Remote sensing of pool contraction and connectivity in the Barwon-Darling (Baawan-Baaka) during 2019-20

The Darling River (Baaka) between Wilcannia and Lake Wetherell

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Cover image: Image of a remnant pool in the upper zone of the Wilcannia to Lake Wetherell reach of the Barwon-Darling. The image was taken in July 2021 by Ellen Ryan

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Acknowledgment of Country

The Department of Planning and Environment acknowledges the Traditional Owners and Custodians of the land on which we live and work and pays respect to Elders past, present and future.

Contents

Summary

Flows and remnant pools

The Barwon-Darling River (Baawan-Baaka) is a key area of the northern Murray-Darling Basin. It provides important habitat during dry periods, flows into the Menindee Lakes, then the Murray River. The river's water-dependent ecosystems are adapted to a variable flow regime. However, human water resource development has influenced the natural flow regime and resulted in more frequent and longer periods of low and no flows (Sheldon 2017). This has reduced hydrological connectivity and exposed aquatic organisms to harsher conditions (e.g. higher temperatures and lower dissolved oxygen). When flows cease remnant pools become important refuges and increase ecosystem resilience (Looy et al. 2019). These refuges are critical habitats for aquatic organisms, such as native fish, to persist until flows return (Australian Academy of Science 2019, Vertessy et al. 2019). There is a need to better understand the spatial and temporal character of remnant pools. However, monitoring the characteristics of pool refugia at a landscape scale remains methodologically challenging. Remote sensing offers a cost-effective alternative to field surveys and has been increasingly used to monitor the spatial dynamics of surface water.

Project objectives

The need to improve understanding of how water management actions impact remnant river pools and the ecosystems they support, has been highlighted by an independent review and in the NSW Independent Commission Against Corruption report (ICAC 2020, Vertessy et al. 2019). Restricting water take is one lever available to protect critical remnant pools in the Barwon-Darling system. The 2020 changes to the Barwon-Darling Water Sharing Plan are predicted to reduce the number of low and no flow events in this system. However, the section of the Darling River between Wilcannia and Lake Wetherell is remote and lacks flow gauging stations for approximately 270 km of river. This lack of data contributes to challenges in low flow management in the reach.

This report used remote sensing (Figure 1) to:

1. quantify the contraction of remnant pools in this river reach during the drought in 2019, and
2. identify the level of downstream connectivity and pool area responses to a small flow pulse at Wilcannia after a no flow period.

The information was used to identify if this technique can be used for future remnant pool monitoring, and evaluate whether the protection of a small flow pulse (peak flow 283 megalitres/day (ML/d)) achieved any hydrological outcomes in this river reach during a temporary water restriction and drought in 2019.

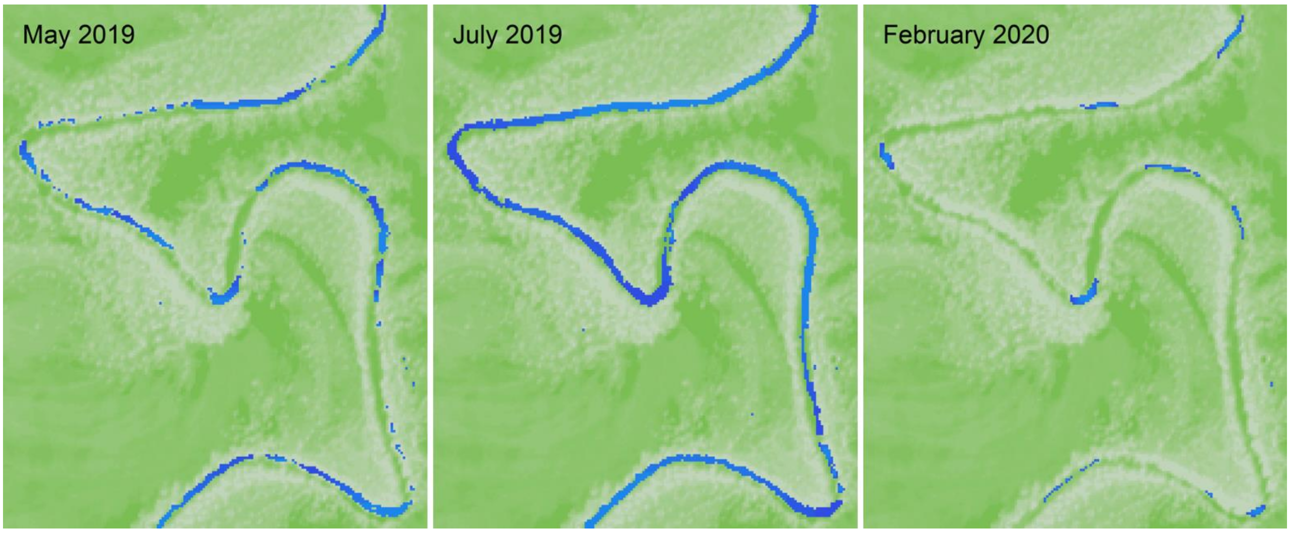

Figure 1. Remote sensing water bodies. These three images show changes to the 3rd pool down from Wilcannia (centre of each image) and its connecting channels.

Key findings

- Upstream pools in the Wilcannia-Lake Wetherell reach expanded during the protected June-July 2019 flow event (total 3,156 megalitres (ML), peak 283 ML/d), whereas downstream pools contracted. This suggests that similar sized events do not connect the entire river reach after a no flow period.
- All pools contracted when the reach ceased to flow following the June-July 2019 flow event.
- Connectivity between upstream pools was poor during no-flow periods, whereas downstream pools likely remained connected to Lake Wetherell.
- Upstream pools are more dependent on flow events, and pools closer to Lake Wetherell are more resilient to no flow conditions as they connect to the Lake Wetherell weir pool until the weir pool is extremely low.
- To provide sufficient connectivity from Wilcannia to Lake Wetherell after a no flow period, flow events would need to exceed the size of the monitored event in this study period. It is likely that flows in excess of 5,000 ML total volume, and 400 ML/d peak flow rate would be required.
- The department has pool depth and water temperature loggers installed in this reach to establish what flows are required at Wilcannia to provide sufficient connectivity (e.g. 30 cm depth for fish movement) across remnant pools under different conditions (e.g. before a no flow period has occurred).

Water management outcomes

Water extraction in the Barwon-Darling River was restricted by a temporary water restriction (section 324 order, *Water Management Act 2000*) during the study period (April 2019 – March 2020).

Water take was limited to critical supplies including town water, and stock and domestic use.

The aim of the restriction was:

- *To cope with a water shortage*.
- Buffer the *threat to public health and safety*.
- To *manage water for environmental purposes*, specifically protecting drought refuge habitat and connectivity.

(NSW Government, 2019).

Remnant pools in the Wilcannia to Lake Wetherell reach were contracting rapidly prior to the small event which occurred between June and July 2019 (~3 GL and peaked at 283 ML/day). This event was sufficient to connect remnant pools between Wilcannia and at least 150km downstream but did not connect to Lake Wetherell. The pools towards the lower end of this river reach were connected to Lake Wetherell for the majority of the study. Pools had contracted in size by more than 50% in the upper zone, 30% in the middle zone and 15% in the lower zone after 50 days of no flow at the Wilcannia gauge. By the end of February 2020 and after more than 200 days of no flow, the average areas for upper, middle and lower zone pools had contracted to 15%, 13% and 37% of their peak size after the June-July 2019 flow.

This study highlights the potential of remote sensing techniques for monitoring connectivity in arid landscapes, especially during drought and low flow periods. It also highlights the importance of protecting low flows for providing low levels of connectivity and remnant pools replenishment. Without the temporary water restriction in place, the level of hydrological connectivity and pool replenishment may not have been achieved. Further, this study shows that restricting access below the amended low flow daily access rule (455 ML/day) in the Barwon-Darling Water Sharing Plan should provide connectivity throughout most of the river reach.

Future monitoring

The department currently has water depth loggers in seven pools and variable depth temperature loggers in five pools within the Wilcannia to Lake Wetherell reach. This data will enhance our understanding of the relationship between flows recorded at the Wilcannia flow gauge and (a) pool connectivity, and (b) temperature stratification in pools.

Project details

Water management context

The key legislative documents that influence how flows within the Barwon-Darling River can be protected for the environment are the *Water Management Act 2000* and the Water Sharing Plan (WSP) for the Barwon-Darling Unregulated Water Sources 2012. Under normal climatic conditions, WSPs set the rules for water extraction. However, during extreme events, such as drought, additional restrictions using provisions within the *Water Management Act 2000* can be applied. The following protections were in place during this study period (April 2019 to March 2020):

1. A section 324 order, or temporary water restriction of the *Water Management Act 2000* was imposed on A, B and C class access licences. This was in place between the 15th of April 2019 to the 30th of August 2019 and again from the 4th of November 2019 to the 31st of December 2019. Further restrictions were imposed in January 2020. This rule overrides the following two rules which would normally be in place in this study period.
2. A daily access rule restriction for A, B and C flow classes as flows were below 455 ML/day at the Wilcannia gauge (425008) (Table 1). This is a new rule proposed for the amended WSP and may not have been implemented at the time of the study.

   Note.The daily access rules and flow classes are defined in Part 8, Division 2 of the plan. The unregulated access rules for A, B and C class (s46) in the Wilcannia to Lake Wetherell Management Zone are defined in Table 1.
3. A No Flow Class announcement was required under the resumption of flow rule (s50D) as there had been flow less than 200 ML/d for more than 90 consecutive days at the Wilcannia gauge (425008).

These restrictions protected flows for the environment and critical human needs.

Table 1. Flow class thresholds for the Wilcannia to Upstream Lake Wetherell Management Zone. This information was sourced from section 49A, Table B of the Barwon-Darling Unregulated Water Sharing Plan 2012.

Management zone	Flow class	Flow class thresholds (ML/day) as at 9:00am	Flow reference
Wilcannia to Upstream Lake Wetherell Management Zone	**No Flow Class**	0 ML/day	Darling River at Wilcannia Main Channel gauge (425008)
	Low Flow Class	More than 0 ML/d and less than or equal to 455 ML/d	
	A Class	More than 455 ML/d and less than or equal to 850 ML/d	
	B Class	More than 850 ML/d and less than or equal to 12,000 ML/d	
	C Class	More than 12,000 ML/d	

Why were flows protected?

Low flows provide the minimum level of flow required to protect and maintain aquatic ecosystems (Rolls et al. 2012, MDBA 2018). Specifically, they:

- maintain pool refugia or low flow level habitat important for a range of aquatic species (Sheldon et al. 2010, Rolls et al. 2012),
- protect water quality and suppress algal growth (Mitrovic et al. 2006, 2011),
- maintain connectivity between pool refugia (Thoms et al. 2005, Webb et al. 2012), and
- provide for dispersal of native fish and other aquatic organisms that use flow to disperse to new habitats (NSW Department of Primary Industries 2019).

Extended dry conditions resulted in a long low flow and no flow period in the Barwon-Darling River. The period of interest was one of the driest on records for the valley, with only a single small flow event in 2019 before flows ceased again. A number of independent investigations and reviews of water management in the Barwon-Darling and more broadly were undertaken within this period (Australian Academy of Science 2019, NRC 2019, Vertessy et al. 2019). Flows were protected to:

1. *cope with a water shortage* as remaining water supplies in the Barwon-Darling River were critically low (drought criticality stage 4 under the Extreme Events Policy),
2. *protect public health and safety* as town water and domestic supplies a crucial for public health,
3. *protect and manage water for environmental purposes* to replenish pools and improve drought refuge habitat.

Project aims

The primary aims of this project were to:

1. test the use of remote sensing methods for monitoring connectivity and pool contraction in a large arid river system such as the Barwon-Darling,
2. quantify the contraction of remnant pools in this river reach during the drought in 2019,
3. identify the level of downstream connectivity and pool area responses below Wilcannia, to a small protected flow pulse after a no flow period, and
4. assess whether the protection of flows during the study period achieved any downstream connectivity outcomes for pool refugia.

Methods

What was the study area?

This study focused on the 271 km reach of the Darling River that extends south-west from Wilcannia to Lake Wetherell at the inflow into Lake Pamamaroo (Figure 2). In the Barwon-Darling Water Sharing Plan, this area is referred to as “Wilcannia to Upstream Lake Wetherell Management Zone” (Department of Planning and Environment [DPE], 2012).

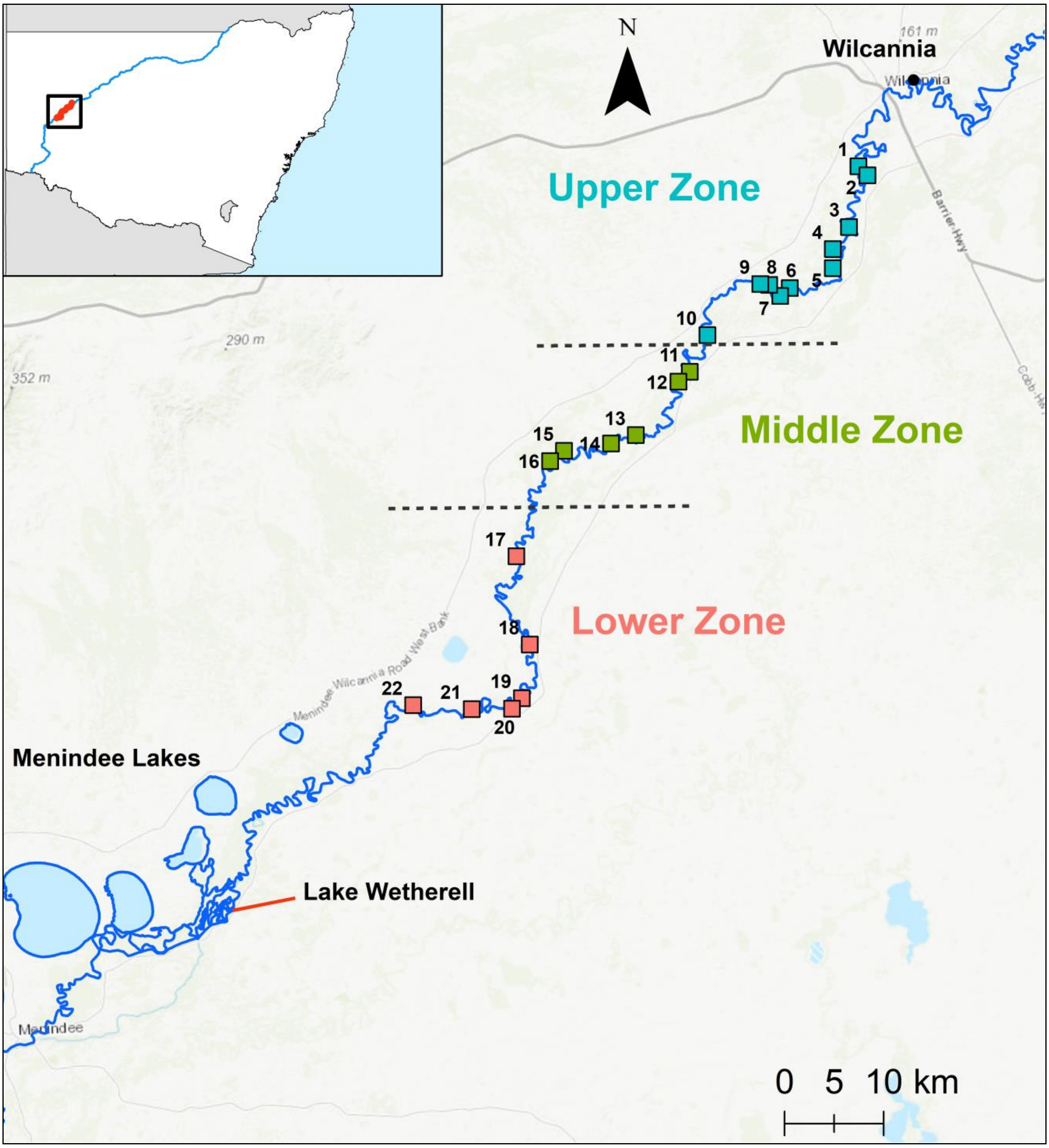

Figure 2. Map of Wilcannia-Lake Wetherell reach on the Darling River. Pools are marked and numbered. Dashed lines on the river mark the boundaries between the upper and middle zones, and middle and lower zones.

The 2019-20 low flow period in this reach was severe with no flow (0 ML/d) recorded at the Darling River at Wilcannia gauge (no. 425008) for 71% (303 days) of days and less than 1 ML/day for 89% of days. The reach experienced a single flow event (where flow was equal to or greater than 1 ML/day) in 2019: a total volume of 3,156 ML passed the Wilcannia gauge between 15th of June and 30th of July 2019, with a peak flow of 283 ML/day on the 17th of June 2019. On the 3rd of March 2020, the reach began to reconnect, following widespread rainfall in the northern Basin (**Error! Reference s ource not found.**). Rainfall in the Wilcannia region averages 265.3 mm annually (BOM 2021), with a dominant pattern of summer rainfall. During 2019, Wilcannia received below-average rainfall (191 mm). The largest rainfall event in 2019 was 65.4 mm on the 22nd of April, and the driest period extended for 181 days (9th of July to 3rd of November), where a total of 0.4 mm of rainfall was recorded.

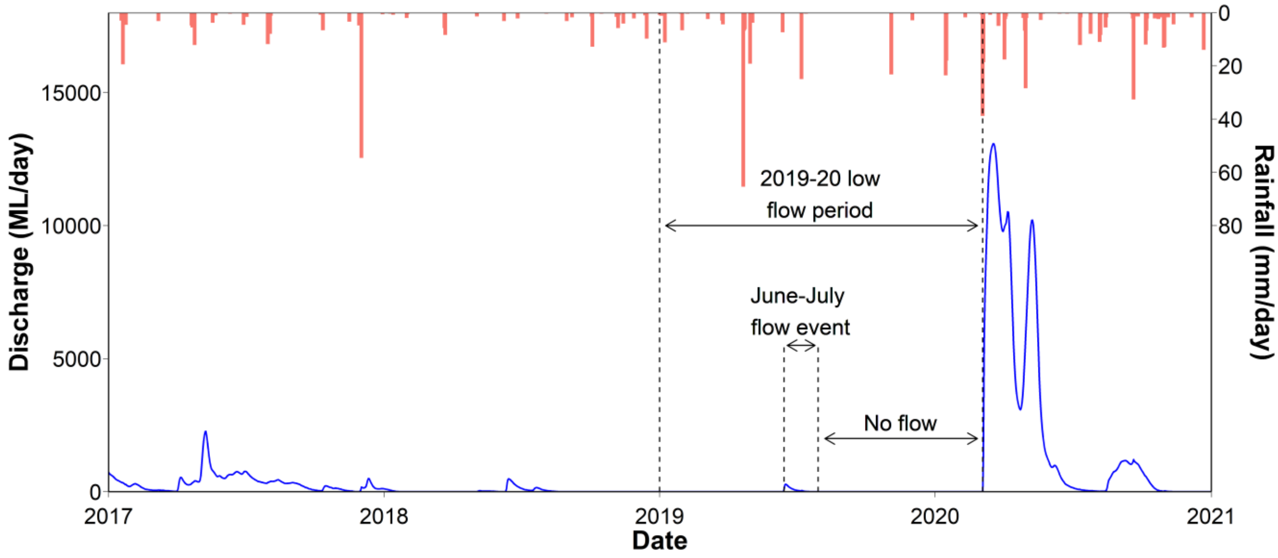

Figure 3. Daily discharge and rainfall at Wilcannia. Discharge (in blue) recorded at the Darling River at Wilcannia gauge (WaterNSW, no. 425008), and rainfall (in red) recorded at Reid St, Wilcannia (BoM, no. 46043).

Quantifying remnant pool areas

We used Sentinel-2 satellite imagery of the Wilcannia-Lake Wetherell reach and Google Earth software to identify 22 sites where remnant pools formed during the 2019-20 low flow period. The hydrograph (Figure 3) was used to identify key periods of extended low and no flow. Each pool was identified using Google Earth high resolution imagery in March 2019 after a long no flow period. Pools were selected at a variety of distances downstream to try and capture a longitudinal spread of sites. These 22 pools were classified into three zones: upper, middle and lower (Figure 2). We subsequently downloaded Sentinel-2 satellite imagery of these 22 pools at 12 different dates (listed in Appendix A, Table A1) during the 2019-20 low flow period for spatial analyses. These dates represented cloud free periods where no additional inflows or rainfall events were likely to disturb patterns of contraction and connectivity. Satellite imagery from the Sentinel-2 Level-1C product provides Top-Of-Atmosphere (TOA) reflectance for 13 spectral bands and is composed of 100 x 100 km^2 tiles; we relied on Tile 54HYK for pools 1-12, and 54HXK for pools 13-22.

To quantify the areas of the 22 pools during the 12 different dates, we calculated the Normalised Difference Water Index (NDWI) using ArcGIS. The NDWI distinguishes between water and dry land in satellite images. Satellite imagery from Sentinel-2 has a spatial resolution of 10 m, and using the reflectance values from Bands 3 ("Green") and 8 ("NIR"), the NDWI was calculated for each 10 m × 10 m pixel with the following formula (McFeeters 1996):

$$\mathrm{NDWI} = \frac{\mathrm{Green} - \mathrm{NIR}}{\mathrm{Green} + \mathrm{NIR}} = \frac{\mathrm{Band\ 3} - \mathrm{Band\ 8}}{\mathrm{Band\ 3} + \mathrm{Band\ 8}}$$

It should be noted that the Modified Normalised Difference Water Index (Xu 2006) was trialled for this project. However, the increased pixel size of the shortwave infrared band used in this index (20 m versus 10 m for the bands used in the NDWI) reduced the mapping accuracy for the small pool areas of interest.

By assessing the histograms of NDWI values for each satellite image, a threshold of -0.12 was chosen: pixels with NDWI values at or above this threshold were classified as water, and pixels with NDWI values below this threshold were classified as non-water (as seen in **Error! Reference source not found.**). The areas of the 22 pools at the 12 different dates were then calculated using ArcGIS.

Each pool was restricted to a section of the Wilcannia-Lake Wetherell reach, and their areas could not infringe beyond their respective sections; this ensured that connecting pools did not have the same area size. We created Thiessen polygons using the ArcGIS analysis tools to define the polygon used for each pool area calculation. This allowed us to standardise pool size to a specific area even when pools were connected throughout the reach.

We used a combination summary statistics and loess regressions to describe the patterns of pool area change and pool connectivity. All analyses were conducted in the statistical software R (R Core Team 2021).

Findings

Changes to pool area during June-July flow event

Pools in the upper and middle zone increased in area in response to the June-July flow event. For the upper zone, the loess regression model (Figure 4) shows the average pool area to peak in mid-July 2019: this peak was an 815% increase from the average area recorded in May 2019. The average area of middle zone pools peaked in the following month: the model estimated a 418% increase in the average pool area in August 2019. These pool dynamics in the middle zone lagged behind those in the upper zone because the middle zone is downstream to the upper zone. Consequently, the middle zone received water from the June-July flow event at a later date. In contrast to the pattern of pool expansion observed in upstream pools, the average area of lower zone pools were decreasing throughout the 10-month study period, though at a marginally slower rate during the June-July flow event.

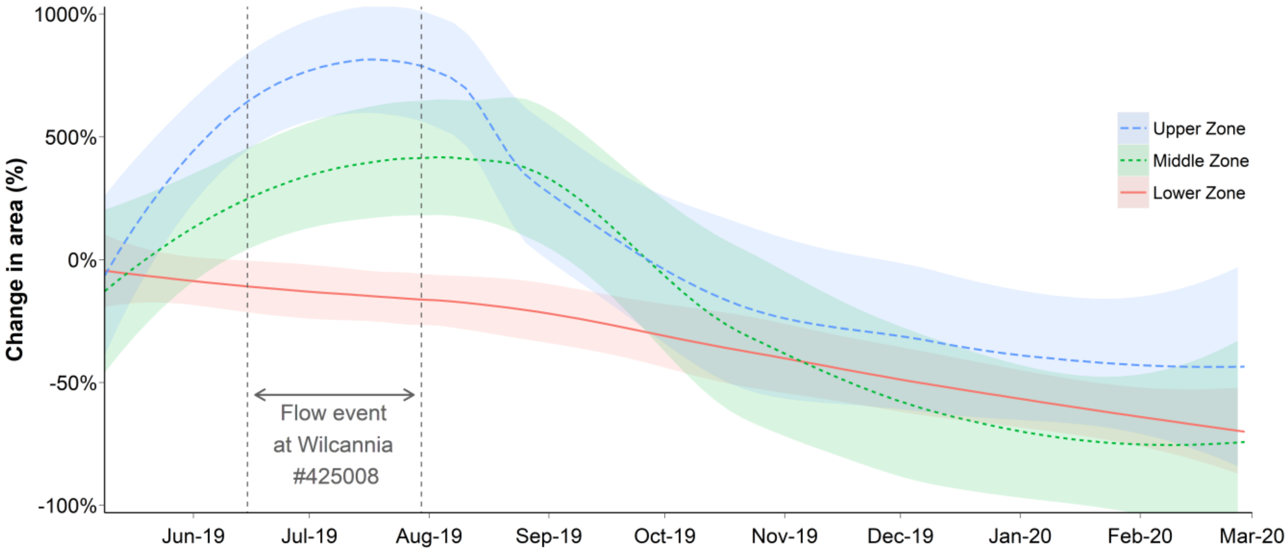

Figure 4. Average change (%) in pool area during 2019-20 low flow period. Areas are compared to the average area of each zone on 9 May 2019. Lines plot the loess curves that highlight the trend in changes to pool area size in the three zones. Coloured shading represents the 95% confidence intervals of the loess curves. The number of pools used (*n*) was 10 for the upper, 6 for the middle and 6 for the lower zone.

Changes to pool area during no flow period

Following the June-July flow event, the Wilcannia-Lake Wetherell reach ceased to flow, and consequently, all pools began to contract (Appendix B, Figure B1). By mid-September 2019 (~55 days of no flow), the average areas of upper and middle zone pools returned to their May 2019 sizes (Figure 4). By the end of February 2020 (213 days of no flow), the average areas for upper, middle and lower zone pools had contracted to 15%, 13% and 37% of their end-of-July 2019 sizes respectively (Figure 5).

These results suggest that the upper and middle zone pools are the most vulnerable to no flow conditions. Lower zone pools appear to be buffered against no flow conditions, likely due to their relatively large sizes (average across study was 2.3 ha for the upper, 8.0 ha for the middle and 30.2 for the lower zone), and proximity/connectivity to Lake Wetherell. Nonetheless, on average, the monitored lower zone pools lost 24 ha in size per pool between August 2019 and February 2020, compared to the 3 and 13 ha lost per pool in the upper and middle zones (Figure 6). This indicates that no flow conditions still significantly alter pools in the lower zone.

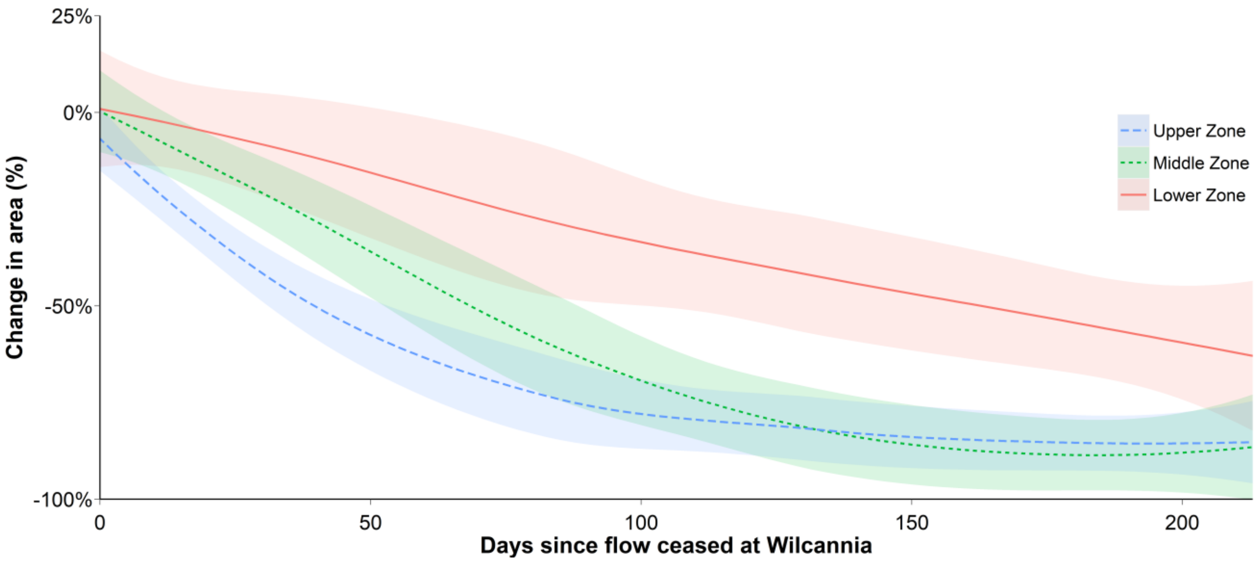

Figure 5. Average change (%) in pool area following the June-July flow event. Areas are compared to the average area of each zone on 28 July 2019. Lines plot the loess curves that highlight the trend in changes to pool area size in the three zones. Coloured shading represents the 95% confidence intervals of the loess curves. The number of pools used (*n*) was 10 for the upper, 6 for the middle and 6 for the lower zone.

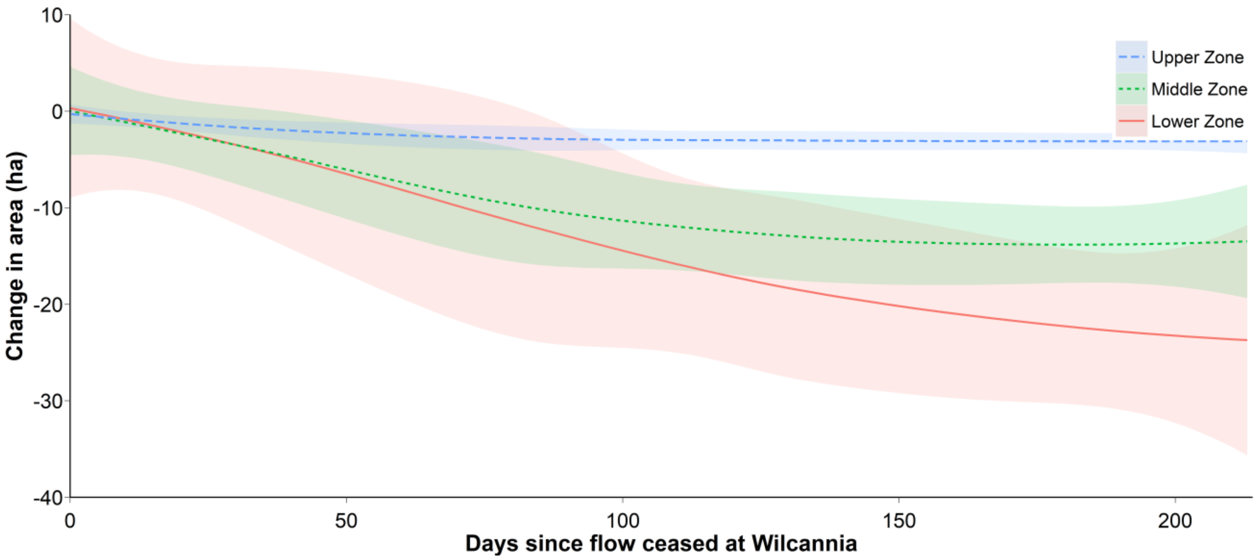

Figure 6. Average change (ha) in pool area following the June-July flow event. Areas are compared to the average area of each zone on 28 July 2019. Lines plot the loess curves that highlight the trend in changes to pool area size in the three zones. Coloured shading represents the 95% confidence intervals of the loess curves. The number of pools used (*n*) was 10 for the upper, 6 for the middle and 6 for the lower zone.

Connectivity of the reach during study period

Remote sensing suggested that pools in the upper zone were generally disconnected throughout the 10-month study period, though connecting channels may have formed during the June-July flow event (Figure 7). All upper zone pools were smaller than 2 hectares during May and June 2019, and generally smaller than 10 hectares during the study period. Thus, connections between the pools were most likely brief and supported by narrow channels which are difficult to detect using the 10-metre spatial resolution of the Sentinel-2 imagery.

Similarly, connectivity between middle zone pools also remained poor throughout the 2019-20 low flow period (Figure 7). However, connecting channels, particularly those between pools 13-16, may have also been undetected by the 10-metre spatial resolution of the satellite imagery. Notably, pools 15 and 16 were likely connected for the first six months of the study period; this may be due to their proximity to the lower zone, where all pools were often connected. The lower zone maintained the most connectively between its pools, potentially because they remained connected to the Lake Wetherell weir pool. These pools were likely connected throughout the study period, though the ability to detect connectivity by remote sensing degraded as the no flow period extended and pool size continued to shrink.

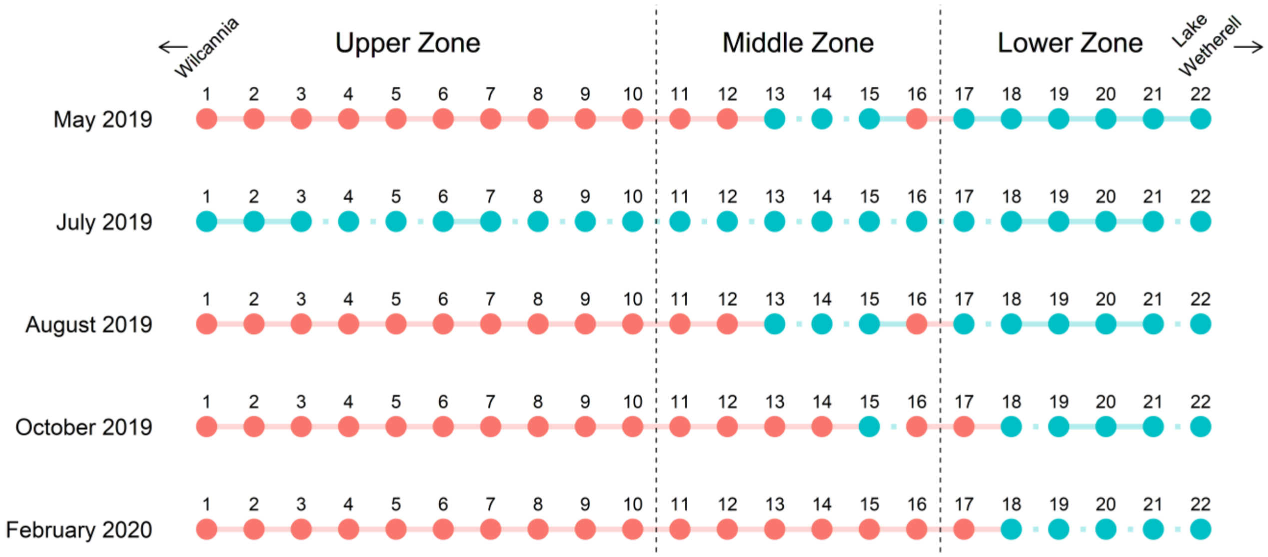

Figure 7. Connectivity between remnant pools during 2019-20 low flow period. Blue links represent connectivity between pools, and red links represent disconnection. Dotted blue links represent potential connectivity between pools that were undetected by Sentinel-2 satellite imagery.

Conclusions

We found that remnant pools in the three zones behaved differently: upstream pools in the Wilcannia-Lake Wetherell reach respond the most to small flow events after a no flow period, whereas pools closer to Lake Wetherell were more resistant to no flow conditions as they are often connected to the Lake Wetherell weir pool.

All pools contracted when the reach stopped flowing after the 2019 June-July flow event. This event may have provided some respite for animals and plants within these remnant pools, but that was short lived. Pools continued to contract after the event, by up to 50% in 50 days in the upper zone. The average areas of upper, middle and lower zone pools were limited to 15%, 13% and 37% of their end-of-July 2019 sizes respectively.

These key findings, derived from Sentinel-2 satellite imagery, suggest that remote sensing offers an efficient alternative to monitoring the spatial dynamics of large water bodies. Where stream width is too small, the pixel size (10m) may become a limitation.

Implications for water management

The protection of flows through a temporary water restriction (section 324 order) prevented extraction of licensed water within the Barwon-Darling between the 15th of April 2019 and the 30th of August 2019, and again from the 4th of November 2019 to the 31st of December 2019. Further restrictions were imposed in January 2020. The conditions in this study period also represent a low flow class (<455 ML/d) cease to pump restriction period in the amended WSP. In the future, periods like those experienced in this study would be protected by such a rule.

Regardless of the type of protection in place, the flow event in June-July provided critical respite to remnant pools in the Wilcannia to Lake Wetherrell reach. If protections were not in place, low level connectivity in the upper and middle zones would not have been achieved. Likewise, pool size would have reached much smaller sizes than identified within this study. It is possible that some pools would have completely dried in the absence of this small flow event.

The department currently has water depth and temperature loggers in a number of remnant pools within this reach. This information will improve our understanding of pool connectivity and thermal stratification within this reach. The project will aim to link flow rates at the Wilcannia gauge to downstream pool level changes, and pool stratification breakdown in this ungauged region of the Barwon-Darling.

More information

This work was completed by the department in collaboration with 2rog consulting. For more information on the findings of this report, contact the following Department of Planning and Environment staff via email.

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Appendix A

Table A1. Sentinel-2 satellite imagery from these dates were analysed to estimate areas of the 22 pools in the Wilcannia-Lake Wetherell reach in the Barwon-Darling.

Relation to June-July flow event	Date
Prior to	9 May 2019
Prior to	14 May 2019
Prior to	6 June 2019
During	28 June 2019 (Pools 7-14 excluded due to cloud cover)
During	13 July 2019
During	28 July 2019
Post	7 August 2019
Post	27 August 2019
Post	21 October 2019
Post	10 December 2019
Post	24 January 2020
Post	28 February 2020

Appendix B

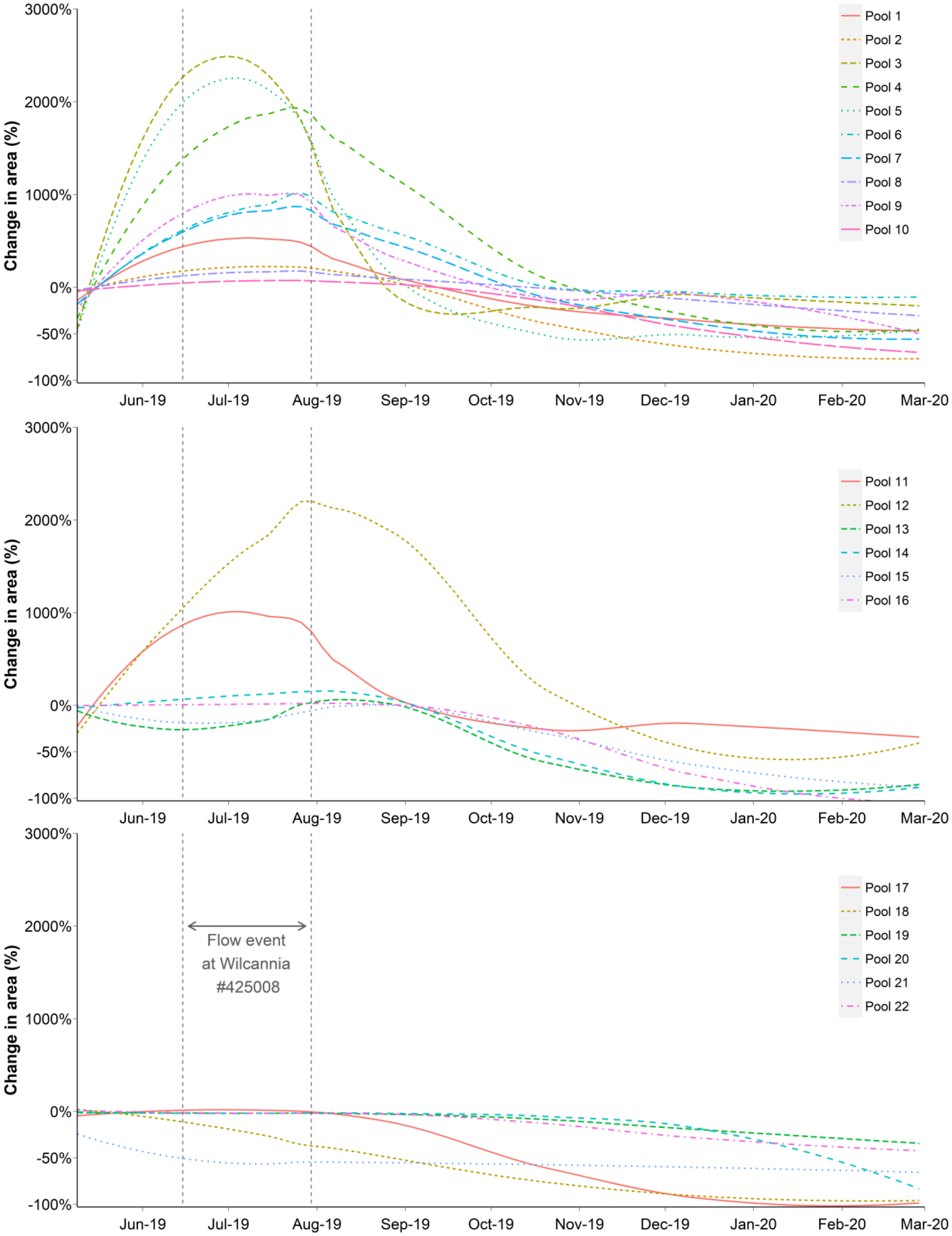

Figure B1. Change in pool area during 2019-20 low flow period. Lines plot the loess curves that highlight the trend in changes to pool area size for each pool.

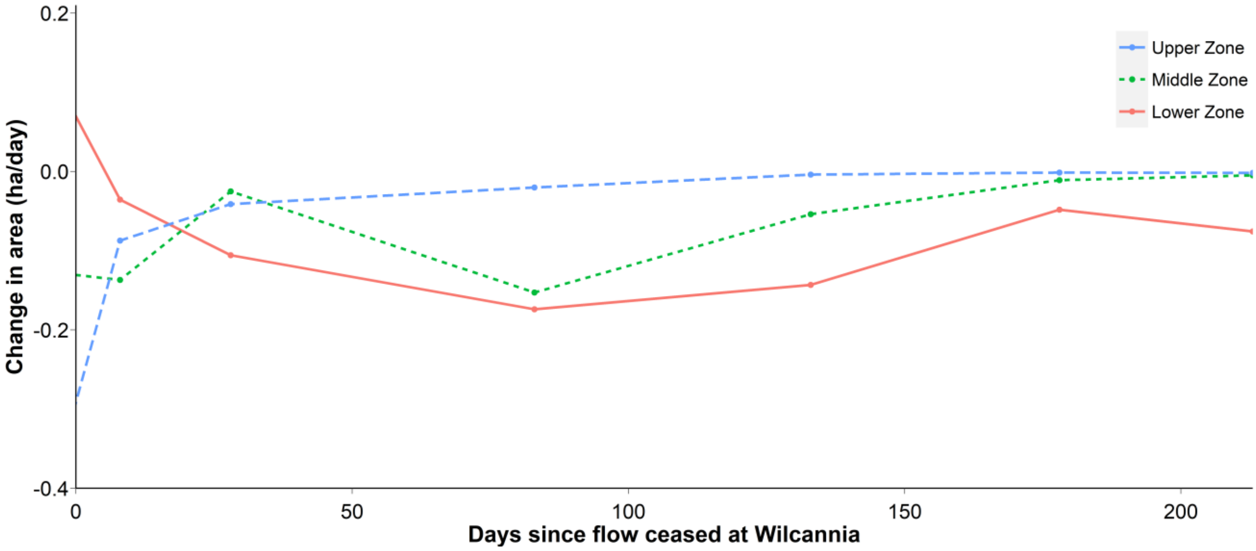

Figure B2: Average rate of change (ha/day) in pool area following the June-July flow event.