Assessment of take and protection during first flush flows in the Northern Basin

A satellite imagery derived assessment of take and water protected in the Northern Basin first flush flows of February 2020.

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More information

Danielle Baker/DPIE Water/Water Analytics

Executive Summary

In late January and throughout February 2020 the New South Wales (NSW) Northern Murray Darling Basin received significant rainfall and inflows, following an extended dry period. These flows were protected from take by s 324 restrictions under the *Water Management Act 2000* to meet critical needs in the northern valleys and to provide an initial target volume of 60,000–70,000 megalitres (ML) at the Menindee Lakes. Restrictions were permanently lifted in the northern valleys by 23 February when this target was assured of being met.

Rainfall and inflows continued beyond what was anticipated, and accordingly in early March the Menindee Lakes target was increased to 200,000 ML to provide a 12-18 month drought reserve for the Lower Darling. When it was clear that this target would be met, restrictions along the Barwon-Darling were progressively lifted.

This report provides the methods and results of three analyses:

- An analysis of water in large on-farm storages using a combination of satellite and aerial survey data and analysis, by a method known as remote sensing. Water in storages may be from active or passive floodplain harvesting, taken from rivers or groundwater and pumped to storage, or from direct rainfall, and on-farm run-off/tailwater capture.
- A water balance that quantifies the inflow to the regulated river systems from catchment run-off (after harvesting) and the take from these flows. The water balance also establishes the volume of water replenishing the natural river environment and the outflows to downstream rivers.
- Comparison of measured supplementary take against the potential supplementary take under standard water sharing plan arrangements.

These analyses combined enable the volumes of water taken to be compared to the take that could have occurred without restrictions. This comparison shows that the restrictions helped protect the first flush flows.

This is a first step in analysing and evaluating the protected first flush flows. This hydrologic assessment characterises the management of the first flush under the Extreme Events Policy (DPI, 2018) as successful, protecting a substantial volume of water critical for achieving public health and environmental outcomes.

Beyond this, future metering, measurement and telemetry will improve how we quantify unregulated and floodplain take, and how we quantify and enforce the protections and the outcomes they deliver.

Key flows and volumes

The key figures that quantify the impact of take on the first flush are:

- A substantial portion of the inflows were protected from extraction and either replenished northern valley systems or passed through to the Barwon-Darling River. During February 422,000 ML flowed into the regulated tributaries, of which only 31,000 ML (7%) was NSW take and 165,000 ML (39%) flowed to the Barwon-Darling River.
- An estimated increase in stored water of approximately 270,000 ML from early February to April.
- If the restrictions weren't in place and the standard water sharing plan arrangements were followed, an additional 100,000 ML of supplementary water could have been accessed.
- An estimated increase in stored water of approximately 30,000 ML from early to mid-February when temporary exemptions applied.

Key findings

The key findings of this assessment are that:

- While remote sensing is a valuable way of capturing data, it has limits as a means of measuring take. There is inherent uncertainty and scientific error in the methods and analysis which limit its use.
- We can characterise the available water and the use of this water to inform managing first flush flows. However, we can’t do this with high accuracy or in close to real time until metering, measurement and telemetry are in place.
- We cannot fully quantify the benefits of the restrictions against a scenario without restrictions using the methods in this report.
- Lessons from this assessment will inform the methods for future assessment, as well as future management of flows for critical needs.

Contents

Figures

Tables

Introduction

From late-January to late-February 2020, substantial rain fell, and rivers flowed in the New South Wales (NSW) Northern Murray Darling Basin. This followed record drought conditions, and severe water shortages for people, animals and the environment. The NSW Department of Planning, Industry and Environment (the Department) restricted water take from rivers and overland flows, under section s324 orders[1] to meet critical human and environmental water needs. These restrictions allowed for the northern tributaries and the Barwon-Darling River to recommence flowing and connect.

The following three temporary water restrictions orders were part of the Northern Basin restrictions:

1. Order prohibiting the take of water by general river pumpers in all the northern valleys and the Barwon-Darling – from 17 January to 31 January, extended to 17 February and then extended again to 28 February;
2. Order prohibiting the take of water from eight designated floodplains in the Gwydir, Namoi (Upper Namoi floodplain, Narrabri-Wee Waa floodplain and the Lower Namoi floodplain), Macquarie (Narromine to Oxley floodplain) and Barwon-Darling Valleys from 7 February, and the Macintyre and the Lower Macquarie from 12 February until 28 February 2020
3. Order prohibiting the take of water by Barwon-Darling river pumpers below Culgoa and from the Barwon-Darling floodplain – from 29 February to 17 April.

The orders allowed for responsive management, that is, for certain limited take to be approved during the period of the orders, and for the progressive lifting of restrictions as sufficient flows passed from upstream areas.

Once it was predicted that flow targets would be met, all restrictions were effectively lifted in the northern valleys and the northern floodplains by 23 February. All restrictions in the Barwon-Darling River above Culgoa were lifted on 27 February and below Culgoa on 6 March, and the Barwon-Darling floodplain by 31 March.

Data from satellite imagery and aerial survey, or remote sensing, was used to estimate the volumes of water taken during the first flush flows. Active and passive water take was estimated based on changes in the presence and surface area of water in large on-farm storages. These are dams primarily used to store floodplain harvesting and unregulated water take, as well as regulated and groundwater take, including supplementary access water. The report includes a February and a February to April water balance for the Northern Basin. This includes an estimation of the regulated river system inflows, as well as licenced take, system replenishments and other losses, and outflows to the Barwon-Darling River. For February, the actual measured take under supplementary access is compared to the potential supplementary take under standard water sharing plan rules. That is, it is compared to the potential take if the s 324 restriction was not in place.

[1] In accordance with the *Water Management Act 2000*

This report presents the:

- timeline of the rain, hydrology, restrictions and supplementary access for the first flush
- characteristics of large on-farm storages in the Northern Basin
- remote sensing method and resulting volumes for active and passive take in large on-farm storages during the first flush
- water balance method and the volumes of water flowing in and out of rivers, and available for system replenishment in rivers
- impact of take on the first flush, and the next steps in monitoring, measurement and management.

This assessment aims to:

- measure take, including passive take, using remote sensing
- characterise available water and use for transparency
- learn lessons to inform future assessment methods, and management to achieve critical public health, environmental and equitable water sharing outcomes.

Background

Regulated rivers and floodplain locations

The major regulated tributaries of the unregulated Barwon-Darling River in the NSW Northern Basin that are presented in this report are the:

- Border Rivers (NSW)
- Gwydir River
- Namoi River (Upper and Lower)
- Macquarie River.

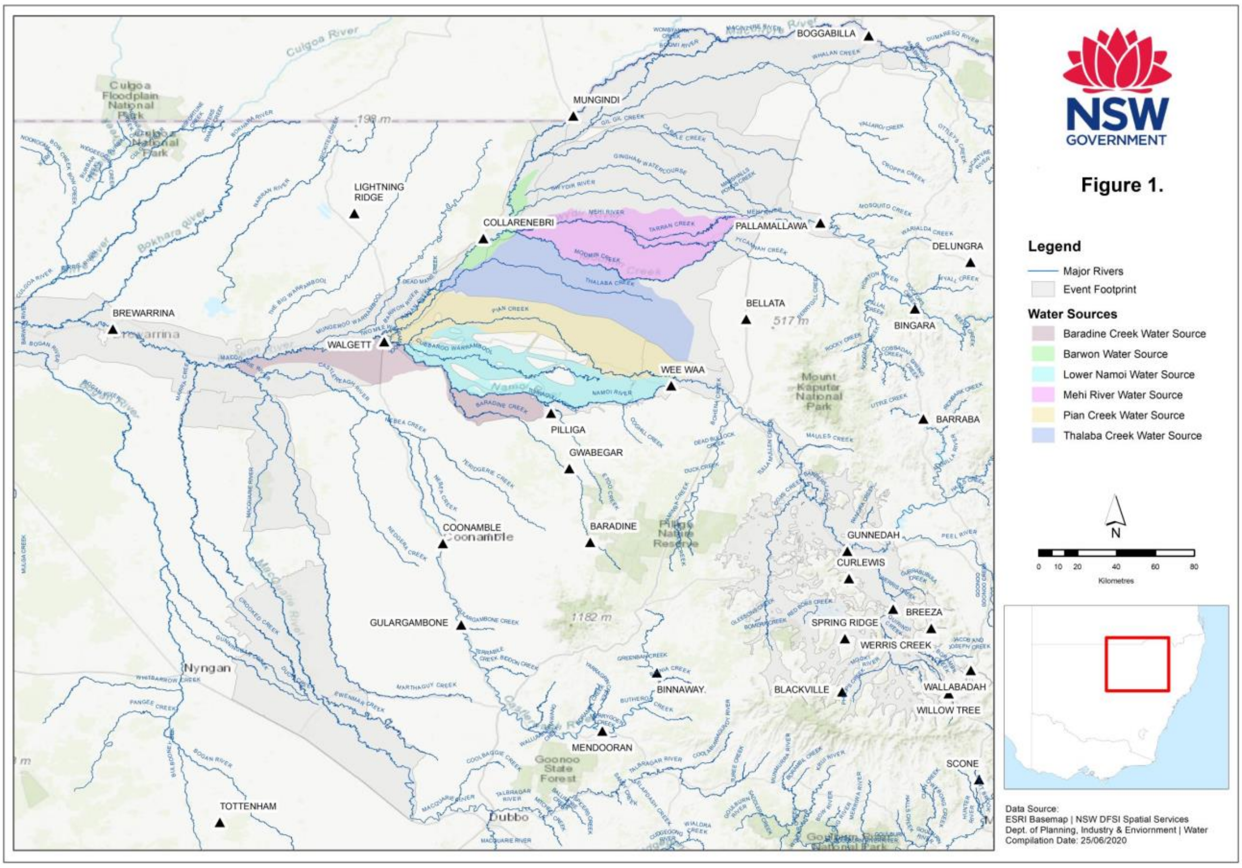

Figure 1: Floodplain locations where restrictions and temporary exemptions were applied

Timeline

During this event rains created flows that restarted and connected the northern tributaries with the Barwon-Darling River. Section 324 orders were made restricting take in the northern and Barwon-Darling rivers and floodplains, with some limited exemptions. Heavy local rain and flooding threatened infrastructure and restrictions were temporarily lifted for four days in some floodplains. By 21 February, the initial target flows of 60,000-70,000 ML were forecast to reach the Menindee Lakes and restrictions began to be permanently lifted in the northern valleys. Some supplementary access was also permitted. The restriction in the Barwon-Darling upstream of Culgoa was lifted on 27 February.

With further substantial rain and inflows from Queensland (QLD), the Barwon-Darling River and the Macquarie River, the volume forecast to reach the Menindee Lakes increased and further supplementary access was announced. The volume forecast to reach the Menindee Lakes became 205,000 – 220,000 ML, meeting the revised target of 200,000 ML and river pumping restrictions in the Barwon-Darling River downstream of Culgoa were lifted on 6 March. By the end of March, the last remaining restriction – the Barwon-Darling floodplain access – was lifted.

From 10 March, the Barwon-Darling River was flowing along its full length from Mungindi on the border, into the Menindee Lakes. Thousands of kilometres of rivers flowed for the first time in many months. Substantial additional rain fell in late-March and April, creating flows in the Marthaguy creek, Castlereagh, Macquarie and Bogan Rivers, and subsequent flows of 480,000 ML at Brewarrina. This was followed by May rainfall of 40-50 mm across central NSW. By the end of June, the Menindee Lakes had received more than 583,000 ML of total inflows, Table 1.

Table 1: Timeline of rain, hydrology, restrictions and supplementary access

Date	Rain and hydrology	Restrictions[2] and Supplementary access[3]
17 January	Northern Basin rain predicted	Section 324 order restricting river take in the northern valleys and Barwon-Darling
26 January -7 February	High rainfall in specific areas	Approval to pump (exemption to s 324) provided in Quirindi Creek and Mooki River unregulated rivers and Peel River high security for specified periods
7 February		Section 324 order restricting floodplain harvesting take in the Barwon-Darling, Gwydir, Macquarie (Narromine to Oxley Station) and the Upper, Mid (Narrabri to Wee Waa) and Lower Namoi floodplains
8-9 February	Heavy local rain 150 – 200 mm and flooding Lower Gwydir and Namoi floodplains	Approval to pump (temporary exemptions to s 324) for unregulated river users in some sections of the Namoi Valley and the Lower Gwydir Valley (between 8 and 17 February), and approval to take on parts of the Gwydir floodplain (between 9 and 12 February)
10-13 February		Approval to take (temporary exemptions to s 324) extended in the Gwydir floodplain and also applied to parts of the Barwon-Darling and Lower Namoi floodplains (covering Pian Creek, Lower Namoi, Baradine Creek, Mehi River, Barwon River between Collarenebri and Walgett and Thalaba Creek)
12 February	10,000 – 30,000 ML forecast to reach Menindee with restrictions	Section 324 order restricting floodplain harvesting take in the Lower Macintyre, Whalan Creek, Boomi River, and Lower Macquarie floodplains
14 to 16 February		Supplementary access permitted in parts of the Gwydir water source
18–19 February	Rain 25 – 75 mm Northern Basin	

[2] Temporary water restrictions can be found here https://www.industry.nsw.gov.au/water/allocations-availability/temporary-water-restrictions
[3] Supplementary access announcements can be found here https://www.waternsw.com.au/supply/regional-nsw/supplementary

Date	Rain and hydrology	Restrictions[2] and Supplementary access[3]
20 February	60,000 – 80,000 ML forecast to reach Menindee without further restrictions (60,000 – 70,000 target predicted to be met)	Supplementary access permitted in parts of the Macquarie regulated river for 2-3 days
21 -23 February		Section 324 permanently lifted for all northern unregulated rivers and floodplains, but not for the Barwon-Darling River or floodplain
22-23 February	QLD rain 200 mm	
25-26 February	Rain and inflows in QLD, the Barwon-Darling River, and the Macquarie River. 150,000 – 170,000 ML forecast to reach Menindee	Suspension of general security account water lifted so that general security users in the Border Rivers, Upper and Lower Namoi water sources could access limited volumes in suspended carryover accounts from run of the river flows Supplementary access permitted in parts of the Border Rivers, Gwydir, Peel and Lower Namoi catchments for specified number of days
27 February		Section 324 permanently lifted for the Barwon-Darling River water source above Culgoa.
2 March	170,000 – 200,000 ML forecast to reach Menindee	
4 March	New 200,000 ML target set	
6 March	205,000 – 250,000 ML forecast to reach Menindee without further restrictions in the Barwon-Darling above Culgoa (200,000 ML target predicted to be met)	Section 324 permanently lifted for the Barwon-Darling River water source below Culgoa
10 March	Barwon-Darling River was flowing along its full length from Mungindi on the QLD border, into the Menindee Lakes	Various supplementary access during March in parts of Gwydir, Peel and Namoi for specified number of days

Date	Rain and hydrology	Restrictions[2] and Supplementary access[3]
31 March	Substantial additional rain fell in central NSW, generating a Barwon-Darling River flow of 480,000 ML at Brewarrina	Section 324 lifted for the Barwon-Darling floodplain Various supplementary access during April in parts of Peel, Macquarie, Border Rivers, Gwydir and Namoi
April		Various supplementary access during April in parts of Peel, Macquarie, Border Rivers, Gwydir and Namoi
May	40 – 50 mm rain across central NSW	
Late-June	Menindee Lakes had received more than 583,000 ML of total inflows	

Large on-farm storage characteristics

There are 1,424 large on-farm storages in the Northern Basin floodplains of the Border Rivers, Gwydir, Namoi, Macquarie and Barwon-Darling valleys. We expect that 1074 (1035 with LIDAR storage curve + 39 without) of these storages will be used to store water taken under a floodplain harvesting access licence. These storages can hold a maximum of approximately 1,292,000 ML, but the volume of floodplain take allowed by these storages is governed by Water Sharing Plans, Table 2. The smallest storage we assessed has a surface area of 3,800 m^2 and is in the Macquarie valley, while the average surface area of storages in the Northern Basin is 540,000 m^2.

Table 2: Northern Basin storages used for floodplain harvesting

Floodplain valley[4]	Storages-with LiDAR curves (number)	Storages-without LiDAR curves (number)	Average volume-storages (ML)	Volume-storages (ML)
Border Rivers	108	2	1,600	175,100
Gwydir	318	1	1,600	498,000
Namoi	376	34	800	301,900
Macquarie	144	2	900	126,500
Barwon Darling	89	0	2,300	205,000
Total	**1035**	**39**	**-**	**1,292,000**

Staff from the Natural Resources Access Regulator (NRAR) rapidly assessed these and other storage locations in the Northern Basin, for notable changes in water surface areas. They developed a shortlist of 250 storages for further investigation. The method is described in the Appendix-Rapid assessment of storage surface area change.

Remote sensing of take method

We assessed whether water was taken from February to April by using remote sensing to determine if and how much water was present in storages in the areas of interest:

- late-January to early-February (23rd-2nd)
    - pre-first flush
- mid-February (circa 18th)
    - during the first flush and following the temporary exemptions
- late-April (circa 27th)
    - post-first flush and when restrictions had been lifted.

If water was taken during these periods, we would expect to see this as an increase in water surface area, and hence volume, in these dams.

[4] These figures are the best available at June 2020.

To estimate a wet surface area, analysts used cloud-free Sentinel-2 satellite imagery at 10m resolution with a 5-day return interval.

The wet surface areas of storages were calculated and translated into a volume estimate using a validated storage capacity curve. The storage capacity curves were derived from aerial survey (LiDAR) data previously captured during 2016. The curve, Figure 2, matches observed water surface height in accordance with the Australian Height Datum (AHD), to surface area (m2) and volume (ML). In this way, a measured wet surface area is turned into a stored volume of water for each storage.

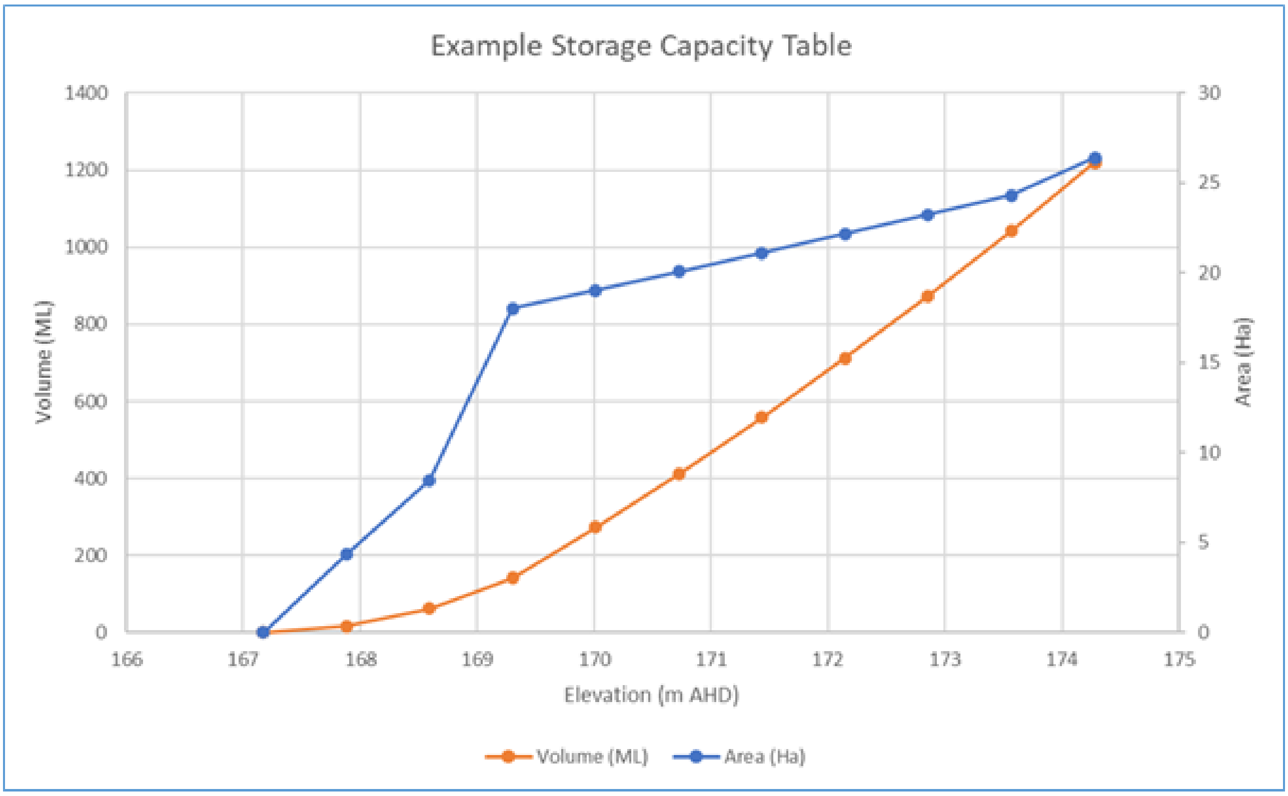

Figure 2: Example Storage Capacity Curve

There are assumptions, limits and uncertainty in this approach:

- The stored volumes are derived from remote sensing information, rather than directly measured. They are estimates only.
- Data derived from satellite imagery is scientifically uncertain and has limits due to image resolution or pixel size, and the image availability or the return internal.
- Our quality assurance indicates a possible error of 5% of Full Supply Volume (FSV) at the upper reaches of the volume estimation curve, and higher errors at lower storage levels. This known error has been factored into our calculations, and data has been presented with upper and lower bounds where volumes are estimated.

Details of how the wet surface area was calculated for the storages and the translation of these surface areas to an equivalent volume is provided in Appendix-Storage volumes limitations and uncertainty.

Remote sensed volume results

We used storages observed in cloud free imagery in the areas of interest as the basis for volume estimates. The total number of on-farm storages, and the number and proportion of these visible in cloud free imagery are summarised in Table 3.

Table 3: Number of visible storages in the area of interest

Location	Number visible pre-first flush	Number visible during-first flush	Number visible post-first flush[5]
Border Rivers	26	45	79
Gwydir	56	132	205
Upper Namoi	51	40	97
Lower Namoi	154	232	207
Barwon-Darling	3	9	65
Macquarie	5	Not available[6]	94

The Sentinel volume estimates and confidence ranges for storages in each of these areas is presented in Table 4.

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[5] In all cases only storages that were visible, had an available storage curve and had an observed wet surface area were included in the count
[6] During-first flush the storages in the Macquarie were not visible due to cloud cover

Table 4: Sentinel estimates and ranges of volumes held in storages

Floodplain	Sentinel volume estimates and ranges[7] (ML)			
	Pre-first flush[8] (ML)	**During-first flush and temporary exemptions (ML)**	**Volume increase pre to during-first flush (ML)**	**Post-first flush and restrictions lifted (ML)**
Border Rivers	2,800 (1,800-4,000)	2,700[9] (2,000 –3,500)	-100	36408 (24,500-46,700)
Gwydir	9,200 (5,400-13,200)	24,900 (16,700-34,000)	+15,700	85946 (52,300-118,000)
Upper Namoi	3,900 (2,000-6,400)	7,100 (4,700-9,200)	+3,200	15098 (8,900-21,900)
Lower Namoi	13,100 (8,500-17,300)[10]	32,900 (22,600 – 41,000)	+19,800	65091 (44,500-78,300)
Barwon Darling[11]	<100	400[12]	+300	126,100 (89,100-149,600)
Macquarie	Assessed using Planet	Refer to Table 6	-	-
Total	**29,100**	**68,000**	**+38,800**	**328,700**

Quality assurance and refinement

We completed a quality assurance process to ensure that the data used was of an appropriate quality. To do so, we obtained a sample of 139 storages in which the satellite images indicated the presence of 50% or greater storage surface area.

Analysts then used Planet satellite imagery at a finer 3m resolution with a daily capture interval, to estimate water surface areas and re-calculate the volumes for the sample storages for the pre and mid-first flush time periods. A comparison of the two sets of volume results is presented in Table 5. At the finer resolution, we typically observed a reduction in wet area and therefore volume. This appears to be due to the finer image resolution, that is, 3m rather than 10m.

[7] A range is indicated ±20% of Full Supply Volume (FSV), up to FSV or down to 5% FSV, to account for some of the limitations in satellite observations and volume capacity curve calculations.
[8] Date of image acquisition varies across floodplains due to cloud cover.
[9] Mid-February observations were constrained for the Border Rivers flood plain at the time of the initial assessment due to cloud cover.
[10] The Lower Namoi was analysed as having 2,700 (1500 - 3800) ML stored on the 23 January.
[11] All storages within Barwon Darling floodplain were estimated/observed to hold volume within the storage borrow pit only, therefore no error bands have been calculated or indicated.
[12] The Barwon Darling floodplain was analysed as having 200 ML stored on 10 February.

Table 5: Comparison of Planet and Sentinel volume estimates

Floodplain Valley	Planet volume estimates (ML)	Sentinel volume estimates (ML)	Difference (ML)
Border Rivers			
Pre-first flush	900	800	-100
Mid-first flush	1,300	1,300	0
Gwydir			
Pre-first flush	3,100	4,000	900
Mid-first flush	5,700	12,300	-6,600
Namoi			
Pre-first flush	7,900	12,700	-4,800
Mid-first flush	30,200	37,000	-6,800
Total	**49,200**	**68,200**	**-19,000**

Accordingly, we applied the measured reduction to the results generated with the Sentinel imagery at the coarser scale to modify the floodplain wide estimates. A scaling factor was calculated and applied to the Sentinel wet areas and the storage volumes recalculated. Table 6 shows the recalculated volumes in each of the areas of interest.

Table 6: Scaled estimated total volume for combined storages

Floodplain	Estimated total volume and range for combined storages (ML)			
	Pre-first flush (ML)	During-first flush and temporary exemptions (ML)	Volume increase pre to during-first flush (ML)	Post-first flush and restrictions lifted (ML)
Border Rivers	2,200	Cloud affected[13] (2,200)	Not available	26,900
Gwydir	6,800	18,700	+11,900	63,300
Upper Namoi	3,100	5,200	+2,100	11,100
Lower Namoi	9,800	24,500	+14,700	47,400
Barwon Darling	100	400	+300	94,400
Macquarie	900	Cloud affected[14]	Not available	48,600
Total	**22,900**	**51,000**	**+29,000**	**291,700**

[13] Mid-February observations were constrained for the Border Rivers flood plain at the time of the initial assessment due to cloud cover, and originally estimated at 2200 ML. Subsequent analysis of curated satellite imagery indicates that the Border Rivers storages may have held as much as 8,200 ML in mid-February (pre-first flush 2200+1100=3,300 ML and during-first flush 2,200+6000=8,200 ML).
[14] Cloud free images were not available over the Macquarie flood plain during the period 12-19 February; therefore, an assessment of surface area or volume was not possible.

Water Balance

To provide some context to the first flush flows, we completed a water balance for the NSW Northern Basin regulated river tributaries. This was based on the following calculation:

[A] Outflows = [B] Total System inflows - [C] System Replenishment - [D] Take

Where:

- **[A] Outflows** = volume estimated to exit the contributing catchment and flow into the Barwon-Darling River
- **[B] Total system inflows** = Northern Basin tributaries inflows including gauged inflows and estimates of ungauged inflows downstream of the major headwater regulating storages[15]
- **[C] System replenishment** = system losses including flows to major environmental assets including wetlands, losses to dry riverbeds, underlying aquifers, evapotranspiration, and flow in transit that has not left the river in the defined accounting period. The item also includes use associated with held environmental water access licences and basic landholder rights
- **[D] Licensed Take** = metered regulated river take (including all licenced take for supplementary, high security, general security, local water utility and domestic and stock licences).

Systems replenishment [C] is the balancing item in the water balance. That means it is calculated, not measured. Only inflow entering each regulated river system from catchment run-off, flow exiting each river system, and licenced take is measured. Floodplain harvesting take from catchment run-off prior to the water entering the regulated system is not considered in the balance, but by nature, would reduce inflows.

Total inflows and outflows for the Barwon-Darling River to Wilcannia, including contributions from the tributaries is provided; however, a full water balance is not presented as metering data is not yet available to quantify the licensed take.

The water balance does not consider flow travel times, and some of the February flows from the Border and Namoi Rivers to the Barwon-Darling River were still in transit in these rivers during February. This shows as a higher system replenishment volume for February when compared with the February to April analysis for these water sources. The lag in the geographically large Northern Basin is substantial, with many weeks of travel time in the Barwon-Darling River between Mungindi and Wilcannia.

Table 7 summarises the results of the water balance, including volumes of water flowing in and out of rivers, and available for system replenishment in rivers as a percentage of inflows. These results are detailed in the appendices section of this report.

[15] Significant replenishments to the major storages was also observed during the event with a net increase of 367,000 ML captured to meet future demands (including Glenlyon Dam which is shared with QLD). Releases from storage are allowed for in the water balance (as an inflow) however these were minimal relative to downstream tributary inflows.

Table 7: Inflows, take and water remaining in the northern regulated river systems and contributions to the Barwon-Darling

Water Source	Inflows (ML)[16]	Licensed take (ML)[17]	System replenishment (ML)	Outflows (ML)
Border Rivers February	164,000	8,800 (5%) QLD 27,200 (17%)[18]	77,600 (47%)	50,100 (31%)
Border Rivers **Total February-April**	**200,800**	**9,900 (5%)** **QLD 27,200 (14%)**	**71,100 (35%)**	**92,500 (46%)**
Gwydir February	60,000	5,200 (9%)	16,700 (28%)	38,000 (63%)
Gwydir **Total February-April**	**100,800**	**17,900 (18%)**	**30,700 (30%)**	**52,200 (52%)**
Namoi February	122,000	3,700 (3%)	42,300 (35%)	76,100 (62%)
Namoi **Total February-April**	**132,800**	**10,900 (8%)**	**26,000 (19%)**	**96,100 (72%)**
Macquarie February	76,000	13,100 (17%)	62,300 (82%)	600 (1%)

[16] Estimated total inflow to the regulated river systems downstream of major storages, 1 to 29 February and 1 February to 28 April for total.

[17] Provides take volumes from the rivers including supplementary water take. Held environmental water usage was 3,700 ML in Gwydir and 4,600 ML in the Macquarie and is included in the system replenishments. The water balance excludes floodplain harvesting activities. That is, any water that was captured on-farm or on the floodplain and did not flow into a river.

[18] Provisional estimate of QLD take for the period 14 to 24 February 2020 supplied by QLD government. No further QLD take volumes are provided.

Water Source	Inflows (ML)[16]	Licensed take (ML)[17]	System replenishment (ML)	Outflows (ML)
Macquarie [19] **Total February-April**	**235,100**	**30,800 (13%)**	**187,800 (80%)**	**16,500 (7%)** **(Bogan[20] 41,000)** **(Marthaguy[21] 90,000)**
Barwon-Darling Total	**876,900[22]** Barwon-Darling inflow from regulated outflows 257,300 Barwon-Darling inflow from other unregulated water sources 619,600	**Not available[23]**	**Not available**	**496,400 (57%)[24]**

Impact of take on the first flush

Stored water

At the start of February, the large on-farm storages held an estimated 23,000 ML, by mid-February 51,000 ML and by the end of April 292,000 ML. We therefore estimate an increase in stored water of approximately 270,000 ML from February to April 2020. This includes an estimated 30,000 ML by mid-February, during which there were four days when restrictions on floodplain harvesting were lifted in specified areas.

Stored water includes floodplain harvesting as well as water actively taken under several different water licence classes including unregulated, supplementary and groundwater and water taken under a basic landholder right. The stored water can also include passive floodplain take i.e. water

[19] Inflows and direct outflows to the Barwon Darling are for the regulated river downstream of Burrendong Dam. The system replenishments presented for the regulated balance are inclusive of flows in Gunningbar Creek (8,000 ML) and Duck Creek (6,000 ML) which connect to the unregulated Bogan River system.

[20] Bogan River cumulative flows recorded at Gongolgon 421023.

[21] Marthaguy Creek cumulative flows recorded at Carinda 421011.

[22] Barwon-Darling River inflow estimate includes the outflows from the regulated Border Rivers, Gwydir, Namoi, and Macquarie Rivers together with an estimate of the contribution from all other unregulated inflow sources such as the Culgoa, Moonie, Castlereagh and Bogan Rivers. An estimate for loss processes and extraction was included which will be refined when further information on extraction volumes is available. The minimum volume inflow volume determined allowing for no loss or extraction was 671,000 ML.

23 The final extraction volumes for the Barwon-Darling were not available at time of publication, due to A class extractions continuing, and the timing of meter reads being scheduled for the end of the water year. The preliminary extraction volume is 230,000 ML. This table will be updated and republished when the final information is available.

[24] Barwon Darling River water balance outflows at Wilcannia Main Channel 425008.

entering gravity fed storages that cannot be restricted by a pump, pipe or regulator and rainfall run-off collected in tailwater drains.

It is likely that the total take estimate of 270,000 ML in on-farm storage contains much of the 69,500 ML of licensed take in taken in the regulated tributaries for the full first flush assessment period. Future telemetry and measurement of floodplain harvesting will improve how we quantify floodplain water take and make information more rapidly available.

Take and system replenishment

The water balance shows a substantial portion of the inflows were protected from extraction and either replenished systems or were passed through to the Barwon-Darling River. During February 422,000 ML flowed into the regulated tributaries that connect to the Barwon-Darling River. Of this volume 165,000 ML (39%) flowed to the Barwon-Darling River. Take in NSW was 31,000 ML (7% of the inflow volume). The remaining portion of the inflow is attributed to take in QLD 27,000 ML (6% of the inflow volume), local tributary system replenishment, natural losses, flows to environmental assets such as the Macquarie Marshes and Gwydir wetlands, or water still transitioning to the Barwon-Darling River, as some of the February tributary inflows did not transit to the Barwon-Darling River until March.

Take increased in the northern tributaries when restrictions were permanently lifted in late-February. Inflows lessened, and apart from Marthaguy Creek and the Macquarie and Bogan Rivers, the proportion of water attributed to replenishment and outflows reduced.

For the full first flush assessment period, 670,000 ML flowed into the regulated tributaries, with substantial flows arriving in the Macquarie during April, and moderate increases occurring in the other regulated tributaries. Take in NSW was 70,000 ML (10% of the inflow volume) and the remaining proportion of the inflow is attributed to take in QLD and system replenishment[25].

Flows started to reach Wilcannia from 5 March, the Menindee Lakes (Lake Wetherell) by 10 March and a substantial volume flowed beyond Wilcannia by the end of April, being 496,400 ML or 57% of estimated inflows to the Barwon Darling, to replenish the regulated Menindee Lakes system and connecting fish populations previously stranded in refuge pools. Many towns benefited from these flows. Water supplies were secured, and all town weir pools were filled.

The estimated inflow to the Barwon-Darling was 877,000 ML, 257,000 ML (29%) of which came from the regulated tributaries. The remaining inflow is attributed to flows from the unregulated water sources including flow transitioning from QLD (refer to appendices for further detail). A total of 316,000 ML (47%) of the regulated tributaries inflow remained in the tributary to replenish local systems or was in transit to the Barwon-Darling River, achieving outcomes for the environment and groundwater systems.

The water balance analysis was for the Northern Basin regulated rivers, and the impacts on the unregulated tributary rivers were not assessed, due to data limitations. The remote sensed (stored water) analysis does consider unregulated areas.

While only flows directly contributing to the Barwon-Darling were assessed in the water balance for the regulated systems, it is significant that these systems also received a net volume increase of 367,400 ML[26] to the major regulating storages during the event. This water provides for critical needs and other system demands ahead.

[25] Flows for non-consumptive purposes except for basic landholder rights take and change in storage volume for the river and weirs which were not quantified in the balance.
[26] including Glenlyon Dam which is a shared resource with QLD

Supplementary access water

Coinciding with the lifting of other restrictions in the northern valleys mostly from 20 February onwards, supplementary water licence holders in the Border Rivers, Gwydir, Macquarie and Lower Namoi valleys then had periods when access was allowed. Table 8 compares the actual supplementary event take against an estimate of what could have been made available for supplementary licence holders under the relevant water sharing plan rules.

Assessing the rules for distributing supplementary water, and the volume of inflow received in February, up to 132,000 ML could have been announced to supplementary access licence holders (of which 124,000 ML is associated with consumptive water users[27]). Comparatively, February supplementary take/use was limited to 31,900 ML (24% of the no restriction estimate). Of this volume, 4,823 ML was associated with held environmental water orders, and the remainder taken for consumptive purposes. The difference between the potential and actual take/use, 100,000 ML, is the volume of water that was protected through the management of the first-flush for critical human and environmental needs.

Table 8: Supplementary take in February and non-restricted potential take for February events

Valley	February take/use[28] (ML)	WSP rules potential[29] (ML)	% of potential
Border Rivers[30]	8,700	35,000	25%
Gwydir	7,200[31]	25,000	29%
Namoi	2,400	57,000	4%
Macquarie	13,600[32]	15,000	91%
Total[33]	**31,900**	**132,000**	**24%**

[27] Assumes maximum demand for supplementary access by the environmental water holder. The proportion of held environmental supplementary water to total supplementary water on issue are 1%,15%,0% and 25% for the NSW Border Rivers, Gwydir, Namoi and Macquarie (below Burrendong Dam) respectively.
[28] Event access is the supplementary licence use including that used by held environmental water licences.Figures represent both the take and the volume announced to supplementary holders as there was 100% demand by holders
[29] Estimation of potential supplementary announcements under standard water sharing plan rules without restrictions
[30] NSW licence holders only
[31] Includes 3,448 ML held environmental water
[32] Includes 1,375 ML held environmental water
[33] Supplementary access water can be held in large on-farm storages, meaning the remote sensing first flush volume estimates will include some of the supplementary take shown in Table 8

Evaluation of the management of the first flush

The Department has appointed an independent panel to assess the management of the Northern Basin first flush event. Among other concerns, it will review the availability of information communicated to stakeholders and evidence to support decision-making and make recommendations on the changes that would improve the management of future events. The analysis and outcomes presented in this report were provided to panel. More information on the Northern Basin first flush assessment can be found on the Department's website.

Conclusion

For the first time, DPIE Water analysed and reported the volume of water take and the volume of water protected during a first flush, using a combination of remote sensing and measured and estimated water balance accounting.

Using satellite imagery to identify changes in water surface area is a well-established and effective means to gather data on the whereabouts and use of water in the landscape. By measuring water surface area changes, we were able to estimate the volume of active and passive take in large on-farm storages using aerial survey (LiDAR) derived storage capacity curves.

Remote sensing has its limitations. Our capacity to quantify wet areas is limited by the frequency of satellite passes, cloud cover obstructions, and the resolution of the different available images. The methods and analysis for this report have sought to reduce the impact of these limitations. In particular, the use of higher resolution Planet imagery to correct volume estimations for a sample of storages, and then applying this correction to all storages assessed, has sought to reduce the impact of image resolution. Converting wet surface areas to volume areas is a known point of uncertainty, managed through using a known and validated volume storage capacity curve.

Despite these known issues, remote sensing is a valuable tool in the absence of on-ground measurement. We estimate there was 30,000 ML of take in the first half of February (including the 4 day period when the restrictions were temporarily lifted), and 270,000 ML of take into on-farm storage from February to April.

The information provided by the remote sensing analysis was complemented by an event water balance analysis that quantified the inflow entering the regulated river systems from run-off (after harvesting), the licenced take from these flows, and the volume of event outflows and in system (including environmental) replenishment.

While the water balance had limitations, the simple method was selected to make use of readily available information that could be assessed without difficulty, and to limit calculation assumptions. It was not able to incorporate detail about the overland flow volumes prior to entering rivers, how water was used in the environment, changes to weir storage, basic rights extraction volumes, or determine absolute inflow volumes in the lower catchment areas, where the gain from runoff and loss from extraction and natural processes becomes complex.

It also did not address the travel times in the extensive Northern Basin. However, it has made volume estimates for water take and water protection available to interested parties within a relevant time frame. The active use of operational models by WaterNSW during the event are a better method of modelling water quantities in real time and could also be use in a more detailed post-event analysis.

This report quantifies the supplementary water protected against a scenario without protections in place when compared to standard water sharing plan arrangements. This is a first step in analysing and evaluating the protected first flush. On balance, this hydrologic assessment characterises the management of the first flush under the Extreme Events Policy (DPI, 2018) as successful, protecting a substantial volume of water for critical human and environmental outcomes.

Beyond this, future improved take metering, measurement and telemetry will improve how we quantify unregulated and floodplain take and how we quantify and enforce the protections and the outcomes they deliver for the people, animals and environment of NSW.

Key findings

The key findings of this assessment are:

- While remote sensing is a valuable way of capturing data, it has limits as a means of measuring take. There is inherent uncertainty and scientific error in the methods and analysis which limit its use.
- We can characterise the available water and the use of this water to inform managing first flush flows. However, we can't do this with high accuracy or in close to real time until metering, measurement and telemetry are in place.
- We cannot fully quantify the benefits of the restrictions against a scenario without restrictions using the methods in this report.
- Lessons from this assessment will inform the methods for future assessment, as well as future of flows for critical needs.

Next steps

The Department, with WaterNSW, will:

- Explore lessons learned from this analysis and the management of the first flush, considering the findings from the independent assessment of the management of the Northern Basin first flush event.
- Use additional available data, and models to analyse volumes of water extracted, flowing in and out of rivers, and available for system replenishment in future first flush flows
- Consider developing new methods to model the full quantum of water in the landscape, the possible extent of unregulated and floodplain take and consider modelling alternate scenarios ranging from no protection to new plan rules, noting some of these analyses take a long time and are resource heavy and costly.

Appendices

Rapid assessment of storage surface area change

The Natural Resources Access Regulator (NRAR) in collaboration with Geoscience Australia and the Murray Darling Basin Authority (MDBA) used satellite imagery to perform a rapid assessment of storages of interest. The approach used a percentage of water pixels method developed by Geoscience Australia for the Digital Earth Australia (DEA) Waterbodies tool, accessible from the Geoscience Australia website. This tool uses satellite imagery to monitor changes in water surface areas using publicly available Landsat satellite imagery and an applied water observation indices.

- Water surface area changes were measured in 3503 on-farm storages larger than 1 hectare (Ha) in the Northern Basin between 17th January – 8th February 2020.
- Of these 2293 were analysed in cloud-free imagery.
- Of these, 250 storages indicated a water surface area increases sufficiently large to be of interest.
- These 250 storages of interest were further assessed by NRAR using higher resolution and return interval Sentinel and Planet satellite imagery to verify and better assess the timing of any water surface area increases.
- Storages of interest were checked against multiple lines of information including rainfall totals, water licensing information, water account information and on-farm water infrastructure plans.
- Similar rapid screening data was supplied by the MDBA and cross-referenced by NRAR against the Geoscience Australia data for quality assurance.

Approximately 89% of storages with cloud-free data showed little or no increases in surface water area.

In comparison, the remote sensing assessment described in the body of this report estimates the change in event volume in floodplain eligible storages both during the temporary exemptions and in April.

Storage volumes limitations and uncertainty

Storage curve accuracy and volume estimation technique

The storage capacity curves developed as part of the Healthy Floodplains Program are known to be inaccurate at low volumes, that is when water only inundates the borrow pit (intentional depression or sink) within storages. It is possible they are inaccurate by a factor of over 100% of estimated volume.

The capacity curves are far more accurate at high volumes, that is when water is around the full supply volume. The high volume estimated error is between 5 and 10%.

Because of this difference, assumptions were made as to whether the water level was constrained to the borrow pit or not, and the calculation method was altered accordingly, Table 9.

Table 9: Volume estimation technique

Wet area percentage of full supply area	Estimated water level	Volume estimation technique
0 -10%	Low within the borrow pit	Use 1% of full supply volume
10–50%[34]	Within the borrow pit	Use 5% of full supply volume[35]
50–100%	Above the borrow pit	Use capacity curve

Figure 3 and Figure 4 show examples of a typical storage borrow pit (orange doughnut shaped borrow) and an atypical borrow pit. In the typical borrow pit, the estimated volume would be inaccurate, in the atypical borrow pit the estimated volume would be far more inaccurate.

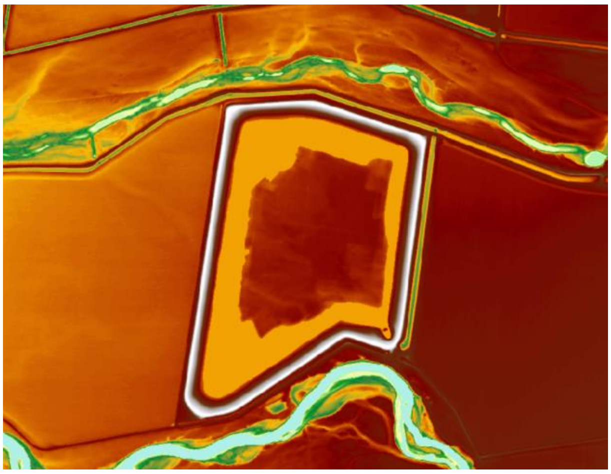


Figure 3: Typical 'donut' borrow pit shape depicted in range shading within a storage.

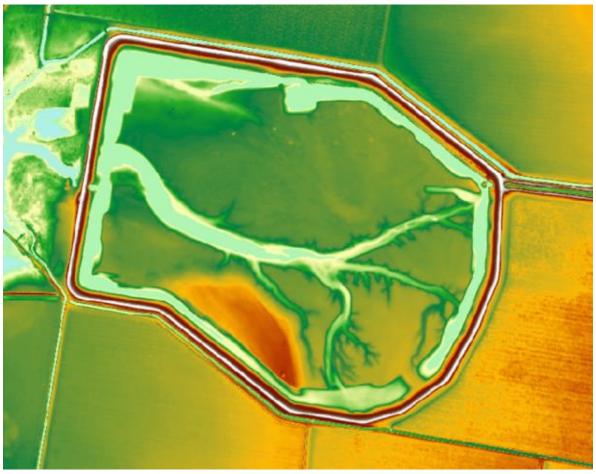


Figure 4: Atypical borrow pit shape made from a mix of excavated area and natural watercourse depression depicted in blue/green shading within a storage.

[34] Sensitivity testing was undertaken on this threshold. Varying it between 40-60% has less than 1% impact on the total volume estimated for the February event.
[35] The borrow pit volume represents around 5–10% of full supply volume. It was felt that 5% was an appropriate estimation.

Storage capacity curve errors

Many aerial survey (LiDAR) derived capacity curves were field verified by ground survey as part of the Storage Bathymetry Model (SBM) project. The SBM curves were typically within 5% of the ground survey equivalent when approaching full supply level. There was no systematic bias in the curves. There was no over or underpredicting.

One issue is that storages have since been modified (i.e. enlarged, deepened, separated or part decommissioned) after the LiDAR and survey used in the SBM project. In some cases, the capacity curves were developed from LiDAR collected over 12 years ago, so it is likely that there are now some modified storages for which are volume conversion will be less accurate.

Storage borrow pit assumed volume error

The volumes assumed within the storage borrow pits are problematic. Sensitivity testing, such as increasing the borrow pit volume to 10% of full supply volume, shows a significant increase in the estimated volume, up to 24% when summing across all storages calculated. This is due to the borrow pit storages representing around 57% of all volume calculations. In short, they are sensitive to the assumptions made and large errors can result.

Approximately 10% of the storages analysed do not currently have a capacity curve and so the volume was not calculated. This is a combination of:

- primarily storages that are not eligible for floodplain harvesting and therefore were not requested or identified
- a small amount that were incorrectly not requested or identified
- a small amount that were not calculated due to data issues.

Given these omissions, the actual volumes are likely to be greater than the estimated volumes. The wet areas of the storages that are missing a capacity curve suggests that they are similar average sizes (90,000 m^2 for observed storages versus 87,000 m^2 for those missing a curve), although those without a curve tend to be shallower surge/temporary storage areas that have a lower area to volume ratio than a typical permanent storage.

Put simply, there are unknowns and scientific uncertainty in the method, but no easy way of correcting or quantifying it.

Translating area to volume errors

There are issues with calculating wet surface area from imagery captured during rain and storm events which bring cloud cover. The sensors and spectral bands used in this analysis to observe water cannot penetrate cloud cover. Therefore, storages were omitted where they were not visible in a phase of imagery acquisition, that is pre, mid, or post-first flush. Further, as cloud moves across the landscape and weather patterns change, different storages were obstructed by cloud and omitted in the different phases.

Sentinel satellite imagery is primarily used. This has a pixel resolution of 10m and a return interval of 5 days. This constrains both aligning image acquisition with key dates and the accuracy of surface area estimation, the later mitigated by factoring after analysing a sample of storages with a higher resolution sensor.

Put simply, satellite imagery has limits due to image resolution or pixel size, and the image availability or the return interval.

Remote sensed components

The following data from each phase of the analysis (pre, mid, post) is available on request:

- Storage ID - Floodplain identifier
- Full supply area – storage curve information
- Full supply volume – storage curve information
- Image – Image date
- Inundated (wet) area – Sentinel observation
- Confirmed to borrow pit – where the area observed is <10% of the full supply volume of the storage
- Estimated volume – Calculation using Sentinel inundated (wet) area
- Revised Planet observation - Calculation using Sentinel inundated (wet) area derived correction factor

This data is available for the floodplains analysed:

- Border Rivers / Macintyre Floodplain
- Gwydir Floodplain
- Upper and Lower Namoi Floodplains
- Macquarie Floodplain
- Barwon-Darling Floodplain.

Water balance - inflow quantification notes

Upper section inflows

Reach section gains were identified to the locations shown in Table 10. These sites were identified as being the last major mainstream site upstream of major diversion and downstream of major tributary inflow. Storage releases are treated as an inflow to the balance.

Table 10: Upper section inflows mainstream gauging sites

Water Source	Site	Mainstream volume (measured)
Border Rivers	Dumaresq River at Glenarbon Weir plus Macintyre River at Holdfast (Yelarbon Crossing)	142,800
Gwydir	Gwydir River at Pallamallawa	81,500
Lower Namoi	Namoi River at Mollee	128,400
Macquarie	Macquarie River at Baroona	235,113[36]

Lower section inflows

Below these measurement points, catchment inflow estimates were provided for Moomin Creek and the Boomi River unregulated systems. The ungauged estimated flow to Boomi Creek is not available to regulated river licence holders, however significant to quantifying total inflows to the Barwon-Darling from the Border Rivers.

Some smaller reach gains were observed in other areas of the catchment from runoff, however in these sections the loss and gain processes both become significant and difficult to individually quantify from flow measurement data.

Some of these observed reach gain observed but not explicitly quantified in the water balance were:

- Namoi water balance: a net gain between Weeta and Bullawa of 4,200 ML was observed (adjusted for Brigalow Creek measured inflow), and a net loss of 1,200 ML between the larger reach of Weeta to Bugilbone. A 1,800 ML net reach gain was observed between Mollee and Gunidgera.
- Gwydir water balance: a net reach gain between Midkin Crossing and Garah of 2,800 ML was observed.

While no direct adjustments were made to the water balance to allow for these gains of smaller magnitude, we recognise a more granular quantification approach to individual reach processes would improve detail for the water balance. As outflows and take are both measured components, any adjustments increasing the inflows presented would also, proportionally increase the system replenishment component as the balancing item.

[36] Where flows/volumes are measured and not estimated the full number is reported and not rounded.

Major storage volume increases

Inflows upstream of major storages were not included in the water balance as they did not contribute to the downstream flows being analysed (storage releases were considered). Table 11 provides the increase volumes to each major storage during the period analysed.

Table 11: Changes to major storage volumes during analysis period

Date and volume (ML)	Pindari Dam	Glenlyon Dam	Keepit Dam	Split Rock Dam	Copeton Dam	Burrendong Dam	Windamere Dam
1/02/2020	12,531	8,569	11,835	6,831	112,922	52,131	98,995
28/04/2020	36,118	35,905	64,590	21,162	187,946	224,869	100,606
Volume increase	23,587	27,336	52,755	14,331	75,023	172,738	1,611
Full supply capacity	312,000	254,310	425,510	397,370	1,361,720	1,190,060	368,120
% increase	8%	11%	12%	4%	6%	15%	0%

Barwon-Darling inflow estimation notes

The targeted method for estimating the total inflow (876,900 ML) to the Barwon-Darling system was to use the mainstream gauging sites reach gains, then add back into this volume the measured reach take once meter readings are finalised. Assumptions and potential ranges for transmissions losses occurring in these reaches may also be approximated. As extraction data was unavailable at the time of this assessment, an initial estimate of 30% was assumed to allow for any flow loss processes with the intent to refine this estimate when more information is available

The absolute reach gains (assuming no loss processes or extraction occurring) between Mogil and Warraweena (last reach gaining site) indicated a minimum of 674,500 ML had entered the system for the period analysed.

The 30% approximation assumed for loss processes was validated by using the tributary gauge measurements on the unregulated systems directly contributing and additionally the outflows from the regulated water sources presented in the water balance. These measurements indicated an inflow volume of 861,575 ML. Tributary measurements on the Warrego (at Dick's Dam) of 43,166 ML and Narran River (Bundah) of 29,295 ML, were excluded for this approximation as significant interception was assumed downstream of these locations prior to meeting the Barwon-Darling system. This approximation from tributary gauging sites also assumes no loss between the gauging measurement and flow entering the Barwon Darling, and does not allow for further contributions from unmeasured tributary flows.

Table 12: Barwon-Darling unregulated tributary flow

Site	Name	Flow	Comment
417001	Moonie River at Gundablouie	75,691	
422031	Narran River @ Bundah	29,295	Significant interception assumed between site and Barwon-Darling River
422005	Bokhara River at Bokhara (Goodwins)	32,206	
422006	Culgoa River at D/S Collerina (Kenebree)	175,871	
423007	Warrego River at Dicks Dam	43,166	Significant interception assumed between site and Barwon-Darling River
420020	Castlereagh River at Gungalman	189,426	
421011	Marthaguy Creek at Carinda	90,203	
421023	Bogan River at Gongolgon	40,905	

Table 13: Barwon-Darling regulated rivers tributary inflow

Water source	Outflow (ML)
Border Rivers (including Boomi River estimate)	92,506
Gwydir	52,210
Namoi	96,093
Macquarie	16,464

Figure 5: Major unregulated catchment inflow to the Barwon Darling

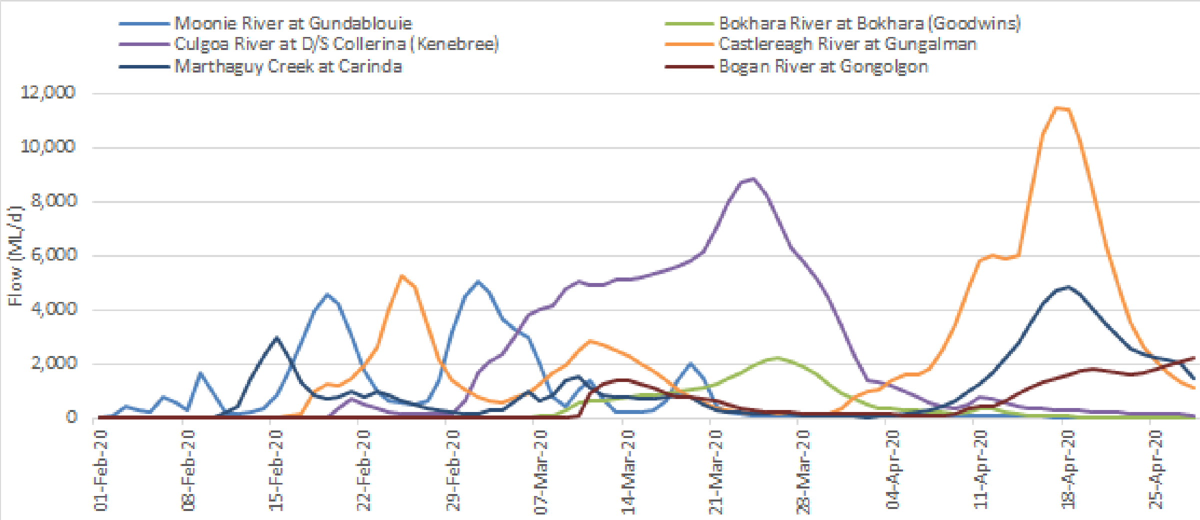


Figure 6: Regulated river inflow to the Barwon-Darling event (including Boomi River estimate)

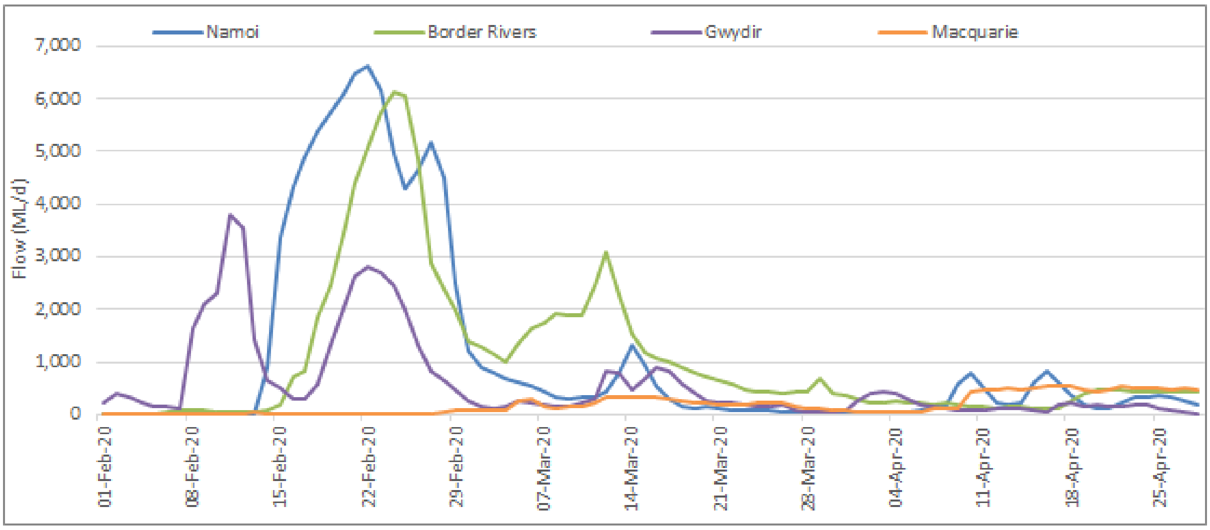
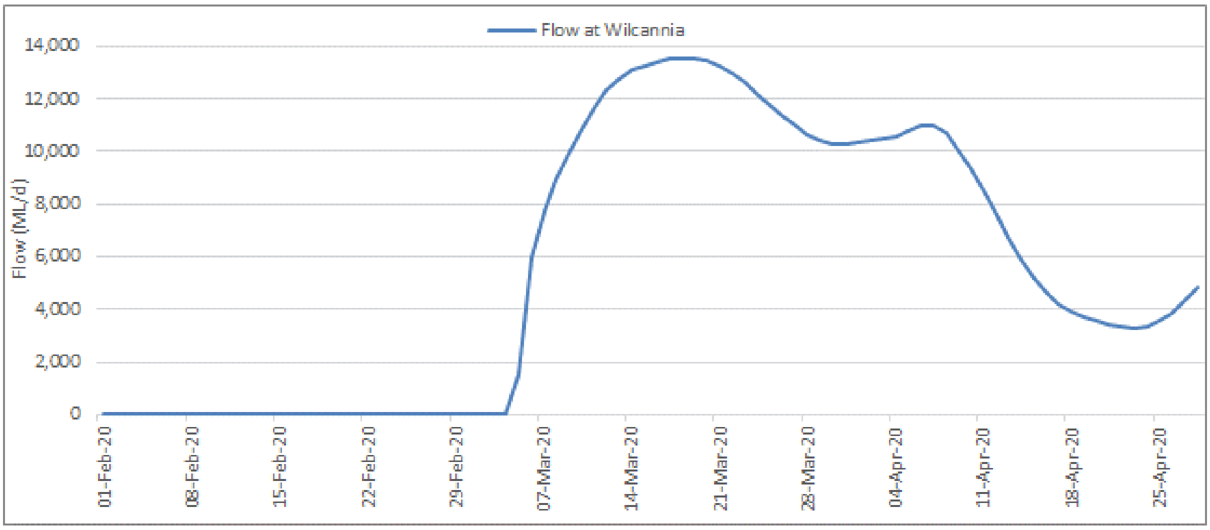


Figure 7: Flow at Wilcannia



Water balance components

Border Rivers water balance components

1 February to 29 February 2020

Inflows	Extractions (NSW)		Extractions (QLD)		Replenishments		Outflows	
ML	ML	% inflow	ML	% inflow	ML	% inflow	ML	% inflow
163,760	8,831	5%	27,200	17%	77,588	47%	50,140	31%

1 February to 28 April 2020

Inflows	Extractions (NSW)		Extractions (QLD)		Replenishments		Outflows	
ML	ML	% inflow	ML	% inflow	ML	% inflow	ML	% inflow
200,781	9,929	5%	27,200	14%	71,146	35%	92,506	46%

Balance inputs

Inflow (estimated)	Component	Flow		Reach gains	
	Macintyre Catchment	Feb	Feb-Apr	Feb	Feb-Apr
416067	Severn River at Ducca Marrin	554	1,563		
416006	Severn River at Ashford	6,815	10,491	6,262	8,928
416012	Macintyre River at Holdfast	19,405	26,902	12,590	16,411
			Reach gain total	18,851	25,339
			Measured section inflows	13,386	19,316
	Macintyre estimated inflow	5,465	6,023		
	Dumaresq				
416011	Dumaresq River at Roseneath	74,391	86,104		
416007	Dumaresq River U/S Bonshaw Weir	85,263	103,178	10,872	17,075
416040	Dumaresq River at Glenarbon Weir	97,163	115,905	11,901	12,727
			Reach gain total	22,773	29,802
			Measured section inflows	8,783	13,685
	Dumaresq estimated inflow	13,989	16,116		
	Boomi catchment				
	Unregulated inflow estimate	2,200	7,800	*	
	Total inflow (estimated)	21,655	29,940		

* volume does not contribute to regulated river system

Inflows (measured)	Gauging site name			Feb	Feb-Apr
416415A	Macintyre Brook at Booba Sands			21,125	21,690
416021	Frazers Creek at Westholme (Ashford)			3,906	6,483
416008	Beardy River at Haystack			8,783	13,685
416010	Macintyre River at Wallangra			9,480	12,833
416011	Dumaresq River at Roseneath			74,391	86,104
416067	Severn River at Ducca Marrin			554	1,563
416207A	Weir River at Mascot			23,866	28,483
	Total Inflows (measured)			142,105	170,842
	Total inflow (measured and estimated)			163,760	200,781

Outflow (measured)	Gauging Site			Feb	Feb-Apr
416001	Barwon River at Mungindi			40,540	75,806

Outflow (estimated)	Component			Feb	Feb-Apr
	Boomi River			9,600	16,700
	Total outflow estimate			50,140	92,506

	Licence Category			Feb	Feb-Apr
Consumptive extractions	Domestic And Stock			89	177
	Domestic And Stock [Domestic]			0	0
	Domestic And Stock [Stock]			0	10
	Local Water Utility			53	75
	Regulated River (General Security A)			0	12
	Regulated River (General Security B)			2	2
	Regulated River (High Security)			0	0
	Supplementary Water			8,688	9,653
	Total consumptive extractions (NSW)			8,831	9,929
	Total consumptive extractions (QLD)			27,200	27,200
	Total consumptive extractions			36,031	37,129

Held environmental usage				Feb	Feb-Apr
	Total held environmental water usage			0	0

Gwydir water balance components

1 February to 29 February 2020

Inflows	Extractions		Replenishments		Outflows	
ML	ML	% inflow	ML	% inflow	ML	% inflow
60,010	5,202	9%	16,728	28%	38,080	63%

1 February to 28 April 2020

Inflows	Extractions		Replenishments		Outflows	
ML	ML	% inflow	ML	% inflow	ML	% inflow
100,825	17,911	18%	30,704	30%	52,210	52%

Balance inputs

Inflow	Component	Flow		Reach gains	
	Upper Gwydir	Feb	Feb-Apr	Feb	Feb-Apr
418026	Gwydir River Downstream Copeton Dam	1,193	3,304		
418012	Gwydir River at Pinegrove	6,725	14,305	5,532	11,001
418013	Gwydir River at Gravesend Road Bridge	45,318	66,410	38,593	52,105
418001	Gwydir River at Pallamallawa	50,685	81,511	5,367	15,101
	Reach gain total			49,492	78,207
	Measured section inflows			27,207	36,028
	Ungauged inflow estimate upper Gwydir			22,285	42,179
	Moomin catchment				
418048	Moomin Creek at Combadello Cutting	2,451	5,034		
418060	Moomin Creek at Glendello	2,944	6,162	493	1,128
418067	Moomin Creek at Clarendon Bridge (Heathfield)	3,542	7,328	598	1,166
418061	Moomin Creek at Alma Bridge (Derra Road)	8,636	13,362	5,094	6,034
418070	Moomin Creek at Moomin Plains	6,082	9,168	(2,553)	(4,194)
	Moomin inflow estimate			6,185	8,328
	Total inflow (estimated)			28,470	50,508

Inflows	Gauging Site	Feb	Feb-Apr
418025	Halls Creek at Bingara	373	489
418015	Horton River at Rider	22,050	29,381
418017	Myall Creek at Molroy	4,784	6,158
418032	Tycannah Creek at Horseshoe Lagoon	910	3,105
416054	Gil Gil Creek at Boolataroo	2,193	7,813
	Copeton Dam releases	1,230	3,372
	Total inflow (measured)	31,540	50,318
	Total inflow (measured and estimated)	60,010	100,825

Outflow	Gauging Site	Feb	Feb-Apr
418070	Moomin Creek at Moomin Plains	6,082	9,168
418058	Mehi River at Bronte	22,275	25,289
416052	Gil Gil Creek at Galloway	9,723	17,753
	Total outflow (measured)	38,080	52,210

	Licence Category	Feb	Feb-Apr
Consumptive extractions	Domestic And Stock	31	237
	Domestic And Stock [Stock]	9	20
	Local Water Utility	-	14
	Regulated River (General Security)	182	184
	Regulated River (High Security)	1,095	1,945
	Supplementary Water	3,884	15,512
	Total	5,202	17,911

	Licence category	Feb	Feb-Apr
Held environmental usage	Regulated River (General Security)	-	-
	Regulated River (High Security)	-	-
	Supplementary Water	3,448	3,698
	Total		3,698

Namoi water balance components

1 February to 29 February 2020

Inflows	Extractions		Replenishments		Outflows	
ML	ML	% of inflow	ML	% of inflow	ML	% of inflow
122,030	3,681	3%	42,285	35%	76,063	62%

1 February to 28 April 2020

Inflows	Extractions		Replenishments		Outflows	
ML	ML	% of inflow	ML	% of inflow	ML	% of inflow
132,826	10,945	8%	25,788	19%	96,093	72%

Balance inputs

Inflow (estimated)	Component	Flow		Reach gains	
	Upper estimate (Keepit to Narrabri)	Feb	Feb-Apr	Feb	Feb-Apr
419007	Namoi River at Downstream Keepit Dam	-	210		
419001	Namoi River at Gunnedah	53,441	62,083	53,441	61,874
419012	Namoi River at Boggabri	79,156	90,882	25,716	28,798
419003	Narrabri Creek at Narrabri	103,403	116,844	24,247	25,962
419039	Namoi River at Mollee	119,363	128,465	15,960	11,622
			Reach gain total	119,363	128,256
			Measured section inflows	89,539	101,605
	Ungauged inflow estimate upper Namoi (estimated)			29,824	26,651

Inflows (measured)	Gauging Site	Feb	Feb-Apr
419006	Peel River at Carroll Gap	46,434	53,747
419084	Mooki River at Ruvigne	9,488	10,780
419032	Coxs Creek at Boggabri	24,509	27,307
419083	Brigalow Creek at Tharlane	2,667	4,361
419051	Maules Creek at Avoca East	9,109	9,770
419007	Namoi River at Downstream Keepit Dam	-	210
	Total inflow (measured)	92,206	106,175
	Total inflow (measured and estimated)	122,030	132,826

Outflow (measured)	Gauging Site	Feb	Feb-Apr
419026	Namoi River at Goangra	75,364	91,923
419049	Pian Creek at Waminda	699	4,170
	Total outflow (measured)	76,063	96,093

	Licence Catgeory	Feb	Feb-Apr
	Domestic And Stock	381	478
	Domestic And Stock [Domestic]	2	2
	Domestic And Stock [Stock]	-	-
	Regulated River (General Security)	419	1,536
	Regulated River (High Security)	63	294
	Regulated River (High Security) [Research]	365	365
Consumptive extractions	Supplementary Water	2,452	8,271
	Total	3,681	10,945

Held environmental usage		Feb	Feb-Apr
	Total held environmental water usage	0	0

Macquarie water balance components

1 February to 29 February 2020

Inflows	Extractions		Replenishments		Outflows	
ML	ML	% of inflow	ML	% of inflow	ML	% of inflow
76,019	13,083.0	17%	62,321	82%	615	1%

1 February to 28 April 2020

Inflows	Extractions		Replenishments		Outflows	
ML	ML	% of inflow	ML	% of inflow	ML	% of inflow
235,113	30,819.9	13%	187,828	80%	16,464	7%

Balance inputs

Inflow (estimated)	Component	Flow		Reach gains	
	Burrendong to Baroona	Feb	Feb-Apr	Feb	Feb-Apr
421040	Macquarie River At Downstream Burrendong Dam	1,857	3,993		
421001	Macquarie River At Dubbo	6,767	47,180	4,910	43,187
421127	Macquarie River At Baroona	76,019	235,113	69,252	187,933
	Reach gain total			74,162	231,120
	Measured section inflows			58,275	158,313
	Total inflow (estimated)			15,887	72,807

Inflows (measured)	Gauging Site	Feb	Feb-Apr
421040	Macquarie River At Downstream Burrendong Dam	1,857	3,993
421042	Talbragar River At Elong Elong	54,569	121,311
421048	Little River At Obley No.2	385	7,580
421018	Bell River At Newrea	496	8,477
421055	Coolbaggie Creek At Rawsonville	2,826	20,945
	Total inflow (measured)	60,132	162,306
	Total inflow (measured and estimated)	76,019	235,113

Outflow (measured)	Gauging Site	Feb	Feb-Apr
421107	Marra Creek at Billybingbone Bridge	58	13,664
421012	Macquarie River at Carinda (Bells Bridge)	134	2,801
	Total outflow (measured)*	615	16,464

	Licence Category	Feb	Feb-Apr
Consumptive extractions	Domestic And Stock	49	173
	Domestic And Stock [Domestic]	0	0
	Domestic And Stock [Stock]	0	0
	Local Water Utility	311	844
	Regulated River (General Security)	17	140
	Regulated River (High Security)	479	635
	Regulated River (High Security) [Research]	0	0
	Supplementary Water	12,227	29,028
	Total	13,083	30,820

	Licence category	Feb	Feb-Apr
Held environmental usage	Regulated River (General Security)	0	0
	Supplementary Water	1,375	4,583
	Total	1,375	4,583