Hawkesbury-Nepean River Flood Study

Technical Volume 5

Lower Hawkesbury Analysis

Final Report

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Cover photo – photo of the Colo River near the Upper Colo Gauge, June 2020.

Acknowledgement of Country

The NSW Reconstruction Authority, Rhelm and Catchment Simulation Solutions acknowledge the Traditional Custodians of the lands where we work and live. We celebrate the diversity of Aboriginal peoples and their ongoing cultures and connections to the lands and waters of NSW.

We pay our respects to Elders past, present and emerging and acknowledge the Aboriginal and Torres Strait Islander people that contributed to the development of this report.

We advise this resource may contain images, or names of deceased persons in photographs or historical content.

Note

In July 2023, the Hawkesbury-Nepean Valley Flood Risk Management Directorate transitioned from Infrastructure NSW (INSW) to the NSW Reconstruction Authority. Any references to INSW should be read as referring to the Authority.

Executive Summary

The Hawkesbury-Nepean River catchment covers some 22,000 square kilometres, including the Warragamba and Nepean catchments, extending as far as Goulburn, Lithgow and Bowral, and downstream to Broken Bay. The focus of the Hawkesbury-Nepean River Flood Study is on the part of the catchment within the Sydney Basin, including much of the urban growth areas of western and north western Sydney.

The key objective of the Hawkesbury-Nepean River Flood Study is:

To improve the understanding of flood behaviour and better inform management of flood risk in the study area, considering available information, together with the relevant standards and guidelines.

This objective was achieved through:

a) Compiling and reviewing all available flood-related information
b) Updating and refining a hydrologic model to reflect contemporary catchment conditions
c) Developing a new, detailed 2-dimensional hydraulic flood model of the Hawkesbury-Nepean River, major tributaries and adjoining floodplain areas
d) Calibrating and validating the hydrologic and hydraulic computer models against information from 11 historical floods, including the 2020, 2021 and 2022 flood events
e) Updating the Monte Carlo model framework described in the 2019 Flood Study to reflect learnings from the 2-dimensional hydraulic flood model and the recent floods
f) Using the calibrated models to simulate flood behaviour for a range of design floods up to and including the probable maximum flood (PMF)
g) Completing various sensitivity and climate change simulations to gain an understanding of how modelling uncertainty and climate change may impact on the results produced by the models.

The various stages of the project are detailed in a number of technical volumes. This **Technical Volume 5** represents a key input to item e) above. It provides a review of the historical Lower Hawkesbury River flood behaviour, and in particular the influence of the Colo River and Macdonald River. It is intended to be read in conjunction with the main Flood Study Report and other associated Technical Volumes.

The flood behaviour of the Lower Hawkesbury River, generally downstream of Sackville, is influenced not only by the Hawkesbury River flows from upstream, but also by inflows from the Colo River and, further downstream, Macdonald River.

Not only are the Colo River and Macdonald River systems relatively large, but the rainfall that falls over these two catchments can be very different in terms of both magnitude and timing to that which falls over the Warragamba River and Nepean River, upstream of Windsor. This can lead to very different behaviours on these three key inflows to the Lower Hawkesbury.

In addition to the complexity of these inflow behaviours, the availability of data in the Lower Hawkesbury for historical events is generally low. With less gauging, and lower population densities, observations of peak levels and timing of those levels has made previous analysis in the area challenging.

However, significant research and investigations have been undertaken as a part of the Hawkesbury-Nepean River Flood Study to collate available information in this area. This has included reviews by the Hawkesbury-Nepean Valley Flood Risk Management Directorate of historical records and newspapers for older historical events in the area.

The March 2021, March 2022 and July 2022 events provided the opportunity to collate extensive additional data in the area, including gauging data, to allow for further investigations. These events were also relatively large at Wisemans Ferry, with the July 2022 event being the 3rd largest event based on a compiled historical record since 1867.

This report provides a review and outcomes of the investigations of the historical flood behaviour of the Lower Hawkesbury River, with a focus on the area downstream of Sackville. The intention of this review is to assist in informing the Monte Carlo analysis and subsequent design flood modelling.

The focus of this analysis has been on the inflows from the Hawkesbury River (from Windsor), the Colo River and Macdonald River, which are the dominant drivers of the flood behaviour in this section of the river.

The first component of the review was to compile an estimate of the historical peak flows for the Hawkesbury River (at Windsor), together with the peak flows for the Colo River and Macdonald River, and peak levels for the Hawkesbury River at Webbs Creek Ferry gauge at Wisemans Ferry. This was undertaken through a combination of gauged levels, observed historical data, and approximation techniques using rainfall to assist in infilling data. The result is a compiled historical flood record for the Lower Hawkesbury.

This record was then used to estimate the relative contribution of the Colo River and Macdonald River to peak flood levels at Wisemans Ferry (referred to as the residual in this report – refer Figure i). It was found that a number of the more significant events at Wisemans Ferry have a large contribution from the Colo and Macdonald rivers. Both March 2022 and July 2022 had relatively large contributions (contributing around 30 – 40% of the peak level), although these are not as significant as 1889, 1913 and 1949. In the case of 1889, 1913 and 1949, the peak level at Wisemans Ferry (Webbs Creek Ferry gauge) is estimated to be more than 50% contributed to by the Colo River and Macdonald River.

The peak levels in the Lower Hawkesbury are influenced not only by the peak flow on the Colo River and Macdonald River, but by the timing of the peak and shape of the hydrographs. A peak flow that occurs much earlier in the Colo River, for example, relative to the Hawkesbury River at Windsor, will not be as influential a scenario as when the Colo River peak flow occurs close to the Hawkesbury River peak at Windsor.

An analysis was undertaken by comparing the timing between the peak at the Victoria Bridge gauge at Penrith (Nepean River) with the Upper Colo gauge on the Colo River, as well as the Windsor PWD gauge with the Upper Colo gauge.

This analysis informed the estimated distribution shown in Figure ii and iii. This distribution provides a key input to the assessment of the Monte Carlo modelling described in **Technical Volume 7**.

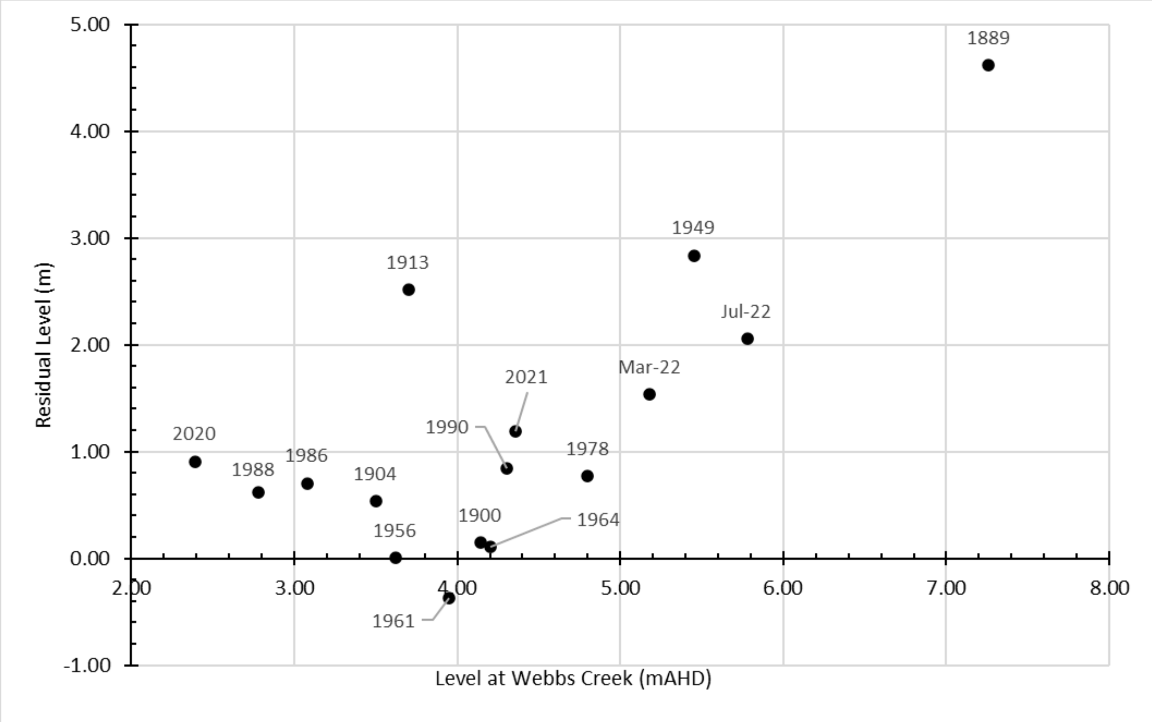

Figure i. Estimated Residual Level vs Recorded Level at Webbs Creek (Wisemans Ferry)[1]

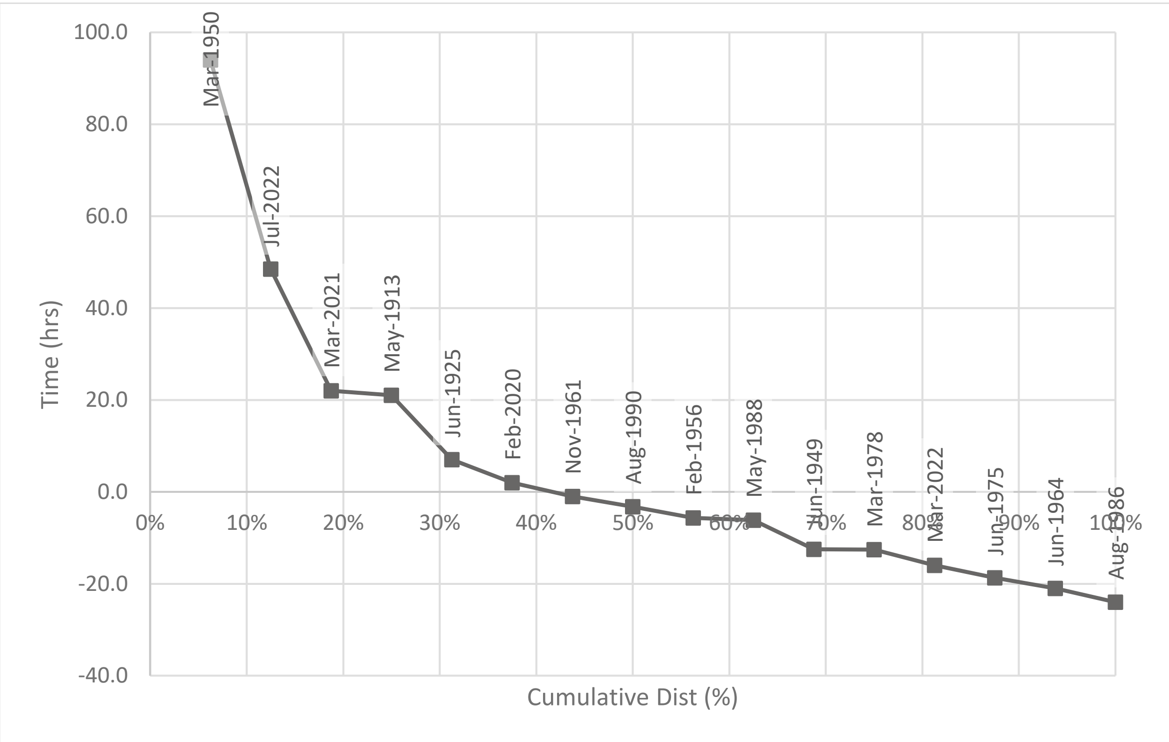

Figure ii. Cumulative Distribution of Observed Time Difference between Nepean River at Penrith Peak and Colo River at Upper Colo Peak[2]

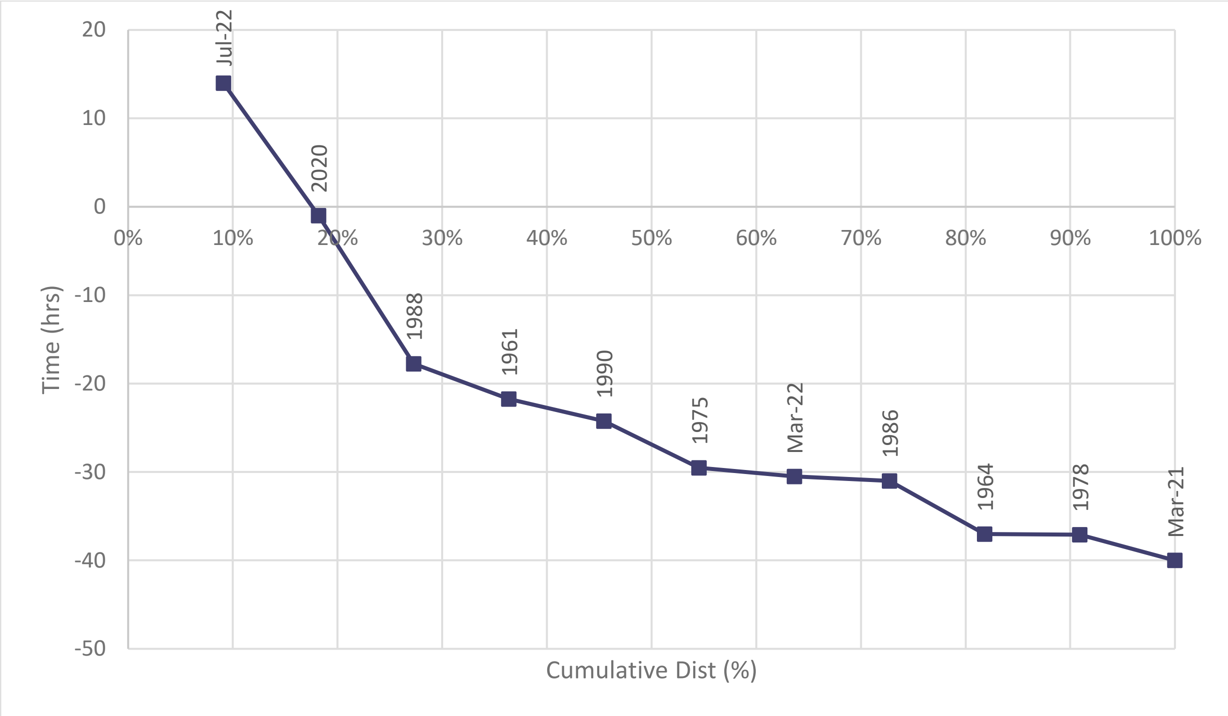

Figure iii. Cumulative Distribution of Observed Time Difference between Hawkesbury River at Windsor Peak and Colo River at Upper Colo Peak[3]

[1] Note that this graph excludes events where Webbs Creek gauge is below 2.5m AHD, given likely uncertainties in the flow level relationship at that level with the influences of the tide. Residual level represents the estimated contribution of the Colo River and Macdonald River to the peak level at Webbs Creek (Wisemans Ferry).

[2] Negative values represent where the peak at Colo River occurs before the peak at Penrith.

[3] Negative values represent where the peak at Colo River occurs before the peak at Windsor.

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Acronyms

1D	One Dimensional
2D	Two Dimensional
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
ARR87	Australian Rainfall and Runoff (Pilgrim et al, 1987)
ARR2019	Australian Rainfall and Runoff (Ball et al, 2019)
ASS	Assumed datum
AWACS	Australian Water and Coastal Studies
BoM	Bureau of Meteorology
DCP	Development Control Plan
DEM	Digital Elevation Model
IFD	Intensity Frequency Duration
FFA	Flood Frequency Analysis
FPL	Flood Planning Level
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
FPRMSP	Floodplain Risk Management Study & Plan
GH	Gauge Height
ha	hectare
km	kilometres
km^2	square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
LiDAR	Light Detection and Ranging
m	metre
m^2	square metres
m^3	cubic metres
mAHD	metres to Australian Height Datum
mm	millimetres
m/s	metres per second

m^3/s	cubic metres per second
ML	megalitres
NSW	New South Wales
OSD	On-site Stormwater Detention
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SES	State Emergency Service (NSW)
SRTM	Shuttle Radar Topography Mission
SWC	Sydney Water Corporation
WBNM	Watershed Bounded Network Model

1 Introduction

The Hawkesbury-Nepean River Catchment covers some 22,000 square kilometres, including the Warragamba and Nepean catchments, extending as far as Goulburn, Lithgow and Bowral, and downstream to Broken Bay. The focus of the Hawkesbury-Nepean River Flood Study is on the part of the catchment within the Sydney Basin, including much of the urban growth areas of western and north western Sydney.

1.1 Hawkesbury-Nepean Flood Strategy

The former NSW Government's *Resilient Valley, Resilient Communities: Hawkesbury–Nepean Valley Flood Risk Management Strategy* (2017) identified the risks and challenges in the Valley and recognised there is no simple solution to managing or reducing the valley's high flood risk. The NSW Government is building on the strategy to deliver a high-priority regional Disaster Adaptation Plan focused on managing flood risk, together with local councils, businesses and the community. The plan will be aligned with the State Emergency Management Plan and the National Strategy for Disaster Resilience to ensure the considerable flood risk across the Valley is appropriately managed. This includes the need for access to contemporary flood risk information.

1.2 Background

The Lower Hawkesbury River, for the purposes of this report, is generally the area from Sackville to Brooklyn. The key focus of this report is the area between Sackville and Spencer. This section of the river is complicated, with inflows from not only the Hawkesbury River (from Windsor) but also from the larger tributaries of the Colo River (nearly 4,500km^2, representing around 20% of the total Hawkesbury-Nepean catchment) and the Macdonald River (around 1,900km^2). The relative timing and magnitude of these inflows can influence the peak flood levels in this section of the river.

The majority of the Colo River catchment lies within the Wollemi National Park and the Blue Mountains National Park and is protected by a World Heritage Listing. The river itself is over 85 km in length with its headwaters on the Great Dividing Range north-east of the Newnes Plateau.

The Macdonald River catchment extends northward from the Hawkesbury River at Wisemans Ferry, with the upper boundary of the catchment bordering the Hunter River catchment.

Not only are these two river systems relatively large, but the rainfall that falls over these two catchments can be very different in terms of both magnitude and timing to that which falls over the Warragamba River and Nepean River, upstream of Windsor. This can lead to different behaviours on these three key inflows to the Lower Hawkesbury.

In addition to the complexity of these inflow behaviours, the availability of data in the Lower Hawkesbury for historical events is generally low. With less gauging, and lower population densities, observations of peak levels and timing of those levels has made previous analysis in the area challenging.

However, significant research and investigations have been undertaken as a part of the Hawkesbury-Nepean River Flood Study to collate available information in this area. This has included reviews by the

Hawkesbury-Nepean Valley Flood Risk Management Directorate (HNV FRMD) of historical records and newspapers for older historical events in the area.

The March 2021, March 2022 and July 2022 events provided the opportunity to collate extensive additional data in the area, including gauging data, to allow for further investigations. These events were also relatively large at Wisemans Ferry, with the July 2022 event being the 3rd largest event based on a compiled historical record since 1867. Further details on the data collection for these events are provided in **Technical Volumes 8**, **9** and **10**.

1.3 Approach

This report provides a review and outcomes of the investigations of the historical flood behaviour of the Lower Hawkesbury River, with a focus of the area between Sackville and Spencer. The intention of this review is to assist in informing the Monte Carlo analysis and subsequent design flood modelling.

The focus of this analysis has been on the inflows from the Hawkesbury River (from Windsor), the Colo River and Macdonald River, which are the dominant drivers of the flood behaviour in this section of the river.

The Hawkesbury River at Webbs Creek Ferry gauge (at Wisemans Ferry) has been used to provide an understanding of the joint influence of the three inflows to this part of the Lower Hawkesbury River. This gauge has the longest compiled historical flood record to allow for a more detailed investigation. While this gauge is located just upstream of the Macdonald River junction, it became clear during the review of data that given its proximity, the gauge can be influenced by the backwater effects of Macdonald River inflows.

There are three key components of this review:

- Compilation of historical data to inform the analysis, including a record of historical data for Windsor, Colo River, Macdonald River and Webbs Creek Ferry based on observed and estimated data
- Using the above record to undertake an analysis of the relative influence of Colo River and Macdonald River on peak flood levels at Wisemans Ferry (as measured at Webbs Creek Ferry)
- Undertake an analysis of the timings of the peak flow on the Colo River, the Hawkesbury River at Windsor, and the Nepean River at Penrith.

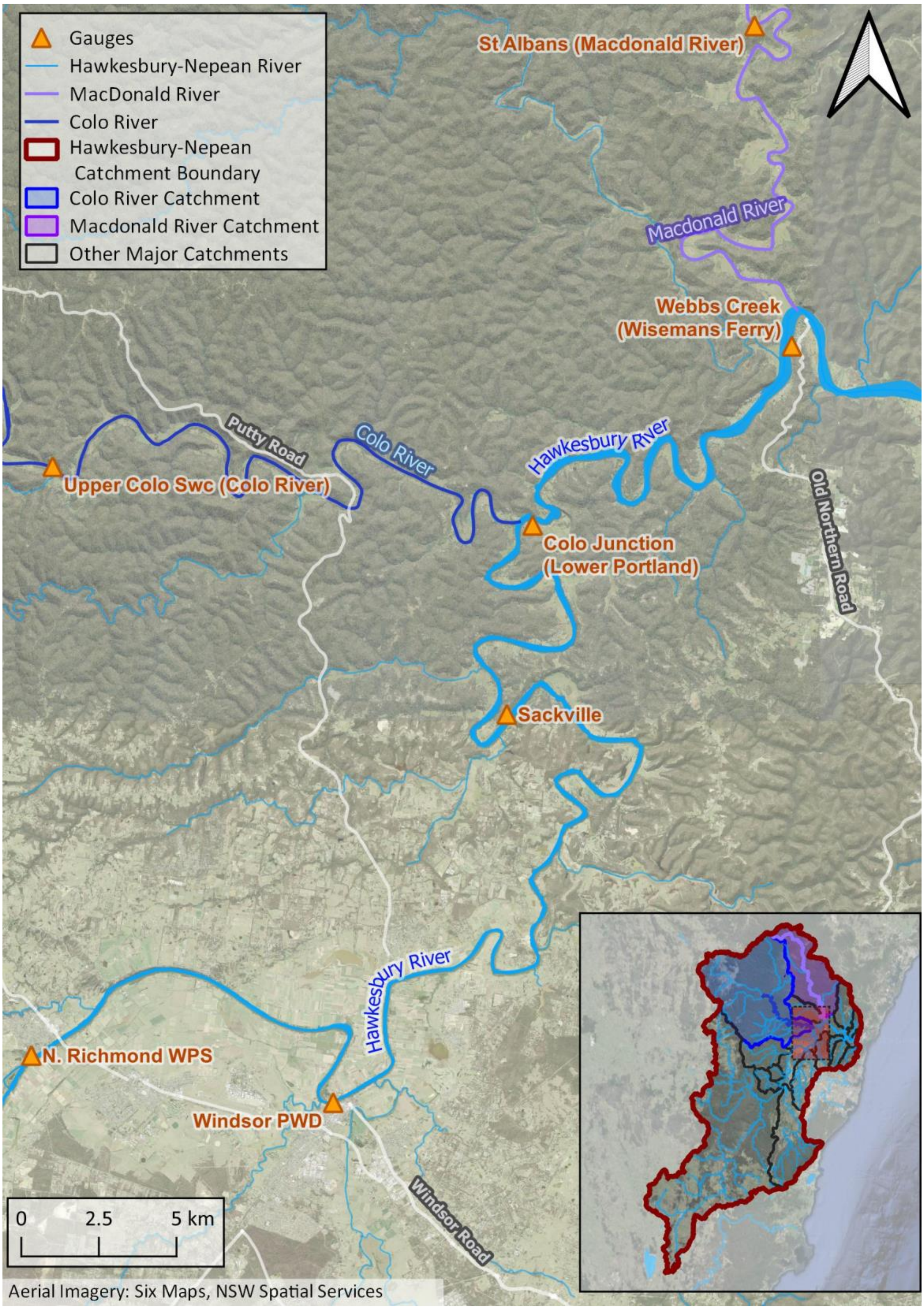

Figure 1-1. Overview of the Hawkesbury River from Windsor to Wisemans Ferry

2 Available Information

2.1 Historical Regional Average Rainfall Data

As part of the 2019 Regional Flood Study, WMAwater undertook an analysis of historical rainfall records across the Hawkesbury-Nepean catchment. This analysis included an estimate of the sub-catchment averaged daily rainfalls for major flood events on the Hawkesbury-Nepean River, from 1889 to 1990.

This information was used to develop catchment averaged rainfall totals for major historical floods. The catchments adopted for analysis are shown in Figure 2-2, with the event total rainfalls summarised in Table 2-1.

Figure 2-1 provides a comparison between the rainfall volume that fell on the Colo River and Macdonald River catchments and the average rainfall on the combined sub-catchments located upstream of Windsor, which include Warragamba River (upstream of the Warragamba Dam – USDamWall in Figure 2-1), Nepean River upstream of Wallacia, Penrith, Grose River and South Creek.

In reviewing this rainfall data, it is important to note that the coverage of rainfall gauges was significantly less for earlier events (e.g., 1889), and therefore there is greater uncertainty on the catchment averaged rainfalls for the older events.

Rainfall for more recent events (such as February 2020 and March 2021) has been compiled in the relevant Technical Volumes of this study.

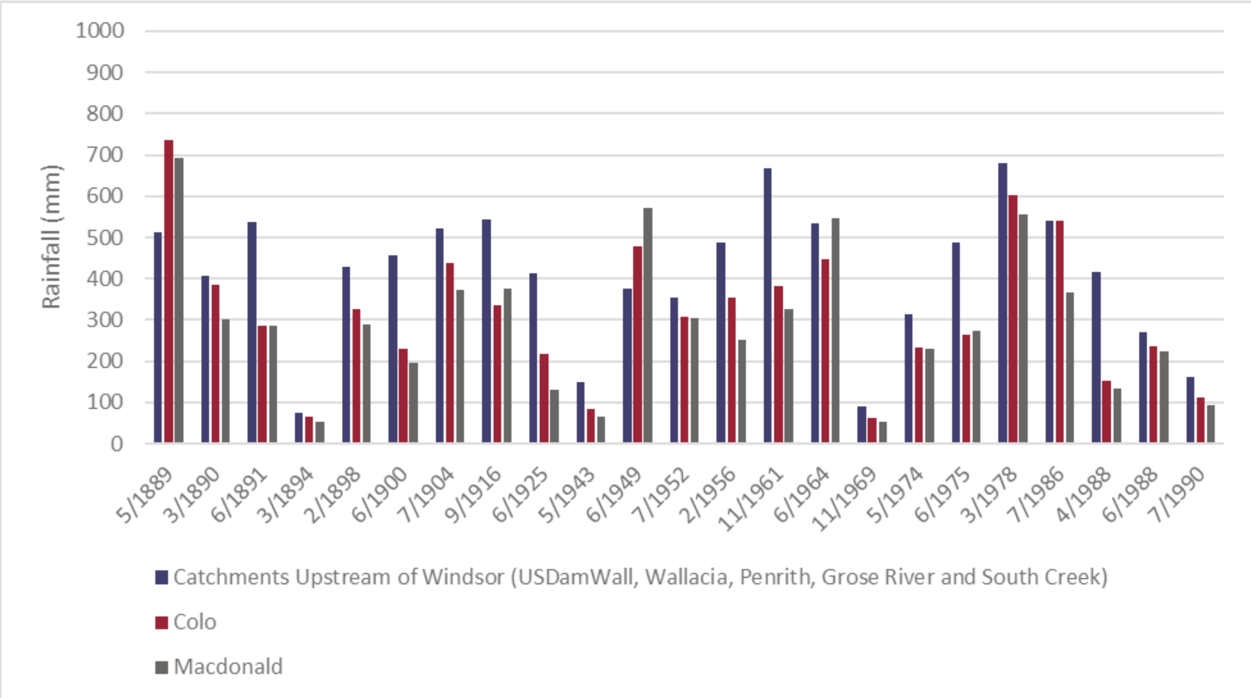

Figure 2-1. Total Event Rainfall Comparison Between Colo and Macdonald Rivers Catchments and Sub-catchments Upstream of Windsor

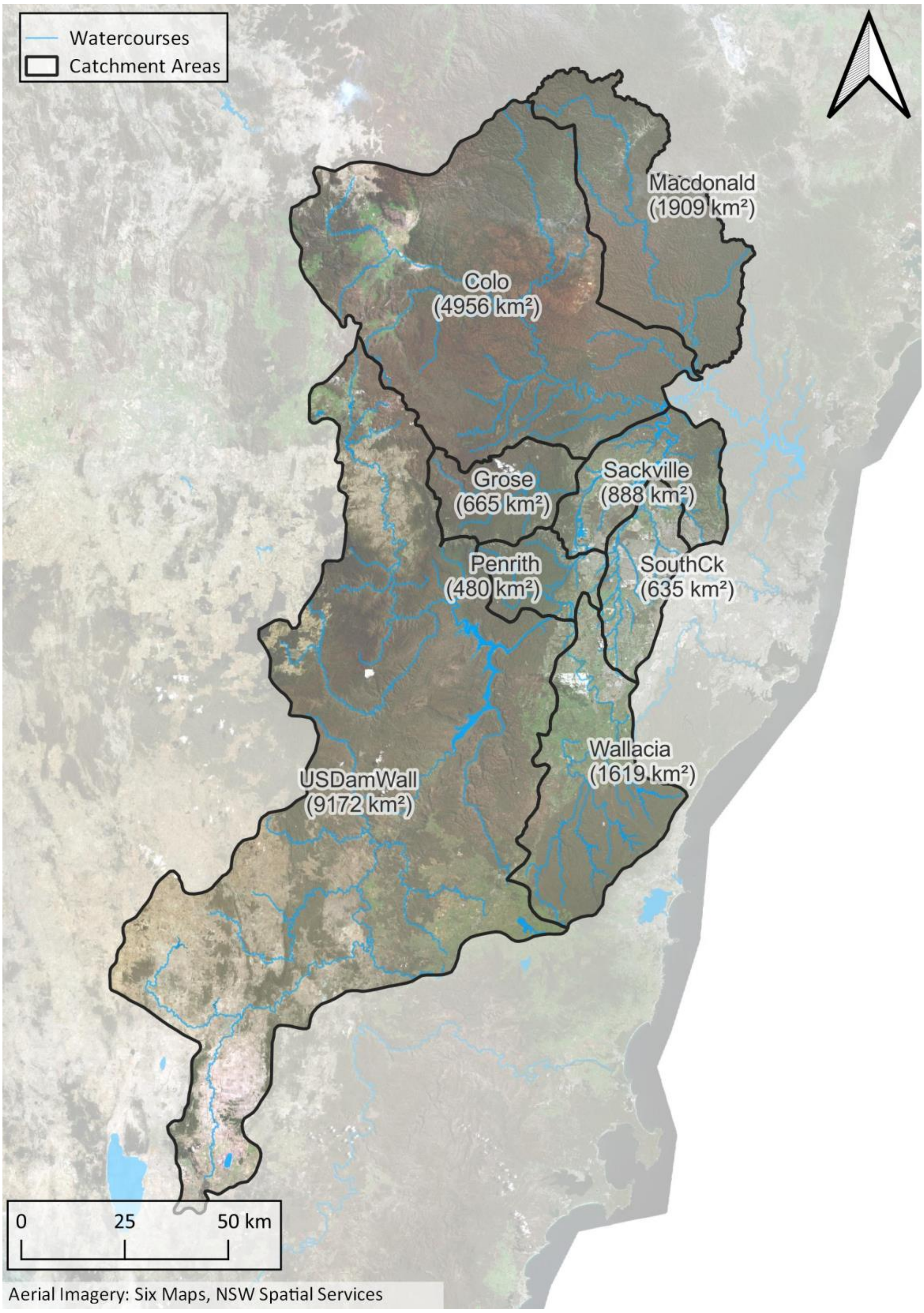

Figure 2-2. Sub-Catchments Adopted by WMAwater for Catchment Averaged Daily Rainfalls

Table 2-1. Summary of Catchment Averaged Rainfalls (based on information provided by WMAwater)

Flood Event	Start Date	End Date	Peak Level in Windsor (mAHD)	Total Rainfall Volume for Event (mm)[4]							
				Colo	Grose	Penrith	Sackville	SouthCk	USDamWall	Wallacia	Macdonald
May 1889	19/05/1889	3/06/1889	12.15	734	1075	820	1146	947	407	628	693
Mar 1890	3/03/1890	18/03/1890	12.28	383	612	468	374	293	392	439	301
Jun 1891	16/06/1891	1/07/1891	11.24	284	459	488	384	442	511	759	286
Mar 1894	12/03/1894	27/03/1894	10.14	64	134	124	95	89	61	117	54
Feb 1898	5/02/1898	20/02/1898	10.08	327	587	497	298	289	381	675	290
Jun 1900	27/6/1900	12/07/1900	14.5	231	454	480	347	383	431	623	195
Jul 1904	2/7/1904	17/07/1904	12.64	438	651	631	501	560	461	772	374
Sep 1916	25/9/1916	10/10/1916	10.97	337	549	577	401	518	511	733	375
Jun 1925	12/6/1925	27/06/1925	11.5	218	511	463	226	231	412	424	130
May 1943	5/5/1943	20/05/1943	10.26	85	140	134	125	93	142	212	65
Jun 1949	12/6/1949	27/06/1949	12.11	479	662	607	486	458	304	570	572
Jul 1952	18/7/1952	2/08/1952	11.76	308	519	541	515	450	300	496	304
Feb 1956	1/2/1956	16/02/1956	13.84	355	787	796	574	586	402	717	251
Nov 1961	10/11/1961	25/11/1961	14.95	383	824	1006	694	671	586	951	327
Jun 1964	3/6/1964	18/06/1964	14.57	447	707	713	607	601	452	846	547
Nov 1969	6/11/1969	21/11/1969	10.21	61	135	155	91	113	66	175	51
May 1974	18/5/1974	2/06/1974	10.43	232	410	356	305	310	287	403	229
Jun 1975	12/6/1975	27/06/1975	11.2	263	474	430	314	317	489	571	275
Mar 1978	11/3/1978	26/03/1978	14.46	601	861	722	608	596	633	887	555
Jul 1986	28/7/1986	12/08/1986	11.35	541	927	813	768	678	457	727	366
Apr 1988	26/6/1988	11/07/1988	12.8	151	446	430	424	534	359	673	132
Jun 1988	21/4/1988	6/05/1988	10.89	236	508	385	270	199	247	287	223
Jul 1990	22/7/1990	6/08/1990	13.5	111	208	156	143	124	152	208	92

[4] Refer to Figure 2-2 for locations.

2.2 Historical Flood Data

Historical gauge data has been used as the basis for this Lower Hawkesbury River analysis. Historical flood data has been compiled for the following gauges:

- Windsor PWD and Windsor Bridge (Hawkesbury River) (collectively used to estimated peak levels at Windsor). This represents the upstream inflow from the Hawkesbury River into the Lower Hawkesbury.
- Webbs Creek at Wisemans Ferry (Hawkesbury River). This has been used to understand the joint influence of the Hawkesbury River, Colo River and Macdonald River on levels in the Lower Hawkesbury River.
- Upper Colo (Colo River)
- St Albans (Macdonald River).

A key consideration is the influence that Warragamba Dam has had on the flood levels after its construction (for events after 1960), which affects flood levels at Windsor and Wisemans Ferry. WMAwater has previously undertaken an assessment to estimate both the pre-dam and post-dam equivalent levels for before and after the dam completion. For the purposes of this analysis of the Lower Hawkesbury, the post-dam equivalents have been adopted for the assessment, for a greater level of consistency with the more recent flood data (and recognising that there has been more data collected on the Lower Hawkesbury River for more recent events).

2.2.1 Windsor

The peak levels for Windsor were primarily based on data provided by WMAwater, and are summarised in Table 2-2, with some more recent flood levels based on gauge data. Peak flows were estimated based on a discharge-level relationship derived from the TUFLOW model, and further described in Section 3.1.

2.2.2 Webbs Creek Ferry Gauge (Wisemans Ferry)

The peak levels for the Webbs Creek Ferry gauge at Wisemans Ferry are shown in Table 2-3, together with the source of the data. A number of the older levels for Webbs Creek Ferry gauge were estimated based on nearby reported peak levels observed within Wisemans Ferry (this is further described in **Technical Volume 7**). These historical levels were translated to an estimate at the Webbs Creek Ferry gauge location based on the TUFLOW model results.

WMAwater provided estimates of the post-dam equivalent levels for events prior to 1960. It is noted that 1900, 1904 and 1913 did not have post-dam peak level equivalent estimates. For the purposes of this assessment (and recognising the uncertainties in the subsequent sections), the unadjusted level has been adopted at this stage. As can be seen for the other events, the magnitude of difference between the pre-dam and post-dam equivalents at Wisemans Ferry is relatively low for a lot of the events.

Table 2-2. Historical Flood Data Windsor

	Event	Flood Level (mAHD)	Post Dam Equivalent Flood Level (mAHD)	Flow (m^3/s)[5]
Pre-Dam	1867	19.68	19.25	11570
	1889	12.15	11.90	4550
	1900	14.50	14.40	6590
	1904	12.64	12.54	5040
	1913	8.47	8.47[6]	2350
	1949	12.11	11.84	4510
	1956	13.84	13.74	6020
Post-Dam	1961	14.95	14.95	7090
	1964	14.57	14.57	6740
	1978	14.46	14.46	6640
	1986	11.35	11.35	4150
	Jul-1988	10.89	10.89	3830
	1990	13.46	13.46	5780
	1992	10.86	10.86	3810
	1998	5.37	5.37	970
	2013	6.46	6.46	1390
	2020	9.27	9.27	2810
	2021	12.93	12.93	5350
	Mar-2022	13.80	13.80	6060
	Jul-2022	13.93	13.93	6180

[5] Values estimated using flow level relationship (refer Section 3.1)

[6] Post dam equivalent not available for 1913, and assumed to be similar to pre-dam estimates for the purpose of this assessment

Table 2-3. Historical Flood Data - Webbs Creek Ferry Gauge at Wisemans Ferry

	Flood Event	Flood Level (mAHD)	Post Dam Equivalent Flood Level (mAHD)	Data Source
Pre-Dam	1867	9.14	8.96	Levels from Technical Volume 7
	1889	7.28	7.26	
	1900	4.14	4.14	Young, T (1984) Volume No 25: Investigation of Major Flood Events at Wisemans Ferry, Draft.
	1904	3.5	3.50	
	1913	3.7	3.70	https://trove.nla.gov.au/newspaper/article/85847240
	1949	5.57	5.45	Levels from Technical Volume 7
	1956	3.71	3.62	
Post-Dam	1961	3.95	3.95	
	1964	4.2	4.20	
	1978	4.8	4.80	
	1986	3.08	3.08	
	Jul-1988	2.78	2.78	
	1990	4.3	4.30	
	1992	1.27	1.27	Level data from Gauge
	1998	1.72	1.72	
	2013	1.58	1.58	
	2020	2.39	2.39	
	2021	4.36	4.36	
	Mar-2022	5.18	5.18	
	Jul-2022	5.78	5.78	

2.2.3 Colo River

The Upper Colo gauge has records that extend back to 1909, although continuous records (measuring the full hydrograph) did not commence until the 1960s. AWACS (1997) also undertook a review of the Upper Colo gauge and extracted peak levels for the full record. This information extended until 1990. As a part of this current study, additional records were extracted for the period after this up until 2022, as well as some infilling of additional event data in the 1980s.

Peak flows for the Colo River (at the Upper Colo gauge) were estimated using the rating curve as per Technical Volume 2. These are shown in Table 2-4. As the gauge was only operational for the events from 1913 onward, earlier events were not recorded.

Table 2-4. Historical Flood Data Upper Colo River Gauge

Flood Event	Flood Level (mAHD)	Flow (m^3/s)[1]
1889	-	-
1900	-	-
1904	-	-
May-1913	14.60	1520
Jun-1949	17.40	2410
Feb-1956	15.26	1710
Nov-1961	9.30	500
Jun-1964	14.61	1530
Mar-1978	20.72	3840
Aug-1986	17.80	2560
Jul-1988	18.31	2760
Aug-1990	15.24	1700
Feb-1992	14.85	1590
Aug-1998	9.56	530
Jun-2013	15.33	1730
Feb-2020	17.24	2350
Mar-2021	16.44	2100
Mar-2022	18.12	2730
Jul-2022	16.44	2090

[1]Values estimated as per Technical Volume 2

2.2.4 Macdonald River

The peak flood level and flow data for the Macdonald River gauge at St Albans was derived from a variety of sources. In some situations, either peak flood level or peak flow data was available, and this was converted into the equivalent level or flow based on the available rating curve (refer Technical Volume 2).

Older peak flood levels were derived based on observation data from that period, rather than specifically from the gauge location. As the peak flood levels were compiled from historical records, levels were not available for all large events that occurred on the Hawkesbury River at Wisemans Ferry, and, therefore, there are some gaps in the record (e.g., 1900).

As noted in other Technical Volumes, St Albans gauge can be influenced by backwater effects from the Hawkesbury River at Wisemans Ferry. Some historical observations may be elevated above the actual Macdonald River catchment driven levels and flows. Therefore, some care should be taken in interpreting these results.

Table 2-5. Historical Flood Data Macdonald River Gauge

Flood Event	Flood Level (mAHD)	Flow (m^3/s)	Source
1867	13.60	1,200	Estimated by HNV FRMD analysis as 5 ft below 1889 peak, based on report in M. Hutton Neve (1982) *The Forgotten Valley: History of the Macdonald Valley and St Albans NSW*, p.54
1889	15.10	1350[1]	Flood mark surveyed by Erskine (1986)
1900	-	-	-
1904	-	-	-
1913	13.90	1220[1]	Estimated by HNV FRMD analysis as 4 ft below 1889 peak, based on report in *Windsor and Richmond Gazette*, Sat 7 Jun 1913 p.2
1949	14.60	1300[1]	Erskine (1986) and Lower Macdonald River Flood Study (Aug 2004)
1956	-	-	
1961	3.8	60[1]	Lower Macdonald River Flood Study (Aug 2004) or Lower Hawkesbury River Flood Study (Apr 1997)
1964	10.4	740[1]	
1978	11.25	890[1]	
1986	5.1	100[1]	
1988	7.9	390[1]	
1990	8.75	540[1]	
1992	9.41	680	Gauge Level data from:212228 - Macdonald River at St Albans
1998	8.32	450	
2013	2.31	0	
2020	8.06	400	
2021	10.44	840	
Mar-22	11.09	910	
Jul-22	12.73	1090	

[1]Values adopted from the Lower Macdonald River Flood Study rather than using the rating curve

3 Historical Flow Estimation

3.1 Windsor Flow/Level relationship

In order to estimate the peak flows at Windsor, a peak flow and peak level relationship was derived. It is noted that these are different to the rating curves derived in Technical Volume 11. Typical rating curves estimate the flow that corresponds to a particular level at a point in time. For this particular assessment, it was of more interest to estimate the likely peak flow that might occur given a peak level at Windsor.

An approximate relationship was derived based on several of the representative events from the TUFLOW model, and it is summarised in Figure 3-1. This shows the overall peak flow and peak water level for each of the representative events at Windsor (where the flows are measured near Pitt Town). For comparison purposes, the previous WMAwater rating curve from the 2019 Regional Flood Study is shown[7].

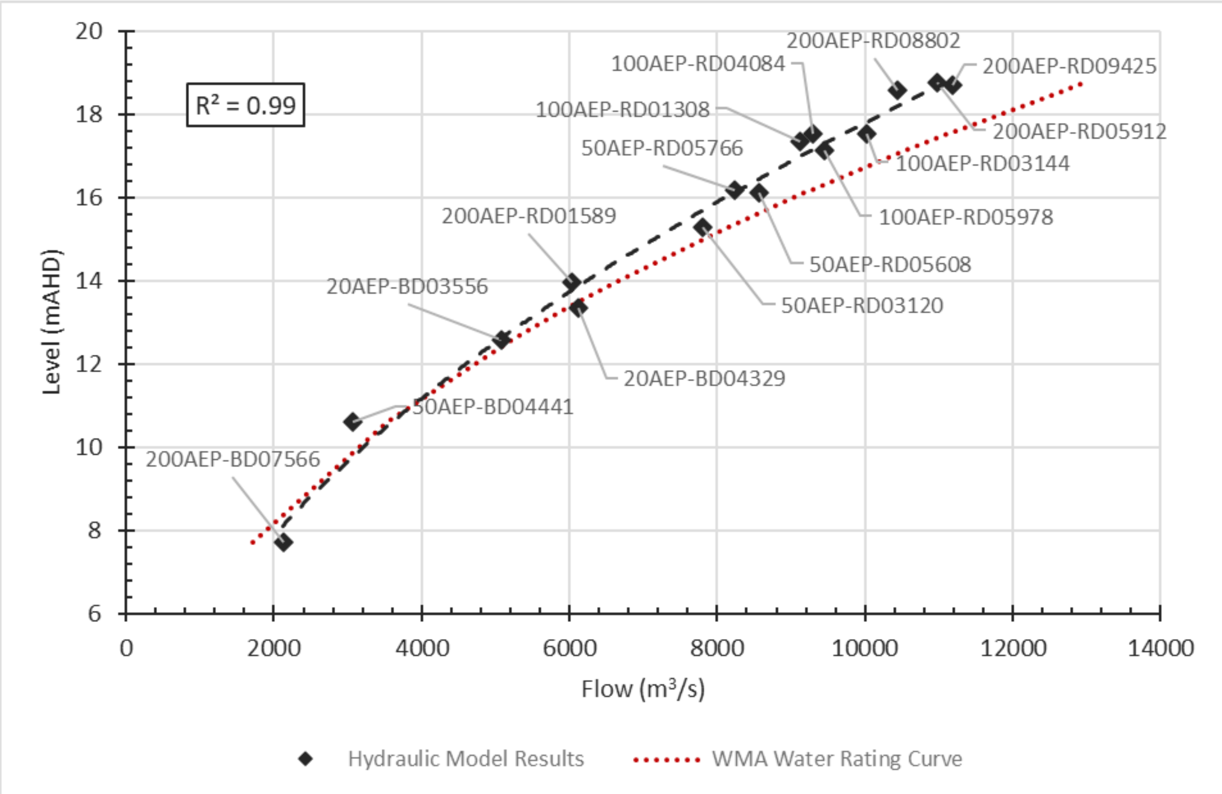

Figure 3-1. Peak Flow-Level Relationship for Hawkesbury River at Windsor[8]

3.2 Flow/rainfall relationships

There are a number of flood events on the Lower Hawkesbury River that were not recorded at either the Colo River gauge at Upper Colo or the Macdonald River gauge at St Albans. In order to extend the data set, an approximate relationship was established between the catchment averaged peak rainfall

[7] Note that the WMAwater relationship was based on a comparison of peak water level at Windsor with discharge at Sackville.

[8] It is noted that these are based on an earlier version of the representative events. However, the peak flow and peak water level relationship would remain consistent.

and the peak flow estimated for recorded rainfall events. This relationship was then used to 'in-fill' flows for historical events where they were not recorded at either St Albans or Upper Colo. The averaged two-day and one-day peak rainfalls were tested to verify which parameter resulted in a better fit, when plotted against flow data. For the Colo River gauge, the one-day averaged peak rainfall provided a better relationship and was adopted, while the two-day averaged rainfall was selected for the St. Albans gauge.

The correlations between rainfall and flow for Upper Colo and St Albans are shown in Figure 3-2 and Figure 3-3.

Overall, the correlations between peak one-day/two-day rainfall and peak flow are reasonably strong, although there remains a degree of variability. This should be considered when viewing the infilled peak flows as these events have a higher degree of uncertainty around them.

3.3 Compiled Historical Data Set

Based on the above analysis, a historical data set was constructed as shown in Table 3-1. This is shown for the larger Hawkesbury River events between 1867 and 2022.

Table 3-1 also shows the relative rank of each of the events at each location[9]. For example, 1889 was the second largest event recorded at Wisemans Ferry, but it was only the 12th highest at Windsor. The large contributions from the Colo River and Macdonald River in this particular event resulted in the much higher levels at Wisemans Ferry.

On the other hand, while 1961 was a relatively large event on the Hawkesbury River at Windsor, the contributions from the Colo River and Macdonald River were relatively small, resulting in a relatively lower level at the Webbs Creek Ferry gauge relative to other events.

It is noted that there may be individual events that were large on the Colo River and Macdonald River that are not identified here. The basis for the assessment focuses on flows in the Colo River and Macdonald River where large flows are observed on the Hawkesbury River at Windsor as well.

[9] Note data for 1867 was not available for Colo and Macdonald rivers

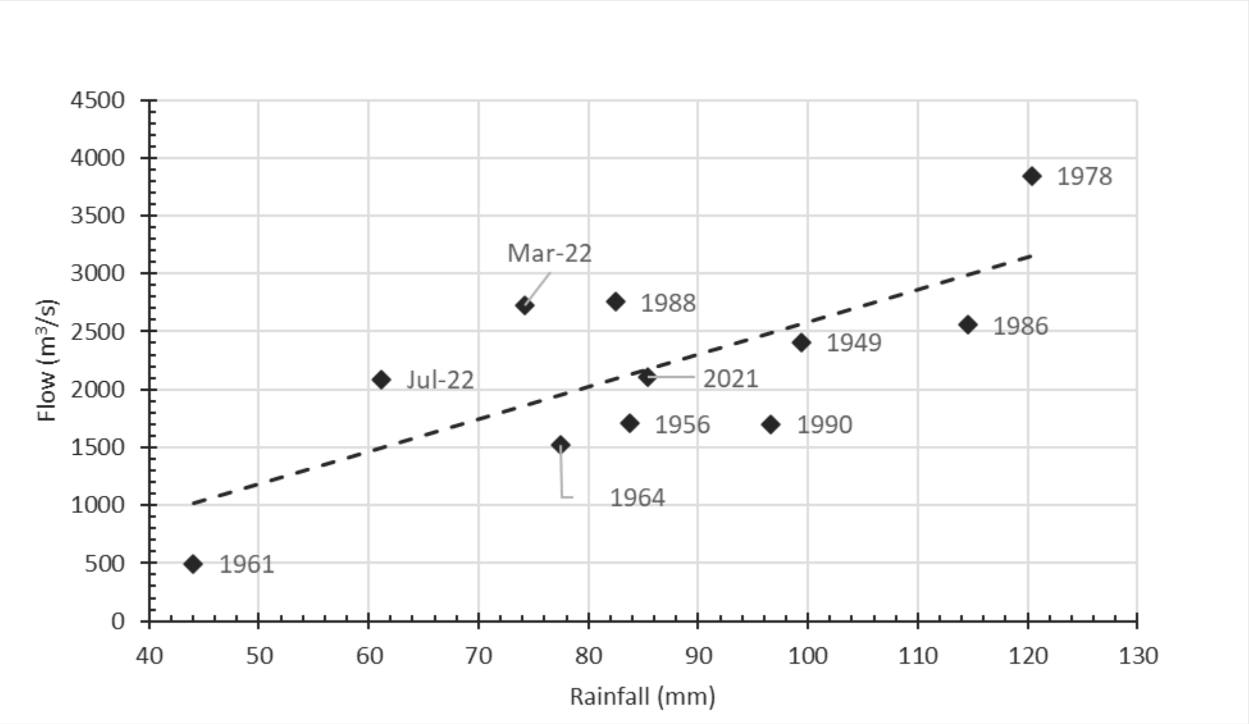

Figure 3-2. Flow-Rainfall Relationship - Colo River Catchment

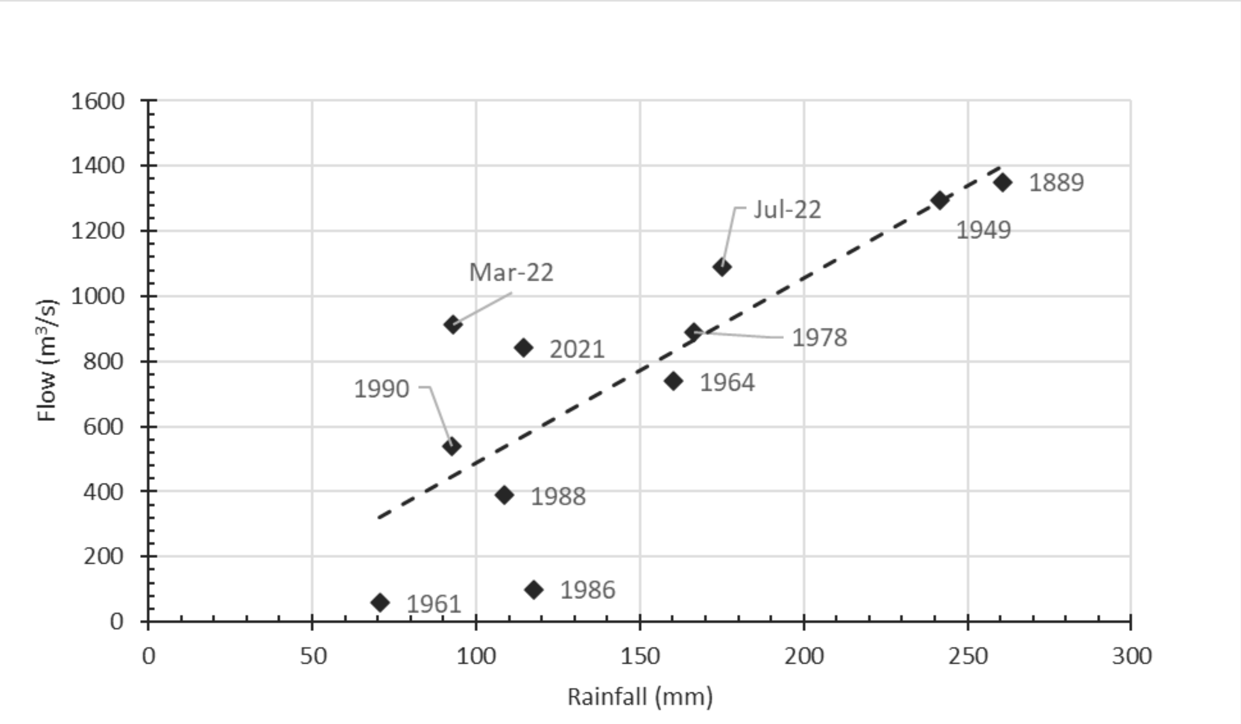

Figure 3-3. Flow-Rainfall Relationship - Macdonald River Catchment[10]

[10] As noted in Section 2.2.4, Hawkesbury River backwater influences may affect this relationship.

Table 3-1. Compiled Historical Data Set, Selected Floods from 1867 to 2022[11]

Flood Event	Level at Windsor (mAHD)[12]	Windsor Flows (m^3/s)	Colo Flows (m^3/s)	Macdonald Flows (m3/s)	Level at Webbs Creek Ferry (mAHD)
Jun 1867	19.3	11570 (1)	-	1200 (4)	9.1 (1)
May 1889	11.9	4550 (12)	3920 (1)	1410 (1)	7.3 (2)
Jul 1900	14.4	6590 (5)	990 (17)	270 (17)	4.1 (10)
Jul 1904	12.5	5040 (11)	2200 (8)	730 (`0)	3.5 (14)
May 1913	8.5	2350 (18)	1520 (16)	1220 (3)	3.7 (12)
Jun 1949	11.8	4510 (13)	2410 (6)	1300 (2)	5.6 (4)
Feb 1956	13.7	6020 (8)	1710 (12)	430 (14)	3.7 (13)
Nov 1961	15.0	7090 (2)	500 (19)	60 (19)	4.0 (11)
Jun 1964	14.6	6740 (3)	1530 (15)	740 (9)	4.2 (9)
Mar 1978	14.5	6640 (4)	3840 (2)	890 (7)	4.8 (6)
Aug 1986	11.4	4150 (14)	2560 (5)	100 (18)	3.1 (15)
Jul 1988	10.9	3830 (15)	2760 (3)	390 (16)	2.8 (16)
Aug 1990	13.5	5780 (9)	1700 (13)	540 (12)	4.3 (8)
Feb 1992	10.9	3810 (16)	1590 (14)	680 (11)	1.3 (20)
Aug 1998	5.4	970 (20)	530 (18)	450 (13)	1.7 (18)
Jun 2013	6.5	1390 (19)	1730 (11)	low (20)	1.6 (19)
Feb 2020	9.3	2810 (17)	2350 (7)	400 (15)	2.4 (17)
Mar 2021	12.9	5350 (10)	2100 (9)	840 (8)	4.4 (7)
Mar 2022	13.8	6060 (7)	2730 (4)	910 (6)	5.2 (5)
Jul 2022	13.9	6180 (6)	2090 (10)	1100 (5)	5.8 (3)

[11] Rank of the event shown in brackets.
[12] Levels and flows at Windsor prior to 1961 are post-dam equivalent.

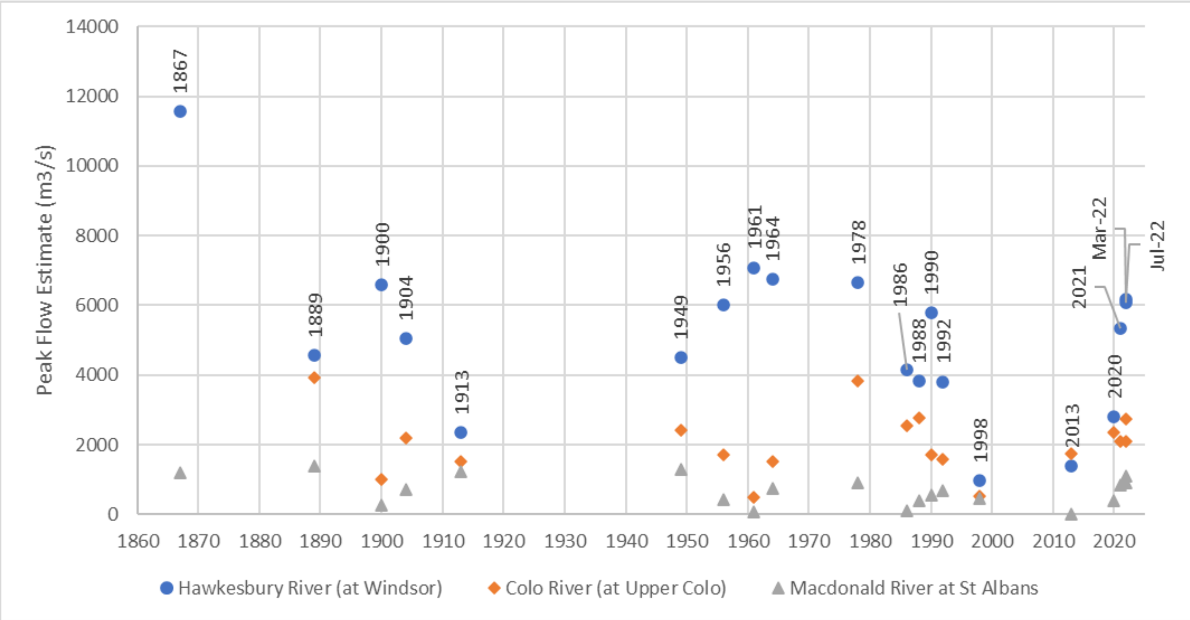

Figure 3-4. Summary of Historical Peak Flow Estimates[13]

[13] Flow estimates for Colo River were not available for 1867. Windsor flows are representative of post-dam conditions.

4 Influence of Colo River & Macdonald River

4.1 Overview

A review of the historical data suggests that the Colo River and Macdonald River can influence the peak water levels on the Lower Hawkesbury, particularly for areas downstream of Sackville. For example, the 1949 event was around 11.8m AHD at Windsor (corresponding to a ranking of 12 from this selection of floods)[14] but was the fourth largest event at Wisemans Ferry (as recorded at the Webbs Creek Ferry gauge).

While the Colo River has a larger catchment than the Macdonald River, reviews of the historical data, and anecdotal information, suggest that large events on the Macdonald River can still influence peak levels at Wisemans Ferry.

An assessment was undertaken to understand the additional contribution of the Colo River and the Macdonald River on the historical peak flood levels at the Webbs Creek Ferry gauge (Wisemans Ferry).

To understand this contribution, the peak flows estimated at Windsor for the historical events were used to understand the 'predicted' level at Webbs Creek Ferry if there was no contribution from the Colo River and Macdonald River. The actual level above this 'predicted' level represents the contribution from Colo River and Macdonald River. This difference between the actual and predicted levels is referred to as the 'residual' in this report.

The assessment was undertaken in the following steps:

- Derivation of a peak flow and peak level relationship for the Hawkesbury River at Webbs Creek Ferry
- Using the estimated flows at Windsor, determine the predicted level at Webbs Creek Ferry based on the above peak flow vs peak level relationship
- Compare the predicted level to the actual level at Webbs Creek Ferry, to understand the 'residual' level.

4.2 Peak Flow vs Peak Level Relationship at Webbs Creek Ferry

The first stage of the analysis was to derive a peak flow and peak level relationship for Webbs Creek Ferry. Similar to the relationship for Windsor in Section 3.1, this was based on peak level and peak flow, where the two may not occur at the same time (in the case of Webbs Creek Ferry, the influence of tidal cycles can change the timing of the peak, for example).

The relationship was derived based on the representative events[15] and the TUFLOW modelling results. This relationship is shown in Figure 4-1.

Overall, there is a strong correlation between peak flow and peak level, regardless of the influence of the tidal cycles. However, some potential variability was identified due to the backwater influence of the Macdonald River (with the junction just downstream of the Webbs Creek Ferry gauge). The peak flows from Macdonald River (and their percentage relative to the Hawkesbury River flows) are also shown on Figure 4-1. Some of the 'outliers' identified would appear to be driven to some degree by higher Macdonald River flows.

[14] Ranked 25th for the record from 1799 to 2022

[15] It is noted that these are based on an earlier version of the representative events. However, the peak flow and peak water level relationship would remain consistent.

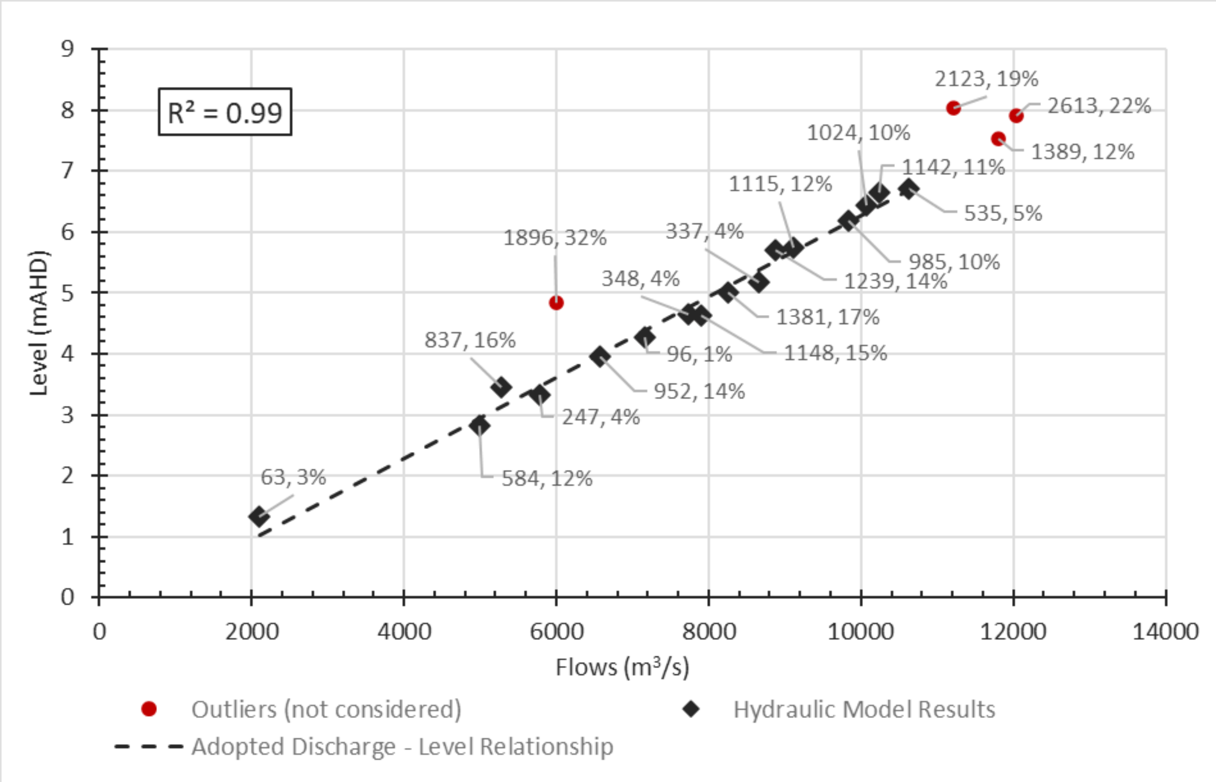

Figure 4-1. Flow-Level Relationship for Hawkesbury River at Webbs Creek Ferry (Macdonald River peak flow, and percentage relative to Hawkesbury River Flow shown as labels)

4.3 Predicted vs Actual Levels at Webbs Creek Ferry

The influence of the Colo River and Macdonald River on Webbs Creek Ferry levels was estimated based on the relationship above. This allowed an estimation of a ‘residual’ level to be derived. The residual level represents the additional level that is estimated to result largely from the Colo River and Macdonald River flows. This was done in the following way:

- Using the flows from Windsor, estimate the peak level at Webbs Creek based on the relationship shown in Figure 4-1. This represents an estimate of the peak level at Webbs Creek if no inflows occur from Colo and Macdonald rivers.
- Based on this, estimate the residual or additional level above this estimate. This represents the additional flood level contribution largely as a result of flows from the Colo and Macdonald rivers.

This process is demonstrated in Figure 4-2. The line shows the predicted level based on the flows at Windsor, with the higher levels from the historical data showing the estimated impact from the Colo River and Macdonald River.

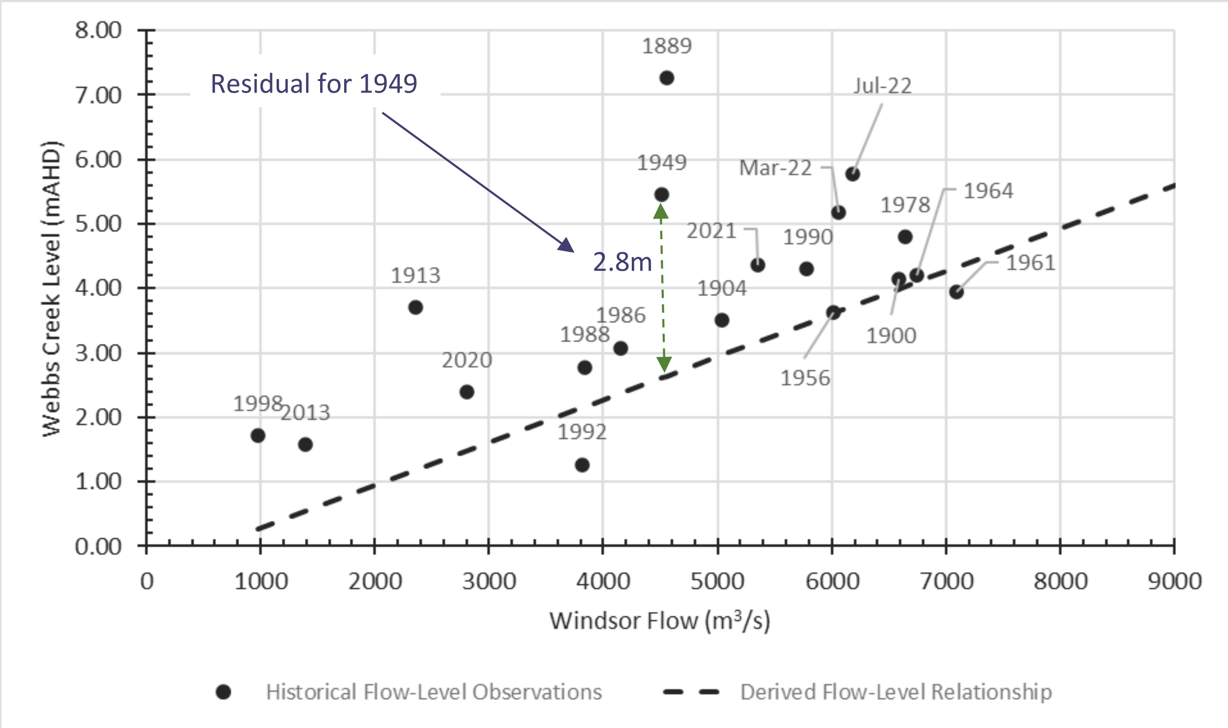

Figure 4-2. Calculation of Residual Levels/Flows at Webbs Creek Ferry[16]

4.4 Contribution of Colo River and Macdonald River

Based on Figure 4-2, a comparison of the estimated residual with the recorded level at Webbs Creek Ferry is provided in Figure 4-3.

It was found that a number of the more significant events at Webbs Creek have a large contribution from the Colo and Macdonald rivers (as reflected by their residual level). Both March 2022 and July 2022 represent relative high residual levels, although these are not as significant as 1889, 1913 and 1949. In the case of 1889, 1913 and 1949, the peak level at Webbs Creek is estimated to be more than 50% contributed to by the Colo River and Macdonald River.

This analysis shows the combined contribution of the Macdonald River and Colo River on the flood levels at Webbs Creek Ferry over and above the Hawkesbury River (at Windsor) inflows. However, the individual contribution of both the Macdonald River and Colo River becomes more challenging to discern. This is because the contribution from these two river systems is dependent not only on their peak flow, but on the shape and timing of their hydrograph relative to the Hawkesbury River. To assist in understanding this analysis, a review of the relative timings was undertaken in Section 5.

[16] Note that there are some levels below the line where there may be uncertainties in the discharge-level relationship adopted, as well as influences such as the tidal levels downstream.

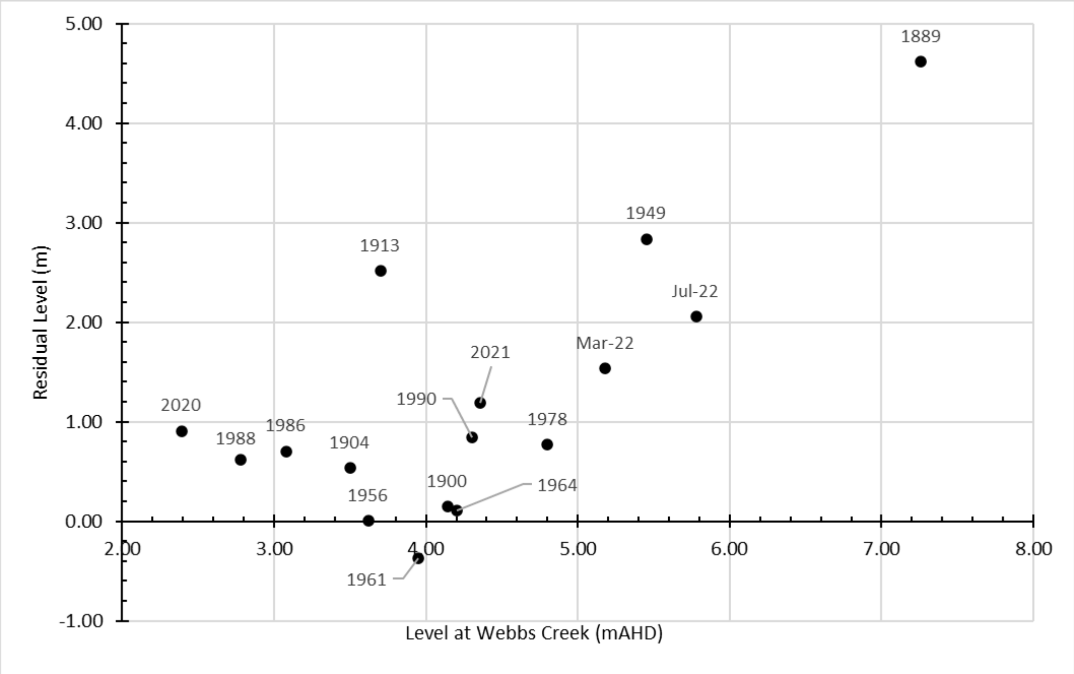

Figure 4-3. Estimated Residual Level vs Recorded Level at Webbs Creek (Wisemans Ferry)[17]

[17] Note that this graph excludes events where Webbs Creek Ferry is below 2.5m AHD, given likely uncertainties in the flow level relationship at that level with the influences of the tide.

5 Historical Timings

5.1 Context

The relative contribution of the Colo River and Macdonald River to peak levels on the Lower Hawkesbury is influenced not only by the magnitude of the peak flows on each of these tributaries, but also on the relatively timing of that peak flow relative to the flows on the Hawkesbury River.

To demonstrate the impact of the timing of the hydrographs, the flows from March 1978 are shown in Figure 5-1 and the flows from July 2022 are shown in Figure 5-2. On both of these figures, a rough estimate of the combined flow downstream of the Colo Junction is also provided. This is an indicative combined flow estimate assuming that the flows from the Colo River at Upper Colo arrive at the Colo Junction at a similar time to the flows from the Hawkesbury River at Windsor[18].

In the case of March 1978, the peak flow from the Colo River at Upper Colo occurs on 20 March around 5pm, while the peak at Windsor occurs later on 22 March at 6am. The result is that by the time the peak flow from Windsor arrives at Colo Junction, the flows from the Colo River are significantly lower (around 1000m^3/s). This results in a combined flow estimate of around 8000m^3/s, or 1000m^3/s higher than the Hawkesbury River at Windsor.

For July 2022, the peaks at Windsor and Upper Colo occur much closer together. This results in a combined flow estimate close to 8,500m^3/s at Colo Junction, roughly 2000m^3/s more than the flow at Windsor.

This aligns with the results of Figure 4-3, where July 2022 had a much higher residual level (resulting from contributions from Colo River and Macdonald River) when compared to March 1978.

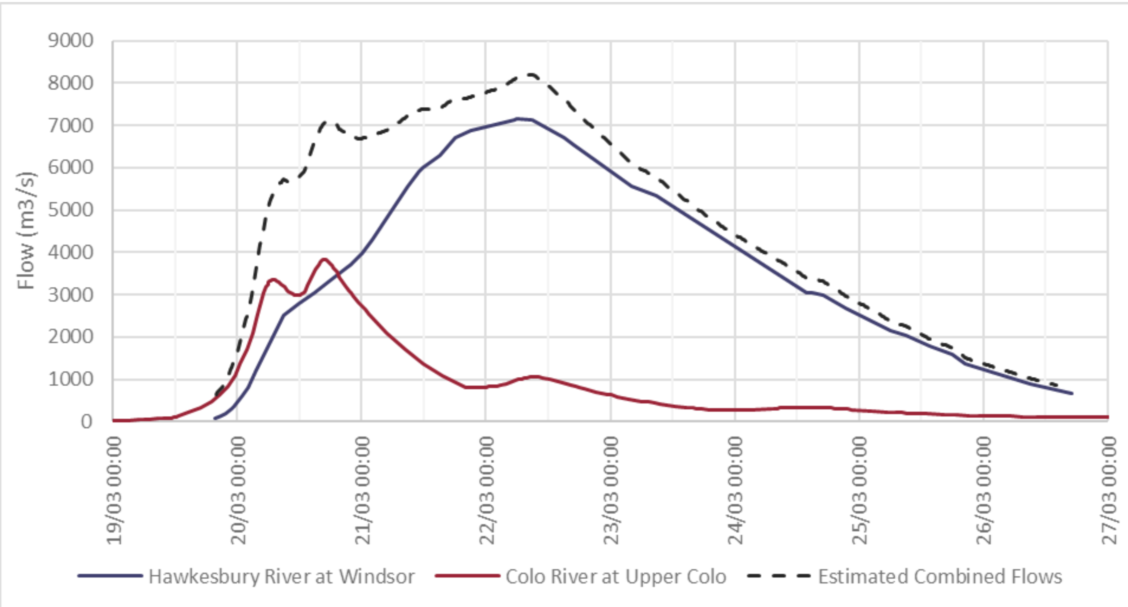

Figure 5-1. March 1978 Event Flows

[18] Previous analysis has suggested that there may be a few hours difference, but for the purposes of this demonstration the timing was assumed to be the same.

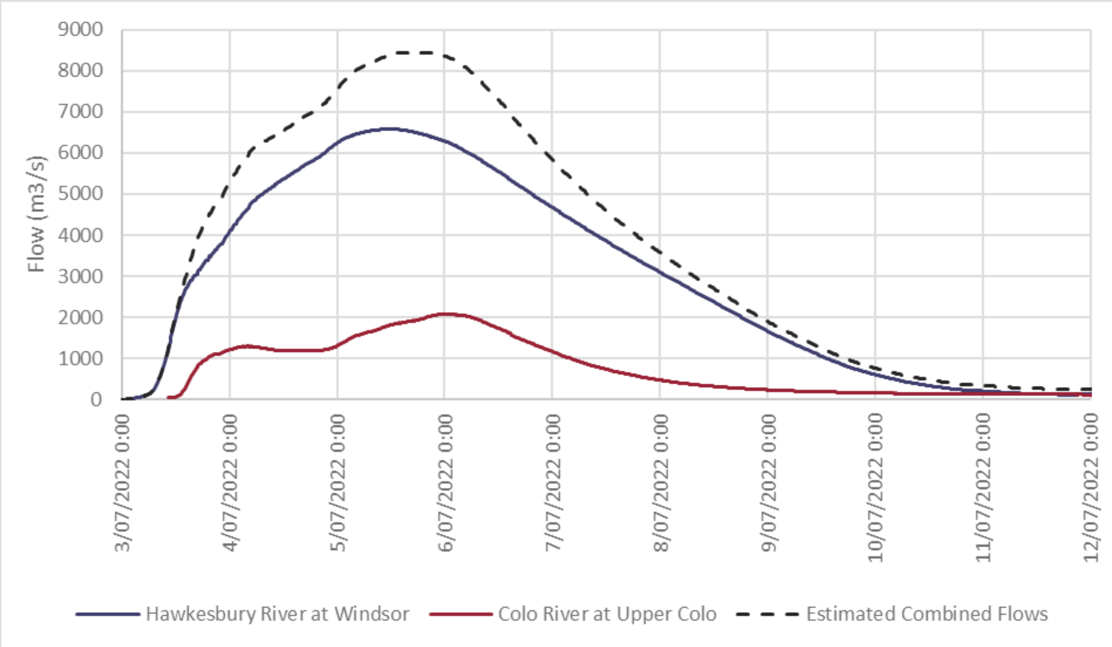

Figure 5-2. July 2022 Event Flows

5.2 Analysis of Historical Timing

Given the significance of the timing of the tributaries (Colo River and Macdonald River) on the levels in the Lower Hawkesbury, an assessment was undertaken to understand the historical distribution of this timing of flood peaks in order to inform the Monte Carlo modelling.

Initially, Windsor was used to assess the relative timing between the Hawkesbury River and the Colo River. However, the hydrograph for Windsor in larger events can generally stay elevated for a longer period of time due to the storage impacts of the Windsor basin. Therefore, it can be difficult to discern the timing of a distinct flood peak.

Therefore, the assessment also included a comparison with the Penrith gauge. The hydrograph peak at Penrith is typically well defined, as there are less storage effects at Penrith for the historical events. Further, for the purposes of the Monte Carlo analysis, Penrith provides an alternative way to compare the timing of flows from Warragamba River and Nepean River.

While the record of peak flows at the Upper Colo gauge dates back to the early 1900s, full event records for the Colo River were not measured until the 1960s. However, records of the timing of the peak were often recorded and were therefore able to be used.

A cumulative distribution analysis of the timing of the peaks between Penrith and Upper Colo is shown in Figure 5-3 (where negative values mean the peak of the Colo River occurs before the peak at Penrith). As shown, the majority of the events see the peak at Upper Colo occurring close to or prior to the peak at Penrith. In these cases, generally the influence of the Colo River would be lower in the Lower Hawkesbury downstream of the Colo Junction, as the larger flows from the Colo River are occurring before the larger flows from the Hawkesbury River (particularly considering the additional lag effect through the Windsor Basin for flows from Penrith).

A similar comparison is provided between Windsor and Upper Colo in Figure 5-4. In the majority of events, the Colo River peaks before the peak at Windsor. However, given the prolonged peak at Windsor due to the storage, it can be more difficult to interpret the timing difference based on peak alone.

In the case where the peak at Penrith and Windsor occurs prior to the peak at the Upper Colo, there is a greater likelihood that the larger flows from the Hawkesbury River will occur closer to the larger flows from the Colo River, resulting in a larger combined peak downstream of the Colo Junction. This is seen in July 2022, where the peak at Penrith and at Windsor occur before the peak at the Colo, increasing the potential for the larger flows from the Colo coinciding with the Hawkesbury River (see Figure 5-2).

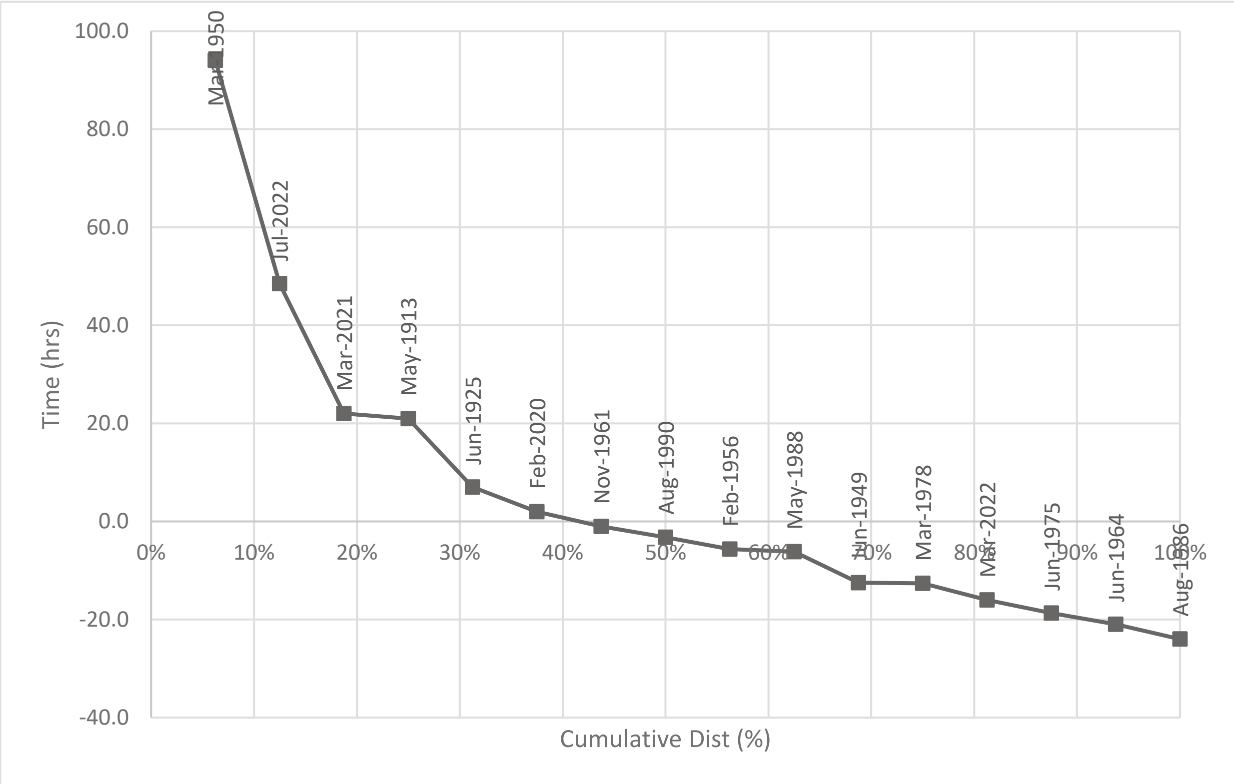

Figure 5-3. Time Difference between Nepean River at Penrith Peak and Colo River at Upper Colo Peak[19]

[19] Negative values represent where the peak at Colo River occurs before the peak at Penrith.

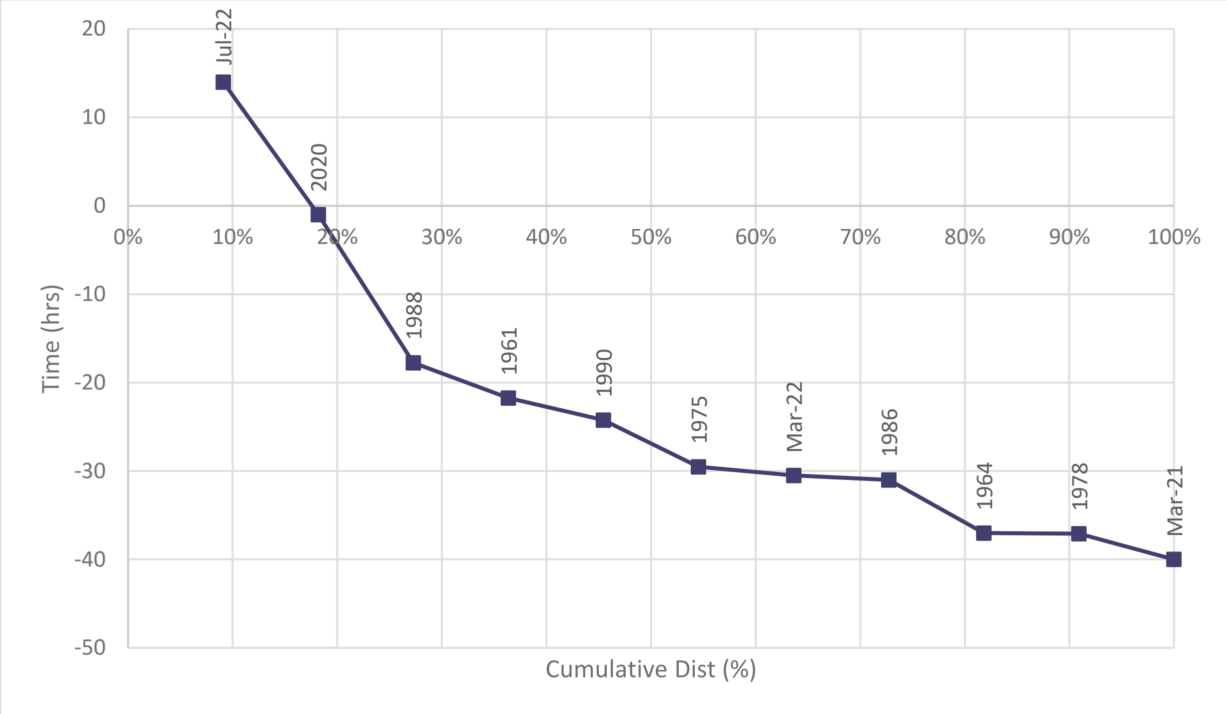

Figure 5-4. Time Difference between Hawkesbury River at Windsor Peak and Colo River at Upper Colo Peak[20]

5.3 Other Considerations

There are other factors that can also influence the outcomes, such as the shape of the hydrograph on both the Colo River and the Hawkesbury River. For example, a longer duration hydrograph on the Colo River increases the likelihood that the higher flows from the Colo River will align with higher flows from the Hawkesbury River (e.g. March 2021 and March 2022 events). However, the above provides some understanding of the general distribution of historical events, which provides a useful validation of the Monte Carlo results.

5.4 Macdonald River

There is significantly less recorded data on peak level timing for the Macdonald River, and therefore a similar analysis to the Colo River could not be undertaken. However, an analysis of historical spatial patterns (refer Technical Volume 7) can provide an understanding of this influence on the shape of the hydrograph.

[20] Negative values represent where the peak at Colo River occurs before the peak at Windsor.

6 Conclusion

The flood behaviour of the Lower Hawkesbury River, downstream of Sackville, is influenced not only by the Hawkesbury River flows from Windsor, but also by inflows from the Colo River and Macdonald River.

This report has undertaken a review of the historical record of the Lower Hawkesbury River, downstream of Colo River Junction, to provide further understanding of the flood behaviour in this area and to inform the subsequent Monte Carlo and design flood modelling.

The first component of the review was to compile an estimate of the historical peak flows for the Hawkesbury River (at Windsor), together with the peak flows for the Colo River and Macdonald River, and peak levels from Webbs Creek gauge at Wisemans Ferry. This was undertaken through a combination of gauged levels, observed historical data, and approximation techniques using recorded rainfall to assist in infilling data. The result is a compiled historical record for the Lower Hawkesbury.

This record was then used to estimate the relative contribution of the Colo River and Macdonald River to peak flood levels at Wisemans Ferry. It was found that a number of the more significant events at Webbs Creek have a large contribution from the Colo and Macdonald rivers. Both March 2022 and July 2022 had relatively large contributions (contributing around 30 – 40% of the peak level), although these are not as significant as 1889, 1913 and 1949. In the case of 1889, 1913 and 1949, the peak level at Webbs Creek is estimated to be more than 50% contributed to by the Colo River and Macdonald River.

The peak levels in the Lower Hawkesbury are influenced not only by the peak flow on the Colo River and Macdonald River, but by the timing of the peak and shape of the hydrograph. A peak flow that occurs much earlier in the Colo River, for example, relative to the Hawkesbury River at Windsor, will not be as influential as a scenario as when the Colo River peak flow occurs close to the Hawkesbury River peak at Windsor.

An analysis was undertaken by comparing the timing between the peak at the Victoria Bridge gauge at Penrith (Nepean River) with the Upper Colo gauge on the Colo River, as well as the Windsor PWD gauge with the Upper Colo Gauge.

This analysis informed an estimated distribution of the time difference between the peak at Victoria Bridge and Windsor PWD with the peak at Upper Colo Gauge. These distributions provide a key input to the Monte Carlo modelling described in **Technical Volume 7**.

7 References

Australian Water and Coastal Studies Pty Ltd [AWACS] (1997). *Lower Hawkesbury River Flood Study*, prepared for the Department of Land and Water Conservation, Report No CFR97/06, Final Draft.

Erskine, WD (1986) 'River metamorphosis and environmental change in the Macdonald Valley, New South Wales, since 1949', *Australian Geographical Studies*, Vol 24, pp.88-107.

NSW Government (2023). *Flood Risk Mangement Manual: The policy and manual for the management of flood liable land*. Department of Planning and Environment.

WMAwater (2019). *Hawkesbury-Nepean Valley Regional Flood Study*, Final Report, prepared for Infrastructure NSW, July.

8 Glossary[21]

Term	Shortened form	Definition	Context for use/additional information
Annual exceedance probability	AEP	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage	AEP is generally the preferred terminology. ARI is the historical way of describing a flood event, for example, a 1% AEP flood has a 1% or 1 in 100 chance of being reached or exceeded in any given year
Australian height datum	AHD	A common national surface level datum often used as a referenced level for ground, floor and flood levels	0.0 m AHD corresponds approximately to mean sea level
Average recurrence interval	ARI	The long-term average number of years between the occurrence of a flood equal to or larger in size than the selected event	ARI is the historical way of describing a flood event. AEP is generally the preferred terminology, for example, a 100-year ARI flood that has 1 in 100 chance of being reached or exceeded in any given year. It is equivalent to a 1% AEP flood
Catchment		The area of land draining to a specific location	It includes the catchment of the primary waterway as well as any tributary streams and flowpaths
Catchment flooding		Flooding due to prolonged or intense rainfall (e.g. severe thunderstorms, monsoonal rains in the tropics, tropical cyclones)	Types of catchment flooding include riverine, local overland and groundwater flooding
Chance		The likelihood of something happening that will have adverse or beneficial consequences	In FRM this generally relates to the adverse consequences of floods with chance being related to AEP, for example, 1% chance or 1 in 100 chance per year is equivalent to 1% AEP
Coastal inundation		Inundation due to tidal or storm-driven coastal events, including storm surges in lower coastal waterways. This can be exacerbated by wind-wave generation from storm events	
Consent authority		The authority or agency with the legislative power to determine the outcome of development and building applications	This may be the relevant local council or Minister
Consequence		The outcomes of an event or situation affecting objectives, expressed qualitatively or quantitatively	Consequences can be adverse (e.g. death or injury to people, damage to property and disruption of the community) or beneficial
Continuing flood risk		Risk to existing and future development that may be reduced by EM measures	Flood risk to the existing development and future development may be reduced by EM measures depending on flood constraints, however, these measures cannot remove all risk and a residual risk will remain

[21] Definitions from the Flood Risk Management Manual (2023)

Term	Shortened form	Definition	Context for use/additional information
Defined flood event	DFE	The flood event selected as a general standard for the management of flooding to development	Aims to reduce the frequency of flooding but does not remove all flood risk, for example, in selecting a 1% AEP flood as a DFE you are accepting that there is a 1 in 100 chance that a larger event will occur in any year. This risk is being built into the decision
Design flood		The flood selected as part of the FRM process that forms the basis for physical works to modify the impacts of flooding	The design flood may be considered the flood mitigation standard, for example, a levee may be designed to exclude a 2% AEP flood, which means that floods rarer than this may breech the structure and impact upon the protected area. In this case, the 2% AEP flood would not equate to the crest level of the levee, because this generally has a freeboard allowance, but it may be the level of the spillway to allow for controlled levee overtopping
Development		May be treated differently depending on the following categorisation: · **infill development**: the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under current land zoning · **new development**: development of a completely different nature to that associated with the former land-use (e.g. the urban subdivision of a previously rural area) · **redevelopment**: rebuilding in an area (e.g. as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale)	New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. Redevelopment generally does not require either rezoning or major extensions to urban services
Development control plan	DCP	See *Environmental Planning and Assessment Act 1979*	
Emergency management	EM	A comprehensive approach to dealing with risks to the community arising from hazards. It is a systematic method for identifying, analysing, evaluating and managing these risks	May include measures to reduce flood frequency or consequences through prevention and mitigation measures, and preparation, as well as response and recovery should a flood occur (see PPRR)
Ecologically sustainable development	ESD	As outlined in the *Local Government Act 1993*	Principles of ESD are outlined in the *Local Government Act 1993*

Term	Shortened form	Definition	Context for use/additional information
Existing flood risk		The risk an existing community is exposed to as a result of its location on the floodplain	Existing flood risk may be reduced by existing or proposed FRM measures leaving a residual flood risk to the existing community. Residual flood risk may be further reduced by addressing continuing risk
Flood		A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal inundation (excluding tsunamis) or catchment flooding, or a combination of both	Flooding results from relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flowpaths associated with major drainage, and/or oceanic inundation resulting from super-elevated ocean levels
Flood (hydrologic and hydraulic) modelling		Hydrologic and hydraulic computer models to simulate catchment processes of rainfall, run-off, stream flow and distribution of flows across the floodplain or similar	They typically involve consideration of the local flood history, available collected data, and the development of models that are calibrated and validated, where possible, against historic flood events and extended to determine the full range of flood behaviour
Flood affected land		Equivalent to flood prone land	See the definition of flood prone land
Flood awareness		An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures facilitating prompt and effective community response to a flood threat	In communities with a low degree of flood awareness, flood warnings may be ignored or misunderstood, and residents confused about what they should do, when to evacuate, what to take with them and where to go
Flood constraints		Key constraints that flooding place on land	These include flood function, flood hazard, flood range, and flood emergency response classification. These can be used to inform FRM including consideration of options such as mitigation works, EM and land-use planning
Flood damage		The tangible (direct and indirect) and intangible costs (financial, opportunity costs, clean-up) of flooding	Tangible costs are quantified in monetary terms (e.g. damage to goods). Intangible damages are difficult to quantify in monetary terms and include the increased levels of physical, emotional and psychological health problems suffered by flood affected people that are attributed to a flood
Flood education		Seeks to provide information to raise community awareness of flooding so as to enable individuals to understand how to manage themselves and their property in response to flood warnings	

Term	Shortened form	Definition	Context for use/additional information
Flood evacuation		The movement of people from a place of danger to a place of relative safety, and their eventual return	People are usually evacuated to areas outside of flood prone land with access to adequate community support. Livestock may be relocated to areas outside of the influence of flooding
Flood fringe areas		That part of the flood extents for the event remaining after the flood function areas of floodway and flood storage areas have been defined.	
Flood function		The flood related functions of floodways, flood storage and flood fringe within the floodplain	Flood function is equivalent to hydraulic categorisation
Flood hazard		A flood that has the potential to cause harm or conditions with the potential to result in loss of life, injury and economic loss	The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, etc.)
Flood impact and risk assessment	FIRA	A study to assess flood behaviour, constraints and risk, understand offsite flood impacts on property and the community resulting from the development, and flood risk to the development and its users	These studies are generally undertaken for development and are to be prepared by a suitably qualified engineer experienced in hydrological and hydraulic analysis for FRM
Flood liable land		Equivalent to flood prone land	See the definition of flood prone land
Flood plan (local or state)	Local (LFP)	A sub-plan of an EM plan that deals specifically with flooding; they can exist at state, zone and local levels	The NSW Government develops flood plans as a legislative responsibility to determine how best to respond to floods. These community-based plans describe the risk to the community, outline agency roles and responsibilities, the agreed community emergency response strategy and how floods will be managed
Flood planning area	FPA	The area of land below the FPL	The FPA is generally developed based on the FPL for typical residential development. Different types of development may have different FPLs applied within the FPA. In addition development controls will vary across the FPA due to varying flood constraints
Flood planning level	FPL	The combination of the flood level from the DFE and freeboard selected for FRM purposes	Different FPLs may apply to different types of development. Determining the FPL for typical residential development should generally start with a DFE of the 1% AEP flood plus an appropriate freeboard (typically 0.5 m). This assists in determining the FPA

Term	Shortened form	Definition	Context for use/additional information
Flood prone land		Land susceptible to flooding by the PMF event	Flood prone land is also known as the floodplain, flood liable land and flood affected land
Flood risk		Risk is based on the consideration of the consequences of the full range of flood behaviour on communities and their social settings, and the natural and built environment	See also risk. The degree of risk varies with circumstances across the full range of floods. It is affected by factors including flood behaviour and hazard, topography and EM difficulties
Flood risk management	FRM	The management of flood risk to communities	
Flood storage areas		Areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood	See also flood function, floodways and flood fringe areas
Flood study		A comprehensive technical investigation of flood behaviour undertaken in accordance with the principles in this manual and consistent with associated guidelines. A flood study defines the nature of flood behaviour and hazard across the floodplain by providing information on the extent, level and velocity of floodwaters, and on the distribution of flood flows considering the full range of flood events up to and including extreme events, such as the PMF	A flood study is undertaken in accordance with the FRM process outlined in this manual to support the understanding and management of flood risk. It is different from a flood impact and risk assessment (FIRA)
Flood warnings		Warnings issued when there is more certainty that flooding is expected, are more targeted and are issued for specific catchments	Flood warnings include more specific predictions of the severity of expected flooding and may give quantitative figures such as expected river water heights at gauge stations
Floodplain		Equivalent to flood prone land	See the definition of flood prone land
Floodways		Areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined	See also flood function, floodways and flood fringe areas. Floodways are sometimes known as flow conveyance areas

Term	Shortened form	Definition	Context for use/additional information
		channels or form elsewhere in the floodplain	
Flow		The rate of flow of water measured in volume per unit time, for example, cubic metres per second (m_3/s)	Flow is different from the speed or velocity of flow, which is a measure of how fast the water is moving
Freeboard		A factor of safety typically used in relation to the setting of minimum floor levels or levee crest levels	Freeboard aims to provide reasonable certainty that the risk exposure selected in deciding on a specific event for development controls or mitigation works is achieved. Freeboards for development controls and mitigation works will differ. In addition freeboards for development control may vary with the type of flooding and with the type of development
Frequency		The measure of likelihood expressed as the number of occurrences of a specified event in a given time	For example, the frequency of occurrence of a 20% AEP or 5-year ARI flood is once every 5 years on average
FRM measures		Measures that can reduce flood risk	FRM measures may include FRM, flood mitigation, EM and land-use planning measures
FRM options		The FRM measures that might be feasible for the management of a particular area of the floodplain	Preparation of an FRM plan requires a detailed evaluation of FRM options
FRM plan		A management plan developed in accordance with the principles in this manual and its supporting guidelines	Previously known as a floodplain risk management plan or floodplain management plan. It may describe how particular areas of flood prone land are to be used and managed to achieve defined objectives
FRM study		A management study developed in accordance with the principles in this manual and its supporting guidelines	Previously known as a floodplain risk management study or floodplain management study
Future flood risk		The risk future development and its users are exposed to as a result of its location on the floodplain	Future flood risk may be reduced by existing or proposed FRM measures and land-use planning controls that consider the flood constraints on the land. This leaves a residual flood risk to the new development and its users. This residual flood risk may be further reduced by addressing continuing flood risk
Gauge height		The height of a flood level at a particular water level gauge site related to a specified datum	The datum may or may not be the AHD
Hazard		A source of potential harm or conditions that may result in loss of life, injury and economic loss due to flooding	

Term	Shortened form	Definition	Context for use/additional information
Hydraulics		The study of water flow in waterways and flowpaths; in particular, the evaluation of flow parameters such as water level and velocity	
Hydrology		The study of the rainfall and run-off process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods	
Integrated planning and reporting framework	IP&R framework	The IP&R framework includes a suite of integrated plans that set out a vision and goals and strategic actions to achieve them. It involves a reporting structure to communicate progress to council and the community as well as a structured timeline for review to ensure the goals and actions are still relevant	Preparation of FRMS and plans and implementation and maintenance of works requires linkages to the IP&R framework
Likelihood		A qualitative description of probability and frequency	See also frequency and probability
Likelihood of occurrence		The likelihood that a specified event will occur	With respect to flooding, see also AEP and ARI
Local environmental plan	LEP	See *Environmental Planning and Assessment Act 1979*	
Local government area	LGA	The area serviced by the local government council	
Local overland flooding	LOF	Inundation by local run-off on its way to a waterway, rather than overbank flow from a waterway	
Local strategic planning statement	LSPS	Local strategic planning statements assist councils to implement the priorities set out in their community strategic plan and actions in regional and district plans	
Loss		Any negative consequence or adverse effect, financial or otherwise	

Term	Shortened form	Definition	Context for use/additional information
Merit-based approach		Weighs social, economic, ecological and cultural impacts of land-use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of the state's rivers and floodplains	The merit approach operates at 2 levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk, which are formulated into council plans, policy and environmental planning instruments At a site-specific level, it involves consideration of the merits of a development consistent with council LEPs, DCPs and local FRM policies, and consistent with FRM plans
NSW Floodplain Management Program	The program	The NSW Government's program of technical support and financial assistance to local councils to enable them to understand and manage their flood risk	The program, manual and FRM guides support the delivery of the policy through a partnership across governments
Prevention, preparedness, response and recovery	PPRR	Involves: · **prevention:** to eliminate or reduce the level of the risk or severity of emergencies · **preparedness:** enhances the capacity of agencies and communities to cope with the consequences of emergencies · **response:** to ensure the immediate consequences of emergencies to communities are minimised · **recovery:** measures that support individuals and communities affected by emergencies in the reconstruction of physical infrastructure and restoration of physical, emotional, environmental and economic wellbeing	In the flood context prevention involves FRM (including flood mitigation), EM and land-use planning measures
Probability		A statistical measure of the expected chance of a flood	For example, AEP
Probable maximum flood	PMF	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP), and where applicable, snow melt, coupled with the worst flood-producing catchment conditions	This is equivalent to the probable maximum precipitation flood in Australian Rainfall and Runoff (ARR). The PMF in ARR is used for estimating dam design floods

Term	Shortened form	Definition	Context for use/additional information
Probable maximum precipitation	PMP	The greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long- term climatic trends (World Meteorological Organization 1986)	PMP is the primary input to PMF estimation
Rainfall intensity		The rate at which rain falls, typically measured in millimetres per hour (mm/h)	Rainfall intensity varies throughout a storm in accordance with the temporal pattern of the storm
Residual flood risk		The risk to the existing and future community that remains with FRM, EM and land-use planning measures in place to address flood risk	FRM measures cannot remove all flood risk, but rather they reduce residual flood risk
Risk		'The effect of uncertainty on objectives' (ISO 2018)	See also flood risk. Note 4 of the definition in ISO31000:2018 also states that 'risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood'
Risk analysis		The systematic use of available information to determine how often specified (flood) events occur and the magnitude of their likely consequences	
Run-off		The amount of rainfall that ends up as streamflow, also known as rainfall excess	
Scenario		A scenario may relate to current, historical or assumed future floodplain, catchment and climate conditions	Flood behaviour varies over time with changes in key catchment and floodplain (such as the scale of development) and climatic conditions (including climate change), and due to the implementation of FRM measures. A range of scenarios are generally needed to understand and assess flood behaviour
Stage		Equivalent to water level; measured with reference to a specified datum	Measurement may relate to AHD, a local datum or a local water level gauge
Storm surge		The increases in coastal water levels above predicted astronomical tide level (i.e. tidal anomaly) resulting from a range of location-dependent factors	These factors may include the inverted barometer effect, wind and wave setup and astronomical tidal waves, together with any other factors that increase tidal water level
Velocity		The speed of floodwaters, measured in metres per second (m/s)	

Term	Shortened form	Definition	Context for use/additional information
Vulnerability		The degree of susceptibility and resilience of a community, its social setting, and the built environment to flooding	Vulnerability is assessed in terms of ability of the community and environment to anticipate, cope and recover from flood events

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