

CHALLENGES OF INTERPRETING FLOOD FLOW ESTIMATE- A CASE STUDY AT HORSHAM (WALMER) GAUGE IN THE WIMMERA RIVER

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Abstract

Hydrological studies have demonstrated significant uncertainty in the estimation of flood flow [6, 7]. This uncertainty is increased for river flow data associated with extreme flood events, when the rating curve is extrapolated beyond the measured range. The height of the Wimmera River during the January 2011 flood event exceeded the previously measured portion of the existing rating table, resulting in flow rates being extrapolated based on historic events. The extrapolated rating curve has a higher level of uncertainty in estimating flood flow [3]. To overcome this challenge a comprehensive hydrologic review of the Horsham (Walmer) gauge was undertaken. Investigation of historic news highlighted inconsistency in reporting of historical flood events particularly those around the turn of 19th century. The 1909 and 1894 historic flood events are attributed with significantly higher peak flows than January 2011, but these older records have significant uncertainty associated with them compared to those used in the more recent events due to changes in technology. A review of historical flood flow estimates was necessary to determine confidence in these historical records. The Walmer gauge records suggest the January 2011 flood was the largest flood event to have occurred within the period of instantaneous streamflow gauging which began in 1963 [1]. Hydraulic modelling developed for the Lower Wimmera Flood Investigation determined previously unknown backwater effects occurring in large flow events from the MacKenzie River confluence located immediately downstream of the Wimmera River Walmer gauge. Given a very high flow in the MacKenzie River (larger than any historic floods recorded at upstream gauges), water was shown to back up the Wimmera River and influence the height of the Walmer gauge by up to 0.19 m in large (>17,000 ML/d) Wimmera River flows. An increase of such height was shown to increase flows by approximately 4,000 to 5,000 ML/d using existing rating tables. The impact on Wimmera River flood peaks is likely to be small as typically MacKenzie River peaks 3 days prior to the Wimmera River given the differences in catchment size and catchment characteristics. Lower Wimmera study found that the MacKenzie River influences the rising limb of the Wimmera River flood hydrograph, distorting the volume in the hydrograph. This potentially questions more than 60 years of flow data from this gauge (Walmer gauge ID 415200D has been collecting flow estimates since 1970 at this location). This work sheds light on concerns regarding the rating curve and the impact of MacKenzie River on Wimmera River flows. The new understanding has been used to develop flood estimates (design floods) for the catchment. These design flood estimates are critical information and are used for flood emergency management decisions and along with risk management measures. Thus improving flood flow estimates will improve flood risk management for Lower Wimmera communities.

Key Words: Flood, Flow estimate, Rating Curve, Wimmera River

Introduction

Hamilton and Moore reported “*Uncertainty in hydrometric data is a fact of life*” [5]. Due to the inherent uncertainties in flood flow estimation floodplain managers need to adopt proper technique to reduce uncertainty. This uncertainty could increase from extrapolation of a Rating Curve, beyond the last measured stage-discharge measured flow, influence on the rating curve from adjacent catchment and estimating old historical flood flows. Floodplain managers need to be aware of the limitations, possible methods to reduce uncertainty and what affect these may have on existing and future floodplain management decisions. The stage-discharge relationship or rating curve is derived, tested and updated to develop flood flow estimates which are a critical information link to flood planning, preparedness and response. Research for this paper highlights hydrological investigations around the world experiencing significant uncertainty in the estimation of streamflow from stage height [5, 6, and 7].

The process of developing a relationship between the height of a river and the volume of water passing within or outside of its banks is challenging to say the least. The dynamic processes of the river which alter daily in a practice of degradation and aggradation make for an extremely challenging process, the results of which should always be considered within their error bounds.

There will always be a number of potential variances that necessitate such thoughts including seasonal variations, vegetation within the stream cross-section, stream bed dynamics, debris, unsteady flow conditions, hysteresis effects, influences of adjacent creeks and rivers and extrapolation outside of the observed range. The last two issues have been identified and discussed in further detail in the case study for Lower Wimmera River flood mapping study 2015 at Walmer gauge. This gauge is one of the oldest gauges in Victoria with more than 120 years of record available. Some old historical floods in late 19th century and early 20th century only have daily gauge readings available with limited quality control discussion. It is important to cross-check historical floods as historical floods have an influence on the design flood. This paper will discuss the challenges of flow estimation and highlight a way forward to verify and minimise the impact of the aforementioned uncertainties using the case study of the Lower Wimmera River mapping project 2015.

The Wimmera River originates in the Pyrenees Ranges and flows generally westward towards Horsham and then northwards to Lake Hindmarsh. The Lower Wimmera River catchment has an area of 4,000 km² and is located in Central West Victoria, (Figure 1) stretching 105 km from downstream of Horsham to its termination point at Lake Hindmarsh, making it the largest endoreic (internally draining) river system in Victoria. It is characterised by a lower gradient than its upper catchment. The study area is dominated by agricultural land with the floodplains of the Wimmera River and its tributaries containing a number of agricultural assets that are likely to be subject to inundation during large flood events. A number of residential areas are also at risk, including properties within the localities of Horsham, Quantong, Dimboola and Jeparit, as well as rural properties at Duchembegarra, Arkona, Antwerp and Tarranyurk.

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

During the flooding of Western Victoria throughout 2010 and 2011, Lower Wimmera River catchments were inundated on three separate occasions; September and December 2010 and January 2011. The January 2011 flood was the largest of the three. The January 2011, Walmer gauge flow estimate was much higher than anything recorded on this gauge since 1910. As such a massive flood had not been recorded in the last hundred years in this catchment, the flood flow estimate using the 2011 rating table was not accurate. The flood flow record suggest the January 2011 flood height was 0.64 m higher than the previously highest recorded height at Walmer [8]. Therefore requiring an extrapolation of historic data to determine the flow rate. This triggered the need for re-rating on this gauge which is located 6 km downstream of Horsham and immediately upstream of the MacKenzie River confluence.

The construction of a rating curve or stage-discharge relationship is based on several assumptions, some of them are simplified and may lead to errors. The geometry of the gauging cross-section is assumed to be stable in time, and gaugings are expected to be conducted in the same location. However the 2011 gauging was undertaken at the Western Highway Bridge at Horsham which is 6 km upstream of the Walmer gauge as the hydrographers could not access the gauge location due to flood waters. To understand the impact of this, the case study performed a cross checking of the re-rating information using a hydraulic model. Hydraulic modelling with the availability of observed streamflow data can accurately reproduce the hydraulic behaviour of natural rivers [6]. This hydraulic model analysis of the rating curve provided confidence of the rating curve information which was required for further flood risk analysis within this catchment.

To reduce uncertainty and improve the accuracy for flow estimate it is important to have a robust and thorough analysis of historical floods, understand the influence of adjacent creeks/streams and verify rating curves with hydraulic models. Advances in flow estimation techniques over the history of this gauge now suggest that some historic flow estimates for the gauge are questionable. Further investigation determined that there is a lot of qualitative and quantitative discussion in the historical newspapers, state archive, daily flow records from 1889 to 1910, and flood photos that provided opportunity to improve our understanding of the historic floods. It is important to have checked all historical flood estimates for future flood planning as all historical floods need to be considered for design flood estimates, with the 1% Annual Exceedance Probability (AEP) flood estimate the design standard for planning in Victoria [9]. The purpose of this paper is to highlight the approach taken to improving the accuracy of flood flow estimates by applying the following methods:

- Verifying rating curves or re-rating information with hydraulic model analysis
- Understanding the confluence of MacKenzie river and Wimmera River
- Cross validating historical flood estimate from qualitative and quantitative discussion

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

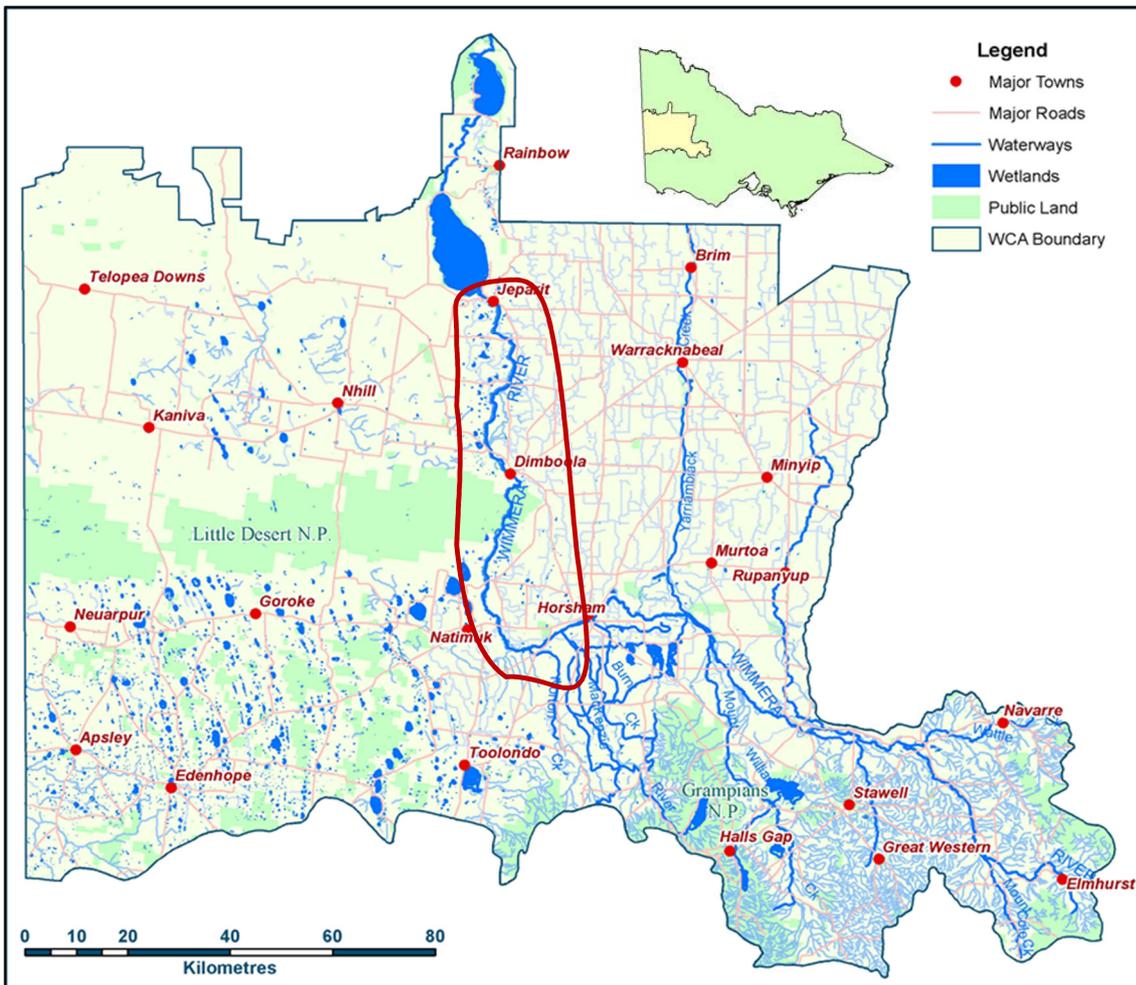


Figure 1: Lower Wimmera River Study Area (mark with red circle) starts at Outskirts of Horsham

Approach & Methods

This flood mapping investigation considered flood frequency analysis (FFA) to estimate different AEP flood flow rate for future flood planning, preparedness and response activities. FFA involves the use of historic flood flow data at a river gauge site to aid in the probability prediction of different magnitude of floods. This was achieved by statistical analysis utilising five different probability distribution methodologies (Log Normal, Log Pearson Type III, Gumbel, Generalised Extreme Value and Generalised Pareto distribution), each modelled to fit to gauged stream flow data.

We adopted a three stage methodology to improve the flood flow estimate in the current Lower Wimmera Flood Mapping project:

- Stage 1: Verify the rating curves using hydraulic model
- Stage 2: Understand the influence of the adjacent creek/river
- Stage 3: Estimate historic floods

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

Stage 1: Verifying the rating curves using hydraulic model

- Due to the characteristics of the Wimmera River and its floodplain, between 70% and 80% of flow in large events is conveyed out of the channel along the floodplain. Gauging this floodplain flow over a wider area with very little slope poses challenges for appropriately constructing a rating curve using traditional means.
- The current investigation considered verifying re-rating information for flow estimation as the previous rating curve had to extrapolate beyond the confidence limit which reduces the accuracy of flow estimates. Analysis was undertaken to cross check this re-rated information.
- It is important to note daily flow records were available from 1889 to 1910 and daily gauge height and flow from 1910 to 1963. From 1963 to current, instantaneous gauge recordings of level and flow is available. Some large historical flood events happened in between 1889 and 1910. Stage three explains how these historical floods (1894 and 1909) were assessed.

Stage 2: Understanding the influence of adjacent creek/river

- Throughout its 127 year life (1894 – 2016), the Walmer gauge has been located in four different physical locations, refer to Figure 2.

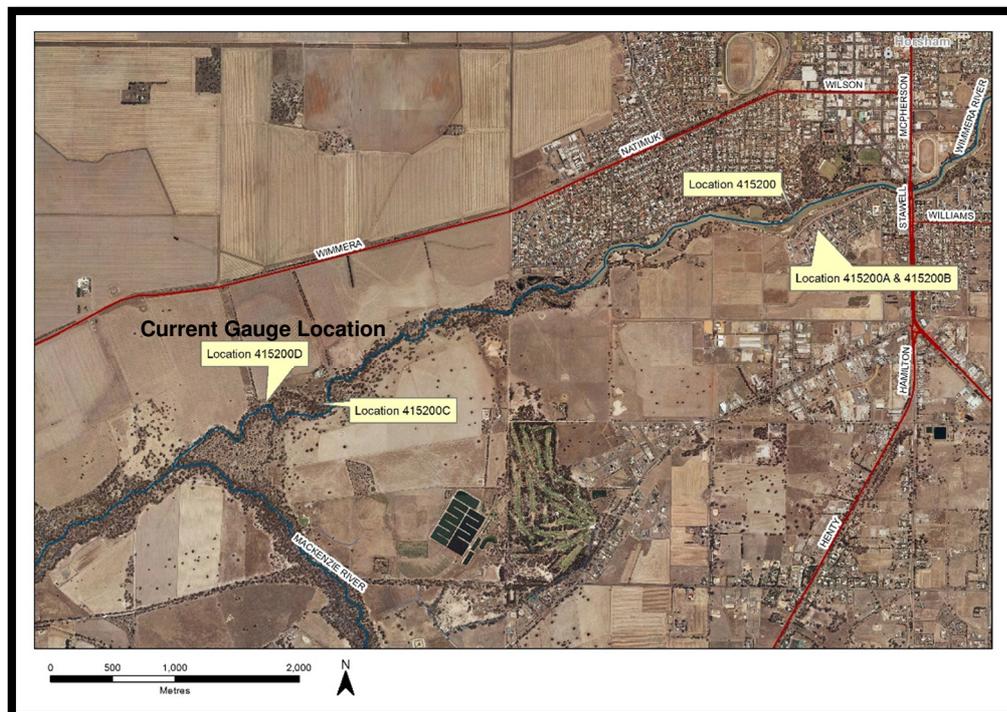


Figure 2: Changes made to the location of the Walmer Gauge over more than one hundred years

- The location 415200A & 415200B used as the gauge location from June 1881 through to November 1968. These locations are within Horsham Township and are not likely to be influenced from Burnt Creek or MacKenzie River contributions.

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

However, due to construction of the town weir the gauge location was moved further downstream. Location 415200C was active from April 1969 to April 1970 and the current gauge location 415200D commenced in April 1970 and continues today. Both location 415200C & 415200D are close to the confluence of MacKenzie River. The current gauged location potentially is influenced in times of MacKenzie River high flows.

- An in-depth hydrologic analysis was completed to identify the influence of the MacKenzie River, considering scenarios of small flows and flood flows in the Wimmera River to understand the impact on gauge readings at the Walmer gauge.

Stage 3: Estimating historic floods

- The oldest available daily gauge flow records are available from 1889 to 1910. Daily gauge height and flow are available from 1910 to 1963, instantaneous gauge records of level and flow is available from 1963.
- As well as these gauge recordings, Horsham Historical Society records documented qualitative discussion of significant floods to justify historical flood information. As a result, daily flow and daily gauge height records from 1889 to 1963 from the gauge were investigated at the State archive.
- Information about the 1894 and 1909 historical gauging flood records on the Lower Wimmera River were obtained from the State archives in Melbourne and also the Horsham Historical Society.
- The consistency of historical flood data from different sources was checked along with qualitative discussion of the historical floods to verify flood flow information.
- Historical flood photos were also considered while verifying historical flow estimates although many were of questionable value due to anthropogenic topographic changes to river channels over time.

Results & Discussion

Verifying the rating curves using hydraulic model

During January 2011, the Wimmera River flow rate was measured at the Western Highway Bridge 6 km upstream of Walmer gauge by Ventia (formerly Thiess Environmental) as the Horsham gauge at Walmer was too dangerous for staff to access. This flow information was used to re-rate the Walmer gauge using recorded water levels at the gauge and measured flows at the Western Highway. The changes between the current rating curve and the rating curve prior to the January 2011 gauging is significant, refer to Figure 3. For example, the January 2011 flood event at Walmer gauge which reached height of 4.277m would be interpreted as 33,000 ML/d with the current rating curve (version 17), however the previous rating curve (version 15) estimate the same height as over 42,000 ML/d. As the previous rating curve (version 15) was exceeded at 3.65 m stage height, but if extrapolated out would estimate a significantly flow variance comparison of more than 9000 ML/d.

Given the large differences in estimated flows with the two latest rating curves, a detailed investigation into the rating curve using an hydraulic model was undertaken. A detailed

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

A 4 metre grid Tuflow hydraulic model was constructed of the Wimmera River floodplain from the Western Highway to approximately 2 km downstream of the MacKenzie River. This localised hydraulic model of the gauge location was developed separately to the larger hydraulic model of the entire Wimmera River downstream of the Walmer gauge as the larger model takes too long to run and was of a coarser resolution. The more detailed local model was more appropriate for the rating curve investigation.

The detailed model was validated to previous hydraulic modelling of the 1% AEP design flood from the Horsham Bypass flood study [10]. A series of steady state flows were tested through hydraulic model analysis to create a modelled rating curve, with the highest flow modelled at 43,200 ML/d. Modelled rating curves were created adopting roughness values of 0.05, 0.075 and 0.1 in the hydraulic model, refer to Figure 4. Purpose of varied roughness were to test the impact of roughness to resultant flows and historic estimations of the rating table. Modelling a range of hydraulic roughness values provides an envelope of possible model results to compare to the traditional rating curves.

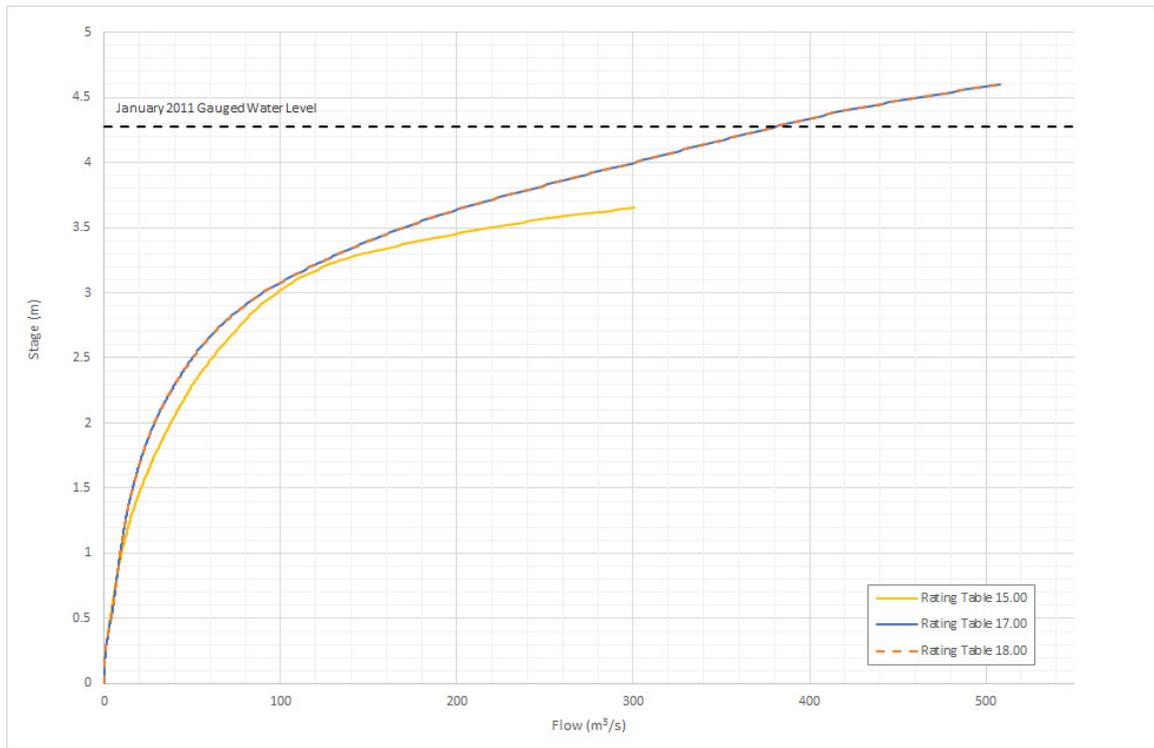


Figure 3: Wimmera River at Horsham current and previous rating curves

A roughness of 0.1 in the river closely reproduced the current rating curve (Rating Curve 17), and the previous rating curve (Rating Curve 15) matched the modelled curves for a roughness between 0.075 and 0.05. The lower roughness of 0.05 resulted in a water level at the gauge 0.3m lower than the observed January 2011 level. To achieve the January 2011 water level a flow outside the bounds of expected flow considering upstream and downstream gauges would be required. Hence this roughness was not tested for further analysis.

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

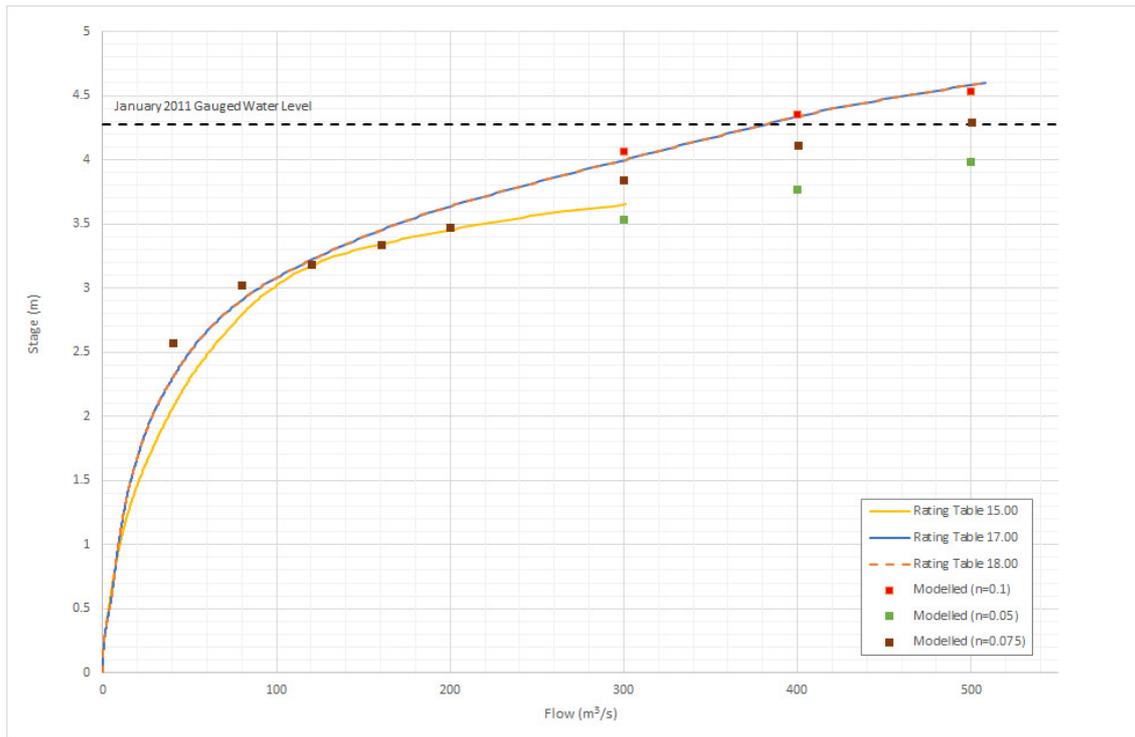


Figure 4: Comparison of model rating curve with current and previous rating curves

To further investigate the suitability of the gauge rating curves at high flows, the full January 2011 flow hydrograph was modelled in the model of the entire Wimmera River downstream of the Walmer gauge. This enabled historic flood observations from the January 2011 event to be used to comment on the suitability of the recorded and modelled January 2011 flow peaks from the analysis presented above. The January 2011 recorded hydrograph was scaled to the peak flow using the modelled 0.1 and 0.075 roughness peak flows. The model of the entire lower Wimmera River used a preliminary version of the MIKE Flexible Mesh model for the entire Lower Wimmera catchment (Horsham to Jeparit).

Both the gauged hydrograph (close match to the modelled roughness of 0.1), and the adjusted January 2011 hydrograph using the modelled rating curve assuming a roughness of 0.075 was modelled. This section of river, downstream of Horsham has quite a high roughness along the waterway and the adopted roughness are not beyond reasonable values, refer to Figure 5. Chow [11] recommends that for “flood ways with heavy stand of timber and underbrush”, roughness values in the range from 0.075 (minimum) to 0.15 (maximum) can be used.

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River



Figure 5: Typical Wimmera River conditions for assessing roughness

Preliminary modelling of the lower Wimmera River reach was compared to 33 surveyed January 2011 flood marks. The existing rating curve have a closer match to the flood marks as compared to the higher flow estimate tested using the modelled rating curve with the 0.075 roughness. Through further discussions with the hydrographers, Ventia, it was decided that on the weight of evidence from the modelling investigation and the level of accuracy of the gauging carried out during January 2011 at the highway bridge, that the current rating curve (Rating Curve 17) would be adopted.

The flexible mesh model has subsequently been refined through the model calibration process with the adopted January 2011 flow estimate from Ventia. Of the 33 survey marks, the model results were within 100 mm of the surveyed level at 22 points, with another 8 within 200 mm, and the remaining 3 were greater than 200 mm different to the survey, refer to Figure 6.

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

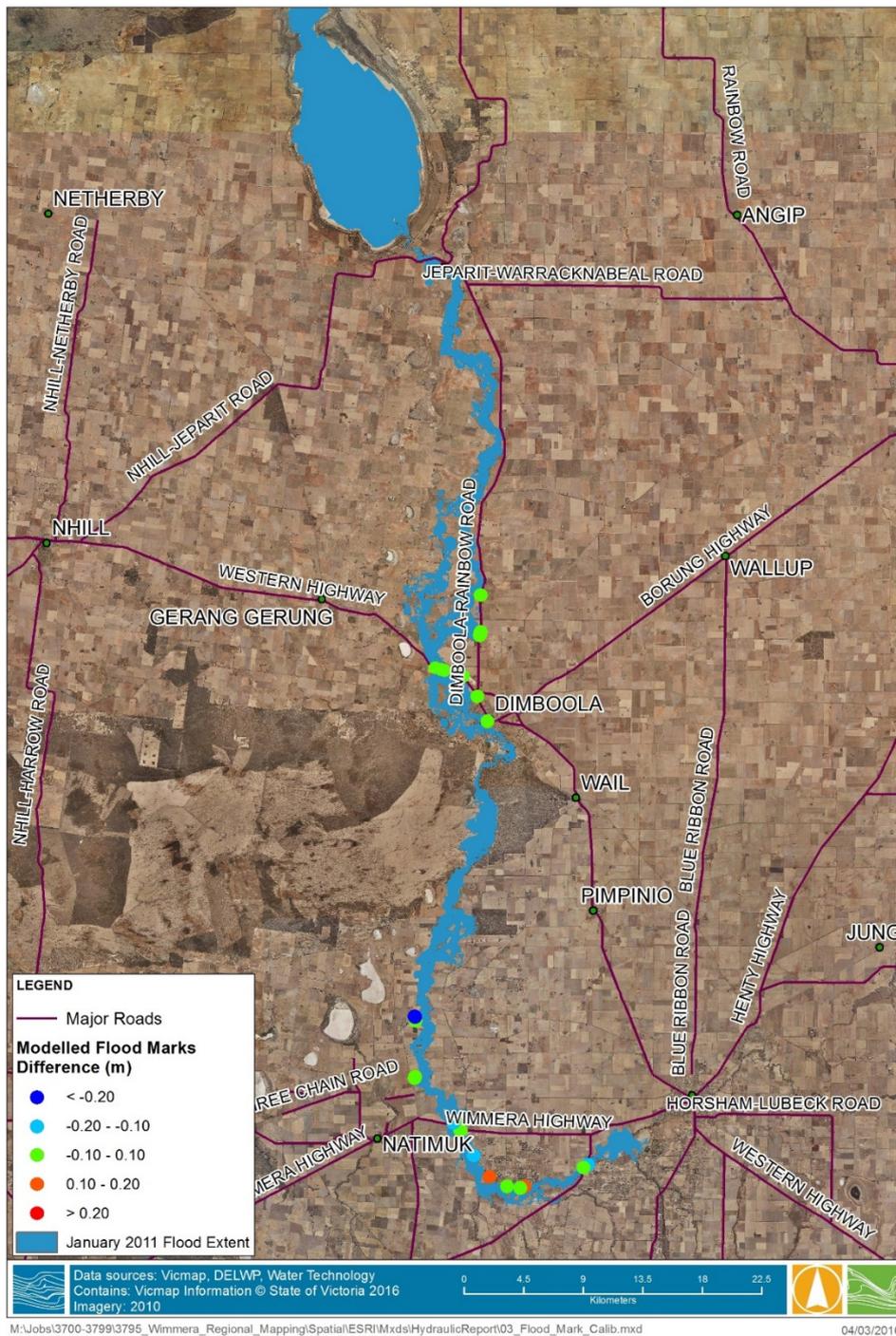


Figure 6: Comparison between observed and modelled flood levels

Understanding the influence of adjacent MacKenzie River

The MacKenzie River flows into the Wimmera River approximately 1 km downstream of the Horsham (Walmer) gauge. A series of hydraulic model scenarios were run to test the potential impact of the MacKenzie River on Wimmera River flow gauging, refer to Figure 7.

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

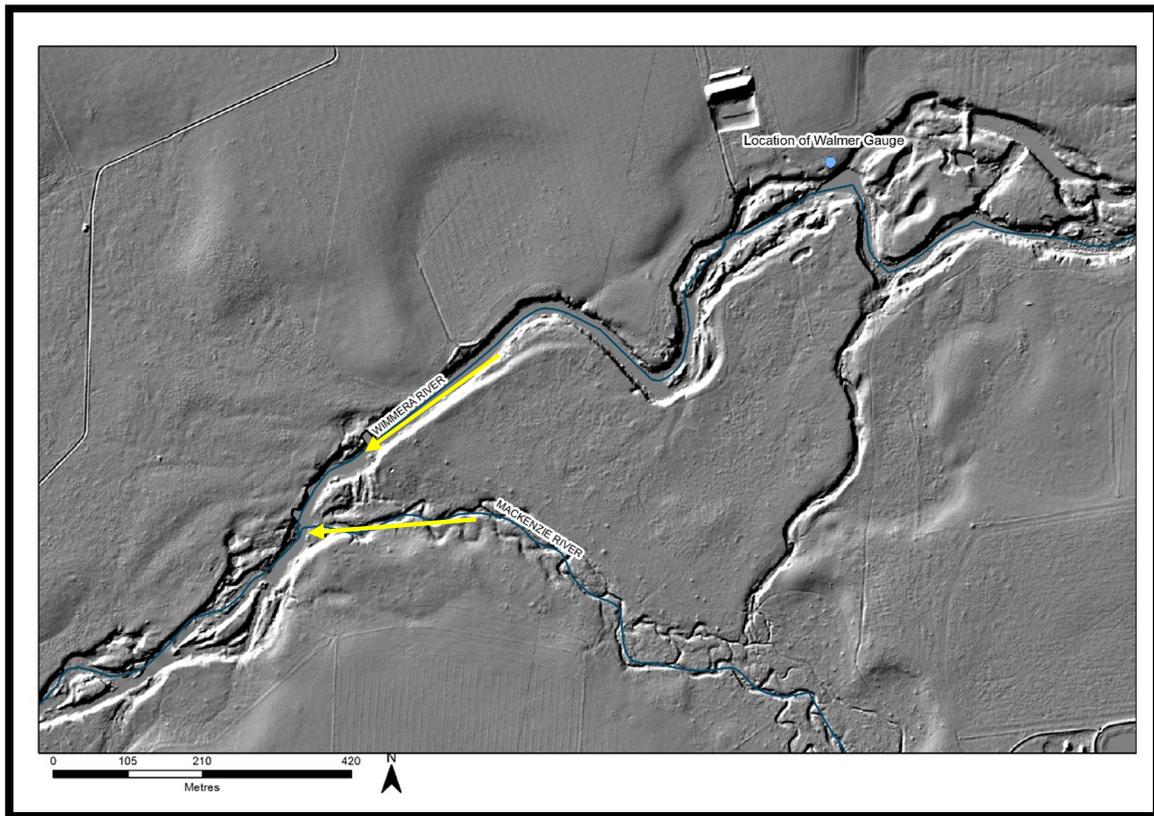


Figure 7: Confluence of MacKenzie River and Wimmera River using Hill-Shade (flow direction is shown as yellow arrow)

Hydraulic model analysis shows that with a low Wimmera River flow of 864 ML/d, the MacKenzie River can have a significant impact on the Wimmera River gauge. With water levels increasing at the gauge by 0.37 m with the MacKenzie flow increasing from 2,160 ML/d to 4,320 ML/d. At these lower Wimmera River flows, an increase in water level at the Walmer gauge of this magnitude translates to an increase in flow of approximately 400-500 ML/d. At higher flows (flood flow scenario), with the Wimmera River at 17,280 ML/d, an increase in MacKenzie River flows from 864 ML/d to 8,640 ML/d results in a water level increase at the Horsham gauge of **0.19 m**. This is a significant increase with respect to the sensitivity of the rating curve on estimated flow. At high Wimmera River flows an increase in water level of this magnitude translates to an increase in flow of approximately **4,000-5,000 ML/d**. It may be appropriate to have multiple Wimmera River at Walmer rating curves, with a different curve for different flows in the MacKenzie River. An example of what these curves may look like is included below, refer to Figure 8.

Due to a relatively small catchment area compared to the Wimmera River, the MacKenzie River generally peaks 2.5 to 3.5 days prior to the peak of the Wimmera River, refer to Figure 9. At the time of the Wimmera River peak flow at Horsham the MacKenzie River at MacKenzie Creek gauge shows the peak has passed and records between 200-630 ML/d of flow over a number of historic flood events where con-current gauging was available. These lower MacKenzie River flows that generally occur at the same time as the Wimmera River peak flows are unlikely to have any real impact on the water level at the Horsham (Walmer) gauge and no impact on flood levels back in Horsham.

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

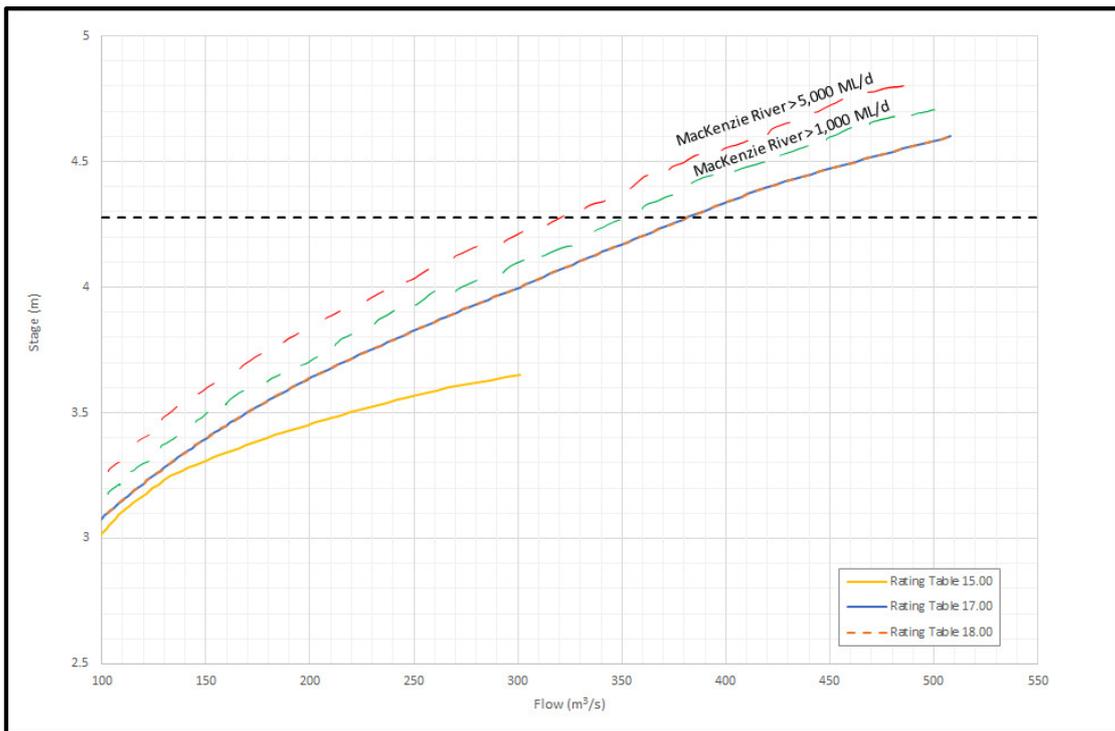


Figure 8: Wimmera River at Horsham (Walmer) rating curve with example of revised rating curves showing impact of Mckenzie River flows

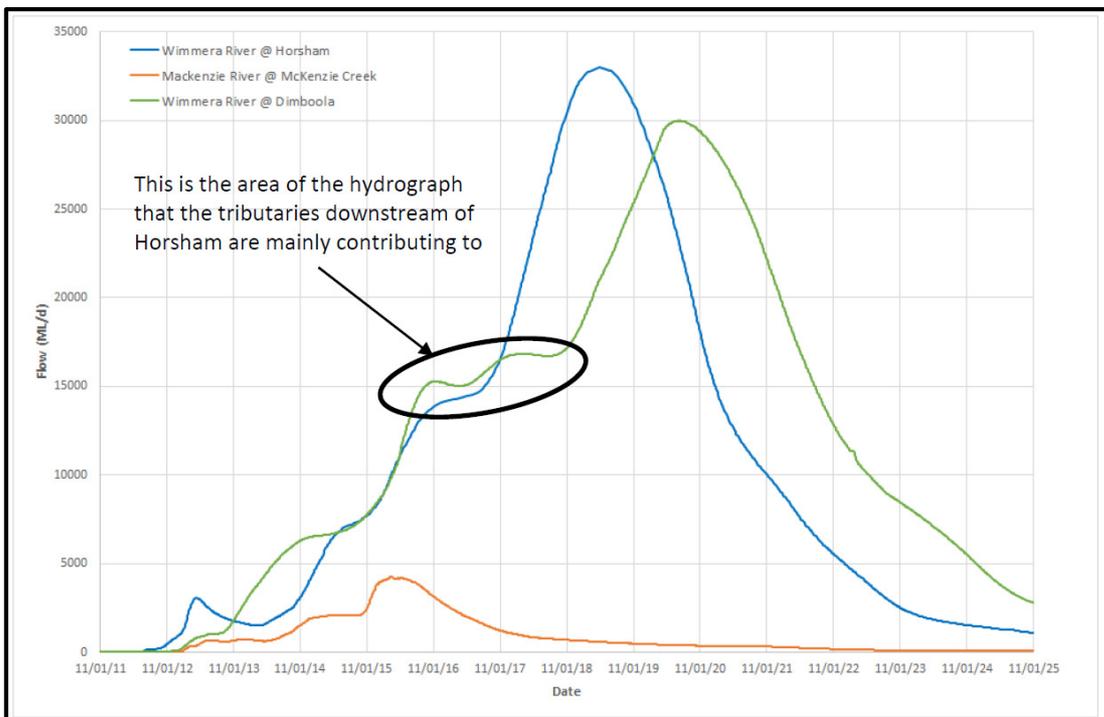


Figure 9: January 2011 Wimmera River and MacKenzie River flow contribution

STAGE 3: Analysis of Historical Flood Information

The Wimmera River streamflow gauge at Horsham (Walmer) has 127 years of complete record to develop an annual series for flood frequency analysis (FFA). The largest event

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

within the instantaneous record occurred during January 2011. The 1909 and 1894 events as reported in the DELWP record suggest higher peak flows than the January 2011 flood. There is significant uncertainty on these old historical floods as only daily flow records are available from 1889 to 1910 and there were limited large events prior to these to allow for the development of an appropriate rating curve for the gauge at the time. The historical gauge record information was verified against historical qualitative and quantitative information collected from the Horsham Historical Society and State archives. These combined with the gauge record has allowed us to recreate a detailed historic record of Wimmera River streamflow at the Walmer gauge. A complete annual series was constructed from 1889 to 2015. The low flows were filtered using the Grubbs Beck test [12], censoring 58 of the 127 years of annual series. A few historical records were found questionable (refer to Table 1), so qualitative and quantitative research was completed to verify and update some historical flood flow estimates.

Table 1: Annual data before and after cross checking from different sources

Year	Before cross check data		After cross check data		Comments
	Peak Flow ML/d	Source	Peak Flow ML/d	Source	
1894	44,249	DELWP	24,792	Horsham Flood Study (1979)	Updated based on gauge book, newspaper article and Horsham Flood Study 1979 record
1909	43,860	DELWP	38,880	Horsham Flood Study (1979)	Horsham Flood Study 1979, Historical data sheet has no record
1912	17,905	DELWP	15,293	Horsham Flood Study (1979)	
1942	16,632	DELWP	14,342	Horsham Flood Study (1979)	
1889	N/A	N/A	21,168	Horsham Flood Study (1979)	
1893	N/A	N/A	13,306	Horsham Flood Study (1979)	
1903	N/A	N/A	16,848	Horsham Historical Society	Historical society document showing 1903 having similar level on Firebrace street
1906	N/A	N/A	14,342	Horsham Historical Society	Historical Society information

A range of statistical distributions were trialled in a flood frequency analysis toolkit known as Flike [13] including LP3, log-normal, Gumbel, GEV, and Generalised Pareto. The LP3 distribution plotted the best against the historic series. Table 2 provides information regarding different magnitude design floods with and without considering some historic floods above and below the January 2011 threshold value. Prior to discovering the Horsham Historical Society and State archive records, FFA was conducted using the gauged record with and without the inclusion of the 1909 and 1894 historic events as peaks above thresholds (January 2011 event used as the threshold). The final adopted flows using the historic information and just the gauged data with and without 1909 and 1894 peaks above threshold method are shown below in Table 2.

Table 2: Comparison of design events with and without a number of historical flood events

AEP (%)	Final Adopted Peak Flow (ML/d) after update	Peak Flow (ML/d) Not including 1909 & 1894 flood	Peak Flow (ML/d) Including 1909 & 1894 flood (peaks above threshold)
20	13,100	11,900	12,600
10	19,200	18,200	19,700
5	25,000	23,600	26,200
2	31,900	29,300	33,200
1	36,500	32,600	37,400
0.5	40,700	35,100	40,700
0.2	45,400	37,500	44,000

The two preliminary FFAs show that if the two historical events were not considered in the FFA the 1% AEP peak flow is much lower and the January 2011 flood becomes greater than a 1% AEP event. The final adopted flows place the January 2011 event as between a 2% and a 1% AEP event at Horsham.

The final adopted flows have utilised a significant amount of additional information, including hydraulic modelling and historic accounts and previous reports of flooding in the catchment. The final adopted flows will enable confidence in design flood mapping for the lower Wimmera River, which will be used for land use planning, emergency response and for flood insurance.

Conclusion

The key findings to reduce uncertainty and improve accuracy of flood flow estimate highlighted the following key discussion points:

- The January 2011 flood exceeded the height of the previous gauge rating curve which lead to uncertainty in the flow estimation. The gauge was re-rated, but doubt existed over the re-rating given the significant difference in the rating curves. It was very important to cross check the gauge re-rating with other information to have confidence in the revised flood flow estimates.
- A sensitivity analysis of the MacKenzie River's influence on the Wimmera River at Walmer gauge for a range of different flow scenarios was conducted. This investigation found the influence of MacKenzie River on peak Wimmera River flood flows is insignificant on past historic floods as the MacKenzie River peaks days prior to the Wimmera River. It most likely impacts on the volume of the Wimmera River hydrograph on the rising limb of a flood. It is also likely to influence the flow estimates at low Wimmera River flows.
- Historical floods in the late 19th and early 20th century required verification as the data was limited to daily flow information only. The gauge record was found to be misleading and historical information from other sources provided a better annual

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

series of peak flows for some of the older events. It is important to cross check historical annual peak flow estimates as these are key events for deriving design flood flows.

- With the adjustment of the historical flood events the design 1% AEP flood events varies around 4,000 ML/d which significantly influences the flood impacts along the river. Without this detailed analysis of past historic events the flood mapping and risk to properties at communities along the Wimmera River may be misleading.

These above conclusions highlight the importance of investigating and improving understanding of gauge rating curves and historic flood flow estimates. This is essential for providing improved design flood flow estimates for flood risk management. It is encouraged that these standard checks using hydraulic models and investigating historical information be used during the course of flood investigations. This will ensure hydrology estimates are as good as possible and will provide flood mapping with improved accuracy, better serving authorities and communities to understand, plan for and respond to flooding.

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References

1. Hydrology Report Version 3, December 2015, *Lower Wimmera Flood Mapping Project (2015)*, Water Technology
2. Hydraulic Report, Version 1, March 2016, *Lower Wimmera Flood Mapping Project (2016)*, Water Technology
3. Importance of Re-rating of Flood Gauges: A Case Study at Upper Wimmera Catchment, 2014, Aziz A, Fennell P, Leister J and Webb R, 20-23 May, Deniliquin FMA Conference 2014
4. Horsham Flood Study 2002, Water Technology
5. A.S. Hamilton & R.D. Moore (2012) Quantifying Uncertainty in Streamflow Records , *Canadian Water Resources Journal / Revue canadienne des ressources hydriques*, 37:1, 3-21, DOI: 10.4296/cwrj3701865
To link to this article: <http://dx.doi.org/10.4296/cwrj3701865>
6. A. Domeneghetti, A. Castellarin, and A. Brath (2012) Assessing rating-curve uncertainty and its effects on hydraulic model calibration, *Hydrol. Earth Syst. Sci.*, 16, 1191–1202, 2012
7. Giuliano Di Baldassarre and Pierluigi Claps (2011), A hydraulic study on the applicability of flood rating curves, *Hydrology Research*, 42.1, 2011
doi: 10.2166/nh.2010.098
8. Wimmera Region Flood Report- August 2011 Water Technology

Challenges of flow estimate at Horsham (Walmer) Gauge in the Wimmera River

9. Draft Victorian Floodplain Management Strategy
http://delwp.vic.gov.au/_data/assets/pdf_file/0004/303619/Victorian-Floodplain-Management-Strategy-revised-draft-FINAL-for-WEB-MARK-3.pdf
10. Horsham Bypass Study 2012, Water Technology
11. Chow, V.T. 1959 Open-channel hydraulics, McGraw-Hill, New York.
12. Grubbs, F. E. (1969), Procedures for detecting outlying observations in samples, Technometrics, 11(1), 1–21
13. Flood Frequency analysis toolkit, 2015 <http://flike.tuflow.com/>