Review of impacts of system-wide drivers on Tar-Ru

Scoping report - Stage 1

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Contents

Executive Summary

Tar-Ru (Lake Victoria) is a naturally occurring shallow freshwater lake approximately 60 km downstream of the Murray–Darling Junction in south-western New South Wales, close to the South Australian and Victoria borders. Since 1928, the lake has been operated by the Murray-Darling Basin Authority (MDBA) and its predecessors as a regulated, off-river storage as part of the River Murray system.

Since the mid-2010s, meeting the May 31 minimum reserve and filling the lake in late spring appears to have become a more frequent challenge. This project was convened by the MDBA on behalf of its joint venture partners to examine why this might be the case.

The historic storage data available for Tar-Ru shows that:

- In the February to May period in the eight years to 2020, the lake level and active storage in Tar-Ru has been lower compared with earlier in the record, especially if the years associated with the Millennium Drought are considered separately.
- The frequency and duration with which Tar-Ru has been full has been less in the post-Lake Victoria Operating Strategy (LVOS; MDBC 2002) and Millennium Drought period compared with the pre-LVOS and Millennium Drought period. The reduced duration of Tar-Ru being full is consistent with the LVOS, because the aim is now to fill Tar-Ru late in winter / spring, rather than keeping it at full supply level.
- In four of the last six years, the active storage in Tar-Ru has been less than the minimum reserve target for May 31. However, there were also years prior to the LVOS and Millennium Drought when active storage was below this target.
- The active storage volume in Tar-Ru in mid-December has been trending down since the end of the Millennium Drought. From the mid-1980s to mid-1990s, Tar-Ru was generally full in mid-December.

These variations in the active storage within Tar-Ru have occurred because diversions to Tar-Ru have been less in the recent historic record compared with earlier years, whereas outflows have been more constant.

Potential drivers of the observed behaviour of Tar-Ru were identified via interviews with the MDBA and representatives from the Basin states. These drivers were then illustrated with case studies at a workshop. Overall, there was broad acceptance that it has often been difficult to fill Tar-Ru over the last decade. There was also general agreement on the broad drivers that have affected the filling frequency of Tar-Ru, and that these drivers often combine or interact.
The main drivers identified were:

Reduced tributary inflows

- The reduction of Darling River flows in the recent historic record (coinciding with periods when the Menindee Lakes are offline) has made it more difficult to fill Tar-Ru. This has been compounded by reduced inflows from the unregulated Kiewa River and Ovens River upstream of Barmah Choke, and NSW's and Victoria's regulated tributaries between the Barmah Choke and the Murray-Darling junction.

Operational constraints and efficiencies

- In response to reduced tributary inflows, more water has been transferred from Lake Hume to fill Tar-Ru. However, changes to Barmah Choke channel due to sedimentation is reducing the in-channel capacity available for these Hume – Tar-Ru transfers.
- The increased efficiency of water delivery and consumptive use, and reduced volumes of rain rejection flows along the River Murray, has reduced the number of opportunistic instances where additional diversions can be made to Tar-Ru.

Demands for water

- Total combined demands for consumptive and environmental water use downstream of the Choke have remained high in the January – April period when overbank flows through the Barmah-Millewa Forest are undesirable. The delivery of water to these demands through or around Barmah Choke uses channel capacity, and therefore limits the in-channel capacity available for Hume – Tar-Ru transfers.
- In contrast, peak monthly demands for water use downstream of the Choke appear to have shifted to spring / early summer, when demand for consumptive and environmental purposes often coincide. This is also the period when Hume – Tar-Ru transfers are most likely to be required.

Local Tar-Ru operations

- Constraints on Tar-Ru water levels are needed to meet cultural obligations and objectives, minimise lake bed and shore erosion, promote revegetation and minimise the salinisation of nearby land.

Based on these findings, the recommended priority for future work is to develop a risk-based framework for making decisions about the timing and volume of Hume – Tar-Ru transfers, to account for reduced tributary inflows, operational constraints and changing water demands in the River Murray system. The proposed objective for this work is to develop Hume – Tar-Ru transfer guidelines or rules that balance the risks of:

- Resource loss (e.g. spills from Tar-Ru; increased conveyance losses)
- Supply shortfalls for water users (e.g. storage in Tar-Ru being insufficient to meet peak downstream demands)
- Deliverability constraints that curtail water orders from the Basin states (e.g. transfers using regulated release and river channel capacities that would otherwise be used to deliver water to consumptive users or the environment).

The development of an agreed risk-based framework for making decisions about Hume – Tar-Ru transfers may take 2–3-years. Table 6-1 provides a high-level summary of the tasks involved. These proposed tasks have been grouped into four sets:

- Develop a fit-for-purpose model for future investigations
- Confirm or re-visit with First Nations, Basin states and other stakeholders the water resource management policies and procedures that influence the operation of Tar-Ru
- Develop a risk-based framework for Hume – Tar-Ru transfers using ‘what if’ scenario testing
- Report and communicate the task outcomes.

1. Introduction

1.1 Tar-Ru (Lake Victoria)

Tar-Ru (Lake Victoria) is a naturally occurring shallow freshwater lake approximately 60 km downstream of the Murray–Darling Junction in south-western New South Wales, close to the South Australian and Victoria borders. Since 1928, the lake has been operated by the Murray-Darling Basin Authority (MDBA) and its predecessors as a regulated, off-river storage as part of the River Murray system. Figure 1-1 presents a schematic of the River Murray system.

The lake plays an important role in the re-regulation of flows and management of water supply and water quality to South Australia. The operation of the lake is guided by the Tar-Ru (Lake Victoria) Operating Strategy that commenced in 2002 (MDBC 2002). To protect the cultural heritage of the Barkindji-Maraura people, Tar-Ru is also operated in accordance with the Lake Victoria Cultural Landscape Plan of Management (MDBA 2019), and an Aboriginal Heritage Impact Permit (AHIP; e.g. MDBA 2020a).

The South Australian Water Corporation (SA Water) manages the storage on behalf of, and in collaboration with the MDBA and a joint venture between Victoria, New South Wales and South Australia. Management of Tar-Ru and its surrounding landscape also involves partnerships between those involved in implementing the Lake Victoria Cultural Landscape Plan of Management (MDBA 2019)[1].

Tar-Ru is generally operated so that active storage is near or at full supply level (27.0 m AHD) as late as possible in spring (MDBC 2002). Water is then released and the lake is drawn down over summer and autumn to supply downstream demands. This results in a drying period similar to that which would have occurred before river regulation, and helps to protect Barkindji-Maraura cultural values, and meet local environmental objectives (MDBC 2002, MDBA 2019). The lake water levels are held below 24.5 m AHD in April and May before filling commences from June 1st. The minimum active storage target on May 31 is 250 GL (Murray-Darling Basin Agreement, subdivision C), which corresponds to a lake level of approximately 24 m AHD.

Filling the lake has historically been a challenge in dry years that have relatively high water allocations. Since the mid-2010s however, meeting the May 31 minimum reserve and filling the lake in late spring appears to have become a more frequent challenge (Figure 1-2; Section 2). Numerous factors may have contributed to this difficulty, including reduced tributary inflows, changed water demand patterns and constraints on water delivery via the River Murray channel. However, the relative contribution of these potential drivers has not been quantified. This project was therefore convened by the MDBA on behalf of its joint venture partners to examine the key environmental and water management drivers that are making it difficult to fill Tar-Ru, whilst still meeting downstream consumptive and environmental water demands and the objectives of the Tar-Ru (Lake Victoria) Operating Strategy (MDBA 2002) and Lake Victoria Cultural Landscape Plan of Management (MDBA 2019).

[1] Barkindji-Maraura Elders Council, Lake Victoria Advisory Committee, Lake Victoria Scientific Review Panel

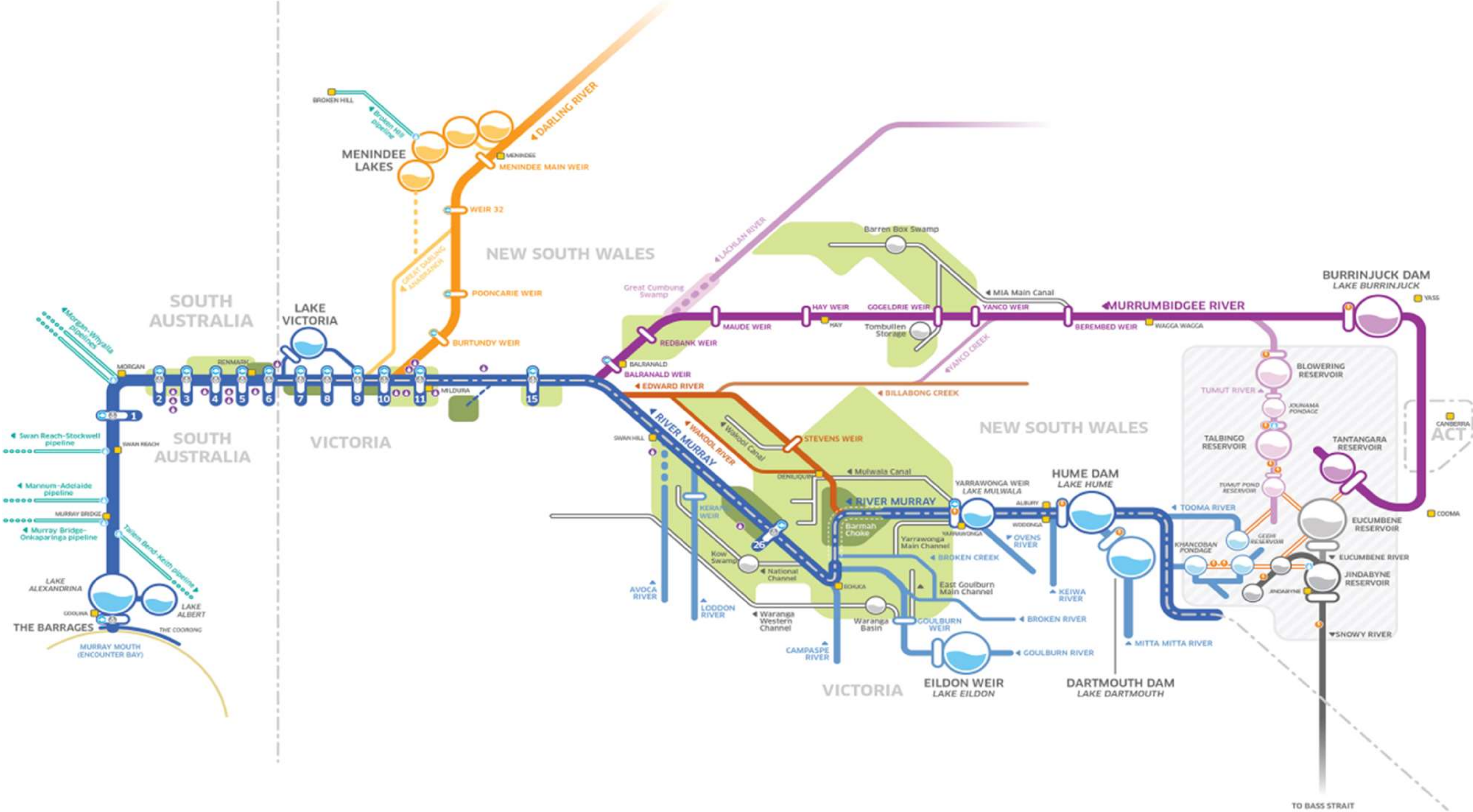

Figure 1-1: A schematic of the southern connected Murray-Darling Basin. Tar-Ru (Lake Victoria) is near the South Australian border.

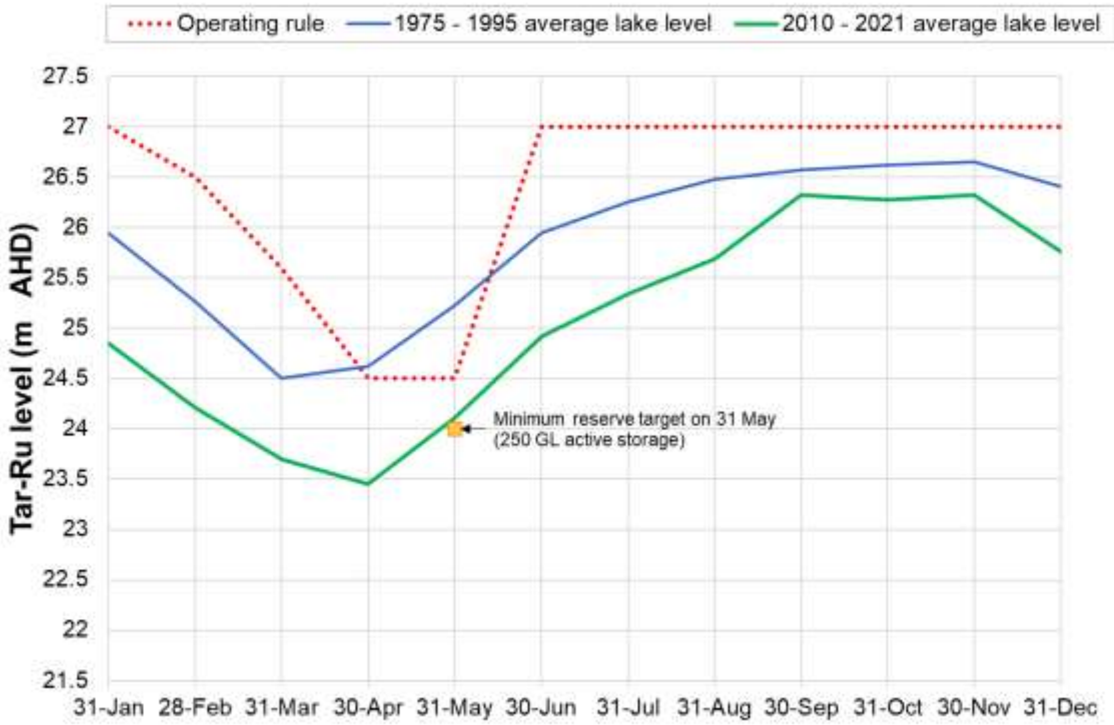

Figure 1-2: Comparison of average monthly water levels at Tar-Ru with the LVOS (2002) operating rules. The 1975–1995 period (blue line) represents pre-Millennium Drought, while the 2010-2021 period (green line) represents the post-Millennium Drought conditions. Further detail on the Tar-Ru filling frequency is presented in Section 2.

1.2 Project objectives

This project is a scoping study that explored the issues surrounding water availability and management in the southern connected Murray-Darling Basin that influence the filling and operations of Tar-Ru. As such, it aimed to identify – with the assistance of the MDBA and stakeholders from the Basin states – the main drivers that affect water availability and delivery to Tar-Ru.

The information and insights gathered during the project will be used by the MDBA to scope and prioritise future work required to fill knowledge gaps and refine Tar-Ru operations, consistent with the objectives of the Tar-Ru (Lake Victoria) Operating Strategy (MDBC 2002), and other obligations such as those contained in the Murray-Darling Basin Agreement (Schedule 1 of the Water Act 2007) that sets out rules and plans for sharing the water from the River Murray system between New South Wales (NSW), South Australia and Victoria.

1.3 Project scope and stages

This project was completed in three phases (Figure 1-3):

- Phase 1: Discovery – existing information was collated, and case studies were prepared to provide an overview of key drivers affecting the filling and operation of Tar-Ru. MDBA River Murray Operations staff also provided the project team with an overview of how the southern connected Basin is operated, with an emphasis on the role of Tar-Ru.

- Phase 2: Consultation – interviews were held with MDBA, jurisdiction, water corporation and environmental water holder staff to gain stakeholder perspectives on drivers and issues (see communication activities undertaken in Appendix A). The interviews were followed by a workshop where findings were presented on the key drivers affecting the filling frequency and operation of Tar-Ru (see key findings in Appendix B).
- Phase 3: Respond and Report – insights gained in the previous project phases were used to identify the knowledge gaps and potential future investigations to be pursued over the next 2-3 years. These investigations will address knowledge gaps and increase understanding of the scope of drivers affecting the filling of Tar-Ru and potential management responses. The recommended investigations were included in a draft project report that was provided for comment. The resulting feedback and suggestions were incorporated into this final report.

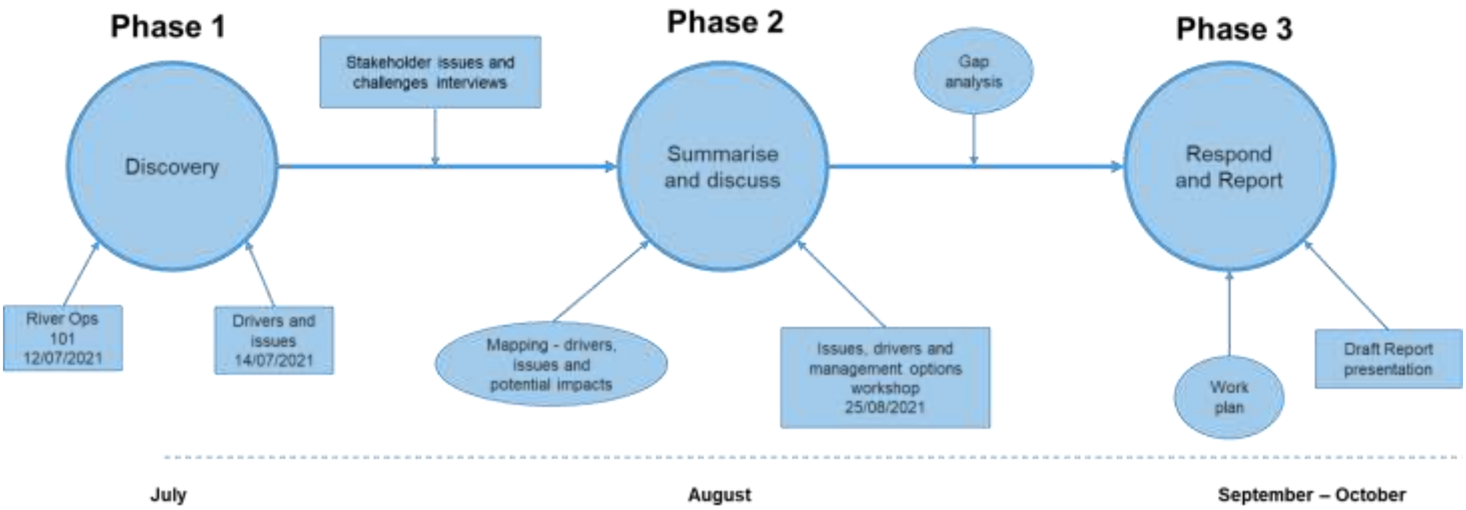

Figure 1-3: An outline of the three project phases

1.4 This report

The remainder of this report is comprised of five sections:

- Section 2 summarises historic records of lake levels and active storage at Tar-Ru, and diversions to and outflows from Tar-Ru.
- Section 3 summarises the potential drivers that have influenced the filling frequency and operation of Tar-Ru in recent years.
- Section 4 provides case studies of three key drivers and the inter-related nature of the drivers affecting Tar-Ru filling frequency.
- Section 5 summarises the existing and potential management instruments and arrangements that influence Tar-Ru operations, as well as potential knowledge gaps to address in future investigations.
- Section 6 presents a high-level concept plan for future work, based on the outcomes of this scoping study.

1.5 Use of new and existing information

The short-term nature of this project (Figure 1-3) meant that both existing information and datasets collated specifically for this scoping study have been used in subsequent sections of this report. In particular:

- Figures related to the hydrologic behaviour of Tar-Ru itself (Section 2) were based on gauge records obtained for this study from the MDBA and Bureau of Meteorology.
- Figures used to illustrate potential drivers (Section 3) and in the case studies (Section 4) were obtained from other reports that are referenced in these report sections.

2. Tar-Ru: historic behaviour

Section 2 of this report provides a summary of the historic gauge records available for Tar-Ru, for the period 1985–2020. [2] The data presented is a combination of records available from the MDBA and the Bureau of Meteorology water data online website (www.bom.gov.au/waterdata/).

2.1 Level and storage

Figure 2-1 and Figure 2-2 show the results of spell analyses for the historic lake level and active storage at Tar-Ru. These figures show periods between 1985 and 2020 where lake levels and active storage was above or between various thresholds[3].

Key thresholds in Figure 2-1 are:

- 24.5 m. This is the level below which Tar-Ru needs to be below in April and May, in accordance with the 2002 Lake Victoria Operating Strategy (LVOS; MDBA, 2002). Tar-Ru holds about 300 GL active storage at this level.
- 26.9 m. This level shows when the lake is essentially full.

Key thresholds in Figure 2-2 are:

- 250,000 ML (250 GL). This is the minimum reserve target for active storage on May 31.
- 565,000 ML (565 GL). This threshold also shows when the lake is essentially full, i.e. close to the approximately 577 GL of active storage at full supply level (FSL).

What is apparent from Figure 2-1 and Figure 2-2 is that:

- In the February to May period in the eight years to 2020 – shown in the dotted black boxes – the spell analyses show that the lake level and active storage in Tar-Ru has been less compared with earlier in the record, especially if the years associated with the Millennium Drought are considered separately.
- The frequency and duration with which Tar-Ru has been full has been less in the post-LVOS and Millennium Drought period compared with the pre-LVOS and Millennium Drought period. The reduced duration of Tar-Ru being full is consistent with the LVOS, because the aim is now to fill Tar-Ru late in winter/spring, rather than keeping it at FSL.

Taking an annual time-step slice through Figure 2-2 also shows that:

- In four of the last six years, the active storage in Tar-Ru has been less than the minimum reserve target for May 31. However, there were also years before the LVOS and Millennium Drought when active storage was below this target.
- The active storage volume in Tar-Ru in mid-December has been trending down since the end of the Millennium Drought. From the mid-1980s to mid-1990s, Tar-Ru was generally full in mid-December.

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[2] This period was chosen to generally align with datasets readily available for use in Section 3 and 4 (potential drivers of Tar-Ru behaviour and case studies of system-wide drivers).

[3] For all spell analyses presented in this report, a spell 'independence' period of 7-days was used. This meant if flow or river level dropped below the threshold of interest for < 7 days but then returned above the threshold, it was still considered the same 'spell'.

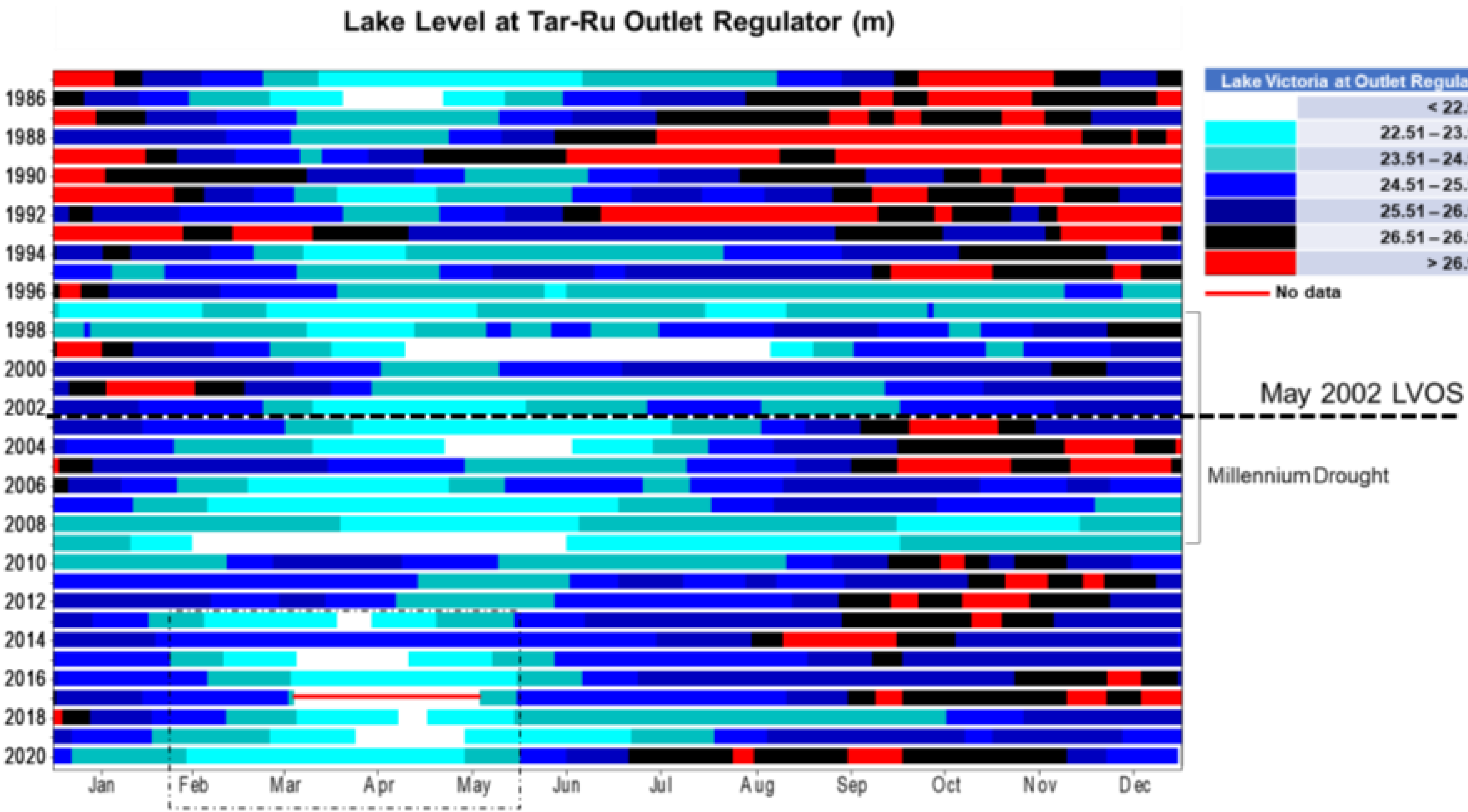


Figure 2-1: Tar-Ru lake levels from 1985–2020

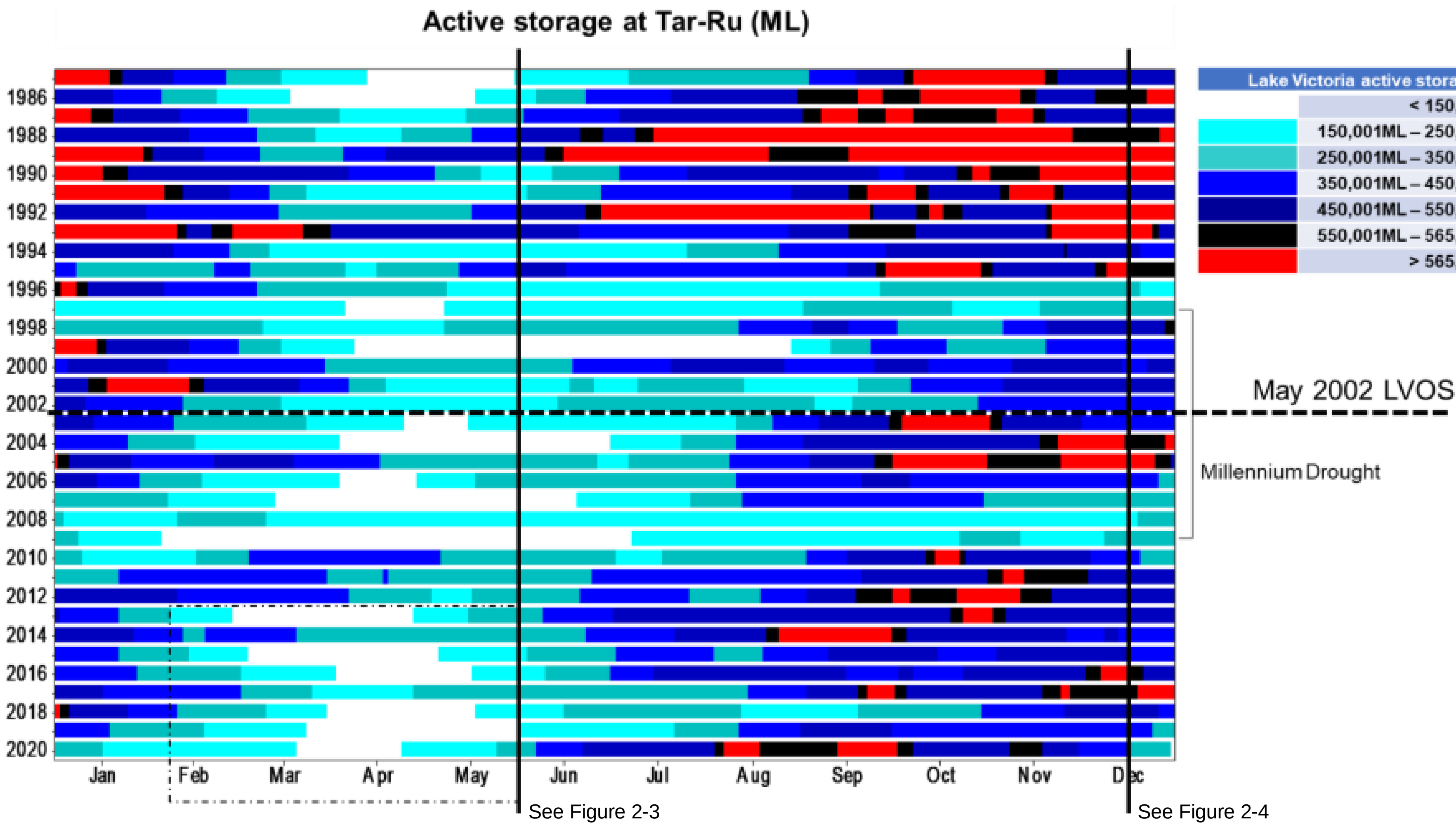


Figure 2-2: Tar-Ru storage from 1985–2020

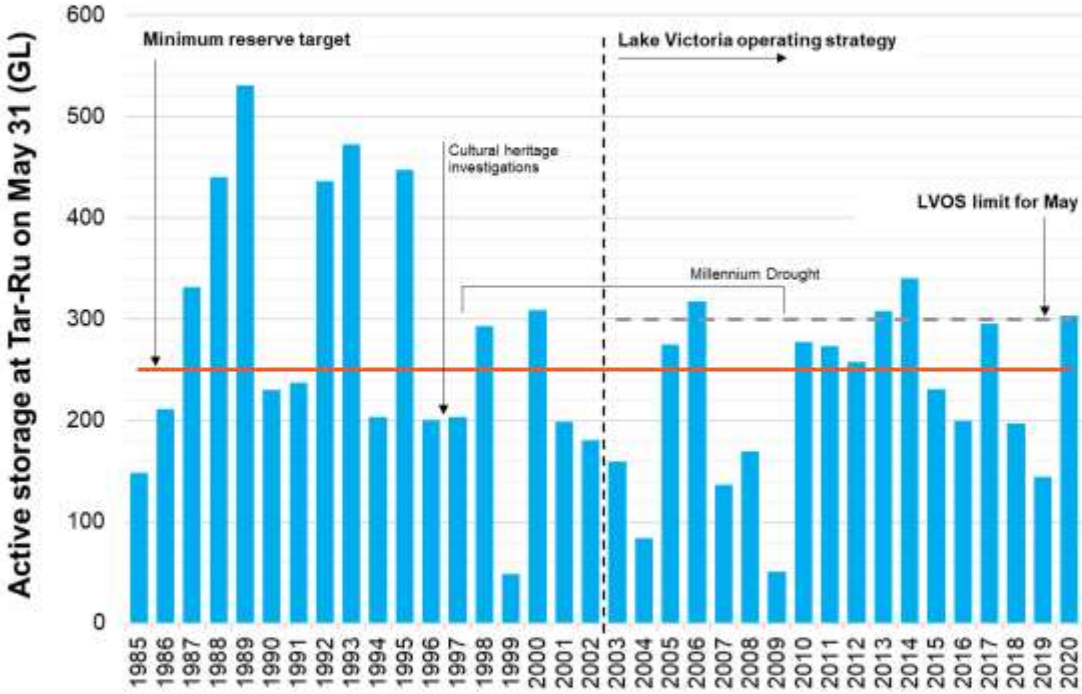


Figure 2-3: Tar-Ru active storage on May 31 from 1985–2020

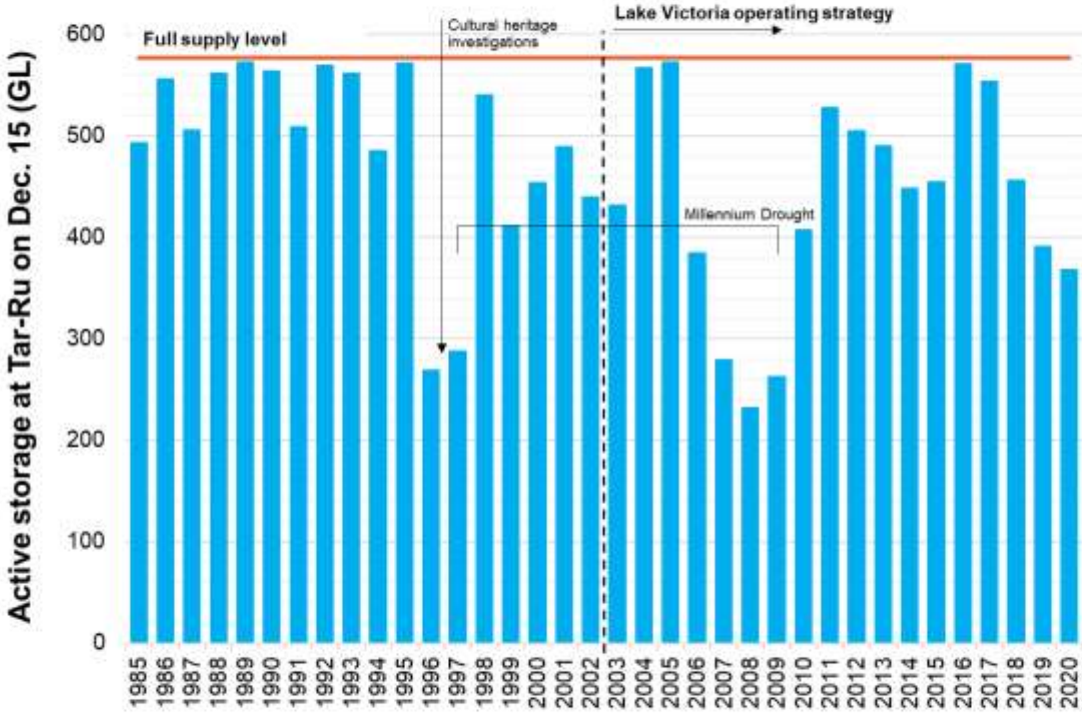


Figure 2-4: Tar-Ru active storage on December 15 from 1985–2020

The volume in Tar-Ru was intentionally kept low in 1996 and 1997 to allow for cultural heritage investigations which led to the development of the Tar-Ru (Lake Victoria) Operating Strategy, and the accompanying Lake Victoria Cultural Landscape Plan of Management and Aboriginal Heritage Impact Permit (MDBA River Operations Improvement Team, pers. comm., October 2021).

2.2 Inflow and outflow

Figure 2-5 and Figure 2-6 show spell analyses of the diversions to and outflow from Tar-Ru respectively from January 1985 to December 2020. Diversions are measured at gauge 4260500 in Frenchmans Creek, and outflows at gauge 4260502 in the Rufus River.

Given the patterns apparent in Figure 2-1 and Figure 2-2, it is not surprising that Figure 2-5 shows that diversions to Tar-Ru from 2014 onwards have been less compared with earlier in the historic record (again, treating the years of the Millennium Drought separately). This is most obvious in the January – April period, but there also appears to be a slight trend in the spell analysis results in the September–December period. Outflows from Tar-Ru in the July – August months appear to have reduced after the LVOS was implemented in 2002, but otherwise, there are no obvious variations over time in the 1985–2020 historic record of outflows (Figure 2-6).

Figure 2-7, which plots the total diversions to Tar-Ru in the January – April[4] period of each year from 1985-2020, provides another example of how diversions have been lower from 2014 onwards compared with years either side of the Millennium Drought. This trend is not as apparent in Figure 2-8, which plots diversions in the September–December period; however, there are a few years in the recent record (2014, 2019, 2020) where diversions have been low compared with other non-drought years.

In summary, the figures shown above and below demonstrate that in the recent historic record mid-December Tar-Ru lake levels have been trending down, and lake levels on May 31 have been below the minimum reserve target in four years from 2015–2020. This is because diversions to Tar-Ru have been less in the recent historic record compared with earlier years, whereas outflows have been more constant. Section 3 examines potential drivers for this observed behaviour.

[4] January to April is also the period when overbank flooding through the Barmah-Millewa Forest is undesirable. Therefore, during these months River Murray flow through the Barmah Choke is generally limited to channel capacity.

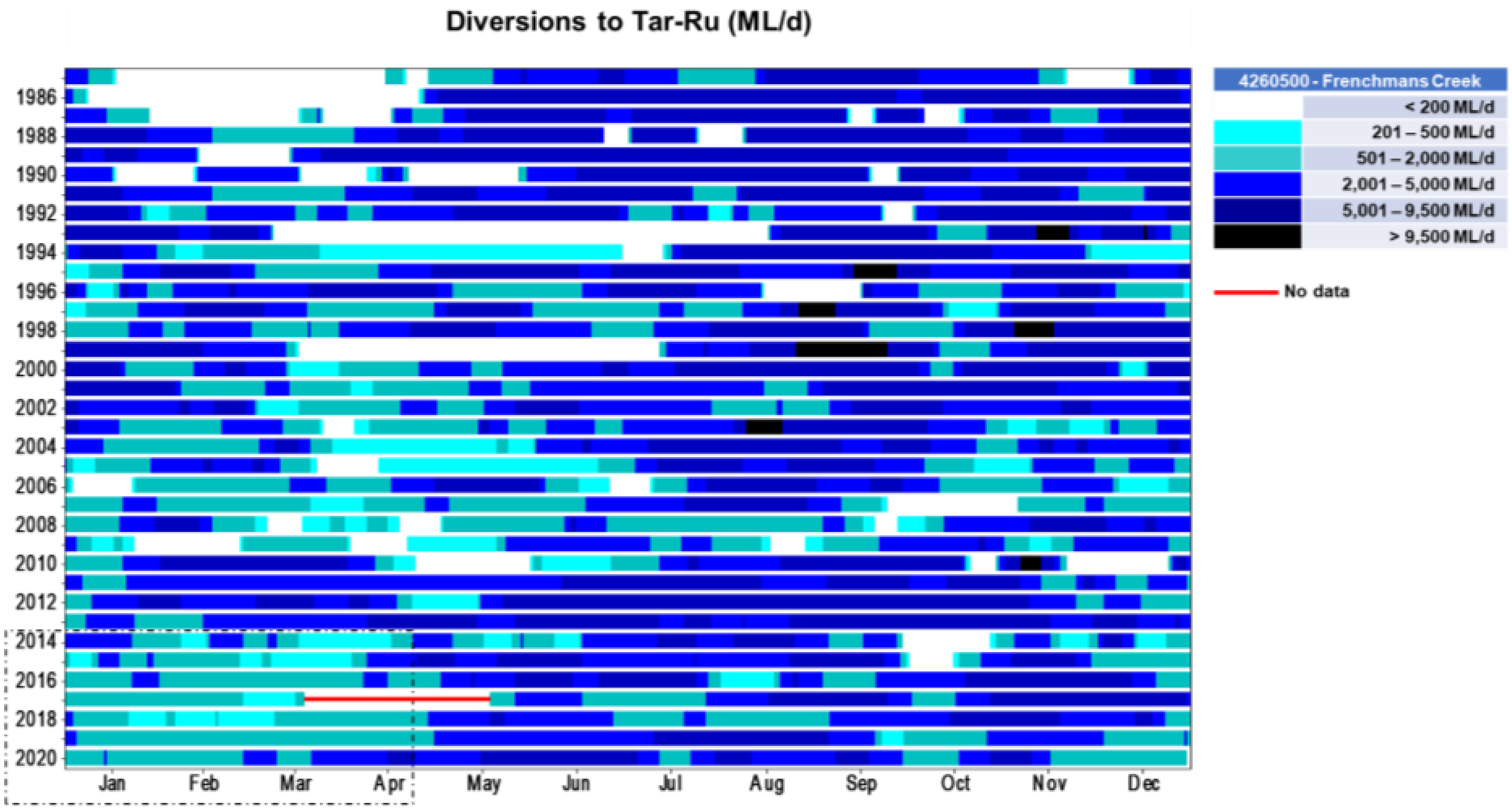


Figure 2-5: Tar-Ru inflows via River Murray diversions to Frenchmans Creek

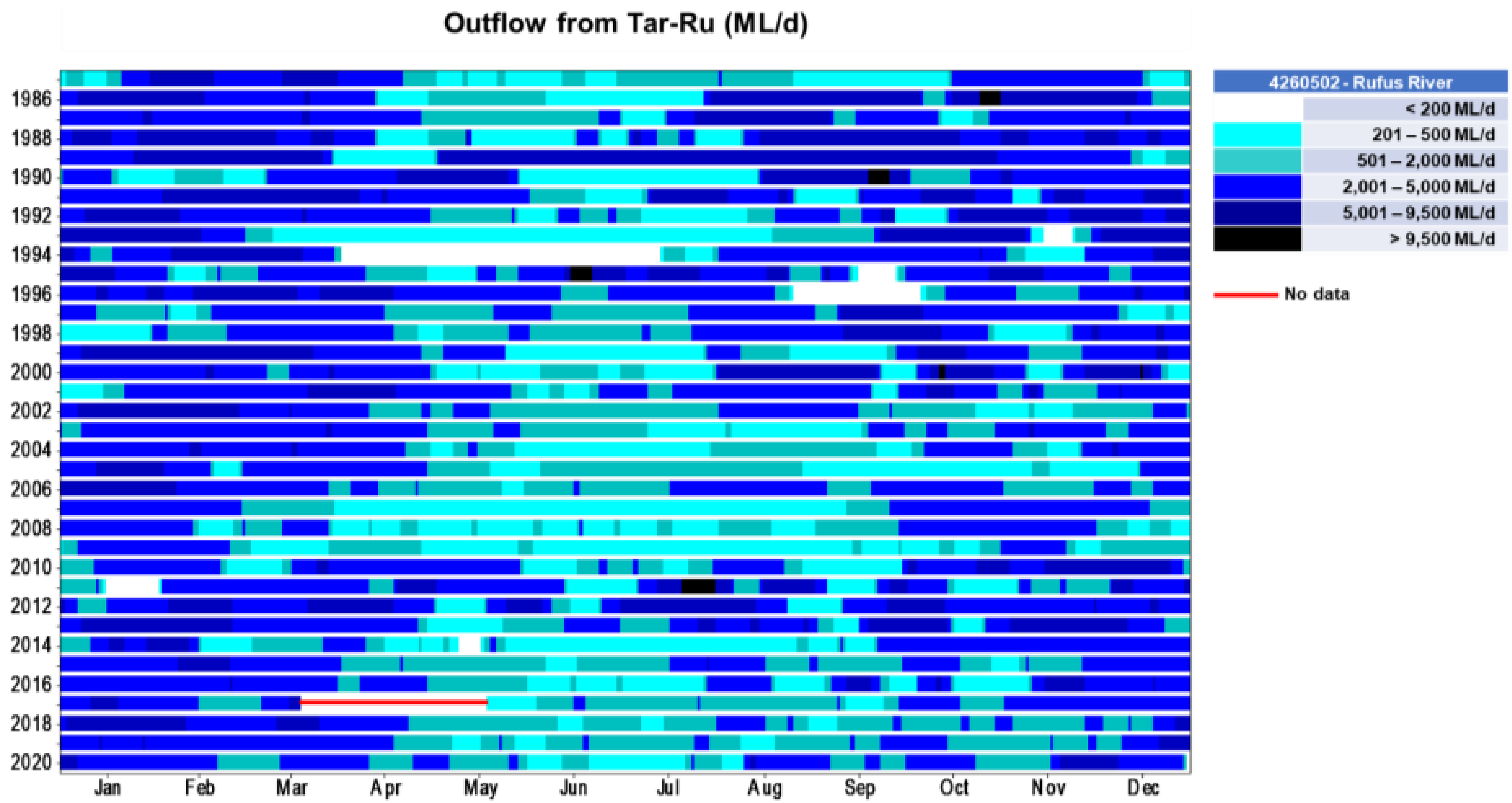


Figure 2-6: Tar-Ru outflows

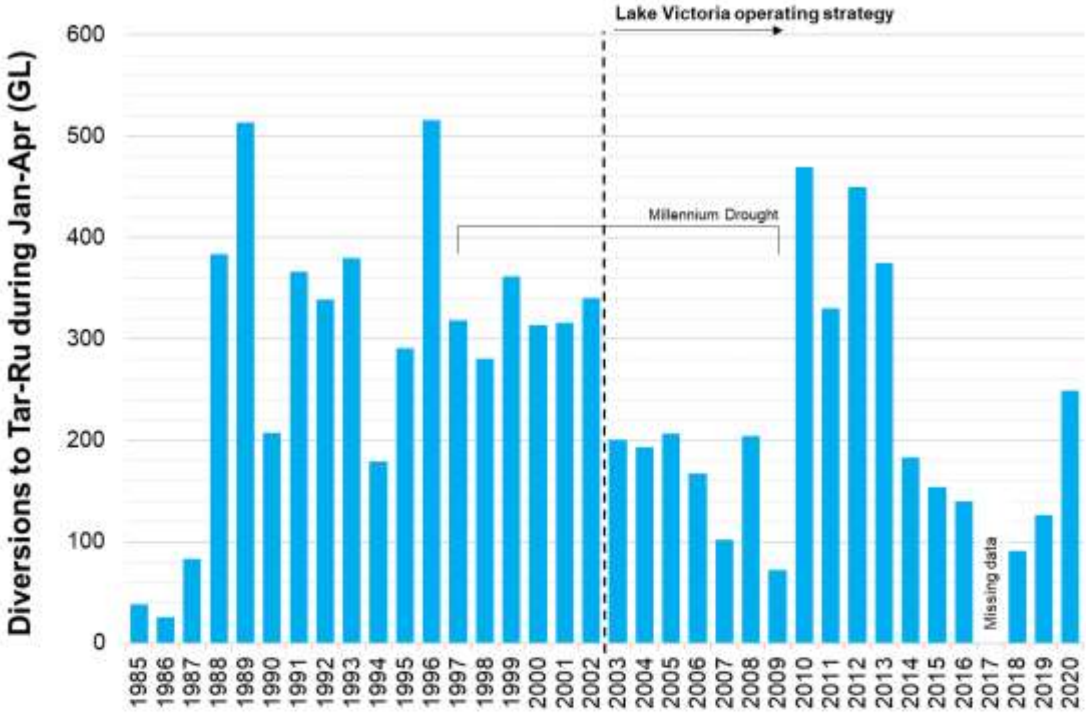


Figure 2-7: Diversions to Tar-Ru during the January – April period of each year from 1985–2020

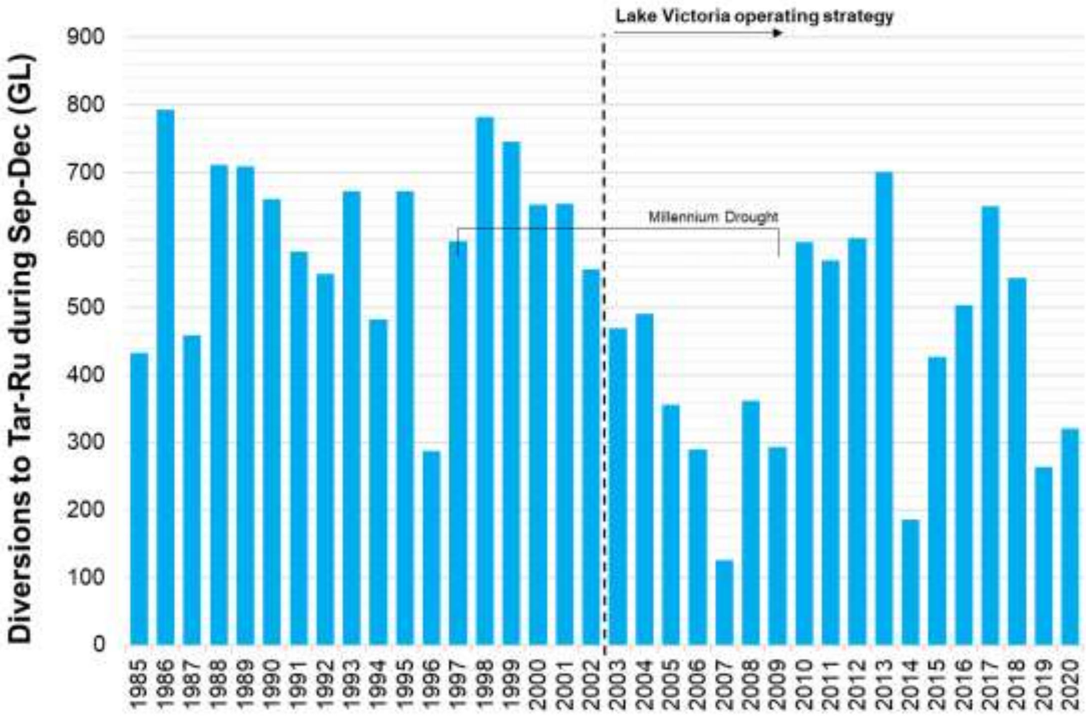


Figure 2-8: Diversions to Tar-Ru during the September – December period of each year from 1985–2020

3. Potential drivers of Tar-Ru behaviour

3.1 Summary

Potential drivers of the observed behaviour of Tar-Ru were identified via interviews with the MDBA and representatives from the Basin states. A summary of the interviews held is included in Appendix A.

Overall, there was broad acceptance by the MDBA and Basin states that it has often been difficult to fill Tar-Ru over the last decade. There was also general agreement on the broad drivers that affect the filling frequency of Tar-Ru in recent years, and that these drivers often combine or interact. The main drivers identified were:

- Reduced tributary inflows
  - The reduction of Darling River flows in the recent historic record (coinciding with times when the Menindee Lakes are offline) has made it more difficult to fill Tar-Ru. This has been compounded by reduced inflows from the unregulated Kiewa River and Ovens River upstream of Barmah Choke, and NSW's and Victoria's regulated tributaries between the Barmah Choke and the Murray-Darling junction.
- Operational constraints and efficiencies
  - In response to reduced tributary inflows, more water has needed to be transferred from Lake Hume to fill Tar-Ru. However, changes to Barmah Choke channel due to sedimentation is reducing the in-channel capacity available for these Hume – Tar-Ru transfers.
  - The increased efficiency of water delivery and consumptive use, and reduced volumes of rain rejection flows along the River Murray, has reduced the number of opportunistic instances where additional diversions can be made to Tar-Ru.
- Changes in water demands
  - Total combined demands for consumptive and environmental water use downstream of the Choke have remained high in the January – April period when overbank flows through the Barmah-Millewa Forest are undesirable. The delivery of water to these demands through or around Barmah Choke uses channel capacity and, therefore, limits the in-channel capacity available for Hume – Tar-Ru transfers.
  - Peak monthly demands for water use downstream of the Choke appear to have shifted to spring / early summer, when demand for consumptive and environmental purposes often coincide. This new period of peak demand is more likely to coincide with when Hume – Tar-Ru transfers are required.
- Local operations
  - Constraints on Tar-Ru water levels are needed to meet cultural obligations and objectives, minimise lake bed and shore erosion, promote revegetation and minimise the salinisation of nearby land.

Additional detail from the interviews are presented in Appendix B, including a list of other insights provided by those who participated. Examples of the drivers summarised above are provided below. More detailed case studies are included in Section 4.

3.2 Basin and regional scale drivers

3.2.1 Reduced unregulated tributary inflows

Inflows from the Kiewa River and Ovens River are important for filling Tar-Ru. However, these unregulated tributary inflows to the River Murray have been less in recent years compared with earlier in the historic record.

For example, in an analysis of annual and seasonal inflows between 1984 and 2019, HARC (2021) found that average and median flow from the Kiewa River and Ovens River to the River Murray was 10% - 50% less in the years 1997/98 to 2018/19 (Millennium Drought and onwards) compared with 1984/85 to 1996/97 (pre-Millennium Drought). This difference pre- and post-1997 (Table 3-1 and Table 3-2) is attributable to changes in rainfall during the cooler months of the year, and reductions in the proportion of winter/spring rainfall that becomes runoff.

More detail about unregulated tributary inflows is provided in the case study in Section 4. For example, Figure 4-6 includes charts of seasonal Ovens River flows from 1985 onwards.

Table 3-1: Flow vs period and season – Kiewa River at Bandiana

	Flow in given season (GL) – Kiewa River at Bandiana							
Period	Summer		Autumn		Winter		Spring	
	Ave.	Median	Ave.	Median	Ave.	Median	Ave.	Median
1985-1996	**88.0**	64.2	**67.1**	71.1	**298.1**	292.1	**299.4**	299.6
1997-2018	**71.9**	54.4	**57.3**	41.3	**189.9**	168.2	**224.0**	196.1
Difference	**-16.1**	-9.9	**-9.8**	-29.7	**-108.2**	-123.9	**-75.4**	-103.5
Difference (%)	**-18%**	-15%	**-15%**	-42%	**-36%**	-42%	**-25%**	-35%

Table 3-2: Flow vs period and season – Ovens River and Reedy Creek at Wangaratta

	Flow in given season (GL) – Ovens River and Reedy Creek at Wangaratta							
Period	Summer		Autumn		Winter		Spring	
	Ave.	Median	Ave.	Median	Ave.	Median	Ave.	Median
1985-1996	**140.1**	97.4	**110.0**	103.7	**931.3**	821.0	**760.2**	718.3
1997-2018	**125.5**	67.4	**76.0**	50.7	**460.1**	394.4	**475.3**	341.0
Difference	**-14.5**	-30.0	**-34.0**	-53.0	**-471.2**	-426.7	**-285.0**	-377.2
Difference (%)	**-10%**	-31%	**-31%**	-51%	**-51%**	-52%	**-37%**	-53%

3.2.2 Reduced regulated tributary inflows

The HARC (2021) analysis of historic streamflow in the southern connected Murray-Darling Basin also examined inflows to the River Murray from regulated tributaries between Barmah and the Murray-Darling junction. This analysis paid particular attention to tributary inflows during the January – April period, which coincides with the months where Tar-Ru levels have been less in recent years compared with earlier in the historic record (Section 2).

The analysis showed that (Figure 3-1):

- From 2013 on, total inflows in January – April were typically >350 GL. In prior years – excluding those with flooding – inflows were generally <350 GL, and often <300 GL.
- From 2002 onwards, inflows excluding inter-valley trade (IVT) and environmental water deliveries have generally been <200 GL. Before 2002, inflows excluding IVT and environmental water deliveries were generally >200 GL, and sometimes >300 GL.

This means that in the January – April period:

- Regulated tributary inflows to the River Murray between Barmah and the Murray-Darling junction have *increased* in total during recent years, but
- The regulated tributary inflows *available* for consumptive use by Murray entitlement holders downstream of Barmah Choke, or for diversion to Tar-Ru, have been less in the early 2000s and onwards compared with the 1980s and 1990s.

More detail about regulated tributary inflows – including from the Darling River – is provided in Section 4.

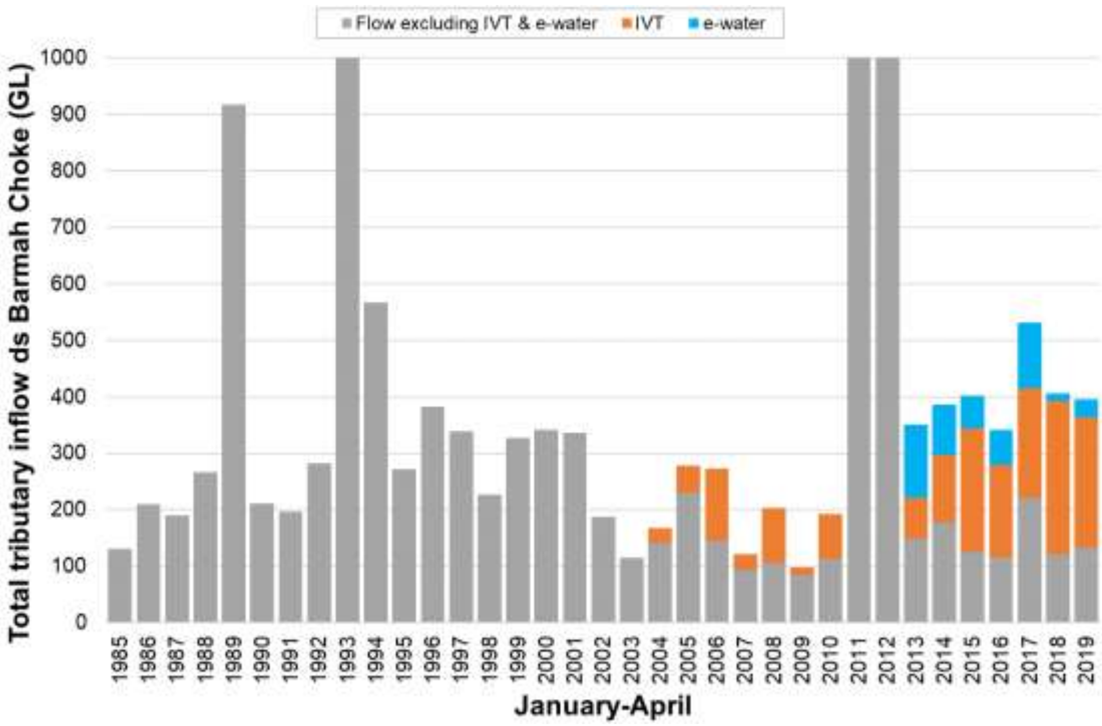


Figure 3-1: Total inflows to the River Murray system from the Murrumbidgee River, Billabong Creek, Goulburn River, Campaspe River, Loddon River and Broken Creek for the January-April (inclusive) months of 1985–2019. The contribution from IVT and environmental water deliveries is shown in orange and light blue respectively (from HARC 2021).

3.2.3 Operational constraints

The reduction in unregulated and regulated tributary inflows to the River Murray in the recent historical record means that the filling of Tar-Ru has been more dependent on regulated transfers from Lake Hume to Tar-Ru. This is borne out by data available from the MDBA, as summarised in Figure 3-2.

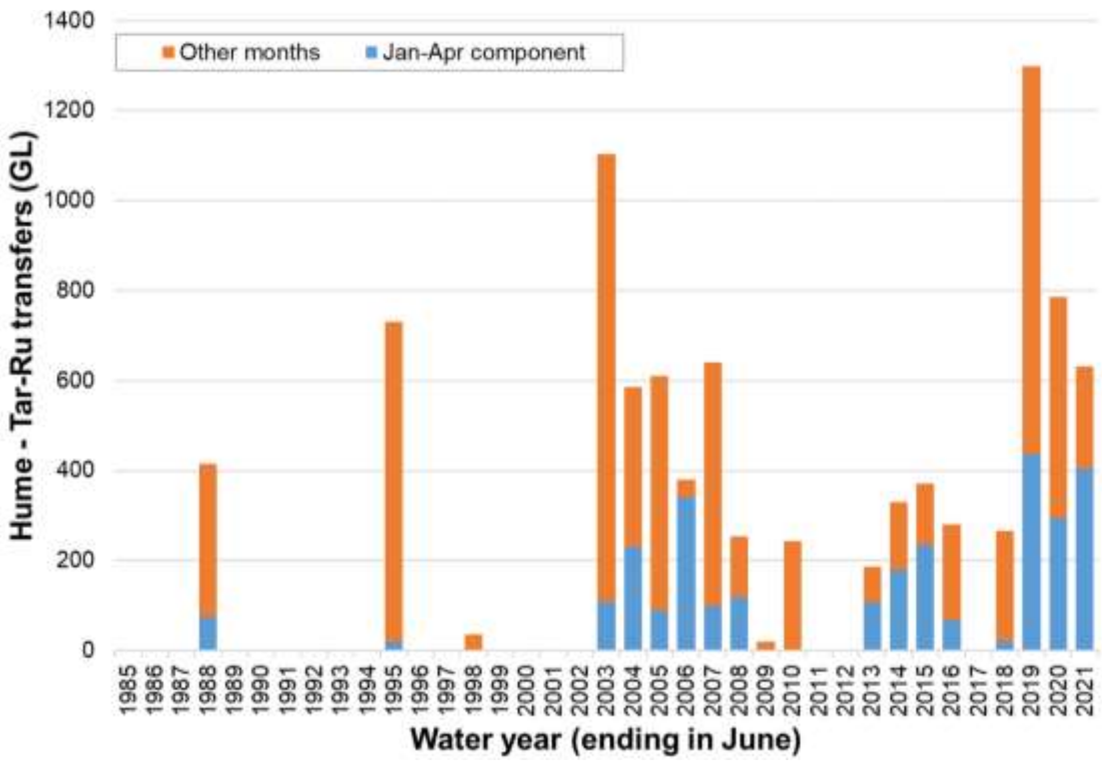


Figure 3-2: Releases from Lake Hume to transfer water to Tar-Ru in water years from the mid-1980s to date. In this report, these releases from Lake Hume are referred to as Hume – Tar-Ru transfers.

Transfers from Hume to Tar-Ru need to pass through the Barmah Choke (Figure 1-1). However, the channel capacity of the River Murray through the Barmah Choke has been decreasing. For example, in a peer review of the MDBA's ongoing Capacity and Delivery Shortfall Project, Doolan et al. (2019) noted that the channel capacity at the Barmah Choke has declined from 11,500 ML/d in the 1980s, to 10,500 ML/d in the mid-1990s to approximately 9,200ML/d in 2019. This 20% decline in channel capacity imposes a constraint on regulated within-channel flows that can be supplied downstream of Yarrawonga Weir.

Whilst there could be multiple factors explaining the decline, the most likely is a sheet of coarse sand shallowing the river, much of which originated from historical gold mining (Rutherfurd et al. 2020). Rutherfurd et al. (2020) found that the whole length of the river through the Barmah Forest has shallowed over the last 30 years, aggrading by 1.9 m at the upstream end and 0.7 m in the most downstream section of the Choke. They also noted that while decreasing downstream flow capacity across the Barmah Fan is a natural characteristic of this type of distributive fluvial system, the sand sheet is accelerating the rate of decline and without intervention, conveyance through the Choke will inevitably continue to decrease until the river avulses into a new channel.

Overall, the continuing reduction in capacity through the Barmah Choke imposes a constraint on regulated within-channel water delivery to Tar-Ru from sources upstream of the Choke (i.e. Lake Hume). This is an area of active interest for the MDBA, jurisdictions, water corporations and environmental water managers in the southern connected Murray-Darling Basin, and options for mitigating the effects of the sand deposition are being assessed in collaboration with stakeholders (MDBA System Review Team, pers. comm., September 2021). More detail on the historic changes to the Barmah Choke capacity is also provided in Section 4.

3.2.4 Operational efficiency

Water recovery in support of the Basin Plan (www.mdba.gov.au/progress-water-recovery) has resulted in 758.5 GL/year and 802.3 GL/year of water recovery (long-term diversion limit equivalent) to September 2021 in the respective NSW and Victorian zones of the southern connected Murray-Darling Basin. Some of the water has been recovered via Commonwealth purchases of water entitlements, and some has been recovered via infrastructure projects such as the modernisation of irrigation distribution systems. The Commonwealth's buyback of entitlements previously used for consumptive purposes, and the upgrades to irrigation infrastructure has enabled river operators to run distribution systems more efficiently. That is, reducing consumptive demands and increasing irrigation efficiency has resulted in less water being returned or re-routed to river systems from irrigation areas (Wang et al., 2018).

An example of improved operational efficiency is provided in Figure 3-3, which shows the number of days in the January–April period when flow in the River Murray downstream of Yarrawonga exceeded the Barmah Choke capacity. Yarrawonga Weir is the diversion point for irrigation areas supplied by the Mulwala Canal (NSW) and the Yarrawonga Main Channel (YMC; Victoria). From January–April, flow through Yarrawonga Weir is often managed so that Mulwala Canal and YMC diversions can be made to meet irrigation demands, while flow downstream remains close to the channel capacity of the Barmah Choke (see Section 4.2).

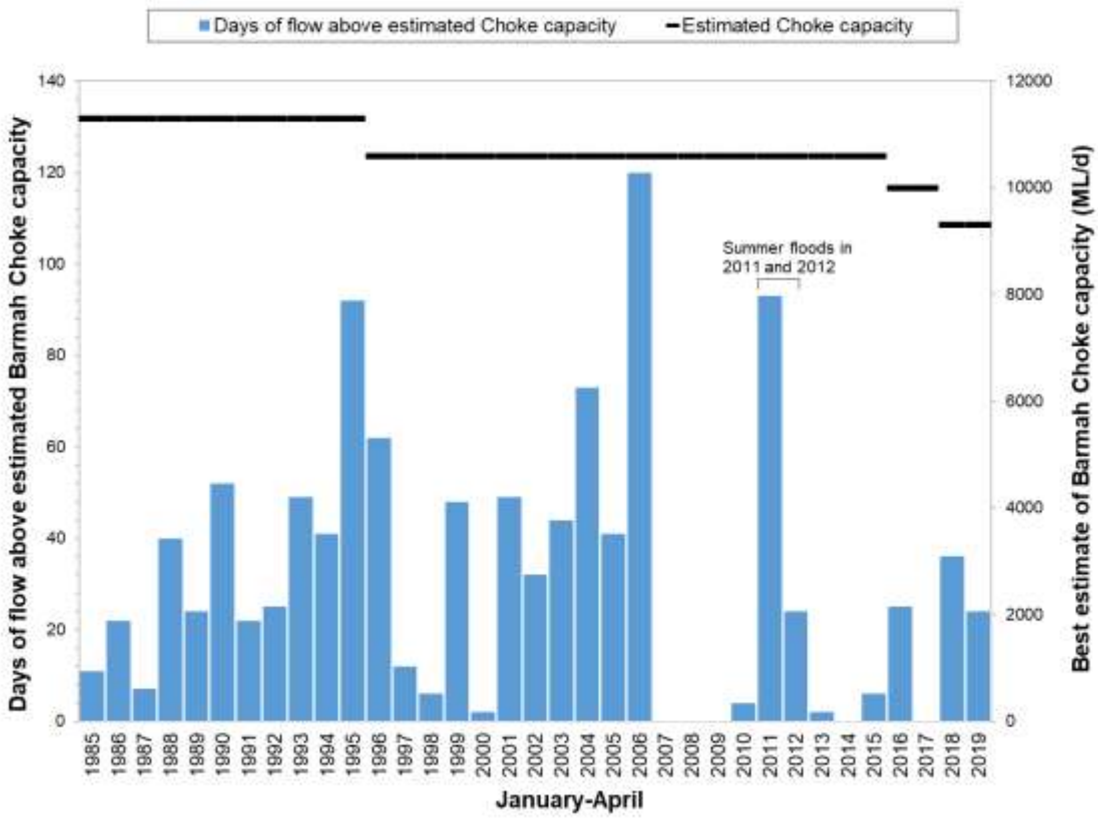


Figure 3-3: Number of days from January–April where River Murray flow downstream of Yarrawonga exceeded the best estimate of Barmah Choke capacity.

If diversions to the Mulwala Canal and/or YMC reduce suddenly because of rainfall or short-notice changes to irrigation demands, this can result in flows downstream of Yarrawonga exceeding the channel capacity of Barmah Choke. These unplanned flow pulses continue downstream and can be diverted to Tar-Ru or used to supply demands.

What is most apparent in Figure 3-3 is that since the mid-2000s there have been fewer days during January – April when flow downstream of Yarrawonga has been above the best estimate of Barmah Choke channel capacity (allowing for floods in 2011 and 2012). This reduction has occurred even though the Choke capacity has decreased from the mid-2010s onwards. This implies that in the recent historical record there has been a reduced frequency of rainfall rejections or short-notice demand changes that have caused unplanned flow pulses downstream of Yarrawonga Weir. This in turn will have reduced the chances for opportunistic diversions from the River Murray to Tar-Ru in the January–April period.

3.2.5 Changed water demands

The Barmah Choke capacity has been reducing (Section 3.2.3), but the volumes of water that need to be delivered downstream of the Choke are still significant (Section 4.3). And although HARC (2020) found that since the mid-1980s there has been little change in demand for River Murray water resources between the Barmah Choke and South Australian border, particularly in the key January – April period, HARC (2020) did show that peak monthly water use in this reach has shifted from typically being in January–April to often occurring from October–December (Figure 3-4).

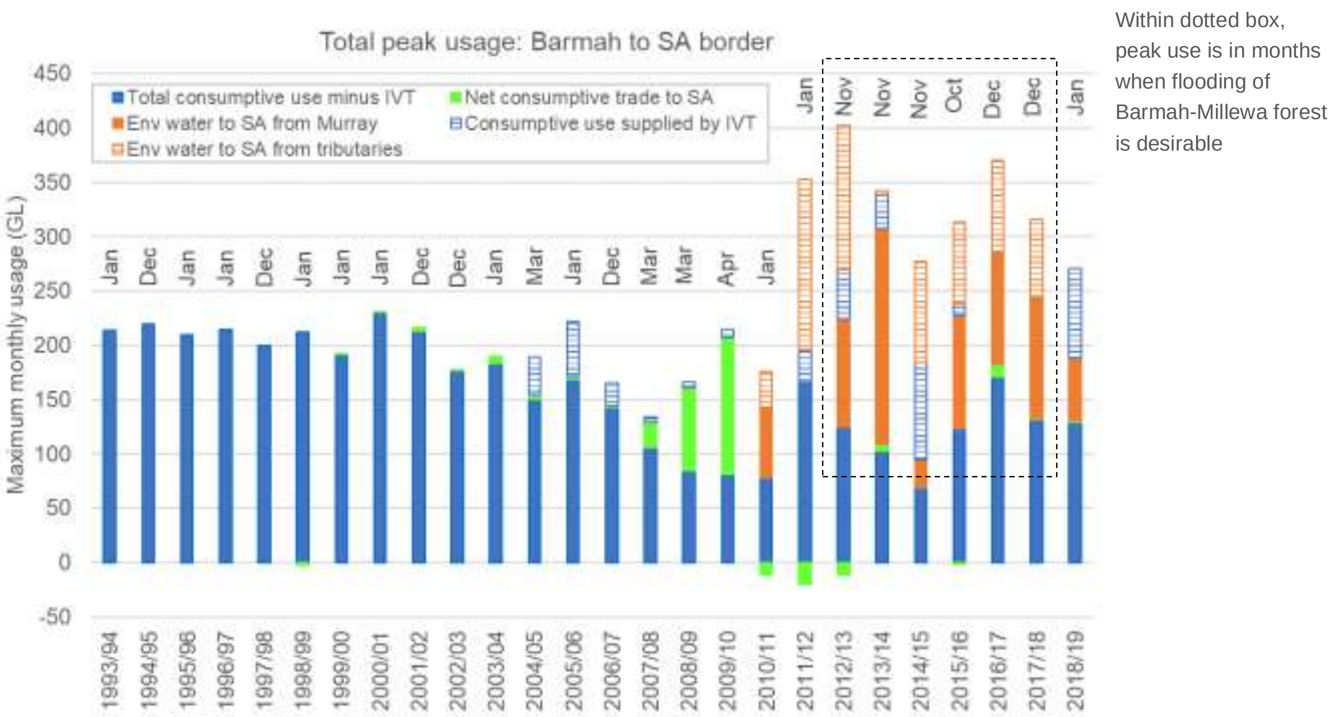


Figure 3-4: Peak monthly water use in the River Murray reach from Barmah to the South Australian border in the water years (July–June) from 1993/94 to 2018/19 (modified from HARC 2020, with additional data provided by MDBA).

Peak monthly usage in October – December, excluding the proportion supplied by IVT or environmental water deliveries from the tributaries, has also been higher than observed in the January–April period. This is not necessarily problematic, because environmental water can be delivered overbank through the Barmah-Millewa Forest when flooding is desirable in winter/spring. However, it does mean that peak water usage downstream of the Barmah Choke has, in the recent historic record, coincided more often with the period in which Tar-Ru is intended to be filled. This will have increased competition for regulated flow capacity downstream of Yarrawonga Weir during this part of the year. More detail about water demands in this part of the River Murray system is provided in Section 4.3.

3.3 Local drivers

The operation of Tar-Ru as part of the River Murray system is strongly influenced by the Tar-Ru (Lake Victoria) Operating Strategy (MDBC 2002) and the Cultural Landscape Plan of Management (MDBA 2019) and AHIP that are in place to protect Barkindji/Maraura cultural heritage by managing lake water levels, and by addressing other localised land and water-based threats. Passage of water into and out of Tar-Ru is also used to improve water quality (e.g. salinity, dissolved oxygen), both in the lake and in the River Murray. All stakeholders consulted for this project reinforced the importance of implementing the Operating Strategy and Plan of Management as agreed, and according to the AHIP.

Other considerations identified by stakeholders about the local operation of Tar-Ru included:

- The current capacity of the inlet channel needs to be confirmed, as there may be differences in the assumed and actual capacity, which in turn affect the rate of diversions from the River Murray. Inlet and outlet capacity should also be part of design considerations for any new infrastructure, given that the current infrastructure at Tar-Ru is aging and will eventually have to be updated or replaced.
- Weir pool manipulations are proposed for locks along the River Murray to improve in-channel habitat for aquatic biota and improve ecosystem function within weir pools (MDBA 2019b). This may involve weir pool fluctuations of ± 1 meter. However, operating weir pools at very low levels could affect the ability to divert water into Tar-Ru. The timing and frequency of when these weir pool manipulations might occur, and management options to mitigate the risks of shortfalls in lake volumes will therefore need to be considered.
- Diversion of water into Tar-Ru can influence hydrographs associated with environmental water deliveries or unregulated river flows, potentially limiting the height and, therefore, the extent of inundation on downstream floodplain areas. Diversion of water into Tar-Ru can also affect the composition of biota such as zooplankton populations (Furst et al. 2018); this may affect the biodiversity and ecosystem function outcomes expected from environmental water delivery.

3.4 Drivers selected for case studies

This scoping study aims to review the system-wide drivers of Tar-Ru's recent behaviour. Therefore, based on the information presented above, a hypothesis about the system-wide drivers of Tar-Ru's historic storage volumes was developed and presented to the MDBA and stakeholders at a workshop on August 25. The hypothesis is shown in Figure 3-5.

Three case studies that illustrate these system-wide drivers in more detail are provided in Section 4. Current water resource management initiatives that address these drivers, and potential foci for future investigations, are summarised in Section 5. Section 6 includes a high-level concept plan to address the recommended priorities for future work. The local drivers of Tar-Ru operations are not the focus of this study and, therefore, are not considered further in Sections 4-6.

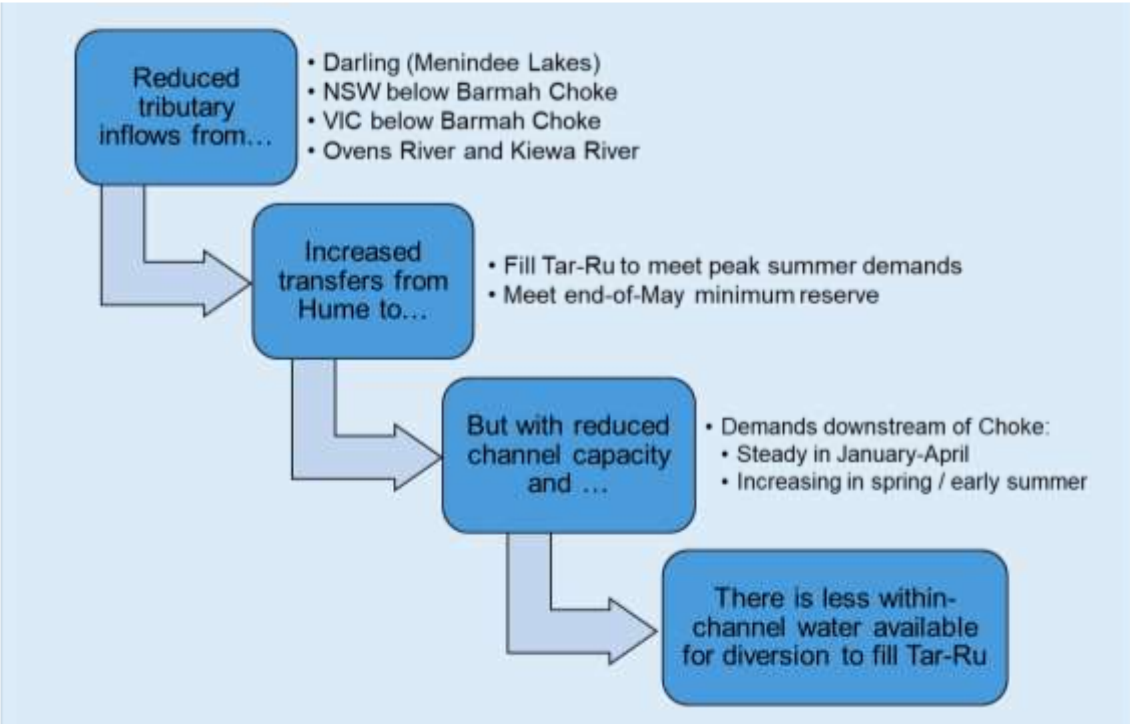


Figure 3-5: Hypothesis based on Section 3 findings, for testing with Section 4 case studies

4. Case studies of system-wide drivers

The case studies in this section of the report are intended to provide more details about three of the system-wide drivers for the patterns of diversions to, and active storage at Tar-Ru, as observed in the recent historical record. The case studies are of:

- Reduced tributary inflows (Section 4.1)
- Barmah Choke capacity (Section 4.2)
- Water demands between Barmah Choke and the South Australian border (Section 4.3).

4.1 Reduced tributary inflows

In Section 4.1, case study information for the Darling River was provided by the MDBA. Datasets presented for the other tributaries are from the HARC (2021) report of historical flows in the southern connected Murray-Darling Basin.

4.1.1 Darling River

The proximity of the Menindee Lakes to Tar-Ru means that these storages are operated in harmony when the MDBA has control of the Menindee Lakes (https://www.mdba.gov.au/water-management/infrastructure/menindee-lakes/management; https://www.mdba.gov.au/water-management/infrastructure/lake-victoria). And when the Menindee Lakes are online, there is a reduced need for transfers from Lake Hume to fill Tar-Ru (Figure 4-1).

Figure 4-1: Hume – Tar-Ru transfers versus a time-series of volumes stored in Menindee Lakes

However, as shown in Figure 4-1, with the exception of 2010/11, 2011/12 and 2016/17 water years, the volume stored in the Menindee Lakes has been significantly less since the early 2000s onwards compared with earlier in the historic record. Consequently, flow from the Darling River to the River Murray – as measured at Burtundy – has been less from the early 2000s onwards compared with the 1980s and 1990s. Figure 4-2 demonstrates this using spell analyses similar to those presented in Section 2. The same January – April period for 2014–2020 included on the spell analyses of diversions to Tar-Ru (Figure 2-5) is shown on Figure 4-2. This illustrates that the period of reduced Tar-Ru diversions coincides with a time when there have been minimal inflows from the Darling River to the River Murray.

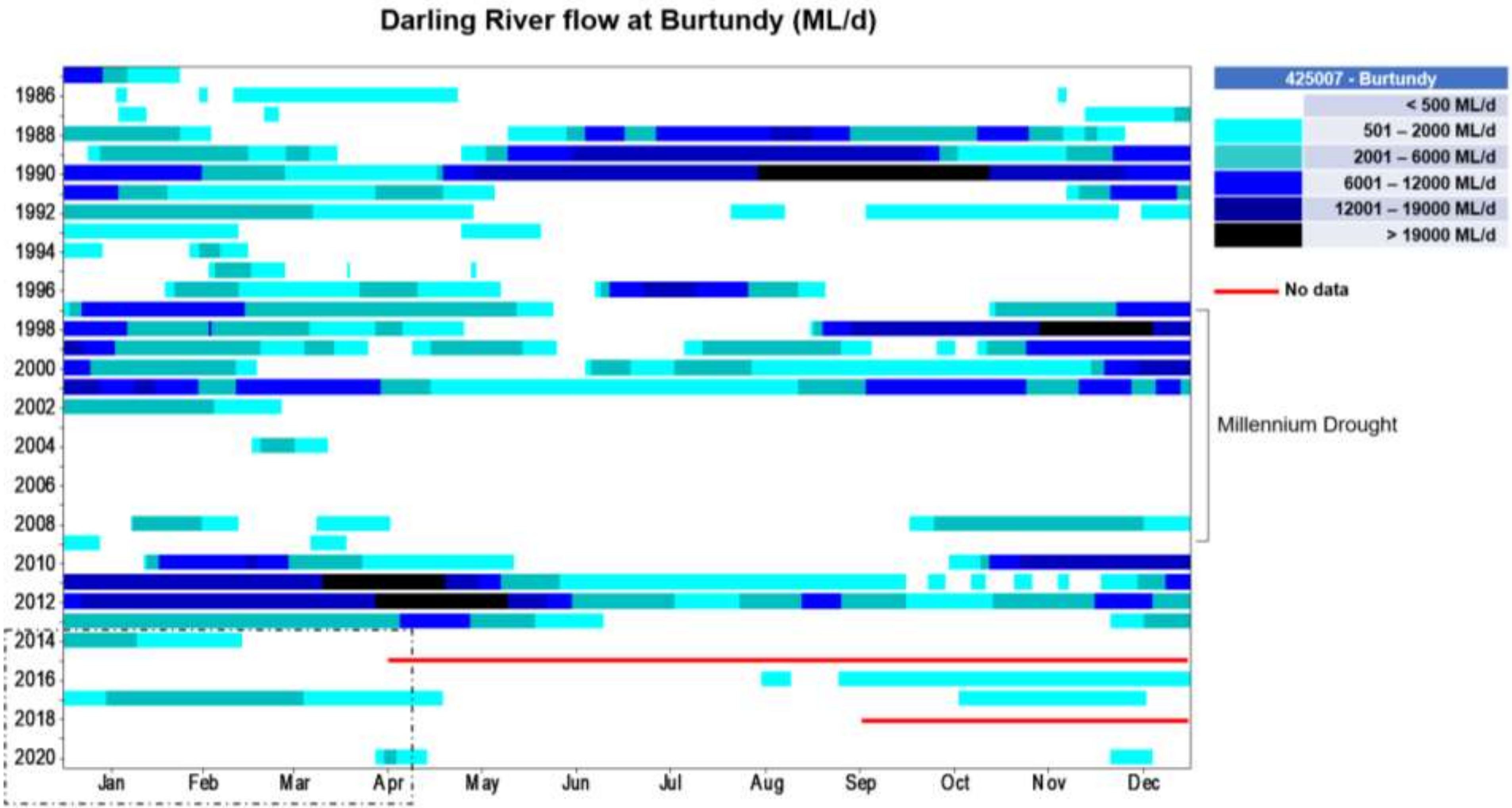


Figure 4-2: Spell analysis of historic flows recorded in the Darling River at Burtundy (gauge 425007)

4.1.2 Regulated tributaries upstream of Murray-Darling junction

Section 3.2.2 includes an annual time-series of January–April inflows from River Murray tributaries between the Barmah Choke and the Murray-Darling Basin. Figure 4-3 shows the same information, this time separated into the inflows from NSW and Victorian tributaries.

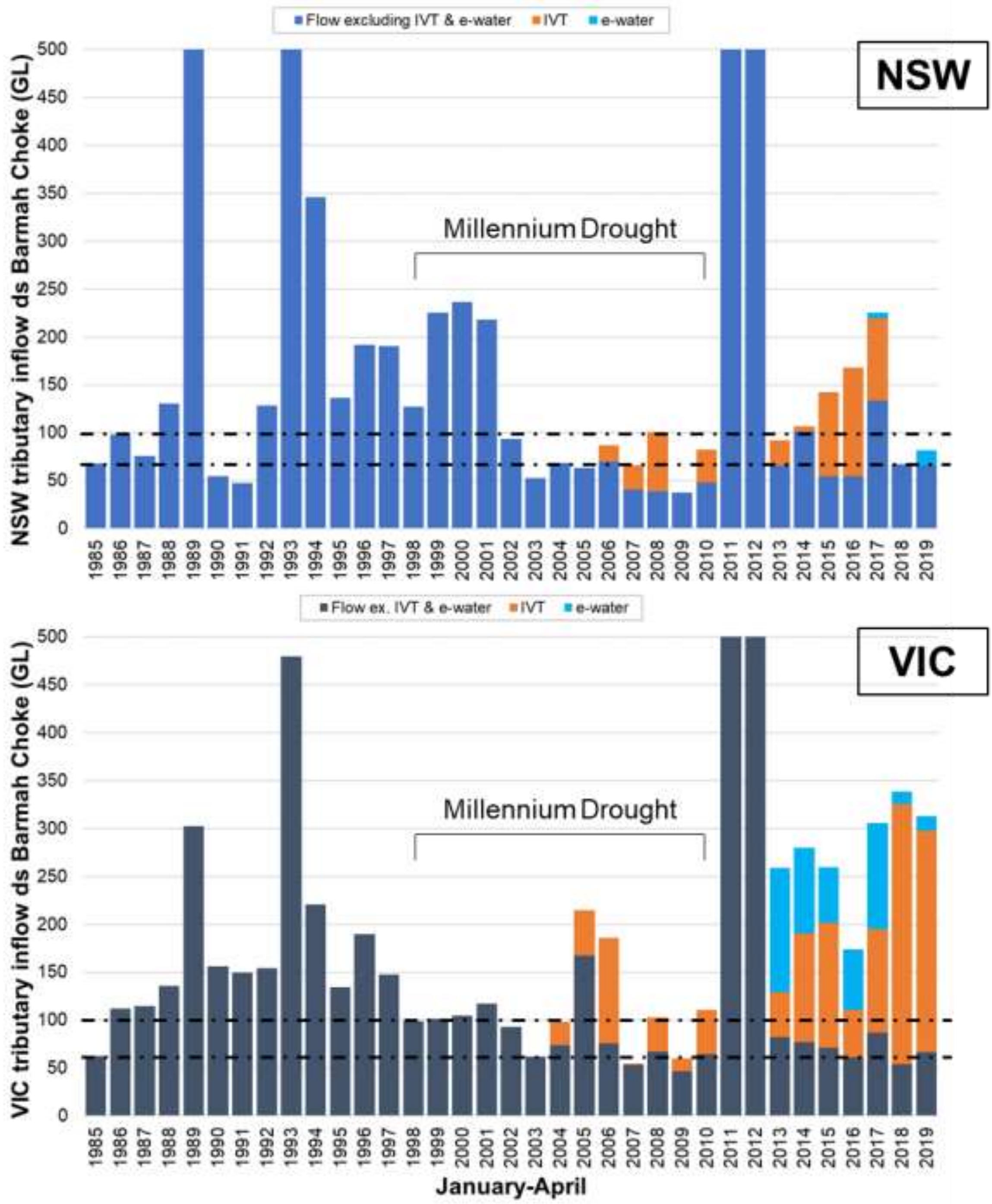


Figure 4-3: Total tributary inflows to the River Murray between the Barmah Choke and the Murray-Darling junction for the January – April period, as divided between NSW (Murrumbidgee River and Billabong Creek) and Victoria (Goulburn River, Campaspe River, Loddon River, Broken Creek) (HARC 2021). Note that inflows >500 GL/year are not shown on these graphs.

Figure 4-3 shows that the reduction in the inflows after excluding IVT and environmental water deliveries occurs across both the NSW and Victorian tributaries. Figure 4-4 and Figure 4-5 present the historic flow patterns for the two major tributaries – the Murrumbidgee River [5] in NSW and the Goulburn River in Victoria – in more detail and for all calendar months.

Figure 4-4 and Figure 4-5 again show – with the exception of the 2010/11, 2011/12 and 2016/17 water years – the degree to which inflows from these tributaries to the River Murray have reduced from the early 2000s onwards compared with earlier in the historic record, once IVT and environmental water deliveries are excluded. For more detail on the historic flows in the Goulburn River and Murrumbidgee River, including the components attributed to IVT and environmental water deliveries, refer to Section 4 of HARC (2021; www.mdba.gov.au/publications/independent-reports/historical-flows-southern-connected-murray-darling-basin). This HARC (2021) report also includes information on how tributary inflows to the lower Goulburn River have changed since 1985, and how these changes correspond with reduced inflows from the Goulburn River to the River Murray.

[5] The Murrumbidgee River data includes the Billabong Creek inflows to the Edward-Wakool system (Figure 1-1). The Murrumbidgee River is not included in Figure 4-5 because information on inter-valley trade and environmental water deliveries was available at a monthly time-step, but not a daily time-step.

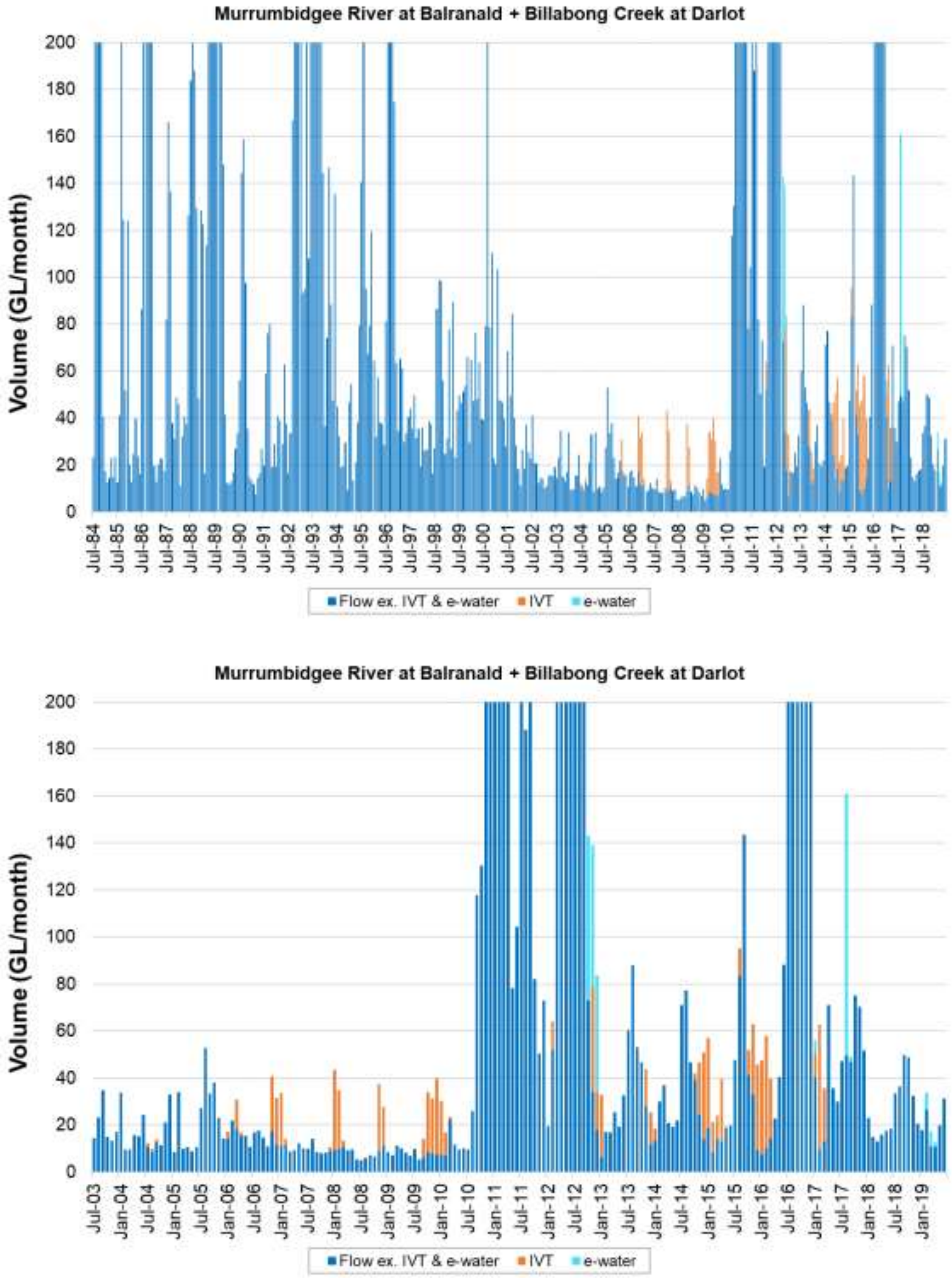


Figure 4-4: Monthly combined flow volumes for the Murrumbidgee River at Balranald, and Billabong Creek at Darlot, for July 1984 to June 2019 (top) and July 2003 to June 2019 (bottom). The contributions from IVT and environmental water deliveries are shown in orange and light-blue respectively (HARC 2021).

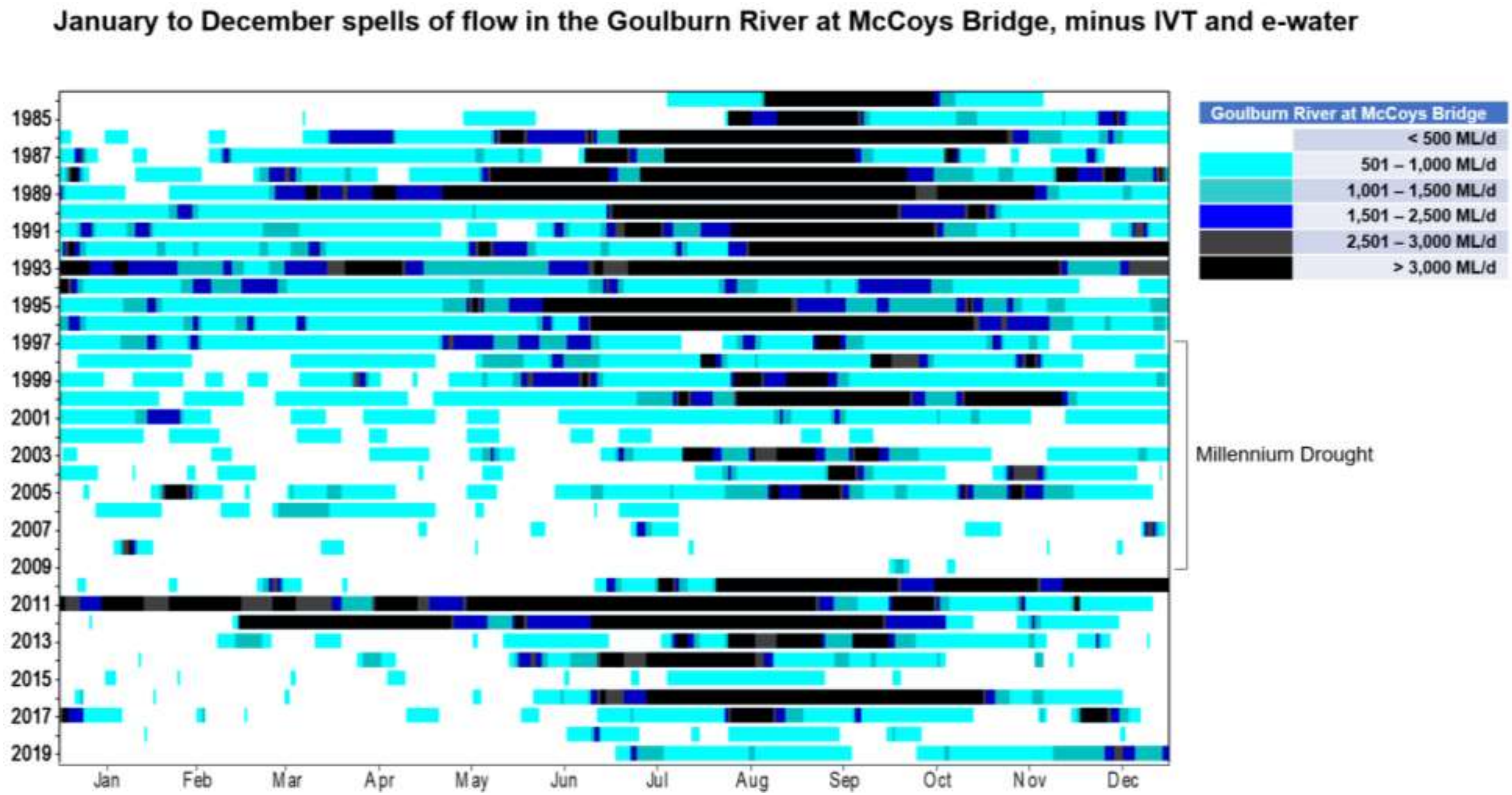


Figure 4-5: Goulburn River flows at McCoys Bridge, excluding inter-valley trade (IVT) and environmental water deliveries (e-water) (HARC 2021)

4.1.3 Unregulated tributaries

Section 3.2.1 included two tables that summarise the change in average and median inflows to the River Murray from the Kiewa River and Ovens River pre- and post-1997. These tables showed that the decline in inflows from these unregulated tributaries has been greatest in volumetric terms in the winter and spring months.

Figure 4-6 demonstrates this in more detail, by plotting annual time-series of seasonal flow in the Ovens River [6] at Wangaratta since the mid-1980s. This figure shows that from the late 1990s onwards, winter flows have reduced and spring flows have become more sporadic compared with earlier in the 1990s and 1980s. That is, the chance that Tar-Ru will be filled by winter/spring inflows from unregulated River Murray tributaries has reduced in the recent historic record, and this has contributed to the observed increase in Hume – Tar-Ru transfers (Figure 3-2; Figure 4-1).

4.1.4 Summary

In summary, this case study has confirmed that tributary inflows to the River Murray[7] have reduced in the historic record, and this reduction is observed for:

- The Darling River
- NSW and Victoria's regulated tributaries upstream of the Murray-Darling junction
- Unregulated tributaries (i.e. the Kiewa River and Ovens River)

Therefore, transfers from Hume – Tar-Ru have been required more often to fill Tar-Ru (Figure 3-2; Figure 4-1).

[6] Including flow in the Reedy Creek anabranch

[7] That is, inflows excluding inter-valley trade and environmental water deliveries

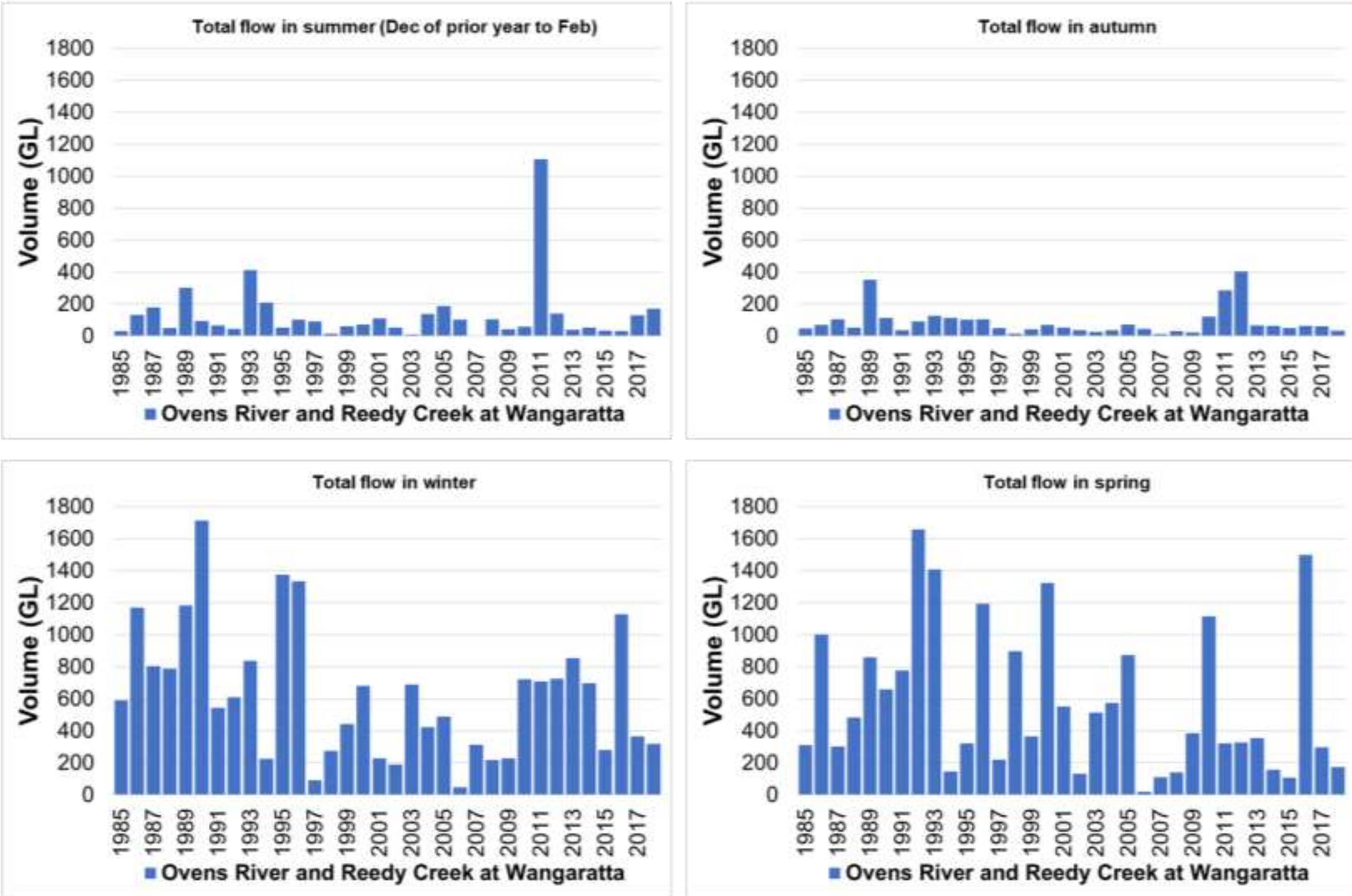


Figure 4-6: Seasonal inflows from the Ovens River to the River Murray, as measured at Wangaratta (HARC 2021)

4.2 Barmah Choke capacity

There are two key operational constraints on transfers from Lake Hume to Tar-Ru:

- From January to April, when flooding of the Barmah-Millewa Forest is undesirable, flows downstream of Yarrawonga are generally operated within the channel capacity of the Barmah Choke.
- During other months of the year, the maximum regulated flow downstream of Yarrawonga is 15,000 ML/d [8] (MDBA 2021; https://www.mdba.gov.au/sites/default/files/pubs/objectives-and-outcomes-for-river-operations-in%20the-river-murray-system-june-2021.pdf)

This report section provides information about the within-channel capacity of the Barmah Choke. This is because the January – April period when this constraint applies, matches the period highlighted in Section 2, when diversions to Tar-Ru from 2014 onwards have been reduced compared with earlier years.

The interaction between flows downstream of Yarrawonga and river levels at the Barmah Choke is complex, and therefore it is difficult to make precise conclusions about the Choke's channel capacity and how this has changed over time. However, previous studies (e.g. HARC 2021) suggest that:

- In the mid-1990s, a step change occurred in the maximum regulated flow downstream of Yarrawonga, from approximately 11,000–11,700 ML/d to 10,500–10,700 ML/d. This was due to a decision by river operators to lower river levels in the Choke to reduce overbank flows in summer and the environmental damage caused by prolonged waterlogging of the Barmah-Millewa Forest.
- The hydraulic capacity of the Choke – as indicated by the river level at Picnic Point corresponding with regulated flow ranges downstream of Yarrawonga (Figure 4-7) – appears to have declined in the mid-2010s, and trended further down in recent years.

This means that at the same time that tributary inflows have been declining (Section 4.1) and Hume – Tar-Ru transfers have been increasing (Figure 3-2; Figure 4-1), the within-channel capacity available for regulated flows through Barmah Choke have also been reducing. This reduced channel capacity would not necessarily influence diversions to Tar-Ru if consumptive and environmental water demands downstream of the Choke were also reducing, however, as shown in Section 4.3 these demands have remained high in the recent historical record.

More detail regarding historic trends in the channel capacity of the Barmah Choke is provided in Section 2.2 of the HARC (2021) report about historic flows in the southern connected Murray-Darling Basin. The HARC (2021) report also includes information about operational constraints through the Edward-Wakool system, and how this has been used in the past to bypass the Barmah Choke.

[8] This can be increased to 18,000 ML/d, but only with agreement from potentially affected landholders and the Basin Officials Committee

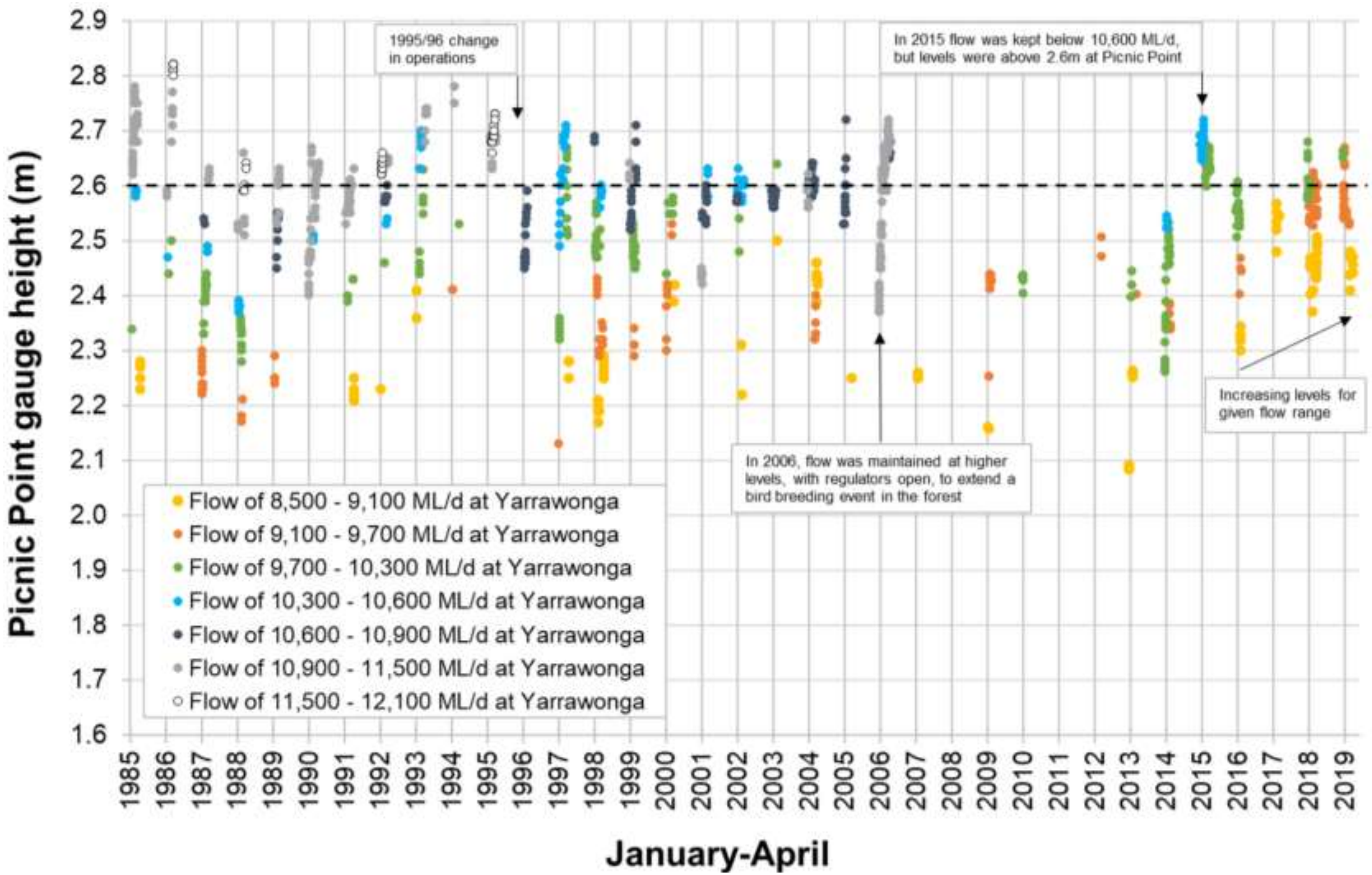


Figure 4-7: Gauge heights at Picnic Point – at the upstream end of the Barmah Choke – compared with selected flow ranges downstream of Yarrawonga Weir (HARC 2021).

4.3 Demands downstream of Barmah Choke

As described in reports by the ACCC (2021), Aither (2020), HARC (2020) and the MDBA (2020), in the historic record there have been significant changes in water use along the River Murray downstream of the Barmah, including:

- expansion in permanent horticulture in the Sunraysia region
- recovery of water for the environment
- increased trade of water from the Murrumbidgee and Goulburn systems to the River Murray, and
- increased flows to SA due to trade and environmental water deliveries.

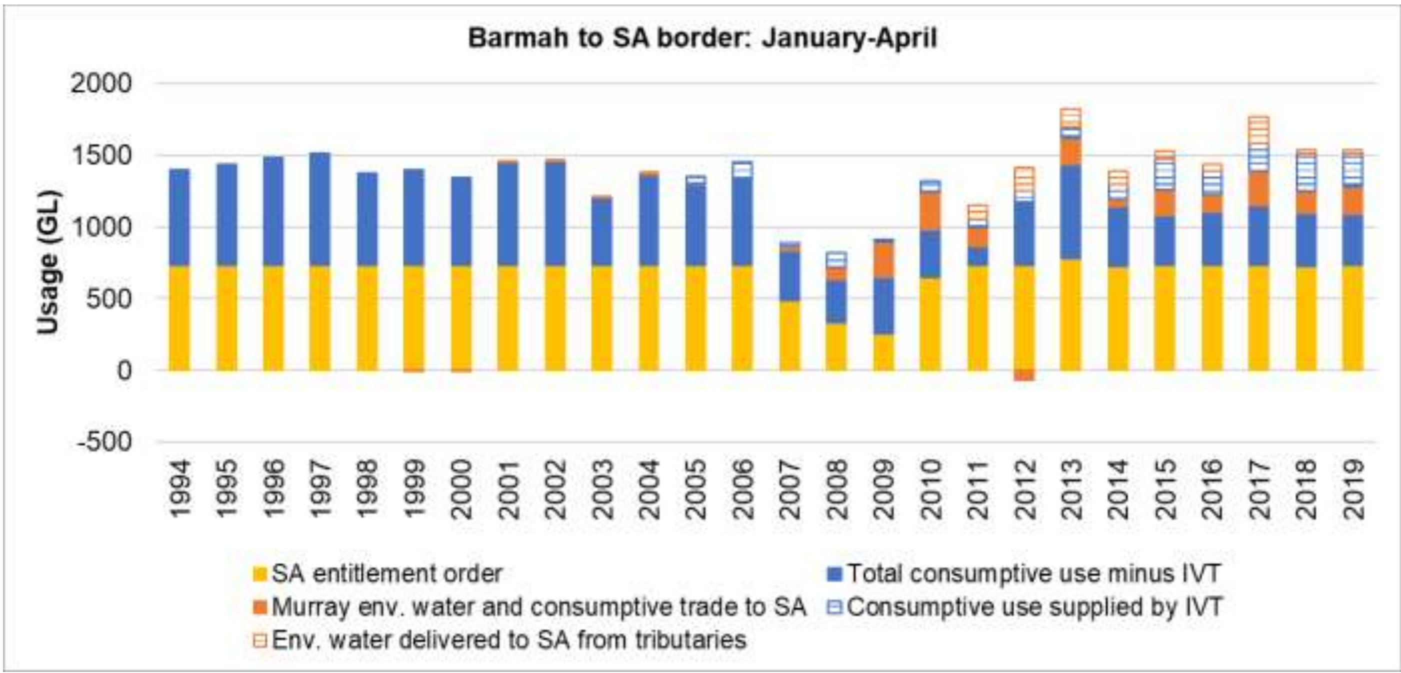
The net result of these changes is summarised Figure 4-8, which shows for the January–April period years since the mid-1990s:

- the consumptive use by NSW and Victorian entitlement holders between Barmah and the South Australia (SA) border, net of demand supplied by inter-valley trade (IVT)
- the component of consumptive use supplied by IVT
- the SA entitlement flow delivered to the SA border
- Murray entitlement water traded across the SA border for consumptive and environmental purposes
- Environmental water delivered to the SA border from tributaries of the River Murray.

Figure 4-8 shows that total environmental water and consumptive use from January – April in this reach of the River Murray has remained relatively constant (top plot), and when IVT and environmental deliveries from the regulated tributaries are accounted for, the volume of River Murray resources needed to supply demand in this reach (bottom plot) has trended downwards slightly. There is one obvious exception though. In 2013, which immediately followed the wet 2010-2012 period, total water use was above prior years in the historic record (even after accounting for IVT and environmental water deliveries from the tributaries).

In 2013 (and 2017), environmental water use in this reach was close to the nominal consumptive demand HARC (2020) estimated would have been realised if the water recovered for the environment had remained in the consumptive pool (Figure 4-9)[9]. In other years from 2012 onwards, most of the environmental water deliveries to the SA border occurred in the winter and spring months (Figure 3-4; Figure 4-9). This implies that January – April water use in this reach is likely to remain within the range observed from the mid-1990s to late 2000s unless there are significant environmental water deliveries in summer/early-autumn. The short period of record available suggests that summers following wet winter/spring periods are the times where relatively large consumptive demands and environmental water deliveries may coincide.

[9] This was done by applying the observed pattern of consumptive water use to the Murray entitlements downstream of Barmah Choke that are held by environmental water holders



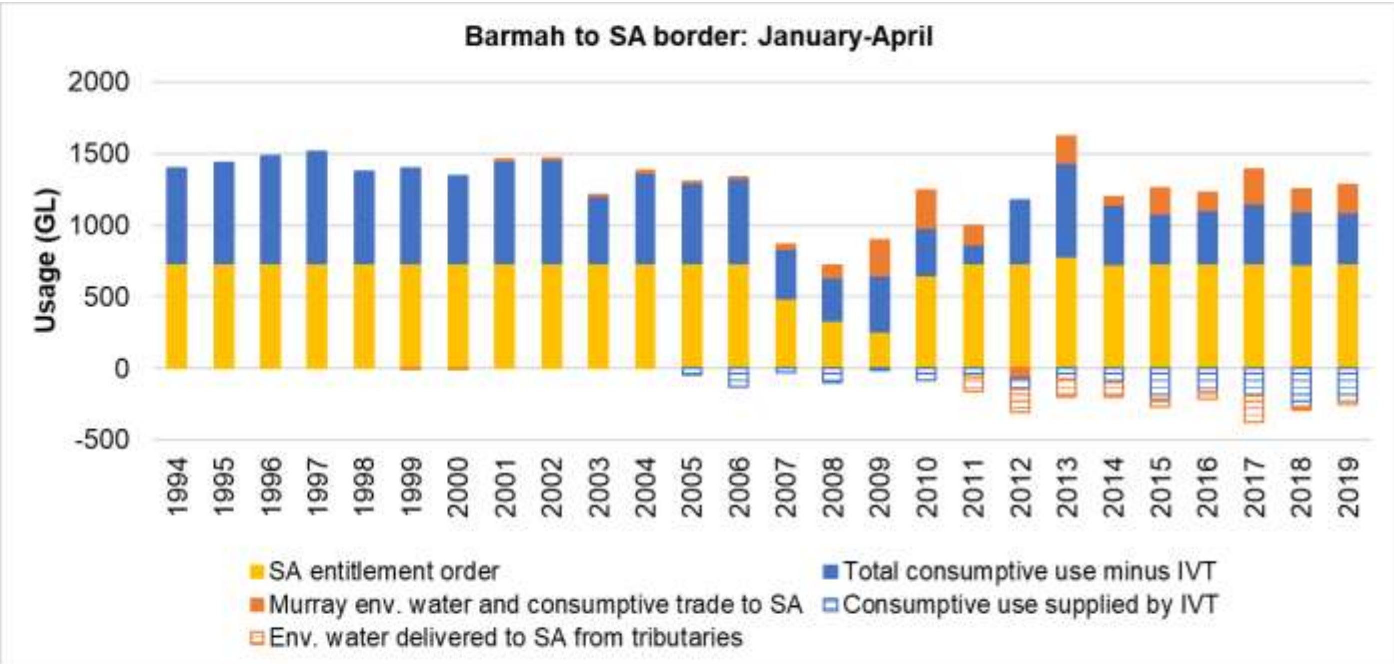


Figure 4-8: Annual time-series of January-April consumptive use by NSW and Victorian entitlement holders between Barmah and the SA border, net of demand supplied by inter-valley trade (IVT); the component of consumptive use supplied by IVT; the SA entitlement flow delivered to the SA border; Murray entitlement water traded across the SA border for consumptive and environmental purposes; and environmental water delivered to the SA border from tributaries of the River Murray. In the top plot, the IVT volumes and environmental water deliveries from tributaries are positive, to show total water use in the reach. In the bottom plot, these values are negative to distinguish them from water use supplied by River Murray resources.

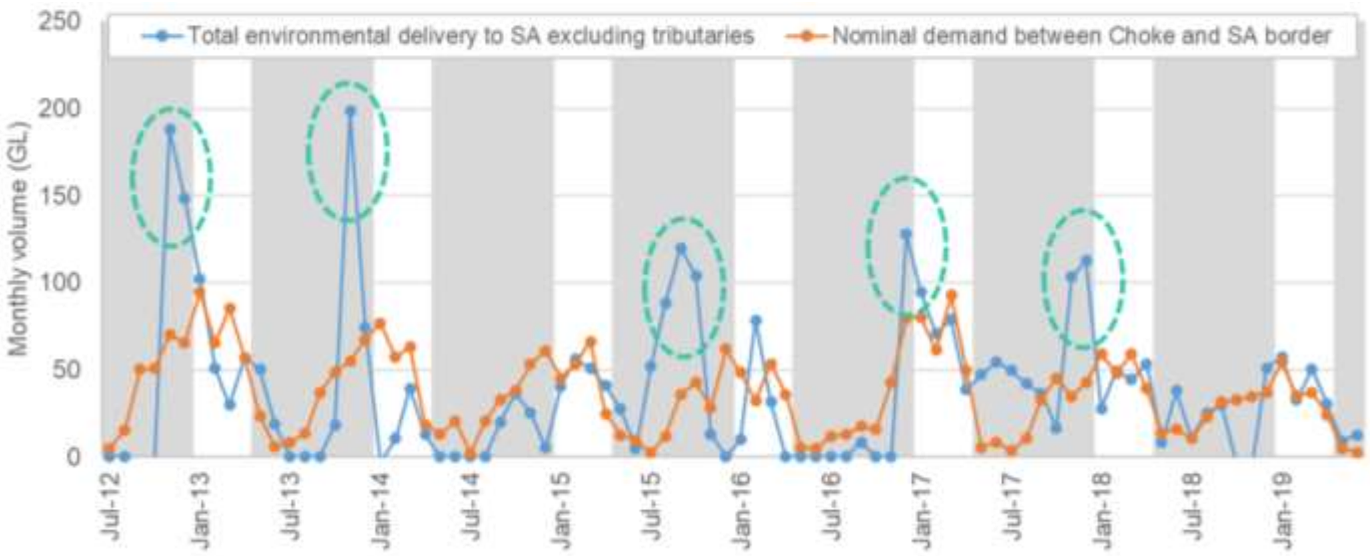


Figure 4-9: Monthly environmental water delivery to South Australia – excluding volumes delivered from tributaries – vs estimated demand had the Murray entitlements downstream of the Barmah Choke associated with the environmental water deliveries remained in the consumptive pool. The white shading is for the January–April period, and the grey shading for May–December.

In summary:

- Water use from January – April in the River Murray reach between Barmah and the SA border has been relatively constant over the period of record shown in Figure 4-8. The exception is 2013, which was the summer following the wet 2010-2012 period. Deliveries to supply these demands [10] have needed to pass through the Barmah Choke, and the in-channel capacity of the Choke has been declining (Section 4.2).
- As discussed in Section 3.2.5, peak monthly water use has generally shifted from the January–April period to late spring / early summer, when the maximum regulated flow downstream of Yarrawonga is 15,000–18,000 ML/d rather than the Choke capacity. Late spring / early summer is now the general period of peak monthly usage because there is often demand for both environmental water deliveries and consumptive use. However, late spring is also the time when Tar-Ru transfers are likely to be required if tributary inflows have not filled the lake (Figure 3-2; Figure 4-1).

4.4 Summary

The three case studies above provide further evidence of the key system-wide drivers of Tar-Ru behaviour that were identified in Section 3. Figure 4-10 provides a schematic representation of how they interact to influence the volume of water available for diversion from the River Murray to Tar-Ru, and in combination have made it more difficult to fill the lake to the minimum reserve target on May 31 and to FSL prior to year's end (Section 2).

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[10] Excluding IVT and environmental water deliveries from the regulated tributaries

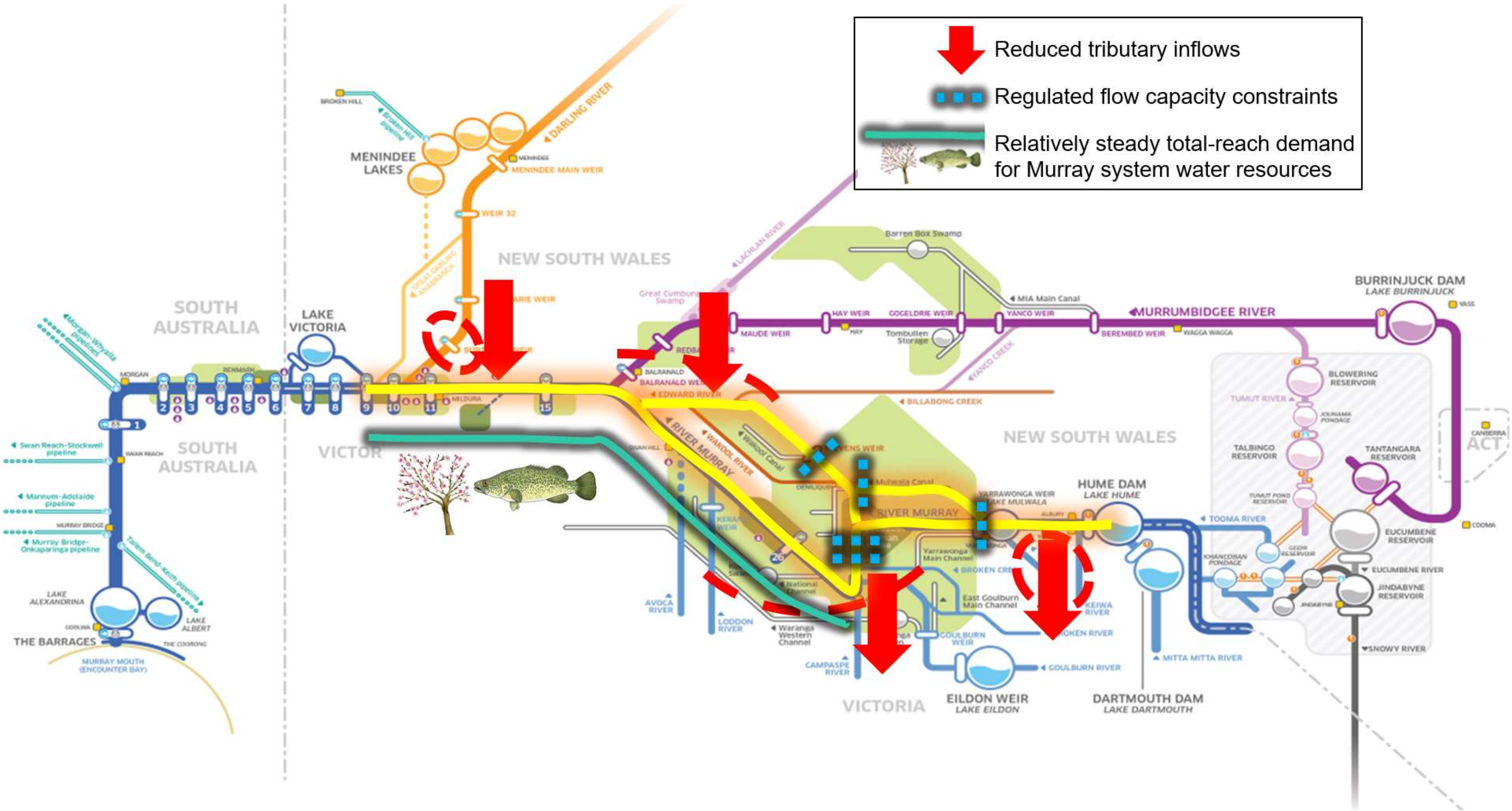


Figure 4-10: A schematic representation of the system-wide drivers influencing the observed historic behaviour of Tar-Ru (Lake Victoria). Reduced tributary inflows have increased the need for Hume – Tar-Ru transfers, but these transfers are competing with consumptive and environmental water demands* for regulated flow capacity downstream of Yarrawonga Weir – including through the Barmah Choke where within-channel capacity is decreasing.

* in the reach from Barmah to the South Australian border

5. Current management initiatives and gaps

5.1 Existing management instruments and initiatives

Existing water resource management instruments and initiatives related to the system-wide and local drivers of Tar-Ru behaviour in the recent record (Section 2) are summarised in Table 5-1. More detail on these current initiatives is provided in Section 6.3. Potential future investigations to address knowledge gaps (Section 5.2) are listed in the most right-hand column of Table 5-1. The recommended focus for these future investigations is described in Section 5.3.

Tar-Ru operating levels have been designed to minimise adverse effects on First Nation (Barkindji / Maraura) cultural heritage. There was broad agreement from participants in this project that management must continue to meet the objectives and outcomes sought in the Aboriginal Heritage Impact Permit (current and successors) and the Tar-Ru (Lake Victoria) Operating Strategy (MDBC 2002). Any investigations and proposals for changed management arrangements for Tar-Ru must proceed in partnership with the Barkindji / Maraura peoples. This should occur through existing partnership arrangements and protocols in a transparent and sensitive manner.

5.2 Knowledge gaps

During the stakeholder consultations (Appendix A), and the preparation of the case studies (Section 4) and this report section, the following knowledge gaps were identified:

System-wide issues

- How severe will the effects of climate change be? Which scenarios are best used for water resource planning?
- Will there be increased use of water entitlements in future because of climate change, historic water recovery and ongoing trade?
- How will Tar-Ru's active storage be used – or bypassed – in future to best meet local and downstream environmental water demands?
- Assuming that Hume – Tar-Ru transfers continue to be required in response to declining tributary inflows, how does this change conveyance losses in the River Murray and who bears the cost?
- What is the ongoing role of South Australian entitlement deferrals in terms of Tar-Ru operations?

Local operating issues

- What is the current capacity of the Frenchman's Creek inlet channel to Tar-Ru? (e.g. 6,000 ML/d or 8,500 ML/d)
- What are the implications for filling Tar-Ru if weir pool manipulations of up to ±1.0 m occur? (e.g. as proposed in the Lock 8 and Lock 9 Weir Pool Manipulation SDL adjustment mechanism project; https://www.mdba.gov.au/basin-plan-roll-out/sustainable-diversion-limits/sdl-adjustment-proposals-state-projects)

Potential future investigations related to these knowledge gaps are listed in Table 5-1. Further detail is provided in Section 6.

5.3 Potential future management focus

To tie together the investigations required to fill knowledge gaps (Section 5.2) and complement existing water resource management initiatives (Table 5-1), it is recommended that future stages of work related to Tar-Ru focus on the optimisation of Hume – Tar-Ru transfer rules.

This is because:

- Hume – Tar-Ru transfers have been required more often in the recent historic record compared with earlier years, in response to reduced inflows from unregulated and regulated River Murray tributaries.
- Hume – Tar-Ru transfers use regulated river capacity that would otherwise be available for other system operations or the delivery of water to consumptive users and environmental water holders. Therefore, if Hume – Tar-Ru transfers are needed more often to fill Tar-Ru, deliverability risks for other water users will increase.
- Hume – Tar-Ru transfers can result in resource loss, by increasing conveyance losses or the risk of spill from storage. This in turn can reduce water availability for consumptive users and environmental water holders.
- Hume – Tar-Ru transfers are directly managed by the MDBA in conjunction with the Basin States (through the Water Liaison Working Group), in contrast to challenges such as reduced tributary inflows which are attributable to causes that are more difficult to influence (e.g. climate variability and change).
- Existing initiatives – such as the MDBA River Murray Capacity and Delivery Shortfall Project (https://www.mdba.gov.au/publications/mdba-reports/river-murray-water-delivery-shortfall-risks) – are already addressing some of the system-wide drivers of Tar-Ru operations.

Section 6 includes a high-level concept plan for this recommended approach.

Table 5-1: Current initiatives related to the system-wide drivers that are influencing diversions to and active storage at Tar-Ru

Driver	Scale	Potential water availability, deliverability or quality impact	Existing management instruments	Current initiatives	Potential future investigations
Reduced tributary inflows: unregulated and regulated	Basin scale	See: ▪ Section 2 ▪ Section 3.2.1 ▪ Section 3.2.2 ▪ Section 4.1 Also: ▪ Future variability in water availability may lead to more conservative water use, and in turn changes to demand and delivery patterns in regulated reaches	▪ NSW Murray and Lower Darling surface water resource plan (pending) ▪ NSW Murrumbidgee surface water resource plan (pending) ▪ Victoria's North and Murray water resource plan (DELWP 2019a) ▪ South Australian River Murray water resource plan (DEW 2019) ▪ Goulburn River IVT trade rule (DELWP 2021) ▪ River Murray objectives and outcomes (O&O) (MDBA 2019a)	▪ MDBA climate workplan (2021-2026)	▪ Preparation of future scenarios (alternative climate and demand settings) – e.g. based on conditions expected / possible in 2030 – for use in the design of water resource management plans, policies and procedures ▪ Appropriate minimum reserve target(s) at Tar-Ru, and filling rules for winter / spring ▪ Risk-based guidelines for Hume – Tar-Ru transfers to fill the lake in winter / spring ▪ Monitoring the impact of new Goulburn River IVT trade rules
Operational constraints: Declining channel capacity at Barmah Choke	Localised constraints, with Basin scale impacts	See: ▪ Section 3.2.3 ▪ Section 4.2 Also: ▪ Potential for increased losses if Hume – Tar-Ru transfers involve overbank flows more often	▪ River Murray objectives and outcomes (O&O) (MDBA 2019a) ▪ MDBA constraints strategy (MDBA 2013) ▪ SDLAM projects (MDBA 2019b) ▪ Restriction on trade from upstream to downstream of Barmah Choke[11]	▪ MDBA investigation of sand management options[12] ▪ MDBA Barmah Choke options feasibility study (pending) ▪ Constraints relaxation – Yarrawonga-Wakool (led by NSW DPIE) ▪ MDBA Hydrodynamic model for Barmah-Millewa Forest	▪ Sharing of the regulated flow capacity downstream of Yarrawonga Weir between system operations, consumptive users and environmental water holders ▪ Alternative arrangements for sharing between system operations, consumptive users and environmental water holders the conveyance losses incurred during overbank flows through the Barmah-Millewa Forest
Operational efficiency:	Basin scale	See: ▪ Section 3.2.4	▪ Water saving initiatives (e.g. Northern Victoria Connections Program,	▪ MDBA River Murray Capacity and Delivery Shortfall Project	▪ Risk-based guidelines for Hume – Tar-Ru transfers to fill the lake in winter / spring

[11] https://www.mdba.gov.au/managing-water/water-markets-trade/interstate-water-trade/barmah-choke-trade-balance
[12] https://www.mdba.gov.au/publications/independent-reports/barmah-millewa-forest-sediment-investigations

Driver	Scale	Potential water availability, deliverability or quality impact	Existing management instruments	Current initiatives	Potential future investigations
Reduced rainfall-rejections for diversion to Tar-Ru			WaterNSW rural valleys assets upgrade, MIL on-farm efficiency projects)		
Demands downstream of the Barmah Choke	Basin scale	See: ▪ Section 3.2.5 ▪ Section 4.3	▪ River Murray objectives and outcomes (O&O) (MDBA 2019a) ▪ CEWH – jurisdiction environmental water delivery agreements (e.g. CEWO & VEWH, 2019; CEWO & DEW, 2019; CEW and DPIE, 2020) ▪ Lake Victoria operating strategy (MDBC 2002)	▪ MDBA River Murray Capacity and Delivery Shortfall Project	▪ Preparation of principles for the use of Tar-Ru in contributing to lower River Murray environmental watering, including the diversion or shepherding of upstream environmental water releases ▪ Sharing of regulated flow capacity downstream of Yarrawonga Weir between system operations, consumptive users and environmental water holders ▪ Assessment of historic and potential future entitlement utilisation by consumptive users and environmental water holders (this may be addressed by a MDBA / HARC project due for completion by February 2022) ▪ Assessment of potential future deferrals of entitlement flows to South Australia
Local land management and water quality (salinity, dissolved oxygen, nuisance algae) objectives and obligations	Local	▪ Operating rules govern the filling and drawdown of Tar-Ru to minimise potential impacts on cultural heritage and values ▪ Tar-Ru operating levels are also influenced by the need to minimise salination impacts on nearby land ▪ Water stored in Tar-Ru can be used to mitigate the impacts of poor River Murray water quality downstream of the lake (e.g. dilution of saline water from the Darling River; injection of oxygenated water into blackwater events)	▪ Lake Victoria Cultural Landscape Plan of Management (MDBA 2019) ▪ Lake Victoria Aboriginal heritage impact permit (NSW OEH, 2015; new AHIP pending) ▪ Lake Victoria operating strategy (MDBC 2002) ▪ SDLAM projects (MDBA 2019b)	▪ Lake Victoria Aboriginal heritage impact permit (AHIP) (NSW OEH, 2015; new AHIP pending)	▪ Confirmation of inlet and outlet capacity at Tar-Ru – existing and for potential future upgrades of infrastructure ▪ Assessment of potential impacts of River Murray weir pool manipulations on diversions to Tar-Ru

6. Concept plan for next stage

The recommended priority for future work is to develop a risk-based framework for making decisions about the timing and volume of Hume – Tar-Ru transfers, to account for:

- Reduced tributary inflows (e.g. Section 4.1)
- Operational constraints (e.g. Section 4.2)
- Changing water demands in the River Murray system (e.g. Section 4.3).

The elements of a high-level concept plan for this recommended action are summarised below.

6.1 Objective

The proposed objective for the investigation is to develop Hume – Tar-Ru transfer guidelines or rules that balance the risks[13] of:

- Resource loss (e.g. spills from Tar-Ru; increased conveyance losses)
- Supply shortfalls for water users (e.g. storage in Tar-Ru being insufficient to meet peak downstream demands)
- Deliverability constraints that curtail water orders from the Basin states (e.g. transfers using regulated release and river channel capacities that would otherwise be used to deliver water to consumptive users or the environment).

6.2 Tasks

There are several tasks required to meet the objective described above. These include:

Developing a fit-for-purpose model for the investigation

The Source Murray Model (SMM) will be the key tool needed for forming a risk-based decision framework for Hume – Tar-Ru transfers. This is because it simulates the River Murray system on a daily time-step over a long period of record. It can therefore be used to model outcomes from 'what if' options for Hume – Tar-Ru transfers. The predecessor to SMM (called MSM) was used to develop the 2002 Lake Victoria Operating Strategy (MDBC, 2002).

For the SMM to be of most use for an investigation of Hume – Tar-Ru transfer rules, it would need to represent River Murray and tributary inflows under current or potential future climate conditions, rather than historic conditions. This is because inflows have reduced in recent years compared with earlier in the historic record (Section 4.1), and there is a strong correlation between tributary inflows and the need for Hume – Tar-Ru transfers. Therefore, one task is to select the climate scenarios that are best used for investigating Hume – Tar-Ru transfer rules, and developing SMM climate and inflow inputs[14] that represent these conditions.

[13] Likelihoods and consequences
[14] This includes inflows from the regulated and unregulated tributaries

The consumptive and environmental water demands represented in the SMM would need to be updated to reflect the selected climate scenario(s). Operational constraints – for example at the Barmah Choke – will also need to be reflected in the SMM using thresholds relevant to the expected lifespan of the risk-based framework (e.g. 2030). Any SDLAM projects completed or likely to be completed in the medium-term should be represented in the SMM, so that any influences of these projects on future operations of Tar-Ru can be considered.

Confirming or re-visiting water resource management policies and procedures

Before a risk-based framework for Hume – Tar-Ru transfer decisions can be developed, a range of water resource management considerations will need to be discussed, and either confirmed as rules or aspects of system operations that could be refined:

Operating rules for minimum reserve(s), drawdown and re-filling of Tar-Ru

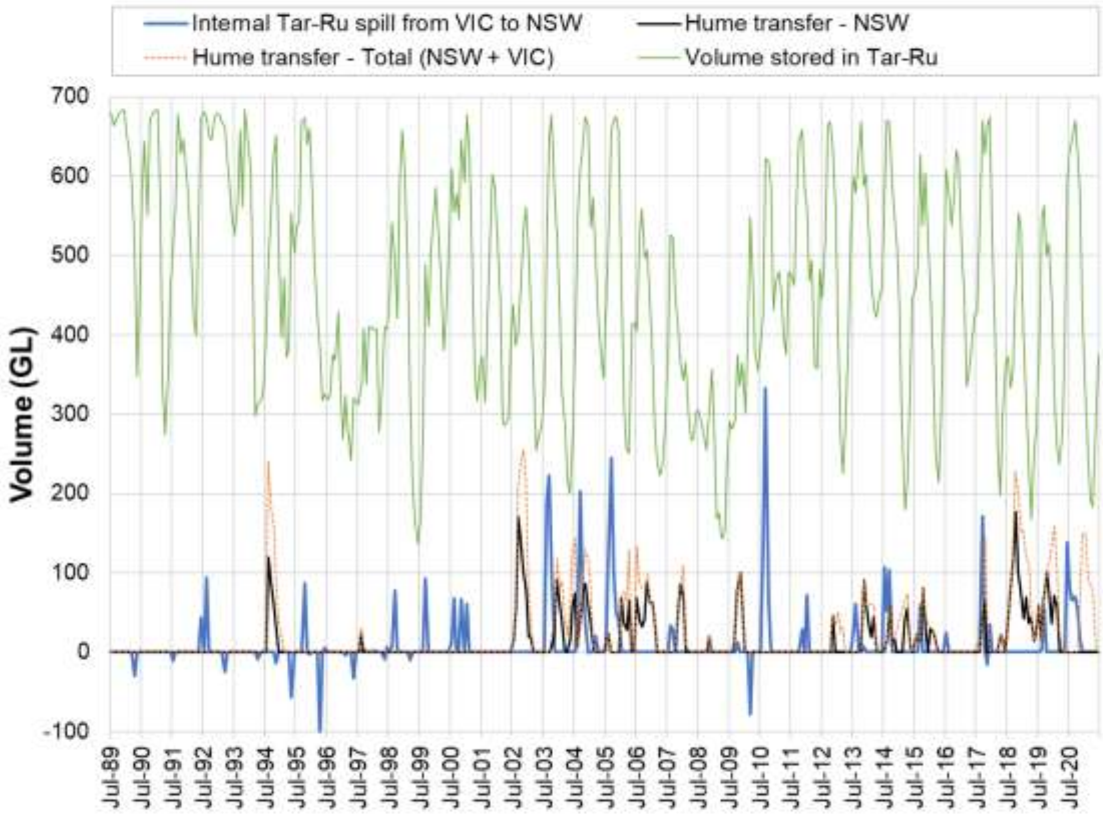
The operating rules for Tar-Ru involve drawing the lake level down below 24.5 m AHD (300 GL active storage) in April and May, and having at least 250 GL active storage in Tar-Ru on May 31 (24 m AHD). This means that on May 31 there is a small range (50 GL) in Tar-Ru storage volumes that River Murray operators manage to. Whether this range is maintained or relaxed will influence future Tar-Ru operations and hence Hume – Tar-Ru transfers.

Another key component of the current Ta-Ru operating strategy is to refill the Lake *as late as possible in winter and spring* (MDBC, 2002). Section 3.3.2 says that *if surplus flows (greater than the volume needed to refill Lake Victoria to capacity) are predicted, then Lake Victoria is drawn down and the Lake is refilled as late as possible. Hindsight will show that in many cases Lake Victoria could have been refilled later* (MDBC, 2002).

Waiting for River Murray system and tributary inflows during winter and spring to fill Tar-Ru was a sound tactic based on historic records available pre-2000s. However, the recent climate conditions mean that the chance Tar-Ru will fill without transfers from Hume has reduced. If these transfers occur late in spring, they are likely to coincide with consumptive and environmental water demands, and increase the risk that delivery constraints (e.g. at Yarrawonga Weir) will result in supply shortfalls or transfers being curtailed. A decision therefore needs to be made about whether the wait for the rainfall-runoff to 'refill the Lake as late as possible' strategy is maintained, or relaxed to balance the risks of spills from Tar-Ru against the risk of reaching system delivery constraints in late winter / spring. Making this decision is likely to involve a discussion of the respective delivery priorities for transfers, consumptive users and environmental water holders during times when regulated releases are at capacity.

Internal spills within Tar-Ru

In the historic record, NSW has been the beneficiary of internal spills from Victoria's share of Tar-Ru, particularly since the 2000s (Figure 6-1). Hume transfers to Tar-Ru have also increased from the early 2000s onwards. Therefore, there will be little incentive for Victoria to consider moving their component of transfers to earlier in winter / spring (Figure 6-2) – thus increasing the risk of internal or physical spills from Tar-Ru – unless accounting arrangements are re-visited. Therefore a decision is required about whether internal spill accounting will continue using existing procedures, or can be revised when investigating Hume – Tar-Ru transfer rules.



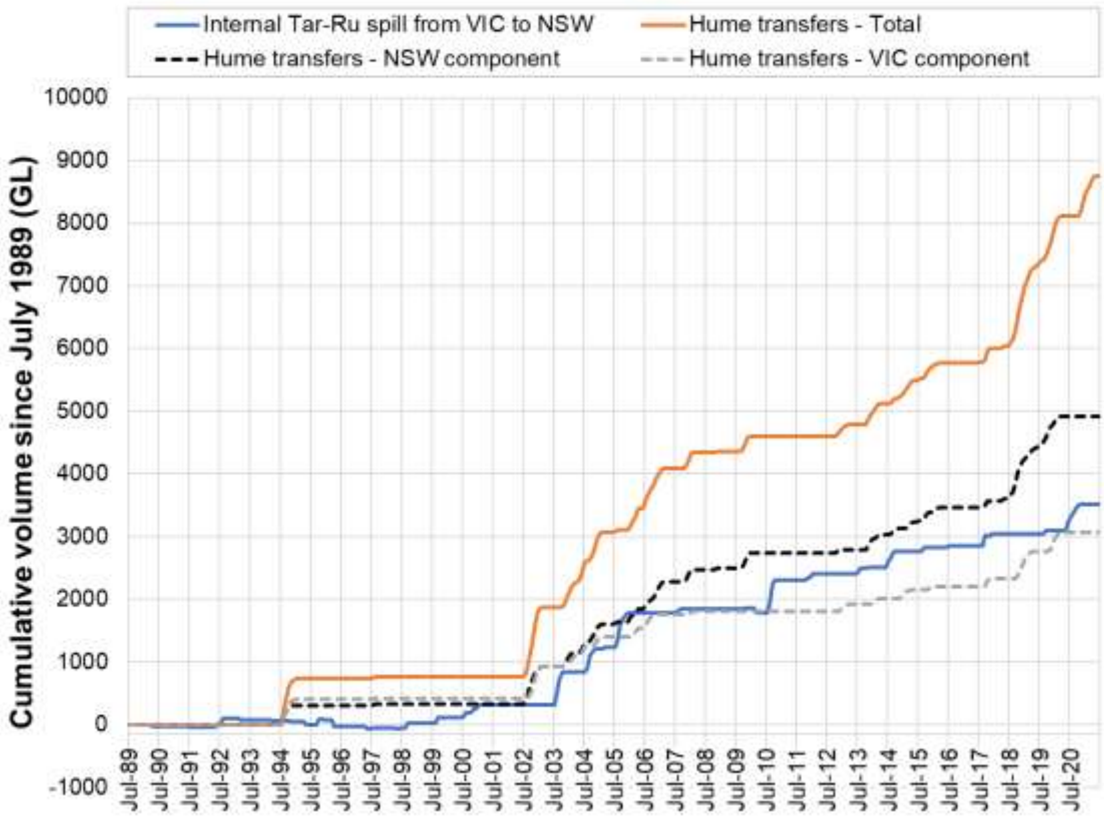


Figure 6-1: Internal spills from Victoria to NSW's share of Tar-Ru since July 1989, versus transfers from Hume – Tar-Ru

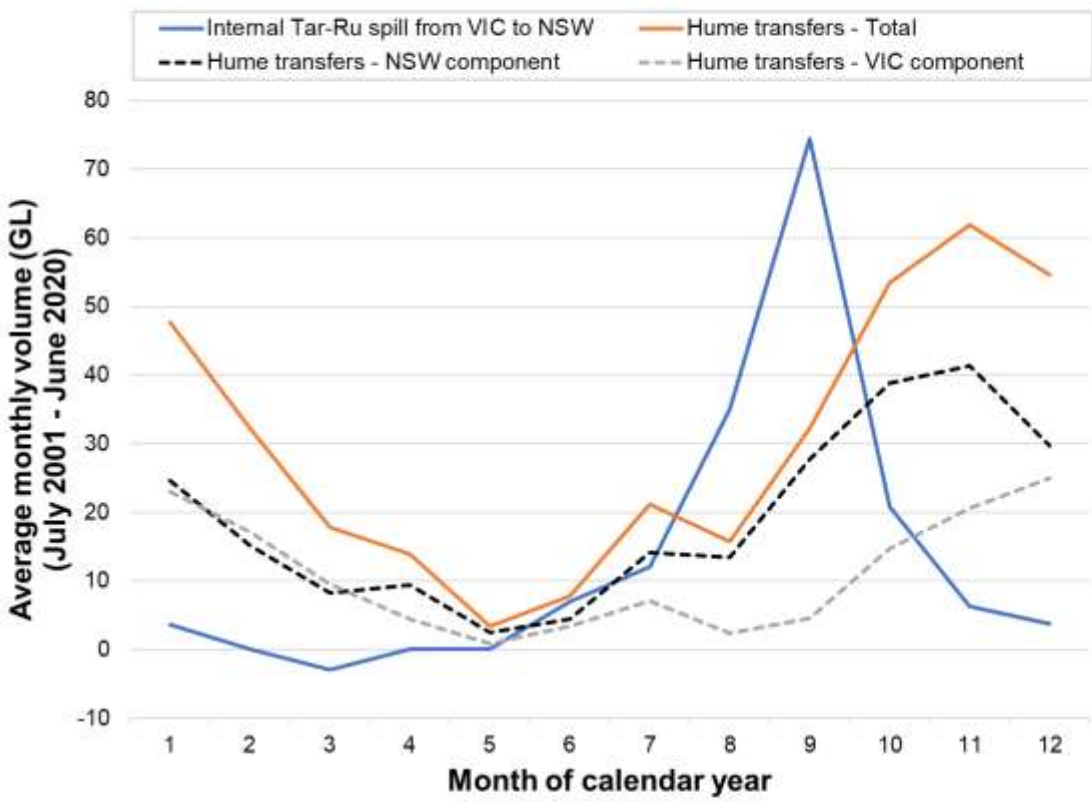


Figure 6-2: The average monthly NSW and Victorian component of Hume – Tar-Ru transfers from July 2001 to June 2020. In this 20 years of the historic record, the NSW component of transfers has typically occurred earlier in the year compared with the Victorian contribution.

Sharing of regulated flow capacity at Yarrawonga Weir

Reduced tributary inflows have increased the need for Hume – Tar-Ru transfers, but these transfers are competing with consumptive and environmental water demands for regulated flow capacity downstream of Yarrawonga Weir, including through the Barmah Choke where within-channel capacity is decreasing. The sharing arrangements for this regulated flow capacity will need to be negotiated and represented in the SMM so that the influence of these sharing arrangements on the timing and volume of Hume – Tar-Ru transfers can be assessed.

Conveyance losses

When transfers are made from Hume to Tar-Ru, some water is lost en route (e.g. to evapotranspiration and seepage). This reduces the pool of water available for consumptive and environmental users. The nature of the system losses – particularly in the Barmah-Millewa Forest – also means that in any given season the water user(s) that initiates overbank flows through the Barmah Choke (in the absence of unregulated inflows) will potentially incur more losses than subsequent users of the regulated overbank flow capacity. This arrangement provides an incentive for water users and those making decisions about Hume – Tar-Ru transfers to wait for overbank flows to be triggered by unregulated flows or water orders by others. Therefore a decision is required about whether the existing conveyance loss accounting associated with Hume – Tar-Ru transfers will be maintained, or whether these can be revisited in consultation with consumptive user representatives and environmental water holders.

Use of Tar-Ru for environmental water deliveries

The extent to which environmental water releases from headwork storages in the River Murray system (e.g. Hume) are diverted to Tar-Ru when they reach Lock 9 (i.e. for later use), or are shepherded to the South Australian border, will influence active storage volumes in Tar-Ru. Therefore, during the development of a risk-based framework for Hume – Tar-Ru transfer decisions, it will be necessary to discuss and decide whether all, some or no environmental water released from upstream storages will be shepherded past Tar-Ru in future. If the answer is ‘some’, guidelines on when diversions to Tar-Ru are acceptable will need to be developed.

South Australian deferrals of entitlement flows

If South Australia defers their entitlement flow (https://www.environment.sa.gov.au/topics/river-murray/river-management-information/south-australias-storage-right), the volume of water that needs to be delivered to the border from Tar-Ru or upstream storages is reduced during the deferral period. Therefore, the degree to and pattern with which South Australia may defer water under the climate scenario(s) used to investigate Hume – Tar-Ru transfer rules will be important to consider and represent in the SMM.

Agreeing on the metrics used to assess and balance the risks of Hume – Tar-Ru transfers

Appropriate metrics will need to be selected to assess how Hume – Ta-Ru transfers contribute to risks of resource losses, supply shortfalls for water users and deliverability constraints on water orders, and whether transfer rules can be modified to balance and minimise these risks. These metrics will be available from the SMM and may include:

- Early and late-season allocations to consumptive users and environmental water holders
- Internal and physical spills from storage
- Conveyance losses
- Flow time-series, exceedance curves and spell analyses at key locations (e.g. constraints, site-specific flow indicators for environmental outcomes)
- Others as suggested by the MDBA and Basin states.

Testing a range of potential Hume – Tar-Ru transfer rules, and using the metrics to assess risk and develop a decision framework that minimises future risks

The SMM can then be used to simulate a range of what-if scenarios, and the associated risks. For example, what if:

- The minimum reserve in Tar-Ru on May 31 was reduced.
- The operating strategy for Tar-Ru did not aim to fill the storage each year.
- The timing and volume of Hume – Tar-Ru transfers were governed by a combination of existing storage volumes and seasonal climate or streamflow forecasts.
- Hume – Tar-Ru transfers were generally made early in winter/spring, thus providing more regulated release capacity for consumptive and environmental water users in late winter/spring.

- Environmental water holders typically released water from storage early in winter/spring, rather than in late spring / early summer, thus providing more regulated release capacity for consumptive water users and system transfers during late spring / early summer.
- Hume – Tar-Ru transfers were combined more often with environmental water releases, and associated conveyance losses were shared between system operations and the environmental water holders.

These modelled outcomes of these scenarios will need to be discussed with the Basin states and other stakeholders (water corporations, environmental water holders), and are likely to lead to exploration of other 'what if' scenarios. Via this process, a suite of Hume – Tar-Ru transfer rules or guidelines that balance the risks can be developed.

6.3 Interactions with other initiatives

There are significant overlaps between the recommended action to develop a risk-based framework for Hume – Tar-Ru transfer decisions and the MDBA's ongoing River Murray Capacity and Delivery Shortfall Project (https://www.mdba.gov.au/publications/mdba-reports/river-murray-water-delivery-shortfall-risks). This project is comprised of four components (MDBA System Review Team, pers. comm. 9 September 2021):

- The development of a shortfall response plan by the Basin states
- Studies of the cumulative impacts of land use and water use changes between the Barmah Choke and South Australian border (e.g. https://www.mdba.gov.au/publications/independent-reports/review-historical-use-water-barmah-south-australian-border)
- The investigation and management of sedimentation of the Barmah Choke channel (e.g. https://www.mdba.gov.au/sites/default/files/pubs/barmah-millewa-forest-sediment-transport-investigation.pdf)
- A feasibility study of the engineering, operational and policy options for optimising the regulated flow capacity through and around the Barmah Choke (https://www.mdba.gov.au/media/mr/murray-darling-basin-ministerial-council-19-june-2020)

In particular, some of the recommendations made in a December 2019 review of the River Murray Capacity and Delivery Shortfall Project (Doolan et al, 2019) are similar to comments made in Section 6.2 (e.g. the representation of climate change impacts in inflows used in the SMM). Therefore, any future work done on a risk-based framework for Hume – Tar-Ru transfer decisions will need to complement and be consistent with the activities and outcomes of the Capacity and Delivery Shortfall Project.

Other current and future water resource management initiatives that may influence the operations of Tar-Ru include:

- The Murray-Darling Basin Constraints Management Strategy (https://www.mdba.gov.au/basin-plan-roll-out/managing-constraints)

  If operational constraints are relaxed, there will be increased opportunities to piggyback system transfers and regulated releases for consumptive and/or environmental uses.

- The Enhanced Environmental Water Delivery (EEWD) project (https://www.mdba.gov.au/basin-plan-roll-out/sustainable-diversion-limits/sdl-adjustment-proposals-state-projects)

  The EEWD project may result in the development and implementation of environmental water delivery scenarios that involve greater or different uses of planned release capacity downstream of Yarrawonga Weir in the same winter / spring window that Hume – Tar-Ru transfers often occur.

- The proposed Integrated River Modelling Uplift (IRMU) program

  The IRMU is a four-year program (2022-2026) that is aiming to develop a framework that integrates all long-term hydrological models within the Basin, and increases each model's capability and accessibility. This program may therefore improve the modelling tools available for investigations of Hume – Tar-Ru transfer decisions.

- The Menindee Lakes SDL adjustment mechanism (SDLAM) project (https://www.industry.nsw.gov.au/water/plans-programs/sdlam/menindee-lakes-project)

  In the historic record, Hume – Tar-Ru transfers have not been required when Menindee Lakes have held significant volumes in storage (Figure 4-1). Therefore, any future changes to the configuration or operation of the Menindee Lakes may influence the need for Hume – Tar-Ru transfers.

- The Locks 8 and 9 Weir Pool Manipulation SDLAM project (https://www.mdba.gov.au/basin-plan-roll-out/sustainable-diversion-limits/sdl-adjustment-proposals-state-projects)

  This project is aiming to achieve better environmental outcomes by changing existing infrastructure and river operation rules so that there is greater variability in weir pool levels. Changes to levels in weir pools where diversions to and from Tar-Ru occur may influence how river operators are able to manage active storage in Tar-Ru.

- Aboriginal heritage impact permit (AHIP)

  Operation of Tar-Ru is in accordance with an AHIP. This AHIP is being renewed, and future management of Tar-Ru will need to continue adhering to this AHIP.

- Review of Basin Plan and State Water Resource Plans

  The Basin Plan will be reviewed in 2026 (https://www.mdba.gov.au/basin-plan/plan-basin/basin-plan-timeline). State water resource plans will then need to be revised in line with any changes to the Basin Plan. If the 2026 Basin Plan and subsequent state water resource plans result in amendments to SDLs or SDLAM projects, this may influence post-2026 water use in the River Murray system, and the need or otherwise for Hume – Tar-Ru transfers to fill Tar-Ru prior to the summer period of peak consumptive demands.

- The MDBA climate workplan (https://www.mdba.gov.au/publications/mdba-reports/climate-change-planning)

  The three-phase plan from 2021–2026 aims to identify adaption options for Basin-scale climate risks and vulnerabilities, and will inform the 2026 review of the Basin Plan.

- The Murray-Darling Basin Agreement (https://www.legislation.gov.au/)

  This agreement includes the minimum reserve target for May 31, and accounting rules for internal spill accounting, Menindee – Tar-Ru transfers and Hume – Tar-Ru transfers.

Likewise, future infrastructure upgrades at Tar-Ru – e.g. to the inlet or outlet regulating structures – will need to be designed so that there is sufficient operational flexibility at Tar-Ru to maximise the benefits and minimise the risks from the above-listed initiatives and any changes to Hume – Tar-Ru transfers.

6.4 Stakeholder engagement

Future work to develop an agreed risk-based framework for making decisions about Hume – Tar-Ru transfers will require significant stakeholder engagement, including with:

- New South Wales (DPIE, WaterNSW)
- Victoria (DELWP, GMW, Lower Murray Water, VEWH)
- South Australia (DEW, SA Water)
- The Commonwealth Environmental Water Office (CEWO)
- Various teams within the MDBA
- Other parties involved with the implementation of the Tar-Ru (Lake Victoria) Operating Strategy (MDBC 2002), Cultural Landscape Plan of Management (MDBA 2019) and AHIP. As noted in Section 5, ongoing management of Tar-Ru must be done in partnership with the First Nations.

The writing and implementation of a stakeholder engagement plan that supports the development of a risk-based framework for Hume – Tar-Ru transfer decisions will therefore be an important task.

6.5 Resourcing

The development of an agreed risk-based framework for making decisions about Hume – Tar-Ru transfers may take 2-3-years. Table 6-1 provides a high-level summary of the tasks involved. These tasks have been grouped into four sets:

- Develop a fit-for-purpose model for future investigations
- Confirm or re-visit water resource management policies and procedures that influence the operation of Tar-Ru
- Develop a risk-based framework for Hume – Tar-Ru transfers using 'what if' scenario testing
- Report and communicate the outcomes

The first two sets of tasks can be done in parallel, and are likely to require 12 – 18 months to complete. The second two sets of tasks would then occur over the subsequent 12 – 18 months. If MDBA and Basin State staff resources equivalent to 1-2 full-time equivalents (FTE) are used to complete these tasks over 2-3-years, the cost may be in the order of $500,000 to $1,000,000.

Table 6-1: A high-level summary of the tasks involved in the development of a risk-based framework for Hume – Tar-Ru transfer decisions

Task	Comments
Develop a fit-for-purpose model for future investigations	
Represent all SDLAM projects completed, or expected to be completed, in the SMM	These tasks will require resources from the MDBA modelling team, and perhaps external advice on options for representing potential future hydroclimate scenarios in the SMM. However, some of these tasks are also likely to be completed as part of the IRMU program, SDLAM projects and MDBA climate workplan described in Section 6.3 Note that the SMM inputs include inflows from the NSW and Victorian tributaries. Therefore, NSW and Victoria will need to provided updated River Murray inflow time-series for their respective tributaries under the same climate scenarios represented in the SMM. These tasks can occur in parallel with the next set of tasks.
Select the climate scenarios that are best used for investigating Hume – Tar-Ru transfer rules	
Develop the SMM climate and inflow inputs that represent the selected climate scenarios	
Update the consumptive and environmental water demands in SMM – both upstream and downstream of Tar-Ru – to reflect the selected climate scenarios	
Represent in the SMM the expected operational constraints for a future year (e.g. 2030) consistent with the anticipated lifetime of the risk-based framework for Hume – Tar-Ru transfer decisions	
Confirm or re-visit water resource management policies and procedures that influence Tar-Ru operations	
Confirm or relax operating rules for minimum reserve(s), drawdown and re-filling of Tar-Ru	These tasks are likely to require a high degree of consultation and negotiation between First Nations, the various Basin states and the MDBA. If existing operating and / or accounting procedures can be relaxed, the bounds of this relaxation will need to be discussed and agreed, so appropriate parameters can be included in the SMM. Some initial runs of the SMM may be required to inform these discussions. Some of these tasks can occur in parallel with the first set of tasks, while others will need to be informed by modelling and/or re-visited during the 'what if' scenario testing described below.
Confirm or revisit internal spill accounting for volumes stored within Tar-Ru	
Confirm or negotiate sharing arrangements for regulated flow capacity at Yarrawonga Weir during Hume – Tar-Ru transfers	
Confirm that the conveyance loss accounting associated with within-channel and overbank Hume – Tar-Ru transfers will be maintained, or revisit these procedures in consultation with consumptive user representatives and environmental water holders	
Discuss and decide whether all, some or no environmental water released from upstream storages will be shepherded past Tar-Ru in future. If the answer is 'some', develop guidelines on when diversions to Tar-Ru are acceptable, and represent these in the SMM	
Estimate the degree to and pattern with which South Australia may defer entitlement flows under the climate scenarios used to investigate Hume – Tar-Ru transfer rules; represent this in the SMM	
Develop a risk-based framework for Hume – Tar-Ru transfers using 'what if' scenario testing	
Discuss and agree the metrics used to assess and balance the risks associated with Hume – Tar-Ru transfers	All prior steps need to be completed before the scenario testing can begin. The metrics used to assess and balance the risks associated with Hume – Tar-Ru transfers will ideally be consistent with or complement risk metrics used in other water resource management initiatives, e.g. the River Murray Capacity and Delivery Shortfall Project. These tasks may require a few iterations before they are complete.
Test a range of potential Hume – Tar-Ru transfer rules in the SMM, and use the selected metrics to assess risk. Discuss these outcomes with the Basin states and other stakeholders, and via this process, develop a decision framework that minimises future risks associated with Hume – Tar-Ru transfers.	

Task	Comments
Report and communicate the outcomes	
Plan and coordinate stakeholder engagement	The stakeholders that need to be engaged in these proposed tasks are listed in Section 6.4.
Formalise and report the risk-based framework for Hume – Tar-Ru transfer decisions	

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Appendix A Communication activities

The following communication activities were undertaken throughout the project:

- **A project inception meeting** – 1 July 2021 – The project inception meeting was attended by Kris Kleeman and Tyson Milne (MDBA), Matt Hardy and Simon Lang (HARC), and Peter Cottingham (PCA). Actions arising were noted in email correspondence from Kris Kleeman on July 1st.
- **A meeting with the MDBA's Senior Director, River Modernisation (Joe Davis)** – 5 July 2021 – Due to the unavailability of the Senior Director for the July 1st meeting, an additional meeting was held on July 5th. At this meeting, the team discussed the background, scope and key issues to be considered in the project.
- **A River Operations 101 discussion** – 13 July 2021 – The session, hosted by River Murray Operations team members, covered key aspects of system operations, and included a discussion of the drivers for, and issues considered in operational decisions. These issues were considered in the context of Tar-Ru and its role in the River Murray System.
- **A workshop with MDBA staff** – 14 July 2021 – Seventeen MDBA staff from key attended an online workshop The workshop aimed to get MDBA's perspectives on:
  - The main issues affecting the filling of Tar-Ru
  - Any available data or information to support the exploration of each issue
  - Other initiatives (underway or proposed) that may influence these issues
  - Key questions for states and environmental water holders.
- **Interviews with jurisdiction, water corporation and environmental water holder staff** – 30th July to 11th August. Eleven staff were interviewed on:
  - What are the key issues or risks that exist around the operation of Tar-Ru and the operating targets and rules that exist to support this?
  - The starting premise for this review has been "it is becoming harder to fill Tar-Ru each year". Drawing on your experience and knowledge of the system are there issues that, in your view, are driving this?
  - We have been looking at flow time series at key sites along the Murray to understand changes over the last 20 years that have implications for Tar-Ru operations. Are there data or information sources that you can identify that might also help to explore these drivers and understand their relative impacts?
  - Are there any projects or other initiatives (in place or planned) that might influence or change operational practices or drivers of Tar-Ru?
  - Are there drivers/issues/questions that the project team should pursue with other jurisdictional representatives as part of this review?
- **A 'findings' workshop** – 25 August 2021 – An online workshop was held to present the feedback on the main drivers affecting the filling and operation of Tar-Ru. All stakeholders contacted during the early stages of the project were invited to attend. Hydrological information highlighting the difficulty in filling Tar-Ru in recent times was presented, along with three case studies of key drivers of this behaviour.

- **Post-workshop follow-ups**. Feedback was sought from DEW regarding South Australian environmental watering projects that might affect or be affected filling or operating Tar-Ru.

A summary of who participated in each of these activities is provided in Table A-1.

Table A-1: Summary of project communication activities

Key Activities					
What/Who	**How/Where**	**When**	**Participants/Invitees**	**HARC participants**	**Notes**
Inception meeting	Video conference	01/07/2021	Joseph Davis – River Modernisation Program Kris Kleeman – Operations Improvements Damian Green – Operations Improvements Neville Garland – Operations Improvements Tyson Milne – System Review	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA Rocianne Pinto – HARC	Joe Davis unavailable. Follow-up meeting conducted on July 5th.
Meeting with Joe Davis	Video conference	05/07/2021	Joseph Davis – River Modernisation Program Matthew Bethune – River Operations Kris Kleeman – Operations Improvements Damian Green – Operations Improvements Neville Garland – Operations Improvements Tyson Milne – System Review	Matthew Hardy – HARC Peter Cottingham – PCA	
River operations 101 session	Video conference	13/07/2021	Kris Kleeman – Operations Improvements Damian Green – Operations Improvements Neville Garland – Operations Improvements Andrew Bishop – River Operations Selfet Kuzu– River Operations Jamie Walker– River Operations	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA Rocianne Pinto – HARC	
MDBDA stakeholder workshop	Video conference	14/07/2021	Joseph Davis – River Modernisation Program Kris Kleeman – Operations Improvements Damian Green – Operations Improvements Neville Garland – Operations Improvements Matthew Bethune – River Operations Adam Mclean – River Operations Andrew Bishop – River Operations Teagan Abbott – River Operations Tyson Milne – System Review Ben Dyer – System Review Ingrid Takken – System Review Amber Craig – System Review Christoph Zierholz – System Review Adam Sluggett – Environmental Management Natalie Dando – Riparian & Environmental Assets Olin Cox – Riparian & Environmental Assets Sam Roseby – Enhanced Environmental Water Delivery Mathew Coleman – Climate Change	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA Rocianne Pinto – HARC	

Key Activities					
What/Who	**How/Where**	**When**	**Participants/Invitees**	**HARC participants**	**Notes**
SA Water interview	Video conference	30/07/2021	Garry Fyffe Peter Weber	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA	Garry Fyffe an apology; followed up via email
Victoria interview	Video conference	02/08/2021	Seker Mariyapillai Penny Clark Andrew Shields Keith Chalmers	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA	
SA Water correspondence	Email	03/08/2021	Garry Fyffe	Peter Cottingham – PCA	Provided additional information on current projects related to Tar-Ru inlet and outlet structures
CEWO interview	Video conference	03/08/2021	Andrew Moore Richard Mintern	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA	
NSW interview	Video conference	03/08/2021	Paul Childs Brian Graham Vince Kelly	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA	Paul Childs an apology
SA DEW interview	Video conference	11/08/2021	Chrissie Bloss Kimberly Williamson Tony Herbert	Matthew Hardy – HARC Peter Cottingham – PCA	Tony Herbert an apology; DEW requested that Teresa Heneker also be invited to the findings workshop

Key Activities					
What/Who	**How/Where**	**When**	**Participants/Invitees**	**HARC participants**	**Notes**
Findings workshop	Video conference	25/08/2021	Chrissie Bloss [DEW] Tony Herbert [DEW] Kimberley Williamson [DEW] Theresa Heneker [DEW] Matthew Hardy [HARC] Seker Mariyapillai [DELWP] Penny Clark [DELWP] Andrew Shields [GMW] Keith Chalmers [VEWH] Garry Fyfe [SA Water] Peter Cottingham [PCA] Simon Lang [HARC] Peter Webber [SA Water] Anthony Moore [AWE] Brian Graham [DPIE] Vince Kelly [WaterNSW] Kris Kleeman [MDBA] Neville Garland [MDBA] Damian Green [MDBA] Joseph Davis [MDBA] Ben Dyer [MDBA] Ingrid Takken [MDBA] Tyson Milne [MDBA] Andrew Bishop [MDBA] Adam Mclean [MDBA] Amber Craig [MDBA] Christoph Zierholz [MDBA] Tegan Abbott [MDBA] Will Lucardie [MDBA] Sean Kelly [MDBA] Adam Sluggett [MDBA] Olin Cox [MDBA] Natalie Dando [MDBA] Matthew Bethune [MDBA] Richard Mintern [Env. NSW] Paul Childs [Env. NSW]	Simon Lang – HARC Matthew Hardy – HARC Peter Cottingham – PCA	
Follow up on SA projects	Email	27/08/2021	Tony Herbert	Peter Cottingham	

Appendix B Summary of stakeholder interviews

The following is a summary of the main drivers described by MDBA, jurisdiction, water corporation and environmental water holder staff in interviews held on the 5th July and then between 30th July and 11th August 2021. All comments have been paraphrased.

Summary of drivers

Overall, there was broad acceptance by the MDBA and representatives of the Basin states that it has often been difficult to fill Tar-Ru over the last decade. There was also general agreement on the broad drivers that affect the filling frequency of Tar-Ru in recent years, and that the drivers often combine or interact. There was also recognition of the increasing complexity associated with operating the southern connected Murray-Darling Basin. The main drivers identified were:

- Reduced tributary inflows
  - The reduction of Darling River flows in the recent historic record (coinciding with times when the Menindee Lakes are offline) has made it more difficult to fill Tar-Ru. This has been compounded by reduced inflows from the unregulated Kiewa River and Ovens River upstream of Barmah Choke, and NSW's and Victoria's regulated tributaries between the Barmah Choke and Murray-Darling junction.
- Operational constraints and efficiencies
  - Changes to Barmah Choke channel due to silting is reducing the in-channel capacity available for the increased Hume transfers needed to fill Tar-Ru as tributary inflows have declined.
  - The increased efficiency of water delivery and consumptive use, and reduced volumes of rain rejection flows along the River Murray, has reduced the number of opportunistic instances where additional diversions can be made to Tar-Ru.
- Changes in water demands
  - While Barmah Choke capacity has been reducing, the total demand for water use downstream of the Choke has remained high in the January – April period when overbank flows through the Barmah-Millewa Forest are undesirable.
  - Peak monthly demands for water use downstream of the Choke appear to have increased and shifted to spring / early summer, when demand for consumptive and environmental purposes often coincide, and may also coincide with Hume – Tar-Ru transfers.
- Local operations
  - Constraints on Tar-Ru water levels are needed to meet cultural obligations and objectives, minimise lake bed and shore erosion, promote revegetation and minimise the salinisation of nearby land.

It was also recognised that the drivers highlighted above often combine or interact to affect the filling and operation of Tar-Ru. There was also recognition of the increasing complexity in operating the River Murray System because of competing objectives (e.g. water availability, water quality, environmental benefits, cultural heritage).

Tar-Ru operating levels have been designed to minimise adverse effects on First Nation (Barkindji/Maraura) cultural heritage. There was general agreement from participants interviewed that management must continue to meet the objectives and outcomes sought in the Aboriginal Heritage Impact Permit (current and successors) and the Lake Victoria Operating Strategy. Any investigations and proposals for changed management arrangements must proceed in partnership with the Barkindji/Maraura peoples. This should occur through existing partnership arrangements and protocols, in a transparent and sensitive manner.

Additional insights on drivers that emerged in discussions with jurisdiction, water corporation and environmental water holder staff included:

- The aim is to fill Tar-Ru whilst maintaining a balance between water availability and water deliverability along the River Murray system. Availability risks are likely to affect all water users, but deliverability risks are heightened for a sub-set of users (especially those below the Choke).
- The preference is for unregulated tributary inflows to fill Tar-Ru. However, inflow variability can be an issue:
  - Spring inflow is generally relied upon to replenish Tar-Ru prior to the onset of demands (usually in October). If the filling of Tar-Ru is delayed (i.e. into summer), then we are ‘starting behind’ and there is an increased risk of supply shortfalls to South Australia in summer. If Tar-Ru is filled too early, there is an increased risk of internal spills and potential for a loss of water resource for Victoria and NSW.
  - If decisions to fill Tar-Ru are delayed (we wait too long), and then weather patterns trend to drier conditions, releases to meet consumptive demand increase and so reduce the channel capacity available for transfers of water to Tar-Ru. This may then result in the need for overbank transfers (with higher conveyance losses). There is a reluctance to use overbank transfers to fill Tar-Ru due to increased water losses, particularly through forest areas.
  - The efficiency of system operations is under a lot of scrutiny. Therefore, making transfers at the right time and rate is important but is becoming more challenging given complex interactions with IVT, environmental water delivery, etc.
  - End of season management is also a challenge; relying on weather and river flow forecasts can be problematic given our conservative approach to managing regulated resources.
- It can be difficult to meet hard-and-fast system operating rules. Groups such as the WLWG focus on maintaining long-term reliability of supply; getting the balance of operations correct is difficult, especially when it is based on forecasts of inflows and demands.
- There is a desire by Victoria and NSW to have flexibility in meeting the end-of-May target at Tar-Ru, or at least be able to explain better the assumptions that resulted in end-of-May target being ‘missed’ (or, if there are internal spills, then why). Therefore, is it possible to introduce a risk assessment approach to meeting or delaying the end-of-May target?
- More needs to be done in explaining the trade-offs in managing internal spills at Tar-Ru versus supply shortfalls. IVT delivery from the Goulburn River has reduced the pressure

of internal spills, but recent limits imposed on Goulburn IVTs may reverse this somewhat.

- Reduced tributary inflows in recent years have made it difficult to judge when best to make winter-spring releases from Lake Hume to fill Tar-Ru. Have tributary flows from the Kiewa, Ovens and Goulburn rivers changed over time (suspect they have) and if so, does this happen every year?
- The Annual Operations Outlook (AOO) is an important document, as it communicates what is being factored into water management decisions. 'Things' are changing, but the tools available to manage the system are the same. It would be good to understand how irrigator behaviour and on-farm water conservation across the southern connected Murray-Darling Basin has changed in the last 10 years.
- Conservatism in consumptive use in wet/average years, and associated trade and carryover (we now get buying of water for carryover), can also make it more challenging to manage the system (i.e. deliver water) in the drier years.
- There is some perception of an increase in water demand along the lower Murray met through purchase of entitlements from further up the southern connected Basin. We need to keep learning about consumptive demands and environmental water demands in the mid-Murray reaches, and how these are changing.
- There is a need to improve the understanding of water conveyance losses along the River Murray, and the component associated with Lake Hume to Tar-Ru transfers.
- There can be difficulty in delivering and maintaining connectivity of environmental water to South Australia when river capacity is dominated by water released to meet consumptive demand. This is also influenced by drivers such as decreased capacity through Barmah Choke and diversion of water to Tar-Ru. Conversely, does Tar-Ru miss out with increased connectivity along the River Murray and passing flows to SA? Does Basin Plan recovery affect Tar-Ru filling due to changed location of demand (including supplementary water in NSW) and changed sources of water?

Summary of other local issues

Additional issues related to the filling or operation of Tar-Ru were also noted in discussions:

- Tar-Ru operating levels have been designed to minimise adverse effects on First Nation (Barkindji/Maraura) cultural heritage and to encourage foreshore vegetation growth. There was general agreement that management must continue to meet the objectives and outcomes sought in the AHIP. Any investigations and proposals for changed management arrangements must proceed in partnership with First Nations – this should occur through existing partnership arrangements and protocols, and should occur in a transparent and sensitive manner.
- Tar-Ru inlet capacity may be underestimated – 6,000 ML/d is assumed but it may be closer to 8,500 ML/d. This should be clarified, as there is potential for increased inlet channel erosion.
- To what extent is the ability to divert water to Tar-Ru constrained by inlet capacity? Has the inlet capacity changed over time, and if so, has this ever resulted in 'not filling' the lake?

- Recent difficulties in filling Tar-Ru are more likely to be related to issues of upstream deliverability and meeting SA obligations, rather than inlet capacity constraints. If so, then deferring water delivery to SA can assist with filling Tar-Ru.
- Tar-Ru releases greater than 8,000 ML/d can pose erosion risks along the Rufus River, particularly if release rates are dropped quickly (i.e. increased risk of bank slumping).
- One operational risk is a power failure leading to inability to operate the structures.
- There has been little need to manage salinity issues in recent years, as water entering Tar-Ru has largely been from Lake Hume and southern Basin tributaries that have relatively low salinity, rather than the higher salinity water delivered by the Darling River.
- Fishways are being considered as part of infrastructure upgrades and as part of SDLAM projects. This has implications for inlet and outlet maintenance and the design of any new infrastructure.
- There are proposals for weir pool manipulations to improve environmental outcomes that have implications for filling Tar-Ru. For example, lowering Lock 9 by up to 1.0 m would make it very hard to fill Tar-Ru with existing infrastructure.

Potential data sources for the future investigations program include:

- SA Water has daily flow and salinity data for the River Murray from 2000 onwards.
- The MDBA will have historical data and water transfer plots for Lake Hume to Lake Victoria, along with consumptive and environmental water demand. The SOURCE model may also be useful for data, as it will have water accounts embedded. Environmental water demand is relatively new, so there will only be limited data (historically) for comparative purposes.
- Flow data for Yarrawonga might be a source of data on rainfall rejections. We can look at spikes in summer inflows and the degree to which they coincide with a reduction in diversions. It might be possible to do this at Torrumbarry also, but probably not further downstream.
- Changes in outfalls – e.g. from MIL – is accessible from WaterNSW and could be used as a proxy for increased storage and/or efficiency on farm. Insights may also be gleaned from aerial imaging collated by the SunRise 21 mapping project.
- Outcomes from the HEW activation analysis that HARC is doing for MDBA may provide some useful insights into re-utilisation of previous sleeper licenses.

Other projects and initiatives that may affect Tar-Ru filling and operation include:

- Infrastructure upgrades related to SDLAM projects may result in the installation of fishways at the Tar-Ru inlet and outlet. Their presence may affect the timing of inlet and outlet maintenance.
- There are other upstream SDLAM projects that may also influence Hume – Tar-Ru transfers, such as the SDLAM projects addressing constraints on the maximum rate of water delivery along the River Murray.
- The outlet infrastructure at Tar-Ru is aging; a replacement is being considered and is likely to be in a different location to the existing outlet.

- Manipulation of weir pools at Locks 7-9 by up to ± 1.0 m can have implications for filling Tar-Ru.
- The MDBA's River Murray Capacity and Delivery Shortfall Project has been reviewing the source/type of water arriving at South Australia. Other findings from this project are likely to be relevant to the future operations of Tar-Ru.
- DEW has been assessing the ecological benefits of storing environmental water in Tar-Ru and delivering it at different times of the year. Tony Herbert from DEW is the relevant contact.
- CEWO water trades can involve direct releases from Tar-Ru, for example, to complement unregulated flows and achieve environmental outcomes in South Australia.
- South Australia can defer its entitlement flow to the benefit of filling Tar-Ru. Data on deferrals can be found in the MDBA environmental accounts, or also on DEW's website.
- System planning and operations may be influenced in future by use of the SOURCE daily model, rather than existing operational spreadsheets, because:
  - Environmental water demands and orders will be more dynamic in future, particularly if existing constraints on flow thresholds are relaxed. Climate change effects could influence constraints in the future too.
  - New trade rules on the Goulburn are likely to influence River Murray flows downstream of the Barmah Choke.

Appendix C Summary of workshop discussion

The questions (Q) below were raised during the workshop on 25 August 2021. Answers (A) were from HARC. Both have been paraphrased. Also included here are observations made by workshop participants during the discussion.

Given it has become harder to fill Tar-Ru:

- Q. Has the role of increased on-farm efficiency in overall reduction in tributary inflows been assessed?
- A. The issues have been raised in conversations but have not been investigated and quantified as a part of this project.

- Q. Have end of system passing flow targets for River Murray tributaries changed in recent times?
- A. Our understanding is that these have not changed over time
  (This was confirmed by GMW for Victoria's tributaries)

With regards to Hume to Tar-Ru transfers:

- Q. Has the frequency of internal spills at Tar-Ru changed in response to changes in Hume releases?
- A. We have not investigated this as yet. This information will be included in the scoping study report.

- Q. What effect does a future of increased transfers from Lake Hume have on the filling and spilling frequency at Tar-Ru?
- A. We have not investigated this as yet; it is beyond the scope of this project but will need to be considered in future investigations.

- Q. We can see climate change effects on summer and autumn tributary inflows; are there similar effects in winter/spring? Also is there an order of preference for sourcing water to store in Tar-Ru (e.g. from Goulburn, Menindee, Murrumbidgee, Murray)?
- A. Noted as topics for future investigations.

Observation – 2013-2020 can be considered as a second Millennium Drought for the Northern Basin. During this time, the Menindee Lakes were often offline and therefore River Murray demands had to be met by Lake Hume and inter-valley trade.

Regarding the case study of Barmah Choke capacity:

Observation – in 2012 the number of days that flows were above the capacity of the Barmah Choke was influenced by summer floods.

Observation – re the relatively limited capacity to deliver large additional volumes through the Choke and Edward system, while 50 GL of additional water is small in terms of overall volumes of water released throughout the River Murray system, it could be the difference between filling

Tar-Ru, or not. Getting an additional 50 GL to the end of the system, given other constraints, is not a trivial exercise and remains a challenge for river operators.

Observation – conveyance loss uncertainties will also play a part in terms of decisions to release additional water through the Choke and Edward system.

Observation – if the Menindee Lakes system is offline, then more pressure is put on the Barmah Choke in order to get water to Tar-Ru. More pressure is also being put on the Edward-Wakool system. Thus, it is increasingly difficult to find alternative sources of water for Tar-Ru; i.e. there are no easy solutions because the system is already being ‘run hard’.

Observation – this project is setting the scene for ongoing discussions between the MDBA, jurisdictions, water corporations and environmental water holders.

Regarding the case study of water use downstream of Barmah:

Observation – the plots of consumptive water use by NSW and Victoria downstream of Barmah does not include the conveyance losses that need to be overcome to supply this water; in contrast the South Australian entitlement includes water both for use and to cover conveyance losses. This difference needs to be kept in mind when comparing these time-series.

Other observations:

Observation – care is needed in the language and descriptions used. For example, reference to ‘increased’ Hume – Tar-Ru releases need to include the caveat that this is only one component of the releases from Hume (that is, there is not necessarily an increase in total releases from Hume).

Observation – there is a cap on water diversions Basin-wide, but what we are seeing in the historic record is a decrease in the reliability of water availability. This has knock-on effects on our ability to fill Tar-Ru.

Observation – SA deferrals of entitlement flows have assisted the filling of Tar-Ru in the past.

- Q. Will this project examine climate change projections, as what we do regarding Tar-Ru operations will depend on how bad things get in future?
- A. This is beyond the scope of the current project, but is an area of active investigation by the MDBA.

Observation – River Murray operations are rarely influenced by one driver in isolation. For example, it can be climate change in addition to reduced capacity at the Choke.

- Q. What is the overlap between this study and the River Murray Capacity and Delivery Shortfall Project?
- A. We will seek clarification from the MDBA.

Observation – it is beyond this current study, but environmental outcomes associated with Tar-Ru operations (local and downstream) is another important aspect to be considered in future discussions.

Observation – workshop participants will need to look at the information presented at the workshop in more detail, in order to provide informed comments about potential future investigations to address knowledge gaps.