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Review of 2010-11 Flood Warnings & Response

REVIEW INTO THE OPERATION OF STORAGES DURING FLOODING

Final 2 | 29 September 2011

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SKM

Review of 2010-2011 Flood Warnings and Response

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Contents

Executive Summary

The flooding that impacted Victoria between September 2010 and February 2011 was among the most severe on record at many communities. As part of the Victorian Floods Review, consideration was given to the impact of storages such as large dams on these flood events. The scope of this investigation covered Lake Eppalock in the Campaspe River System, Tullaroop Reservoir, Cairn Curran Reservoir and Laanecoorie Reservoir in the Loddon River System and Wartook Reservoir and Lake Lonsdale in the Wimmera River System.

The focus of the review was to understand and summarise the impact of the storages on the flood events and the operating policies and procedures the storage managers had in place (and whether they were followed) during the flood events. No consideration was given to potential improvements in providing flood mitigation at the storages.

The review was based on a large volume of documentation provided by the storage managers, Goulburn-Murray Water (G-MW) and Grampians Wimmera Mallee Water (GWMWater) Interviews were also conducted with key staff from both organisations.

The following key findings on the operation of storages during flooding have been determined during the course of this review:

What are the purposes of the storages?

- As storage managers under the Victorian *Water Act 1989* and *Water Industry Act 1994*, G-MW and GWMWater have obligations to ensure reliable supply of water to primary entitlement holders and manage the storages safely. The legislation also lists a number of other objectives including provision of "flood mitigation, where possible" (ie without compromising reliability of supply and dam safety).
- The primary purpose of the storages on the Campaspe, Loddon and Wimmera River Systems is to supply water for irrigated agriculture, stock and domestic use, urban areas and environmental entitlements. Whilst these storages do provide flood mitigation benefits, such benefits are incidental to their primary purpose. The storage managers are highly constrained in their ability to provide flood mitigation by the need to supply primary entitlement holders and ensure dam safety.
- Provision of additional airspace for flood mitigation is constrained by the relatively small capacity of low-level outlets at the storages considered in this review. The reliability of forecast rainfall information at the regional scale means little more than four days warning of heavy rainfall is available. At the catchment scale, reliable warning of heavy rainfalls upstream of a particular reservoir may allow a lead time of two days or less.

What are the governance arrangements, including operating rules, for the storages?

- Flood operating rules put in place by the storage managers for the storages under consideration consist of monitoring the inflows, outflows and water level at each storage and communicating this information with key external agencies including the Bureau of Meteorology and emergency services.

- In the special case of Cairn Curran Reservoir, the flood operating rules put in place by G-MW consist of adjusting the gate openings at the storage to ensure the water level does not rise above full supply level. The flood operating rules for Cairn Curran do not permit deliberate surcharging of the storage to provide flood mitigation. This is in accordance with the intent of the storage and G-MW's legislative requirements, however a clearer statement of this purpose could be included in the flood operating rules for Cairn Curran.
- The operating policies and procedures put in place by G-MW and GWMWater are generally consistent with their legal requirements under the Water Act and the Water Industry Act as they pertain to management of floods. In some cases, the clarity, accuracy and relevance of information in the various operating procedures could be improved. In particular, greater attention could be given to procedures outlining how the authorities interact with emergency response agencies at the regional level and during widespread flooding when multiple catchments are affected.

What influence did the storages have on flooding?

- The majority of the storages considered in this review are fixed crest (ie ungated) structures. The nature of fixed crest storages means that peak outflow is always less than or equal to peak inflow. The magnitude of the attenuation (change in peak outflow below peak inflow) is increased if the water level in the storage is below full supply level prior to the start of the event.
- Between September 2010 and February 2011 the storages in question provided significant mitigation of flooding in Victoria. This influence was most pronounced for downstream communities close to the storages, where in some cases a large degree of attenuation of the flood hydrograph was observed. For communities further downstream, this impact became less significant due to additional local inflows and the effects of floodplain attenuation.
- Between September and November 2010 a large volume of floodwater that would otherwise have resulted in moderate to major flooding of communities such as Rochester and Horsham was mitigated by storages on the Campaspe, Loddon and Wimmera River Systems. The mitigation was primarily a result of the very low water levels in these storages due to the prolonged period of drought.
- The majority of the storages under consideration filled and spilled during the floods in January and February 2011. However, the attenuating effect of passing the floods through the storage spillways ensured that in the majority of cases a degree of flood mitigation was provided.
- In all cases, the storages under consideration provided some flood mitigation benefit or held peak outflow equal to or less than peak inflow. The storages did not contribute to increasing the frequency, magnitude or impact of the floods. The storages did delay timing of peak flows for communities in the area immediately downstream, however this effect was not significant for areas further away due to the impact of local inflows and floodplain attenuation.

- Many of the storages reviewed are subject to target filling curves. These arrangements are used to provide airspace in the reservoir over the winter /early spring period, typically to maximise harvesting of water. The airspace provided by target filling curves does allow additional flood mitigation, however the floods of interest occurred outside the winter /early spring period when targets are applied. As such, these arrangements were not influential on the recent floods.

How were the storages operated and was this consistent with their arrangements?

- G-MW operated their storages in accordance with their published policies and procedures. At Cairn Curran Reservoir, the storage was not deliberately surcharged in order to provide flood mitigation benefits. Gate operations were used to mitigate flooding at the Baringhup community where possible at the start and end of the flood events. At the other storages, the floods were monitored as they were routed through the storages and the appropriate communication links with external agencies were established.
- G-MW should investigate development and use of an operational flood forecasting model for Cairn Curran Reservoir. This would aid decision making on pre-releases from the storage.
- G-MW provided advice to the community and individuals downstream of Cairn Curran Reservoir via SMS messaging. This is a responsible approach from G-MW, however this arrangement should not be regarded as a replacement for formal flood warning services. The content, format and timing of these messages should be reviewed to ensure that they are consistent with other flood warning / flood advice arrangements.
- GWMWater generally operated their storages in accordance with their published policies and procedures. The floods were monitored as they passed through the storages (where possible given access to the storages) and the appropriate communication links with external agencies were established. The main exception to this was at Lake Lonsdale, where telemetered reservoir water levels were not available and access to the reservoir was lost due to flooded roads.
- In some cases GWMWater's operating manuals would benefit from being reviewed and updated. Addition of requirements for and procedures to calculate flood inflow during a flood event should be considered. An opportunity exists to undertake such revisions as part of the current development of storage management rules in light of the new Wimmera Bulk Entitlement. The authority should also consider having access to telemetered water levels at its unmanned storages during flood events. In addition, a formal, external review of GWMWater's flood operations would be beneficial.

1. Introduction

From September 2010 to February 2011, Victoria experienced a series of major flood events that caused significant community impacts, with several thousand homes and businesses affected. The Victorian Government has established a review of the 2010-2011 Flood Warnings and Response, known as the Victorian Floods Review (VFR). The VFR has undertaken extensive public and agency consultation since February 2011, and as part of this, communities and some agencies have raised questions around the adequacy of the operation of storages during the flood events.

This project has been initiated by the VFR to address those questions. The objective is to document the governance arrangements for the storages, and assess whether the storages were managed consistently with these arrangements during the 2010-2011 floods. The focus of this study is on the following six storages:

- Lake Eppalock (Campaspe River System);
- Cairn Curran Reservoir, Tullaroop Reservoir and Laanecoorie Reservoir (Loddon River System); and,
- Wartook Reservoir and Lake Lonsdale (Wimmera River System).

Other storages in the Wimmera-Mallee System headworks (specifically Lake Fyans and Lake Bellfield) were considered as deemed appropriate. A map showing the storages of interest as well as key river systems and locations is shown as Figure 1-1. The original project brief supplied by the VFR is included as Appendix A.

The review was based largely on documentary information supplied by the relevant water authorities. This was supplemented with interviews of key staff involved in flood operations and storage management at these authorities. The report was independently reviewed by David Dole; refer to Appendix B for the independent reviewer's assessment. The water authorities and the Department of Sustainability and Environment were also provided with an opportunity to comment on the report prior to its final release.

1.1 Credentials of the authors

This review was led by Peter Hill. Peter is a flood hydrologist and dam safety risk specialist with over 18 years experience. Peter has worked on and led dozens of flood hydrology and dam safety risk management projects across Australia. He has authored more than 60 technical papers and been awarded 4 prizes for technical presentations. Peter is currently a member of the National Committee on Water Engineering.

The review itself was undertaken by Kristen Sih and David Stephens. Kristen has over 7 years experience in flood hydrology and dam safety risk management. David is a flood hydrologist with over 8 years experience in dam flood hydrology, dam safety risk management and operational flood forecasting.

An independent review of the report was undertaken by David Dole. David has had some 48 years experience as an engineer in water resources management in Victoria, the Murray-Darling Basin and a number of overseas countries. In Victoria he held state wide responsibilities for design, construction, modernisation and management of major rural water conservation and supply systems as well as drainage and salinity mitigation works and measures. He has also had extensive experience in development and application of river and flood plain management policies and practices. David was involved with the Murray-Darling Basin initiative for over 30 years including serving several years as General Manager, River Murray Water where he had operational responsibility for directing the management of the Murray River and Lower Darling River Systems.

1.2 Reliance statement

The sole purpose of this report and the associated services performed by SKM is to review storage flood operations in accordance with the scope of services set out in the contract between SKM and the VFR. That scope of services, as described in this report, was developed with the VFR.

In preparing this report, SKM has relied upon, and presumed accurate, certain information (or absence thereof) provided by external sources. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be inaccurate or incomplete then it is possible that the observations and conclusions as expressed in this report may change.

SKM derived the data in this report from a variety of sources. The sources are identified at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. SKM has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose of the project and by reference to applicable standards, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by SKM for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, the VFR, and is subject to, and issued in connection with, the provisions of the agreement between SKM and the VFR. SKM accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

Figure 1-1: Campaspe, Loddon and Wimmera River Systems

2. Legal context

The *Water Act 1989* and the *Water Industry Act 1994* are the relevant legislations that govern the way water is managed in Victoria. Under these acts, the management of water storages is assigned to a storage manager (*Water Act 1989* S122ZK). The role of the storage manager is to control and manage the storages, and in doing this they must have regard to:

- Protecting the reliability and quality of the water supply (*Water Act 1989* S122ZL 2b);
- Developing and implementing strategies to mitigate flooding, where possible (*Water Act 1989* S122ZL 2d);
- Provide, manage, operate and protect water supply systems (*Water Industry Act 1994* S80);
- Supply of water to licence holders as dictated under the relevant Bulk Entitlements, specifically (*Water Act 1989* S34b):
  - Not release more water from its storages than is required to supply licence holders excepting transmission losses, dilution flows for serious water quality concerns or headworks maintenance;
- Comply with the Statement of Obligations (SoO) issued to them under the Water Act, specifically (*Water Industry Act 1994* S8):
  - Include in any plan, system or process to manage its risks, measures to deal with emergencies and incidents, including measures to deal with a dam failure (SoO 12.1c);
  - Undertake such periodic training and exercises as may be necessary to ensure that an emergency management plan can be implemented effectively (SoO 12.2);
  - Develop and implement a dam safety monitoring and surveillance program for each dam (SoO 14.3).

The role of the storage manager has been assigned to several water authorities within Victoria. For the purposes of this study, the storage managers are Goulburn-Murray Water (G-MW) and Grampians Wimmera Mallee Water (GWMWater).

2.1 Goulburn-Murray Water

G-MW operates under two relevant Bulk Entitlements. The Bulk Entitlement (Campaspe System – Goulburn-Murray Water) Conversion Order 2000 and the Bulk Entitlement (Loddon System – Goulburn-Murray Water) Conversion Order 2005 prescribe the means under which the authority is to harvest water, store it and supply it to entitlement holders.

The key component of these Bulk Entitlements as they relate to storage operations prior to and during floods is Clause 12.6 (Campaspe System) and Clause 13.6 (Loddon System), which state that as storage manager G-MW must not allow water to be released from Lake Eppalock, Tullaroop Reservoir, Cairn Curran Reservoir and Laanecoorie Reservoir except as it is required:

- To supply of primary entitlements;
- To supply transfers of primary entitlements including losses;
- To supply dilution flows to overcome serious water quality concerns; and
- For purposes of maintenance of the headworks system.

The instruments appointing G-MW as storage manager for the Campaspe and Loddon River Systems also include a clause stating that G-MW must account for any flood releases (including pre-releases and releases from low-level outlets during floods while storages are spilling). These releases must be accounted to the primary entitlement holders as specified in the Bulk Entitlements.

2.2 Grampians Wimmera Mallee Water

A new Bulk Entitlement for the Wimmera and Glenelg Rivers was finalised in October 2010 to recognise the Wimmera Mallee Pipeline. This document details the volume of water that GWMWater are able to extract from the Wimmera-Mallee system. In addition to the Bulk Entitlement, a legal instrument has also been developed that appoints GWMWater as storage manager for the Wimmera-Mallee System headworks. This instrument requires GWMWater to manage the storages to achieve a number of objectives, including:

- Maintain the structural and operational integrity of the headworks;
- Maintain and enhance the security of water supply to entitlement holders;
- Manage floods to conserve water and manage impacts on communities, including the supply of water to recreational lakes where this is compatible with the environmental objectives.

From this, it can be seen that there are several competing requirements for GWMWater in managing the storages. In particular, the requirement to manage floods does not specifically require that GWMWater reduce flooding, but states that floods should be managed to conserve water and manage impacts on communities – impacts that include damage due to floods, as well as maintaining a secure water supply after the flood event has passed.

The manner in which each of these competing objectives are balanced is to be detailed in storage management rules. These rules must be developed in consultation with entitlement holders and the Department of Sustainability and Environment (DSE), and are to be in place within 12 months of the commencement of the instrument (ie October 2011). These rules have not yet been finalised and as such, the flood events of interest occurred during a time of transition for the operation of the storages.

3. Constraints to operation for flood mitigation

Large on-stream storages can have a significant impact on riverine flood hydrology. By collecting water from their upstream catchments and routing it through a fixed control structure such as a spillway, storages typically play an attenuating role on peak flood flow rates. Storages can be divided into fixed crest dams and gated dams, with the principal difference being that gated dams allow a degree of control over the water level within the storage via adjustable spillway gates.

The impact of the attenuating effect of storages on floods is controlled by several key factors, listed below in decreasing order of influence. Storage managers can exert day-to-day operational control only over the last two factors.

- The magnitude of the inflow flood to the storage;
- The size of the storage (ie storage capacity and spillway capacity);
- The volume of airspace in the storage prior to the event; and
- The arrangement and operation of the storage spillway control structures (if any).

In Australia, examples of storages with formal flood mitigation roles are typically limited to flood retarding basins located in urban areas. There are rare exceptions to this for large storages, none of which are in Victoria.

Figure 3-1 shows the typical components of fixed crest and gated dams. The spillway usually consists of a fixed crest, such that when the water level in the storage exceeds the crest level water spills from the storage. The full supply level (FSL) for a storage is usually defined to be at the spillway crest level. The storage manager has no operational control over spillway outflows from a fixed crest storage. Gated dams are slightly different as the spillway gates allow water to be stored above the spillway crest, and provide a degree of control over outflows from the storage.

Where large storages have been built primarily for water supply it is recognised that flood mitigation is a useful but secondary side effect. In the case of fixed crest dams, such benefits can only be enhanced by controlling the level of airspace in the storage prior to the onset of a flood. This depends on the storage manager having sufficient reliable forewarning of the flood event to release water through the dam's low level outlet. These low level outlets frequently have a capacity that is orders of magnitude lower than inflows during a large flood. As such, if warning of an oncoming flood event is not sufficiently early then the operator typically has limited opportunity to create additional airspace via the low level outlet. Typically reliable forecast lead times of three to four days can be provided by the Bureau of Meteorology at the regional scale. However, this does not always translate into accurate forecasts over reservoir catchments, which generally only clarify within one or two days of the event.

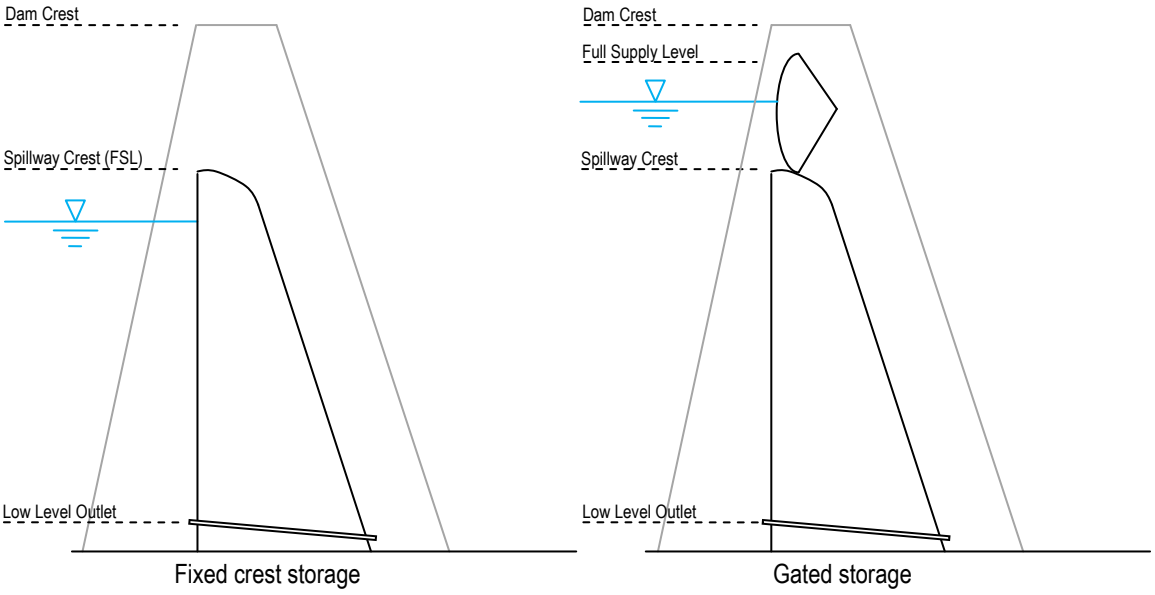

Figure 3-1: Example of typical storage arrangements

Conversely, if the rainfall or flood forecast is not sufficiently accurate then the dam operator runs the risk of releasing large volumes of valuable water intended for supply that may not be able to be recaptured if the forecast flood fails to materialise. This can have a significant impact on the reliability of supply to primary entitlement holders, and may be prohibited under the clauses of the Bulk Entitlements that storage managers are subject to.

Storages with gated spillways allow some additional flexibility to mitigate flood events, however the same risks related to loss of stored water still apply. Pre-releases from gated storages must also be carefully managed to ensure that they do not result in flooding downstream prior to the onset of the riverine flood. In addition to this, operation of gated storages during floods must be undertaken such that the safety of the dam is not compromised. Operating the spillway gates such that the outflow is less than the inflow will result in the water level in the storage rising above full supply level. This is referred to as 'surcharging'.

Some storages are manually lowered at the start of winter and then allowed to fill gradually over the wetter period of the year. The rate at which they are filled is controlled by manual releases such that the water level in the storage does not exceed a "target filling curve". This operation is generally designed to maximise the volume of water being harvested, as the manual releases are transferred to downstream off-line storages (where they exist). Target filling curves provide some incidental flood mitigation benefits by providing additional airspace in the storage over the winter months, however to ensure reliability of supply for entitlement holders the storage is typically allowed to fill by the start of spring.

3.1 Storage characteristics

The key characteristics of the storages that have been considered as part of this review are documented in Table 3-1.

Table 3-1: Storage characteristics

Storage	Owner	River System	Type	Capacity (ML)	Low Level Outlet Capacity (ML/d)
Lake Eppalock	G-MW	Campaspe	Fixed crest	304,650	2,600
Cairn Curran Reservoir	G-MW	Loddon	Gated	147,130	1,600
Tullaroop Reservoir	G-MW	Loddon	Fixed crest	73,690	750
Laanecoorie Reservoir	G-MW	Loddon	Gated*	7,930	1,300
Lake Bellfield	GWMWater	Wimmera	Fixed crest	78,550	860
Lake Fyans	GWMWater	Wimmera	Fixed crest	18,460	80
Lake Lonsdale	GWMWater	Wimmera	Fixed crest	65,550	600
Wartook Reservoir	GWMWater	Wimmera	Fixed crest	29,360	500

* Laanecoorie Reservoir is gated but its relatively small size means that little operational control over floods can be exerted at the storage

Note that Coliban Water's storages on the Coliban River upstream of Lake Eppalock were not considered as part of this review.

4. Flood operation policies

Both of the storage managers considered as part of this review have a number of policies and procedures in place that guided how their storages were managed in the floods of interest.

4.1 Goulburn-Murray Water

G-MW's flood operations policies and procedures are set out in a range of documents. Advice from G-MW indicates that some of these documents are currently being revised, and as such this review has primarily focused on the documents that were in place between September 2010 and February 2011.

4.1.1 Board policy

G-MW have an explicit policy on flood operations, adopted at board meeting number 83, 29 June 2001. This policy states that the primary purpose of flood operations is to ensure dam safety (ie, to ensure that dam crests are not overtopped). The background to this policy notes that eight of the storages managed by G-MW have gated spillways, whilst the other nine have fixed crest spillways.

The policy effectively places defined limits on the flexibility of flood operations at G-MW's gated storages to ensure that dam safety is not compromised. The policy states that "surcharging of structures is not permitted, except in accordance with documented operational procedures for the structure approved by the Manager Headworks" (G-MW, 2001).

G-MW have included a documented provision to surcharge for flood mitigation at Lake Eildon. Their other gated storages, including Cairn Curran Reservoir, may not be deliberately surcharged to provide flood mitigation, in accordance with board policy.

4.1.2 Dam safety management system

G-MW have established a dam safety management system that provides a framework for how each of their storages is to be managed. The dam safety management system is composed of several key documents for each storage, namely:

- Dam safety emergency plan (DSEP)
- Operation and maintenance manual (O&M manual)
- Asset management system / risk management plan
- Flood incident management system
- Land and on water management plan / water quality and biodiversity management plan

G-MW have advised that whilst this framework is not fully established for all their storages, they are moving progressively towards it by revising and reformatting existing storage management manuals to ensure consistent manual structure and terminology across all storages.

The key documents provided and considered as part of this review were the O&M manuals for the four storages in question. The flood management rules for Cairn Curran Reservoir were also provided that contain the procedures for gate operations during floods. It is currently being revised, however this review has primarily focused on the version in place during the floods of interest. Flood incident management systems are not yet developed for the fixed crest storages.

Governance arrangements for each storage are described in the O&M manuals and are divided amongst the following sections:

- Dams operations and maintenance section: responsible for daily operation and maintenance of G-MW storages, including responding to emergency situations;
- Reservoir staff: responsible for directing and monitoring the physical performance of the relevant storage. Reservoir staff are required to be on stand-by with response times varying from 10 minutes to one hour. Their duties including routing, monitoring and recording flood events.
- Regulated systems team: primarily responsible for delivery of G-MW's water resources practices and policies however also assist dams staff in flood management.

Lines of communication are also documented in the O&M manuals, and for flood releases typically include the following:

- The regulated systems duty officer will liaise directly with the reservoir duty officer to obtain reservoir levels and spillway flows;
- The reservoir duty officer must notify the operations and maintenance manager prior to commencing flood releases.

Under the O&M manuals and accepted internal procedure, decision making during flood events is undertaken using a collaborative approach, with input from reservoir staff, the dams unit and the regulated systems team. Additionally, if DSEP procedures are triggered the dam safety manager will also be involved. The exact nature of the incident control response within G-MW depends on the nature of the flood event – smaller events are typically handled by duty officers with supervision from senior management as required. Larger events are handled by the establishment of an incident control centre and feature significant and regular involvement from staff including the Manager Regulated Systems, the Manager Dams and above.

Communication arrangements between external agencies and G-MW staff during a flood incident are also documented in the O&M manuals. Of particular relevance, the regulated system duty officer is nominated as the contact for the Bureau of Meteorology (BoM) in cases where information is required to inform the preparation of flood warnings. The Cairn Curran flood management rules also include provision for the reservoir duty officers to maintain contact with the Bureau of Meteorology. Communication with emergency services is undertaken by both reservoir duty staff at the local level and the incident management team at the wider (regional) level. Communication requirements for reservoir duty staff and regulated systems duty staff are well defined in the documentation for each storage. The frequency and nature of

higher level communication between G-MW senior management and SES incident control centres appears to be informal in nature and is not yet finalised.

Whilst the O&M Manuals and Cairn Curran flood management rules are reasonably clear in their definition of roles and responsibilities, these procedures are highly specific to the individual storages. There do not appear to be documented procedures covering the nomination and responsibilities of the incident controller and arrangements for wide scale response when several catchments are in flood concurrently. It is understood these procedures are currently being developed by G-MW.

4.1.3 Target filling curves

Target filling curves are not used at G-MW's fixed crest storages. At Cairn Curran Reservoir, the target filling curve (documented in the O&M manual) specifies target reservoir volumes over the period from 1 June to 1 August. If the reservoir water level rises above the target curve during this period it is to be drawn down using the low level outlets (subject to some criteria on rates of drawdown). After 1 August the reservoir level is to be maintained between an interim full supply level of 208.16 m AHD and normal full supply level of 208.46 m AHD. Filling of the reservoir in spring is subject to seasonal conditions however the aim is for the reservoir to be filled prior to the onset of irrigation demands. The target filling curve is shown in Figure 4-1.

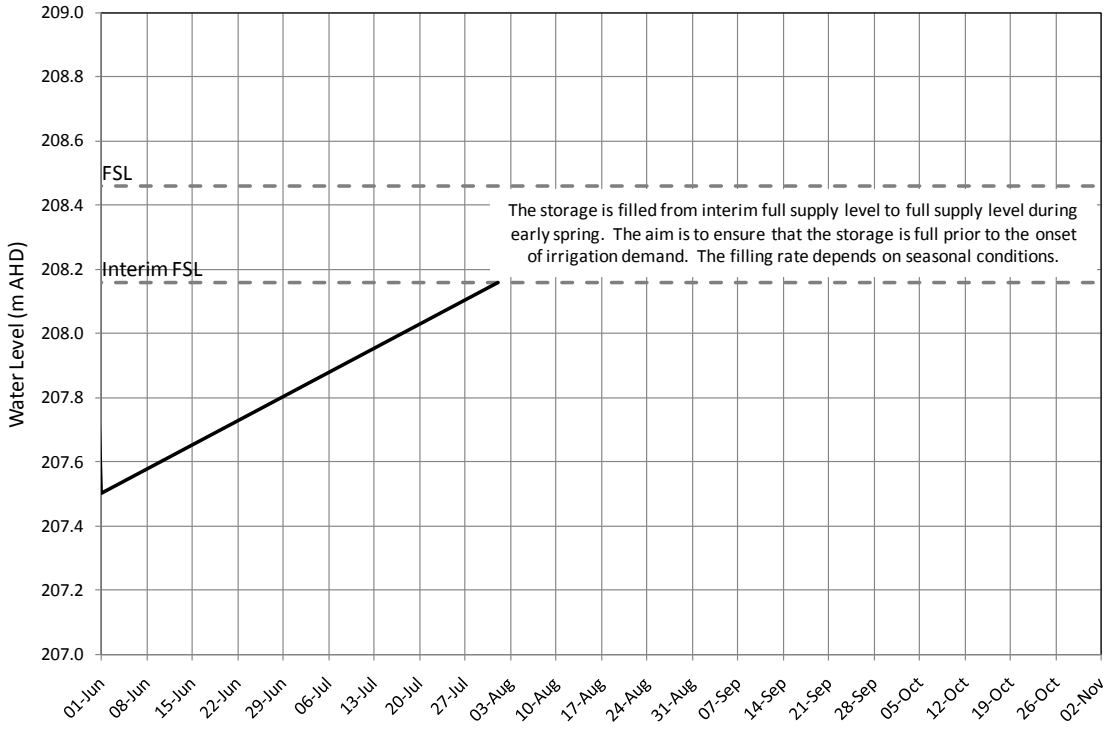

Figure 4-1: Cairn Curran Reservoir target filling curve

It is understood that the Cairn Curran target filling curve has been established in order to provide some flood mitigation benefit over the wetter winter and early spring period whilst ensuring that a reliable supply can be provided to entitlement holders.

4.1.4 Cairn Curran Reservoir

As the only gated storage with sufficient capacity to provide an attenuating impact for large floods within the scope of this review, special consideration was given to Cairn Curran. Laanecoorie Reservoir is also a gated structure however due to its size relative to the size of the upstream catchment has little ability to attenuate floods. Flood operations at Cairn Curran are governed by the flood management rules, which cover a range of topics such as hydrological forecasting, modelling, gate operations and communication internally and with external parties.

The flood management rules state that the objectives of gate operations at Cairn Curran are to ensure the safety of the dam during the passage of all floods. The document specifically references the G-MW board policy on surcharging of dams. The list of duties and responsibilities of the reservoir duty staff include a requirement to operate the spillway gates to prevent full supply level being exceeded.

The gate operations rules for Cairn Curran can be summarised as follows:

- Releases less than 1,600 ML/d to be made via low-level outlets;
- Releases greater than 2,000 ML/d and less than 10,000 ML/d to be made via the centre spillway gate;
- As the reservoir approaches full supply level, releases to be evenly distributed over all three gates.

The Cairn Curran flood management rules also identify a range of communication activities that must be undertaken by either the reservoir duty staff or the regulated system duty officer during various stages of flood releases. These communication requirements are documented in multiple places throughout the flood management rules, including Sections 9, 14, and 15. The rules include both internal G-MW communication (ie between the reservoir duty staff, regulated systems staff, the manager dams, the dam safety manager, the Laanecoorie Reservoir duty staff and G-MW offices in Kerang and Pyramid Hill) as well as communication with external agencies (including the Bureau of Meteorology, Mount Alexander Shire, Loddon Shire, Victoria Police, Victorian State Emergency Service and AGL Hydro). There is also a requirement to notify private citizens and landowners (including residents at the Loddon House Caravan Park at Baringhup) at a number of release and reservoir water level conditions.

Providing advice to communities that may be impacted by storage operations is a responsible approach by G-MW. In the particular case of the Loddon House Caravan Park, direct advice from the authority is currently an essential component of public safety in a rapidly developing flood situation when timely reaction from emergency agencies is unlikely. It is acknowledged that these arrangements engender a range of difficulties for G-MW, including maintaining an up to date database of flood-aware individuals and contact numbers. As such, the advice provided by G-MW is not equivalent to flood warnings and should not be seen as a replacement for formal flood warning services. A greater understanding by Police and SES of the need for rapid reaction (including evacuation) to major flood situations at the caravan park would significantly enhance the overall emergency management response for this community.

4.1.5 Summary

G-MW's documented policies and procedures reflect the primary intent of their storages, which is for water harvesting and supply. Some of the procedures are currently being revised to ensure consistency across all operational documents.

The O&M Manuals and flood management rules for Cairn Curran include clear roles and responsibilities for authority staff during flood events. Further consideration should be given to GMW's role in providing warnings and advice to communities and individuals downstream of Cairn Curran during flood events.

4.2 Grampians Wimmera Mallee Water

GWMWater have developed Operation, Inspection and Maintenance Manuals (OIM Manuals) for their storages, which include details on how the storages are to be operated on a day-to-day basis. The focus is generally on the operation of the storages for the purposes of water harvesting and supply, although there are some areas where the operation of the storages during flood events is mentioned. The OIM Manuals were developed between 2003 and 2010, and the versions provided for this study are described as drafts. GWMWater has subsequently indicated that controlled hardcopies of the final versions are in use at the storages and in GWMWater's head office. The OIM Manuals are generally complete for Wartook Reservoir and Lake Lonsdale. The development of storage management rules associated with the new Bulk Entitlement for the Wimmera River System provides an opportunity for GWMWater to clarify their obligations to provide flood mitigation, where possible.

In addition to the OIM Manuals, individual DSEPs have been developed for manned reservoirs, and a generic DSEP has been developed for unmanned reservoirs. These have been developed through a planning committee consisting of GWMWater, DSE, Victoria Police and the Victorian State Emergency Service. The plans are referenced in the flood plan of the Horsham Rural City Emergency Management Plan. Although the focus of these plans is on dam safety, a flood notification flow chart is also included for events that are not related to dam safety.

The general internal governance arrangements for the storages are described in Figure 4-2. The Reservoir Keeper is the central figure in the governance arrangements as they will be on site in an emergency situation. Where there are issues with the dam structure, the keeper is required to contact the GWMWater Headworks Assets Manager as well as the headworks consultants (currently SMEC Victoria). The Reservoir Keeper is also required to keep the GWMWater Water Resources Manager informed on the day-to-day variables affecting the supply, and the need and timing of releases from the storage. It is not clear how routing of floods through the storages is monitored and the procedure for calculating reservoir inflow is not documented.

It is also explicitly stated that effective communication must be maintained between GWMWater staff and members of the public or parties affected by the operation of the system, however the process for undertaking this communication is not clearly described in the OIM Manuals, beyond provision of key contact details in an appendix.

4.2.1 Eastern Headworks System – Lake Lonsdale, Bellfield and Fyans

Lake Lonsdale, Lake Bellfield and Lake Fyans are part of GWMWater's Eastern Headworks System, as shown in Figure 4-3. The operating rules for all three storages are focused on supplying entitlements to downstream licence holders. There are some exceptions to this for Lake Lonsdale, as the reservoir is subject to high evaporative losses. The water in Lake Lonsdale is only supplied via natural inflows and is typically used first in order to maintain the storage at a relatively low level. Lake Lonsdale remains an active storage and there is a consequent need to monitor and manage inflows and outflows there during flood conditions. Lake Lonsdale and Lake Fyans are unmanned and are operated and maintained on a day-to-day basis by Reservoir Keepers based at Lake Bellfield and Wartook Reservoir.

Lake Bellfield is operated to a target level (referred to as a 'flood reserve') of 276 m AHD (0.5 m below spillway crest level) over the months of April to September. The primary purpose of this target level is stated as minimising the effects of wave action on the embankment and shoreline, however it has a secondary purpose of providing airspace for flood mitigation. The Wannon Diversion is only operated over the period from June to October inclusive. If it is in operation, and heavy flood conditions already exist in Fyans Creek, then the diversion is shut off. The Lake Bellfield OIM Manual specifically states that the Reservoir Keeper has no obligation to advise downstream landowners of flood releases via the low-level outlet unless advised by the Senior Water Resources Engineer.

Lake Fyans is an off-stream storage and consists of a bank across a natural swamp. The inlet channel to the reservoir crosses over several catchments, and as such, cross flow enters the channel through numerous inlets during flood events. These inlets are kept open to allow flood water to flow through Lake Fyans, to minimise inconvenience to landholders.

Lake Lonsdale is operated at 0.5 metres below the spillway level. Transfers into the storage are no longer made from Lake Bellfield, with inflows being supplied from the natural catchment. However, when Bellfield is spilling, this does enter Lonsdale as the Lonsdale Bypass (capacity of approximately 350 ML/day) is rarely used.

As Lake Lonsdale and Lake Fyans are unmanned, the generic dam safety emergency plan for unmanned storages is applied to them. This was developed in May 2003, although some changes have been made recently to the document. This document is focussed on dam safety, and states that no dam safety emergency action is required by GWMWater unless extremely large floods occur. For the case of Lonsdale, the extremely large flood trigger inflow is 23,700 ML/day. No extremely large flood trigger inflow is provided for Lake Fyans. An incident plan that details actions required during an extremely large flood is also provided.

As Lake Bellfield is manned, an individual DSEP has been developed for it. Similarly to the unmanned storage DSEP, this DSEP is for use in extreme flood events, with it being triggered when inflows to Bellfield exceed 20,000 ML/d. Where the Bellfield Reservoir Keeper computes the inflow into the storage as 20,000 ML/d, the dam safety emergency notification chart applies. If the inflows increase above this, then the notification chart for actual or imminent dam failure threat is to be initiated.

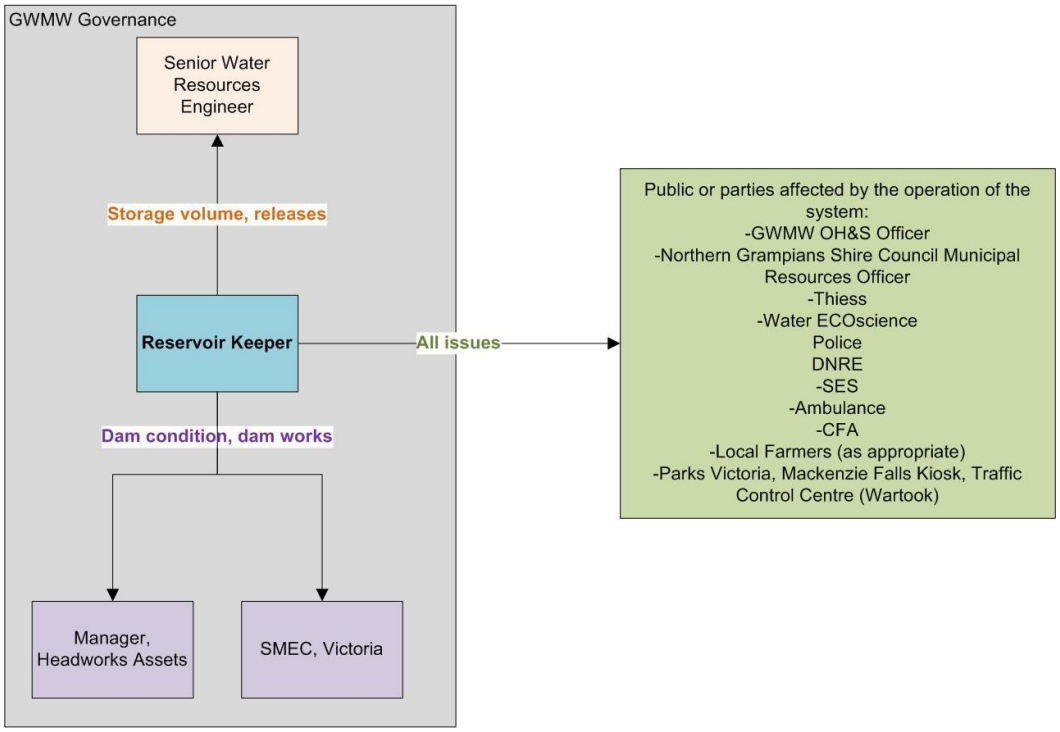

Figure 4-2: Governance procedures for the operation of GWMWater storages

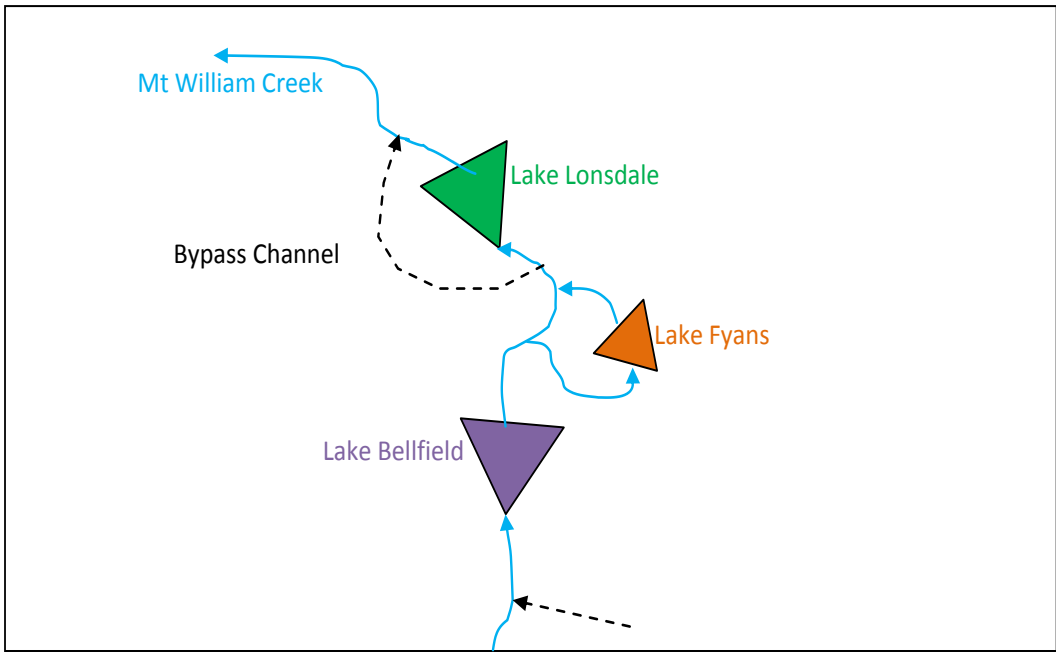

Figure 4-3: Eastern headworks system layout

Although the focus of the Lake Bellfield DSEP is on dam safety, it also contains notification procedures for flood events not related to dam safety. This has been reproduced in Figure 4-4. Other useful information included in the Bellfield DSEP are clear descriptions of the roles of various agencies, including their responsibilities and action plans during a dam safety emergency.

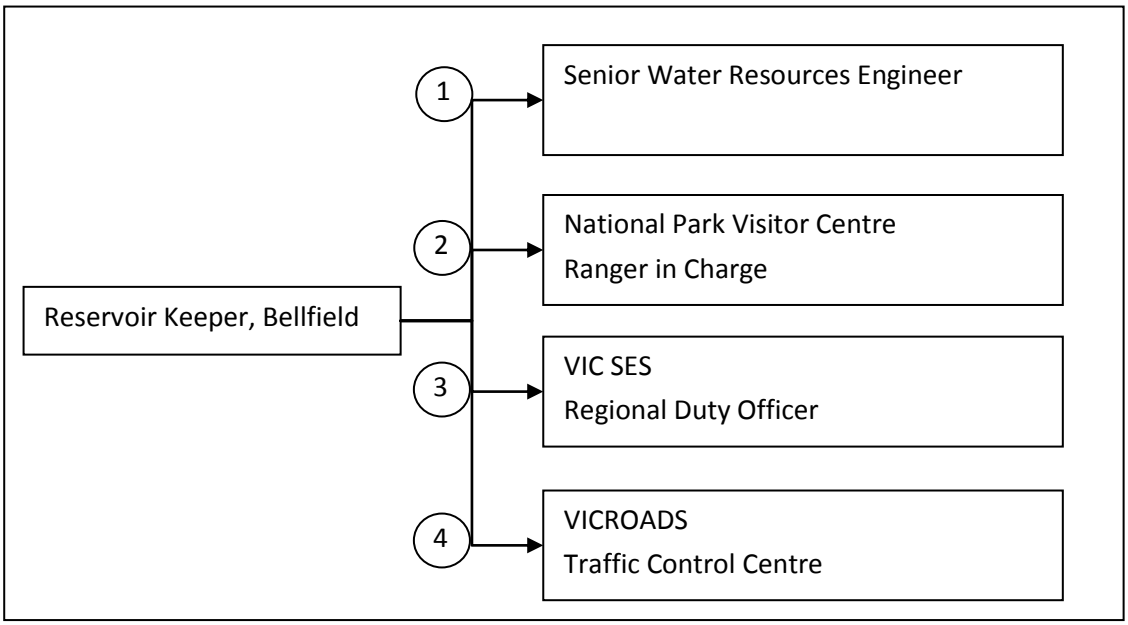

Figure 4-4: Lake Bellfield flood notification procedures

4.2.2 Wartook Reservoir

Wartook Reservoir is the primary supply source for Horsham, and also provides backup for the Wimmera Mallee Pipeline.

A target filling curve (referred to as a 'flood reserve') is applied at Wartook, which requires the storage operator to adhere to the target water levels shown in Figure 4-5. Barlow (1987) states that the 'flood reserve' was initially put in place to prevent uncontrolled flows from the spillway causing inconvenience and damage downstream. However, the current operation of the 'flood reserve' is used to maximise harvesting. Water is transferred from Wartook Reservoir to Taylors Lake at the start of the wet season in order to optimise the total volume of water stored at the start of summer.

As Wartook Reservoir is manned, the DSEP has been developed in a similar way to that for Lake Bellfield. The DSEP provides a description of the role of each of the different agencies, along with action guides that detail the response required of each agency.

There is a section in the DSEP that details the operation of the dam during flood events. This states that the storage is continuously manned during flood events, with the GWMWater Senior Water Resources Engineer and the Reservoir Keeper being in regular contact. When flow occurs through the primary spillway, flooding of the McKenzie Creek at Zumsteins (just over 8 km downstream of the reservoir) is probable and the Reservoir Keeper is to make direct daily

contact with the GWMWater Senior Water Resources Engineer, Chief Ranger Parks Victoria and VicRoads.

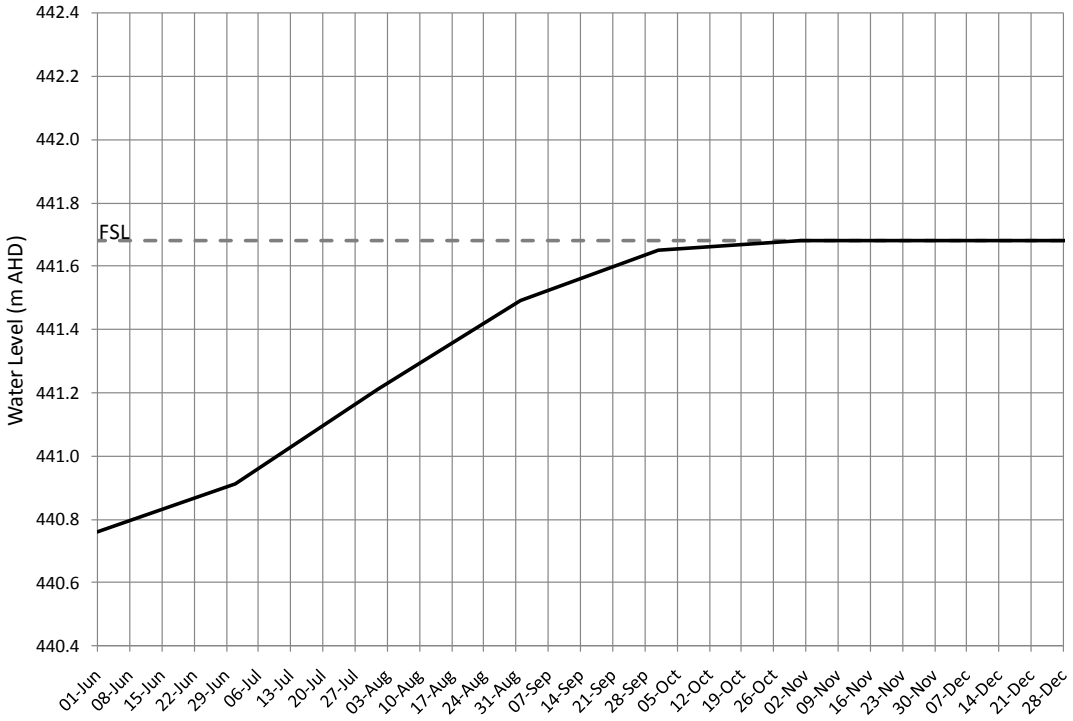

Figure 4-5: Wartook Reservoir target filling curve

Access to the embankment is lost when the reservoir water level reaches 441.79 m AHD. It is stated that significant flooding will already be occurring downstream at this level, and therefore Emergency Action 1 will be initiated. This requires a number of stakeholders to be notified. There is also a notification flow chart (similar to the Lake Bellfield chart shown in Figure 4-4) that should be used in the case of flooding not associated with an actual or imminent dam safety situation.

4.2.3 Summary

In general, GWMWater's procedures reflect the intent of the storages as primarily for water harvesting and supply. Flood mitigation opportunities have been built into the operating procedures (as target filling curves or 'flood reserves') where these do not impact the authority's ability to supply downstream entitlement holders. The development of storage management rules associated with the new Bulk Entitlement for the Wimmera River System provides an opportunity for GWMWater to clarify their obligations to provide flood mitigation, where possible.

Arrangements for monitoring and recording flood events as they are routed through the storages are not clearly documented. Communication requirements at different levels of flood inflows are well documented and can clearly be followed through the use of flowcharts. Communication procedures for floods not involving a dam safety emergency could be included in the OIM Manuals instead of in the DSEPs.

GWMWater's OIM Manuals and DSEPs may need to be reviewed in light of lessons learnt from the 2010-2011 flood events.

5. Impact of storages on the 2010-11 floods

Time series data provided by G-MW and GWMWater was analysed together with publicly available streamflow data in order to quantify the hydrological impact of the storages of interest on the 2010/2011 Victorian floods. The analysis was focused on selected flood events that were of particular interest due to their magnitude or impacts. Given the nature of the data available and the scope of this review, the investigation was limited to first order analysis of gauged hydrographs. No hydrological or hydrodynamic modelling was undertaken.

5.1 Campaspe River System

Lake Eppalock had a significant attenuating impact on major floods in the Campaspe River System in November 2010 and January 2011. The November 2010 event occurred after a period of prolonged drought across much of Victoria, the result of which was that the water level in Lake Eppalock was well below full supply level. This provided a significant volume of airspace equivalent to approximately two-thirds of the volume of the inflow flood. As such, a flood event which would have resulted in major flooding downstream of the storage was attenuated such that outflows from the storage were less than the minor flood level. Time series plots of calculated reservoir inflow as well as gauged reservoir outflow and water level are shown in Figure 5-1.

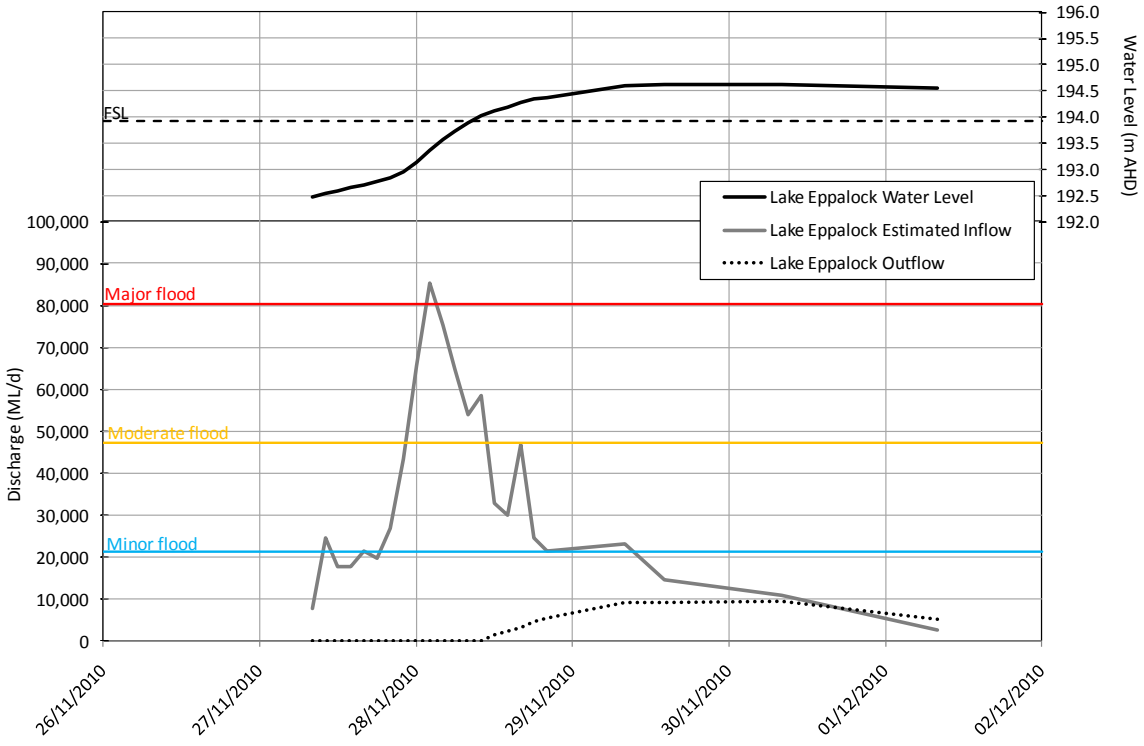

Figure 5-1: Lake Eppalock hydrographs – November 2010

The Campaspe River flood in January 2011 was significantly larger than the November event. Additionally, the water level in Lake Eppalock was at full supply level and as such there was no airspace available as was the case in November. However, the reservoir still played a key role

in attenuating the flood peak and thus mitigating the flood impacts to communities downstream of the storage. As shown in the time series plot in Figure 5-2, the peak inflow to the storage was approximately 140,000 ML/d, whilst the outflow peak was close to 80,000 ML/d. Figure 5-2 also shows that there was further, although relatively small additional attenuation of the flood peak between Lake Eppalock and Rochester, where this event resulted in severe flood impacts. The increase in peak flow and hydrograph volume between Barnadown and Rochester is most likely the result of local inflows in that area. As a result of this analysis, it was concluded that Lake Eppalock played a significant role in mitigating flooding even for communities as far downstream from the storage as Rochester.

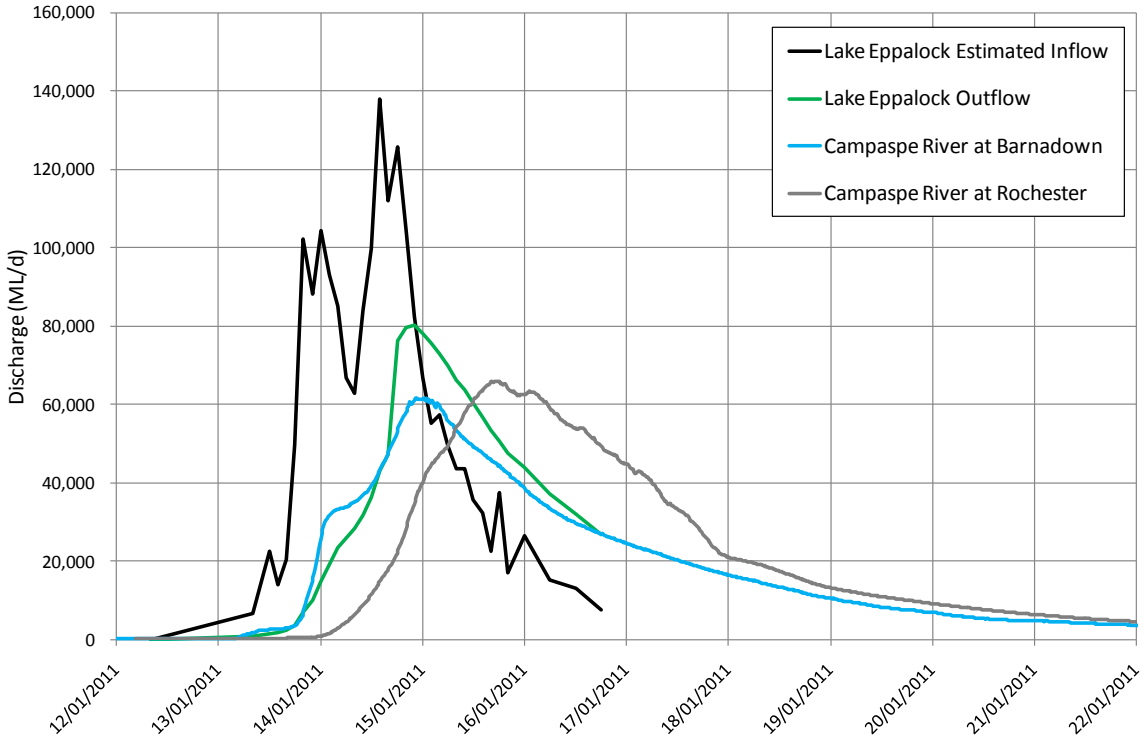

Figure 5-2: Campaspe River System hydrographs - January 2011

5.2 Loddon River System

Major flooding occurred in the Loddon River System in November 2010 and January 2011. The November event was somewhat smaller than the January event, however still resulted in major flooding downstream of Cairn Curran Reservoir. Figure 5-3 shows time series hydrographs of estimated inflow and gauged outflow and water level at Cairn Curran during the November 2010 flood event. It can be seen that the reservoir water level was close to full supply level prior to the event, and that outflows from the storage generally matched inflows, save for some attenuation of the flood peak flow.

It can also be seen that on the falling limb of the inflow hydrograph a second peak in inflows occurred close to 4 pm on 28 November 2011. The attenuating effect of the reservoir was such that outflows from the storage did not rise again, but remained below major flood level. The reservoir water level peaked approximately 100 mm over full supply level for the event. On 29

September, outflows from the reservoir were maintained at greater than the moderate flood level for some 12 hours during which the inflows fell below this level. G-MW advised that this was done to draw the reservoir level down below full supply level in order to provide some airspace. This appears to have been an operational decision made in light of conditions in the catchment at that time. Maintaining outflows at this level for this period of time would have been unlikely to have any material bearing on the severity of flood impacts to downstream communities.

At Tullaroop during the same event, outflow from the storage peaked at less than 2,300 ML/d. Further downstream, outflows from Laanecoorie Reservoir peaked at close to 80,000 ML/d, as a result of additional inflows downstream of both Tullaroop and Cairn Curran. This flood peak was attenuated significantly by the time it reached Loddon Weir, with peak flows there of approximately 36,000 ML/d. There was significant lag and attenuation between Loddon Weir and Kerang, with flows peaking some 10 days later at approximately 5,000 ML/d. This degree of attenuation is the result of the large volume of floodplain storage available in the Loddon River downstream of Bridgewater. In addition to this, the prolonged period of drought prior to the November 2010 flood event had left the catchment very dry, leading to significant losses in flood volume below Loddon Weir. Loddon River System flood hydrographs in November 2010 are shown in Figure 5-4.

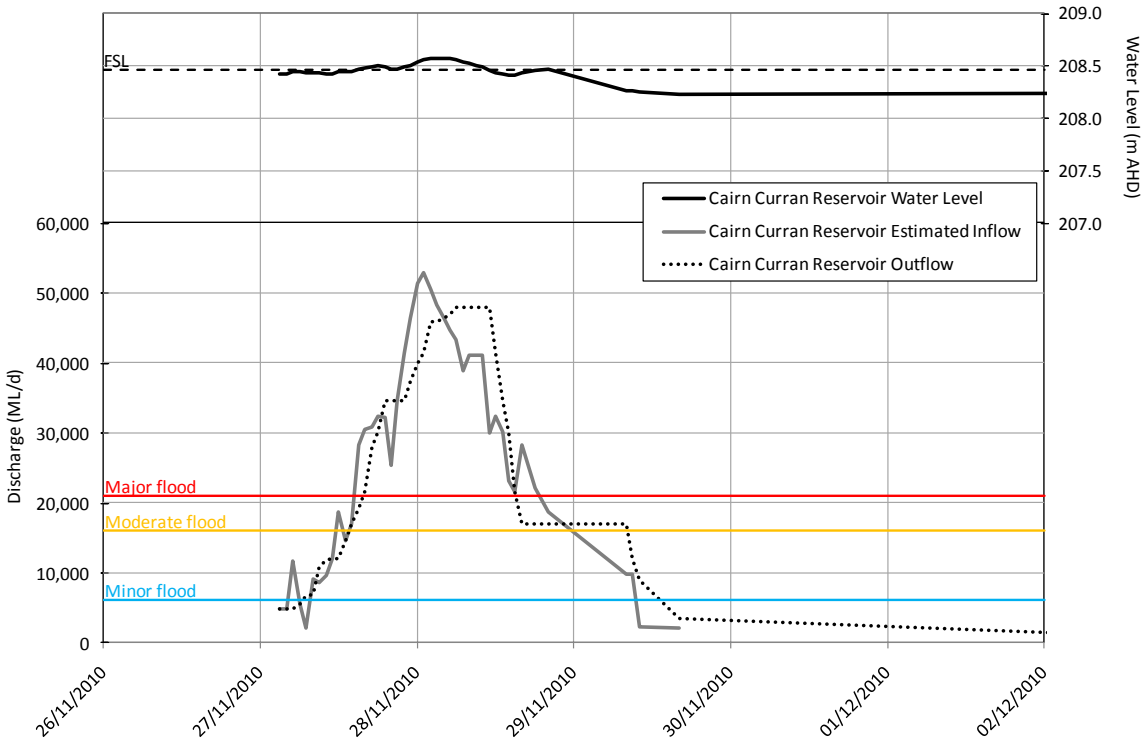

Figure 5-3: Cairn Curran Reservoir hydrographs – November 2010

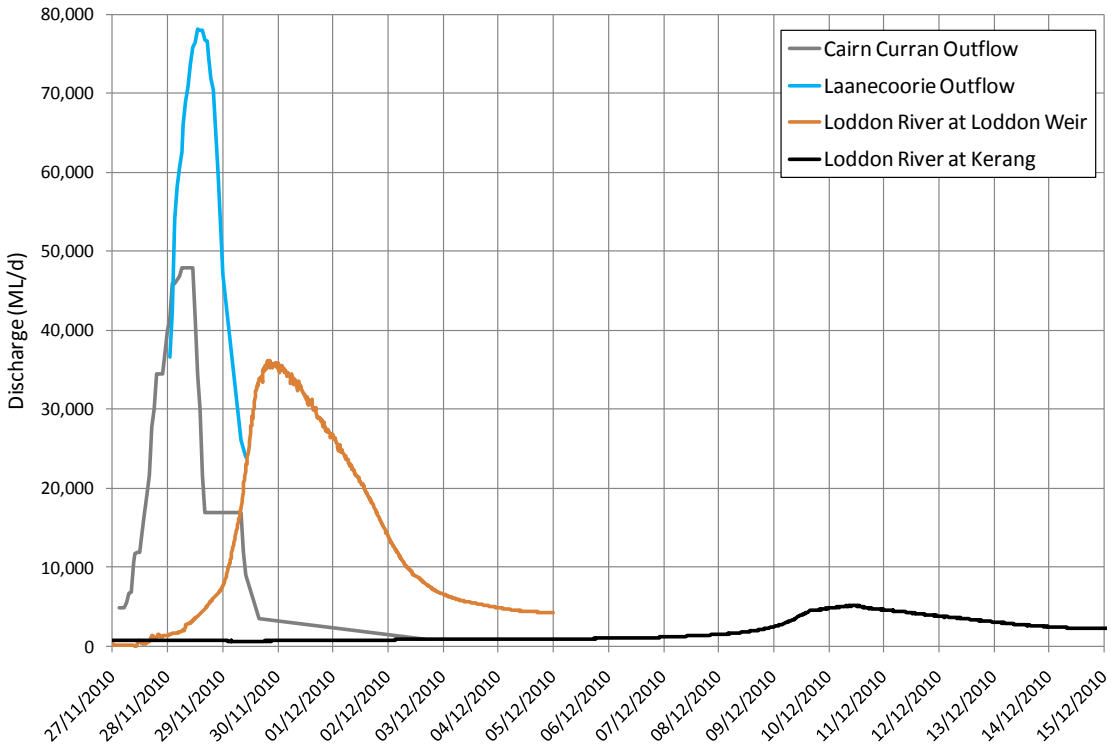

Figure 5-4: Loddon River System hydrographs – November 2010

The January 2011 flood event saw large inflows to both Tullaroop and Cairn Curran Reservoirs. At Tullaroop, the reservoir attenuated the flood peak flow by approximately 20,000 ML/d, despite the storage being close to full supply level at the start of the event. This can be seen in the time series plot shown in Figure 5-5. At Cairn Curran (Figure 5-6), the water level in the reservoir was 250 mm below full supply level at the start of the event, which provided a degree of airspace in the storage, delaying the onset of moderate flooding at Baringhup for almost 24 hours. The reservoir outflows generally matched inflows for the remainder of the event, save for the flood peak being attenuated by close to 10,000 ML/d.

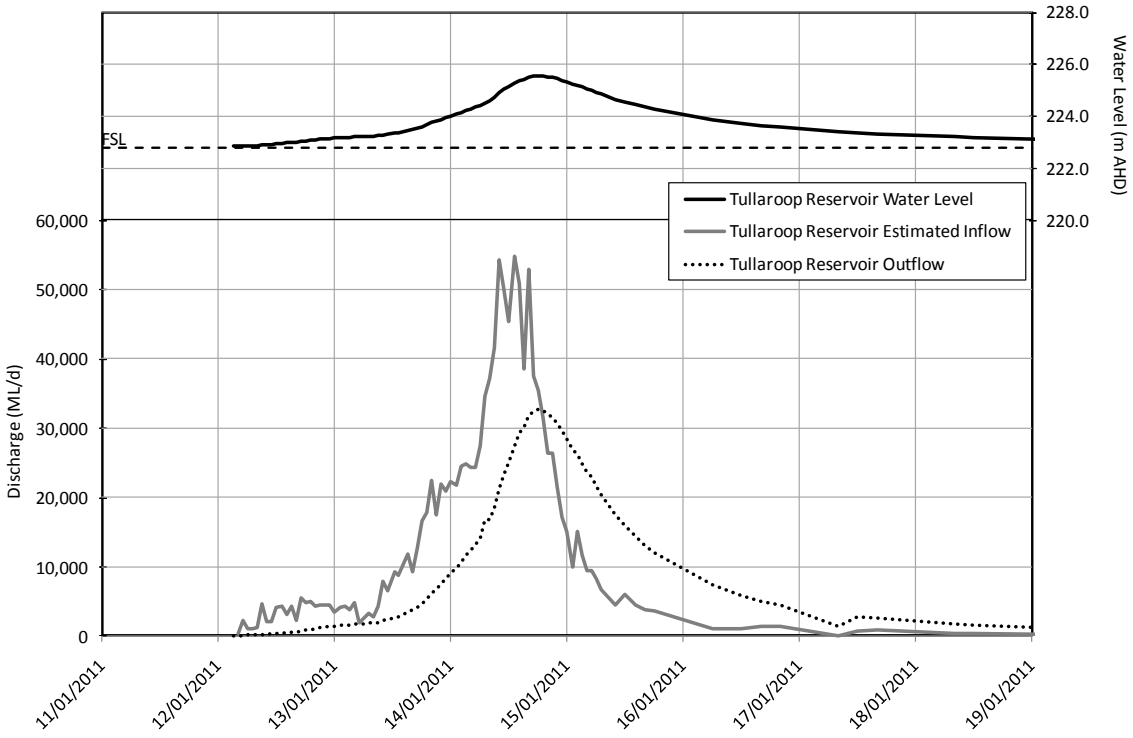

Figure 5-5: Tullaroop Reservoir hydrographs – January 2011

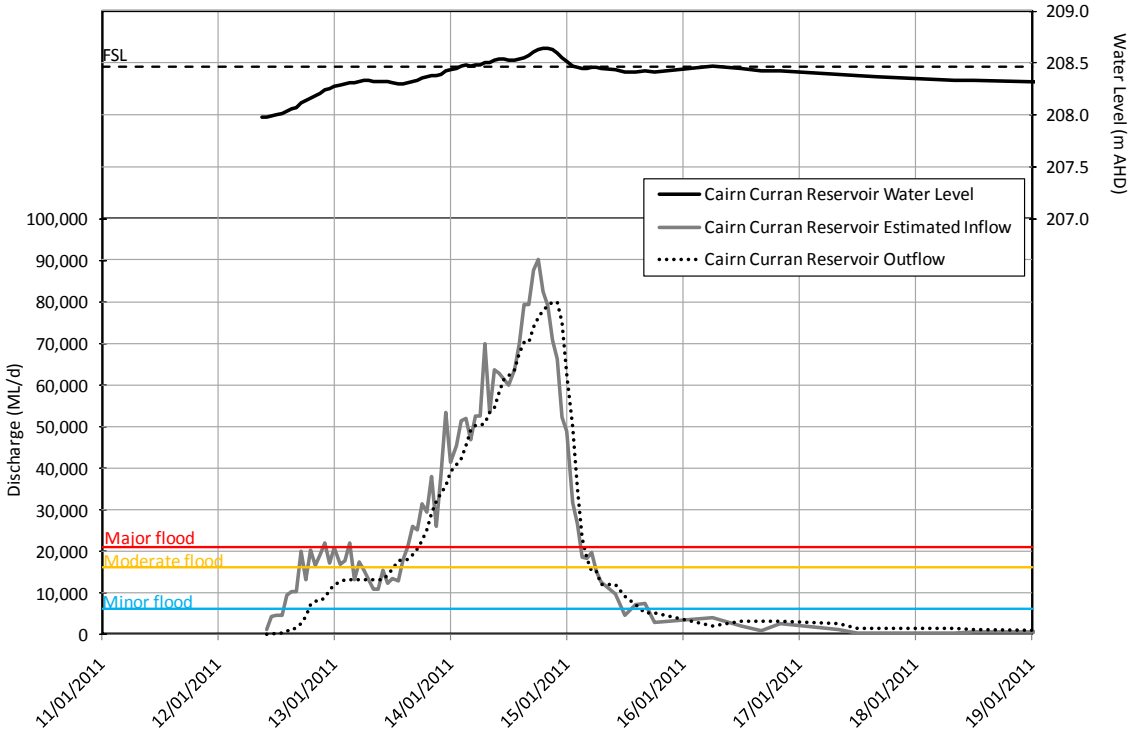

Figure 5-6: Cairn Curran Reservoir hydrographs – January 2011

The significant outflows from both Tullaroop and Cairn Curran Reservoirs contributed to inflows of almost 200,000 ML/d at Laanecoorie Reservoir. The increase in both peak flows and hydrograph volume between combined outflows from Tullaroop and Cairn Curran to Laanecoorie was the result of inflows from the Loddon River and its tributaries (such as Bet Bet Creek) between the storages. The combined catchment area upstream of Tullaroop and Cairn Curran (2,340 km^2) is only just over half of the total catchment area of Laanecoorie (4,120 km^2) and as such it is to be expected that there would be significant additional inflows downstream of Tullaroop and Cairn Curran. The magnitude of the inflow flood to Laanecoorie was many times larger than the capacity of the storage there and so very little attenuation occurred. Outflows from Laanecoorie were very similar to inflows.

Downstream of Laanecoorie Reservoir, the Loddon River becomes highly anabranched. This results in large volumes of the floodplain being engaged to store and attenuate floodwaters. As a result, the peak outflow from Laanecoorie Reservoir of almost 200,000 ML/d was attenuated to less than 50,000 ML/d at Loddon Weir, downstream of Serpentine. At Kerang, the flood peak was less than 20,000 ML/d. This is shown graphically in Figure 5-7. Whilst these flood peaks resulted in major flooding and severe impacts to communities such as Kerang, they demonstrate that the attenuating effect of storages such as Tullaroop and Cairn Curran was relatively localised. Whilst Tullaroop provided some flood mitigation benefits for local communities immediately downstream, these effects were not significant downstream of Laanecoorie Reservoir. Similarly, Cairn Curran Reservoir was able to provide some flood mitigation benefits to Baringhup, but these benefits did not propagate further downstream.

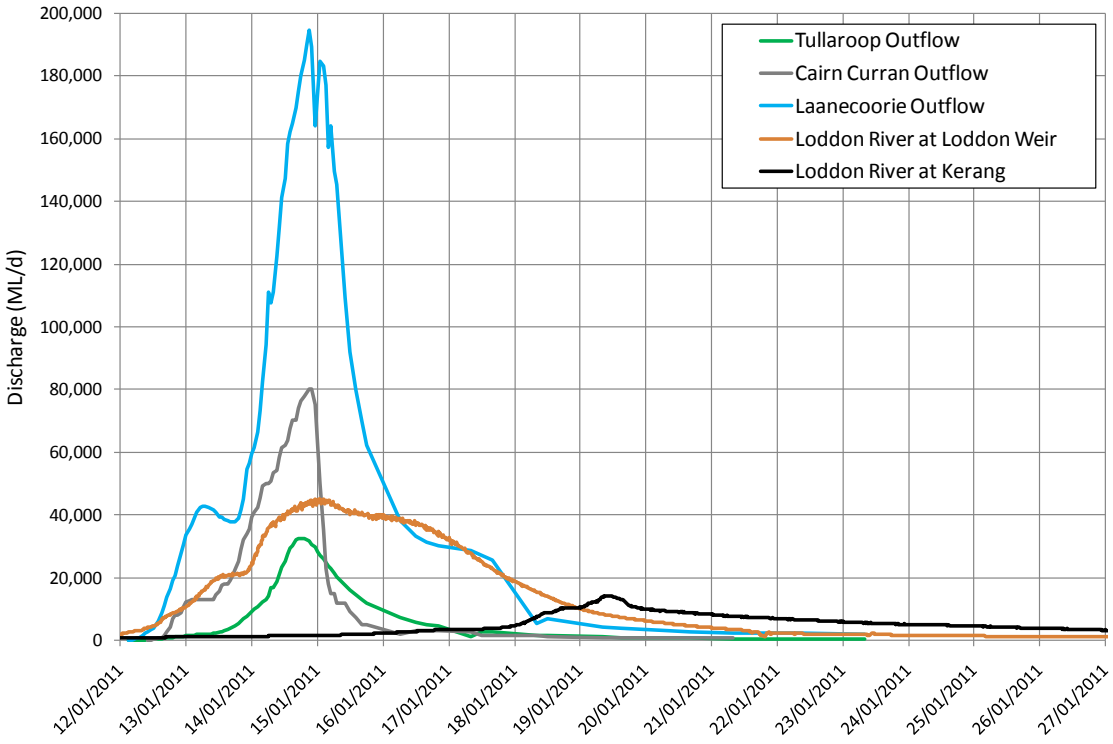

Figure 5-7: Loddon River System hydrographs - January 2011

5.3 Wimmera River System

Heavy rainfall in September 2010 resulted in large inflows to both Lake Lonsdale and Wartook Reservoir. However, the water levels in both storages were well below FSL, and as such there were no significant outflows. The airspace available in these reservoirs resulted in virtually no contribution to floodwaters at Horsham during this event.

The major flood in the Wimmera River System in January 2011 resulted in severe impacts to a number of communities including Horsham. Outflows from storages such as Lake Lonsdale were amongst the largest experienced and resulted in access to the reservoir being cut off. As such, no estimates of peak reservoir inflow were able to be provided. However, it is likely that the storage provided some attenuation of the inflow hydrograph. At Wartook Reservoir, a peak inflow estimated to be in excess of 15,000 ML/d resulted in a peak outflow of less than 4,000 ML/d despite the dam being close to FSL prior to the event. A time series plot of estimated reservoir inflow and gauged reservoir outflow and water level is shown in Figure 5-8.

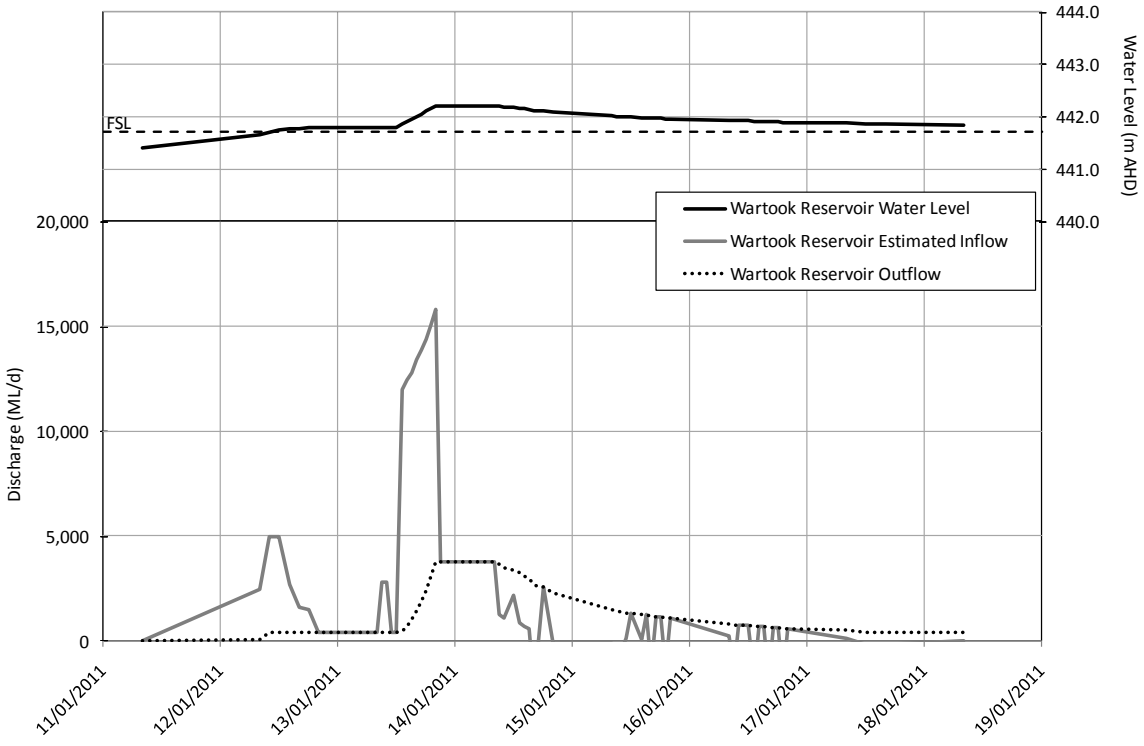

Figure 5-8: Wartook Reservoir hydrographs - January 2011

Quantifying the impacts of the Wimmera River System storages on flooding at Horsham is difficult given the available data. However, it is clear from the time series hydrographs shown in Figure 5-9 that a large proportion of the total flood volume at Horsham was contributed from the upper reaches of the Wimmera River (upstream of the gauge at Glenorchy Weir). The increase in peak flow and hydrograph volume between Glenorchy Weir and Horsham is due to inflows from Mount William Creek and other tributaries downstream of Glenorchy, of which discharge from Lake Lonsdale was a component. It should also be noted that some of the Wimmera River flood volume spilled into Yarriambiack Creek prior to reaching Horsham. No floodwaters were

contributed from the Fyans Creek catchment upstream of Lake Bellfield as the water level in the reservoir did not rise above spillway crest level.

Outflows from Wartook Reservoir on the Mackenzie River join the Wimmera River immediately downstream of the gauge at Horsham. Flows from this catchment would have had little if any contribution to flooding at Horsham given the relative difference in peak flow and hydrograph volume.

As fixed crest storages, it is clear that Lake Bellfield, Lake Lonsdale and Wartook Reservoir were able to provide some flood mitigation benefits to local communities immediately downstream by attenuating the peak flood flow rate. This can be quantified as being significant for both Lake Bellfield and Wartook Reservoir. Estimated inflows are not available for Lake Lonsdale and as such the flood mitigation provided by this storage cannot be quantified. The impact of the storages on flooding at Horsham is difficult to determine using the available data and would require complex hydrodynamic modelling.

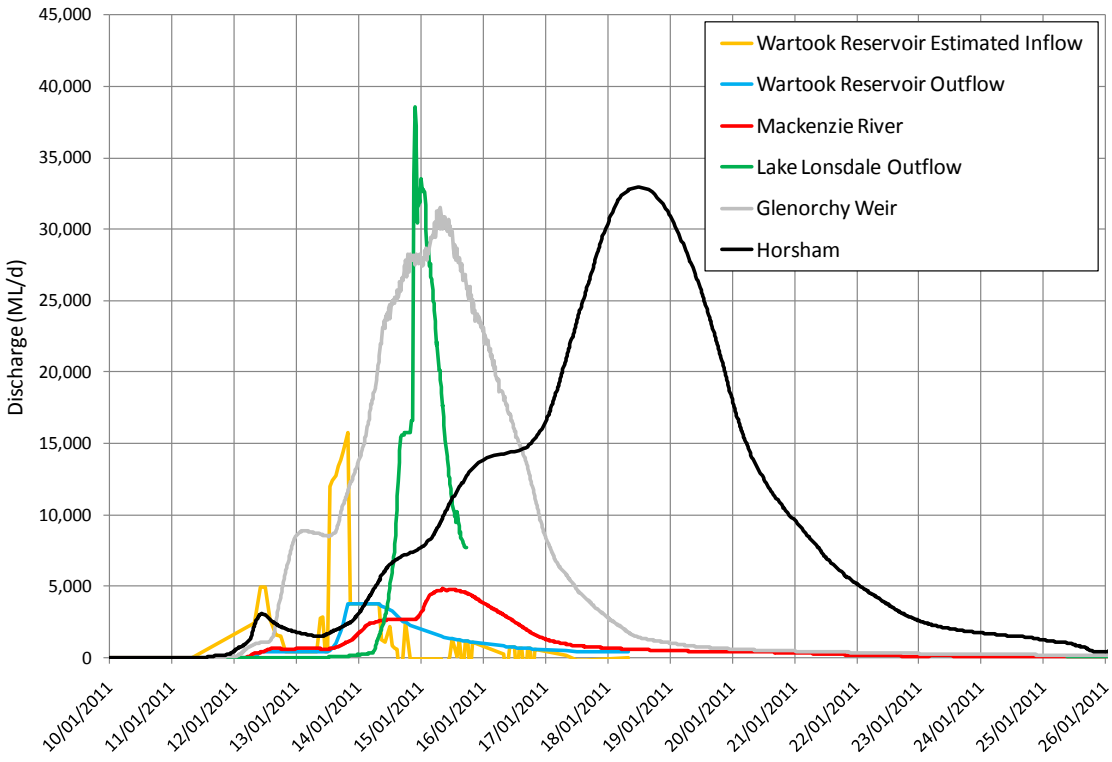

Figure 5-9: Wimmera River System hydrographs - January 2011

6. Response during the 2010/2011 flood events

6.1 Goulburn-Murray Water

6.1.1 Prior to floods

G-MW conduct annual desktop flood routing exercises which involve operational staff from the reservoirs as well as members of the regulated systems team. The purpose of these simulations is to practice flood routing techniques similar to those that may be experienced during the course of a flood.

The target filling curve levels at Cairn Curran were maintained over the winter of 2010. Specific releases were not required to do this as inflows to the dam were low. Persistent rainfall in late winter / early spring saw the reservoir level rise towards FSL

Commencement of flood operations for each of the flood events was driven by forecast rainfall information provided by the Bureau of Meteorology. G-MW typically utilised the four day forecast as a reliable indicator of the need to escalate monitoring of reservoir catchments and begin incident response procedures. Forecast rainfall information was also used to inform decision making on pre-releases, particularly from Cairn Curran Reservoir. Whilst pre-releases also occurred at the other storages in the January 2011 event, the magnitude of releases was constrained by the capacity of low-level outlets.

At Cairn Curran, minor pre-releases were implemented on 24 November 2010, almost three days prior to the arrival of significant inflows at the storage. This was increased to 3,500 ML/d on 26 November following the release of a flood watch for the catchment by the Bureau of Meteorology. These pre-releases created almost 2,300 ML of airspace in the reservoir. In January 2011, pre-releases commenced at midday on 12 January and were gradually increased to 8,000 ML/d during the course of the day. Such pre-releases were generally in accordance with G-MW's obligations to balance reliability of supply with provision of flood mitigation, where possible. With the benefit of hindsight, pre-releases could have commenced earlier at Cairn Curran in January 2011 on the basis of forecasts issued by the Bureau close to midday on 11 January. However, even assuming that the downstream bankfull flow rate (ie the rate of releases from Cairn Curran which does not result in downstream flooding) of 8,000 ML/d had been released 24 hours earlier, the additional volume of airspace created would have been unlikely to result in significant additional flood mitigation.

Decision making on pre-releases from Cairn Curran would be aided by the development and use of an operational flood forecasting model for the storage. This would ideally be a simple computer model that predicts the inflow hydrograph for the storage based on different scenarios of forecast rainfall and runoff rates. Whilst it is recognised that scenario modelling of this sort can be undertaken by the Bureau of Meteorology, it is suggested that the utility of such a system being set up in-house for use by regulated systems staff would be of some benefit.

6.1.2 During floods

During the flood events, the reservoir duty staff undertook regular monitoring of storage levels and outflows, and used this information to estimate inflows to the storages. A duplication of these calculations was undertaken by the regulated systems duty officer based in Tatura.

Internal communications by telephone call/teleconference were regularly undertaken between the regulated systems duty officer and reservoir staff. A range of management staff from the dams unit (including the Manager Dams, the Dam Safety Manager and the Operations and Maintenance Manager) were also involved in these conferences. The conferences were used to share flood and operational intelligence and as a guide to decision making and incident control. A debrief was conducted after each event that allowed lessons learnt to be identified and incorporated in later events.

During the January floods, G-MW developed a situation report that was periodically updated and used as for internal and external communication. This was recognised to be a time-saving device to rapidly provide up to date information to a range of stakeholders. These situation reports could be reviewed in more detail with a view to adopting them as part of formal flood operations procedure.

At Cairn Curran, the reservoir staff initiated communication with a range of external agencies and individuals. This included the manager of the Loddon House Caravan Park in Baringhup, Mount Alexander Shire and emergency services (police and SES). The reservoir staff were also dealing with a large range of issues including public enquiries, communication and essential services supply and access to the storages. Communication with the Bureau of Meteorology was largely initiated by the regulated systems duty officer, however it is noted that the Bureau were contacting both the regulated systems staff and the reservoir staff to obtain information on outflows from storages.

The requirements to provide advice on releases from Cairn Curran to individuals and communities downstream of the dam were generally followed. This was done via telephone calls from the reservoir duty staff and also provision of SMS messages to a pre-determined list of numbers. A key concern associated with this method of advice is the potential for it to be relied upon by individuals as a trigger for evacuation. It should be noted that these arrangements are not considered to be a substitute for flood warning procedures, and should be continually reviewed to ensure that individuals in the caravan park are provided the maximum possible level of safety.

At G-MW's fixed crest storages, there was no operational control that could be exercised following the start of the flood events. However, in accordance with the O&M manuals, monitoring of reservoir water levels and estimation of inflow was undertaken in accordance with procedure.

Overall, it is recognised that gate operations at Cairn Curran Reservoir generally followed G-MW's policies and procedures. The storage was not deliberately surcharged in order to provide flood mitigation to downstream communities. Rather, gate operations were adjusted to provide flood mitigation benefits on the rising and falling limbs of flood events, where doing so did not

threaten the safety of the storage. The time series comparison of gate openings and inflow for the January 2011 event (shown in Figure 6-1) demonstrates that the gates were progressively opened as reservoir water levels (and inflows) rose.

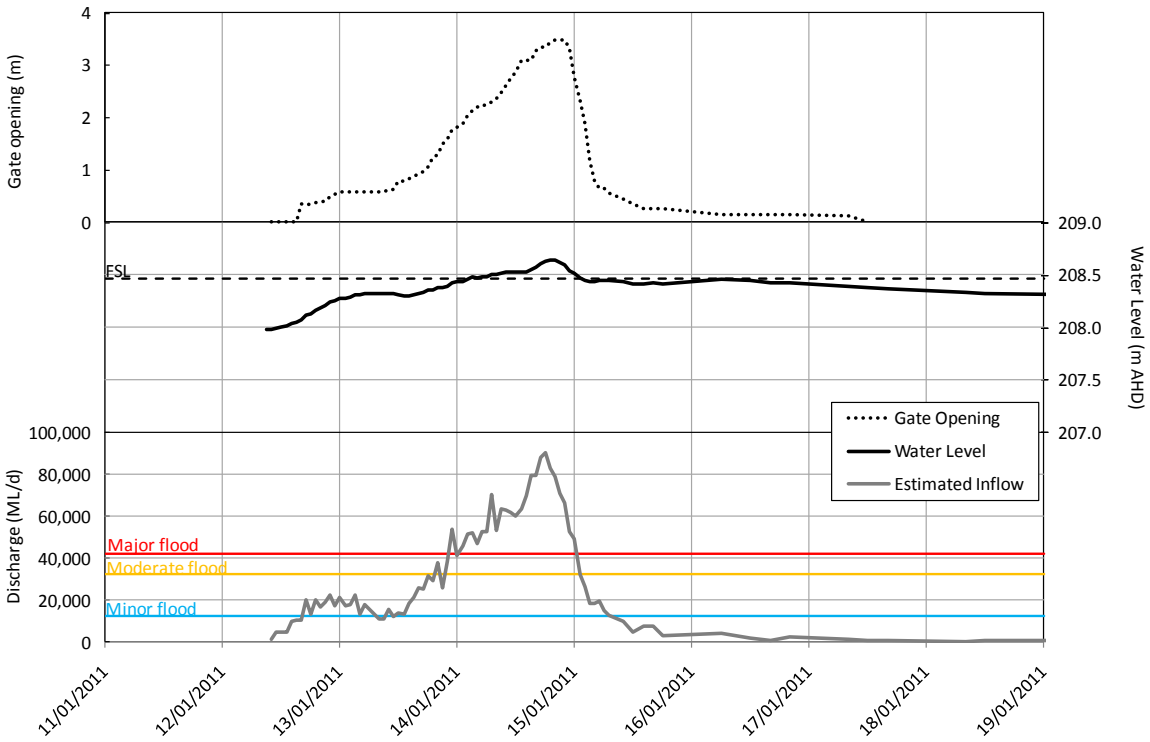

Figure 6-1: Cairn Curran Reservoir gate openings – January 2011

6.2 Grampians Wimmera Mallee Water

Prior to the flood events, GWMWater maintained a watch on publicly available rainfall forecast products from the Bureau of Meteorology. However, this information was regarded as insufficiently accurate to allow for pre-releases from storages (where this water could not be used downstream) until 3 or 4 days prior to the event. This is consistent with GWMWater's obligations to provide reliable supply to entitlement holders.

Internal communication during the flood events primarily involved the GWMWater Senior Water Resources Engineer disseminating the forecast information from the Bureau of Meteorology across the whole GWMWater business. This was generally followed up by an informal internal meeting of key staff, with the meeting outcomes being circulated by email. During the event, regular contact between GWMWater headquarters (in Horsham) and the reservoir duty staff was maintained. The Senior Water Resources Engineer was also able to provide a significant amount of useful information to different organisations during the flood events. In particular, in the September 2010 event, GWMWater alerted the Bureau of Meteorology to the fact that key streamflow gauges were malfunctioning, and that river levels at these locations were actually higher than thought.

It is understood that GWMWater have undertaken a process of debrief and review following the flood events. A formal external review of flood operations would also be desirable.

6.2.1 Eastern Headworks System – Lakes Lonsdale, Bellfield and Fyans

Lake Bellfield was maintained below the target filling curve level for all flood events of interest. No releases were made from Bellfield for any of the events and the water level never rose above FSL. The water level in Lake Fyans was maintained below the target level (300 mm below FSL in wet weather) throughout the flood events of interest. There was no outflow from Lake Fyans and the water level never rose above FSL. The airspace in these storages, particularly for the January 2011 flood event, provided flood mitigation and may have resulted in a measurable decrease in flood severity for local communities immediately downstream.

Table 6-1 provides a list of the actions required to be undertaken when operating the Eastern Headworks System during a flood event. GWMWater achieved the majority of these requirements during the flood event, with the exception of adhering to the Lake Lonsdale DSEP. The peak outflow from Lonsdale during the January event is estimated to be in excess of 35,000 ML/d, and so it can be inferred that the peak inflows exceeded the 23,700 ML/d required to trigger the DSEP. As the storage is not telemetered, and the site was inaccessible during the flood event, the water levels in the storage were unable to be monitored by GWMWater. After the event, GWMWater contacted the dam safety engineers (SMEC) who inspected the dam. Provision of reliable water level telemetry at unmanned storages would be useful for monitoring and managing future flood events.

Although the extremely large flood event trigger for Bellfield was not reached, the Bellfield DSEP has an emergency response plan for flood events not related to dam failure (see Figure 4-4). As the level in Bellfield remained well below the spillway crest throughout the event, this was not triggered.

Table 6-1: Eastern Headworks System flood operations

Action	Source	Response
Maintain target filling curve at Bellfield	General Operation OIMM	Y
Discharge rules to maintain target level at Bellfield		Y
Wannon diversion shut off		Y
Cross-flow allowed into Fyans inlet channel		Y
Lake Lonsdale bypass not engaged		Y
Extremely large flood trigger initiated[1]: Bellfield inflows 20,000 ML/d Lonsdale inflows 23,700 ML/d	DSEP	 N Y
Lonsdale – DSEP incident plan for extremely large flood followed		N[2]
Bellfield - DSEP flood notification procedures for flood events not related to dam failure followed		N[3]

[1] No extremely large flood trigger is provided for Fyans.

[2] Lonsdale was inaccessible during the flood event, and the site is not telemetered. As such the incident plan in the DSEP was unable to be fully adhered to.

[3] As the level in Bellfield remained well below the spillway crest, these actions were not triggered.

6.2.2 Wartook

Prior to the early September 2010 flood event, the level in Wartook was below the target level and rising. GWMWater increased outflows over the period from 27 August 2010 to 12 September 2010, to a maximum flow of 450 ML/d on 5 and 6 September. Increasing these outflows ensured that the reservoir level did not exceed the spillway crest, which is the objective of operation of the storage during flood events.

After the September 2010 event, the level in the storage was generally kept at the target filling curve level, and was at this level at the onset of the December 2010 event. After the December 2010 event, the storage was drawn down using the outlet valve. These releases continued throughout December and early January 2011, resulting in the water level falling to 441.4 m AHD (0.28 m below FSL). This provided a large volume of airspace in the dam during the January 2011 flood event, and resulted in significant attenuation of the flood peak as it passed through the storage.

A summary of the documented storage operation requirements for Wartook Reservoir are provided in Table 6-2. Wartook Reservoir DSEP requirements were triggered during the January 2011 event. The Reservoir Keeper and GWMWater headquarters were in regular contact during the event. As it was known that Parks Victoria had evacuated the area well in advance of the flood event, including the Smiths Mill camping ground, daily contact was not maintained with Parks Victoria. GWMWater were in regular contact with the SES incident control centre, which included representatives of VicRoads and Police.

Table 6-2: Wartook Reservoir flood operations summary

Action	Source	Response
Target filling curve maintained	General Operation OIM Manual, Barlow (1987)	Y
Releases through outlet valve ≤ 500 ML/d		Y
Continuously manned during flood event	DSEP	Y
Notification flow chart for flood events not associated with actual or imminent dam failure		Y[1]
Spillway Level Exceeded - Daily contact with Senior Water Resources Engineer (GWMWater), Chief Ranger Parks Victoria (Halls Gap), VicRoads		Y[1]
441.79 m AHD exceeded - Emergency Action 1 initiated		Y[1]

[1] Although not strictly adhered to, in the circumstances these requirements are considered to have been adequately met.

7. Findings

A number of findings have been determined throughout the course of this review. For clarity, the findings are grouped under each of the key questions that established the scope of the review.

What are the purposes of the storages?

- As storage managers under the Victorian *Water Act 1989* and *Water Industry Act 1994*, G-MW and GWMWater have obligations to ensure reliable supply of water to primary entitlement holders and manage the storages safely. The legislation also lists a number of other objectives including provision of "flood mitigation, where possible" (ie without compromising reliability of supply and dam safety).
- The primary purpose of the storages on the Campaspe, Loddon and Wimmera River Systems is to supply water for irrigated agriculture, stock and domestic use, urban areas and environmental entitlements. Whilst these storages do provide flood mitigation benefits, such benefits are incidental to their primary purpose. The storage managers are highly constrained in their ability to provide flood mitigation by the need to supply primary entitlement holders and ensure dam safety.
- Provision of additional airspace for flood mitigation is constrained by the relatively small capacity of low-level outlets at the storages considered in this review. The reliability of forecast rainfall information at the regional scale means little more than four days warning of heavy rainfall is available. At the catchment scale, reliable warning of heavy rainfalls upstream of a particular reservoir may allow a lead time of two days or less.

What are the governance arrangements, including operating rules, for the storages?

- Flood operating rules put in place by the storage managers for the storages under consideration consist of monitoring the inflows, outflows and water level at each storage and communicating this information with key external agencies including the Bureau of Meteorology and emergency services.
- In the special case of Cairn Curran Reservoir, the flood operating rules put in place by G-MW consist of adjusting the gate openings at the storage to ensure the water level does not rise above full supply level. The flood operating rules for Cairn Curran do not permit deliberate surcharging of the storage to provide flood mitigation. This is in accordance with the intent of the storage and G-MW's legislative requirements, however a clearer statement of this purpose could be included in the flood operating rules for Cairn Curran.
- The operating policies and procedures put in place by G-MW and GWMWater are generally consistent with their legal requirements under the Water Act and the Water Industry Act as they pertain to management of floods. In some cases, the clarity, accuracy and relevance of information in the various operating procedures could be improved. In particular, greater attention could be given to procedures outlining how the authorities interact with emergency response agencies at the regional level and during widespread flooding when multiple catchments are affected.

What influence did the storages have on flooding?

- The majority of the storages considered in this review are fixed crest (ie ungated) structures. The nature of fixed crest storages means that peak outflow is always less than or equal to peak inflow. The magnitude of the attenuation (change in peak outflow below peak inflow) is increased if the water level in the storage is below full supply level prior to the start of the event.
- Between September 2010 and February 2011 the storages in question provided significant mitigation of flooding in Victoria. This influence was most pronounced for downstream communities close to the storages, where in some cases a large degree of attenuation of the flood hydrograph was observed. For communities further downstream, this impact became less significant due to additional local inflows and the effects of floodplain attenuation.
- Between September and November 2010 a large volume of floodwater that would otherwise have resulted in moderate to major flooding of communities such as Rochester and Horsham was mitigated by storages on the Campaspe, Loddon and Wimmera River Systems. The mitigation was primarily a result of the very low water levels in these storages due to the prolonged period of drought.
- The majority of the storages under consideration filled and spilled during the floods in January and February 2011. However, the attenuating effect of passing the floods through the storage spillways ensured that in the majority of cases a degree of flood mitigation was provided.
- In all cases, the storages under consideration provided some flood mitigation benefit or held peak outflow equal to or less than peak inflow. The storages did not contribute to increasing the frequency, magnitude or impact of the floods. The storages did delay timing of peak flows for communities in the area immediately downstream, however this effect was not significant for areas further away due to the impact of local inflows and floodplain attenuation.
- Many of the storages reviewed are subject to target filling curves. These arrangements are used to provide airspace in the reservoir over the winter /early spring period, typically to maximise harvesting of water. The airspace provided by target filling curves does allow additional flood mitigation, however the floods of interest occurred outside the winter /early spring period when targets are applied. As such, these arrangements were not influential on the recent floods.

How were the storages operated and was this consistent with their arrangements?

- G-MW operated their storages in accordance with their published policies and procedures. At Cairn Curran Reservoir, the storage was not deliberately surcharged in order to provide flood mitigation benefits. Gate operations were used to mitigate flooding at the Baringhup community where possible at the start and end of the flood events. At the other storages, the floods were monitored as they were routed through the storages and the appropriate communication links with external agencies were established.

- G-MW should investigate development and use of an operational flood forecasting model for Cairn Curran Reservoir. This would aid decision making on pre-releases from the storage.
- G-MW provided advice to the community and individuals downstream of Cairn Curran Reservoir via SMS messaging. This is a responsible approach from G-MW, however this arrangement should not be regarded as a replacement for formal flood warning services. The content, format and timing of these messages should be reviewed to ensure that they are consistent with other flood warning / flood advice arrangements.
- GWMWater generally operated their storages in accordance with their published policies and procedures. The floods were monitored as they passed through the storages (where possible given access to the storages) and the appropriate communication links with external agencies were established. The main exception to this was at Lake Lonsdale, where telemetered reservoir water levels were not available and access to the reservoir was lost due to flooded roads.
- In some cases GWMWater's operating manuals would benefit from being reviewed and updated. Addition of requirements for and procedures to calculate flood inflow during a flood event should be considered. An opportunity exists to undertake such revisions as part of the current development of storage management rules in light of the new Wimmera Bulk Entitlement. The authority should also consider having access to telemetered water levels at its unmanned storages during flood events. In addition, a formal, external review of GWMWater's flood operations would be beneficial.

8. References

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G-MW (2010b), O&M Manual Tullaroop Reservoir: Volume 1 – General. Goulburn-Murray Water.

G-MW (2010c), O&M Manual Cairn Curran Reservoir: Volume 1 – General. Goulburn-Murray Water.

G-MW (2010d), O&M Manual Laanecoorie Reservoir: Volume 1 – General. Goulburn-Murray Water.

G-MW (2011), Submission to Parliament of Victoria Environment and Natural Resources Committee Inquiry into Flood Mitigation Infrastructure. Goulburn-Murray Water.

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GWMWater (2003a), Lake Lonsdale OIM Manual. Grampians Wimmera Mallee Water.

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GWMWater (2010), Bellfield Reservoir OIM Manual. Grampians Wimmera Mallee Water.

GWMWater (2011), Submission to the Review of 2010-11 Flood Warnings and Response. Grampians Wimmera Mallee Water.

Water Act 1989 (Vic).

Water Industry Act 1994 (Vic).

Appendix A: Project brief provided by Victorian Floods Review

Request for Quotation

Review of 2010-2011 Flood Warnings and Response (Victorian Floods Review)

Specification for

Review into the operation of storages during flooding

1.1 Introduction

From September 2010 to February 2011, Victoria experienced a series of major flood events. In some areas floods were the largest ever recorded. Major community impacts occurred and a whole of government emergency response was led by the Victoria State Emergency Service to minimise the threats to life and property. Several thousand homes and businesses were affected across Victoria.

Flooding varied from flash flooding in communities situated in the upper sections of catchments to long duration flooding with lead times of several days in the lower parts of catchments.

In February, the Victorian Government announced a review of the 2010-11 Flood Warnings and Response. The review will examine:

- the adequacy of flood predictions, including technology and modelling techniques used
- the adequacy, timeliness and effectiveness of flood warnings and public information
- emergency services command and control arrangements utilised to manage the emergency
- the adequacy of evacuations of people at greatest risk including health and aged care facilities
- the adequacy of clean-up and recovery arrangements
- the adequacy of service delivery by State and Federal Government agencies, local governments and volunteer-based organisations; and
- the adequacy of the funding provided by the State and Federal Governments in the form of emergency grants in their various categories.

The Victorian Floods Review (VFR) has undertaken extensive public and agency consultation since the February 2011. Communities and some agencies have consistently raised the adequacy of the operation of storages during the flood events.

Water storages in Victoria have a primary purpose of water supply. However, most water supply storages have some capacity to mitigate downstream flooding.

Although the operation of storages for flood mitigation are not specifically within the terms of reference, due to the levels of concern about storage operations it is appropriate that the VFR ensures that storages were managed consistently with their intent and relevant governance arrangements during the floods.

2. Project Scope

2.1 Project Objective

The objective of this project is to examine the operation of storages in the context of their governance arrangements during the Victorian floods (September 2010 to February 2011).

This project will not investigate or recommend opportunities to change storage operation or review trade-offs between reliability of supply and flood mitigation. It is assumed that the storages continue to operate with the primary aim of water resource harvesting. Also, the project will not consider the value of undertaking works such as structural modification and installation of gates to enhance the flood mitigation capability of the storages.

2.2 Storages to be reviewed

The storages to be covered by this project are the major storages located in the river systems of interest. It is the operation of these storages that potentially has an impact on downstream flooding. These storages are

- Eppalock (Campaspe Basin);
- Cairn Curran, Tullaroop and Laanecoorie (Loddon Basin); and
- Wartook and Lonsdale (Wimmera Basin). The operation of Wartook and Lonsdale should also be examined in the context of the other Wimmera headworks storage as appropriate.

2.3 Scope of review

The review must answer the following questions –

1. What are the purposes of storages?
2. What are the governance arrangements, including operating rules, for storage operation?
3. How were the storages operated in the flood events between September 2010 and February 2011?
4. What influence did storages have on flooding?
5. Were the storages operated consistent with their arrangements?

In answering the questions, the review should cover the following:

- **Design intent** – the design documentation shall be reviewed to assess what flood mitigation provision was included in the design of the water storages. Such capacity can include specific allocation of storage capacity and/or planned drawdown procedures. The key corollary question is that if there was such a design intent, was it properly recognised in the operational procedures.

- **Process** in place by operators for determining and formally adopting operational procedures
- **Operational procedures** –the assessment shall confirm or otherwise that operation including emergency response has been carried out in accordance with the documented procedures.
- **Constraints to operation for flood mitigation** – the existing limits to operation for flood mitigation at the storages shall be assessed. These include the impact on the reliability of water entitlements attached to the storage, the limits to drawdown capacity in response to an impending flood inflow and the safety of the structure.
- **Adequacy of flood monitoring and provision of information to emergency service organisations during the flood events** – an assessment shall be made of the adequacy of flood monitoring equipment and provision of information to emergency service organisations.

2.4 Peer Review Process

As part of the project, the consultant will contract an eminent expert with relevant experience in water storage operation and governance to conduct a peer review. The consultant will seek endorsement from the VFR on the proposed expert.

2.5 Consultation

All relevant water authorities and DSE will be asked to provide relevant documentation on operation of storages during the period of recent flooding on the Goulburn, Campaspe, Loddon, and Wimmera Rivers. The consultant will consult with water authorities and DSE during the preparation of the report on matters of fact.

Appendix B: Independent review

Review into the operation of storages during flooding- Sinclair Knight Merz –September 2011

Summary

The objective of the Consultant's study is to examine the operation of a number of storages under the control of Goulburn Murray Water (G-MW) and Grampians Wimmera Mallee Water (GWMW) in the context of relevant governance arrangements during the floods of September 2010-February 2011.

In my view the report meets its terms of reference using analytical techniques appropriate to the data available.

Its findings are sound and defensible.

Review Involvement

With the agreement of the Client, I had the opportunity to engage with the Consultant's team at all stages of the investigations. This enabled me to progressively review the nature and the extent of the Consultant's work and to suggest matters for clarification and further analysis. I believe this process worked effectively whilst retaining my independence as Reviewer.

Scope of analysis

The Consultants describe the scope of their review as being *".....limited to first order analysis of gauged hydrographs. No hydrological or hydrodynamic modelling was undertaken."* This is consistent with the terms of reference and the available data.

The conclusions reached from such a first order analysis are considered to be soundly based but, of their nature, only give a broad indication of the degree of influence of storage operations on the characteristics of downstream flooding. First order analysis, as used in this study, is sufficient to demonstrate that the effect of storages on flood flows passing through them is that peak outflows are less than peak inflows. In a number of instances, where storages were below full supply level (FSL) prior to flood inflows, the flow rate and volume of flood outflows were significantly , even fully, reduced.

The precise influence of these modifications on downstream flooding characteristics in large and complex river systems could only be further determined by detailed hydrologic and hydrodynamic modelling which was beyond the scope of this study.

In responding to past major flood events, including within catchments relevant to this study, such models have been developed and applied effectively. To further pursue detailed analysis of the 2010-11 flood events beyond a first order approach, it would be necessary first to review

the current availability of such models and where necessary to bring them up to contemporary standards.

Purpose of Storages and Governance

The report correctly points out that the existing primary purpose of each of the storages under review is for water conservation. Management of flood flows through each storage is primarily based on objectives relating to the safety and security of each dam structure.

Flood mitigation as a specific objective is not the primary purpose of any of the storages. At its highest, this purpose is qualified by the term “where possible” and has consistently and in my view properly, been interpreted as secondary to the primary purpose of water conservation. However it is a fact that the hydraulic effect of each of the dam structures as operated is, more or less, to result in peak outflows being less than peak inflows.

The essential point is that flood mitigation is not a primary objective. To the extent it occurs, it is secondary and incidental to the prime purpose of the storages and their operation.

This hierarchy of objectives is specified in relevant legislation and orders and reflected in the relevant operating protocols adopted by the respective water authorities.

The report shows that the operation of the gated spillway at Cairn Curran followed the prior decision of G-MW only to permit surcharge of storages above adopted FSL by specific exemption, which in the case of Cairn Curran, had not been provided.

The Consultants have clarified that despite the versions of some of GWMW’s OIM Manuals referred to them for the purposes of this study being marked “draft”, the actual versions in use are controlled and finalised documents. Whilst there is nothing to suggest that flood inflows were not routed appropriately, it would seem sensible for GWMW to fix this potential confusion. The Consultant’s observation about the need for these protocols to be reviewed and updated is endorsed. To that end the suggestion that a *“formal external review of GWMWater’s flood operations would be beneficial”* is supported.

The lack of contemporary information of inflows to Lake Lonsdale during the January 2011 event is a matter that should be addressed by GWMW primarily from the perspective of dam safety. It is reasonable to conclude, as the report does, that for the relevant event, peak outflow from Lake Lonsdale was less than peak inflow and therefore no adverse effect on downstream flooding conditions occurred. The events illustrate the importance of ensuring that even if the purpose of a storage may, from time to time, undergo change, the capability to comprehend and act upon flood inflows, flood outflows and storage levels in real time, remains essential.

Influences of Storages on Flooding

Within the limits of the analytical methods used, the conclusion that all the storages provided some degree of flood mitigation benefit is sound. In the case of Laanecoorie the effect in major floods is negligible due to its small storage volume compared with inflow volumes many times greater. On the other hand the mitigation effect of Lake Eppalock in January 2011 is very

significant in absorbing an initial peak inflow of some 100,000 Ml/d and modifying a subsequent peak inflow of some 140,000 Ml/d to a maximum outflow of 80,000 ML/d .

The effect of Wartook in January 2011 is similar in characteristic although the flow magnitudes are less. The analysis of the impact of Lake Lonsdale operations on the flood hydrograph at Horsham is, by its nature, quite limited. The conclusion that there was some mitigation is based on the reasonable assumption that the peak outflows from the storage would have been less than peak inflows. Nothing further could be discerned without detailed and complex modelling.

Operational Compliance

With the exception previously noted of the lack of information relating to flood inflows to Lake Lonsdale, all storage operations and responses during the flood events of November 2010-February 2011 were in accord with adopted procedures.

The incidental flood mitigation benefits were for all practical purposes as much as could have been expected given the nature and primary purposes of the storages. For example the operational hydrograph for Cairn Curran for the period 12-18 January 2011 illustrates a combination of timely and expert management by G-MW of a major flood event in accordance with formally adopted procedures.

David Dole

Independent Reviewer

29 September 2011