risk management arrangements in Queensland and how they compared with best practice principles.

The report recommended that further review of the hydrometric FWGN was necessary to prioritise essential future investment in the network. It was noted that the review needed to include a risk-based assessment of the spatial configuration of the network, and the standards of instrumentation.

Other relevant recommendations of the report included examining options for facilitating an extensive program of works to upgrade or improve the hydrometric FWGN, and the need for standardised instrumentation guidelines for hydrometric gauges.

The report findings on flood risk management arrangements in Queensland identified that the state did not meet best practice roles and responsibilities outlined in the 'Managing the Floodplain' Handbook 7 (CoA 2013a), particularly in areas of establishing frameworks for legislative, policy and administrative arrangements. Options for improving governance of the flood risk management arrangements included:

- designating a State Government department with responsibility for developing a strategic Queensland flood risk management policy
- clearly defining, monitoring and maintaining a record of flood risk management roles and responsibilities across government departments
- clearly defining, monitoring and maintaining a record of relevant legislation
- assigning a lead agency to each key activity within the flood risk management framework (in instances where this had not already occurred)
- developing and monitoring KPIs to assess the performance of state and local governments in meeting flood risk management best practice principles.

During the conduct of this review, no evidence was found that would detract from or be in conflict with those recommendations.

3 Existing Flood Warning Gauge Network in Queensland

Findings

- The FWGN is actually an amalgamation of networks and is not well suited to central control.
- There are currently 2,924 gauges in Queensland that provide flood warning data, comprising 1,038 ALERT stations, 941 Telemeter stations, and 945 manual or remote operator terminals.
- There are 458 stream water level gauges, 1,556 rain gauges and 1,119 combined stream water level/rain gauges.
- There is a range of communication systems in use in the FWGN including carrier-based communications (Next G or FTP), fixed line, radio communications (VHF) and no connection (Manual). The communication system in use is not well understood by some gauge owners.
- There are over 54 separate owners of gauges and assets used in collecting flood warning data in Queensland, comprising councils, state and commonwealth departments and private companies.
- There is a range of technologies that are in use to perform similar functions within the FWGN.
- There are no consistently applied standards for flood warning instrumentation, monitoring and data collection. Individual owners often have their own standards, and these vary between owners.
- One of the difficulties identified with implementing standards for FWGN instrumentation is that gauges and stations often serve a number of purposes, and flood warning may not be the primary purpose.
- ALERT systems are considered by BoM to be the most robust of all systems available. VHF radio used by the ALERT system is extremely reliable, does not rely on third parties and as a consequence there are fewer points of failure (BoM owns the VHF network and infrastructure).
- There is only one BoM-approved supplier of ALERT, so the lack of commercial competition and opportunity for innovation could be a pr oblem in the future. This could be overcome by moving towards performance specification rather than product (technology) specification.
- Telemetry systems record data, which can offer an advantage over ALERT in situations where communications are temporarily lost and data resolution is important.
- There is a benefit in maintaining diversity in the systems used on the FWGN, since this provides redundancy in the event that one system fails.
- At least 250 gauges have been identified that do not form part of the FWGN network. Major owners include Department of Transport and Main Roads (DTMR), Seqwater, councils and private organisations.

The infrastructure, technology and ownership models currently employed throughout the FWGN have been reviewed. The review finds that given the mixed use and the variety of owners, there is a wide spectrum of gauge types, technologies and models, not always in locations best suited to flood warning.

BoM determines which gauges are incorporated into the FWGN based on a number of requirements. However, these requirements do not have high visibility outside of BoM. One of the better known determining requirements is the availability of real-time data from that gauge.

BoM has an asset register of the gauge stations that they have approved for inclusion into the FWGN, this includes both BoM-owned assets and assets owned by other organisations. During the review, at least 250 additional gauges across the state were identified that could be considered for inclusion in the FWGN.

3.1 GAUGE TYPES

Of the 2,924 gauges recorded in the revised asset management database, 1,356 are rain gauges, 458 are stream water level gauges and 1,119 incorporate combined service (both stream and rainfall). During this review, 19 discrepancies were identified between the gauge functions described in the BoM dataset and the information received from councils. It is possible that these discrepancies were due to the BoM database not being updated to reflect changes in the field (e.g. a rainfall sensor removed from a site, due to algae, that has not been updated in the central dataset). These differences need to be resolved.

3.2 DESCRIPTION OF DIFFERENT GAUGE TYPES

3.2.1 Manual gauges

Manual rain and stream water level gauges within the FWGN are read daily (usually at 9am or on demand) and recorded by individuals physically visiting gauging sites. This data is then provided to BoM by telephone, Remote Observer Terminal (ROT) or internet.

Other manual gauges also exist (some of which are included in the FWGN) that are not read daily, but still perform a valuable function during floods or for calibrating automatic recorders.

Gauge readers also provide additional local flood information to BoM and councils and to others within the community. This local networking of additional flood information is extremely valuable and contributes to the overall robustness to the system where automatic gauges might not exist.

Manual gauges are low cost and generally reliable, but subject to user error and damage from physical elements. For example, stream (and dam) levels are read from gauge boards, generally a plate ruler set to zero at the elevation of the hydraulic control. These boards are exposed to fire, flood damage and vandalism and need to be resurveyed and physically adjusted if there is a difference in reading between the automatic recorder and the board.

The number of manual stations has decreased over time as they have been replaced with newer technology, but manual stations still form a valuable component of the FWGN.

An example of a manual gauge is shown in Figure 3.1.

Figure 3.1
MANUAL RAIN GAUGE

3.2.2 Automatic gauges

Automatic sites generally fall into two categories:

- Telemetry (TM) gauges that record data electronically on a logger and then transmit at predetermined intervals
- event-based communication (such as a change in water level or upon each trip of a tilting rain gauge bucket) that is the method employed in the ALERT systems.

Telemetry (TM) gauges provide data automatically at periodic intervals utilising telephone networks such as landline, mobile or satellite. Telemetry stations in the Queensland network are usually supported by data loggers that record and store the data. If communications are unable to get through via the phone line, the data is not lost, but rather stored in the data logger and retrieved manually or transmitted when communications resume. TM gauges tend to have a slight delay, but depending on the transmission setting can provide near real-time data or can provide data at regular interval as necessary.

The ALERT system relies on a recorder, transducer, transmitter (usually VHF radio), and power supplied by a battery recharged using a solar panel. ALERT stations provide real-time data automatically and continuously. The VHF radio network is a key component of the ALERT stations and is discussed further below. As the latest stream water levels and accumulated rain are provided continuously, there is no need for data logger or similar technology.

Automatic rain gauges (pluvios) are usually of the tilting bucket type that tips when sufficient rain has filled one side of a bucket. Each tip is an event that is transmitted or logged. This system is fairly uniform between different gauge brands and whilst minor manufacturing differences may exist, the technology is relatively consistent. An example of an automatic rain gauge is shown in Figure 3.2.

Figure 3.2
POLE MOUNTED PLUVIO CONNECTED TO ALERT NETWORK

Stream water level gauges use two main technologies, a float in a wet well that as water level rises, a counterweighted tape turns a wheel that causes a signal change as shown in Figure 3.3.

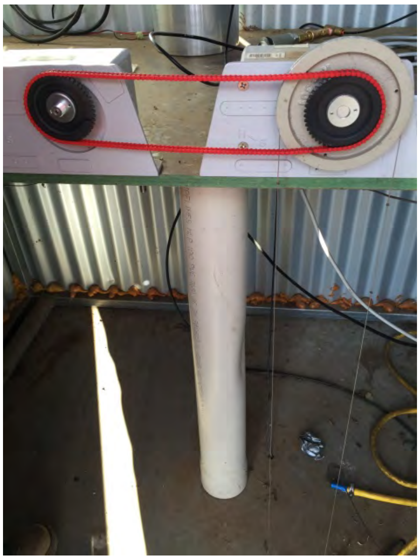


Figure 3.3
WET WELL SHAFT ENCODER

The second technology incorporates a gas bubbler water level recorder and relies on gas being forced through a capillary from the station housing to a point in the stream. As water levels rise, the gas pressure in the line is increased by the gas supply regulator to match the hydraulic pressure from the water. The hydraulic gas pressures are monitored, logged and transmitted via the corresponding communication technology. The gas bubbler technology can include the use of either nitrogen (stored in bottles within the housing unit - see Figure 3.4) or air (which relies on a mechanical compressor).

Figure 3.4
NITROGEN BOTTLE, REGULATOR AND ALERT CANISTER

3.2.3 Installation types

Across the FWGN, gauges typically occurred in three main types of installation: pole-mounted (e.g. Figure 3.5), a cabinet on a platform at ground level (e.g. Figure 3.6) and a contained hut (e.g. Figure 3.7).

Figure 3.5
POLE MOUNTED STREAM WATER LEVEL AND RAIN GAUGE

Figure 3.6
TYPICAL RAIN AND WATER LEVEL STATION WITH SOLAR PANELS

Figure 3.7
DNRM STATION FOR MEASURING STREAM WATER LEVEL AND RAIN, WITH STAFF GAUGE IN THE BACKGROUND

Each installation described above has different workplace health, safety and environment (WHS&E) issues that should be considered and documented during installation to enable ongoing maintenance and operation of the unit to be achieved safely. An assessment of the WHS&E issues should be included as part of the Asset Management Register discussed in Section 6.1.

Since the release of the recommendations of the QFCI and the availability of funding from the Commonwealth Government, the reported size of the FWGN in Queensland has increased. Table 3.1 presents the results of QRA (2012) and this study (2015). Note that the numbers may not be directly comparable since different methodologies could have been applied to each study.

Table 3.1 Comparison of reported gauge numbers

Gauge types	QRA 2012	Current (2015)
Stream water level only	459	458
Rain/Stream water level	787	1119
Rain only	904	1356
Total reported stations	2,150	2,924

3.3 GAUGE TECHNOLOGY

Typically gauging stations contain a range of technical equipment to collect, store and communicate rain and/or stream water level data. Figure 3.8 provides a visual representation of the technical components included in the FWGN. These components are outlined below with further information included in Appendix Q.

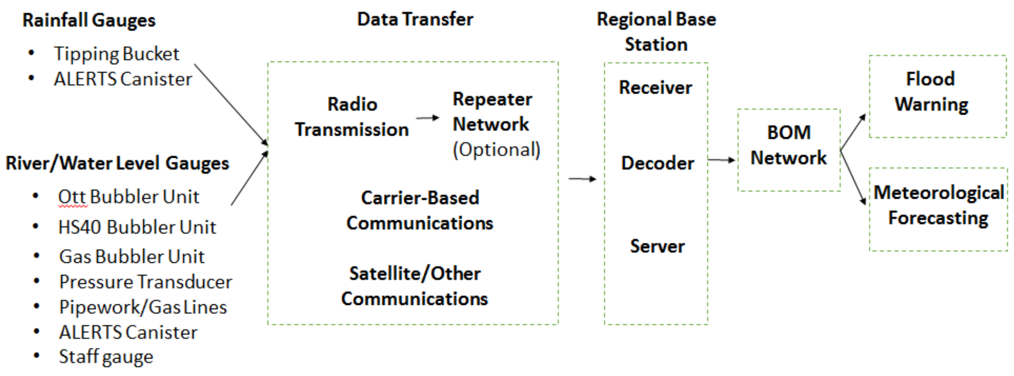


Figure 3.8
TECHNOLOGY CONFIGURATION IN THE FWGN

3.3.1 Gas bubbler

The pressure in a gas cylinder pushes compressed nitrogen down a capillary line run from the cylinder to the river bed. As the stream water level changes it exerts back pressure in the capillary line. A stream water level reading can be inferred from this back pressure using a pressure transducer.

A range of models and cylinder sizes are available.

A gas regulator ensures the gas coming from the cylinder is coming at a rate commensurate with the resisting hydraulic pressure (gas line pressure increases with flood depth)

A range of models are available.

3.3.2 Pressure Transducer

The pressure transducer outputs an electrical current dependent on the pressure being exerted on it. It is attached to the capillary line and thus outputs a current relative to the stream water level.

A range of models is available.

3.3.3 Shaft Encoder

The shaft encoder uses a float to rotate wheel backwards or forwards as the stream water level changes. They are commonly installed in dams and float wells.

A range of models is available.

3.3.4 Electromechanical gas compressor

This unit takes the place of the gas cylinder and gas regulator and can also be purchased with an internal pressure transducer.

A range of models is available.

3.3.5 Rain Gauge Tipping Bucket

The rain gauge tipping bucket measures rain in varying increments depending on the bucket size. As rain falls into the funnel, it runs through a filter and syphon to slow the rate of delivery on to either side of a pair of small buckets. As one bucket fills up to the calibrated amount, it pivots, emptying the water and allowing the other bucket to fill. As it pivots past the middle point it pulls a magnetic read switch which is recorded by the data logger/ALERTs canister.

There is a range of bucket sizes available and a number of common manufacturers including McVan and Hydrological Services.

3.3.6 ALERT Canister

The ALERT canister receives the electrical signal from the transducer, turns it into a stream water level reading and sends the stream water level, rain and battery readings via radio transmitter to either a repeater (5W or 25W options are available) or a base station.

3.3.7 Data loggers

Data loggers are often used if the site is not installed on the ALERTs network.

DataTaker and Campbell Scientific are the most common logger manufacturers found in flood sites in Queensland.

3.3.8 3G/Satellite data modems

3G/satellite data modems are often used by councils where VHF radio transmission is limited by geographical features. Satellite transmission is not always reliable in heavy rain.

There are many manufacturers of 3G/satellite data modems and there is no standardised modem employed by the industry.

3.3.9 Power systems

Most gauge stations are solar charged and battery powered. In some cases 240V mains electricity is used, but this adds additional health and safety issues and requires a fully certified electrician to service.

Most gauges will have a 2.5-20W solar panel and battery between 12-28Ah. The canisters have an internal solar regulator but if a data logger is used, generally a separate regulator will be used.

3.4 COMMUNICATIONS NETWORK

There is a range of technologies that can be employed to facilitate communication between a gauge and a receiver. This technology is an integral consideration in the design and manufacture of the gauge station.

Manual stations are reliant on observers (i.e. community members) physically visiting gauging sites and taking a manual reading, this data is then provided to BoM by telephone, internet or ROT (Figure 3.9).

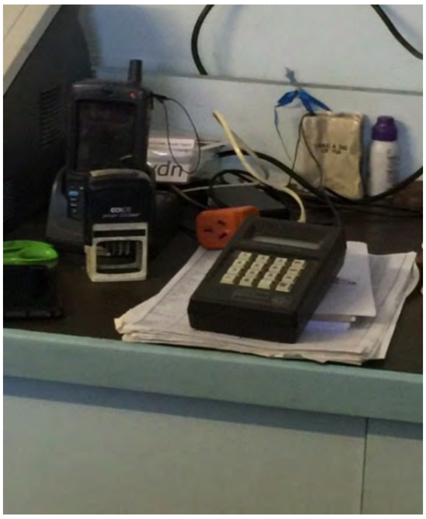


Figure 3.9
ROT DEVICE

3.4.1 Types of communication systems

The communication system for ALERT stations relies on a custom built VHF radio network to transmit the data. Data collected at the field station is coded then transmitted via the VHF radio network. Repeater stations are able to retransmit a weak radio signals in a "store then forward" fashion. They are usually located at geographical high points and rely on a 'line of sight' to transmit the coded signal.

TM stations that record and store data prior to transmitting the data have a wider range of communication options. The communication network most commonly encountered in the FWGN used the carrier-based telephone network (this includes a combination of telephone hardware such as Next G or FTP communications). Basically, the station is connected to the internet and is able to utilise the existing telecommunications network to transmit data.

Other less common types of communication methods include using satellite (3G/4G) or microwave technologies. Satellites provide a simple and effective communication solution that is not heavily dependent on significant communications networks in the vicinity of the station (i.e. it is useful for remote locations).

Microwave technology requires similar network construction to the VHF network described for ALERT stations and is seldom used.

The communications systems within the FWGN (based on feedback from the respondents) included 537 gauges using carrier-based (Next G or FTP), 133 using fixed line, 831 using manual, 691 using radio (or VHF) and 85 using satellite as well as 647 gauges for which the communication system was not stated. Table 3.2 provides an overview of the number of different gauge types owned by each entity in the current FWGN.

Table 3.2 Overview of gauge type and ownership

Owner*	Manual	Telemetry (TM)	ALERT	Total Stations	Percentage of Total
BoM	864	158	57	1,079	37%
DNRM	21	510		531	18%
Councils	5	75	821	901	31%
Shared with BoM	32	3	16	51	2%
Supplier	12	126	143	281	10%
Other	11	69	1	81	3%
TOTAL	945	941	1,038	2,924	100%

* Some gauges have shared ownership. For the purposes of presentation (and to avoid duplication) only one owner is shown

3.4.2 Benefits and vulnerabilities

The VHF communication network uses reliable, stable communication technology but is limited in its transmission range requiring relay stations every 100 km or so between the field station and the data storage unit. The largest vulnerability in the network is failure of a relay station. However, if there are multiple repeater stations within range of the transmitting station data can still be communicated bypassing one station. VHF ALERT communication signals are omnidirectional which provides alternate communication pathways.

Relay station failures usually arise from high winds and cold temperatures leading to a structural failure of the mast. Local birdlife has been known to rupture the aerial casing and allow water entry. Intense rain (in excess of 150mm/hr) has been known to cause some distortion in the signal. The power requirements of the repeater stations rely on a solar panel backed up by a rechargeable lead acid battery.

The TM stations that use existing telecommunications networks rely on a third party to maintain the communication network. The existing network (usually Telstra-owned copper wire network) is susceptible to breakdown at vulnerable points during flood events (when data communication is vital). The gauge stations are further reliant on the proximity to the communication network which offers challenges in remote locations. The proposed upgrade of the Telstra network from copper wire to the National Broadband Network may also present some challenges regarding new hardware and costs.

There are a number of benefits of a third party communication carrier network including lower establishment costs, and minimal ongoing repair and maintenance costs. The network also allows two-way communication which is of benefit for remote access and data interrogation and quality assurance. The inability to have control of the communication network, particularly when the network is down, is offset by the use of data logger technology in the TM stations which records and stores the data collected, even when it cannot be transmitted. This data can be retrieved manually at any time, but this functionality is usually of little benefit for flood warning, where near real-time data is required.

Satellite, 3G and 4G technology all present a viable, cost-effective solution for communication, particularly in remote locations, as there are minimal establishment costs. The satellite network during periods of heavy rain is highly variable, and can be unreliable.

Microwave technology is seldom used as it is expensive to construct and has high power requirements. While there are some benefits to using microwave technology the network still relies on 'line of sight' repeater stations and would further complicate data coding and decoding requirements.

3.5 OWNERSHIP

BoM owns the largest number of assets in the FWGN with 1,077 gauges in Queensland. BoM also uses gauges located in NSW and Northern Territory to improve warning accuracy. The Queensland state government owns 552 gauges: DNRM (515), DSITI (26), Maritime Safety Queensland (6) and Queensland Rail (5). South Australia's Department of Water Land and Biodiversity Conservation own one gauge at Birdsville. Councils throughout Queensland collectively own 901 gauges (across 38 separate local government areas). Entities involved in water supply, including SunWater, Seqwater and the Gladstone Area Water Board, collectively own 287 gauges across the State. Entities that own a small number of gauges include private organisations and the NSW government.

The full list of owners is presented in Appendix I.

Some FWGN gauges have shared ownership; 40 gauges are shared between the Queensland State Government and other entities and 12 gauges are shared between councils and BoM. The individual ownership agreements for each gauge were not provided for this review, so the breakdown of responsibilities is unclear for some gauge stations.

At least 250 additional gauges have been identified that do not provide data for flood warning purposes. It is not clear how much value these gauges may add to the FWGN or whether the owners are willing make their data available and/or modify their gauging stations to meet BoM data requirements. The major owners of these gauges include State Government departments (i.e. DTMR), Government organisations (i.e. Seqwater) and councils. Some private organisations were also identified as owners including BHP Billiton Mitsubishi Alliance (BMA), Glencore, Peabody, Anglo American, Vale, Wesfarmers and Q Coal. South West NRM Ltd has also installed and continues to maintain a number of gauges in the Murweh and Paroo region.

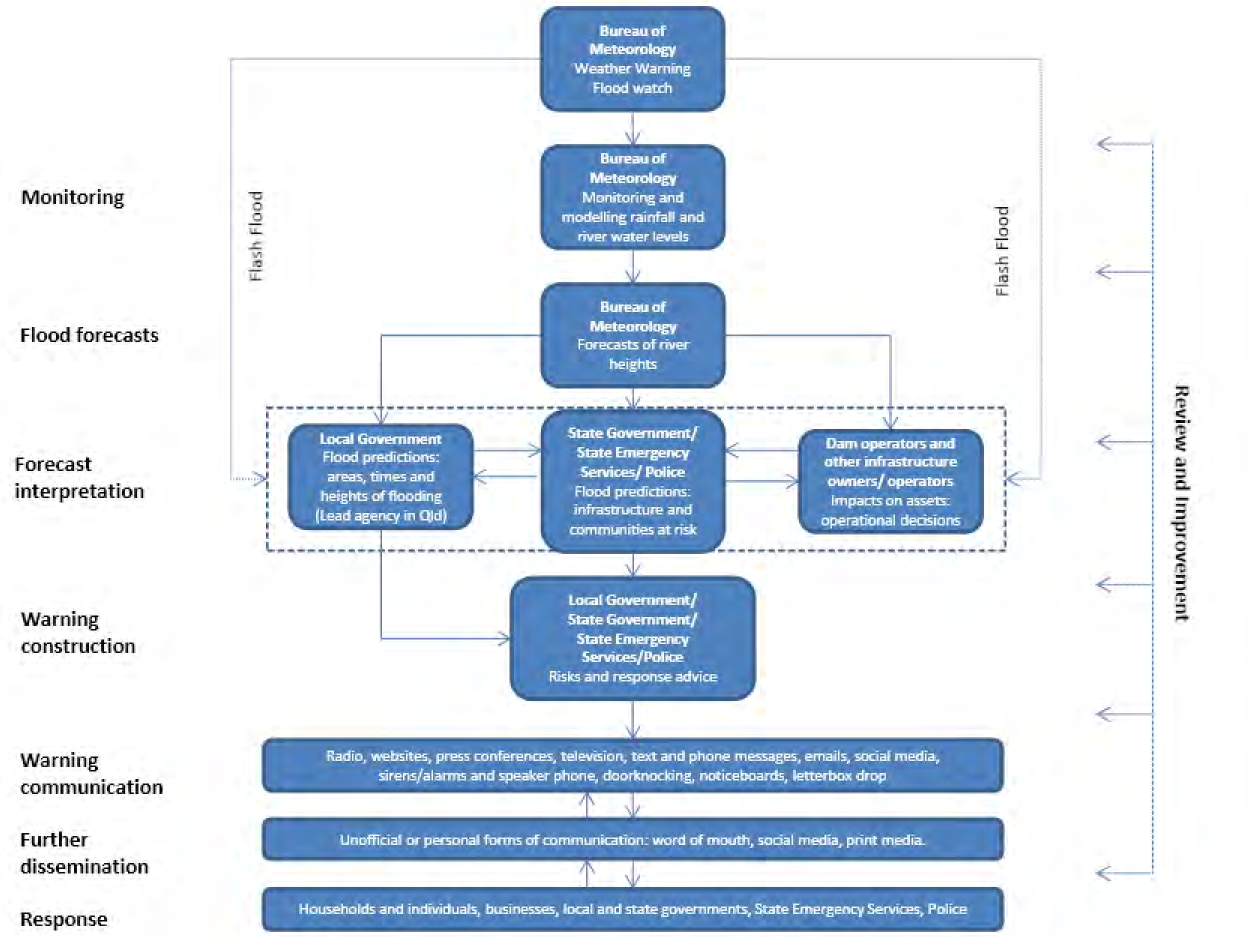
3.6 ENVIROMON

ENVIROMON is a proprietary software package used by BoM to receive and manage 'real-time' rain and stream water level data provided by the ALERT system. The software is made available to councils and other key stakeholders by BoM and includes the following functionalities:

- receiving data from a radio link
- storing data in a database
- reviewing data through a GIS-based GUI, in point, table or graphical form.

The software can couple and run hydrologic models for flood forecasting where rainfall data is extracted from the database and modelled stream hydrographs are compared to recorded stream water levels in both hindcast and forecast modes. Many of BoM's web-based products also rely on ENVIROMON data.

A visual representation of how flood warning data is collated by BoM to form flood warnings is shown in Figure 3.10.



Components of a flood warning system, noting that the precise arrangements vary between states. While flash floods are not covered in this figure, the Bureau of Meteorology also provides severe weather warnings, which can include general warnings of potential flash flooding, via its website. Compiled by the Science, Engineering and Technology Panel.

Figure 3.10
FWGN OVERVIEW (SOURCE: BoM)

4 Data collection and collation

4.1 DNRM SUPPLIED INFORMATION

At the start of the review, DNRM provided information including gauge data, FloodHub, past reports, spatial data files, DNRM asset management overview, and contact information for councils. During the review, DNRM continued to provide additional information as it was discovered.

4.2 CONSULTATION

Effective, efficient and unbiased consultation with stakeholders formed an important part of the data collection process for this review. The objectives of the consultation were to:

- provide stakeholders with balanced and objective information to help them understand the purpose, process and intended outcomes of the review
- obtain stakeholder input (perceptions/opinions and technical information) to enable a thorough review.

The adopted consultation approach was multilayered and targeted, focusing on stakeholders identified in liaison with DNRM and Pentair/Greenspan. The main consultation activities carried out were:

- meeting with the Key Stakeholder Group (KSG)
- introducing the review to other stakeholders and confirming appropriate contacts (carried out by DNRM)
- collecting and collating information from stakeholders through:
  - questionnaire (councils only)
  - in-depth interviews and site inspections (selected councils)
  - meetings and requests for information via email and formal letters (commonwealth and state government agencies, government-owned corporations and private sector businesses).

The timing of consultation activities aligned to the project schedule, allowing gathered information to be appropriately incorporated into the review.

The consultation activities undertaken are outlined below and detailed in the Consultation Report (Appendix N).

4.2.1 Questionnaire

A questionnaire was prepared and distributed to 77 councils throughout Queensland. The package of materials that accompanied that questionnaire included:

- Cover letter
- Project overview factsheet
- Questionnaire factsheet
- Basin Map (showing sub-basin boundaries, local government areas, the location of known rain and stream water level gauges accepted by BoM, and settlements known to flood)

- Gauge Metadata Spreadsheet (if there were rain and stream water level gauges within the local government area that were accepted by BoM)
- Template (spreadsheet) for providing additional gauge meta-data.

Copies of the questionnaire, project overview factsheet and questionnaire factsheet are included in Appendix N.

The questionnaire was designed to collect information on five topic areas:

- settlements and critical infrastructure impacted by flooding
- rain and stream water level gauge locations
- use of data from gauges
- rain and stream water level gauge reliability
- asset management.

A 68% response rate to the questionnaire was achieved with information being supplied by the 53 councils listed in Table 4.1.

Table 4.1 Councils that responded

Balonne Shire Council	Fraser Coast Regional Council	Murweh Shire Council
Barcaldine Regional Council	Gladstone Regional Council	North Burnett Regional Council
Barcoo Shire Council	Goondiwindi Regional Council	Quilpie Shire Council
Blackall-Tambo Regional Council	Gympie Regional Council	Rockhampton Regional Council
Boulia Shire Council	Hinchinbrook Shire Council	Scenic Rim Regional Council
Brisbane City Council	Ipswich City Council	Somerset Regional Council
Bundaberg Regional Council	Isaac Regional Council	South Burnett Regional Council
Burdekin Shire Council	Livingstone Shire Council	Southern Downs Regional Council
Burke Shire Council	Lockhart River Aboriginal Shire Council	Sunshine Coast Council
Cairns Regional Council	Lockyer Valley Regional Council	Tablelands Regional Council
Carpentaria Shire Council	Logan City Council	Toowoomba Regional Council
Cassowary Coast Regional Council	Longreach Regional Council	Torres Strait Island Regional Council
Central Highlands Regional Council	Noosa Council	Townsville City Council
Charters Towers Regional Council	Mackay Regional Council	Western Downs Regional Council
City of Gold Coast	Maranoa Regional Council	Whitsunday Regional Council
Cook Shire Council	Mareeba Shire Council	Weipa Town Authority
Croydon Shire Council	Moreton Bay Regional Council	Woorabinda Aboriginal Shire Council
Diamantina Shire Council	Mount Isa City Council	

Approximately half of the respondents attached additional information (as requested) to their questionnaire response including:

- copies of organisational policies, procedures and technical standards relating to the installation, operation and maintenance of gauges
- details of any gauges the organisation operated and maintained that were not accepted by BoM but might be considered for augmentation and inclusion in the FWGN
- field observations recently recorded in the floodplain that might have impacted the FWGN
- suggestions for any changes to rain or stream water level gauges

- copies of existing rain and stream water level gauge asset registers
- copies of documented operation and maintenance plans
  - details of the maintenance regimes in place for the rain and stream water level gauges in the council area
  - frequency that gauges were calibrated
- reliability issues with gauges.

The feedback received from these interviews was collated by KBR (Appendix N) and incorporated into the findings of this review and a GIS database.

4.2.2 Interviews with councils

In-depth interviews were held with 27 selected councils (Table 4.2). The interviews were conducted across a three week period (between 6 July 2015 and 24 July 2015).

These interviews were used to discuss the FWGN in Queensland and gain a more detailed understanding of:

- council approaches
- council needs
- suggestions for improvements
- capacity
- concerns in relation to the FWGN.

The interviews were also used to explore council responses to the questionnaire and their knowledge and preparedness with regard to flooding and flood warning.

The team visited each council at their offices and often met with a mix of representatives: political, council executive, members of the LDMG and technical specialists involved in flood management. The project team that attended the interviews was also a multidisciplinary group, comprised of representatives from DNRM, KBR, Pentair/ Greenspan and the BoM Hydrology Team. Many councils took the opportunity to learn from the team specialists.

Table 4.2 Councils interviewed

Balonne Shire Council	City of Gold Coast	Murweh Shire Council
Barcaldine Regional Council	Gympie Regional Council	Paroo Shire Council
Banana Shire Council	Hinchinbrook Shire Council	Rockhampton Regional Council
Brisbane City Council	Ipswich City Council	Sunshine Coast Council
Burdekin Shire Council	Lockyer Valley Regional Council	Tablelands Regional Council
Cassowary Coast Regional Council	Longreach Regional Council	Toowoomba Regional Council
Central Highlands Regional Council	Mackay Regional Council	Whitsunday Regional Council
Cherbourg Aboriginal Shire Council	Mareeba Shire Council	Woorabinda Aboriginal Shire Council
Goondiwindi Regional Council		

In addition to the above, in-depth interviews via telephone were held with two councils:

- Bundaberg Regional council
- Mount Isa City council.

The feedback received from these interviews was collated by KBR (Appendix N) and incorporated into the findings of this review and a GIS database.

4.2.3 Meetings with other organisations

Requests for information were made to 17 other organisations with gauge ownership or interest/knowledge of gauges. Face-to-face meetings were held with five organisations:

- BoM
- DNRM
- Queensland Rail
- Seqwater
- SunWater Limited.

Written responses where received from seven organisations:

- BoM
- BHP Billiton Mitsubishi Alliance
- DNRM
- Gladstone Area Water Board
- Seqwater
- Stanbroke Pty Ltd
- SunWater Limited.

The feedback received from these meetings and written responses was collated by KBR (Appendix N) and incorporated into the findings of this review and a GIS database.

4.3 Gauge site inspections

Inspections of gauging sites were undertaken to:

- confirm the accuracy of the FWGN Asset Register maintained by BoM
- assess the condition of the gauging stations
- check operation and maintenance was current.

4.3.1 Site selection criteria

Visiting all the rain and stream water level gauging sites in the FWGN Asset Register was not possible due to a range of constraints including:

- site ownership, location and access arrangements (e.g. some gauging stations were located on private property and required landholder consent)
- project timeframes
- travel logistics and time
- coordination with council interviews that were being undertaken during the same period.

The 81 gauge s tations visited represents 4.4% of the 1,845 gauge sites available to visit. The gauges owned by BoM were excluded from the review. This 4.4% is statistically significant and extrapolations to assess the overall condition might seem achievable but should be treated with caution. The inspections undertaken were predominantly visual and el ectronic connections to assess battery charge, signal strength, preliminary calibration accuracy were not made. Accordingly extrapolations should be considered a guide only.

A condition assessment of the entire network infrastructure should be performed as part of the periodic maintenance cycle and become a mandatory report to the Lead Agency at each annual inspection and the master report database updated accordingly. This would create a baseline for maintenance, network performance, cyclic replacement and financial planning.

The following criteria were applied to select the gauging sites:

- Level of settlement risk (as assigned by BoM and DCS (BoM 2013a)). Note that while the majority of sites inspected where higher risk sites, some low risk sites important to the FWGN based on advice from councils were also inspected.
- Flood warning time available from an observable (and measureable) event to impact. The scope of the BoM flood warning system excluded towns subject to flash flooding (ibid) but settlements within a 6-12hr flood wave travel time were assessed for the purposes of field inspections as having a higher priority than settlements with longer flood wave travel times.
- For the 6-12hr threshold, stations within a range of 24km in flatter streams and 96km in steeper stream were of interest for the initial visit. Gauge sites identified in Schedules 2, 3 and 4 of the SLS were assigned an 'indicative level of priority' based on the expected impact on BoM's forecasting service without considering the priorities of third party owners or other users (ibid). Table 4.3 below shows the indicative level of priority.
- Proximity to council offices that were being visited for face-to-face interviews.
- Access arrangements for the site (i.e. In order to reduce access issues, council-owned gauges were prioritised over DNRM owned gauges).

Table 4.3 Indicative Site Priority Level (Source: BoM 2013a)

Priority Level	Impact on performance	Impact on service delivery	Description
High	Very difficult to meet target	Direct and significant high level impact for the site and/or downstream locations	Degradation of service highly likely.
Medium	Difficult to meet target	Some impact for the site and/or downstream locations.	Possible degradation of service.
Low	Not likely to affect meeting targets	Little impact on the site and/or downstream location	No change in service. Lower possibility of degradation of service.

Inspection of BoM gauges did not form part of the scope of the study.

4.3.2 Selected sites

A selection of 81 gauge stations, across 22 different local government areas, was inspected as part of this review.

The types of gauge stations included combined rain/stream water level gauges, stream water level only gauges, rain only gauges and float wells. The owners of the gauge stations included DNRM, councils and Seqwater and SunWater.

4.3.3 Inspection methodology

An inspection check-list was used to promote consistency across the assessments that were undertaken (Appendix O).

Generally representatives from council, DNRM and BoM attended and provided additional insights into the rationale for the gauges and how the gauge information was used.

Copies of service records and calibration checks were only available for the project team to inspect at the DRNM sites. Records for sites serviced and calibrated by BoM are understood to be retained by BoM at its offices and copies are forwarded to council (these records were not inspected by the project team). Similarly, records for sites maintained by contractors were not sighted by the project team but it is likely that copies are also forwarded to councils.

Samples of service records were provided by Seqwater for all gauges inspected.

5 Roles and responsibilities

Findings

- DNRM has been assigned the role of lead agency for the state's hydrometric flood warning gauge policy.
- There is no single entity with absolute responsibility for the FWGN in Queensland. The current model that evolved organically involves distributed ownership across 54 organisations with the operations and maintenance task varying significantly in scope and quality. This is hampering development and oversight of the FWGN.
- There is no specific model for the governance of the FWGN. There is governance and strategy around the hydrometric network of individual organisations that contribute to the FWGN, but not of the FWGN as a whole. This appears to be a result of a legacy of distributed ownership, irregular funding and ill-defined responsibility for the FWGN.
- Due to the different climatic and hydrologic regimes, social context and capability and capacity within councils a one-size-fits-all governance model seems inappropriate.
- BoM is responsible for approving new hydrometric installations into the FWGN and maintenance of the FWGN Asset Register. There are a number of factors that must be considered to determine suitability for inclusion in the FWGN.
- BoM currently provides advice to some councils investigating augmentation of the FWGN in their local government area. This includes advice in relation to hydrometric gauge design, instrumentation and installation options.
- Funding of capital for the FWGN in Queensland is currently derived from a range of sources including: Commonwealth Government funding to BoM, Commonwealth Government grants, State Government funding of agencies operating gauges, State Government grants, Local Government funding derived from the rates base and private enterprise operating gauges.
- Funding of maintenance is generally through annual budget allocations from Commonwealth departments (BoM), State departments and agencies, councils and private industry. In some instances, a council will fund BoM's maintenance of council gauges or fund a contractor.
- Gauge ownership is not always clearly defined. This occurs primarily where gauge installations are jointly funded and where there have been legacy agreements between BoM and councils. Gauge housing may contain instruments owned by others.
- Responsibility for regular assessment and review of the FWGN is not clear. Various reviews have been commissioned by State Government, BoM and councils. If an agency were given overarching responsibility, then prioritisation and oversight would be improved.
- BoM is responsible for providing a flood warning service and relies on the FWGN to provide this service. However, BoM does not control the other 53 asset owners. Competing priorities of individual asset owners can hamper the effectiveness of the FWGN.
- There is an opportunity to incorporate data collected by gauges owned by private enterprise (e.g. mining companies) into the FWGN. However, the incentive for private enterprise to contribute to the FWGN is not compelling given the additional responsibility placed on them to provide reliable hydrometric data.

Each of the 54 agencies that own gauges in the FWGN has dedicated roles and responsibilities, and this section explores some of the current arrangements in place, the understanding of those arrangements, and how the different stakeholders interact to provide flood warning services.

5.1 COMMONWEALTH GOVERNMENT ROLES

Most of the technical/operational roles of the Commonwealth Government in providing flood warning services are facilitated by BoM,

The Commonwealth Government also fulfils non-technical roles within the flood warning service, particularly in areas of policy, funding and oversight of the provision of flood warning services (at a national level). The Commonwealth Government is ultimately responsible for Emergency Management and Incident Management through operation of the Australian Government Crisis Coordination Centre, which consolidates actions during complex national crises and manages the national capacity to respond to such a crisis.

The Commonwealth Government also provides funding and research and development support for the flood warning service through the Attorney General's Department. The Attorney General's Department is responsible for Australian Emergency Management and publishes the Emergency Management Handbooks and Manual Series.

5.1.1 Bureau of Meteorology

BoM was established by the Commonwealth Meteorology Act 1955 and fulfils a role as Australia's national weather, climate and water agency. BoM works closely with state and local government agencies in order to provide meteorological and hydrological advice.

BoM is responsible for a range of routine planning, data gathering and modelling activities to support the TFWS. BoM also coordinates communication material for councils. The role and responsibilities of the BoM in Queensland are detailed in the SLS.

BoM undertakes continuous flood monitoring and provides qualitative and quantitative flood predictions using data collected from BoM weather stations, its own hydrometric stations and from the FWGN supplied under data sharing arrangements with key stakeholders. BoM does not provide any flood warning service for flash floods however BoM does provide meteorological or storm warnings that can help to identify flash flood risks.

BoM is committed to publishing forecasts and warnings on their website, but the communication and dissemination of those warnings is a responsibility of the council.

BoM owns and operates a number of weather stations and hydrometric gauge sites at critical locations across Queensland. BoM is responsible for the operation and maintenance of all hydrometric equipment at those sites.

As BoM is the entity that undertakes the modelling and forecasting services, it has strict standards for the reliability of information for input into flood forecasting models. If the equipment or technology does not meet BoM's standards of instrumentation the gauge will not be accepted into the FWGN and the data will not be used.

Finally, BoM provides support and advice to councils and other organisations about augmenting flood warning gauge assets, installing equipment, and operating and maintaining existing gauge assets. This assistance is provided under individually agreed service arrangements.

5.1.2 Flood Warning Consultative Committee

Each state and territory has a FWCC that is chaired by BoM. The FWCC is made up of representatives from organisations that are recognised by BoM as key stakeholders for flood warning in the given state. The FWCC usually meets biannually, but may meet more frequently based on events or activity.

The role of the FWCC in Queensland is to provide BoM's key stakeholders with a consultation mechanism for the flood forecasting and warning services provided by BoM.

5.2 STATE GOVERNMENT ROLES

The roles and responsibilities of the state governments are not summarised in any one place because of differing governmental structures.

The BoM SLS (Section 2.5) is an agreement between BoM and the most relevant State Government department. In Queensland the agreement is with the Chair of the Queensland FWCC.

There is also a broader National Arrangement for Flood Forecasting and Warning (BoM, 2015a) that describes the role of the State Government at a higher level. Here the State Government roles and responsibilities include supporting the real-time collection of data for flood prediction, providing and coordinating emergency management and flood responsiveness activities, disseminating BoM flood predictions to provide a local understanding of the predictions and developing and implementing flood awareness programs at a local level.

5.2.1 Department of Natural Resources and Mines

DNRM has an integral role in the management of flood risk in Queensland and prime responsibility for policy development for the management of natural resources. DNRM is also responsible for overseeing statutory bodies such as river improvement trusts (responsible for preventing or mitigating riverine flooding of land) and drainage boards (responsible for managing drainage systems).

The role of lead agency for the hydrometric gauge network policy was assigned to DNRM in October 2013 to improve clarity around the roles and responsibilities of different organisations involved in the Queensland FWGN. As the lead agency, DNRM is responsible for:

- identifying actions to improve effectiveness of the current hydrometric network
- ensuring contestability of the hydrometric gauge network
- examining options for integrating management of the gauge network, flood mapping and the FloodCheck web portal.

As part of its wider water resources role, DNRM owns and operates a network of hydrometric gauges that are used to monitor surface water quality for water accounting across the State. Some of those gauges provide valuable data for flood monitoring and forecasting purposes by BoM. DNRM is responsible for maintaining DNRM-owned hydrometric gauges. DNRM and BoM have a data sharing agreement (specified in the SLS) under which DNRM is to provide reliable and accurate rain and stream water level data to BoM.

DNRM also assists other government departments in the area of flood planning and management including assisting QFES and PSBA to capture spatial imagery and undertake spatial information analysis.

5.2.2 Queensland Flood Consultative Committee

The Queensland Flood Consultative Committee (QFCC) was set up as a forum to coordinate the many aspects of flood management. The QFCC has not been active since July 2010. Following the Queensland Flood Commission of Inquiry (QFCI) and other findings, it is desirable to reactivate and clarify the role and responsibilities of the QFCC in Queensland.

5.3 COUNCIL ROLES

The Floodplain Management Handbook 7 (CoA, 2013a) designates that the majority of direct management roles during a flood event should be the adopted by local governments on the basis that local issues are best dealt with locally. They include flood response planning, flood disaster management, promotion of local flood awareness amongst the community and interpretation of flood predictions.

According to the National Arrangements (BoM, 2015a), councils are responsible for contributing to real-time flood warning by providing assistance in the data network.

Councils also hold a range of related roles and responsibilities for water supply and emergency management, including monitoring local water storage and releases of the council-owned storages.

Councils are responsible for disseminating BoM riverine flood warnings to the public and attributing meaning to those warnings within the local context. BoM generally enters separate service agreements with individual councils regarding the provision of warnings and BoM may provide assistance to operate and maintain some council-owned assets. Given the scale of differences between councils, individual service agreements can vary greatly. In some councils contribution to the FWGN includes ownership, operation and maintenance of hydrometric gauges. In other councils the contribution is less, providing some general oversight and localised information and dissemination of BoM warnings.

Flash flooding is a key consideration for local governments, and given the localised and unique impacts which flash flooding entails, can be hard to predict in advance. Preparation for flash flooding is intrinsically linked to local knowledge, knowing where low-lying areas are, understanding the local waterways and how they respond during storms. BoM provides assistance to councils in identifying flash flood areas and providing guidance to establish flood warning systems but ultimately the responsibility for preparation and response to flash flooding belongs to local councils.

After the 2010–2012 flood events in Queensland, QFCI identified that there was a need for councils, with support from BoM, to identify areas that may be susceptible to flash flooding.

5.4 OTHER ORGANISATIONS WITHOUT DIRECT RESPONSIBILITIES FOR FWGN

There are a number of other organisations throughout Queensland that play a part in providing data for flood warning purposes. State-owned SunWater Limited and Seqwater hold responsibilities in relation to supplying water to Queensland (predominantly around monitoring water storage, release and distribution). These organisations record dam levels and other data relevant to their own operations. Where possible this data is made available to BoM.

Other organisations, such as Queensland Rail, DTMR, Aurizon and Ergon Energy have responsibilities regarding the provision of essential public services, including monitoring stream water levels and rain to ensure protection of their essential assets. Whilst these organisations collect useful data that could potentially be used for flood warning purposes, they do not appear to have any direct roles or responsibilities in relation to the FWGN.

5.5 OBSERVATIONS FROM CONSULTATION ON ROLES AND RESPONSIBILITIES

Responsibility for regular assessment and review of the FWGN is not clearly defined under the current arrangements. Various reviews have been commissioned by State Government (e.g. QRA 2012, this review), BoM (following events) and councils (catchment specific flood study initiatives). If one agency were given overarching responsibility, then prioritisation and oversight would be improved.

5.5.1 Bureau of Meteorology

Feedback from consulted stakeholders about the current operation of the FWGN and how different levels of government and agencies co-operated was generally positive. It was well understood that BoM was responsible for providing flood warning and forecasting services, although understanding of the number of forecast locations for which the BoM provided warnings was not well articulated. BoM was seen as a trustworthy and reputable source of information in the field of flood warning and forecasting.

Councils that were receiving support from BoM thought that support was of a high standard and assisted the council's understanding of BoM flood warnings. This made dissemination of warnings easier for councils and allowed for more relevant and targeted warning messages from the council. Councils also saw value in seeking assistance with operation and maintenance or advice about potential upgrades to the gauges within their areas.

5.5.2 Department of Natural Resources and Mines

Feedback from councils gave the impression DNRM was generally meeting its obligations. However, councils felt DNRM should be responsible for the standardisation of technical standards for flood warning purposes and the preparation of guidance documentation for funding arrangements and grants.

5.5.3 Councils

Feedback from consultation with councils indicated that their abilities to meet their obligations varied widely. Considerable variability was observed in the knowledge held by each council, their preparedness for flood warnings, and the independent modelling, monitoring and flood warnings undertaken.

5.5.4 Flash flooding

Flash flooding was an area of particular interest and a key concern for all parties. As a responsibility of councils, it was often noted that while some councils were more prepared for flash flooding, a majority were not able to, or did not understand how to address, prepare and respond to flash flooding.

As there was no standard system design or guidance documentation available for local governments that outlines what was necessary to provide a functional and resilient flash flood warning system, councils were generally unsure of what their responsibilities entailed. Flash flooding is discussed further in Section 10.

5.5.5 Funding

Funding was a recurring theme raised by councils. Despite the availability of grants from the commonwealth government, many of the respondents were unsure of what funding was available and exactly what the funding could be used for.

Another recurring point was that grants and funding that were available typically covered capital components, but not the ongoing cost of operation and maintenance.

5.6 GAUGE OWNERSHIP AND CAPACITY TO MAINTAIN

Ownership and the availability of capital is a key consideration for the FWGN as these dictate the field instruments installed, the format in which data will be transmitted and the timing of the received data; all considerable factors in the consistency, reliability and effectiveness of the FWGN.

Consultation with the councils, BoM, DNRM and other organisations has identified a number of issues in relation to the consistency of data collection, and ownership of gauging stations.

Table 5.1 provides an overview of the number of gauges owned by each entity (and the number of different owners in QLD). There are 54 different owners of gauging stations currently in the FWGN in Queensland.

Table 5.1 Overview of gauges

Owner*	Manual	Telemetry (TM)	ALERT	Total Stations	Percentage of Total
BoM	864	15	57	1,079	37%
DNRM	21	510	-	531	18%
Councils	5	75	821	901	31%
Joint with BoM	32	3	16	51	2%
Supplier	12	126	143	281	10%
Other	11	69	1	81	3%
TOTAL	945	941	1,038	2,924	100%

* some gauges have shared ownership. For the purposes of presentation (and to avoid duplication) only one owner is shown

Reaching a consensus across all entities about the appropriate technology, placement and data sharing arrangements is a significant challenge.

The current ownership of gauging stations is closely related to the budgets and funding that has been made available, and the capacity of different organisation to install, operate and maintain the gauging stations.

The suitability of gauges for incorporation into the FWGN depends on the installed technology, availability of communications, potential value to the FWGN, cost of integration so it can be used by BoM, future ownership and maintenance costs.

The ownership model issues encountered for each of the key entity/agencies are discussed below.

5.6.1 Bureau of Meteorology

BoM currently owns 1,077 of the 2,924 gauging stations (37%) within the FWGN in Queensland.

BoM-owned gauging stations are housed in separate units which only house BoM technology and there are generally no agreements in place with other entities/organisations to co-locate different technology.

Most of the BoM gauging stations are ALERT stations so data is accessible in real-time.

BoM sites are prioritised in line with key river networks which are most relevant to the 143 locations (and 128 settlements) for which BoM provides a flood warning service.

5.6.2 Department of Natural Resources and Mines

DNRM owns 551 gauging stations across the State. The primary function of these sites is for water monitoring services however the gauges have been approved and accepted by BoM into the FWGN for flood warning purposes and generally report by TM or ALERT systems.

There are a number of “co-located” arrangements where council-owned technology is located within DNRM-owned gauge housing.

5.6.3 Councils

Many councils have assumed an ‘ownership regime’ for gauges in their local area. The size, spatial distribution, and f unction of these gauges vary significantly between councils. The review showed councils that better understand their flood warning responsibilities tend to own more gauges.

Across the State, councils own 30% of all flood-related gauges. Most of the councils visited during the review owned gauge station assets that allowed the staff to be better prepared and provide more accurate, locally relevant flood advice. While BoM may provide a broad flood warning, not all settlements are covered by the 143 sites for which BoM provides flood warning forecasting.

5.6.4 SunWater Limited

SunWater owns 82 gauging stations. As is the case with DNRM, the primary purpose of the SunWater gauges is not for flood warning and prediction purposes, however these gauges provide valuable data to the FWGN.

5.6.5 Seqwater

Seqwater owns 184 gauging stations in south east Queensland. As is the case with DNRM and SunWater, the primary purpose of the gauges is not for flood warning and prediction purposes, but these gauges provide valuable data to the FWGN.

5.6.6 Queensland Rail

Queensland Rail currently monitors more than 100 hydrometric stations across Queensland as part of its internal monitoring program. The Queensland Rail owned hydrometric stations record track temperature, rain and water heights at bridges. Data collected by each of the hydrometric stations is communicated via shared radio networks.

BoM and Queensland Rail are presently trialling hydrometric stations in the Warrego Basin with a view to determining the suitability of sharing data from the Queensland Rail network for flood warning purposes.

5.6.7 Department of Transport and Main Roads

DTMR operates a number of asset monitoring stations that observe water heights around key parts of the transport network across Queensland. Internet-based technology solutions are also being trialled which potentially could be linked to the BoM flood warning service. Currently, DTMR does not own any gauges associated with the FWGN.

5.6.8 Ergon Energy

Ergon Energy is investigating the feasibility of a program for the installation of approximately 600 environmental stations spread uniformly across the State with one in every major community under the ROAMES (Remote Observation Automated Modelling Economic Simulation) program (QRA, 2012).

It is not clear whether this program has been approved yet, or if it will be feasible for the stations to be integrated into the FWGN. The intention of the project is not focussed on rain or stream water level. Despite a cooperative intent, there is little incentive for Ergon Energy to integrate its gauges with the FWGN.

5.6.9 Extractive industries

A number of mining and resource companies with environmental water monitoring requirements are potentially an additional source of meteorological data.

This could be explored further, but was not considered as part of this review.

5.7 OPERATIONS AND MAINTENANCE

Operation and maintenance of the assets within the FWGN is currently the responsibility of the asset owner. The resources provided for maintenance vary widely by gauge owner and maintainer. There is a range of ownership arrangements in place throughout the State, and councils do not always have the capacity to provide the ongoing care and maintenance required for the gauges in their area so BoM provides some assistance.

The councils interviewed with greater capacity for operation and maintenance generally had individuals or a team who were responsible for the operation and maintenance of their gauging stations. The arrangements differed between councils, some staff had dedicated positions and their responsibilities revolved around the calibration, upkeep and servicing of data collection and interpretation units; others had a more mixed role and their responsibilities were less well focused or defined.

In cases where operation and maintenance were not a priority, many councils advised they lacked staff with the technical expertise to maintain the gauging stations, and funding was a key inhibitor.

Currently BoM provides a number of local governments with assistance in the form of operation and maintenance for key gauges which BoM relies upon for flood warning modelling and prediction purposes.

Councils are also afforded assistance from DNRM in the area of operation and maintenance should the council own/operate any technology within DNRM-owned housing/shelter.

The amount of interest in the operation and maintenance of the gauging stations, and ancillary assets related to the FWGN, was often related to the final use of the data collected from the gauging stations. Where councils were involved in independent flood modelling and monitoring, the operation and maintenance of gauges tended to be incorporated into the council operations.

Some organisations that maintain and calibrate gauges and discharge other obligations with respect to gauges and data appear to have potential resourcing challenges. The following table compares the number of gauges by type with the number of hydrographers that service them. Many councils rely on BoM and whilst only four such councils are included in Table 5.2, the data suggests a significant burden upon BoM. It is understood that BoM only has two teams that travel around the state to maintain the flood warning gauges. This is a key resourcing constraint and may need to be reviewed to ensure the consistency of the level of service provided to each local government.

Table 5.2 Maintenance obligations

Organisation	Stream water level	Rain	Combined stream water level / rain	Number of hydrographers
BoM	112	816	213	4
DNRM	138	102	291	21
SunWater Limited	63	0	19	2
Seqwater	32	52	104	3
Brisbane City council	27	26	19	1
Banana Shire council	0	23	9	Private Contractor
Central Highlands Regional council	0	16	20	Rely on BoM
Lockyer Valley Regional council	0	13	11	Rely on BoM
Mackay Regional council	1	10	15	Rely on BoM
Whitsunday Regional council	0	5	4	Rely on BoM

Direct comparisons of gauges and maintenance resourcing cannot be made without understanding the burden each gauge presents. Stream recorders require more site time than pluvios, have more parts that fail, and require considerable data storage and processing.

BoM also has All Weather Stations (AWS) that provide information for flood warnings. These are excluded from the above table as they are maintained by another team.

Comparisons between the number of staff devoted to gauges owned by BoM, DNRM and Seqwater are not appropriate due to staff having other duties. Nevertheless, the table suggests that BoM hydrographers dedicated to the FWGN have considerable maintenance responsibilities. Any resourcing problems would be exacerbated if the FWGN were expanded.

The review of operation and maintenance procedures across the FWGN highlighted some key areas which require attention to ensure continued high level of quality data provided by the FWGN. A combined asset management register or database would be a useful guide to assess the condition and upkeep of the gauges within the FWGN. This endeavour should be undertaken as part of an oversight role for the operation of the FWGN.

The calibration procedures, and data correctness (verification) check procedures were not well understood at a number of the councils, which is likely an ancillary issue associated with the lack of consistent technical guidelines in place.

If a single ownership model were adopted and BoM relinquished co-owned assets to councils, costs associated with owning, operating and maintaining the gauges (which are currently largely borne by BoM) would fall to local governments. A majority of the councils identified that they were unable to estimate the potential cost. Councils reliant upon BoM generally felt they lacked the capacity to absorb the additional cost, and that this would likely result in a reduction in data provision.

5.8 FUNDING

A simple SMAUG (seriousness, manageability, acceptability, urgency and growth) analysis suggests gauge owners face several funding challenges.

- Manageability has been taken as meaning the ease by which individual elements changes can be implemented.
- Acceptability is taken to reflect a community attitude to failure. The community is more likely to accept failure from a *force majeure* situation than the omission of a planned maintenance operation.
- Growth reflects the questions: is the problem becoming larger?
- Seriousness: about 600 settlements have been identified at risk of flooding, but this number will be refined as the vulnerability to flash flooding becomes more clearly defined. There are also many suburbs in cities that are excluded from the list of settlements considered.

- Manageability: there are difficulties to be overcome if the management of the FWGN is to improve:
  - directions of/from the State
  - ownership
  - funding
  - maintenance and operations
  - technological disparities within the existing network
  - expanding competition to improve choice and reduce costs
  - privatisation
  - human resources, etc.
- Acceptability:
  - for those communities that have already experienced flooding, any improvement in flood warning time would be highly desired
  - for those communities that are protected to a defined flood event, they will accept the need, but may not willingly accept any additional financial burden
  - those disaster managers that recognise that a larger flood than the defined flood event can occur, will recognise the need for as great a warning time as possible
  - western councils in drought might not see any need to maintain gauges.
- Urgency is related to the collective and current level of immunity of settlements expressed as Annual Exceedance Probability (AEP) for whole or part of a community. Those communities known to flood regularly (a high AEP) must have a strong, resilient and efficient FWGN.
- Growth: the elements that reflect problems becoming larger over time include:
  - population
  - climate change
  - maintenance costs
  - renewal / upgrading of existing infrastructure
  - possible reductions in funding and available resources
  - increasing rate of technological advances
  - decay rate of fixed line communication systems
  - increasing congestion in the radio spectrum brought on by the number of stations, the potential data signal length and two-way communications.

Under the current expectations and based on existing budget allocations, the development of the FWGN is unlikely to keep pace with the likely future demands, primarily due to the required maintenance and replacement of existing assets. Additional financial implications are presented if there is a requirement for augmentation and upgrade of existing assets to meet any implemented industry standards or associated changes to the communication network (converted from TM to VHF coverage in response to changes to Telstra's existing copper wire network).

Feedback from councils reflected that they felt they were unable to meet the financial obligations of maintenance and potential upgrade of the existing FWGN without financial assistance. Priorities for FWGN augmentation and upgrade should consider a systematic and collective approach that incorporates guidance on funding to assist councils. This could potentially lead to increased efficiencies and economies of scale and would assist councils in managing the costs associated with operations and maintenance of their network assets.

If economics of scale could be achieved, it would mean the Queensland Government need not assume responsibility for costs currently borne by other entities. Options should be explored for reducing the total cost of operating and maintaining the network by sharing costs across agencies through a coordinated program of works.

A similar model has been adopted by the Victorian Government, which maintains its gauging network through Regional Water Monitoring Partnerships (DELWP, 2015). Through this program, a number of public and private organisations collectively contract services to reduce administration expenses, produce more reliable and consistent data, and increase the transparency of cost-sharing arrangements. The Victorian Department of Environment and Primary Industries acts as a key partner and manager of the program. DNRM could play a similar role in Queensland.

5.8.1 Capital

The following section provides a brief overview of the capital costs associated with the gauge stations which are present in the existing FWGN.

ALERT flood towers containing stream water level equipment can cost between $25,000 to $60,000, depending on remoteness, access, length of pressure line run from tower to creek and also how many sites are to be installed in one time.

For rain gauges with ALERT capability, the associated costs vary with remoteness, access and number of sites to be installed (shared overhead). Costs are generally in the range of $10,000 - $20,000.

For rain gauges installed with satellite capability, the pricing is usually slightly less than an ALERT capable system, but remains variable. Costs generally range from $5,000 to $20,000 depending on the remoteness, access and number of sites. However, the ongoing communication costs have to be considered.

The shared housing model which commonly includes DNRM housing with council-owned assets can be a very cost-effective option depending on the sharing arrangement. The installation of ALERTs capable equipment within a shared housing unit can vary between $10,000 and $30,000.

5.8.2 Operation and Maintenance

Annual operation and maintenance for a gauging station is generally between 5% and 10% of the installation cost. In addition, replacement costs for internal components of the gauging station (i.e. ALERT Canisters or data loggers) can cost up to $5,000 (most equipment has a 5-10 year lifespan). Batteries and solar panels have a lifespan up to five years but should be considered for replacement every two years.

Funding for operation and maintenance is notionally borne by the asset owner but BoM has assumed some responsibilities.

A further list of some of the costs of replacement equipment is included in Appendix Q.

5.9 GOVERNANCE

The preliminary findings indicate several shortcomings in the overall management of Queensland's flood warning gauge network. Historically some gauges were installed for purposes other than flood warning (e.g. water management) but have since been incorporated into the FWGN.

The FWGN has evolved over time with little governance. The assets that have been installed have variable standards of technical consistency and data reliability for flood warning and modelling purposes.

There are several aspects to be considered:

- which department or agency would have overall responsibility for the FWGN
- what other departments or agencies would support the lead agency and how
- how are different geographic and hydrological areas to be treated
- are remote and small councils to be supported differently from larger and financially stronger councils.

It is assumed that neither the Queensland Government would relinquish responsibility, nor BoM would accept responsibility in a revised governance model.

5.9.1 Current issues

The robustness of the network can be strengthened with greater direction, allocation of responsibilities, more funding for new installations, better operation and maintenance, and active research into equipment with lower maintenance or improved reliability. Further, the introduction of the NBN poses a risk of additional expense but also provides opportunities for higher data loads.

To improve the overall quality, management and administration into the future of the diverse technologies, a new governance strategy is recommended.

The issues and multiple concerns that have been identified would provide input for Terms of Reference for any department or agency assigned responsibility for the FWGN.

5.9.2 Responsible state department or agency

The selection of a department or agency to hold responsibility for the FWGN could be selected considering the following:

- have a significant interest in minimising flood disaster impacts have close links with Treasury and able to influence the supply of related funding to other agencies
- have strong linkages to the Department of the Premier and Cabinet
- include people with strong and extensive personal networks with local governments
- have governance, administrative, technical oversight, and technician support related to gauge provision and operation.

Under the current structure of the government, the following departments and agencies would have an interest:

- Premier and Cabinet
  - the Premier assumes a public role during a natural disaster and requests assistance from the Federal Government as required.
- Treasury
  - responsible for public funds and disaster management.
- Natural Resources and Mines
  - Given policy responsibility for the flood warning network in 2013
  - Maintains a hydrometric gauge network for a number of purposes (water resources, water quality) and its gauges comprise a substantial part of the FWGN
  - Guidelines for flood levees and embankments.
- Local Government
  - land use planning
  - public safety
  - counter disaster planning and management
  - funding.
- State Development, Infrastructure and Planning
  - policy direction and land use planning.
- Science Information Technology and Innovation
  - Technical responsibility for hydrology and technology.

- Energy and Water Supply
  - management of dams.
- Queensland Police
  - lead roles in disaster management and public safety.
- Queensland Fire and Emergency Services
  - support services during emergencies.
- Public Safety Business Agency
  - provides a range of services including finance, human resources, information and communication technology, ministerial and executive services, media and business strategy to its partner agencies: the Queensland Police Service, Queensland Fire and Emergency Services and the Office of the Inspector-General Emergency Management.
- Queensland Reconstruction Authority
  - manages and coordinates the Government's program of infrastructure reconstruction within disaster affected communities
  - role has also been extended to cover historical and continuing disaster events in Queensland.
- Inspector General Emergency Management
  - responsible for oversight of public safety, through the establishment and implementation of an assurance framework to direct, guide and focus work of all agencies, across all tiers of Government to the desired outcomes of the disaster and emergency management arrangements for Queensland.
- State Disaster Control Centre
  - coordinating role and operations, analysis events, situational awareness, passage of information to affected councils and other relevant agencies, tasking of State Emergency Service Groups in response to requests for assistance from the general public, procuring and transporting a wide range of resources that were requested by Local Governments, and briefings to key decision makers and forward planning.
- Seqwater
  - a government commercial entity established to provide safe, secure and reliable water supplies for South East Queensland, as well as providing essential flood mitigation services and managing catchment health
  - owns, operates and maintains a considerable network of hydrometric gauges and dams in South East Queensland.
- SunWater
  - manages a regional network of bulk water supply infrastructure that spans across Queensland owns, operates and maintains a considerable network of hydrometric gauges and dams in South East Queensland.

Selection of where the ultimate responsibility will lie is a matter for the Premier and Cabinet, however a weighted analysis can be undertaken to select the most appropriate custodian. The level of engagement by supporting department or agencies will be dependent on the needs of the prime agency or disaster responders prior to or at the onset of a severe event. Examples include prompt review of funding applications, support for determining new sites, or prioritisation of sites (where land use planning has resulted in significant potential flood impact), and the ability to respond to urgent maintenance and repair issues.

5.9.3 Consideration of councils

Councils in Queensland differ greatly in their size, communities they serve, industries, financial and human resources and flood risk. These differences need to be reflected in the governance model to be applied.

The governance model finally selected should seek to answer:

- how are different geographic and hydrological different areas to be treated
- are remote and small councils to be supported differently from larger and financially independent councils.

The selection process needs to consider the levels of guidance provided, the levels of direction to be mandated, and then outline implementation processes that consider the differentiation needed to accommodate the state's diversity.

Unfortunately, efforts directed to disaster planning and preparation for emergency response diminish with the time since the last event, and memories fade. When another drought occurs, councils will be faced with financial decisions to continue to support and fund their own gauge system. Should sufficient councils fail to maintain the gauges necessary for effective flood warning, then it is arguable the funding responsibility should be with the state.

Whilst it is not within this project's purview to nominate how the state is to be managed the following aspects can be considered:

- BoM has prime responsibility for issuing weather and flood warnings
- councils have responsibilities to protect their communities, and respond to impending disasters and recovery
- Local Disaster Management Groups need to assess hazards
- some councils need the financial assistance of the state
- the flood warning system should be prioritised depending on the level of risk, potential exposure and rapidity of event escalation
- a minimum number of gauges needs to be maintained to provide flood warning coverage for the state and to support BoM's responsibilities, and the density will depend on site priorities and the need for back-up/redundancy. These critical gauges could become the responsibility of the state to own and maintain.
- assigning a second order of priority to gauges that BoM considers provide additional surety to the provision of BoM flood warnings
- assigning a third order of priority to assisting councils in the understanding and attribution of meaning to the local disaster response effort.

Whether there is a specific level of funding required by the FWGN, sourced across the state and councils, is dependent on a future decision by the state.

5.9.4 Recommendations

One department or agency should be given responsibility for ensuring the effective operation of the FWGN in Queensland, but it would need support by inter-departmental/agency service agreements.

The terms of reference or designation of responsibilities should be directed to resolving the various issues arising from the study findings.

The level of engagement by supporting department or agencies should be dependent on the needs under particular circumstances. Examples include prompt review of funding applications, support for determining new sites, or prioritisation of sites (where land use planning has resulted in significant potential flood impact), ability to respond to urgent maintenance/repair requests, etc.

6 Asset inventory

Findings

- BoM maintains a database that contains information on some components of the flood warning gauge network. The database is not exhaustive and gauge ow ners or third party providers typically hold additional information in separate databases.
- Feedback from the councils and data collected during the field investigation highlight a need t o validate the data in the database. There is also scope to expand data capture to assist with asset management.
- There is currently no public accreditation system for instrumentation used in the FWGN
- There is no rating, hierarchy or assessment within the FWGN database that assigns more confidence to certain gauges than others, for example based on the operation and maintenance regime or the type of equipment installed.
- Manual gauges provide a robust direct measure of water level that does not rely on technology (other than communications). Readings can be s ubject to human error and i naccuracies caused by turbulence and debris interference.
- The lack of a manual gauge board at many telemetry or ALERT gauge sites makes calibration more difficult.

6.1 ASSET DATABASE

As part of the review, an asset database was prepared which was geospatially linked but was exported to a spreadsheet for manipulation. The fields in this database include basic overview information such as station ID, location, ownership agency as well as station function, flood class, communication and instrument type.

This database combines BoM data, information received from councils and other asset owners as well as data collected in the field. Additional database fields include the gauge survey datum, gauge zero level, installation date, technical details of the equipment installed in the gauge as well as recent inspection dates.

An asset database which is maintained for all gauges in the FWGN could be useful to give an indication of:

- breakdown of instruments, technology and related systems used by the network
- breakdown of class, type and geospatial location of network assets
- asset ownership and maintenance responsibilities.

This information could be used to understand the condition of the assets within the FWGN, and identify potential upgrade opportunities and assess network vulnerabilities.

6.2 CONDITIONAL ASSESSMENT

One of the objectives of this review was to assess the performance and condition of the rain and stream water level gauges in the FWGN. The total number of gauges included was 2,924, of which 81 were inspected across a 3 week period as described in Section 4.

The gauge inspection assessed the status of the equipment and allowed gauge owners to provide feedback about the reliability and ongoing maintenance of their assets. The inspections also included validating the asset database and evaluating site risks.

The information to be collected included:

- historical information provided from the database to understand the natural variances and fluctuations in data collection at that site
- a check of the power systems
- a check of the rain gauge (operation and calibration check)
- an overview of the condition of the cabinet and housing
- confirmation of the river gauge (operation and calibration check)
- follow-up telemetry check (information received in the database).

An example of the gauge inspection checklist is included in Appendix O. A description of the typical components of gauges is included in Section 3.3 and Appendix Q.

The conditional assessment of gauges was limited due to the technical level of the checks (calibration required to perform the full gauge inspections was excluded) and the limited data received from some of the gauge owners. A full gauge inspection requires disconnection of hardware to conduct independent validation and checks. The decision was made to proceed with those gauge inspections which limited disruption to normal operation. Therefore the conditional assessment of the equipment is qualitative. In some cases gauge access was limited or not possible in which case the assessment was performed based on visual inspection of the external condition of unit housing.

6.2.1 Assessment Rating

The physical condition and functionality assessed for each inspected asset included the housing, pipework, staff gauge and likelihood of impact from sedimentation. Each component was assigned a rating from 0 to 4 based on the descriptions provided in Table 6.1. Physical condition was generally assessed by the appearance, relating primarily to the condition of various components such as the equipment housing, pipework and staff gauges; and also relating to the general environment including the potential for sedimentation and other factors which might impact the condition and functionality of the gauges (i.e. potential damage from cyclones or lack of access for maintenance). A more detailed assessment of gauges and equipment condition could be made where safe access to equipment housings was permitted. For the purposes of consistently assessing each of the inspected gauges, assessment ratings were given for the housing, pipework and staff gauge equipment for each station and a rating for the potential for sedimentation was assigned (Table 6.1 and 6.2). All gauge sites visited were assigned an overall rating based on a rating scale provided in Table 6.3.

Table 6.1 Rating scale for equipment (housing, pipework and staff gauges)

Rating	Description
0	Not Applicable or not assessed
1	Fair condition, equipment in need of repair or equipment missing i.e. staff gauges or pipework
2	Reasonable condition, some sign of corrosion or damage, equipment may need repair or aging is evident
3	Good condition – no major issues noted
4	Brand new equipment or excellent condition

Table 6.2 Rating scale for vulnerability to sedimentation

Rating	Description
0	Not Applicable or not assessed
1	Very susceptible to sedimentation or sedimentation impacts (i.e. blockages) already observed
2	Possibly susceptible to sedimentation
3	No sedimentation observed, impacts on equipment due to sedimentation unlikely

Table 6.3 Overall condition assessment rating

Rating	Description
Needs Repair	Equipment is generally damaged and in need of repair, signs of corrosion or aging is evident
Reasonable	Equipment is generally in fair condition. Equipment in need of repair or some equipment missing which may not greatly affect functionality i.e. missing staff gauges.
Good – Some issues noted	Equipment is generally in good condition. Some components may need cleaning or equipment may be older but in right working order. Some issues noted during site inspection.
Good – No Major issues noted	Equipment is generally in good condition – no major issues noted during site inspection.

6.2.2 Factors affecting the condition

There were several factors identified as affecting the condition of a gauging station and equipment. These were generally dependant on:

- Locality – Some of the gauges were in remote areas, and generally in harsh environments (particularly due to the nature of the equipment). A number of rain gauges were also identified as being obstructed by foliage which could have impacts on the reliability of the gauges and did not meet a suitable standard for the placement of gauges.
- Maintenance – There is a broad variation in the maintenance regime between organisations. The majority of gauges inspected had a 6-monthly or 12-monthly maintenance schedule, however based on responses to the questionnaire, some organisations had only a minimal maintenance regime and were heavily reliant on annual BoM maintenance visits.
- Corrosive or destructive environment – Some of the most common issues with gauges related to the presence of algae or sedimentation blockages in water level gauge pipework. The potential for fire or damage due to extreme weather events and floods was also identified as a risk to some of the gauges.
- Age of equipment – Different pieces of equipment and technology have different operational shelf lives. In some cases the installation date of the equipment was recorded which provided insight into the likely remaining operational time of the equipment.

6.2.3 Condition Assessment

The information provided by questionnaire respondents suggested that approximately half considered the reliability of rain and stream water level gauges in their area as very good. The others did not note any major issues regarding the reduced reliability.

Based on the conditional assessment (described above) of the 81 gauges inspected as part of this review the findings were as follows:

- 41 gauges (50%) were deemed to be in good condition, with no major issues noted and no need for immediate repair.

- 18 gauges (22%) were considered to be in a good condition with some issues noted. In the majority of these cases, this generally related to the absence of a staff gauge which can be easily installed. In some instances equipment was visibly aged or some corrosion was noted, or some potential blockages from algae or sedimentation. At the time of the inspection however, the gauges were in working order. Ongoing maintenance and possibly some minor repair would be of benefit.
- 11 gauges (14%) were of a reasonable condition. Generally, it was noted that one or more components were of a fair condition with signs of corrosion and blockages noted. The condition appeared likely to affect the reliability of the gauge, and repair should be considered in the near future.
- 11 gauges (14%) were identified as in need of repair. Some of the gauges showed corrosion of equipment, visible signs of aging and/or damage. In one case fire damaged equipment was noted. The integrity of these gauges could not be relied upon, and some form of immediate repair was required.

A full copy of the condition assessment table is included in Appendix P.

Assuming the findings are representative of the entire FWGN, the results suggest that up to a third of the gauges in the FWGN may be in need of some repair in the near future. This is difficult to corroborate, as there may have been technical issues or calibration problems at gauges that could not be assessed visually. Additionally, the small sample size (~4.4%) (BoM gauges were not included) may not be representative of the condition of the remaining gauges.

6.3 COMMUNICATION PROTOCOLS

The scope of this review did not include an assessment of the communication network. Repeater stations for ALERT stations were not visited and it was difficult to assess the reliability of communications without historical data, and calibration data being assessed at the gauge sites.

Information was also collected on the communication protocol at each gauge station. This information appeared to be poorly understood and was not readily communicated. Further, there was limited information available about the location and design of repeater networks for the ALERT system. A starting point would be a layered map of the existing communication systems.

The assessment and collation of data about the communications network should be included in the Asset Management Database and as part of the FWGN asset assessment in the future.

6.4 STANDARDS OF INSTRUMENTATION, MONITORING AND DATA COLLECTION

Stream water level and rain gauges and other equipment associated with the FWGN have to be fit for purpose and provide BoM and other users with sufficient and accurate data in a timely manner.

The technical guidance currently employed varies across the entire FWGN and while BoM does provide some guidance (and has developed standards for its own needs) there are no national or state technical standards for hydrometric gauges for flood warning purposes (PWC, 2012). This limits the consistency of data provided by gauges across the state.

A number of technical standards have been compiled into a register (Appendix H).

As stakeholders install monitoring equipment for a variety of purposes it is difficult to encourage standards related to flood warning. Nevertheless, stations not primarily designed for flood warning can provide useful and important data.

7 Network analysis

Findings

- 43% of council respondents have plans or advice to upgrade or increase the number gauges in their local government area.
- The leading cause of reliability problems reported from the respondents was communication dropouts and aged equipment.
- There are 215 settlements in Queensland that, based on the review's GIS modelling, are likely to be affected by riverine flooding. BoM provides a riverine flood warning service for 123 of these settlements. (The GIS modelling requires on-ground verification.)
- 186 settlements have at least one stream water level gauge upstream providing at least 6 hours warning, however these gauges do not necessarily monitor all contributing tributaries.
- 190 settlements estimated to have a riverine flood risk do not have any stream water level gauges with at least 6 hours warning upstream.
- The river basins where modelling indicates that improvements are most required, and are likely to deliver benefits to multiple high risk settlements, are the Condamine-Balonne and Fitzroy basins.
- The distribution of gauges across the state is not necessarily correlated to areas of greatest need as identified by the GIS modelling. This is often a consequence of gauges being at sites for other purposes (e.g. water resources planning), installation constraints (e.g. availability of communications, availability of access), funding issues or political factors.
- The gauges installed specifically for flood warning purposes need to be fit for that purpose. More attention should be directed to those locations vulnerable to flooding.
- Eight settlements depend heavily on one or two critical stream water level gauges for flood warning purposes. These gauges are not identified or prioritised and so they receive the same operations and maintenance regime as other less critical gauges. In many circumstances there is no or limited gauge or communications redundancy.
- The findings from the GIS model need to be verified in consultation with local governments, BoM and relevant state agencies.

7.1 INTRODUCTION

Analysis of the existing FWGN is based upon four fundamental tenets:

- the existing gauge network configuration provides a gross warning time for each settlement included in the flood warning system
- the warning time must be sufficient for evacuation
- large floods may require some whole communities to evacuate
- the time needed for evacuation varies with the size and nature of the settlement.

This section of the study analyses the existing FWGN with the aim of identifying improvements to the spatial coverage and the reliability of gauges in the network. The analysis was used a risk-based methodology to identify and prioritise those improvements with the greatest benefit.

The risk-based assessment methodology was designed to meet the following requirements:

- be robust and produce logical outcomes
- follow a transparent process
- minimise the need for subjective input
- be applicable state-wide (i.e. use datasets that cover the whole state)
- be repeatable, so that it can be updated in future.

Section 7.2 details the risk-based assessment method that was applied and Section 7.3 describes the findings.

7.2 METHOD

The FWGN analysis was completed in the following series of steps:

- Step 1: Settlement identification
- Step 2: Catchment analysis
- Step 3: Flood exposure
- Step 4: Flood warning requirements
- Step 5: Analysis of flood warning components (rain gauges, stream water level gauges)
- Step 6: Scoring and weighting
- Step 7: Settlement prioritisation.

These steps are described below. Appendix E provides a detailed flow chart of the analysis process.

The model results, being based on simplifying assumptions, need to be verified by consultation with local governments, BoM and relevant state agencies.

7.2.1 Step 1: Settlement identification

Step 1 was to identify settlements in Queensland susceptible to flooding so that the adequacy of the flood warning gauging above those settlements could be assessed.

Flooding was defined as any inundation leading to damage within a town. It was not practical to link the flood definition to severity or frequency since there was insufficient data to do this in a standardised manner across the state.

Previous studies and assessments have identified Queensland towns at risk of flooding, and this step built on those studies. Settlement identification involved:

- compiling a list of Queensland towns from previous BoM and the former Department of Community Safety (DCS) flood risk ratings
- consulting with councils to review the list and identify any additional towns that have a flood risk.

Settlements that are susceptible to isolation by flooding (e.g. road network cut for more than 48 hours) were also included in the analysis. These towns were identified based on existing databases and council input.

Size of population was used as a proxy for critical infrastructure such as hospitals and airports. These facilities are usually located in or near to settlements and were considered as part of the settlement in which they are located.

Settlements that have flood mitigation measures in place (e.g. levees) were included in the analysis. Flood mitigation measures are usually only effective up to a certain design event, and flood warning is therefore still important.

7.2.2 Step 2: Catchment analysis

State-wide spatial datasets were compiled for use in the assessment as follows:

- Town characteristics, including existing population, population at risk, land use and demographics. The assessment was based on the latest census (2011) population.
- Hydrological setting, including catchment area, stream network and dams. The assessment made use of the Australian Hydrological Geospatial Fabric (Geofabric), which registers the spatial relationships between important hydrological features such as catchments, rivers and water bodies. An important consideration for flood warning is the travel time between different parts of the river network.
- Flood warning gauge network, including location of gauges, type of gauges, communication system adopted at each gauge, gauge owner, gauge installation date and other pertinent gauge information available from the asset database developed for the project (refer Section 6.1).

The catchment and s tream characteristics above each settlement were characterised using these datasets as the foundation of the analysis. This involved:

- Mapping settlement extent - The boundaries of each settlement were mapped in GIS by reviewing land use information across the state.
- Assessing settlement disruption caused by flooding - the Queensland Flood Assessment Overlay (QFAO) was compared to the settlement extents across the state. The proportion of each settlement covered by the QFAO was used as a m easure of the disruption to a s ettlement by flooding. The type and area of land use within the flood zone was also recorded to estimate the population directly affected by flooding.
- Mapping catchments above each settlement - the catchment above each settlement was mapped by first assigning a nearby watercourse that leads to flooding (some settlements flood from multiple watercourses). The catchment extent was these determined using SRTM topography data. Statistics on the gradient variation within the catchment were also generated. Mean annual rainfall was also assigned to each catchment based on BoM gridded data.
- Stream network mapping - connections between streams were generated based on existing stream mapping and the Geofabric.
- Travel time calculation - travel times are a very important aspect of the assessment, since it is the travel time that dictates the warning time. The travel time calculation involved several tasks as follows:
  - analysing recorded hydrographs from a number of stream water level gauge locations (DNRM gauges) across the state. A relationship was observed between stream gradient and speed, from which a regression relationship was developed
  - tracing the watercourse from the settlement to an upstream water level gauge - refer Figure 7.1(a)
  - determining the gradient of each portion of the watercourse - refer Figure 7.1(b)
  - calculating the travel time for each portion of the watercourse, using the gradient and the regression relationship developed in the earlier step - refer Figure 7.1(c).
  - Determining the straight line distance between the gauge and the settlement.
  - Repeating this process for all gauge and settlement combinations across the state
  - Compiling the straight line distance and travel time data for each sub-basin and developing a relationship between the two. An example of this relationship is shown in Figure 7.2. Full details of the relationships derived for each sub-basin are included in Appendix M. This relationship allows indicative travel time radii to be drawn around each settlement, taking into account typical stream gradient and sinuosity characteristics of the sub-basin within which the settlement lies.

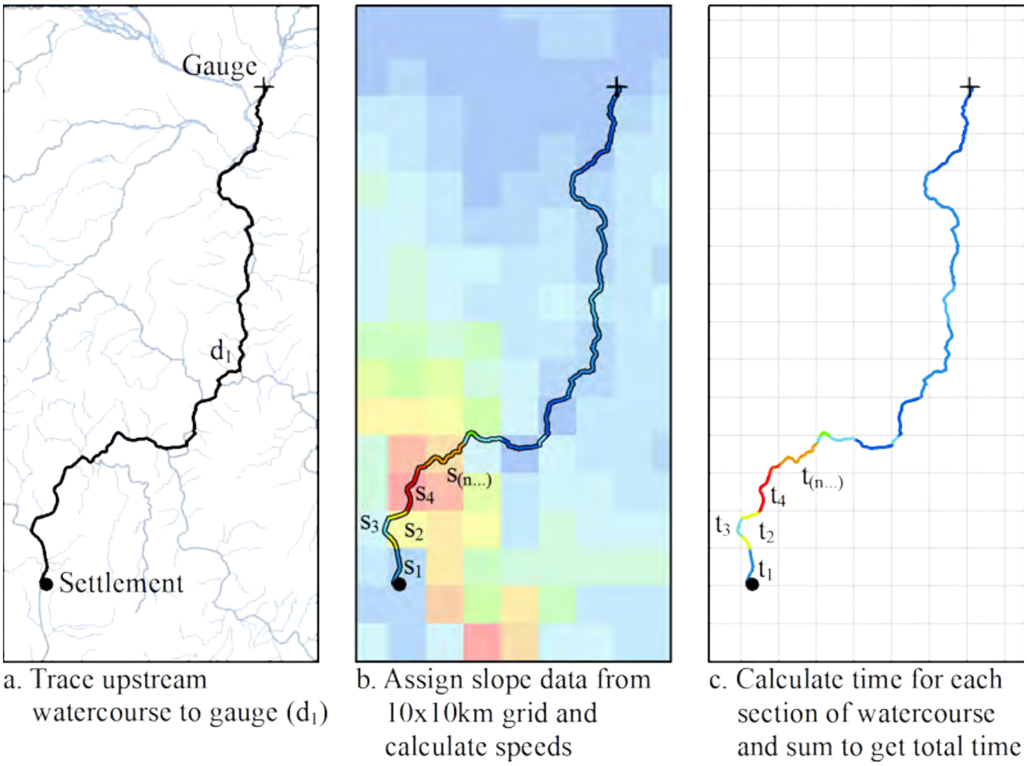


Figure 7.1
CALCULATION OF TRAVEL TIME FROM GAUGE TO SETTLEMENT

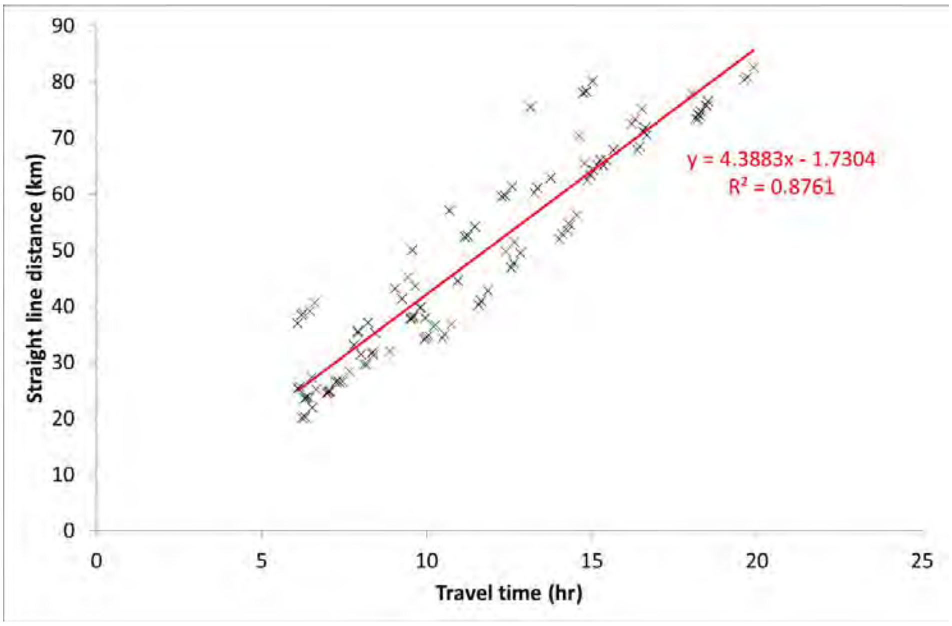


Figure 7.2
TRAVEL TIME RADIUS DETERMINATION - EXAMPLE FROM ALBERT RIVER SUB-BASIN

- Extracting statistics on the FWGN within travel time bands - using the relationship developed in the previous step, travel time bands were nominated for each catchment in the following increments: <6hr, 6-9hr; 9-12hr, 12-24hr, 24-48hr, >48hr. Statistics on the gauge network within each travel time band were extracted for analysis.

7.2.3 Step 3: Flood exposure

Two flood types are recognised in this study as follows:

- Flash flood - flood events from intense local rainfall resulting in less than 6 hours between the rain falling and the flood occurring.
- Riverine flood - flood events from rainfall in a catchment that has at least 6 hours lag between the rain falling in the catchment and the flood occurring.

The type of flood risk affecting some of the settlements considered in this study has been determined previously by BoM and these classifications were adopted for this study.

Where BoM determinations had not been previously made, GIS analysis was undertaken to determine the flood risk type. This involved:

- Assessment of catchment size - the portion of the catchment from which runoff would reach the settlement within 6 hours was mapped. Where this area was similar to the whole catchment extent it was considered a probable flash flood risk. Where the time period greatly exceeded 12 hours it was considered a probable riverine risk. Between 6-12 hours both riverine and flash flooding could occur.
- Overlay of mainstream flood extent - the Queensland Flood Assessment Overlay (QFAO) which covers the state (except the SE corner) was compared against the settlement extents. Where the QFAO encroached into the settlement extent this was considered a probable riverine flood risk.

Where both the assessment of catchment size and the overlay of mainstream flood extent indicated a probable riverine flood risk, the settlement was deemed to be a riverine flood risk. If one or none of these criteria were met, then the settlement was not considered a riverine flood risk.

7.2.4 Step 4: Flood warning requirements

The flood warning required for effective action typically increases with population as detailed in Appendix R. The analysis nominates a desirable flood warning time for each settlement across the state based on population as summarised in Table 7.1.

Table 7.1 Desirable warning time based on population

Population	Desirable warning time
<2,000	9-12 hours
2,000-4,000	12-24 hours
>4,000	24-48 hours

The warning time that is possible (with an effective FWGN) is a function of the catchment characteristics. For example, the best warning available for a short catchment with fast response may be 9 hours, whereas the desirable warning time for effective action based on the population may be 24 hours. The analysis identifies these situations and seeks to provide a gauging that achieves the desirable flood warning time, or where this is not possible, the maximum feasible warning time for that catchment (reported in Appendix L).

The process is explained diagrammatically in Figure 7.3.

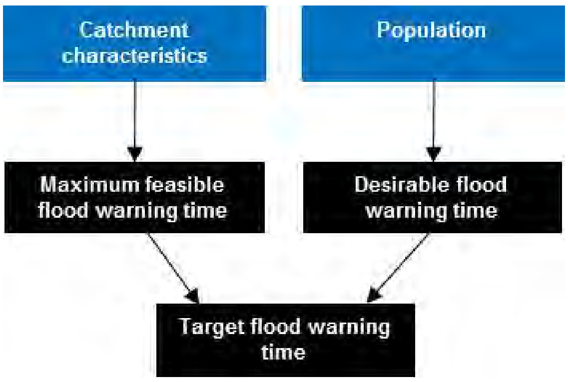


Figure 7.3
NOMINATING THE TARGET FLOOD WARNING TIME FOR SETTLEMENTS

7.2.5 Analysis of FWGN components

The FWGN consists of two types of gauges: rain gauges and stream water level gauges. The relative importance of rain gauges compared to stream water level gauges varies depending on the catchment size and characteristics. More emphasis is placed on the rain gauge components of the FWGN for catchments with a fast response (e.g. <9hr), whereas more emphasis is placed on stream water level gauge components of the FWGN for catchments with a slow response (e.g. >48hr).

The rain gauge and stream water level gauge components of the FWGN were analysed separately, and then combined to produce an assessment of the FWGN above each settlement (refer Figure 7.4).

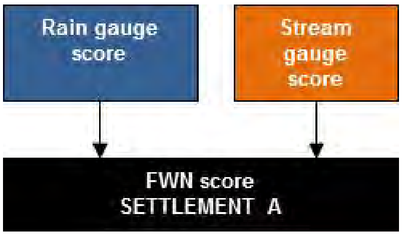


Figure 7.4
ANALYSIS OF FWGN COMPONENTS

Rain gauge analysis

The density of rain gauges in a catchment is a key indicator of its suitability to detect rainfall for flood warning purposes. WMO (1974) provides guidance on minimum rain gauge densities for a range of hydrographic units. These are presented in Table 7.2 (refer column 2).

Table 7.2 Minimum densities of stations (adapted from WMO, 1974)

Hydrographic unit	Minimum Density (km^2 per station)	Radius (km)
Coastal	900	53
Mountains	250	28
Interior plains	575	43
Hilly/undulating	575	43

While density is a useful measure of rain gauge suitability in a catchment, there may be clustering of gauges in portions of the catchment, particularly where gauges are not primarily for flood warning. This could lead to the non-detection of areas of a catchment with fewer gauges than desirable for flood warning. A spatial analysis technique was developed to detect these situations.

The method reports the proximity of gauges to each other by calculating the time-based radius from each gauge that results in 25%, 50%, 75%, and 100% coverage of the catchment. The radius leading to 100% coverage of the catchment is a measure of the lowest density in the catchment. This can be compared to the minimum densities suggested by WMO (1974). Table 7.2 (column 3) reports the minimum densities in terms of coverage radius so that direct comparison to the analysis method can be made. Figure 7.5 demonstrates the technique adopted to measure catchment coverage.

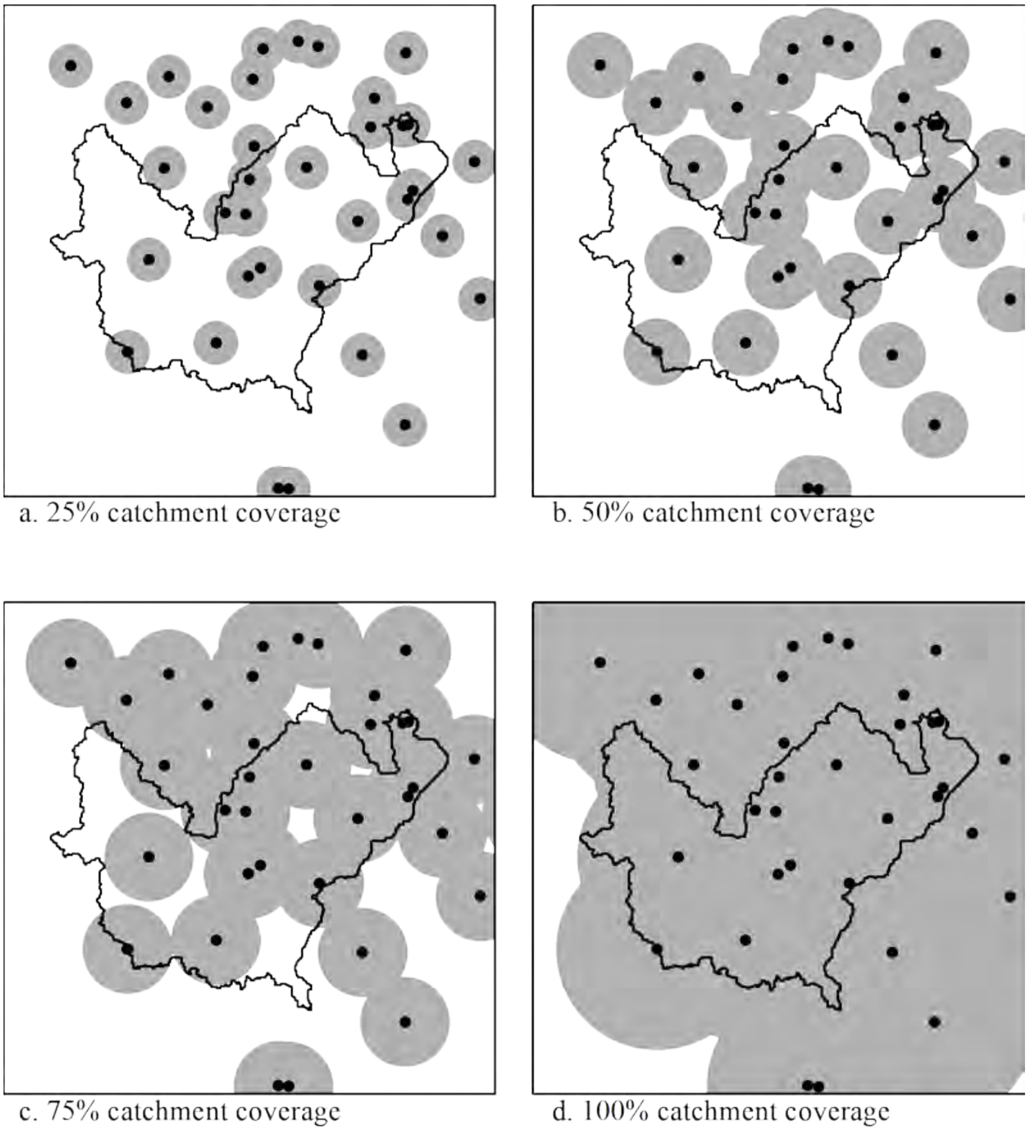


Figure 7.5
CATCHMENT COVERAGE ANALYSIS FOR RAIN GAUGES

Reliability and redundancy of the components that form the network is an important consideration in defining a resilient network. Aspects considered by the analysis include diversity of gauge types (a flood warning requires timely data, but also redundant gauges). A diverse network that has a mixture of manual and automatic gauges is desirable.

Communication systems are the highest cause of problems in the FWGN. Radio is anecdotally the most reliable, although if only one communication system is relied upon this presents a potential vulnerability. It is useful to maintain a mix of communication types, but with a weighting towards radio and 3G technologies. Satellite is unreliable when there is heavy cloud but may be the only viable method in remote locations (without very expensive radio repeater or 3G installations).

Stream water level gauge analysis

Stream water level gauges are an important component of riverine flood warning, providing confirmation that a flood is approaching. Stream water level gauges should be located as far up a catchment as possible to provide early indication of flooding, but not in the catchment headwaters. Rain gauges are more useful in the headwaters.

The analysis of stream water level gauges was:

- The proportion of the catchment covered by stream water level gauges providing <6 hour warning, 6-9 hour warning, 9-12 hour warning, 12-24 hour warning, 24-48 hour warning and >48 hour warning was calculated.
- The number of gauges and the proportion of the catchment area above gauges providing at least the target warning time were calculated. The nominated target was to have at least 80% of the catchment gauged with better than the target warning time. The higher the percentage of the catchment above the gauge the greater reliance that can be placed on the known magnitude of the impending flood.

Figure 7.6 explains the process that was used to analyse stream water level gauge coverage of the catchment.

While this approach identifies gaps in the FWGN, in large catchments the ungauged ar ea may be substantial and present an unacceptable risk if there were heavy rainfall in that part of the catchment. An additional criterion was therefore applied to screen the residual ungauged portion of the catchment.

The same reliability criteria applied to rain gauge analysis were used for stream water level gauges. This included reviewing the diversity of the network and the communication systems used.

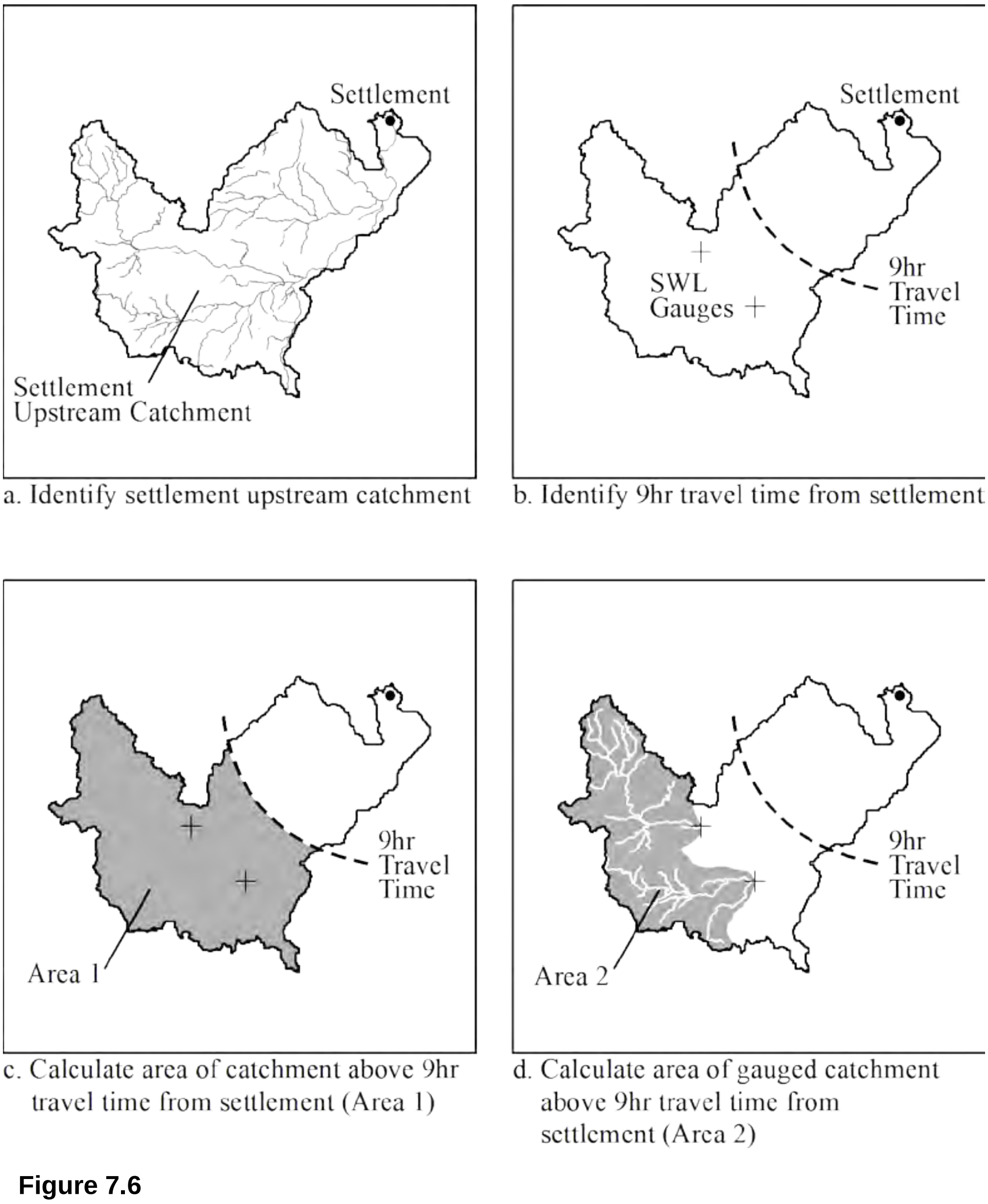


Figure 7.6
STREAM WATER LEVEL GAUGE CATCHMENT COVERAGE ANALYSIS

7.2.6 Step 6: Scoring and weighting

A risk-based approach scored individual components of the FWGN using objective criteria (refer Appendix E). These components were weighted for an overall score for each settlement. The weightings were based on professional judgment. A sensitivity analysis tested the effects of the weights and is detailed in Section 7.4.

As described in Section 7.2.5, the relative importance of stream water level gauges compared to rain gauges depends on the catchment size and characteristics, both of which can be related to the maximum feasible warning time. Table 7.3 details the split that was adopted between stream water level gauges and rain gauges.

Table 7.3 Stream water level gauge and rain gauge weights

Maximum feasible warning time (based on catchment characteristics)	Stream water level gauge weight	Rain gauge weight
<6 hr	0%	100%
6-9 hr	0%	100%
9-12 hr	20%	80%
12-24 hr	20%	80%
24-48 hr	50%	50%
>48 hr	80%	20%

The weightings that were applied to the other scores used in the analysis are summarised in Figure 7.7. Appendix E provides full details.

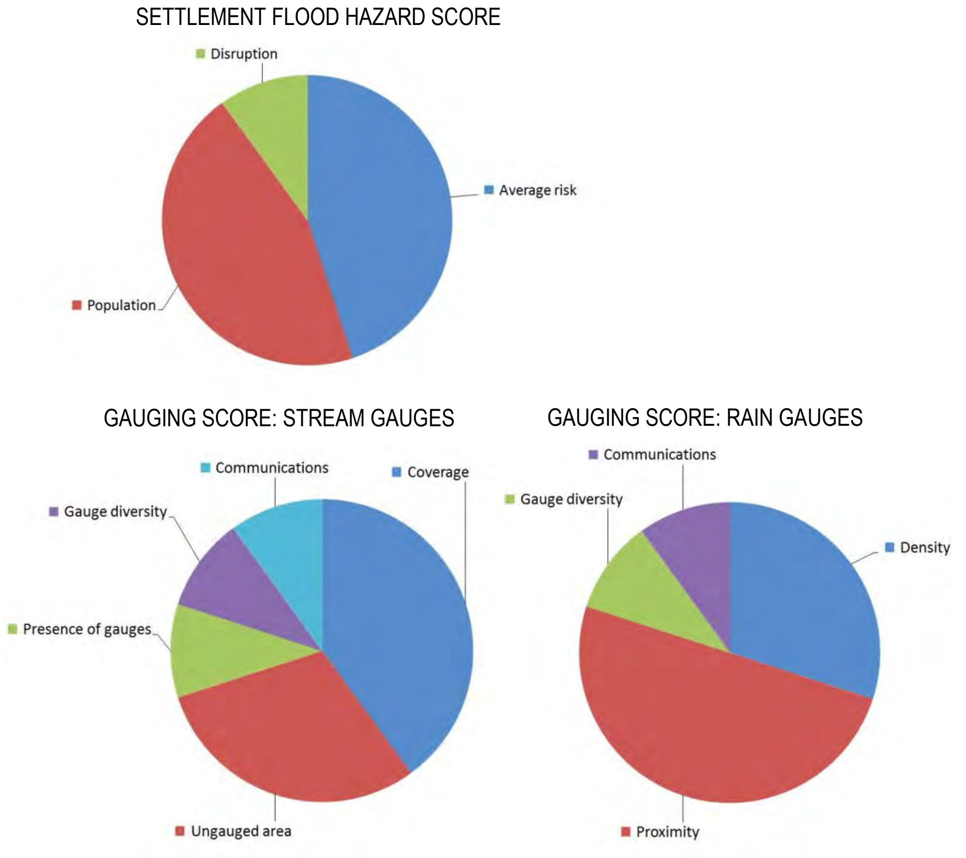


Figure 7.7
ADOPTED WEIGHTINGS

7.2.7 Step 7: Settlement prioritisation

Settlement priority was determined based on consideration of the flood hazard at the settlement and the suitability of the gauging above the settlement. This is explained diagrammatically in Figure 7.8.

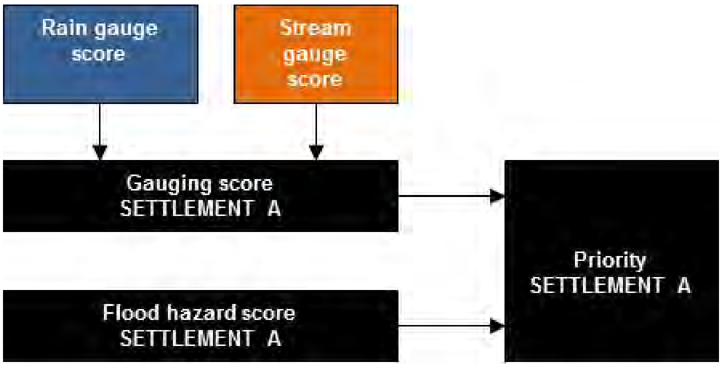


Figure 7.8
DETERMINING SETTLEMENT PRIORITY

A priority matrix (Figure 7.9) was used to determine the settlement priority on the basis of the two variables. The priority matrix is skewed towards FWGN improvement opportunities which prevents locations with a very high flood hazard but excellent gauging (e.g. Brisbane) from receiving priority above a location with lesser flood hazard but poor gauge provision. The figure does not represent a hazard rating but a priority rating.

Settlement flood hazard	Upstream FWN rating: Excellent (5)	Good (4)	Average (3)	Poor (2)	Very Poor (1)
Very High (5)	VL	M	H	VH	VH
High (4)	VL	L	H	VH	VH
Moderate (3)	VL	L	M	H	VH
Low (2)	VL	VL	M	H	VH
Very Low (1)	VL	VL	L	M	H

Figure 7.9
PRIORITY MATRIX

7.3 ANALYSIS OUTCOMES

7.3.1 FWGN assessment

Assessment criteria have been developed to flag quickly aspects of the FWGN above a settlement that are fit for purpose and those where improvements are required. A "traffic light" system has been developed as shown in Table 7.4.

Table 7.4 Traffic light system for interpretation of results

Assessment	Description
🟢	Suitable / fit for purpose
🟡	Some improvement required
🔴	Major improvement required

An example of the results generated is provided in Table 7.5. A full breakdown for all settlements included in the analysis is provided in Appendix F.

Table 7.5 Example of FWGN assessment results

Settlement		FWN assessment											Rating		
Name	Target flood warning time	Rain gauges					Stream gauges						FWN score (1=poor, 5=excellent)	Flood hazard score (1=low, 5=high)	Priority
			Spatial distributio		Reliability			Spatial distribution			Reliability				
		Importance	Catchment density	Proximity	Gauge diversity	Communications	Importance	Coverage	Ungauged area	Presence of gauges	Gauge diversity	Communications			
ABERCORN	9	80%	🟢	🔴	🟢	🟡	20%	🟡	🟢	🟢	🟢	🟡	3	4	High
ABERGOWRIE	9	80%	🟢	🟡	🟢	🟢	20%	🟢	🟢	🟢	🟡	🟢	4	2	Very low
ADAVALE	6	100%	🟢	🟢	🔴	🔴	0%	🔴	🟢	🟢	🔴	🔴	4	4	Low
ALPHA	9	80%	🟢	🔴	🔴	🔴	20%	🔴	🟡	🟢	🟢	🔴	2	4	Very high
ALTON	9	80%	🟡	🔴	🔴	🔴	20%	🟢	🟡	🟢	🔴	🔴	2	2	High
AMBERLEY	9	80%	🟢	🟢	🟡	🟢	20%	🟢	🟢	🟢	🟡	🟢	5	3	Very low

Some key observations from the analysis of the 215 riverine flood risk settlements are:

- The density of rain gauges across catchments was acceptable for flood warning purposes upstream of 73% of settlements. There were many instances of multiple purpose rain gauges clustered together while large areas were without rain gauges. Only 13% of settlements met the proximity criteria (which identifies gaps in spatial distribution of rain gauges). Half of those that did not meet the criteria scored very poorly (red).
- More than half of the settlements scored well (green) on rain gauge diversity, with less than 15% scoring very poorly (red).
- The variation in rain gauge communication scores was spread evenly across all categories.
- 95 settlements scored well (green) on stream water level gauge coverage with 84 settlements scoring poorly (red).
- The great majority of settlements had at least one stream water level gauge upstream of the settlement, although 118 settlements did not have a manual gauge board within 2 km of the settlement.
- Approximately 30% of settlements scored well (green) for stream water level gauge diversity. The majority of the other settlements have some improvement required (orange).
- Consistent themes were a reliance on manual gauges at many locations and vulnerability due to the dominance of one technology in particular regions.

A summary of the distribution of results is presented in Table 7.6.

Table 7.6 Stream water level gauge and rain gauge results

	Green	Orange	Red
Rain gauges			
Catchment density	158	40	17
Proximity	27	94	94
Gauge diversity	121	63	31
Communications	79	71	65
Stream water level gauges			
Coverage	95	36	84
Ungauged area	142	62	11
Presence of gauges	203	0	12
Gauge diversity	70	114	31
Communications	101	52	62

7.3.2 Settlement prioritisation

As described in Section 7.2.7, the gauging score and the settlement flood hazard score were used to allocate priorities for improvements to the FWGN. The priority for each settlement is detailed in Appendix F. The model prioritisation reveals:

- 21 very high priority settlements across 14 drainage basins
- 33 high priority settlements across 16 drainage basins
- 31 medium priority settlements across 16 drainage basins
- 70 low priority settlements across 27 drainage basins
- 60 very low priority settlements across 22 drainage basins.

Table 7.7 provides a breakdown of settlement priorities across each drainage basin. There are additional benefits that may be realised where there are multiple towns in the same basin (i.e. one gauge benefits multiple settlements). Figure 7.10 shows the settlement priorities of moderate and above across the state.

Table 7.7 Prioritisation of Flood Warning Gauge improvements

Basin	Number of settlements in basin				
	Very High Priority	High Priority	Medium Priority	Low Priority	Very Low Priority
Baffle				1	
Balonne-Condamine	3	1	2	9	4
Barron				4	8
Border Rivers	1			4	3
Boyne			3		
Brisbane				11	9
Bulloo	1		1	1	
Burdekin	1	1	2	2	
Burnett		3	3	4	7
Burrum				1	2
Cooper Creek	3	5	2	1	1
Daintree	1				

Basin	Number of settlements in basin				
	Very High Priority	High Priority	Medium Priority	Low Priority	Very Low Priority
Diamantina	1	2			
Don					1
Fitzroy	2	5	6	6	1
Flinders	1	3		1	
Georgina	2	1		1	
Gilbert		2		1	
Haughton				2	1
Herbert				5	2
Johnstone				2	2
Kolan				1	2
Leichhardt			1		
Logan-Albert				1	7
Maroochy					1
Mary		1	4	1	3
Mitchell		1			1
Moonie	1	3	1		
Mulgrave-Russell					1
Nicholson	2		1		
Noosa			1	2	
Norman				1	1
Normanby			1		
Paroo	1	1	1		
Pioneer			1	2	
Plane				1	
Proserpine				1	
Ross					1
South Coast					1
Stewart		1			
Tully				3	1
Warrego	1	2	1	1	
Watson		1			
Grand Total	21	33	31	70	60

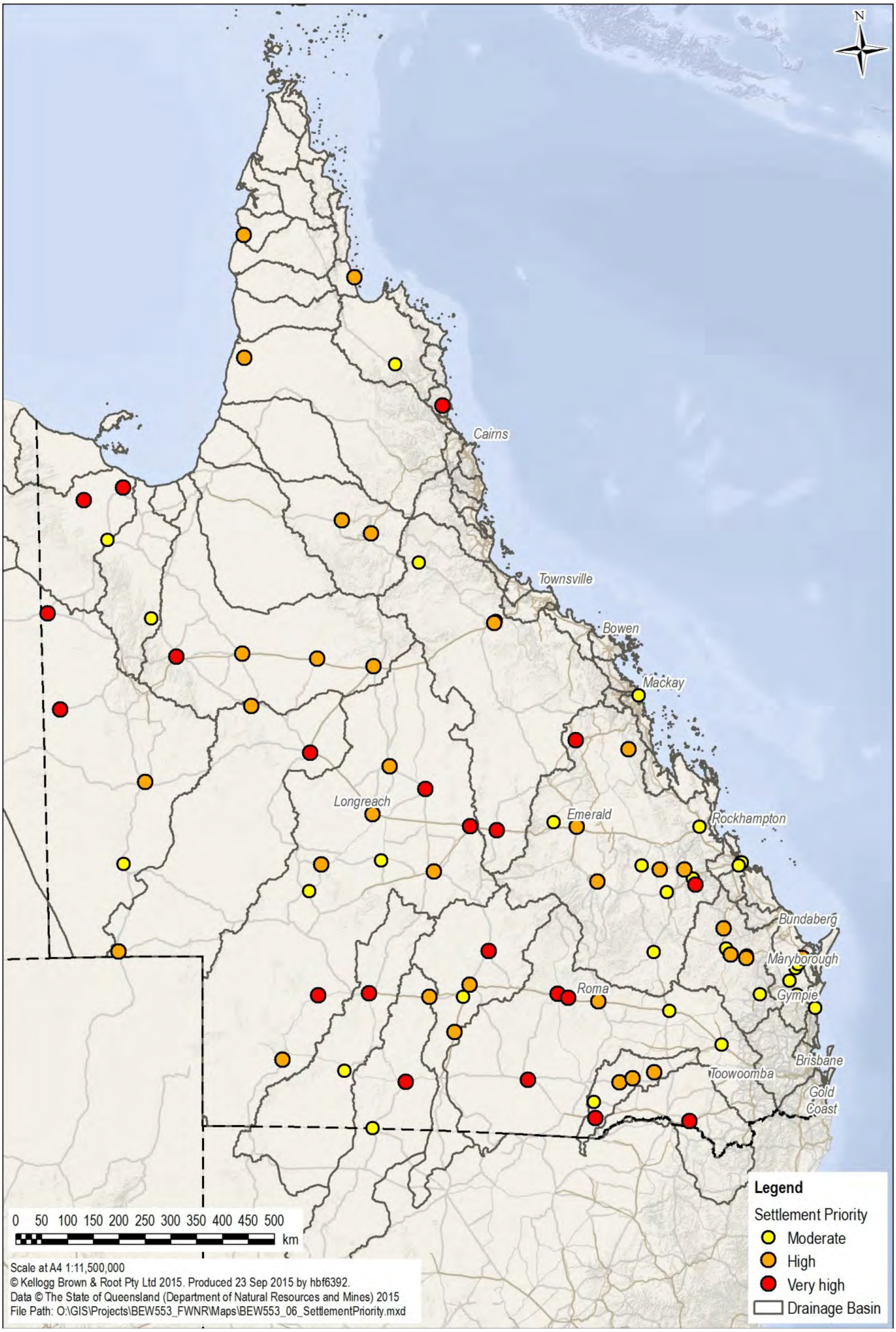


Figure 7.10
SETTLEMENT PRIORITISATION (MODERATE AND ABOVE)

7.4 Sensitivity analyses

Sensitivity analyses were performed on the factor weightings to test the effect of these on the overall assessment and prioritisation. Weights were adjusted in three sensitivity scenarios as follows:

- Sensitivity 1 focused on **flood hazard** and involved providing more emphasis on population than risk rating.
- Sensitivity 2 focused on **stream water level gauges** and involved providing more emphasis on coverage, diversity and communications and less on ungauged area.
- Sensitivity 3 focused on **rain gauges** and involved providing more even emphasis to catchment density and proximity, and additional weighting on diversity and communications.

Table 7.8 details the weights that were applied for the sensitivity scenarios.

Table 7.8 Sensitivity analysis - weighting adjustments

	Score	Weights (W)			
		Base Case	Sensitivity 1	Sensitivity 2	Sensitivity 3
Flood hazard	Average risk	45	35	As per Base Case	As per Base Case
	Population	45	60		
	Disruption	10	5		
Stream water level gauges	Coverage	40	As per Base Case	50	As per Base Case
	Ungauged area	30		10	
	Presence of gauges	10		10	
	Gauge diversity	10		15	
	Communications	10		15	
Rain gauges	Catchment density	30	As per Base Case	As per Base Case	35
	Proximity	50			35
	Gauge diversity	10			15
	Communications	10			15

Appendix G provides a detailed list of the priority for each settlement with the different weightings applied. The results are summarised in Table 7.9.

Table 7.9 Sensitivity analysis - results

Count of priority settlements	Base Case	Sensitivity 1	Sensitivity 2	Sensitivity 3
Very High	21	12	21	17
High	33	34	31	27
Medium	32	38	34	26
Low	69	64	71	64
Very low	60	67	58	81

The sensitivity analysis showed that the weightings do have an effect on the priorities, although the effect is relatively small. The number of settlements with a priority of medium or higher was between 84 and 86 for the Base Case, Sensitivity 1 and Sensitivity 2. The number was lower for Sensitivity 3 (70), although this is to be expected given the vastly different performance results for catchment density and proximity.

The sensitivity analysis suggests that the prioritisation would be largely similar even if moderately different weightings were adopted.

8 Improvements

8.1 IDENTIFICATION OF IMPROVEMENTS

Recommendations for improvements to the FWGN are based on identified deficiencies. The deficiencies are those components of the FWGN that received either an orange or red rating (Appendix F contains a summary of the analysis of the FWGN components for each settlement).

Improvements were identified based on the procedure detailed in Table 8.1.

Table 8.1 Identification of improvements - orange and red only

Type	Issue	Metric	Method of identifying improvements
Stream water level gauge (riverine flood warning)	Spatial distribution	Coverage	Visual inspection (plus previous QRA/BoM recommendations)
		Ungauged area	Visual inspection
	Performance	Gauge diversity	Calculate number of replacements to achieve benchmark
		Communications	Calculate number of upgrades to achieve benchmark
Catchment rain gauge (riverine flood warning)	Spatial distribution	Density	Calculate number of new gauges to achieve benchmark
		Gaps	Visual inspection of best location for additional gauges
	Performance	Gauge diversity	Calculate number of replacements to achieve benchmark
		Communications	Calculate number of upgrades to achieve benchmark

8.2 SUMMARY OF IMPROVEMENTS IDENTIFIED

The following improvements are proposed, subject to consultation to verify model results:

- Capital works improvements
  - Priority 1 - Installation of 43 rain gauges, 12 rain/stream water level gauges and 3 stream water level only gauges in very high priority settlements
  - Priority 2 - Installation of 74 rain gauges, 26 rain/stream water level gauges and 1 stream water level only gauge in high priority settlements
  - Priority 3 - Installation of 19 rain gauges and 80 rain/stream water level gauges in medium priority settlements.
- Potential replacements/upgrades
  - Priority 4 - Approximately 260 new manual stream water level gauges to provide a gauge in each riverine flood-prone settlement and also at existing ALERT or TM gauges without gauge boards
  - Priority 5 - Resurvey of approximately 290 existing manual stream water level gauges
  - Priority 6 - Renewal of approximately 180 existing manual stream water level gauges
  - Priority 7 - Upgrade approximately 100 manual rain gauges to ALERT or TM
  - Priority 8 - Upgrade approximately 17 manual stream water level gauges to ALERT or TM

– Priority 9 - Upgrade landline/satellite communications at approximately 400 s tations to 3G or radio

– Priority 10 - Renewal of approximately 160 existing manual rain gauges.

Detailed maps have been prepared of the proposed capital works improvements. These are presented for each settlement with medium or above priority in Appendix D and also on a basin scale in Appendix J. An example of the settlement maps showing the existing and proposed gauges and analysis procedure is provided in Figure 8.1.

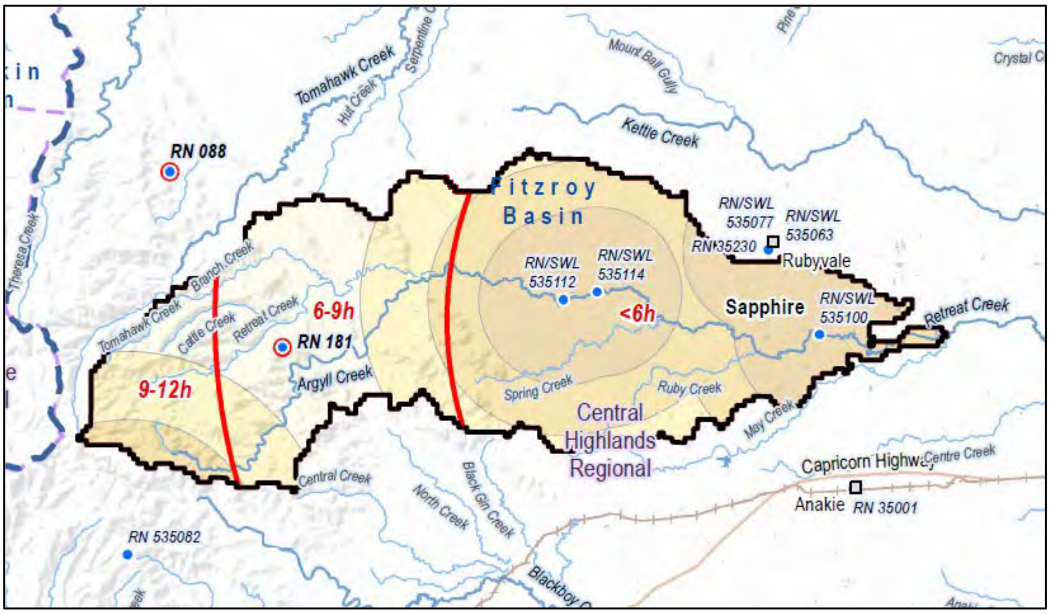


Figure 8.1
EXAMPLE OF SETTLEMENT CATCHMENT MAP

These maps identify the potential location of Priority 1, Priority 2 and Priority 3 gauges. The actual locations need to be validated with local knowledge and professional judgement.

8.3 BUDGET ESTIMATES FOR IMPROVEMENTS

8.3.1 Unit rates

Budget estimates have been dev eloped for the proposed capital works improvements and po tential replacements/upgrades (Table 8.2). These are indicative, based on rule of thumb allowances provided by BoM, DNRM and a private contractor specialising in gauge installation based on recent experience.

It is noted that installations costs will vary due to local factors, however the overall price is expected to be useful as a rough indication of the costs involved in improving the FWGN. The budget estimate should be refined by more detailed assessment at a basin or sub-basin scale in a subsequent program of works.

Table 8.2 Unit rates for budget estimates

Station type	Capital costs		Operating costs per annum	
	Range	Adopted for estimate	Range	Adopted for estimate
Manual rain	Up to $3,000	$3,000	Approx $600	$600
Manual stream water level	Up to $10,000	$5,000	Approx $1,000	$1,000
Telemetry rain	$5,000-$20,000	$10,000	Approx $1,000-$2,000	$1,000
Telemetry stream water level/rain	$50,000-$100,000	$60,000	Approx $5,000-$10,000	$6,000
ALERT rain	$10,000-$20,000	$15,000	Approx $1,000-$2,000	$1,500
ALERT stream water level/rain	$50,000-$100,000	$60,000	Approx $5,000-$10,000	$6,000

8.3.2 Budget estimates

Proposed capital works improvements

Table 8.3 provides a summary of the proposed capital works improvements and an indicative budget. The capital works improvements total approximately $5m.

Table 8.3 Summary of proposed capital works improvements

Priority	Improvement			Budget Estimate
	Rain Gauge (RN)	Rain and stream water level gauge (RN/SWL)	Stream water level gauge (SWL)	
1 (Very high)	43	12	3	$1,545,000
2 (High)	74	26	1	$2,730,000
3 (Medium)	19	8	0	$765,000
TOTAL	134	46	4	$5,040,000

Potential replacements/upgrades

Table 8.4 provides a summary of the potential replacements/upgrades and an indicative budget. These suggested works total approximately $7m.

Table 8.4 Summary of potential replacements/upgrades

Priority	Improvement	Basis			stimate
4	New manual stream water level gauges	At least 1 manual stream water level gauge at each riverine flood-prone settlement	118#	$5,000	$590,000
		At least 1 manual stream water level gauge at each TM or ALERT location (assumed 20% of TM and ALERT have no manual gauge)	242	$5,000	$1,210,000
5	Resurvey of existing manual stream water level gauges	80% of existing gauges resurveyed	286	$2,500	$715,000

Priority	Improvement	Basis			stimate
6	Renewal of existing manual stream water level gauges	50% of existing gauges renewed	178	$5,000	$890,000
7	Upgrade manual rain gauge to ALERT or TM	Target at least 20% of rain gauges in catchment ALERT or TM	21	$15,000	$315,000
		20% of manual rain gauges within 0-12 hours of riverine risk settlements upgraded to ALERT or TM	77	$15,000	$1,155,000
8	Upgrade manual stream water level gauge to ALERT or TM	Target at least 20% of stream water level gauges in catchment ALERT or TM	1	$60,000	$60,000
		20% of manual stream water level gauges within 6-12 hours of riverine risk settlements upgraded to ALERT or TM	16	$60,000	$960,000
9	Upgrade landline/satellite communications to 3G or radio	At least 66% of the FWGN within a basin should be 3G or radio	402	$2,500^	$1,005,000
10	Renewal of existing manual rain gauges	20% of existing gauges renewed	162	$1,500	$243,000
					$7,143,000

Notes: ^ *upgrade of communications systems requires a study of network availability*

\# *Appendix T provides a list of riverine risk locations without a manual gauge board.*

8.3.3 Program of development works

A program of works that prioritises, plans and establishes budgets for rectification and improvement works has not been developed as it will depend on the governance model determined and funding allocations over a period yet to be defined.

9 Operation, maintenance and asset management

Findings

- There is currently no public accreditation system for instrumentation used in the FWGN
- Gauges located in upstream parts of the catchment can be totally funded by one council but relied upon by downstream councils that are unlikely to contribute to maintenance
- Implementation guidelines are required for new gauge installations that are primarily for flood warning, that cover: demonstrated need, funding sources, budgets, capacity and support requirements, site assessments, implementation, commissioning and certification, and operation and maintenance.
- Of the 36 councils that provided information on their maintenance practices, BoM was involved with around half those councils. Contractors were also involved in maintenance in around half of the respondents. Only 15% of council respondents undertook maintenance without any external assistance.
- The level of understanding and flood experience amongst council officers varied greatly. Some officers may not have the ability to ascribe meaning to a warning or predicted flood level.
- Reduction in external support to councils in the form of advice or funding for flood warning activities would compromise the ability of some councils to fulfil their obligations. A carefully planned transition strategy would be required.
- The model whereby council employs a private contractor to maintain and calibrate gauges is a risk to councils and BoM. This may be the result of a lack of certification and a missed opportunity for council to directly engage with BoM hydrographers and forecasters.
- There was a need to establish maintenance protocols or agreements between councils within a catchment, particularly where the downstream council relies on a good upstream network.
- BoM provided maintenance services to more than 750 non-BoM-owned gauges.
- A number of council budgets for gauge maintenance were based on historic spending and did not necessarily capture the deteriorating condition of gauges
- Only one council discussed the need for flood immunity for gauges.
- There were many examples where hydrometric equipment from multiple owners was co-located in single housing. This appears to be sensible and most effective when co-located in DNRM housings as this provides multiple observation opportunities (and reporting of problems to owners).
- There was no consistent approach to asset management, operation and maintenance across the FWGN. Internal or organisation standards were implemented by asset owners or maintenance agencies.
- The location of gauges recorded in databases usually related to the location of the housing. The location of the orifice at which the water level is measured was often not recorded.
- There were opportunities for efficiencies in the operation, maintenance and asset management for gauges in the FWGN.

9.1 OPERATIONS AND MAINTENANCE

Operation and maintenance of the FWGN assets is carried out in a variety of ways across the state as might be expected given the 54 separate owners. There are currently no national technical standards in place that define how operation and maintenance of flood warning gauges are to be carried out.

- The lack of current standards is identified in AMZEMC (BoM 2015), which recommended the development of national technical standards and Strategic Flood Warning Infrastructure Plans. Once the standards are developed, instruments and associated infrastructure should be supplied, constructed, installed, calibrated and maintained to those standards, and certified as such. No mechanism is available that would provide that certification. This also implies a need for a formal or semi-formal qualification system for hydrographers.
- Section 2.4 above notes only one supplier is used by BoM as it has developed equipment that melds to the ALERT network. This restricts competition. A more open and formal performance-driven engineering specification is desirable, based on the national technical standards and guideline. This provides an avenue for technological improvements to be introduced.
- Many of the issues surrounding the operation and maintenance of the FWGN stem from the capacity of the ownership agency. During this review, four separate operation and maintenance arrangements were encountered:
  - undertaken by council
  - undertaken by council with major annual servicing and calibration undertaken by BoM
  - shared responsibility with DNRM
  - contractor engaged by a council.

Larger councils employ an individual/team, either solely or partly responsible for maintaining and ensuring the operation of FWGN and other related assets. The capacity of the council to deliver such a team varied significantly. In some cases there were teams within the council offices responsible for the data once it reached the servers - followed by independent modelling and sensitivity testing based on future rainfall or standard IFD and temporal patterns.

The benefits of this in-house system include a lower cost incurred for councils (depending on the level of service and size of the team) and retention of knowledge. This promotes understanding and preparedness of council staff and better policy and decision making.

The BoM assists in a variety of capacities. BoM assists some councils regarding the benefits of additional gauges, location, testing, design, construction and full maintenance. This establishes professional and personal relationships between the council and BoM hydrographers and forecasters. This shared knowledge of catchment behaviour potentially leads to a personal interest and care factor that should not be understated. Better council understanding of gauge needs leads to stronger and more successful funding applications.

The third modus operandi is shared cost/assistance between DNRM and council, however, as the assets owned and maintained by DNRM are not primarily for flood warning, this arrangement may not be as effective in delivering the FWGN.

Finally, a council may engage a contractor to maintain and review the status of the assets within a council area. This arrangement presents one of the highest risks as a third-party is introduced with no reference to the operation of the broader network. This can be expensive for council, depending on extent of the service, and there are no recognised certifications for contractors. Many hydrographers are members of the Australian Hydrographers Association, an expert community of interests, and their professionalism provides more assurance.

The current arrangements are highly variable and in most cases consist of a combination of two or more of the arrangements described above. This has resulted in multiple field teams servicing different gauges in the same area at different times. A more coordinated and streamlined approach should be feasible.

The level of understanding and experience in the maintenance, operation and ongoing commitment to the FWGN differed greatly across all of the councils interviewed. If the arrangements between councils, BoM and DNRM were scaled back, much of the access to technical knowledge would be lost to the councils with a risk of less effective delivery of flood warning services. This is particularly relevant for councils needing to take on more flood warning responsibility.

9.1.1 Cost sharing arrangements

As described above, there are four operation and maintenance regimes commonly employed by councils in Queensland. Some of the current models have intrinsic benefits such as good relationships and understanding between BoM and council operators, but most councils cited difficulty in expanding significantly their current operation and maintenance schedule.

Each council makes an independent decision about the most appropriate routine it can afford. This approach is potentially inefficient and could leave some councils exposed should BoM or DNRM reduce their operation and maintenance schedules.

Given the scale of ongoing operation and maintenance required, there should be opportunity to explore efficiencies of scale and cost sharing arrangements. The issue however is complicated by the variety of technology employed and the knowledge and capacity of each council.

A centralised FWGN asset management register or database is the first useful guide to assess the condition and upkeep of the gauges within the FWGN. This endeavour should be undertaken as part of an oversight role for the operation of the FWGN. As part of this asset register, a technical standard for the operation and maintenance and calibration of gauges should be prepared which accounts for the variety of technologies, ownership and purposes implicit in gauges that provide flood warning data. Such a technical standard would clarify the operation and maintenance requirements across the FWGN in Queensland.

The initiative to improve the operation, maintenance and calibration of gauges used for flood warning purposes should be undertaken by an overarching body, with strategic oversight of the FWGN and input from key stakeholders, particularly those with technical understanding. There may be considerable benefit to coordination of operation, maintenance and calibration tasks based on council areas with a cost sharing agreement in place.

The model currently being explored in Victoria includes a cost recovery model where BoM is responsible for flood prediction services. Capital costs for new gauges are shared between the state and federal governments, ongoing maintenance costs are funded through local government programs with scope for cost sharing based on regional floodplain benefit (DELWP, 2015).

Similar arrangements could be adopted in Queensland provided some oversight and direction from an overarching body or responsible state-based agency.

9.2 RESOURCING

Most of the councils had a LDMG (or similar) responsible for the communication of flood warnings and management during a flood event - and were considerate of the flooding impact/scale, but there was usually a disconnect between these people and the technical flooding specialists. In some councils, gauge maintainers and flood specialists worked very closely with the LDMG. This facilitated a positive relationship where flooding was well understood and the appropriate action pathways were in place. Even so, much of this information was retained by a couple of individuals and was not written down or prescribed.

In worse cases, the LDMG was not supported by any technical flooding specialists and they were heavily reliant on BoM (or in some cases surrounding councils).

The willingness and capacity to provide appropriate resources was often related to the risk and recent flood history of a given council area. Where there had been recent flooding, it was seen as a higher priority and more funding was available. There was little Commonwealth or State government financial support to assist councils in ensuring technically proficient flood response staff were employed.

There were a few standout councils that had highly skilled technical teams with a thorough understanding of flooding, flood modelling, and hydrography - and where that existed it generally facilitated a good working relationship with BoM hydrographers and hydrologists. On the other end of the scale, however, the response mechanisms during flooding were focused around disaster management, and post event clean up.

9.3 LIMITATIONS

Funding was the most significant limitation for asset management and was raised by almost all stakeholders interviewed. This was at the heart of all issues raised by the councils and particularly funding for additional staff to be responsible for flooding and flood warning.

The majority of councils were aware they were eligible for grants for the capital costs associated with additional gauging stations. Once installed, the new assets incur annual operation and maintenance costs estimated to be 10 % of the capital expenditure that must be borne by councils. More than one council expressed that gauges were not maintained as they lacked the resources.

Councils had a particular difficulty in attracting and retaining skilled staff for flood preparation, evaluation and management. Some councils noted that their staff simply did not have the required skills for operation and maintenance of some of the newer technologies in the FWGN.

In some councils, a few individuals had detailed understanding of flood-related information, processes and protocols, but this was personal knowledge and not documented. The loss of critical flood-related knowledge is a major risk for some councils.

9.4 ONGOING MANAGEMENT

The policy lead agency for Queensland's FWGN currently lies with DNRM. Whether this arrangement continues is not known, however it is obvious from councils that there are significant opportunities for greater oversight, more investment, more resources and upskilling of council staff.

The number of Full Time Equivalent (FTE) staff that could be utilised reflects the additional scope possible for the lead agency. The following requirements are built from subjective assessments of council competency and capability made during the field visits and from questionnaire responses.

9.4.1 Forecast locations

The number of forecast locations within Queensland is currently 143, which provides a flood forecast for 123 settlements. The GIS analysis indicated that there are 92 flood prone settlements that do not receive a flood warning service and further consideration should be given to whether a service should be offered for these locations. Appendix V provides a list of those locations, along with an assessment of prioritisation. Increasing the number of forecast locations could have implications for the workload of BoM hydrologists.

9.4.2 Competency within councils

The technical ability within councils varied significantly. For the purposes of this report four levels of competency have been nominated:

- Level 1: fully competent (ability to complete build of a new station, calibrate instruments, and change any component) with BoM agreeing to site and connection to the ALERT system
- Level 2: skilled competency where staff could change canisters
- Level 3: semi-skilled with the ability to change solar panels, gas bottles and batteries
- Level 4: knowing where the gauges are located but engaged in LDMG activities.

Fully competent council officers had awareness of the responsibilities of LDMG, evacuation requirements and understood the findings of flood studies, however officers of all competencies should be aware of LDMG activities or be able to support the LDMG in some capacity.

Ideally, all council staff engaged in flood-related activities should be fully competent, but the needed competencies depend on flood risks and the anticipated flood emergency management burden, as well as on the current and future expectations of state government.

To fulfil current state expectations, most councils identified a need for additional human and financial resources and ongoing flood-related skills support. Based on review surveys and interviews, of the 77 councils in Queensland, a first pass estimate is that:

- 12 councils have flood risk requiring at least Level 4 competency

- 10 councils require Level 3 competency
- 25 councils require Level 2 competency
- 5 councils might need Level 1 competency.

Competency rates appear to be between 30% and 50% of the estimated requirements. A more detailed assessment is required, in cooperation with council staff and relevant government agencies.

The ability to resource staff and equipment for flood-related activities was an issue for most councils, with the majority under-resourced. In some cases the elected councillors did not fully understand the burden of responsibility on council staff. The provision of state guidelines might assist.

Based on the competency levels outlined above and the simple estimates made, an additional 10-20 FTEs could be required across Queensland councils at a technical officer or equivalent level, particularly if councils undertake increased responsibilities for gauge maintenance.

The training should include identification of structural and non-structural flood mitigation measures within each council area and establishing an external skill base to draw upon during an emergency. With additional training these staff could be engaged in education and engagement processes to improve community flood resilience.

9.4.3 Mentoring for councils

For the above to be successfully implemented, training and facilitation would be needed, most likely from state resources. This might require two FTE staff (of the hydrographer level or equivalent) for a two year period and then an ongoing training requirement for at least one FTE. These numbers would vary depending on the rate of uptake and the distribution of responsibilities between state and councils.

Funding for training and support would likely be in the order of $10,000 per annum for each council and would allow council staff to attend mentoring sessions (conducted by state or BoM mentors) and develop cooperative relationships with neighbouring and co-catchment located councils.

9.4.4 State organisational requirements

Effective support for councils requires state oversight and coordination. The strategic direction could come from DNRM as the policy lead agent for the FWGN, or from another suitable agency. There is a need for a functional group to oversee the flood-related capability of councils. Support for councils could include:

- Clear strategic direction from an overarching body.
- A leader of the functional group who is responsible for identifying and recommending funding priorities, in consultation with BoM and other state agencies.
- A technical co-ordinator who manages engagement with hydrographers (especially DNRM and BoM), provides technical advice and assists the group leader.
- Two mentors for engaging directly with councils and developing training programs.
- One financial and administrative FTE.

9.4.5 Program costs

The above would require funding in the order of $2,500,000 per annum over the next two years. Further detail is provided in Table 9.1.

Table 9.1 Summary of proposed system direction, administration and training costs (annual costs)

Improvement	Basis	No.	Unit rate^	Budget Estimate
Additional hydrographer	2 FTE to achieve target maintenance frequency	2	$120,000	$240,000
State oversight	5 FTE	2	$180,000	$360,000
Council maintenance	10 FTE	10	$120,000	$1,200,000
Annual training/conferences	Allowance for 50 councils with flood risk	50	$10,000	$500,000
				$2,300,000

^ *Unit rates include allowance for overheads, management and leave*

9.5 STRATEGIC ASSET MANAGEMENT PLAN

One item important to an ongoing effective FWGN is a s trategic asset management plan with accompanying guidelines designed for application and use by BoM, the state and its agencies. Such a plan should be managed at level with more detailed assessments at river basin level.

Each of the owners should have its own asset register and maintenance register with the detail appropriate to the perceived needs of the owner. The structure of each register would be different, making it difficult for the transfer and effective consolidation at both basin and state levels of interest. If local asset registers were well scoped and robust, there would be no need to duplicate that process at state level, but simply base a state strategic plan on local data.

The Lead Agency should determine what its strategic needs are in consultation with stakeholders and relevant Inter-Departmental Committees and dev elop an out line of possible asset database structures required at state, basin and ow ner level. Once these tiered structures have been s tandardised, asset owners should restructure and populate their own registers. Gaps and er rors in the asset database should be addressed at the next routine inspection by the asset owner.

Development of local, regional (basin) and state asset registers for the FWGN should be do ne in accordance with the ISO 55,000 series Australian / International standards suite of standards for asset management. It should include:

- Asset Management Policy
- Asset Management Guideline and Engineering standards
- Strategic Asset Management Plan (StAMP)
- Asset management Implementation Plan
- Implementation of a suitable networked Asset Management System for all asset owners, operators and maintainers administered by a central agent.

The capital and technical costs of developing the guidelines, asset database structures, populating the various tables and the purchase of commercial-off-the-shelf software and the ongoing maintenance has not been estimated but local, regional and state costs could exceed $2 million depending on the level of integration required (personal communication R. Anderson (Oct 2015)).

10 Flash flooding

Findings

- The number of rain gauges in the FWGN is insufficient to cover all identified potential flash flood areas
- BoM does not provide a flash flood warning service, however it does provide rainfall forecasts and an indication of intensities that may lead to flash flooding
- The responsibility for flash flood warning is not currently defined in legislation. The Inspector General Emergency Management's Assurance Framework has a w arning standard that recognises all stakeholders share responsibility to ensure the outcome that "communities at risk of impact from an event, receive fit-for-purpose, consistent, accurate warnings through all phases of events"
- BoM and the states/territories are currently negotiating a National Agreement that, when finalised, will clarify responsibilities. It is likely the responsibility for flash flood warning will be as signed to state government in partnership with local government, with support provided by BoM in the form of forecasts and warnings for severe weather conditions and potential heavy rainfall conducive to Flash Flooding.
- The nature of flash floods makes forecasting and delivery of appropriate warnings challenging. Some councils use rainfall predictions from BoM, while others have specialised software to assist with forecasting. Less well-resourced councils consider flood forecasting is outside of the normal duties of staff.

Flash flooding occurring in less than four hours is usually dealt with as an operational matter by councils unless causing severe damage. When the storm event is forecast to commence in four hours or more a council may discuss a 'lean forward' position with the LDMG. A more formal peak flood height warning based on BoM hydrologists forecast is usually associated with riverine events.

Given the resources of small councils, it is often the case that the LDMG is led by the shire engineer or the officer in charge of the operations pool. In these situations, the six hour definition is probably suitable.

For the larger councils where local stream flooding and facilities can occur, the interim forecasts band of 4 to 10 hours is recommended.

- Flash floods are characterised by rapidly rising water levels following short intense bursts of rainfall (commonly from thunderstorms) and tend to occur in built up areas and areas where the surrounding terrain is naturally more hilly or mountainous. In Queensland severe storm cells can produce 200 - 500 mm of rain in an afternoon. These downpours can cause pluvial flooding - when the runoff ponds and is restricted from leaving an area by congested stormwater flow paths. These events can be disruptive for up to six hours. Due to the rapid onset of flash floods, they are by nature difficult to predict and provide effective localised warning for without appropriate local knowledge.
- Flash events can be characterised by "straight" or "direct" flowing water which tends to move quickly through urban streets and local streams. Flash floods can also be the result of levee or dam failure, or a sudden release of water by debris upstream.

There are two types of warnings issued by BoM: flood warning forecasts provided by hydrologists, and severe weather warnings issued by meteorologists. The severe weather warnings advise the likelihood of storm fronts and very heavy rainfall for relatively short periods of time. An opportunity exists for council hydrologists to develop a library of local flood impacts based on a range of rainfall events. The library of rainfall observations could be linked to storm management operational plans.

Flash flooding is a cooperative responsibility for LDMG and councils and given the localised nature and rapid onset of flash floods, local governments are generally best placed to respond operationally. Preparation for flash flooding is intrinsically linked to local knowledge, knowing where low-lying areas are and understanding the local waterways and how they respond during storms.

The capacity of councils to prepare for and deal with flash flooding varied significantly across councils. Some councils advised that they had dev eloped software/websites that described the potential flash flooding extents based on historical information available and provided warnings based on the anticipated duration and intensity of rainfall across the catchment. Other councils reported that they relied solely on BoM forecasts for flooding, and where severe storm warnings were not provided, the council lacked the capacity to implement any form of warning or management plan.

Individual storms can often affect entire regions across multiple catchments and an opportunity exists to develop a cooperative regional flash flood management strategy. A cooperative approach could provide efficiencies, combining management of flash flooding, potentially sharing costs of the FWGN, and augmenting the network to provide additional warning time. The opportunity to form cooperative regional flood management teams should be further examined.

The potential for generalised district-scale flash flood warning based around BoM's existing services should be examined. This may assist councils that lack the capacity to undertake and prepare local flash flood warning and management systems.

Given the speed of flash flooding, prediction is heavily reliant on the rain gauge network but there are currently no recognised guidelines or standards to assist councils understand what improvements may be necessary.

Flash flood forecasts produced by councils in house are mostly based on rainfall data and forecasts applied to sub-catchment scale hydrological models, such as used by the Brisbane City Council (BCC). BCC provides an interactive mapping service that provides granularity between river, creek, storm tide and overland flow flood extents. The warning network relies on predictions of heavy rain by BoM meteorologists rather than BoM hydrologists.

The following screen shots demonstrate the implications. Figure 10.1 shows the limits of creek flooding and provides a link by which residents can register for the Creek Flood Alert Service.

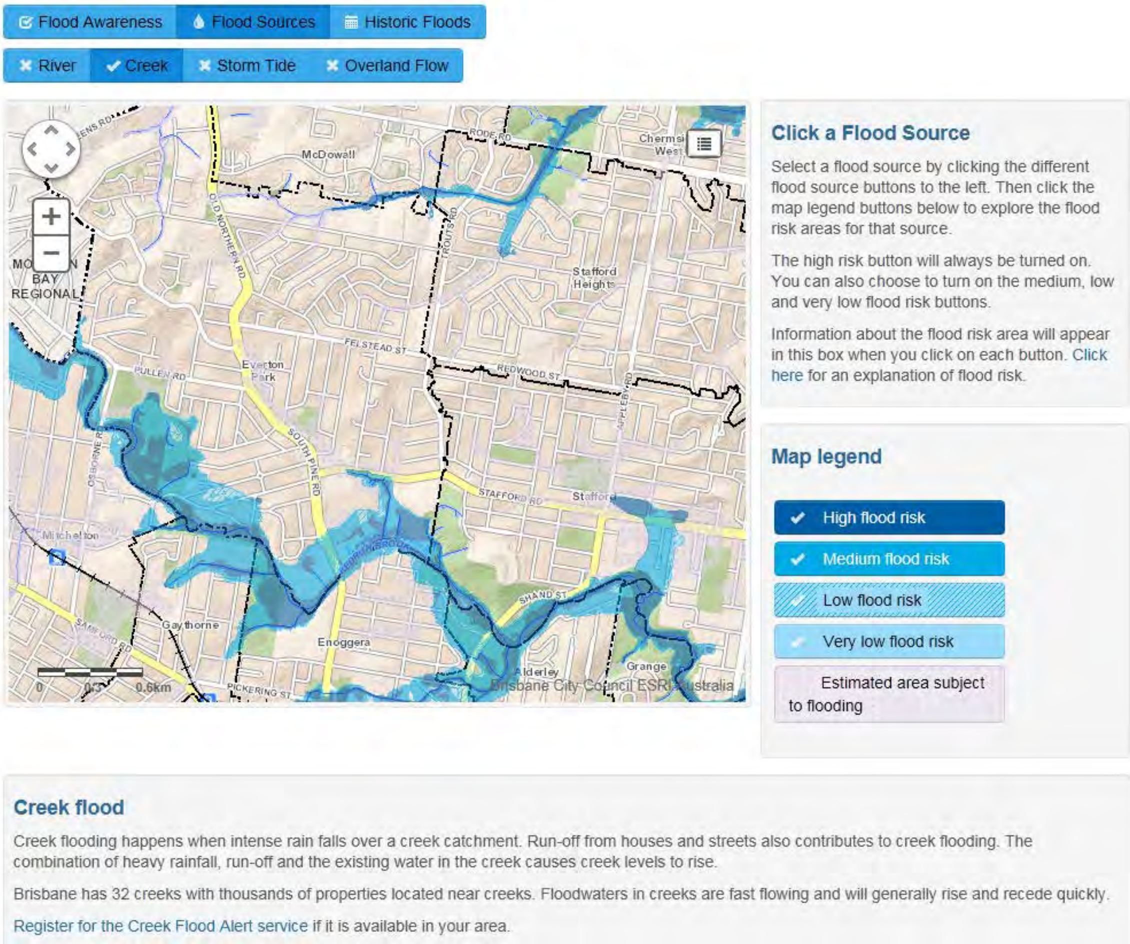


Figure 10.1
BCC FLOOD MAP - CREEK FLOODING

Figure 10.2 shows the same area but depicts the possible extent of overland flow, with an explanation below the map. Overland flow areas are the upper extents of creek flooding.

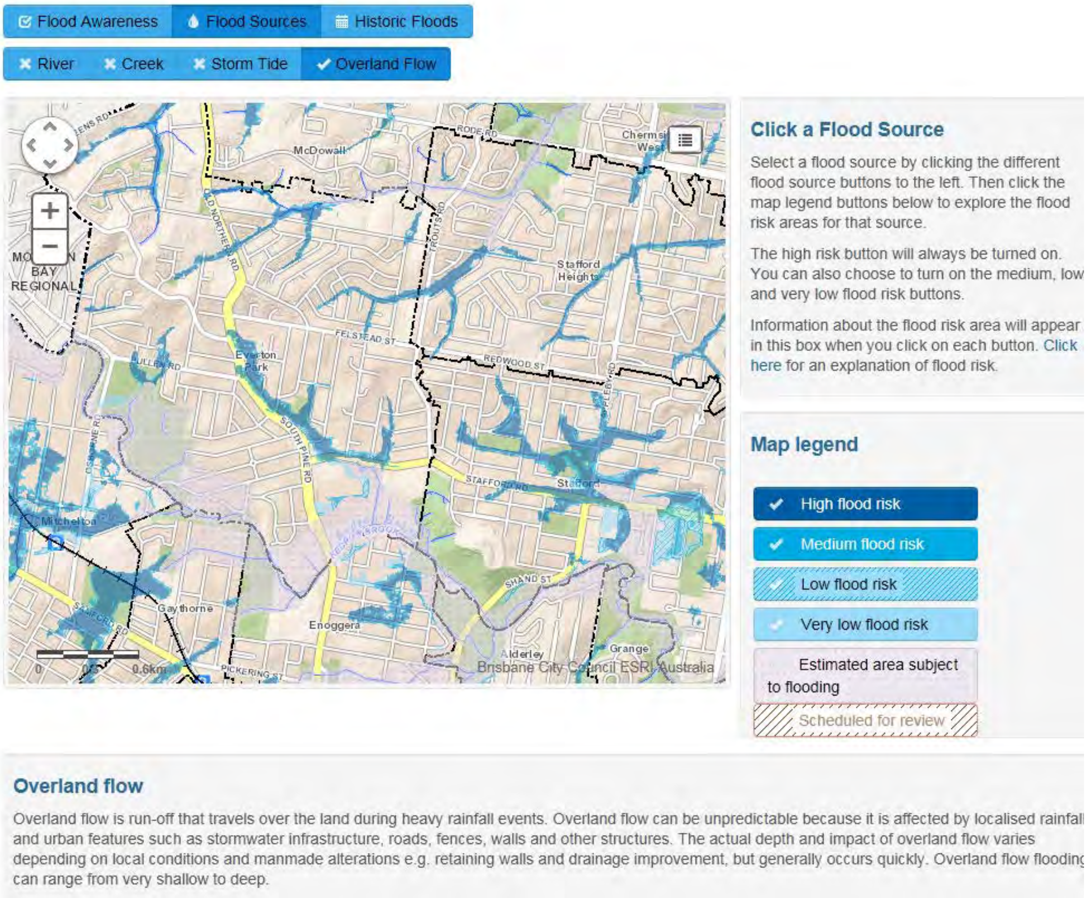


Figure 10.2
BCC FLOODING - OVERLAND FLOW

10.1 FLASH FLOOD RISK ANALYSIS

10.1.1 Method

The flash flood analysis is similar to that adopted for riverine flooding (refer Section 7), but with some modifications to account for the specific circumstances surrounding flash flooding. Flash flooding often occurs either as a result of local runoff from the immediate vicinity (i.e. within 5km of the settlement) or within a broader catchment that has a fast response time of less than 6 hours. Such catchments typically extend 25 to 45 km upstream of a settlement, depending on the terrain.

The analysis for flash flooding considers the suitability of the FWGN to detect both local intense rainfall and rainfall in the broader catchment. Flash flood warning is most appropriately implemented through automatic rain gauge located throughout the catchment. Some councils have installed video cameras at key road and stream locations. Only automatic rain gauges (ALERT or TM) were included in the analysis.

The scope of the local rainfall assessment (within 5 km of the settlement) and catchment rainfall assessment is shown in Figure 10.3. For settlements that experience both flash and riverine flooding only the local rainfall assessment was conducted for flash flooding. This is explained in Table 10.1.

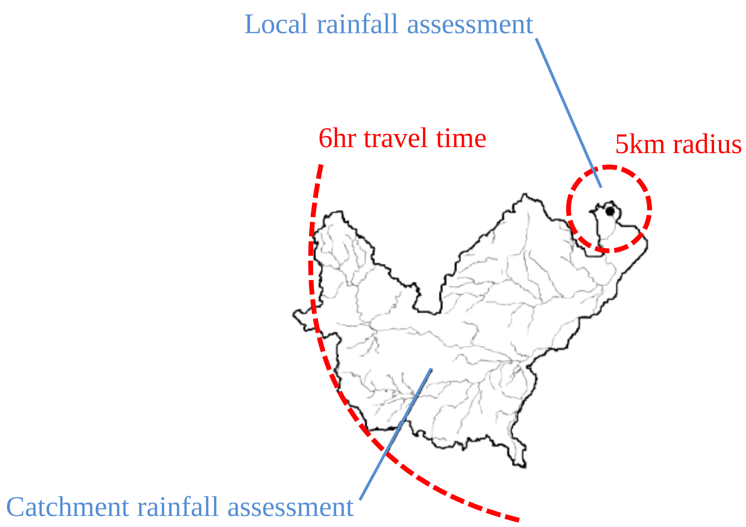


Figure 10.3
RAIN GAUGE ASSESSMENTS FOR FLASH FLOOD LOCATIONS

Table 10.1 Application of flash flood assessment methods

Flood risk	Number of settlements	Catchment rainfall	Local rainfall
Riverine + flash	42	✓ Refer Section 7	✓
Flash only	52	✓	✓
Total	94		

NB: 320 settlements have not had a previous assessment of flash flood risk

The density of rain gauges in a catchment is a key indicator of its suitability to detect rainfall for flood warning purposes. WMO (1974) provides guidance on minimum rain gauge densities for a range of hydrographic units. These are presented in Table 10.2.

Table 10.2 Minimum densities of rain gauges (adapted from WMO, 1974)

Hydrographic unit	Minimum Density (area in km2 per station)	Application to flash flooding
Coastal	900	Applied to catchment of major watercourse near settlement (generally <6 hour response time)
Mountains	250	
Interior plains	575	
Hilly/undulating	575	
Urban area	20	Applied to area within 5 km buffer of settlement boundary

10.1.2 Results

A summary of the density analysis is presented in Appendix S. Very few flash flood-prone settlements meet the required rain gauge density (13 out of 94). Those that do meet the minimum density criteria are:

- Strathpine (10 km^2/gauge)
- Nambour (11 km^2/gauge)

- Bald hills (12 km²/gauge)
- Logan central (15 km²/gauge)
- Mudgeeraba (16 km²/gauge)
- Ipswich (18 km²/gauge)
- Burpengary (19 km²/gauge)
- Brisbane (19 km²/gauge)
- Caboolture (19 km²/gauge)
- Maroochydore (20 km²/gauge)
- Townsville (20 km²/gauge)
- Nerang (20 km²/gauge)
- Samford (20 km²/gauge)

Although these settlements satisfy the minimum density criteria, an i nspection of the distribution of gauges in the local area is required to ensure the siting of gauges is appropriate for the local conditions and flood risk areas. As described above, flash flood risk and preparation is heavily influenced by localised factors, terrain, small tributaries with short flow/response time and urban development. These factors will need to be considered when completing a more detailed inspection at each location.

Table 10.3 details the additional rain gauges that are required to achieve the minimum density criteria for the remaining settlements.

Table 10.3 Additional ALERT rain gauges required to achieve minimum density criteria

Basin	Additional gauges to meet local rain gauge density criteria	Additional gauges to meet catchment rain gauge density criteria
Balonne-Condamine	143	11
Barron	16	0
Border Rivers	4	0
Brisbane	81	2
Burnett	58	2
Burrum	15	2
Cooper Creek	17	1
Diamantina	6	0
Don	16	1
Fitzroy	61	3
Flinders	16	0
Herbert	16	0
Johnstone	3	0
Leichhardt	12	1
Logan-Albert	13	0
Maroochy	1	0
Mary	27	5
Mulgrave-Russell	17	1
Noosa	4	0
Pine	4	0
Pioneer	9	1
Ross	1	0
South Coast	17	3
Total	557	33

590 ALERT rain gauges would be required to meet minimum density criteria in flash flood locations, which would cost in the order of $9m. This compares with approximately 184 ALERT rain gauges identified through the QRA (2012) study. The QRA study adopted different criteria for gauging flash flood risk areas and prioritising investment.

The density criteria adopted for this study should provide an adequate coverage in those areas, however there are many additional local factors that need to be considered when designing a scheme. Such considerations may reduce the number of additional installations required, perhaps closer to the number presented by QRA (2012).

Irrespective of the rain gauge network in place, there are other fundamental problems with flash flood warning in Queensland that need to be resolved before such infrastructure investment is warranted. These include:

- detailed assessment of flash flood risk locations (94 identified flash flood locations, plus the additional 320 settlements for which no determination of flash flood exposure has been made)
- establishing clear accountabilities for flash flood warning and response
- communication of those accountabilities
- establishing response plans so that effective responses can be made on warnings that are issued (either based on forecasts or observed rainfall)
- detailed assessment of the rain gauge network in flash flood risk locations so that improvements can be tailored to the local conditions
- prioritisation of improvements.

11 Other issues

Findings

- Dam operators report water levels in mAHD rather than relative to spillway crest. This can be confusing to LDMGs and communities
- Some gauge sites within the FWGN do not satisfy current Occupational Health and Safety (OHS) requirement. In some situations these would need to be entirely relocated, in other situations modifications to the existing installation would be sufficient.
- Most DNRM gauges are mounted in a hut with access via steps and hand rails etc. and meet OHS requirements.
- Potential OHS improvements to the older gauge installation have been identified. These include: kick plate around the platform, solid gate or side entry to the platform, mechanical winch for raising or lowering items (e.g. gas bottle, tools) to/from the platform, and suitable anchor point of personnel harnesses and equipment for fall prevention.
- Rating curves (that relate water level to flow) are rarely updated and there is no mechanism of reporting to BoM when floodplain changes occur that affect rating curves.

11.1 RATING CURVES

Rating curves are used by forecasting hydrologists to convert hydrologic model-derived flow rates into forecast water levels. The rating curves produced by DNRM have a data quality code that is used to define the degree of confidence in the recorded data at each individual station. The code values change depending on the data of interest, such as the stream water level gaugings or the derived discharge values.

All monitoring data is required to have an associated quality code and the codes for the stream flow data are shown on the hydrographs. The standard DNRM data quality codes and values for recorded streamflow data are outlined in Table 11.1.

Table 11.1 DNRM quality codes & values

Quality code	Value
Normal	5
Good	10
Fair	20
Poor	30
Estimate	60
No data	130

It may be noted that the maximum stage recorded at each gauging station is often far in excess of the maximum gaugings at the site that are used in the development of the rating curve for the site. For example, the maximum gauged stage for the Nogoa at Craigmore is 10.56 m with a flow of 983 m^3/s. However, the maximum stage recorded at the site is 18.16 m with a derived flow of 5,870 m^3/s. The records show that the data quality flag for flows above 500 m^3/s is tagged as 'poor' and there is considerable uncertainty associated with the recorded flows in this range. This has a bearing on the calibration of the hydrologic models as the flows during the flood events are considerably higher than the maximum gauged flows at the gauging stations.

Synthetic rating curves can be developed from two-dimensional model data as shown in Figure 11.1.

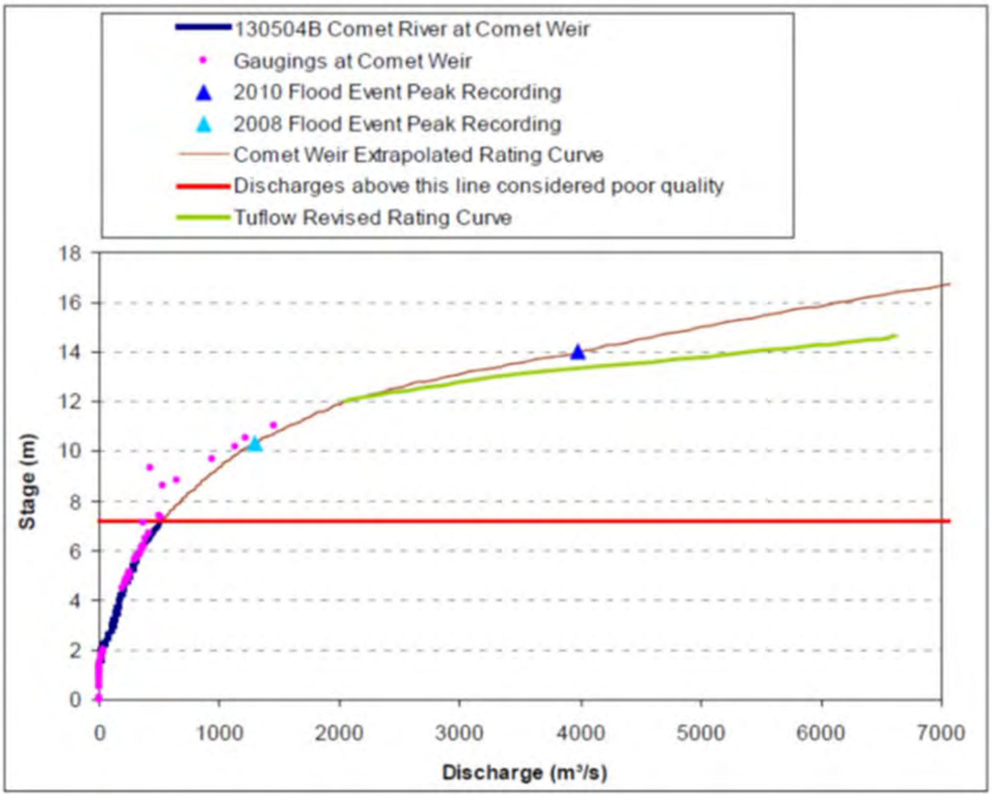


Figure 11.1
SYNTHETIC RATING CURVE

In the above figure it became evident that a significant flow was bypassing the gauge. Hydraulic modelling of the wide section (including by-pass) provided a more accurate rating.

Reassessments of rating curves can affect flood frequency analyses and change overall perceptions of flood risk and perceived flood immunities. Should the perceived flood immunities of existing or proposed flood mitigation strategies change (as occurs over time), it is incumbent on the hydrologist to advise the LDMG, and engineering and planning staff within councils. This advice may require adjustments to existing Flood Risk Management Plans, Planning Schemes, development guidelines, pending flood mitigation strategies and design loads on bridges. The adjusted rating curve may also affect infrastructure benefit-cost ratios.

Rating curves need to be reviewed during each flood study.

11.2 GAUGE ZERO

11.2.1 Dams

Both Seqwater and SunWater set their water level gauges to Australian Height Datum (AHD) for dam operational purposes. When the dam begins to fill and is expected to discharge over the spillway, water levels are conveyed to councils, their Local Disaster Management Groups and State Disaster Control Centre in AHD.

Water levels reported in AHD have little meaning to councils and disaster managers unless they have information on the dam storage and spillway crest level. They prefer and understand depths in metres below or above the spillway. This means a numerical calculation is required to ascribe meaning and unfortunately arithmetic errors can occur. Councils and their LDMGs would prefer dams to have a second set of gauges that reports water levels with respect to spillway crest.

11.2.2 Stream water level gauges

Stream water level gauges are set to zero which represents the point in the stream where flow does not occur, i.e. where the hydraulic control is just dry.

With erosion over time or shifting stream braids, gauge zero may not represent zero flow. This will impact on the accuracy of rating curves.

Gauge zero, should also be surveyed to AHD so that hydraulic grades can be determined between gauging stations and estimates for flood wave celerities (speeds) more easily determined.

11.3 GEOLOCATION

The latitudes and longitudes of gauges are not always accurate and can be a result of translation errors when resetting AMG Zones, survey or conversion errors.

Georeferenced photographs should be taken at each gauge visit and used to update the asset register. The locations of both the gauge housing and sensor should be determined.

11.4 WORKPLACE SAFETY

A number of the existing pole-mounted platforms used for stream water level equipment have safety issues as identified in Section 3. These need to be captured at each inspection (using a standard safety review/safety-in-design template), entered into a database for inclusion into an immediate or future works program. The safety issues need to be reviewed, classified on a risk-based prioritisation as to whether they require ‘immediate’ or ‘desirable’ rectification or seen as a legacy condition in accordance with the standard hierarchy of risk control.

Given there might be several hundred sites of concern, remedial work has to be programmed and funded. Remedial work for high risk sites might be considered grounds for state contributions to asset owners depending on their flood forecasting or other need.

12 Recommendations

Item	Scope	Recommendation	Additional considerations
1	Governance	That the State Government establish a cross-agency forum (modelled on the previous Queensland Flood Consultative Committee) to oversee improvements in the strategic and operational arrangements of the Queensland flood warning gauge network and the implementation of the recommendations outlined in this review.	Oversight should be provided by a high-level disaster mitigation committee. The differences in size and flood risk management and flood warning capabilities within councils should be recognised in the governance model. The State Government should provide flood emergency specialist support on flash flood warning and flood planning assistance to those local governments that are unable to provide those services themselves.
2	Engagement with BoM	That State Government continue to work collaboratively with BoM and respective local governments to review the number of flood forecast locations in Queensland and confirm that the identified 92 settlements that have a riverine flood risk actually require a flood warning service.	The cross-agency forum should facilitate engagement between councils and BoM to improve knowledge of catchment response, flood behaviour and flood warnings. Currently BoM engages with councils on a one-to-one basis, with knowledge and understanding shared where strong relationships have already been forged.
3	Funding strategies	That the recommended cross-agency forum facilitate the development of an implementation plan for improvements to the hydrometric gauges used to support flood warning, including funding arrangements and investment strategy guidelines for local governments.	New gauges should be strategically located to maximise the warning time commensurate with the required warning and evacuation burden as identified in Section 7.2.4 of this report. Gauge locations should be confirmed by ground truthing and consultation between the cross-agency forum, BoM and local governments. Consideration should also be given to forecast lead time as defined in the Service Level Specification. Any additions and expansions of the flood warning gauge network should meet the technical and

Item	Scope	Recommendation	Additional considerations
			functional requirements of and support BoM's flood forecasting activities. This requires published technical standards. Capital improvements should be implemented by the local government with oversight from BoM and the cross-agency forum. The cost of proposed capital improvements is estimated to be approximately $5m. Upgrades of existing gauges that are used for flood warning should be implemented by the asset owner, with financial assistance from the State, where required. The replacements and technology upgrades are estimated to cost $7m. These upgrades should take place progressively in line with prioritisation identified. Funds should be made available to the cross-agency forum to support governance and delivery of training to local governments. This is estimated to cost $3m annually for two years for administration, training and direction arrangements. Ongoing funding will also be required, but at a diminishing rate as the knowledge base increases and gov ernance arrangements become engrained.
4	Funding strategies	That the cross-agency forum implement a coordination program to reduce the overall burden of gauge oper ation, maintenance and administration expenses, for example sharing costs on a c atchment basis under a s haring formula.	The cross-agency forum, in consultation with BoM, should identify which local governments require additional financial support to meet their obligations. Many of the local governments providing feedback highlighted funding as a key limitation to the effective upkeep and upgrade of the gauge assets in their area. The cross-agency forum should implement a coordination program that facilitates cost sharing arrangements. Cost sharing initiatives could reduce the overall burden of operation and maintenance, particularly administration expenses. The coordination program should identify local governments and other organisations that are able to share costs on a c atchment basis, and possible cost-sharing formulas. The cross-agency forum should oversight the management of the program to ensure effective implementation. The cross-agency forum should prepare guidelines to assist local governments prepare applications for funding of flood ameliorating and flood mitigation activities. Feedback from local governments highlighted the need for assistance by way of policies or guidelines. The application guidelines should include a s ummary of types of funding available from which departments/agencies, the requirements for successful application and a des cription of the purpose or intent of the funding detailing the type of technology which can be considered.
5	Capacity Building	That the cross-agency forum facilitate the roll-out	The cross-agency forum should oversight the preparation and dissemination of guidance documents

Item	Scope	Recommendation	Additional considerations
		of an education and training program and the preparation and dissemination of guidance documents to local governments to clarify their flood responsibilities and access to tools	to local governments that clarify their flood responsibilities and link to tools and resources that can assist them. The burden of responsibility for local governments was not uniformly understood. The wide variation in competency and understanding of flooding, flood warning, and flood warning operations is a considerable challenge. The capacity of local governments should be reinforced including with technical guidance regarding the content and scope of flood studies that should be undertaken. This will lead to better local knowledge about the flood risk and catchment response to flood waves. The cross-agency forum should oversee the roll-out of a training program to local governments. The training should include the hydrometric network, floodplain management and flood emergency planning activities. Competency was a key limitation at a number of the local governments interviewed.
6	Asset management	That the cross-agency forum oversee the collaborative development of an individual local government and aggregated state-wide asset management system (AMS), that will work at a local, catchment or basin basis. The AMS should serve the respective needs of local governments and overall state management needs. The state amalgamated asset management system should align with the BoM AMS in key database fields. The BoM and the cross-agency forum should collaborate to define the fields of the AMS.	The cross-agency forum should collaborate with BoM to record and provide reasons for non-acceptance by BoM of some gauges for flood warning purposes. Lack of information can frustrate local governments and allows repetition of mistakes. The cross-agency forum should coordinate a condition assessment of the whole network. The cross-agency forum should develop and implement a program of rectification works. The cross-agency forum should oversee the development and implementation of catchment flood warning plans on a priority basis. The cross-agency forum should instigate a safety review of all gauging stations, for collation and classification regarding the need for safety improvements.
7	Asset management	That the cross-agency forum work with the BoM to share radio and telecommunications communication network information with state agencies and local governments. This will assist in identifying gaps in the overall communications network, refining potential upgrade costs and system integration for new gauges.	The cross-agency forum should seek VHF radio network maps and discuss their provision with BoM. These maps would ideally show the signal strength contours. The cross-agency forum should seek to obtain 3G and 4G signal strength maps from telecommunication providers.
8	Operation and maintenance	That the cross-agency forum, work with the BoM to develop an outcomes-based accreditation	The cross-agency forum should encourage the development of National Technical Standards for rain and stream water level gauges.

Item	Scope	Recommendation	Additional considerations
		system for instrumentation used for flood warning purposes, based on the outcomes of the Australia New Zealand Emergency Management Committee (ANZEMC) initiatives. This would include developing implementation guidelines for new flood warning gauges to demonstrate need, determine funding sources, establish and seek budgets, assess capacity and support requirements, conduct site assessment, and plan for implementation, commissioning and certification, and operation and maintenance.	The cross-agency forum should develop a mechanism that provides certification of instruments/installations, accompanied by a formal or semi-formal qualification system for hydrographers.
9	Operation and maintenance	That the cross-agency forum and BoM develop a rating, hierarchy or assessment within the database that assigns more confidence and more importance to certain gauges than others.	Any additions and expansions of gauging installations, primarily intended to provide flood warning data to the BoM, should meet the BoM technical and functional requirements.
10	Operation and maintenance	That the cross-agency forum and BoM develop a strategy that encourages competition and the entry of new suppliers of equipment.	
11	Operation and maintenance	That the cross-agency forum regularly review the effective life of asset components and oversee upgrades or refurbishments as needed.	
12	Technology	That BoM advise the cross-agency forum with regard to the impacts of delays for the implementation for ALERT2. (BoM's ALERT and ENVIROMON systems currently limit the number of new stations that can be incorporated into its flood warning system.)	The cross-agency forum should investigate the implications of the NBN replacing Telstra's copper wire network.
13	Flash flooding	That the cross-agency forum develop a strategy in collaboration with the BoM to identify and publish locations that are likely to be affected by flash flooding, and identify opportunities to	

Item	Scope	Recommendation	Additional considerations
		improve flash flood warning systems on a regional basis.	
14	Flash flooding	That the cross-agency forum develop a strategy to integrate warning services for flash flooding across multiple catchments. (This could lead to economies and efficiencies of scale, combining and consolidating management of flash flooding with potential cost sharing for gauges used for flood warning.)	
15	Flash flooding	That the cross-agency forum work with the BoM, as part of the National Flash Flood Repository project, and in recognition of related BoM supplementary services, to disseminate generalised district-scale flash flood warning services based around BoM's existing severe weather warning services.	
16	Flash flooding	That gauge owners continually examine workplace health and safety risks for the different types of installations, with a view to modification of existing sites or designs for proposed sites when possible and convenient.	
17	Other issues	That the cross-agency forum facilitate an assessment of rating curves used for flood forecast locations for accuracy and require rating curves to be reviewed and updated during each relevant flood study.	
18	Next Steps	That the operational recommendations and outcomes of this report be validated on the ground with the respective local governments, dam owners, QFES, BoM etc. (This will ensure the consideration of issues such as the impact of storages not considered in the state-wide GIS	

Item	Scope	Recommendation	Additional considerations
		analysis.)	
19	Next Steps	That the Queensland hydrometric networks used for flood warning be reviewed periodically and the findings of this report be updated.	

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