Bareena Wetland Hydrological Study

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1 Introduction

Salients was engaged by Central Coast Council to investigate the hydrological relationship between Avoca Lagoon and Bareena Wetland, with the primary objective of examining how Bareena Wetland drains and fills relative to Avoca Lagoon.

This assessment will inform a study presently being undertaken to investigate the population dynamics, distribution, and habitat use of the green and golden bell frog (GGBF) at Bareena Wetland.

An assessment of rainfall, water level and water quality data for Avoca Lagoon and Bareena Wetland from January 2020 to June 2021 was undertaken and is presented in this report. The following data were obtained:

- Rainfall and water level data from permanent recorders inside Avoca Lagoon from January 2020 to June 2021, provided by the Department of Planning and the Environment (maintained by Manly Hydraulics Laboratory (MHL))[1].
- Tidal data from a permanent water level recorder in Sydney Harbour from January 2020 to June 2021, from DPIE (also maintained by MHL).
- Salinity, temperature, and water levels from a temporary recorder inside Bareena Wetland provided to us by MHL. Water levels were recorded from February 2020 to mid-May 2021, and salinity and temperature were recorded from mid-January 2020 to early February 2021. The location of the recorder is shown in Figure 1. Malfunction of the sensor which occurred post February 2021 meant that data from that recorder were not available beyond February 2021.
- Salinity and temperature data from May 2020 to June 2021, at three locations as shown in Figure 1, provided to us by the University of Newcastle (UoN). There are inconsistencies between salinity measurements made by the MHL recorder and a recorder installed nearby by UoN. These inconsistencies have been investigated, but the reasons for them have not been resolved.

In addition, a camera was installed, by Salients, in May 2020 to capture a photographic record of water levels in Bareena Wetland. Photographs were taken at 15- or 20-minute intervals during daylight hours from May 2020 to early March 2021. The approximate location of the camera is indicated in Figure 1. The permanent recorder in Avoca Lagoon is located within the South Arm of the waterbody, some 450m south-west of the Bareena Wetland (not shown in Figure 1).

[1] https://www.mhl.nsw.gov.au/ , Accessed 21/06/2021.

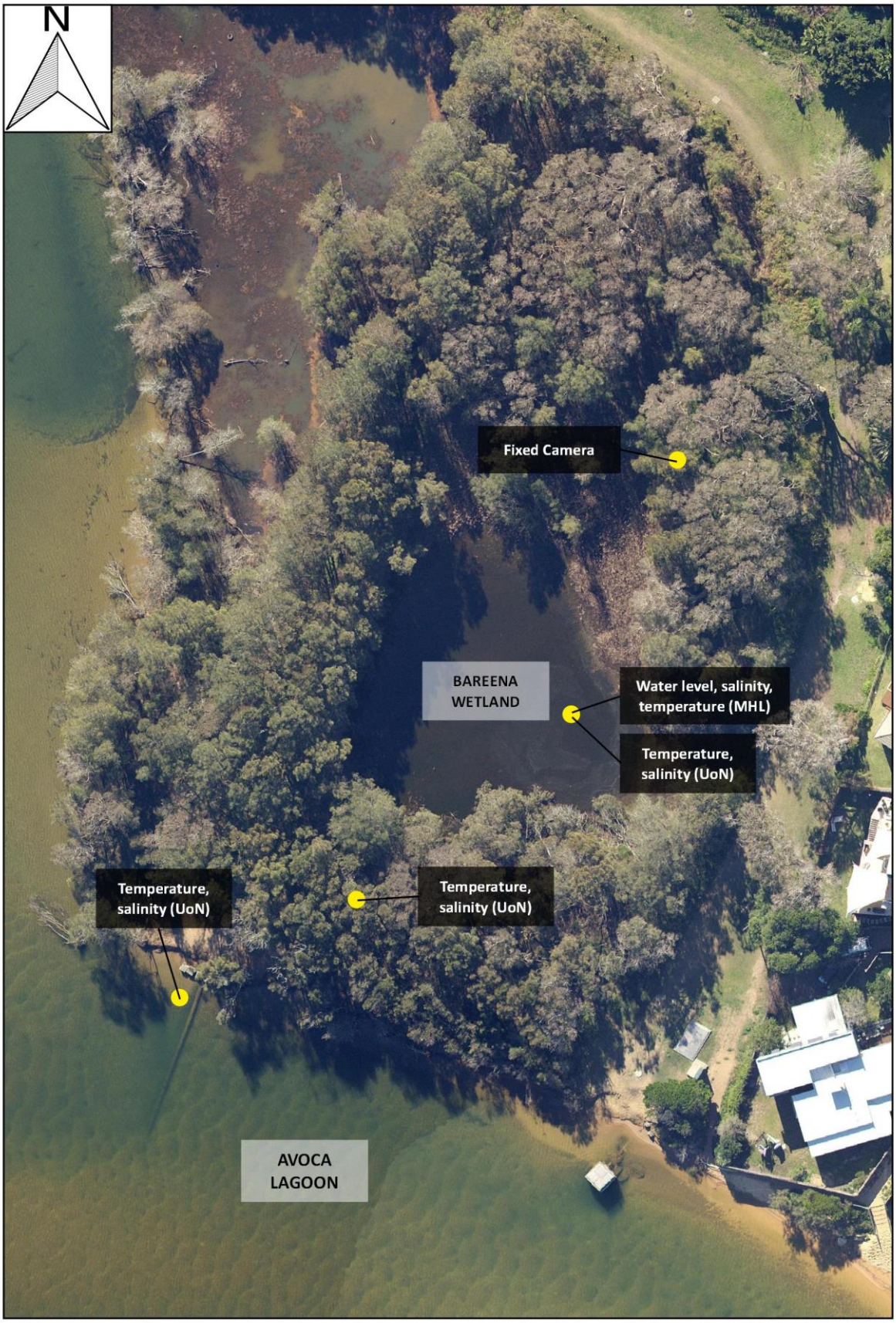

Figure 1: Monitoring Locations

0 10 20 30 m

APPROX SCALE

Bareena Wetland Hydrological Study

REV	DRAWN	CHECK
A	EN	DJW

GIS File: "Z:\BusinessShare\Them\Projects\P00096_BareenaWetlandHydrologicalStudy\Outgoing\Figures\MonitoringLocations.qgz"

Salients

2 Analysis

2.1 Analysis and Supplementary Data

The following analysis is based on collation and comparison of the available rainfall, tidal, water level and salinity data. Monthly plots of rainfall, Sydney tides, water levels inside Avoca Lagoon and Bareena Wetland, and salinity in Bareena Wetland, for January 2020 to February 2021, are provided in Appendix A.

Inconsistencies are noted between salinity data recorded by MHL and UoN at the same location inside Bareena Wetland. Plots comparing the salinity data at this location, for the months where data from both recorders are available, are provided in Appendix B. It is common for the salinity recorded by UoN to be slightly less than twice (in PSU) the salinity measured by the MHL recorder (e.g., Figure B8, December 2020) but this is not always the case (see Figure B4, August 2020).

Monthly time lapse animations for June 2020 to March 2021 were generated from the photographs captured by the camera installed in the wetland. These have been supplied with this report, alongside the full set of still photographs. The animations provide a visual record of how the wetland drains and refills. These animations were also considered in the interpretation provided below.

2.2 January 2020

Between 1-17 January, the water level of Avoca Lagoon was around 0.55m AHD. 57mm of rainfall was recorded over 24 hours on 17-18 January, during which time the water level rose to 0.68m AHD.

The salinity and water level in Bareena Wetland were recorded from 17 January; but the wetland was dry during this time. The water level in Avoca Lagoon throughout January was below the lowest elevation (i.e., 1.85m AHD) of the barrier between Avoca Lagoon and Bareena Wetland (located south of the wetland).

2.3 February 2020

Around 350mm of rainfall was recorded between 6-10 February. The water level of Avoca Lagoon rose to 2.2m AHD on 9 February, at which time the entrance was breached and the lagoon drained to 0.7m AHD over the following four hours. Bareena wetland was dry for the beginning of February, then rose from 0.94m (the elevation of the bed at the recorder location) to 2.2m AHD at the same time as Avoca Lagoon.

The rate at which the water level of the wetland fell when the entrance was breached was similar to that of Avoca Lagoon but slowed markedly after around 1.5 hours once the water level in the lagoon dropped below ~1.85m (below the level of the barrier between Avoca Lagoon and Bareena Wetland, to the south of the wetland). Bareena

Wetland then continued to drain at a slower rate between 10-13 February until dry again. This slowing of drainage rate, compared to that in Avoca Lagoon, is indicative of a switch from surface overflow of the barrier separating Bareena Wetland from Avoca Lagoon to drainage via seepage through the porous barrier and via groundwater.

Avoca Lagoon remained open for the rest of the month under tidal influence with average water level around 0.5m AHD, but the tidal signal was gradually constrained as the entrance to the ocean closed.

The salinity of Bareena Wetland increased as the water level rose from 7-9 February, with the most marked increase occurring during the initial rise. On 9 February, there was a sharp increase in salinity that occurred when the water level in Avoca Lagoon exceeded the barrier to Bareena Wetland and reached a maximum of 15ppt before the Avoca entrance was breached. The salinity then decreased to around 6.5ppt over the next three days as the wetland drained.

2.4 March 2020

The ocean entrance to Avoca Lagoon closed in the first few days of March 2020. The water level of Avoca Lagoon rose from around 0.5m AHD at the beginning of March, to around 0.8m AHD by 6 March following 50mm of rainfall that fell on 5 March. Bareena Wetland remained dry until around 10am on 7 March, after which time the water level rose to 1.1m between 7-12 March. During this period, the water level of Avoca Lagoon also increased to around 1.1m at the same time. Both remained close to 1.1m AHD from 12-15 March.

The salinity of Bareena Wetland was relatively constant between 9-15 March at around 5-5.5ppt, then fell to 4.5ppt on the 16th following 30mm rain over the preceding 24 hours. Both the salinity and water level of Bareena increased between 15-20 March following 40mm rainfall which was recorded from 15-16 March. The water level of Avoca Lagoon exhibited a similar pattern, although it increased around 12 hours earlier than Bareena Wetland.

The water level of both water bodies continued to rise until the end of March, reaching around 1.5m AHD. 65mm of rainfall was recorded between 23-30 March, and during this period the salinity of Bareena Wetland steadily increased to 13ppt.

2.5 April 2020

The water levels of both Avoca Lagoon and Bareena Wetland gradually increased up to 1.6m AHD by 8 April. 18mm of rainfall was recorded on the 8th, and the water level of Avoca Lagoon increased by 0.1m between 8-11 April. Bareena Lagoon also rose by 0.1m, albeit around 12 hours after Avoca Lagoon. The water level of both water bodies

then slowly decreased over the rest of the month to around 1.65m AHD, with minimal rain recorded.

There was a step change in salinity on 2nd April, which remains unexplained. The salinity of Bareena Wetland was around 14ppt from 10-12 April, then slowly decreased during the remainder of the month, to around 12.2 on 27 April. No rainfall was recorded during this period.

2.6 May 2020

The water levels of both Avoca Lagoon and Bareena Wetland were at around 1.65m AHD for the first two weeks of May. On 14 May, 60mm of rainfall was recorded, during which time the water levels rose simultaneously to around 1.8m AHD by 16 May and remained at this level until 22 May. While there was some rainfall on 22 May, it seems most likely that water levels in both Avoca and Bareena Lagoon rose, by around 0.15m because of swash overtopping the ocean barrier, noting the particularly high tide levels between 22nd and 25th May. Following rainfall on 25th May, the Avoca Lagoon was breached on 26 May, when the water level had reached around 2.2m AHD. Avoca Lagoon then drained to 0.6m AHD over 7.5 hours. Bareena Wetland drained at a similar rate until the water level fell below ~1.85m AHD, which occurred after around 3 hours, and then continued to drain at a markedly slower rate until dry, by 29 May.

The salinity of Bareena Wetland was around 13-14 ppt for the first half of May, then from 15 May the salinity gradually decreased as the water level increased. The salinity decreased to 10ppt by 24-25 May, then increased again to around 12ppt from 25-26 May as water levels increased due to inflow from the ocean. The rainfall on 25-26 May seems to have moderated this increase in salinity over the next few days as the wetland drained following the entrance opening.

2.7 June 2020

Avoca Lagoon remained open to the ocean for all of June. Bareena Wetland was dry, except for 4-5 July, where a small amount of water was present (with water level in Avoca Lagoon between 0.94-0.98m, due to inflow during large ocean tides) over a 24-hour period. No rainfall was recorded during this time.

2.8 July 2020

During the first fortnight of July, the entrance to Avoca Lagoon remained open (at least to the higher spring tides), with the water level typically between 0.75-0.85m AHD. Bareena Wetland was dry during this time.

20mm of rainfall was recorded over 13-14 July. On 14 July, the water level in Avoca Lagoon increased by 0.4m (from 0.85 to 1.25m AHD) over ~12 hours. This rise seems

out of proportion to the rainfall event, but the 'pulsed' nature of the rise synchronised with the high tide peaks (albeit during neap tide conditions) indicates that there were large waves causing overwash from the ocean into Avoca Lagoon over this period. The rapid increase in salinity within Bareena Wetland to relatively high levels (>20ppt) also supports the interpretation that filling of Avoca Lagoon (and subsequently Bareena Wetland) was from the ocean and not the catchment. The water level was 1.75m AHD on 16 July.

Bareena Wetland began to fill around six hours after the water level in Avoca Lagoon began to rise, and at a slower rate (~0.2m in 12 hours). The water level reached 1.4m AHD on 16 July, then filled to 1.75m AHD over the following 12 hours. The water levels of both Avoca Lagoon and Bareena Wetland were at around 1.8m AHD from 16-20 July.

The salinity of Bareena Wetland increased as the water level rose from 14-16 July, and reached around 27ppt on the 16th, when the water level had reached 1.75m AHD. The salinity then gradually decreased to 25ppt while the water level remained constant over 16-20 July.

On 21st July, Avoca Lagoon began to fall, and it is unclear why this occurred as it was below Council's let out level. The breach was relatively weak and may have been caused by relatively high tides overtopping the entrance barrier, late on the July 20, with waves lowering the saddle of the barrier enough to cause a 'natural' breach. It is possible that it was breached manually, although the water level was well below the normal let out level adopted by Council. Avoca Lagoon drained to around 0.75m and was then closed to the ocean within a couple of days (by the 24th) and Bareena Wetland was almost completely empty by the 26th.

Water levels of both Avoca Lagoon and Bareena Wetland increased over 26-29 July, in response to 110mm of rainfall. Bareena Wetland began to fill around two hours after Avoca Lagoon, and at slower rate. The salinity in Bareena Wetland increased as the water level rose and reached 22ppt when the water level was at 1.2m AHD, the salinity remained at 22ppt as the water level continued to rise. The water level of both Avoca Lagoon and Bareena Wetland reached 1.75m AHD at same time on 29 July, then gradually increased to 1.85m over the remainder of the month. The steady nature of this rise is consistent with a continuing inflow of groundwater and/or baseflow to the Lagoon from the catchment.

2.9 August 2020

The water level of both Avoca Lagoon and Bareena Wetland was at around 1.85-1.9m AHD for the first nine days of August. 30mm of rain was recorded over a 24-hour period from 9-10 August, and both water levels rose by 0.1m during this period to

around 2.0m AHD. For the remainder of August, the water levels of both Avoca Lagoon and Bareena Wetland remained constant, at around 2m AHD.

The salinity of Bareena Wetland continuously decreased for the entire month, from 22ppt to around 8.5ppt by the end of August. The most significant decrease in salinity occurred during the second half of the month, during which time no rainfall was recorded. Water levels only marginally exceeded the barrier between the Lagoon and Wetland over this time. The steady water level decrease and lack of rainfall, combined with a falling salinity is indicative of dilution of the salinity within Bareena Wetland, due to inflow from some source other than rainfall. Without a measurement of salinity in Avoca Lagoon itself, it is difficult to be certain of the dynamics.

However, if Avoca Lagoon had a lower salinity than Bareena Wetland, we would expect there to have been a sudden drop in salinity when Bareena wetland reconnected with Avoca Lagoon following its emptying in late July. The evidence seems to point towards an ongoing inflow of fresh water, potentially from a perched lens of freshwater contained in the dunes between Bareena Wetland and the coast to provide an ongoing dilution to the water in Bareena Wetland.

Noting that this dynamic provides a dynamic whereby salinities in Bareena Wetland are driven below 10ppt and sustained at these levels (see conditions in September) this may be of particular importance to the viability of the habitat for the Green and Golden Bell Frog.

2.10 September 2020

Both water levels remained at around 2.0m AHD during September. Around 40mm of rain in total was recorded during the month. The salinity of Bareena Wetland was also constant over the whole month, at around 8.5ppt.

2.11 October 2020

The water level in both Avoca Lagoon and Bareena Wetland gradually fell by 0.1m from 1-18 October, most likely through evaporation. Following ~17mm rainfall on 18 October, water levels remained at around 1.9m AHD until 24 October. The salinity of the wetland remained at around 8.5ppt during this period.

155mm rain was recorded from 24-27 October. Water levels in Avoca Lagoon and Bareena Wetland simultaneously increased by 0.5m over a 24-hour period on 26 October during the heaviest rainfall period, before the entrance was breached with the water level reaching 2.5m AHD. The water level of Avoca Lagoon fell by 1.3m over the following 12 hours. The level of Bareena Wetland fell at the same rate until the water level fell below 1.85m AHD (after around 3 hours), with the Wetland then continuing to drain at a slower rate over the next four days until dry.

The salinity of the wetland began to decrease following rainfall from 24-27 October. The salinity decreased to around 7ppt by 30 October before the wetland was empty.

2.12 November 2020

Avoca Lagoon was open to the ocean from 1-6 November, with the water level ranging between 0.5-0.75m AHD. Bareena Wetland was dry during this time. The water level of Avoca Lagoon rose to around 1.0m AHD on 6 November, following 19mm of rainfall which was recorded on 5 November. The level of Bareena Wetland began to increase around 12 hours after Avoca Lagoon. Both remained at around 1.0m AHD for the remainder of November.

The salinity of the wetland was at around 7ppt on 7 November and slowly increased between 7-22 November, except for a slight decrease on 13-14 November, after rain. The salinity reached 10ppt by the 22nd and remained at around 10-12ppt for the rest of the month. Given that there was limited exchange between the Lagoon and Wetland, the most likely cause of the increase in salinity would have been evapo-concentration.

2.13 December 2020

Both water levels were ~1.0m AHD for the first half of December. The salinity in Bareena Wetland remained around 10ppt during this period, with a slight drop (by ~3ppt) following rainfall of 13mm on the 1st and again following 19mm on the 5th.

There is an intriguing pattern of minor repeated oscillations in water level (slight) and salinity (by about 1ppt) over the period 9th through 16th December, as spring tides in the ocean are getting larger. This is not seen in the water level in Avoca Lagoon. This pattern is diurnal seeming to lag the high tide peaks in the ocean. The ultimate effect is to slightly increase salinities in Bareena Wetland as spring tides are becoming larger as part of the fortnightly tidal cycle. Rainfall from the 15th to 16th onwards results in an increase in the water levels and a reduction in salinities following this period.

The behaviour outlined in the previous paragraph point again to groundwater dynamics in the elevated dunes between the Wetland and the Ocean which may be important. Monitoring a series of 3-4 groundwater bores with water level, and salinity measurement variations with depth (if possible) across the dunes between the ocean and the wetland and subsequent interpretation may help to explain this behaviour.

Both water levels simultaneously increased to 1.25m AHD on 22 December after 60mm of rain was recorded from 19-21 December. The water level of Avoca Lagoon and Bareena Wetland both remained around this level for the rest of December. The salinity of Bareena Wetland gradually decreased over this period and was around 6.5ppt at the end of December.

2.14 January 2021

From 1-28 January, the water levels of both Avoca Lagoon and Bareena Wetland were at around 1.3m AHD, slowly falling to 1.25m AHD by the 28th. The salinity of the wetland was at around 6.5ppt at the beginning of the month, and slowly increased to around 8ppt by the 28th, with this likely caused by evapo-concentration.

From 27-30 January, 60mm of rainfall was recorded. The water level of Avoca Lagoon rose by around 0.2m from 28-30 December. Bareena Wetland also rose by ~0.2m, but this occurred over three days from 28-31 December. The salinity of Bareena remained at around 8ppt.

2.15 February 2021

Between 1-12 February, the water level of both Avoca Lagoon and Bareena Wetland was around 1.45m AHD. The salinity of Bareena Wetland was only recorded on 1-2 February and was around 8ppt. The salinity record inside Bareena Wetland is unavailable from this time forwards.

30mm of rain was recorded on 13 February, following which the water level of both Avoca Lagoon and Bareena Wetland simultaneously rose to 1.5m AHD. Both water levels remained at this level for the rest of the month.

3 Summary and Conclusions

Based on our analysis of water level data from January 2020 to February 2021, the water level of Bareena Wetland typically begins to rise around 6-12 hours after Avoca Lagoon begins to rise following rainfall. Additionally, Bareena Wetland generally fills at a slower rate, although on some occasions it is observed to increase at the same rate and time as Avoca Lagoon, most notably when there is a surface water connection across the southern embankment separating Bareena Wetland from Avoca Lagoon (~1.85m AHD).

When the entrance to Avoca Lagoon is breached, the water levels of both Avoca Lagoon and Bareena Wetland fall simultaneously, until the water is below the barrier. Following the entrance opening, the water typically drains to the height of the barrier within 1.5-3 hours. Once the water level is below the barrier, Bareena Wetland drains at a much slower rate than Avoca Lagoon, generally becoming dry after around three days.

There were no trends observed in the relationship between water level and salinity in Bareena Wetland that occurred throughout the 12-month period for which data are available. There were some months where salinity increased as water levels rose (e.g., following rainfall in February and March 2020) and decreased as the water level fell (April 2020). There were some occasions where the salinity gradually decreased while the water level remained constant (e.g., July, August, and November 2020), and there were two months where the salinity decreased as the water level increased with rainfall (May and December 2020).

The salinity dynamics in Bareena Wetland are only partially understood. Evapo-concentration during warmer months has an effect, but there also seem to be complex dynamics relating to groundwater recharge from the dunes between the ocean and Bareena Wetland, and behaviour which seems to be related to both diurnal and fortnightly tides in the Ocean.

A further 12-month period of monitoring may be worthwhile, incorporating groundwater bores to better understand the dynamics of recharge and flow from the dune system to the east of the Wetland.

Appendix A Monthly Rainfall, Tides, Water Levels and Salinity

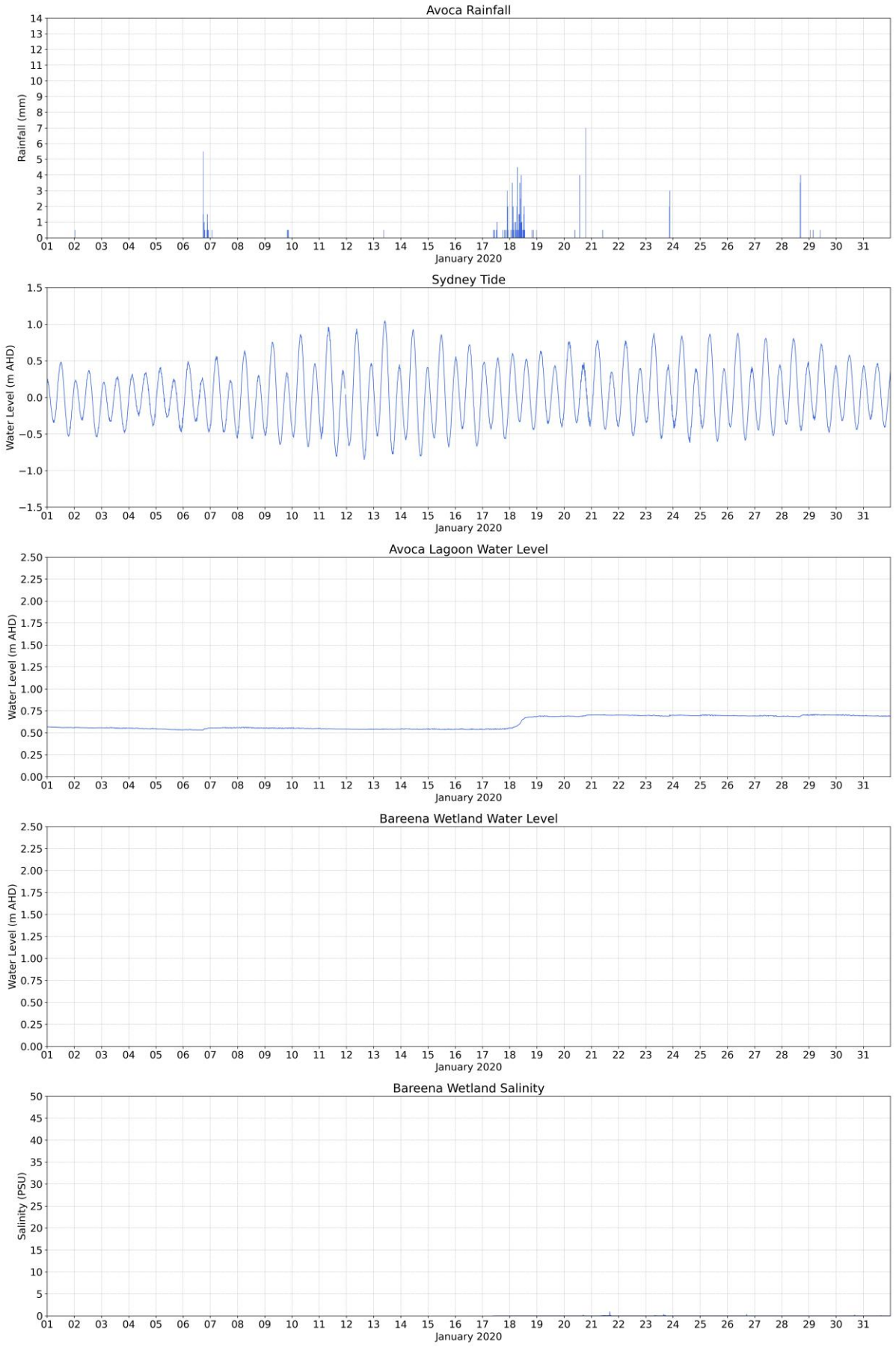

Figure A 1 January 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

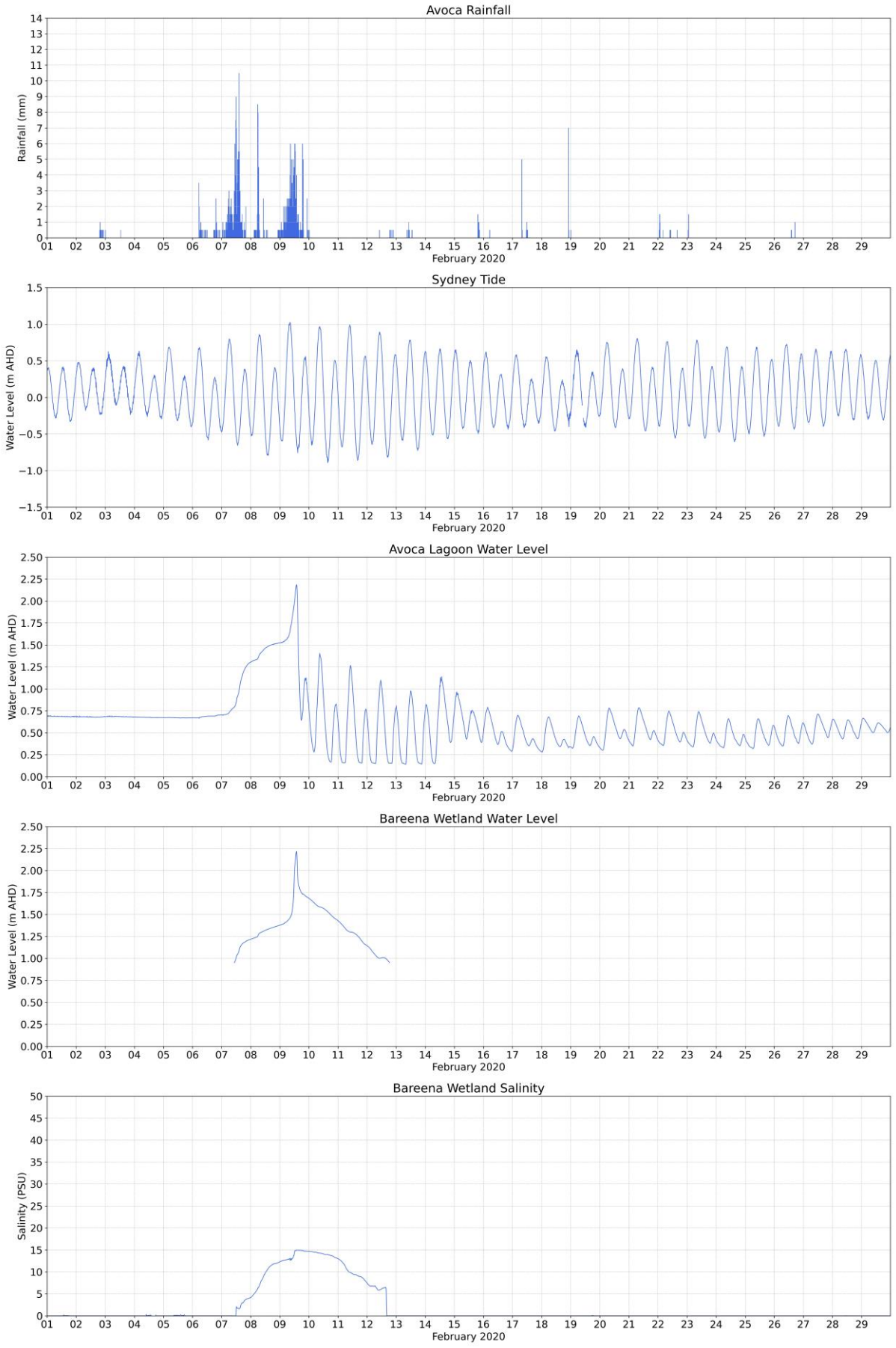

Figure A 2 February 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

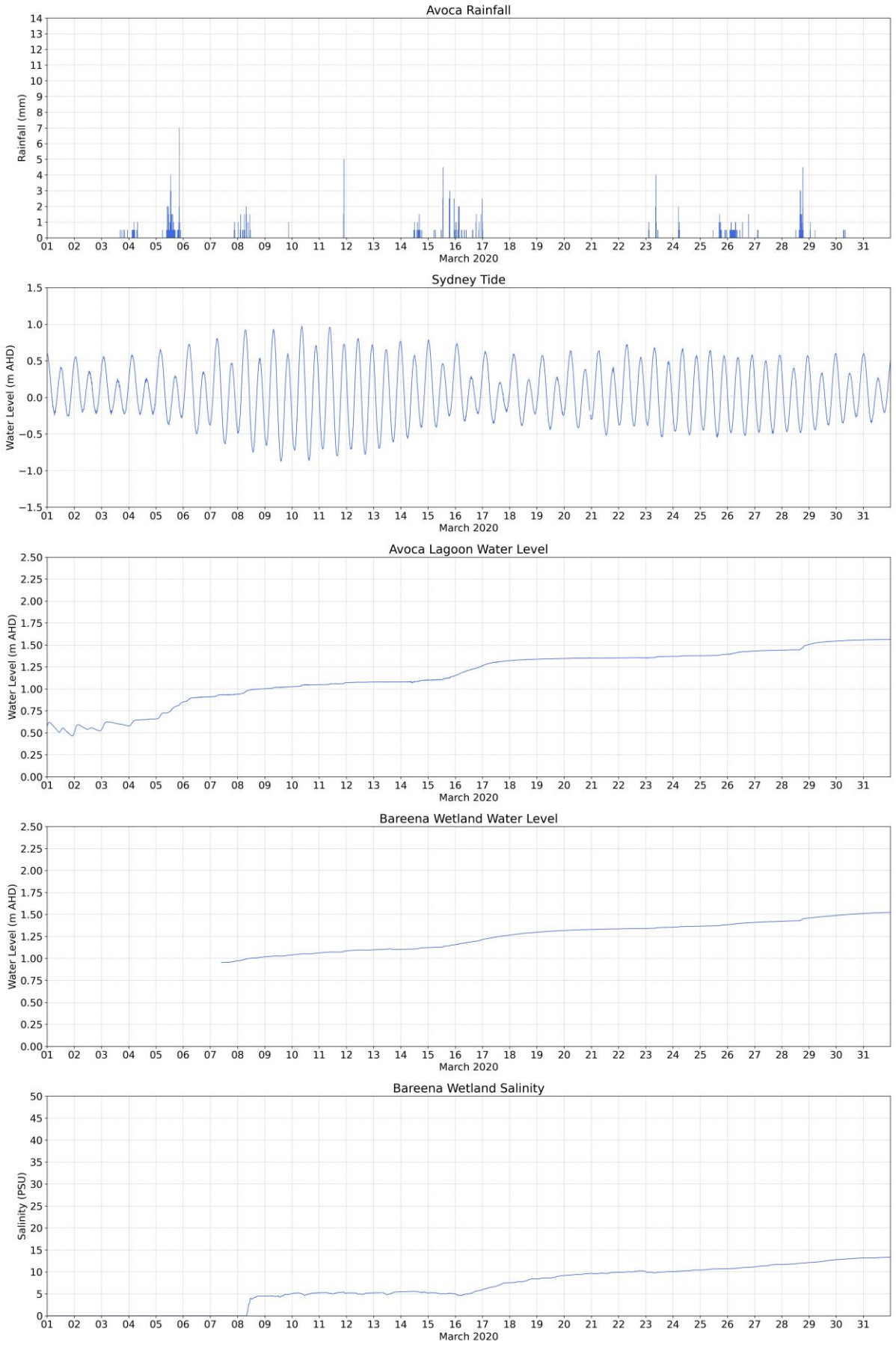

Figure A 3 March 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

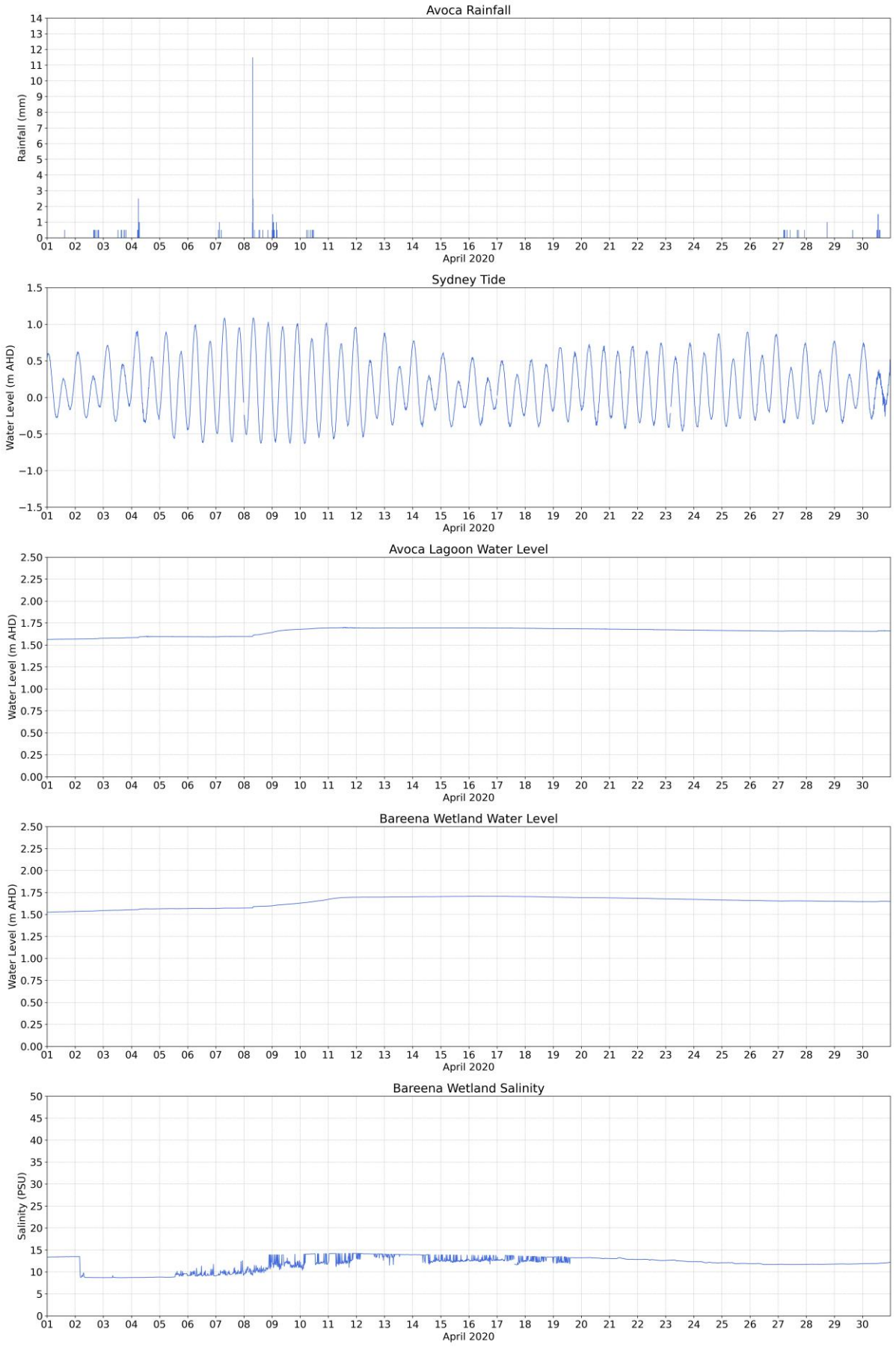

Figure A 4 April 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

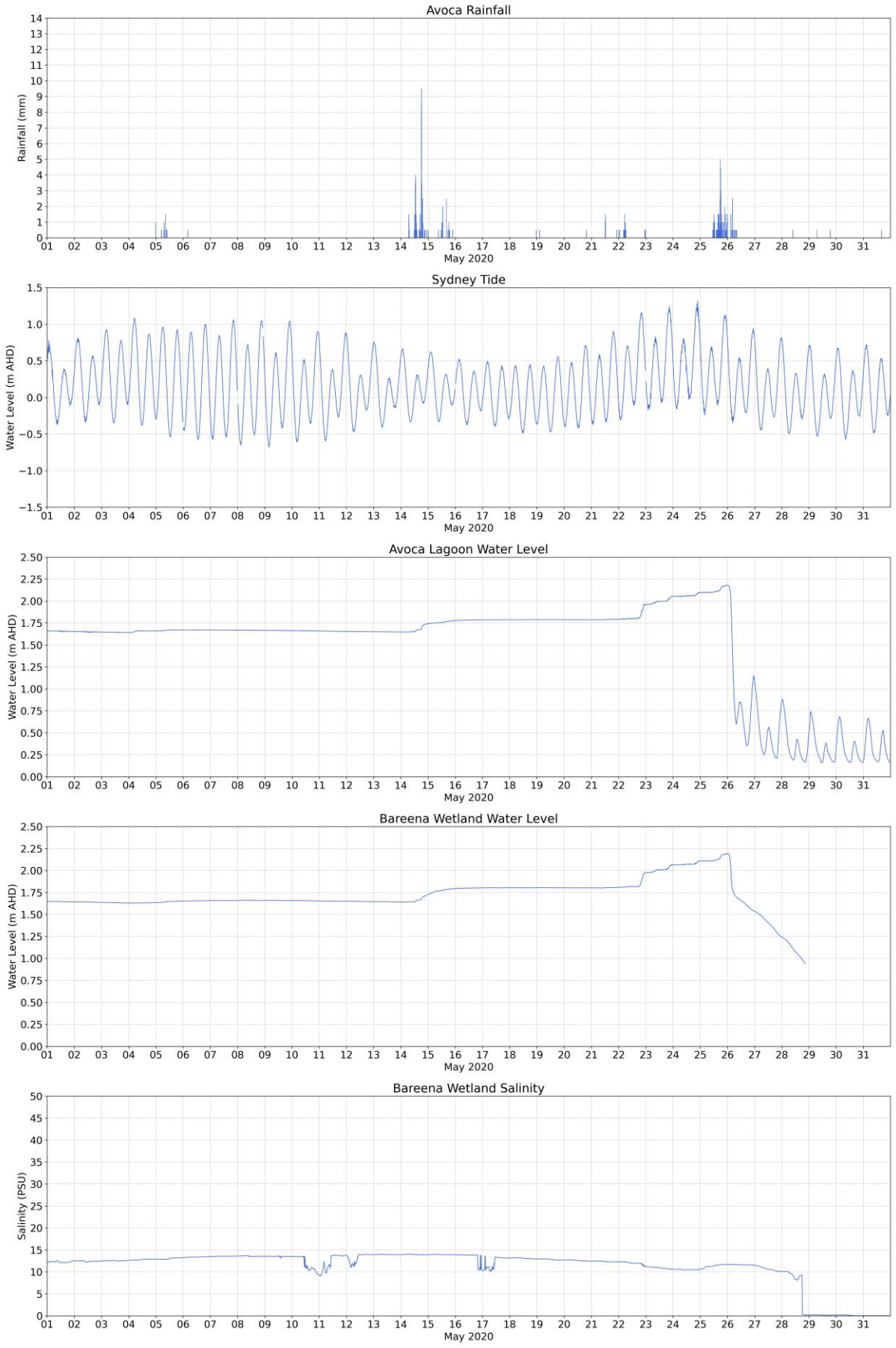

Figure A 5 May 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

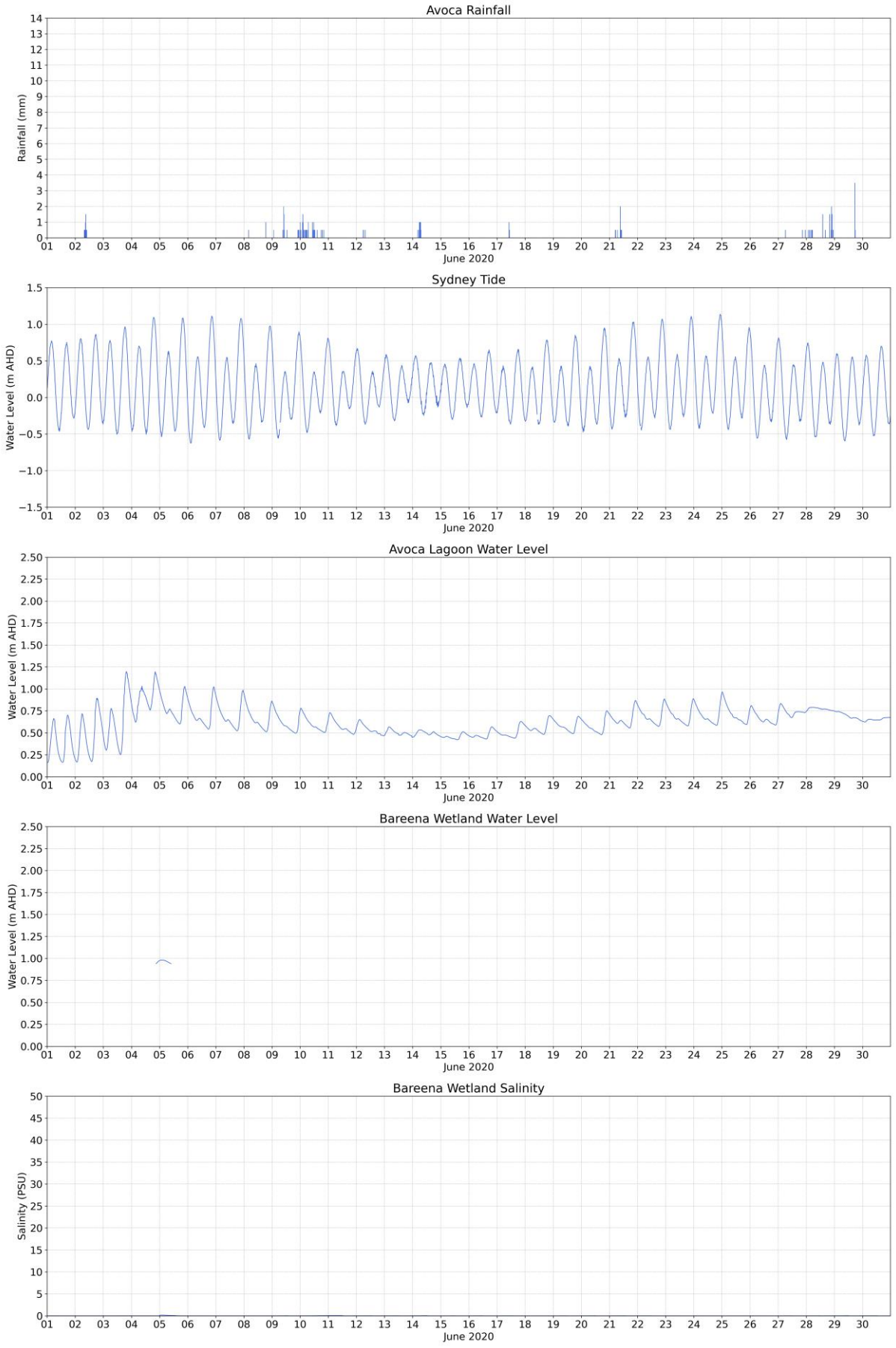

Figure A 6 June 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

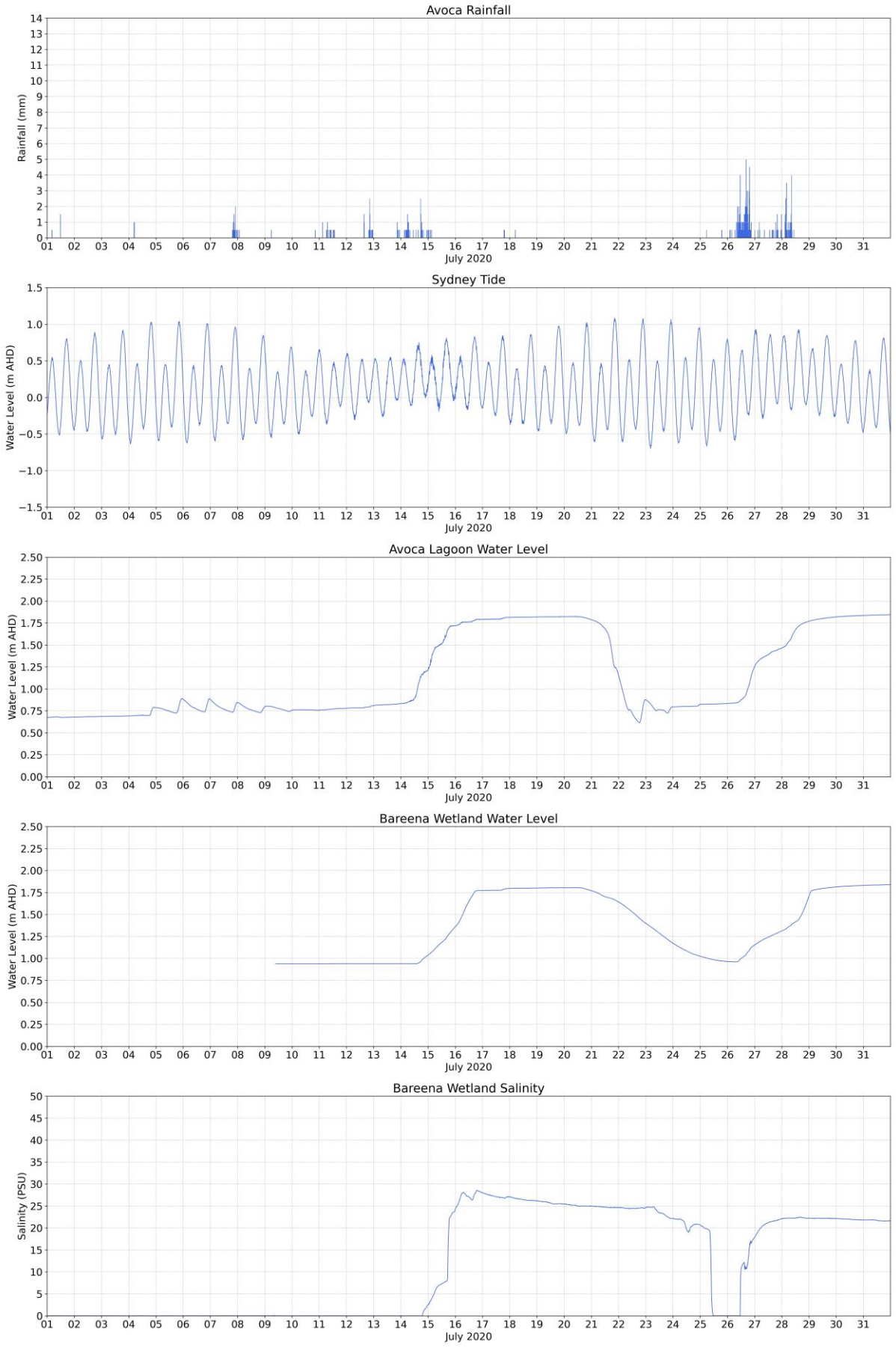

Figure A 7 July 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

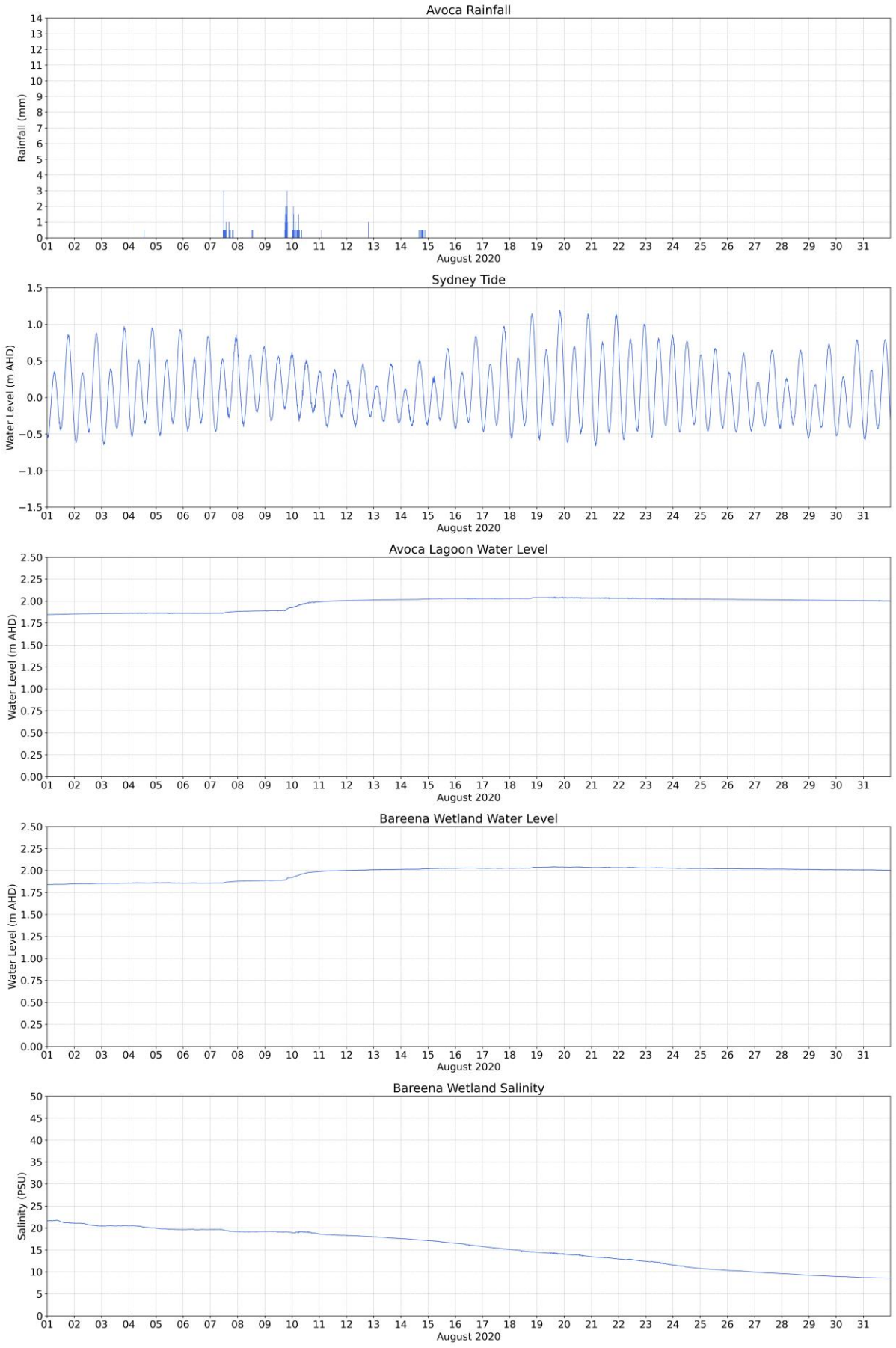

Figure A 8 August 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

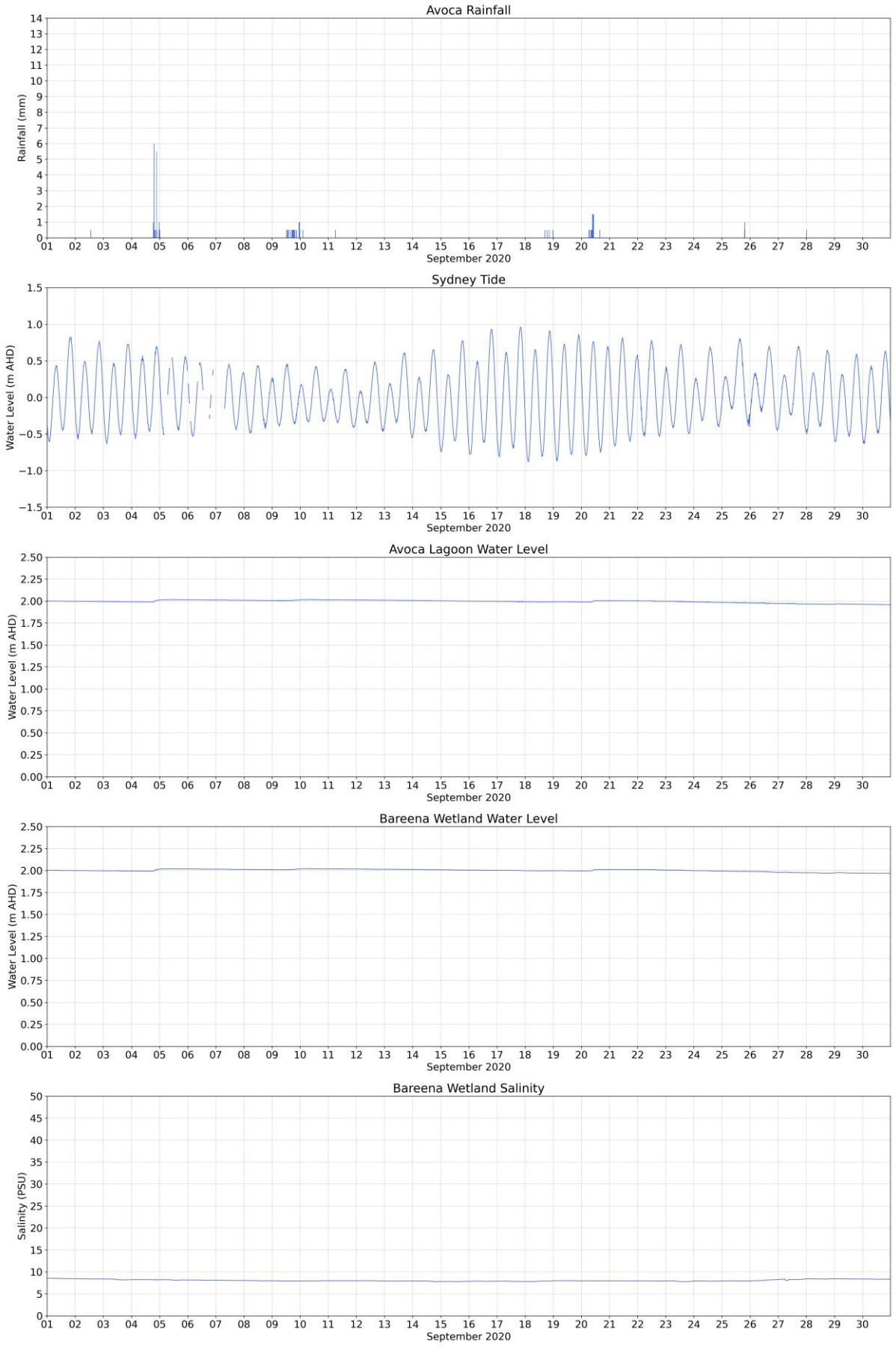

Figure A 9 September 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

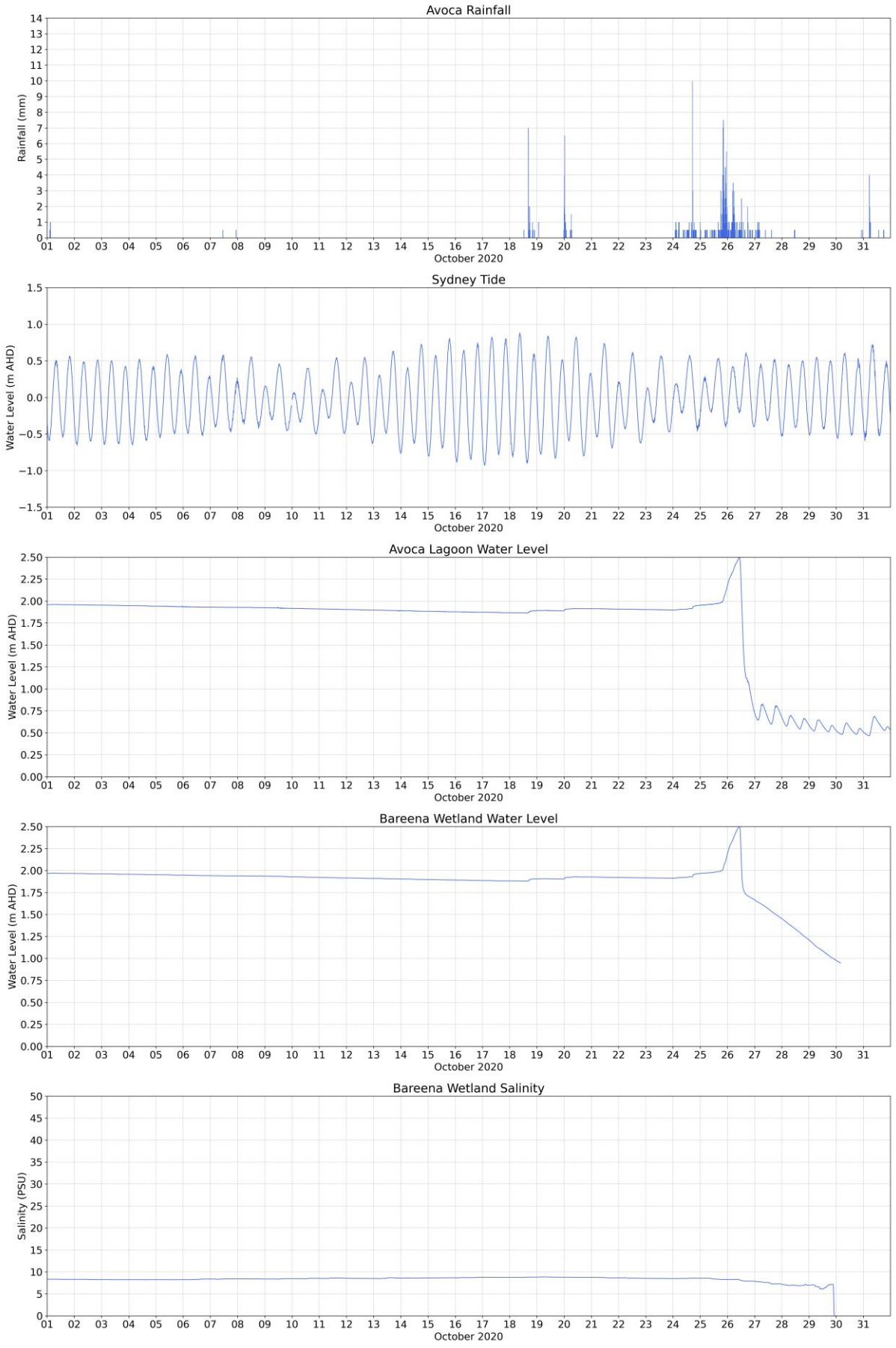

Figure A 10 October 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

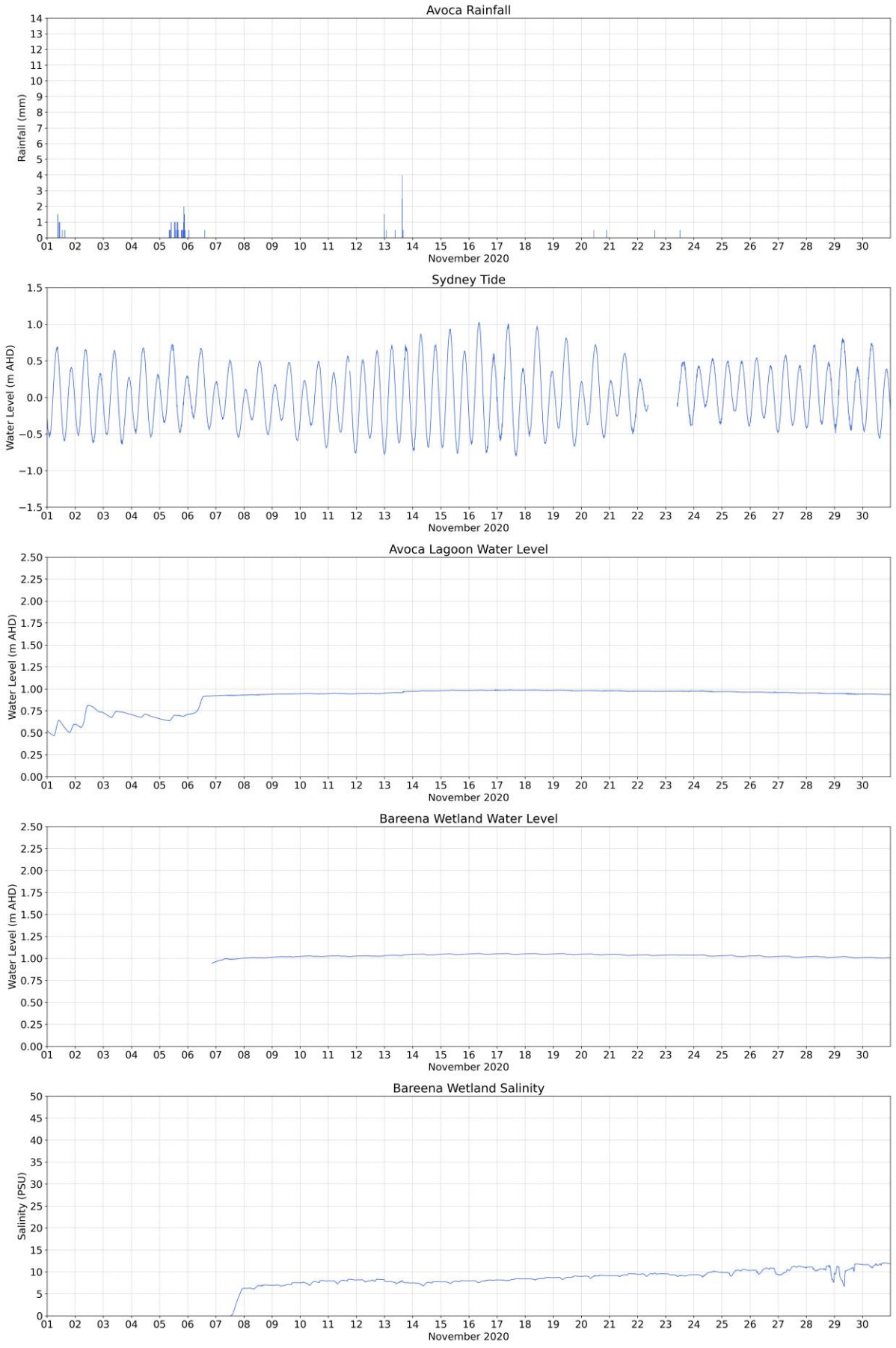

Figure A 11 November 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

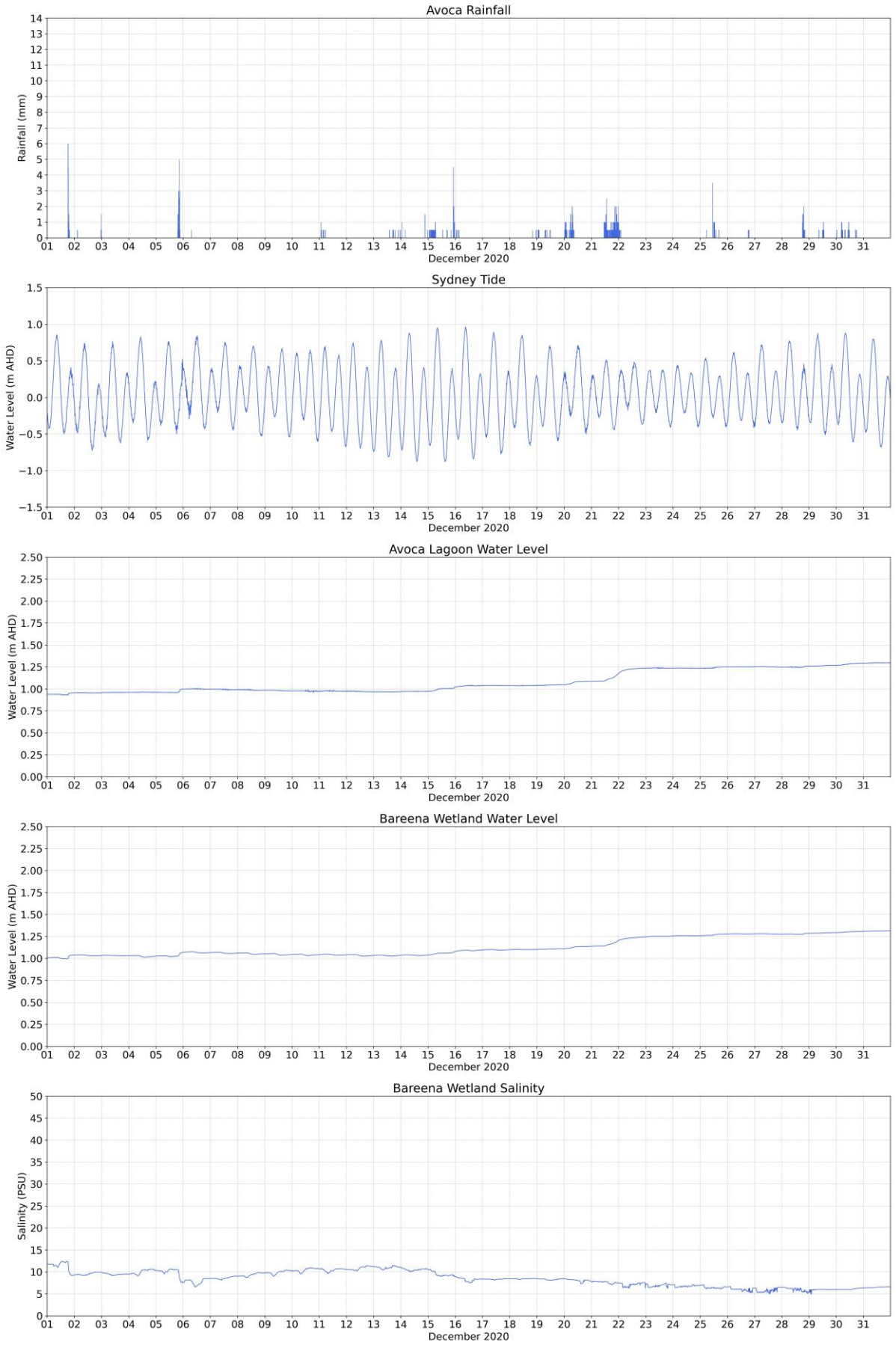

Figure A 12 December 2020 - Rainfall, Sydney Tides, Water Levels and Salinity

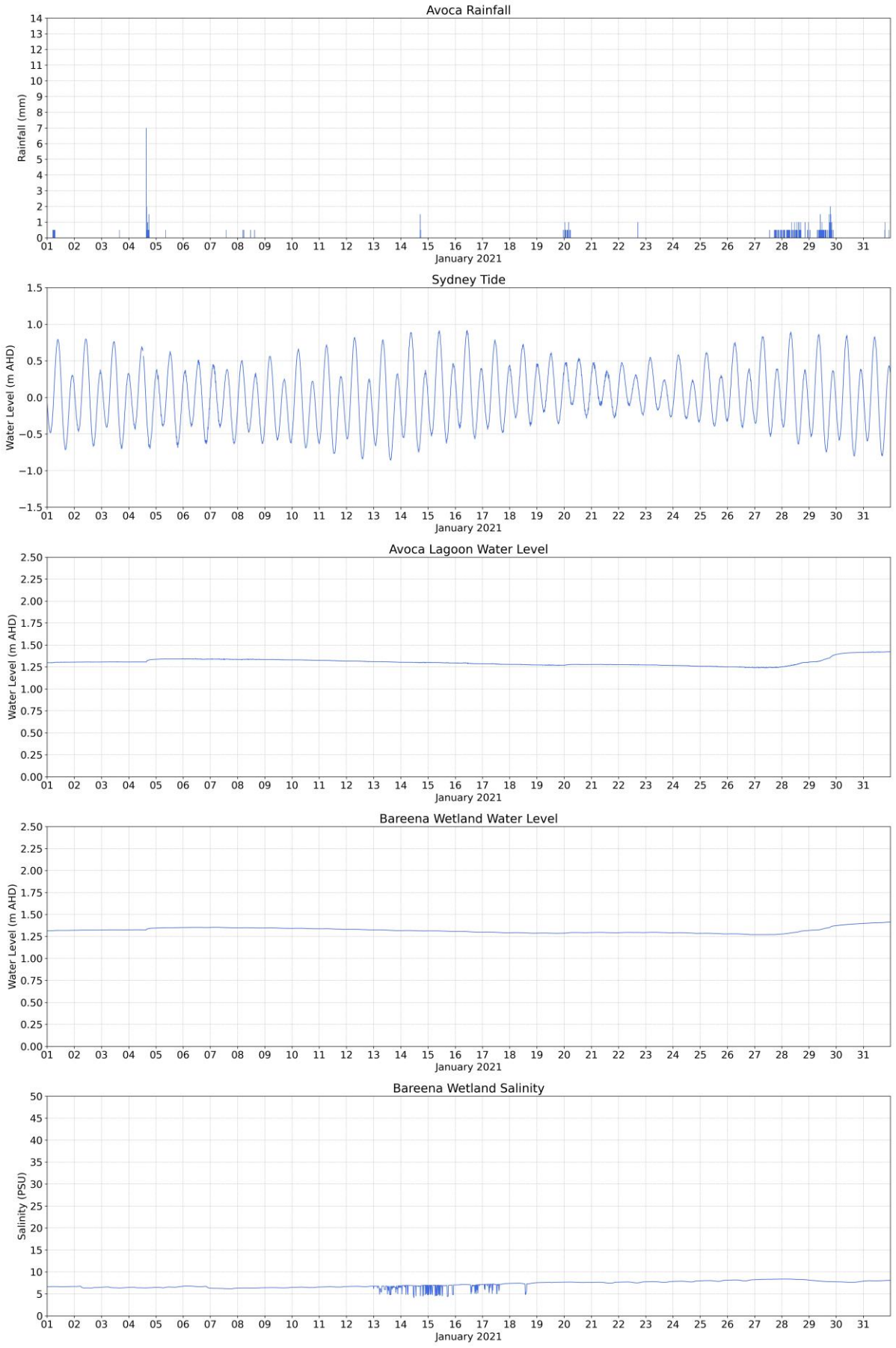

Figure A 13 January 2021 - Rainfall, Sydney Tides, Water Levels and Salinity

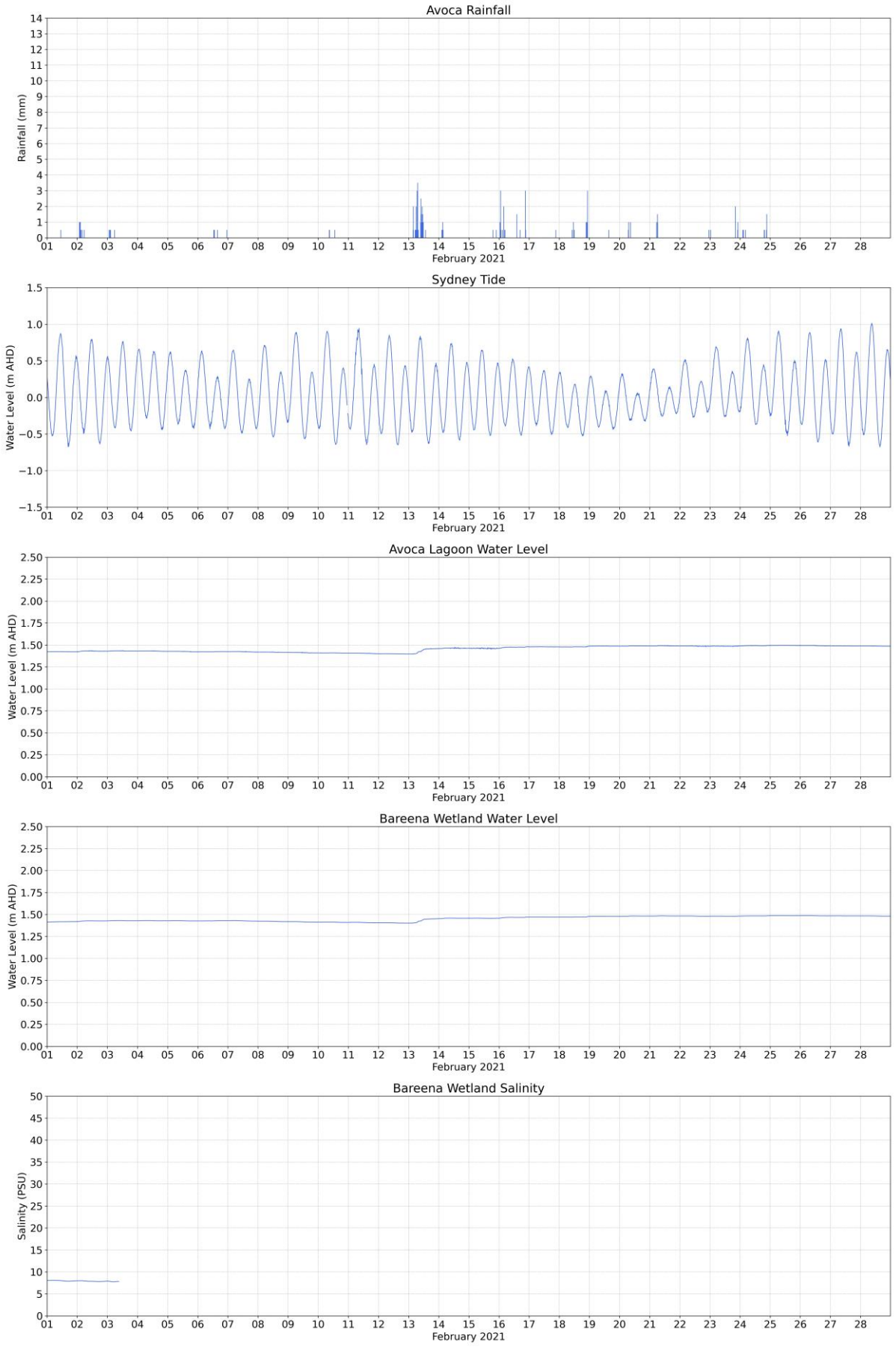

Figure A 14 February 2021 - Rainfall, Sydney Tides, Water Levels and Salinity

Appendix B Comparison of Salinity Data Collected by MHL and UON

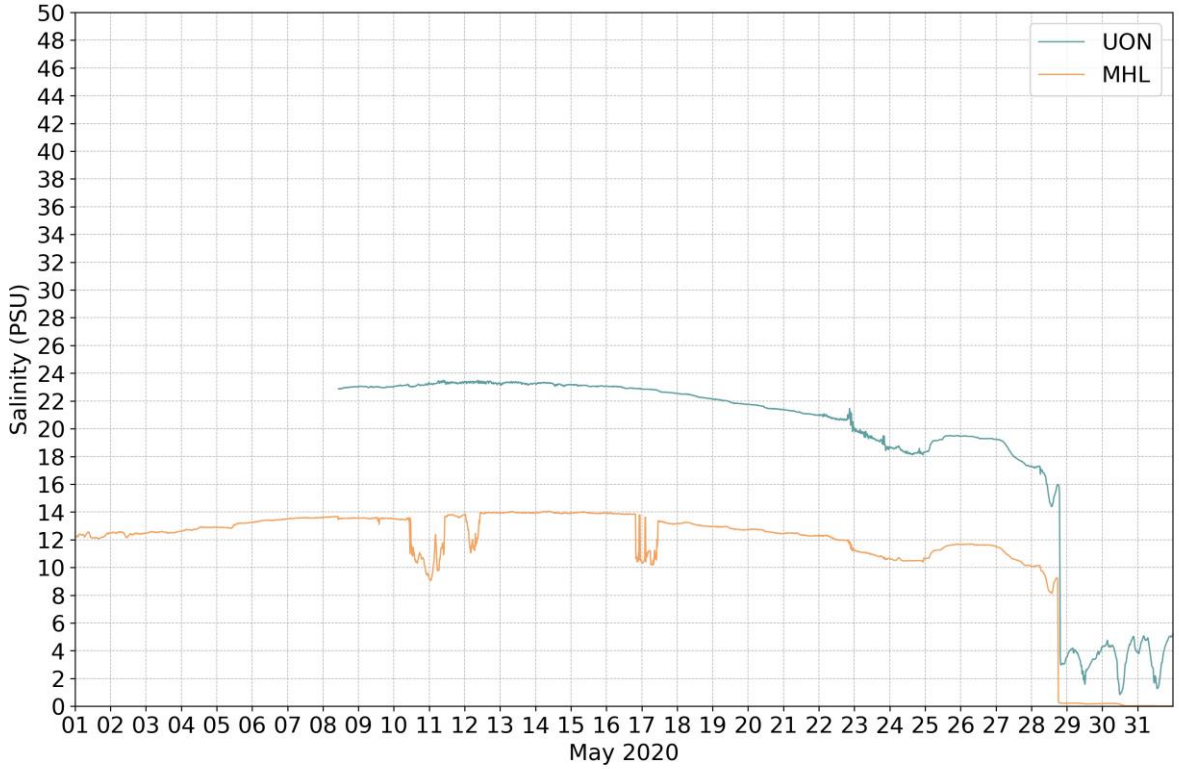

Figure B 1 Bareena Wetland Salinity, UON and MHL, May 2020

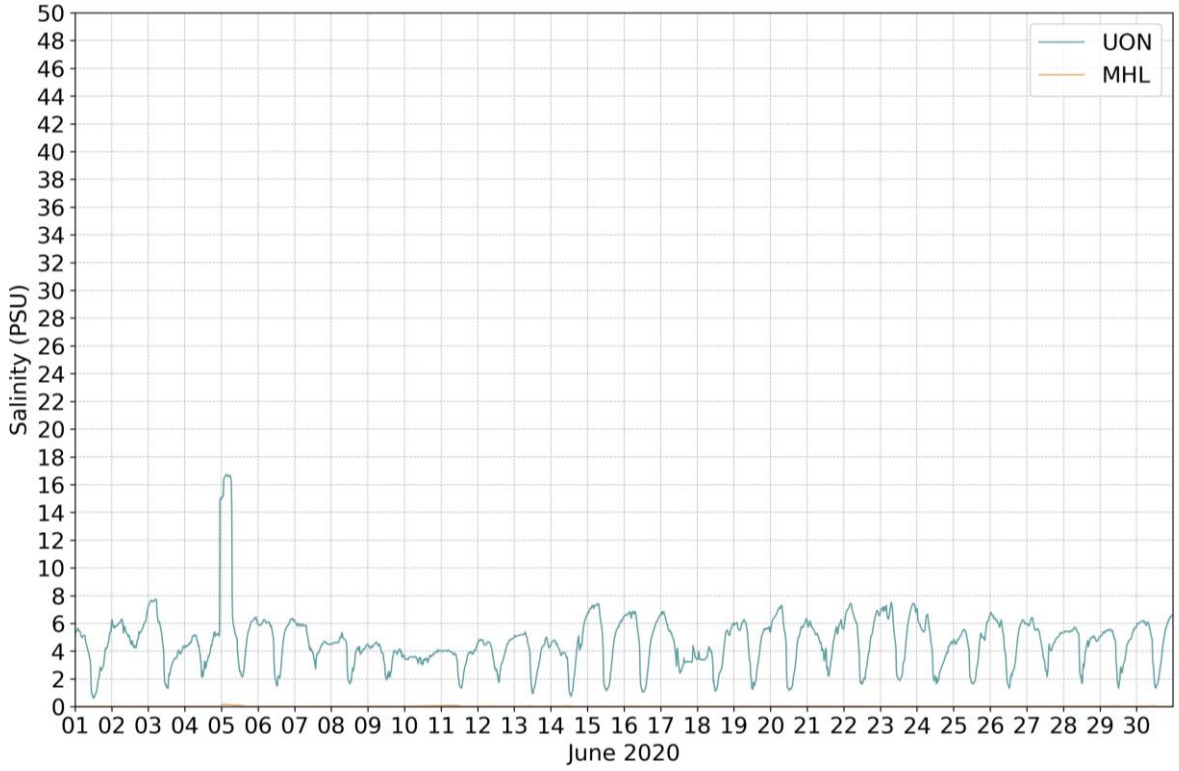

Figure B 2 Bareena Wetland Salinity, UON and MHL, June 2020

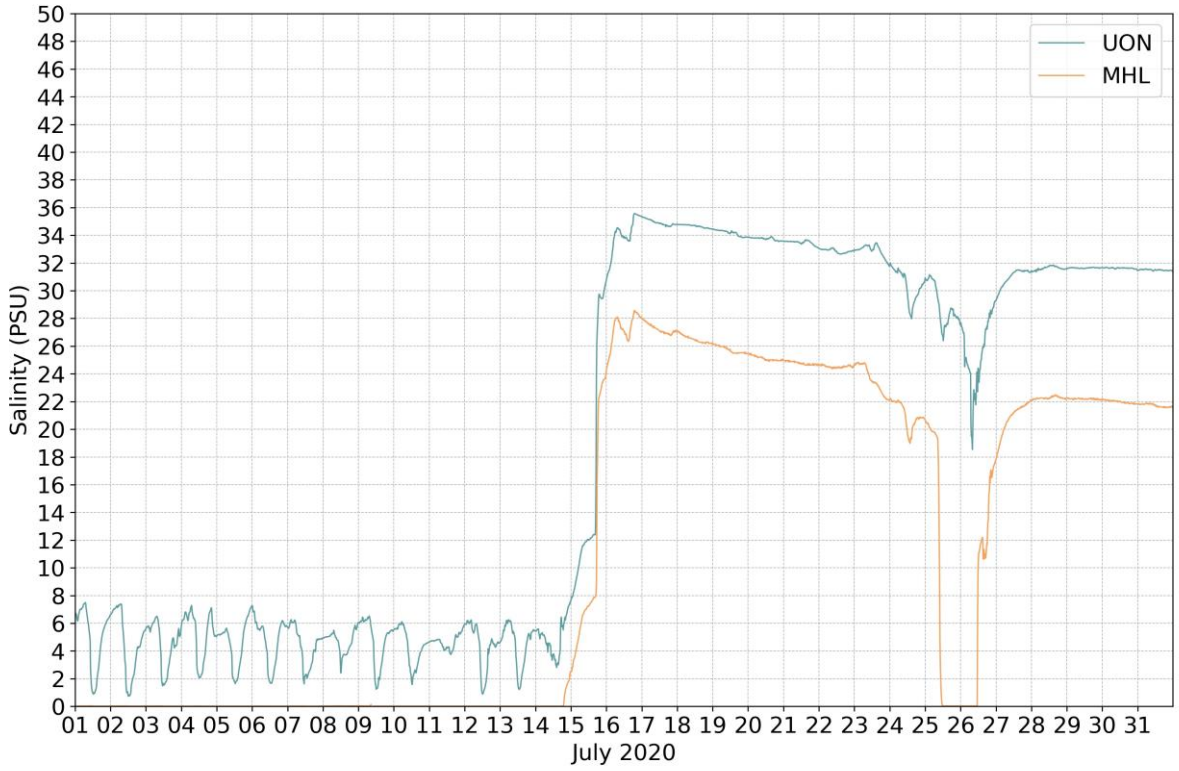

Figure B 3 Bareena Wetland Salinity, UON and MHL, July 2020

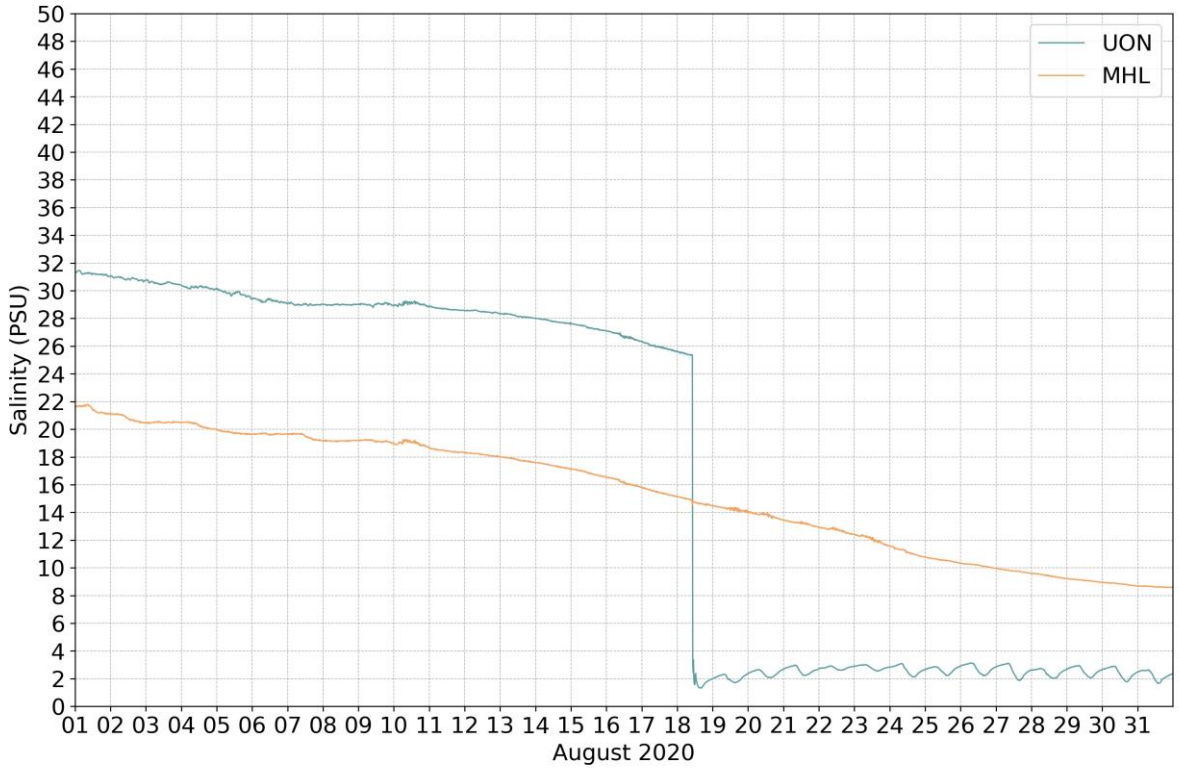

Figure B 4 Bareena Wetland Salinity, UON and MHL, August 2020

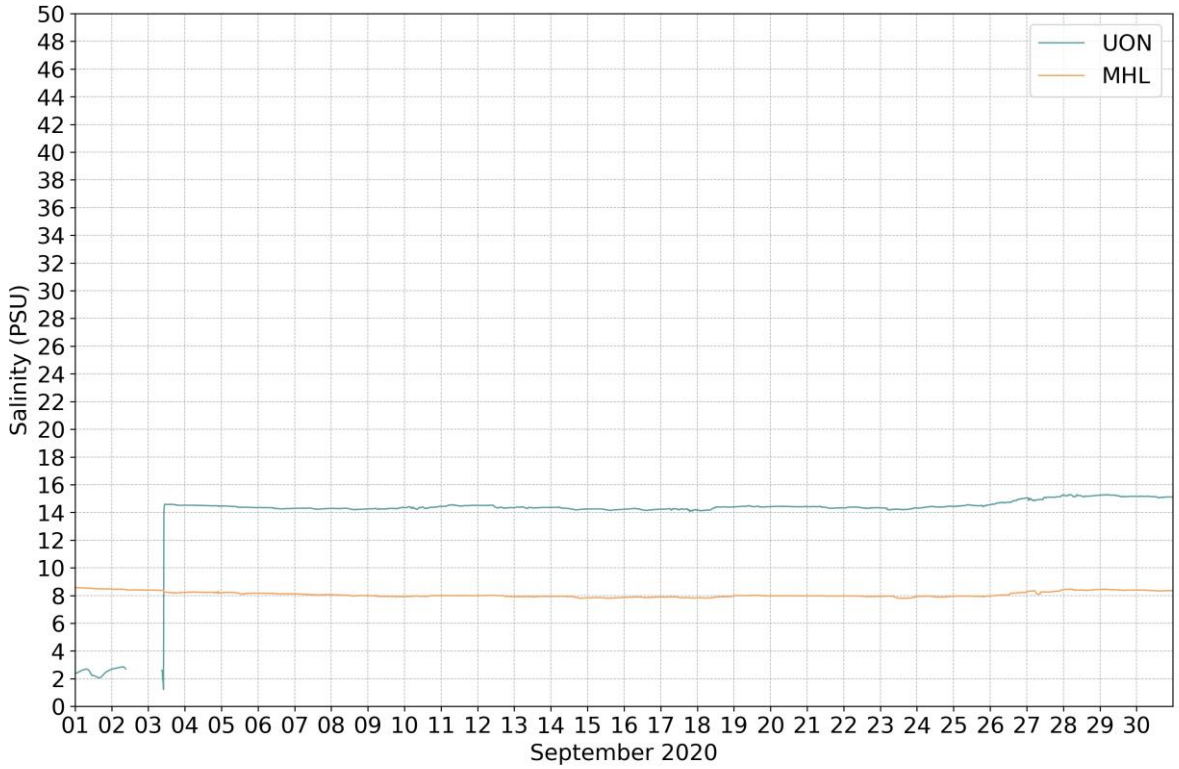

Figure B 5 Bareena Wetland Salinity, UON and MHL, September 2020

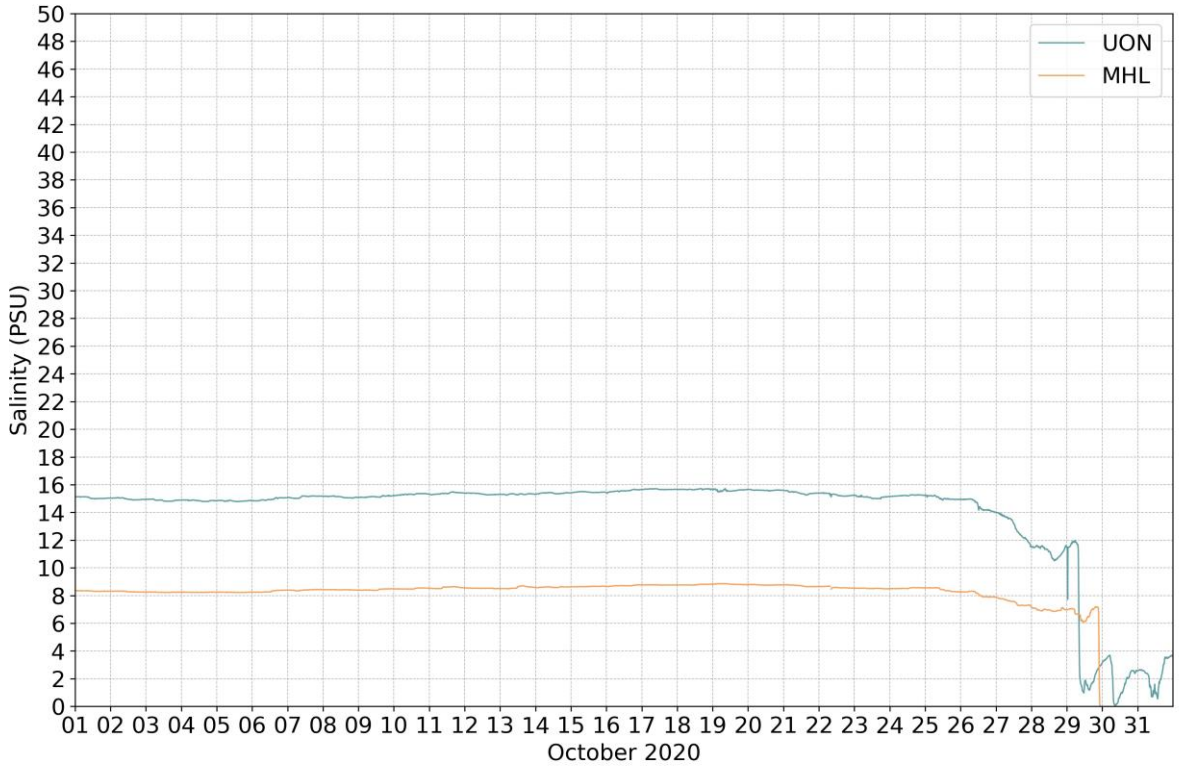

Figure B 6 Bareena Wetland Salinity, UON and MHL, October 2020

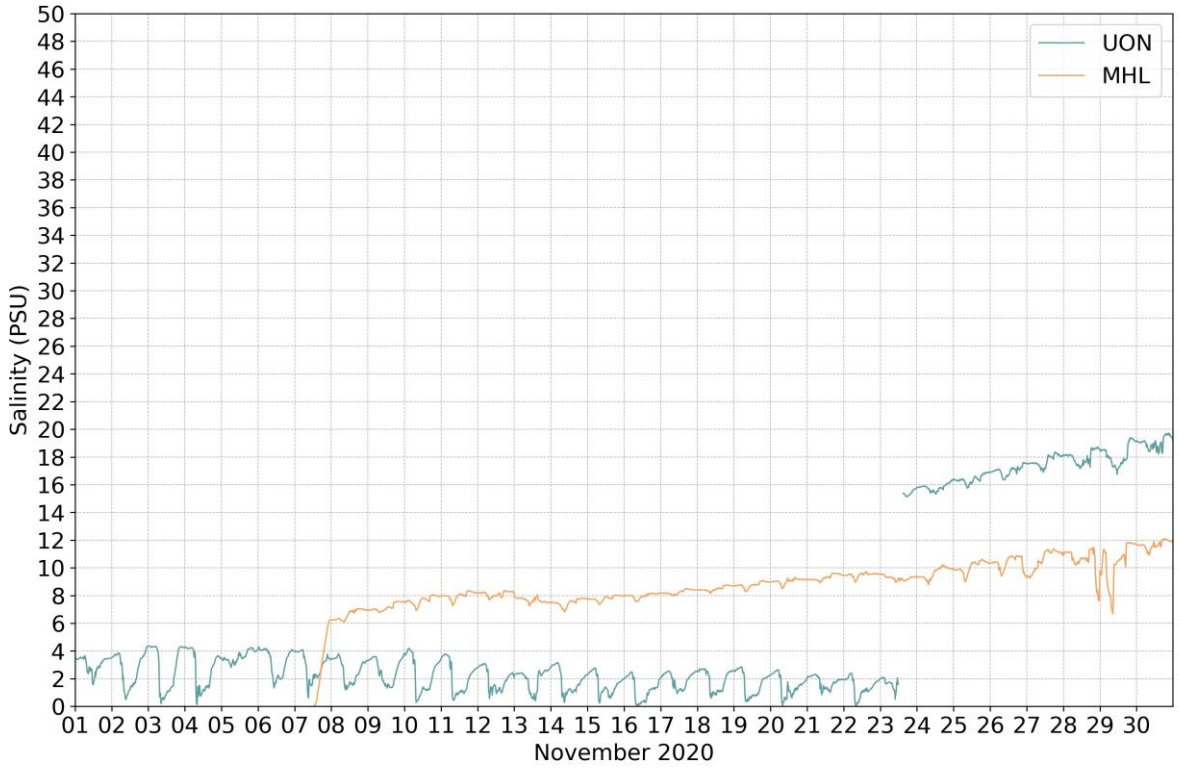

Figure B 7 Bareena Wetland Salinity, UON and MHL, November 2020

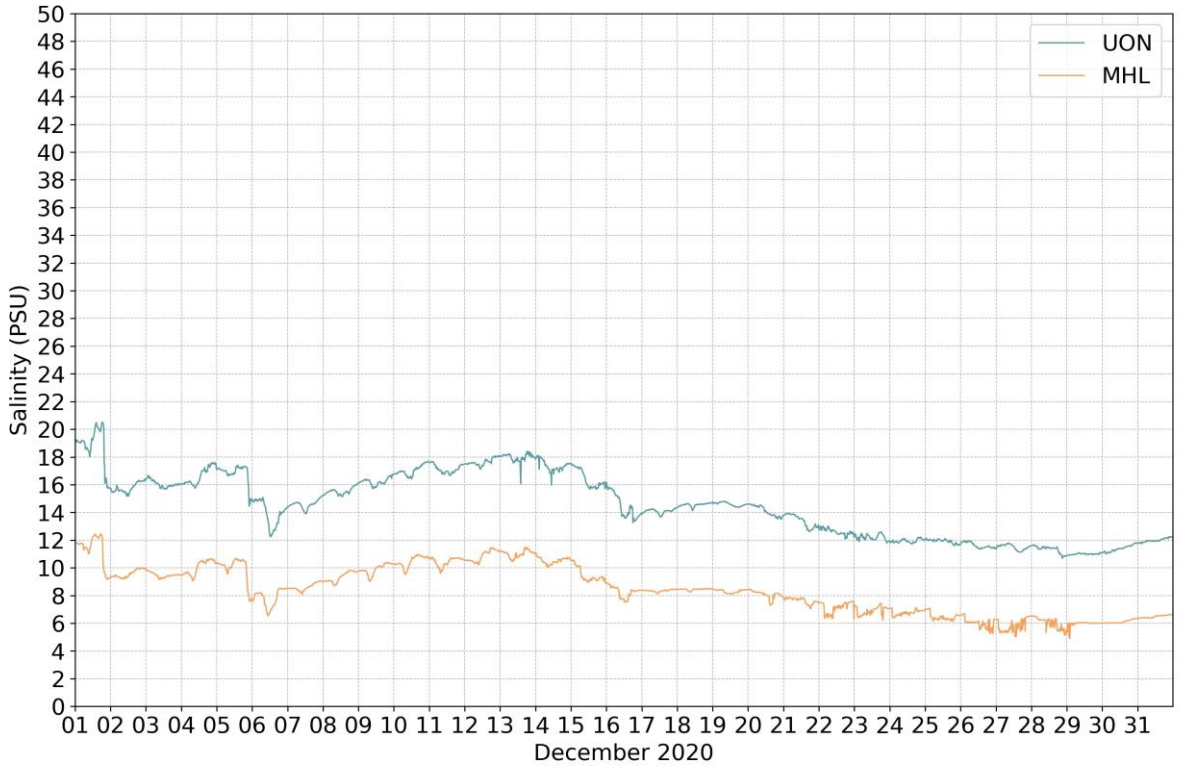

Figure B 8 Bareena Wetland Salinity, UON and MHL, December 2020

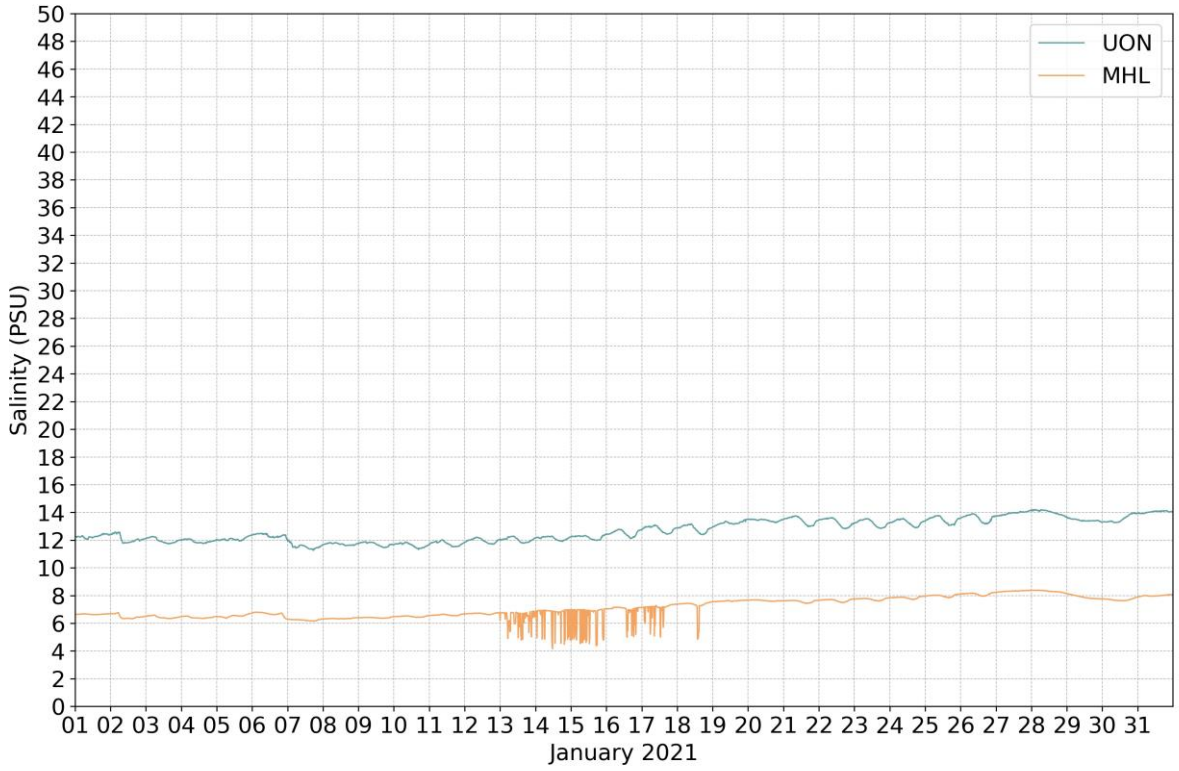

Figure B 9 Bareena Wetland Salinity, UON and MHL, January 2021

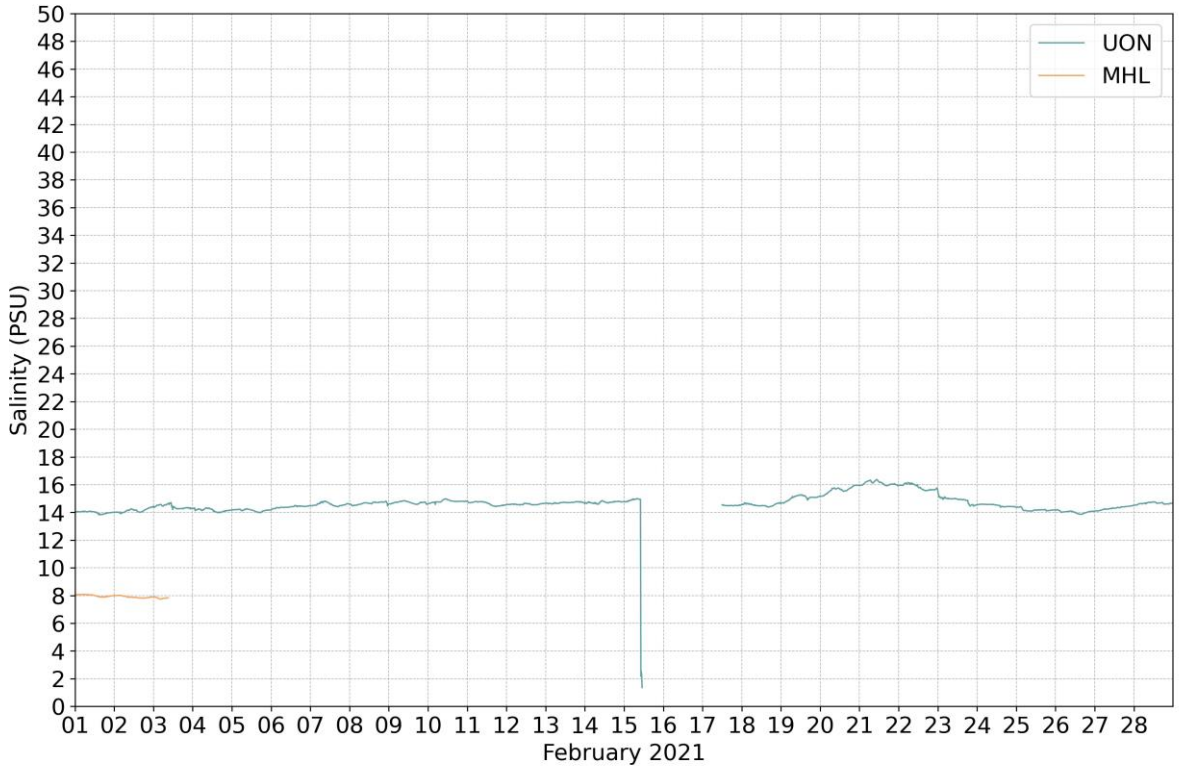

Figure B 10 Bareena Wetland Salinity, UON and MHL, February 2021