MEMO

To:	Stantec
From:	Agrimin Technical Team
Subject:	Long-term lake groundwater monitoring
Date:	13 November 2021

1. Overview

Lake Mackay hosts a dynamic groundwater system that fluctuates in response to seasonal variations and long-term weather cycles. Regular and long-term water level measurements enable characterisation of baseline lake conditions, calibration of groundwater models and evaluation of groundwater fluctuations over time in response to weather events and climate change.

A network of eleven monitoring bores equipped with data loggers have been established across the lake. Details of these bores are summarised in Table 1. The bores are installed to depths of between 9 m to 30 m in the surficial unconfined lakebed sediments. Monitoring locations were selected based on their geographical distribution across the lake surface (Figure 1) and bore collar photos are shown in Figure 4. Two monitoring bores are located on large islands in the eastern region of the lake. Collectively, these locations provide data from a range of lake elevations, surficial sediment types and geomorphological features.

Meteorological data used for the interpretation of groundwater trends and fluctuations are sourced from two monitoring locations. Local weather is recorded at the Pilot Pond weather station located on the southern shoreline of the lake (Figure 1 and 2). Weather records from this station are available from 2017. Due to its proximity to the lake, this station provides the best correlations between weather events and groundwater level fluctuations although it must be noted that monitoring bore locations on the lake may be up to 60km from the weather station. The Bureau of Meteorology's Walungurru weather station located 100 km south east of Lake Mackay at the township of Kintore has weather records dating back to 1994. Weather data from this station has been used to correlate large regional rainfall events to groundwater level fluctuations observed on the lake between 2015 and 2017, prior to the Pilot Pond weather station being installed. Data for the two stations is presented in Figure 3.

Table 1 – Monitoring bore summary

Bore ID	Hole Depth (m)	Location Description	Record Start
MA02	16.7	Western region	2015
MA05	18.7	Western region	2016
MA09	30	Eastern region	2016
MA13-A	26	Eastern region	2015
MA13-B	6	Eastern region	2015
MC01	10.4	Western region	2019
MC05	9.75	Lake island	2018
MC13	11.25	Lake island	2017
MC37-Deep	11.25	Western region	2018
MC46-Shallow	6	Western region	2018
MC46-Deep	11.25	Western region	2018

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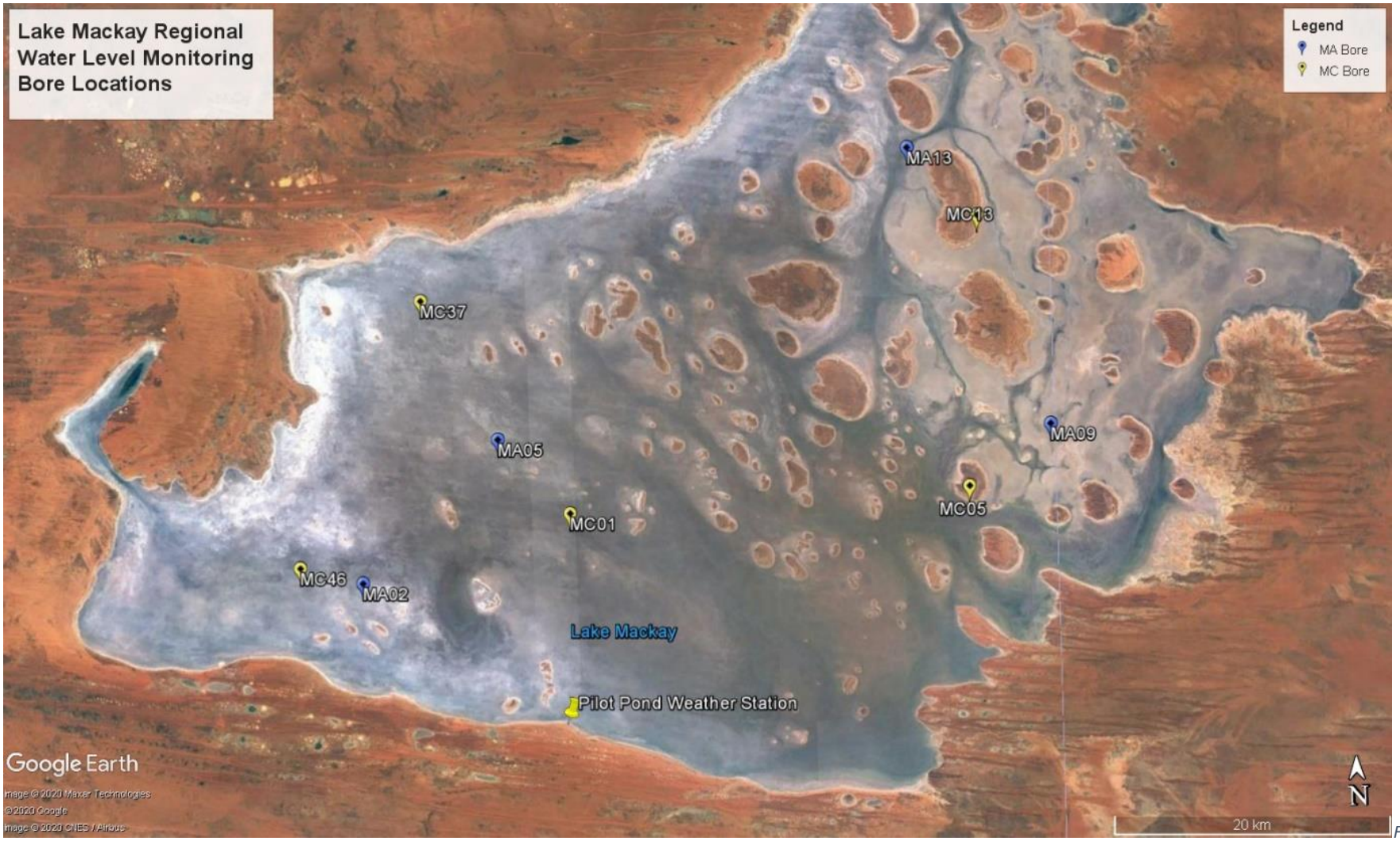

Figure 1 – Regional water level monitoring bore locations

Figure 2 – Pilot Pond weather station

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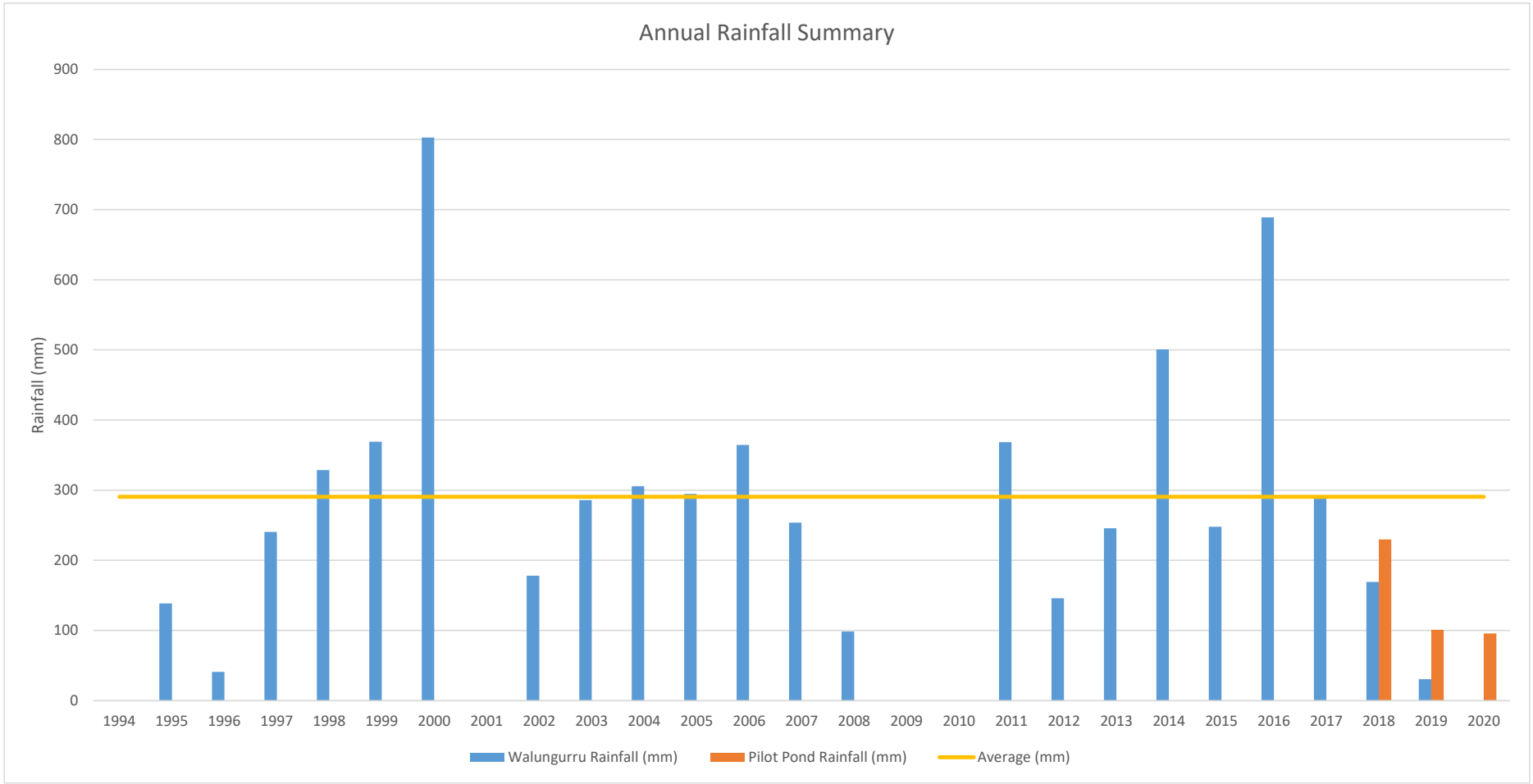

Figure 3 – Walungurru annual rainfall (BOM, 2020)

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Figure 4 – Regional monitoring bore collars. (A) MA02, (B) MA09, (C) MA13B, (D) MC46-Deep, (E) MA05, (F)MA13A, (G) MC05, (H) MC46-Shallow

2. Monitoring Regime

Data loggers were programmed to record water level measurements at either 6, 12- or 24-hour intervals. Downloads were periodically conducted, and the data processed to produce hydrographs for each location. Manual water level measurements were recorded at the time of download to enable manual off-set adjustments to the logger data if required. Barometric corrections were applied to the logger data to account for variations in atmospheric pressure. All data presented in the hydrographs has been filtered to show daily measurements only to allow for direct comparison between plots and weather records. Collar photos of the bores are shown above in Figure 4.

3. Hydrographs

Monitoring bore hydrographs are presented in Appendix A.

3.1 MA02

MA02 is located in the western region of the lake which corresponds to a zone of low infiltration (Figure 1). Monitoring at this location began in September 2015 and is one of the longest continuous groundwater records for the lake.

From 09/2015 to 06/2017 there is only a minor decline seen in water levels during the 2016 dry season. For the remainder of the interval the trend is flat indicating that rainfall recharge and evaporative discharge were balanced resulting in no net water level decline for the interval. This corresponds directly to a period of above average rainfall (Figure 3). Significant water level declines are observed over the 2017, 2018, 2019 and 2020 dry seasons. The decline observed is due to the below average rainfall received by the region during this period.

*Data logger failed 14/05/2020

3.2 MA05

MA05 is located in the western region of the lake which corresponds to a zone of low infiltration. The bore shows an immediate response to rainfall events followed by a rapid decrease. Water levels are sustained throughout the wet season and decline during the dry season. Two events, 03/2017 and 05/2020 show the effect of unseasonal rainfall on groundwater level trends. In both instances, the groundwater levels increase and decreased sharply, with the dry season declining trend resuming once levels had stabilized. The hydrograph shows an overall declining water level for the monitoring period at this location.

3.3 MA09

MA09 is located in the eastern region of the lake in a zone of very high infiltration. The bore shows a more subtle response to rainfall events, with exception to a large inundation event in December 2016. This greater response is due to the high infiltration capacity of the surface sediments at this location allowing water to rapidly infiltrate and affect the groundwater levels. Possible surface inundation may have also occurred as a result of this >200mm rainfall event. The remaining period of the hydrograph shows an overall declining water level trend. Barometric correction was applied to the data from April 2019 resulting in a smoother trend for the remainder of the monitoring period.

3.4 MA13A & MA13B

MA13A/B show a declining water level trend over the 2015-2019 monitoring interval. Seasonal fluctuations are marked by frequent spikes in water level due to rainfall events in the wet season, and a gradual decline in water levels during the dry season.

3.5 MC01

MC01 is located in the central western region of the lake in a low infiltration zone. The data shows a strong correlation between the wet-dry season cycle and groundwater level fluctuations. The graph shows immediate water level responses to rainfall inundation. The overall water level trend for the bore is a slight decline.

3.6 MC05

MC05 is located on a medium lake island in the eastern high infiltration zone of the lake. The hydrograph shows a gradual increase in groundwater levels over the 2018-2019 wet season followed by a gradual decline in the following 2020 dry season. Barometric corrections were applied to the data from April 2019 onwards. The increasing water level trend of the graph is attributed to the relatively short monitoring interval. Once several wet-dry season cycles are added to the data set it is predicted that the trend will show an overall decline, consistent with the other long-term monitoring bores.

There is a significant water level increase recorded on 03/03/2020 which coincides with a 20 mm rainfall event recorded by the pilot pond weather station. This sharp water level increase is followed by a rapid water level decline, likely a result of groundwater equalisation and dispersion following the rainfall event, however the linear trend may also be an artefact of barometric correction. Additional data for this monitoring location will help understand the significance of this anomaly.

3.1 MC13

MC13 is located on a large landform island in the north eastern high infiltration zone of the lake. The hydrograph shows a gradual water level decrease over the entire monitoring period (approx 60cm over almost 3 years). There are no sharp water level spikes in the hydrograph.

3.2 MC37-Deep

MC37-Deep is in the north western region of the lake. The hydrograph for this location shows a strong correlation between rainfall events and groundwater level spikes after rainfall events. Water levels recede following these events.

This region of the lake is topographically higher than the rest of the lake area however due to the prevailing wind direction, the area is frequently inundated by wind blow water migrating over the lake surface. As a result, this region is more likely to experience a higher frequency and duration of inundation. The trendline shows a gradual increase in water level however this is due to the short recording interval. Additional wet-dry season data will result in an overall declining trend that is consistent with other monitoring bore locations.

3.3 MC46-Shallow

MC46-Shallow is located in the western region of the lake. The monitoring bore shows immediate responses to rainfall events. The hydrograph shows an overall increasing water level trend however this is attributed to the short monitoring period and is expected to show an overall decline once subsequent wet-dry season cycles have been recorded.

3.4 MC46-Deep

MC46-Deep shows an overall increasing water level trend for the monitoring period. The seasonal trend of the hydrograph is opposite to what has been seen in other plots, whereby there is a decrease in the water level over the wet season and an increase during the dry season. This is likely attributed to the fact that the bore has only 1 length of slotted casing at the base of the hole and has a bentonite

seal to surface. There are several sharp peaks throughout the log that correspond to rainfall events indicating that under some conditions, the water level of the bore is immediately affected by rainfall events.

Logger failed 30/04/2020

4. Discussion and Conclusions

- There is a strong correlation between groundwater fluctuations and seasonal variation in the monitoring bore data. Water levels fluctuate approximately 0.30 m to 0.5 m between the November to April wet season and the May to October dry season. The lake groundwater levels sharply increase in response to the first major rainfall event of the wet season. Sharp spikes in the hydrographs indicate a rapid rise in the groundwater level, typically associated with inundation in the immediate vicinity of the bore. These peaks decline as the water equalizes with the lake water table. As rainfall frequency decreases toward the end of the season, the lake water levels begin to recede in response to groundwater discharge via evaporation. This gradual decline in water level continues until the cycle resets at the commencement of the following wet season.
- Hydrographs for bores located on lake islands (MC13 and MC05) do not display the same sharp level increases in response to rainfall events however MC05 has shown some sharp responses to 1 rainfall event. The bores are not directly influenced by surface inundation due to their elevation above the surface of the lake.
- The long-term hydrographs show an overall declining groundwater trend in the water levels over the wet season-dry season cycles. This trend has been attributed to the below average rainfall received by the region since detailed groundwater monitoring began. The 25-year average rainfall for the region is 290.5 mm (BOM, 2020). Rainfall for the previous two years of monitoring has been significantly below average, with 169 mm received in 2018 and 30.4 mm for 2019. Data for the 2020 period is not yet complete however to date the amount of rainfall received has been below average (Figure 3).
- The composition and physical properties of the surface sediments in the vicinity of the monitoring bores appears to influence how the water levels in the bores respond to inundation. Bores in regions of low infiltration with sediments dominated by silty clay at the surface appear to show rapid water level increases due to inundation (MA02, MA05, MC37). Bores in regions of high infiltration with gypsiferous surface sediments lack the spikes associated with rainfall, as rainfall in these areas infiltrates before it can inundate the surface resulting in a more gradual water level response (MA09).
- The comparison of rainfall events at the Pilot Pond weather station and/or Walungurru are guides only, the vast distance between monitoring bores and these recording stations must be taken into consideration during interpretation.

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5. Regional Monitoring Summary

ID	Record Start	Data Duration (years)	Location/Lake Region	Surface Description/Characteristics	Summary of Observations
MA02	2015	5	Western region	Fine silt and clay Low infiltration rate	• Declining water level trend • Immediate response to rainfall • Logger failed at last download
MA05	2016	4	Western region	Fine silt and clay Low infiltration rate	• Declining water level trend • Immediate response to rainfall
MA09	2016	4	Eastern region	Coarse gypsum sand High infiltration rate	• Declining water level trend • Likely surface inundation occurred Jan-May 2017
MA13A	2015	5	North eastern region	Fine silt and clay Low infiltration rate	• Declining water level trend • Delayed response to rainfall
MA13B	2015	5	North eastern region	Fine silt and clay Low infiltration rate	• Declining water level trend • Immediate response to rainfall
MC13	2019	4	North eastern region (island)	Aeolian sand High infiltration rate	• Declining water level trend • No direct response to rainfall
MC05	2018	2	Eastern region (island)	Aeolian sand	• Increasing water level trend (biased due to short duration of monitoring period). • No direct response to rainfall with exception to March 2020 event.
MC37-Deep	2017	2	North western region	Fine silt and clay Low infiltration rate	• Slight increasing water level trend (biased due to short duration of monitoring period) • Immediate response to rainfall events
MC46-Shallow	2018	2.5	Western region	Fine silt and clay Low infiltration rate	• Slight increasing water level trend (biased due to short duration of monitoring period) • Immediate response to rainfall events
MC46-Deep	2018	2.5	Western region	Fine silt and clay Low infiltration rate	• Slight increasing water level trend (biased due to short duration of monitoring period) • Immediate response to rainfall events • Logger failed at last download

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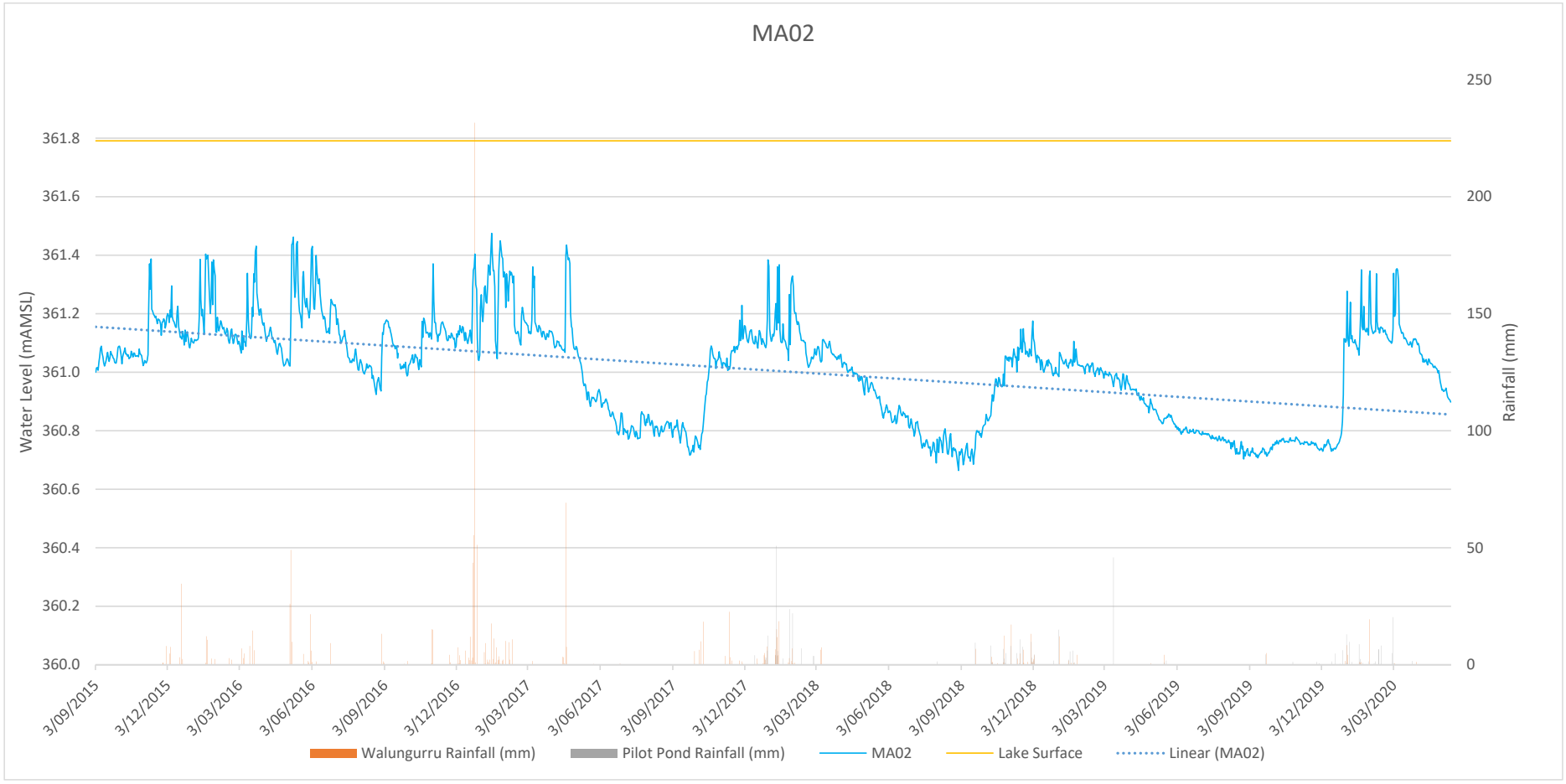
Appendix A-Hydrographs

MA02



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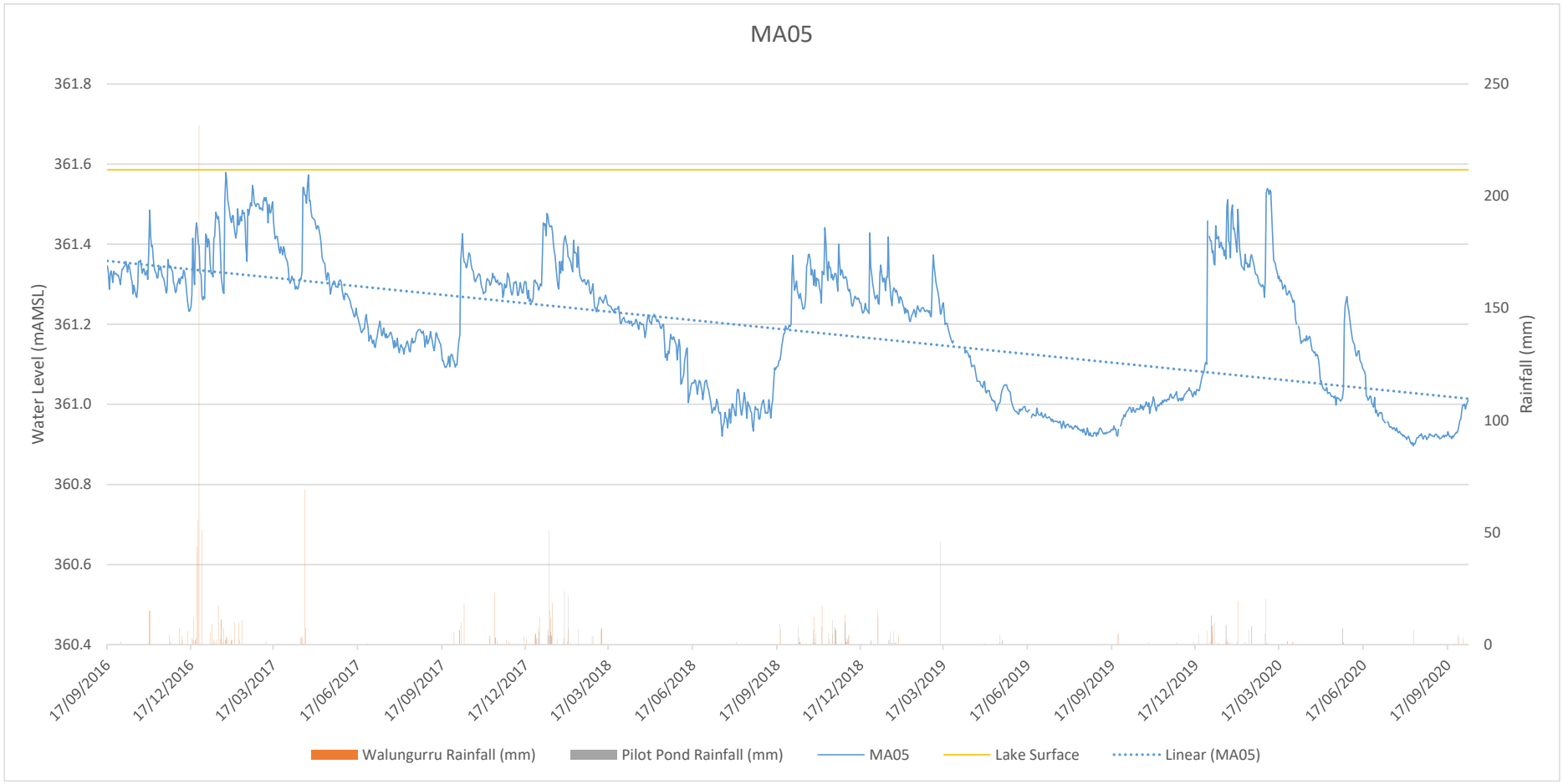
MA05


MA05
Water Level (mAMSL)
Rainfall (mm)
361.8
361.6
361.4
361.2
361.0
360.8
360.6
360.4
250
200
150
100
50
0
17/09/2016
17/12/2016
17/03/2017
17/06/2017
17/09/2017
17/12/2017
17/03/2018
17/06/2018
17/09/2018
17/12/2018
17/03/2019
17/06/2019
17/09/2019
17/12/2019
17/03/2020
17/06/2020
17/09/2020
Walungurru Rainfall (mm)
Pilot Pond Rainfall (mm)
MA05
Lake Surface
Linear (MA05)

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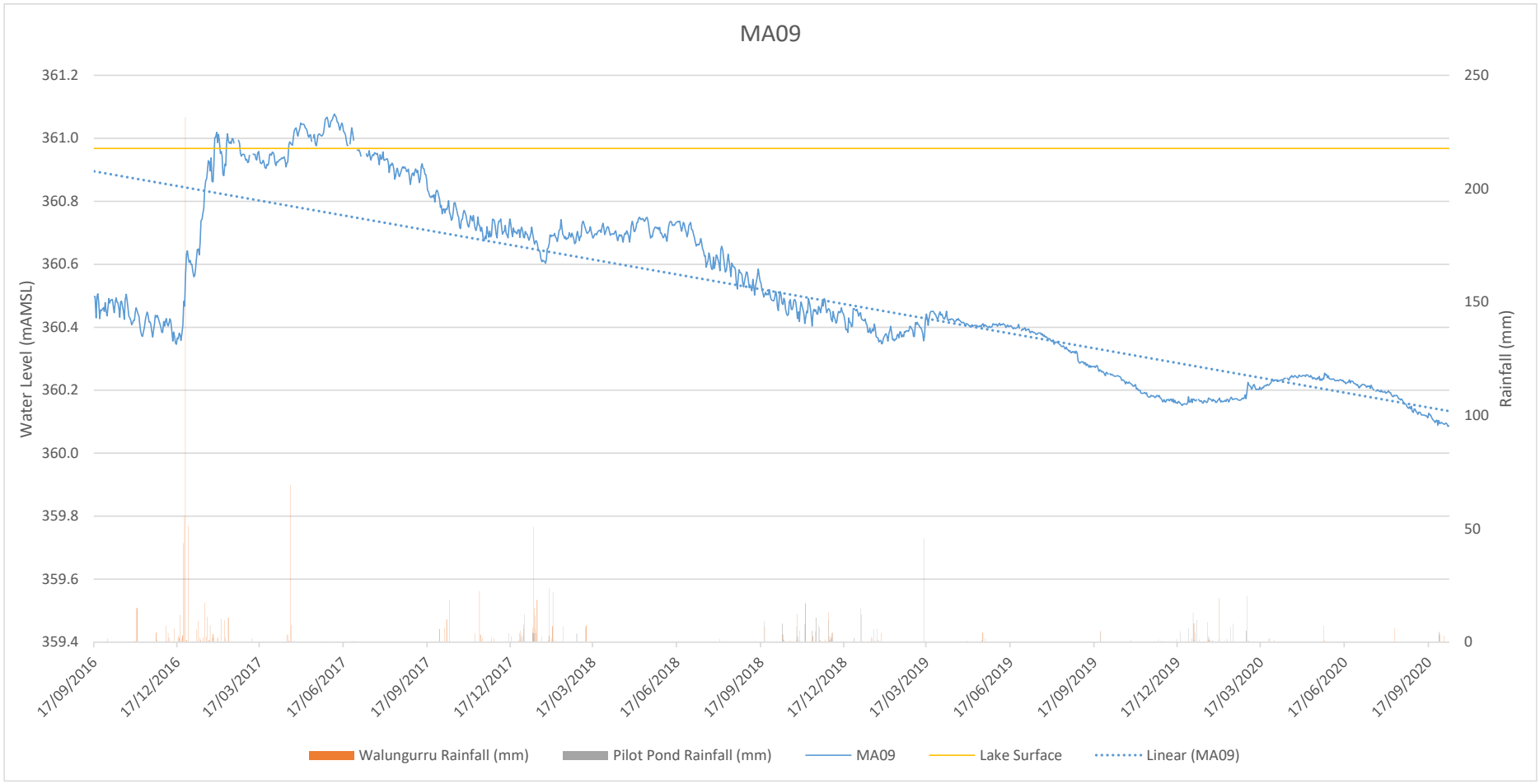
MA09


MA09
Water Level (mAMSL)
Rainfall (mm)
361.2
361.0
360.8
360.6
360.4
360.2
360.0
359.8
359.6
359.4
250
200
150
100
50
0
17/09/2016
17/12/2016
17/03/2017
17/06/2017
17/09/2017
17/12/2017
17/03/2018
17/06/2018
17/09/2018
17/12/2018
17/03/2019
17/06/2019
17/09/2019
17/12/2019
17/03/2020
17/06/2020
17/09/2020
Walungurru Rainfall (mm)
Pilot Pond Rainfall (mm)
MA09
Lake Surface
Linear (MA09)

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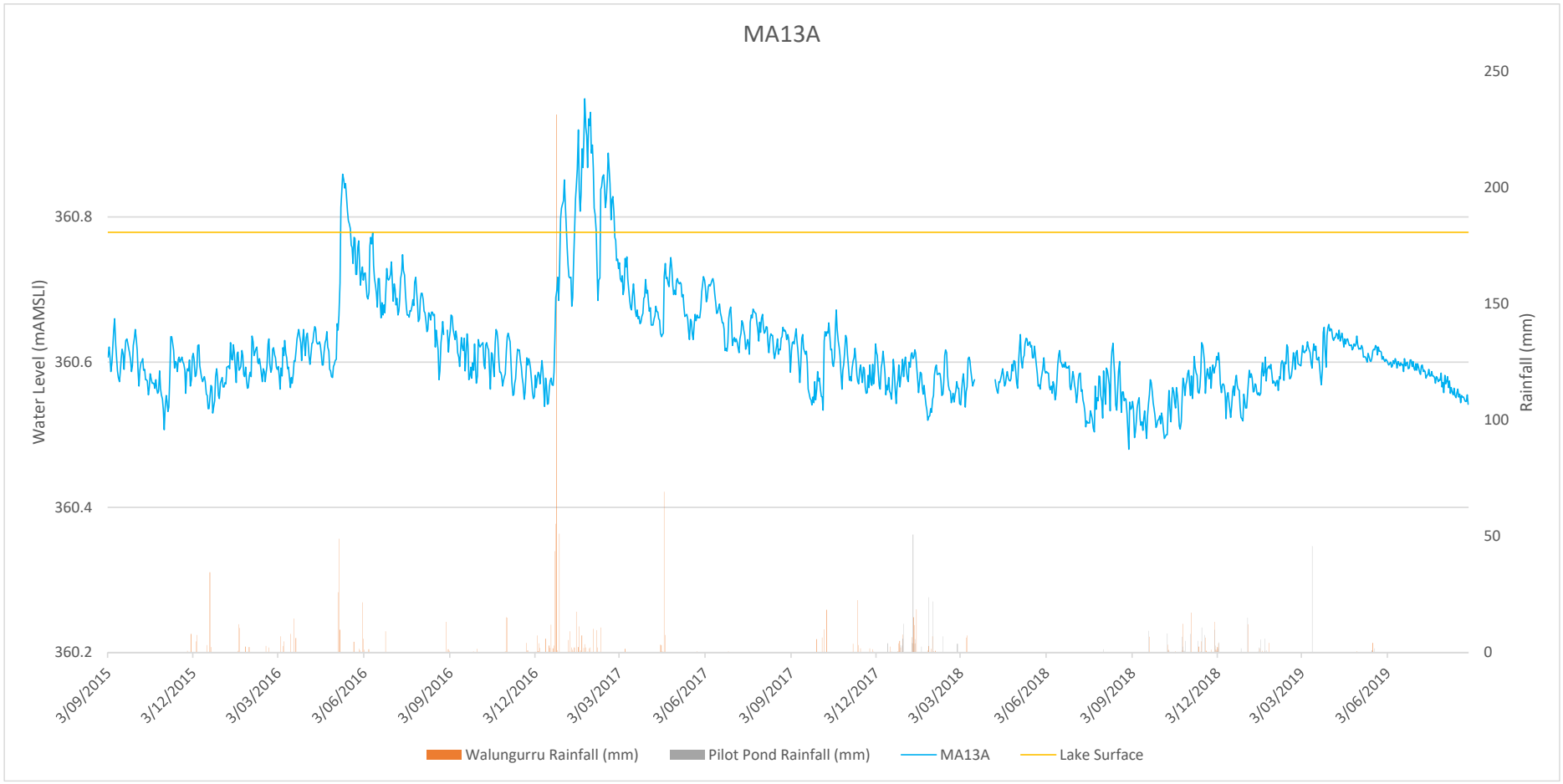
MA13A


MA13A
Water Level (mAMSLI)
Rainfall (mm)
360.8
360.6
360.4
360.2
250
200
150
100
50
0
3/09/2015
3/12/2015
3/03/2016
3/06/2016
3/09/2016
3/12/2016
3/03/2017
3/06/2017
3/09/2017
3/12/2017
3/03/2018
3/06/2018
3/09/2018
3/12/2018
3/03/2019
3/06/2019
Walungurru Rainfall (mm)
Pilot Pond Rainfall (mm)
MA13A
Lake Surface

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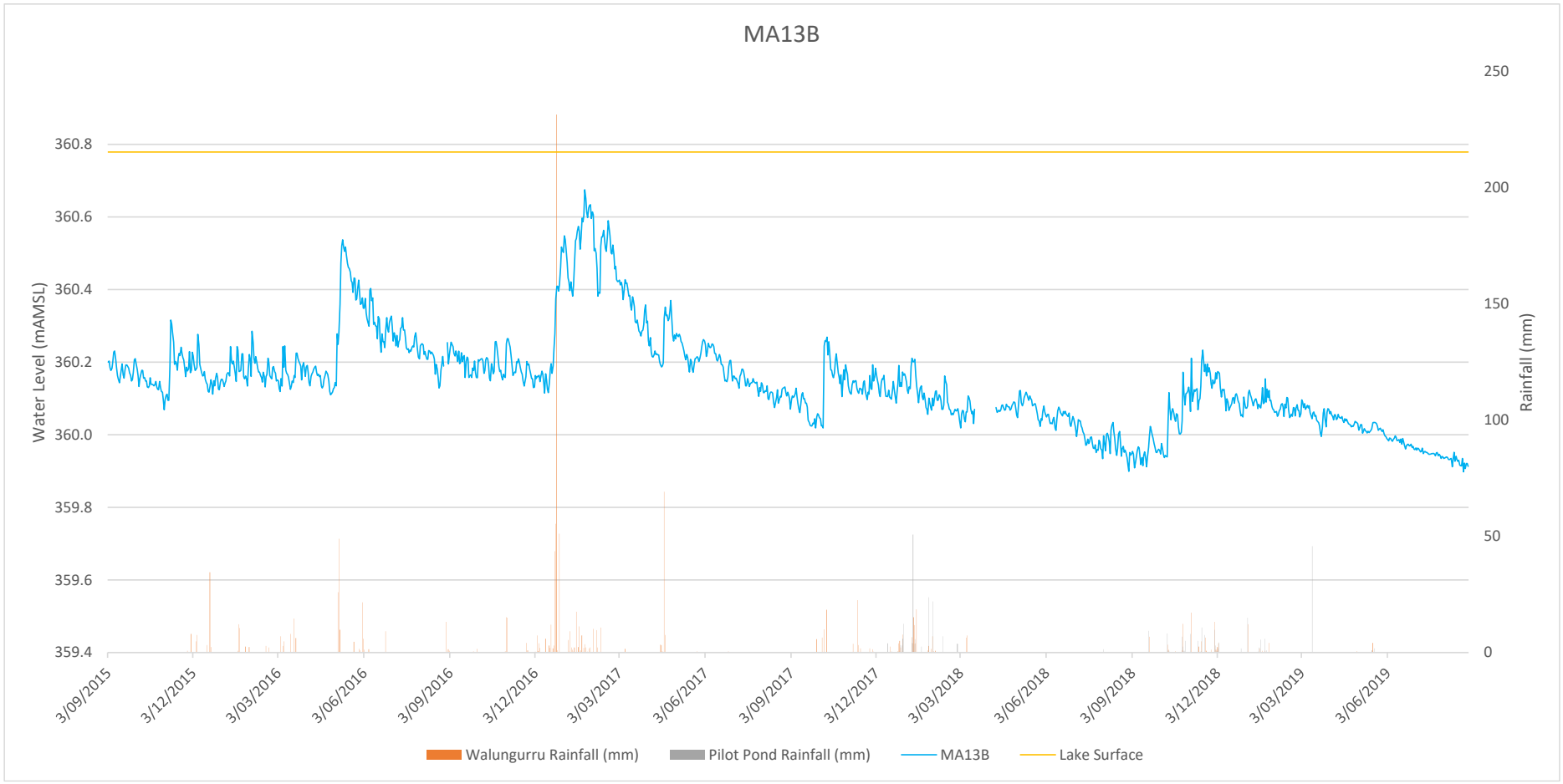
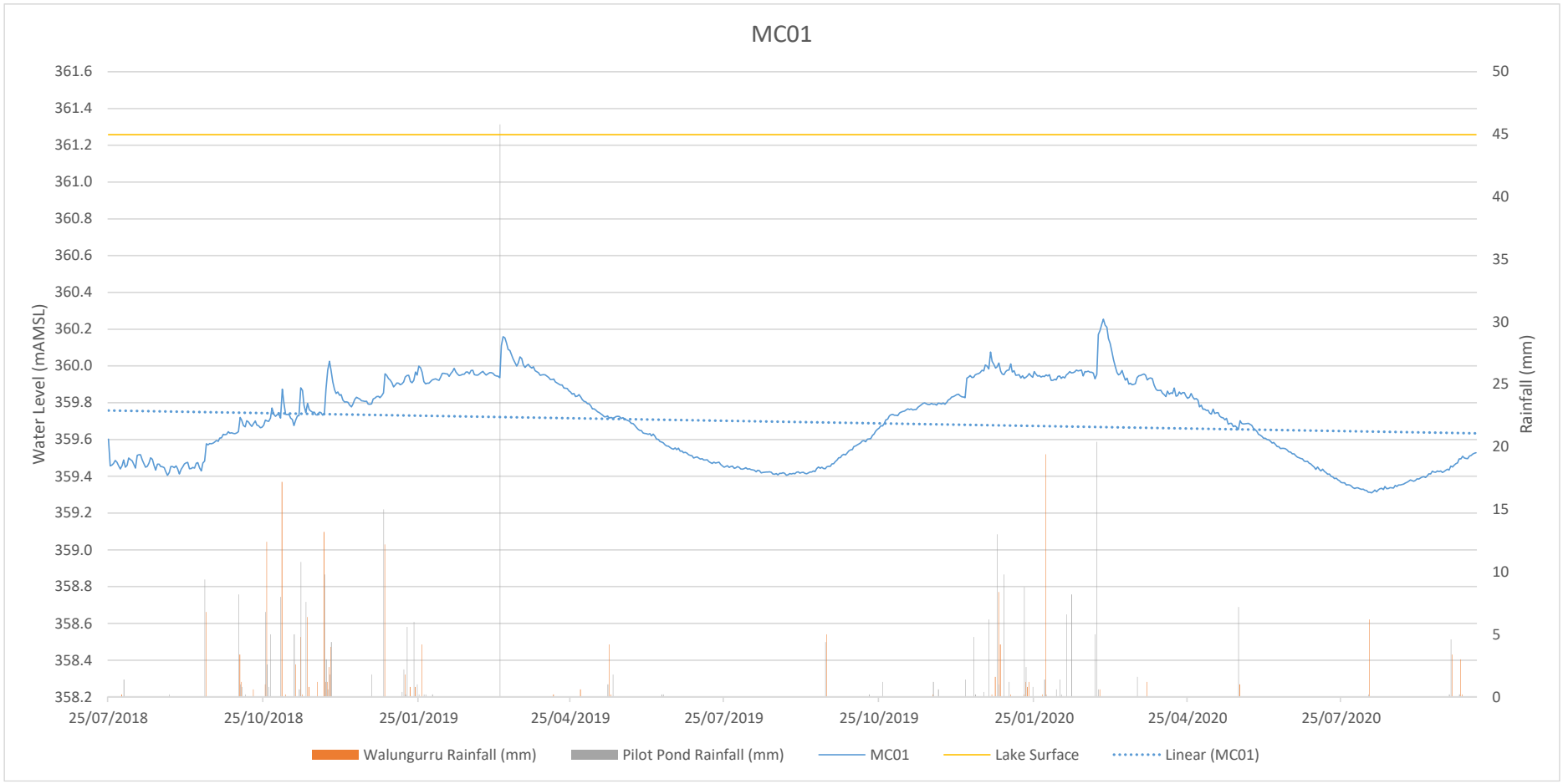
MA13B


MA13B
Water Level (mAMSL)
Rainfall (mm)
360.8
360.6
360.4
360.2
360.0
359.8
359.6
359.4
250
200
150
100
50
0
3/09/2015
3/12/2015
3/03/2016
3/06/2016
3/09/2016
3/12/2016
3/03/2017
3/06/2017
3/09/2017
3/12/2017
3/03/2018
3/06/2018
3/09/2018
3/12/2018
3/03/2019
3/06/2019
Walungurru Rainfall (mm)
Pilot Pond Rainfall (mm)
MA13B
Lake Surface

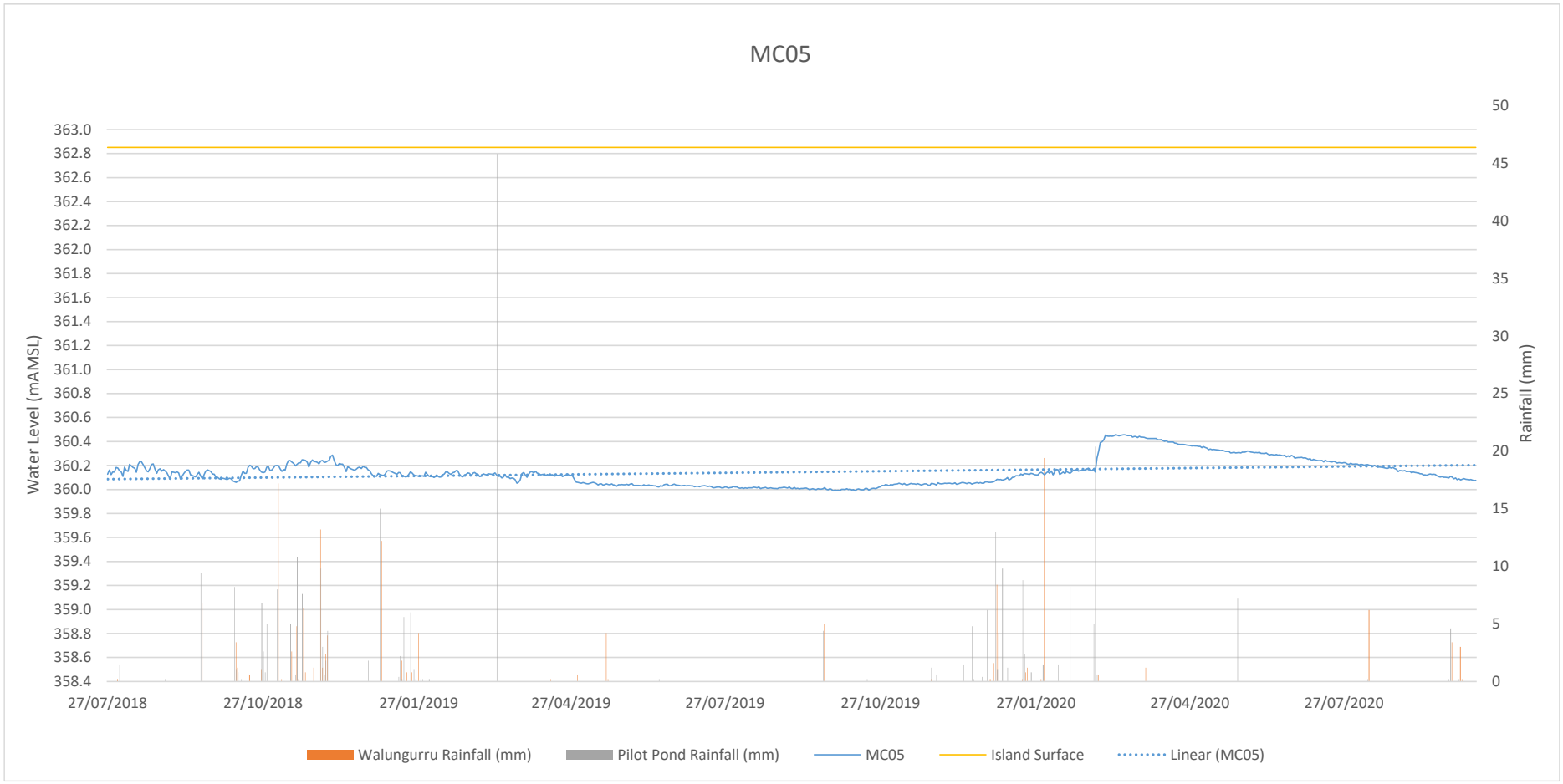
MEMO

MC01


MC01
Water Level (mAMSL)
Rainfall (mm)
361.6
361.4
361.2
361.0
360.8
360.6
360.4
360.2
360.0
359.8
359.6
359.4
359.2
359.0
358.8
358.6
358.4
358.2
50
45
40
35
30
25
20
15
10
5
0
25/07/2018
25/10/2018
25/01/2019
25/04/2019
25/07/2019
25/10/2019
25/01/2020
25/04/2020
25/07/2020
Walungurru Rainfall (mm)
Pilot Pond Rainfall (mm)
MC01
Lake Surface
Linear (MC01)

MEMO

MC05


MC05
Water Level (mAMSL)
Rainfall (mm)
363.0
362.8
362.6
362.4
362.2
362.0
361.8
361.6
361.4
361.2
361.0
360.8
360.6
360.4
360.2
360.0
359.8
359.6
359.4
359.2
359.0
358.8
358.6
358.4
50
45
40
35
30
25
20
15
10
5
0
27/07/2018
27/10/2018
27/01/2019
27/04/2019
27/07/2019
27/10/2019
27/01/2020
27/04/2020
27/07/2020
Walungurru Rainfall (mm)
Pilot Pond Rainfall (mm)
MC05
Island Surface
Linear (MC05)

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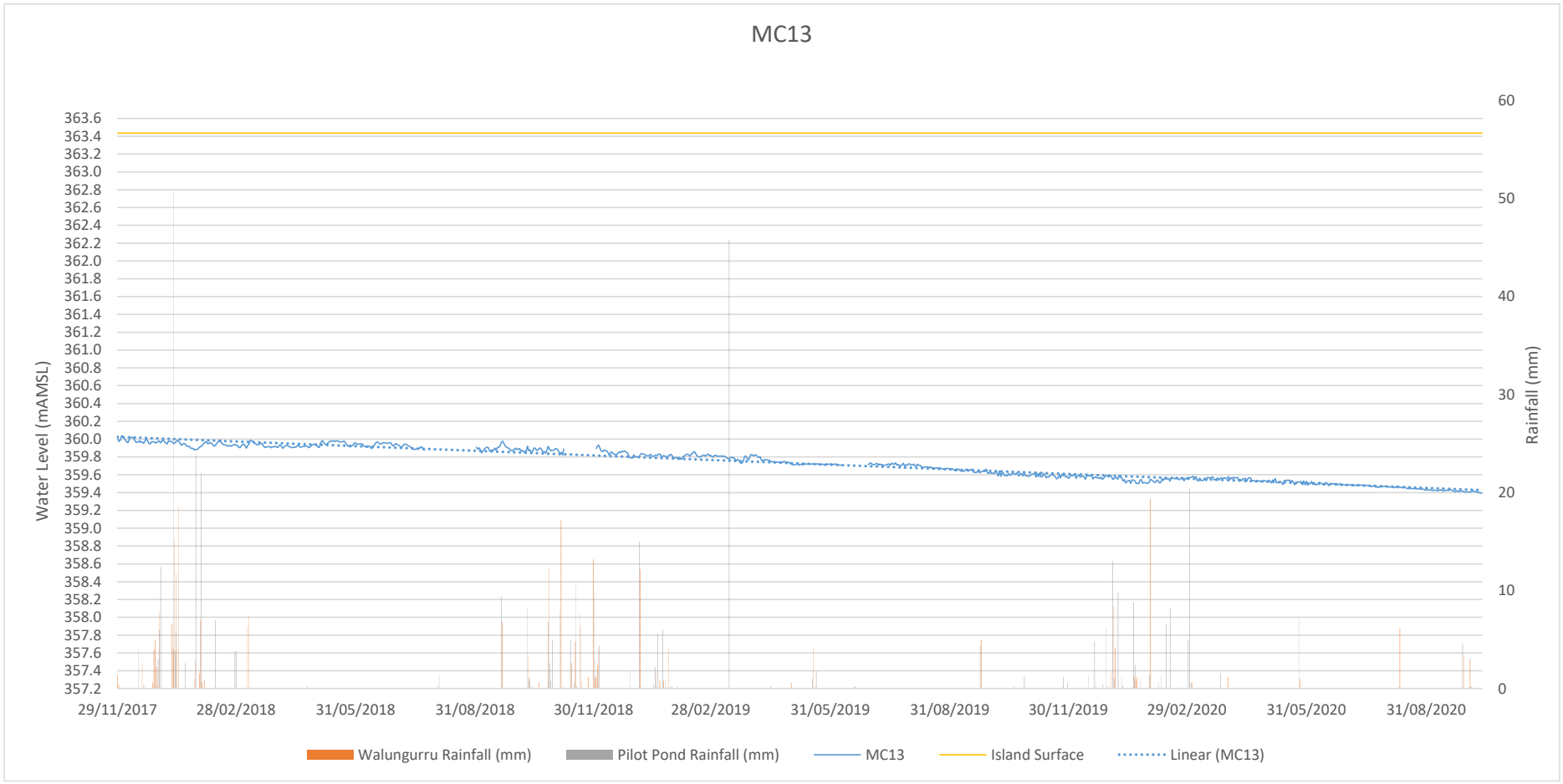
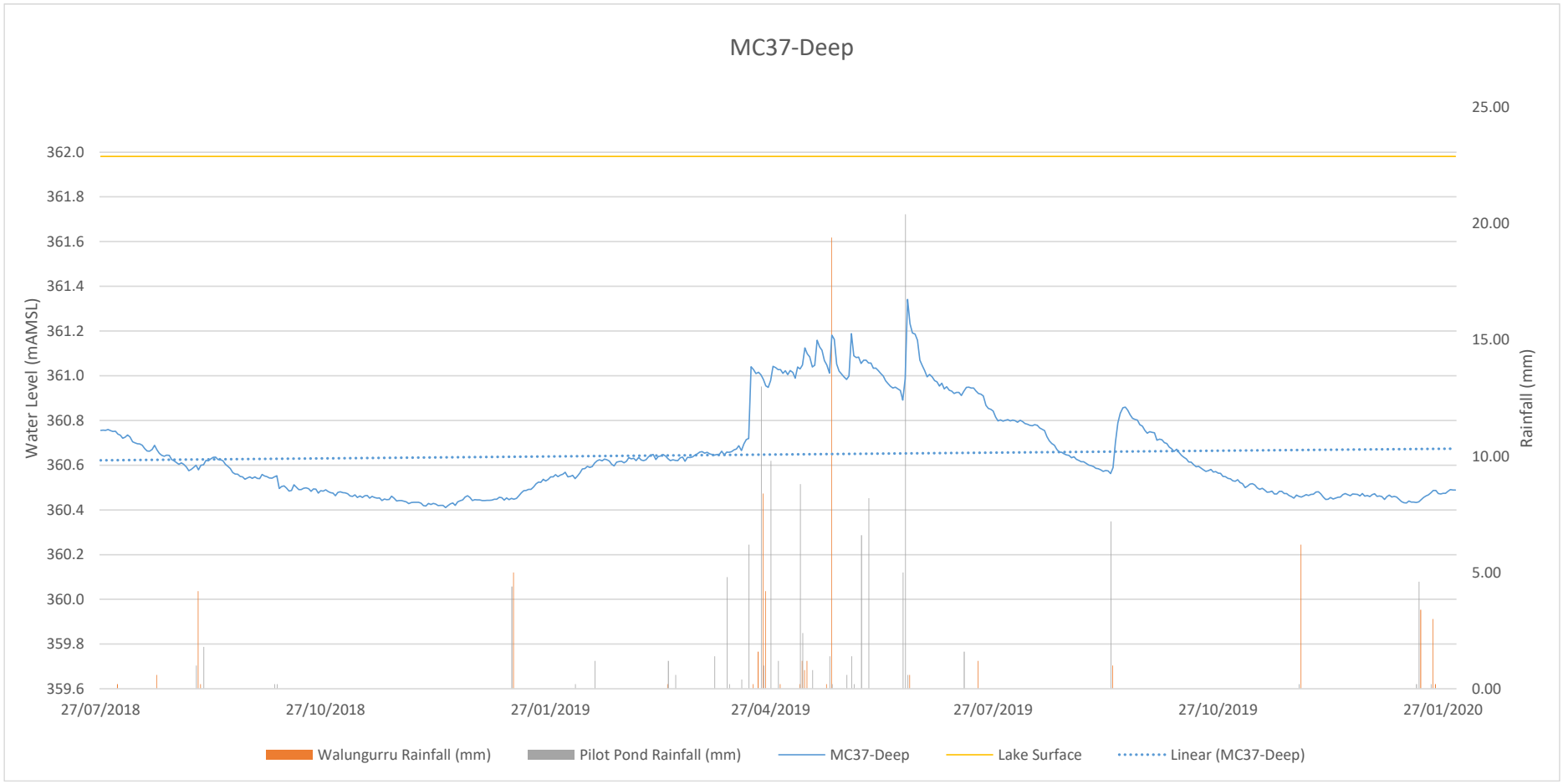
MC13


MC13
Water Level (mAMSL)
Rainfall (mm)
363.6
363.4
363.2
363.0
362.8
362.6
362.4
362.2
362.0
361.8
361.6
361.4
361.2
361.0
360.8
360.6
360.4
360.2
360.0
359.8
359.6
359.4
359.2
359.0
358.8
358.6
358.4
358.2
358.0
357.8
357.6
357.4
357.2
60
50
40
30
20
10
0
29/11/2017
28/02/2018
31/05/2018
31/08/2018
30/11/2018
28/02/2019
31/05/2019
31/08/2019
30/11/2019
29/02/2020
31/05/2020
31/08/2020
Walungurru Rainfall (mm)
Pilot Pond Rainfall (mm)
MC13
Island Surface
Linear (MC13)

MEMO

MC37-Deep



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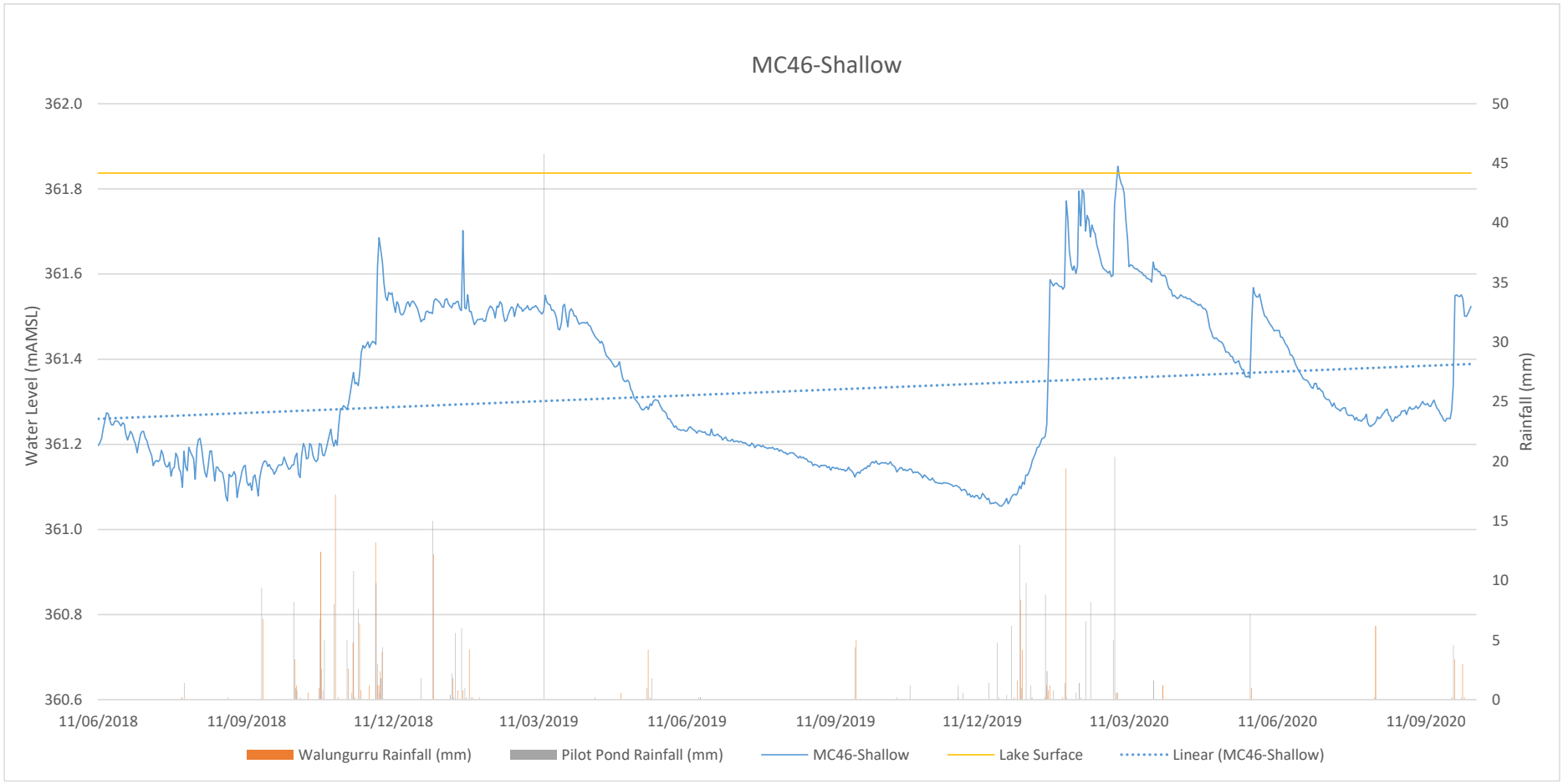
MC46-Shallow



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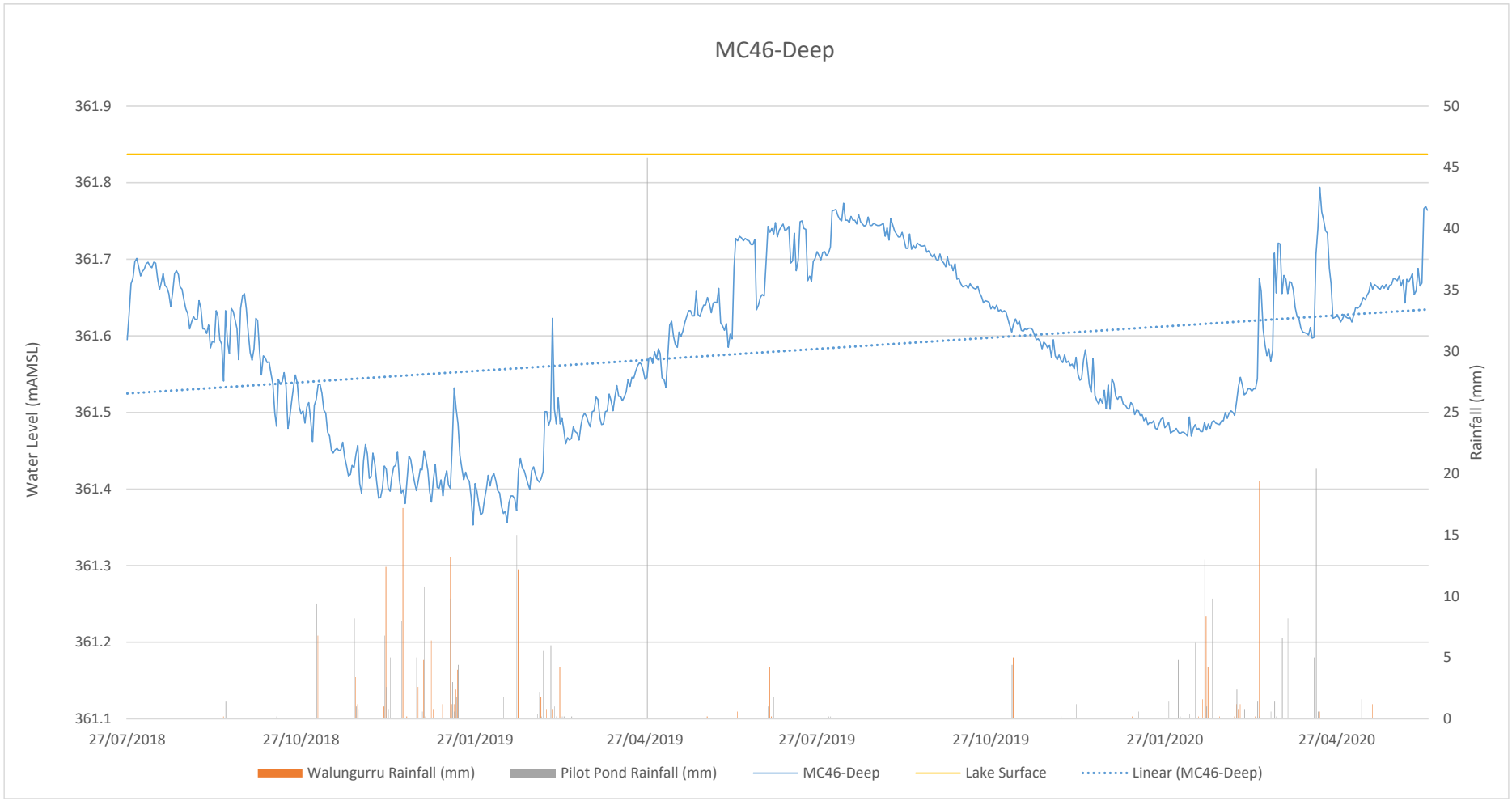
MC46-Deep



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All hydrographs