Abbot Point Ambient Water Quality Monitoring

October 2015 to October 2016

North Queensland Bulk Ports

November 2016

Phone: 61 7 4972 7530 | Unit 3, 165 Auckland St | PO Box 1267, Gladstone QLD 4680 |

www.visionenvironment.com.au

REPORT CONTRIBUTORS

Role	Team member
Project Management	Leonie Andersen, Felicity Melville
Fieldwork	Matt Frapple, Ralph Alquezar, Mark Jensen, Carsten Wolff, Col Andersen
Reporting & Review	Felicity Melville, Ralph Alquezar, Leonie Andersen, James Sadler

CITATION

This report should be cited as:

Vision Environment (2016). *Abbot Point Ambient Water Quality Monitoring: October 2015 to October 2016. North Queensland Bulk Ports*. Vision Environment, Gladstone Australia.

DOCUMENT CONTROL

Document draft	*Originated by*	*Edit and review*	*Date*
Draft issued for internal review	FM, MF, MJ, RA	FM	25/11/2016
Draft 2 issue for internal review	RA	FM	28/11/2016
Draft issued to Client	FM	LA	02/12/2016
Final issued to client	LA FM	JS	07/06/2017

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FILE REFERENCE

07062017 Abbot Point Ambient Water Quality Monitoring Report October 2015 to October 2016 Final_VE

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Acronyms

APHA	American Public Health Association
AWQG	Australian Water Quality Guidelines
BOM	Bureau of Meteorology
BPAR	Benthic Photosynthetically Active Radiation
BTEXN	Benzene, Toluene, Ethylene, Xylene and Napthalene
DO	Dissolved Oxygen
DNRM	Department of Natural Resources and Mines
DSITIA	Department of Science, Information Technology, Innovation and the Arts, Queensland
EHP	Department of Environment and Heritage Protection
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
HSEQ	Health, Safety, Environment and Quality
K_d	Light attenuation coefficient
LDS`	Least Significant Difference
LOR	Limits of Reporting
MS	Management System
NOx	Oxidised nitrogen (includes nitrate and nitrite)
NTU	Nephelometric Turbidity Units
NQBP	North Queensland Bulk Ports
PAR	Photosynthetically Active Radiation
QA/QC	Quality Assurance/Quality Control
QWQG	Queensland Water Quality Guidelines
SMART	Self-Monitoring Algorithm in Real Time
TDP	Total Daily PAR
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
VE	Vision Environment
WBDDP	Western Basin Dredging and Disposal Project
WQO	Water Quality Objective

SUMMARY

Baseline water quality monitoring at Abbot Point over a 12 month period from October 2015 to October 2016 has resulted in the following summarised results:

- The 2015/2016 Wet Season recorded lower than average rainfall, while the 2016 Dry Season experienced almost double the average rainfall. Significant rain periods in January and February 2016, and to a lesser extent June, resulted in high river flow from the Don and Elliot Rivers and Euri Creek, with lower discharge recorded at other times.
- Winds were found to be predominantly north-easterly from November 2015 to February 2016, before switching to become predominantly south-easterly from March to mid-September 2016. Winds from the north-east again dominated from mid-September to the end of October 2016. Wave height patterns paralleled wind speed patterns and were the predominant driver of sediment resuspension events during non-rainfall periods.
- Additional antifouling techniques for the continuous physicochemical loggers have considerably improved validated data recovery, as evidenced during the May to July 2016 deployment, as has the establishment of multiple log files on each logger during the deployment period. However fouling will remain problematic over a long deployment period. Shortening the time between maintenance periods would result in a higher data retention rate.
- Overall, turbidity across the six sites was significantly higher during the Wet Season than during the Dry Season, although the majority of values were within a small range. Most mean turbidity values were higher than the QWQG of 1 NTU, as recorded in previous monitoring programs, although the trigger value established for open coastal waters could be considered conservative in relation to the Abbot Point background environment. Higher wind speeds, which increased wave heights, resulted in higher turbidity values, suggesting that turbidity in Abbot Point is predominantly wind and wave-driven. Sedimentation results supported this with increased sediment resuspension (flux) in periods of high wind and waves, compared to there being little response to tidal phases and rainfall. A more typical climatic season encompassing more significant rainfall events could potentially produce different results.
- Patterns of sediment movement (e.g. deposition or erosion) were also highly influenced by wind direction, particularly at the shallower AMB1 site. With the seasonal wind direction change at the end of February 2016, overall deposition patterns at AMB1 switched to overall erosion patterns. Continued monitoring will determine if deposition patterns continue to alter in response to future seasonal wind changes. Sediment movement at AMB2 was less volatile and unresponsive to external variables, perhaps due to its deeper location, beyond the direct influence of river flows.
- Benthic PAR across the monitoring sites was also impacted predominantly by the depth of the site. Shallower sites recorded significantly higher BPAR, with deeper sites recording significantly lower BPAR. Significantly higher ambient PAR and BPAR was also recorded during the Wet Season than during the Dry Season, despite the significantly lower turbidity recorded during the latter season. However as this was not a typical climatic season where the number of cloudy days and/or rainfall would generally expected to be higher, results may be different for subsequent monitoring seasons.
- Significant seasonality was evident for water temperature, as expected. Conductivity also exhibited seasonality, with significantly lower conductivity during the Wet Season, most likely as a result of freshwater inputs into coastal waters surrounding Abbot Point. Decreased conductivity in response to rainfall was most evident at AMB1, which is

closest to the Euri Creek and Don Basin discharge area, both of which had recorded discharges of approximately four times higher than the Elliott Basin.

- The pH and DO remained reasonably stable across all sites, although diurnal fluctuations at AMB3 and AMB5 were recorded on occasion. These fluctuations (higher pH and DO during the day, and lower during the night) are thought to be caused by nearby biological activity (photosynthesis and respiration). At AMB5 the fluctuations have been attributed to the adjacent coral reef and increased activity of coral associated, photosynthetic organisms. At AMB3 fluctuations were likely a result of nutrient runoff, potentially from nearby aquaculture facilities and wetlands during the period when rainfall was highest. Surface algal blooms and/or an increase in benthic algae may have occurred in the vicinity of the AMB3 logger. AMB3 and AMB5 are the two shallowest sites experiencing the highest benthic PAR values and therefore likely to exhibit higher levels of photosynthesis and diurnal fluctuations in DO, compared to deeper sites. Both parameters were generally within their respective QWQG ranges.
- Depth profiling of physicochemical parameters determined that the waters were generally well-mixed, as found in previous monitoring programs.
- Water quality analyses indicated that while phosphorus remained low throughout the year, some seasonality may be evident for nitrogen forms, with elevated concentrations during the Wet Season. Despite its close proximity to potential aquaculture facility and wetlands run off, concentrations of nutrients at AMB3 were within range of other sites. Continued monitoring in January 2016 should uncover further temporal patterns.
- Dissolved metal and organics (hydrocarbons, BTEXN and herbicides) concentrations were mostly below laboratory reporting limits or were low where recorded, and well below AWQG.

RECOMMENDATIONS

The following recommendations are suggested as amendments to improve the Abbot Point Baseline monitoring program.

1. Increase the sampling and maintenance frequency.

Due to the level of biofouling at Abbot Point, as a result of warm temperatures and available ambient light, it is suggested that maintenance visits be increased from quarterly to every two months. This should ensure a higher level of validated data return.

2. Reduce the number of logger sites.

In order to provide an economically sustainable program, the removal of loggers at several sites may be required. The 2015/2016 data has shown that the AMB6 logger is not providing any more useful information than that provided by AMB1, and potentially can be removed from the program. Additionally the site at AMB3 was initially monitored to detect increased nutrient loads from aquaculture facility and wetlands storm water run-off. Therefore removal of the logger but continuation of water sampling/profiling at AMB3 is suggested.

3. Transition from benthic logger deployment to surface logger

Surface logger data is typically less noisy and more reliable than benthic data. The ramp-up to telemetry during construction phases is comparatively simple for surface loggers compared to benthic loggers. In the shallow environment of Abbot Point where the water column is well mixed, surface loggers would provide more cost effective and higher quality data than benthic loggers. During a transition phase, it is suggested that a surface logger be deployed at AMB1 concurrently with the benthic logger and data compared with a view to transitioning to surface loggers at all remaining sites.

4. Relocation of altimeters

With potential removal of the AMB6 logger, relocation of the dual altimeters to AMB1 as an alternative site is suggested. As sedimentation and the smothering of benthic habitats such as coral is a concern, the relocation of the second set of dual altimeters from AMB2 to AMB4 at Camp Island adjacent to coral habitats would serve a better purpose for the collection of sedimentation data.

5. Reduce the number of BPAR sites

Benthic PAR is a useful measurement when deployed adjacent to sensitive benthic habitats such as coral or seagrass. Therefore it is suggested that BPAR only be measured at AMB4 and AMB5 (coral habitats) and AMB1 (seagrass and benthic habitats).

6. Increase water sampling frequency

With an increase in the number of maintenance visits there is an opportunity to increase the frequency of depth profiling and modify the water sampling program. It is also suggested to add total metals sampling to AMB1 and AMB3 concurrent with dissolved metals.

1. INTRODUCTION

The Port of Abbot Point is Australia's most northern coal port (NQBP, 2012), and is located within the Great Barrier Reef (GBR) lagoon between Cape Upstart and Bowen. The port consists of coal handling and stockpile areas, rail facilities, conveyors, two berths and ship loaders, which are located along a single trestle jetty stretching 2.8 km offshore (NQBP, 2012).

North Queensland Bulk Ports (NQBP) sought the implementation of an ambient marine water quality monitoring program at Abbot Point as part of their Environment and Sustainability Plan. The monitoring program has been designed to monitor ambient conditions during periods when no development is being undertaken, with the inbuilt flexibility to ramp up during development to ensure that any potential impacts on sensitive receptors are able to be effectively managed. Previous monitoring programs undertaken at Abbot Point identified a high level of seasonal variability in water quality, influenced by rainfall and resulting runoff, as well as climatic events such as cyclones (GHD, 2009, 2010, 2012, Worley Parsons, 2014).

The current monitoring program commenced in October 2015 and includes the use of continuous benthic loggers to measure physicochemical parameters, benthic light and sedimentation/sediment transport, as well as water quality chemical analysis and physicochemical depth profiling. Sites extend 27 km along the Abbot Point coastline, from Camp Island in the NW to the mouth of the Don River towards the SE, extending offshore to Holbourne Island. Sites in the network align with key sensitive receptor habitats (e.g. corals and seagrass) along with key features in the study region (e.g. river flows).

This report presents the data collected from one year of monitoring: October 2015 to October 2016. A summary of climatic conditions (Wet Season: 1 November to 30 April and Dry Season: 1 May to 31 October as defined by the Department of Environment and Heritage Protection (EHP, 2013a, b) and the Department of Science, Information Technology, Innovation and the Arts (DSITIA, 2014)) during this period is provided, including an interpretation of the factors that may have influenced the Abbot Point marine environment. A comparison of results with appropriate water quality guidelines is provided for reference.

1.1 Sampling Rationale

One of the most important physicochemical parameters to measure in coastal waters where development occurs is water clarity. In this program, water clarity was determined by measuring total suspended solids (TSS), turbidity, Benthic Photosynthetic Active Radiation (BPAR) and sedimentation (in the form of bed level changes resulting from deposition and erosion processes).

1.1.1 TSS & Turbidity

TSS refers to the amount of organic and inorganic non-dissolved solids within the water column (APHA, 2005), with a higher concentration of solids leading to lower water clarity. However, this parameter cannot be measured *in situ*, requiring laboratory analyses to obtain a result. Turbidity is an expression of the optical property of light to be scattered and absorbed rather than transmitted through the water sample (APHA 2005). The higher the amount of suspended and colloidal matter within the water column, the higher the amount of light scattering, and thus the higher the turbidity. Discrete and continuous (logged) turbidity (and other physicochemistry) measurements can be gained *in situ* through the use of water quality meters. Water quality meters can be converted to telemetry thus enabling the delivery of real time turbidity data for compliance and management purposes, as required.

1.1.2 BPAR

The measurement of BPAR provides information on whether the water clarity is sufficient to permit adequate light to reach the phototrophic organisms on the seafloor, to meet growth requirements and maintain health (GBRMPA, 2010). The benthic environment can be particularly susceptible to resuspension of sediments due to natural and anthropogenic influences. High levels of sediment in the water column has the potential to not only cause a reduction of light (and therefore decrease primary productivity) but also to smother benthic habitats such as corals (De'ath and Fabricius, 2008, GBRMPA, 2010) and impede growth of seagrass.

1.1.3 Sedimentation Rates

Revolving sediment deposition and erosion is the process of benthic sediment movement or transportation from one area to another. This process may be accelerated by natural forces such as tides, wind and cyclones, or by anthropogenic activities such as dredging. Measuring sedimentation rates, which includes the level of sediment flux in addition to cumulative bed level change, can assist in understanding sediment transport processes.

1.1.4 Physicochemical Parameters

Other physicochemical parameters measured in this program include pH, conductivity/salinity, temperature, and dissolved oxygen (DO). The pH is a measure of the acidity of water, which has the potential to be impacted by a number of variables, including the precipitation, coagulation and perturbation of benthic sediments (APHA 2005). A change in pH can have a direct toxic effect on aquatic biota (ANZECC/ARMCANZ, 2000) and may also alter metal bioavailability to aquatic organisms. Exposure of benthic sediments during development, particularly those with acid-sulfate soils, has the potential to increase the amount of acidity in the water column if not properly managed.

Conductivity is the ability of water to conduct an electrical current, which is affected by the presence of inorganic dissolved solids, such as salts (APHA, 2005). Conductivity (a stressor rather than toxicant) provides an indication of the amount of catchment rainfall entering the system. Temperature is an important parameter to measure in the coastal waters of northern Australia, as corals can suffer stress when water temperatures increase above normal maxima (GBRMPA, 2010).

Dissolved oxygen is the amount of gaseous oxygen (% saturation) that has dissolved in water. Measurements of DO can assist in the validation of the presence of algal blooms. While these physicochemical parameters rarely directly measure potential development impacts, they can provide information on natural and anthropogenic effects which may be causing underlying stress to the ecosystem (ANZECC/ARMCANZ, 2000).

1.1.5 Water Sampling

A number of other water quality parameters may be affected during development projects and are therefore important to measure during baseline conditions. Phosphorus and nitrogen are essential for the growth of organisms (APHA, 2005). High nutrient concentrations are not necessarily considered to be directly toxic to aquatic organisms, but can directly affect the ecosystem and biota (ANZECC/ARMCANZ, 2000). Eutrophication (excess nutrients) can stimulate the growth of macrophytes and algae (including toxic cyanobacteria), which can result in an increase in chlorophyll *a* in the water column. Chlorophyll *a* is a green pigment found in plants, which is utilised in photosynthesis (USEPA, 1997), and is measured as an indicator of algal biomass (APHA, 2005).

Algal blooms can contribute to the TSS concentration in the water column and therefore result in a reduction in water clarity. Nuisance blooms have the potential to result in adverse impacts to the aquatic ecosystem through toxic effects (mortality and/or displacement of species), reduced light availability to benthic species, excessive fluctuations in pH, reduction in DO and changes in biodiversity (Valiela et al., 1997).

Total metals are the concentration of metals (elements) determined in an unfiltered sample (including metals bound to sediments and colloidal particles), while 'dissolved' metals are those still detected in water (APHA, 2005), when passed through a 0.45 µm membrane filter. Some metals are essential to plant and animal growth but can become toxic at elevated concentrations (APHA 2005). Dissolved metals are considered to be the potential bioavailable fraction (ANZECC/ARMCANZ, 2000), and have been measured in this program. The disturbance and resuspension of potential contaminants in benthic sediments can result in the addition of metals to the water column (Erftemeijer and Lewis III, 2006). Changes in water chemistry (e.g. decrease in pH), also have the potential to result in an increase in metal bioavailability by increasing the proportion of dissolved metals (those no longer bound to sediments and thus potentially more bioavailable).

2. METHODOLOGY

2.1 Site Selection

The location of monitoring sites was guided by the results of computer models, which indicated the potential zones of impact if proposed dredging activity was to go ahead (GHD, 2012), in addition to results gained from the previous monitoring program (Worley Parsons, 2014). Sites were located in order to capture an understanding of ambient water quality conditions, as well as being able to define any changes related to future potential development activities (such as dredging). The monitoring sites are described in Table 1 and depicted in Figure 1. Table 2 summarises the field instrumentation utilised and sampling regime undertaken at each monitoring site.

Table 1 Location of water quality monitoring sites.
GPS coordinates captured in WGS84, degrees decimal minutes. Description outlines the potential impact zoning of the sites if the proposed dredging was to commence, as per modified GHD (2012).

Site	Depth (m)	Coordinates	Description
AMB1	9.0	S19 54.281 E148 08.510	Background comparison for seagrass habitat and source effects from the Don River
AMB2	12.2	S19 50.663 E148 00.464	Background comparison during ambient monitoring but potentially high impact site during periods of development
AMB3	3.9	S19 53.534 E147 56.210	Background comparison (potential wetlands and aquaculture discharges)
AMB4	8.5	S19 50.503 E147 54.346	Zone of influence (not within predicted plume area) and adjacent to coral communities
AMB5	6.3	S19 44.145 E148 21.557	Background (adjacent to coral habitats)
AMB6	13.1	S19 52.297 E148 06.292	Zone of influence (not within predicted plume area)

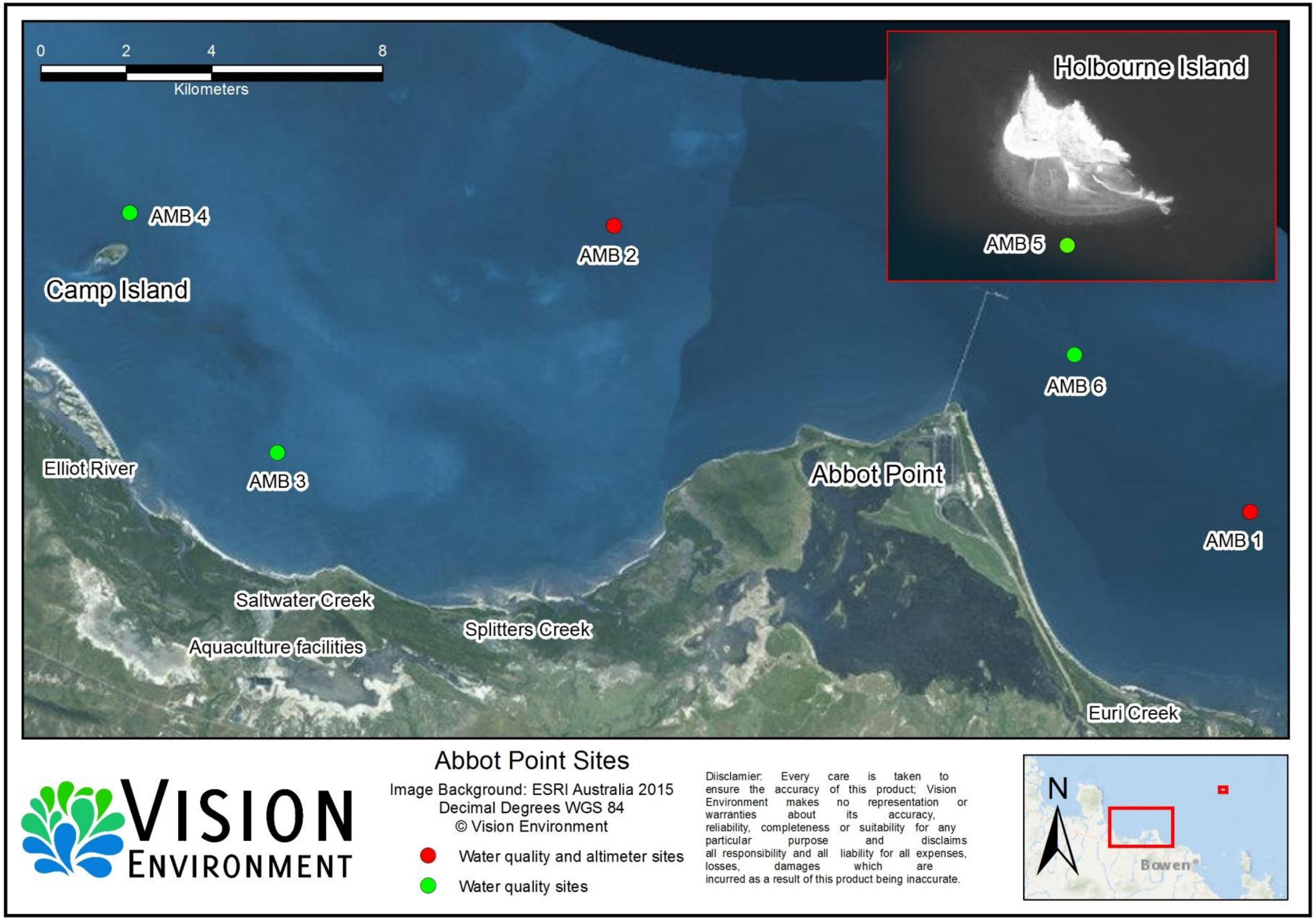

Figure 1 Location of Abbott Point monitoring sites.

Table 2 Summary of sites & ambient sampling regime.
Note that physicochemistry includes the following parameters: temperature, pH, conductivity, salinity, turbidity and dissolved oxygen. Water samples are collected from the subsurface (0.5 m depth).

Site	Continuous benthic loggers	Quarterly depth profiling	Quarterly water sampling	Biannual water sampling
AMB1	Physicochemistry, BPAR & Sedimentation	Physicochemistry & PAR	Nutrient suite, Chlorophyll *a*	Dissolved metals, TSS, Hydrocarbons & pesticides
AMB2	Physicochemistry, BPAR & Sedimentation	Physicochemistry & PAR	Nutrient suite, Chlorophyll *a*	Dissolved metals, TSS, Hydrocarbons & pesticides
AMB3	Physicochemistry & BPAR	Physicochemistry & PAR	Nutrient suite, Chlorophyll *a*	Dissolved metals, TSS
AMB4	Physicochemistry & BPAR	Physicochemistry & PAR	Nutrient suite, Chlorophyll *a*	Dissolved metals, TSS, Hydrocarbons & pesticides
AMB5	Physicochemistry & BPAR	Physicochemistry & PAR	Nutrient suite, Chlorophyll *a*	Dissolved metals, TSS
AMB6	Physicochemistry & BPAR	Physicochemistry & PAR	Nutrient suite, Chlorophyll *a*	Dissolved metals, TSS
Surveys/exchanges undertaken to date	• 20 to 22 Oct 2015 • 7 to 9 Jan 2016 • 2 to 4 May 2016 • 22 to 24 Jul 2016 • 27 Oct to 1 Nov 2016	• 7 to 9 January 2016 • 2 to 4 May 2016 • 22 to 24 July 2016 • 27 Oct to 1 Nov 2016	• 7 to 9 January 2016 • 2 to 4 May 2016 • 22 to 24 July 2016 • 27 Oct to 1 Nov 2016	• 7 to 9 January 2016 • 22 to 24 July 2016

2.2 Field Instrumentation

2.2.1 Continuous Physicochemistry Loggers

Autonomous dataloggers (Hydrolab DS5X sondes with self-cleaning wipers) were programed to record temperature (°C), conductivity (mS/cm), salinity (ppt), pH, turbidity (NTU) and DO (% saturation) powered by external batteries. Triplicate sondes were fixed into a custom metal deployment frame, locked by SCUBA divers into a fixed metal triangle and anchored to the benthos by plough anchors (Figure 2). Sub-surface marker buoys with an accurate GPS coordinate were utilised to minimise boat strike or tampering. The vertical orientation of the monitoring station was assured through the use of the anchored triangular sub-frames.

Logger exchange was scheduled every three months (pending weather conditions), where the deployment frame was retrieved by divers and taken to the surface to exchange the loggers. The recorded data was then downloaded at the Vision Environment (VE) base. Each logger was calibrated and tested prior to deployment as per the VE HSEQ Management System protocols. Calibration methodology included two-point calibrations for turbidity (1 and 20 NTU), conductivity (0 and 56.9 mS/cm), and pH (7 and 10), in addition to a one-point calibration for DO (100% saturation at ambient atmospheric pressure). Post-calibration testing involved a log test for turbidity in a 10 NTU solution, logging at 10 minute intervals over a 24 hour period. Turbidity values at 10 NTU ± 1 NTU during the log-test were considered acceptable.

During the first two deployment periods (October 2015 to May 2016), biofouling of individual probes (Figure 3) resulted in low validated data retention rates, despite the use of antifouling paint and copper cages. Accordingly, logger deployments from May 2016 onwards incorporated additional antifouling measures, including wrapping individual probes with copper tape and copper mesh (sparing sensor), and replacing the DS5X wiper with a more robust external wiper (Figure 4). Validated recovery rates after May 2016 improved greatly, although fouling still remained problematic in the warmer months (see Section 3.2.1).

2.2.2 Continuous BPAR Loggers

Dual autonomous light loggers (Odyssey submersible photosynthetically irradiance recording system) with external hydrowipers were placed in the benthic frame alongside the physicochemistry loggers (Figure 5), recording BPAR at 15 minute intervals. Loggers were exchanged during the physicochemistry logger exchange and the recorded data downloaded at the VE base.

In order to record daily ambient changes in total available photosynthetically active radiation (PAR), dual autonomous light loggers were also deployed on land at Bowen Base (an unshaded antenna at Aussie Reef Dive, Howard St, Bowen). The inclusion of the Bowen Base data allowed for variation in daily ambient PAR (e.g. due to cloud cover) to be accounted for, thus acting as a 'control' PAR site and aiding in the interpretation of BPAR levels at Abbot Point . The Bowen Base loggers recorded decreased levels of sunlight during overcast days, which assisted in the interpretation of some fluctuations in BPAR within the dataset. While small scale daily weather patterns such as scattered cloud were not consistent across Bowen and Abbot Point, substantial overall daily changes were recorded and significant reductions in ambient PAR were accounted for.

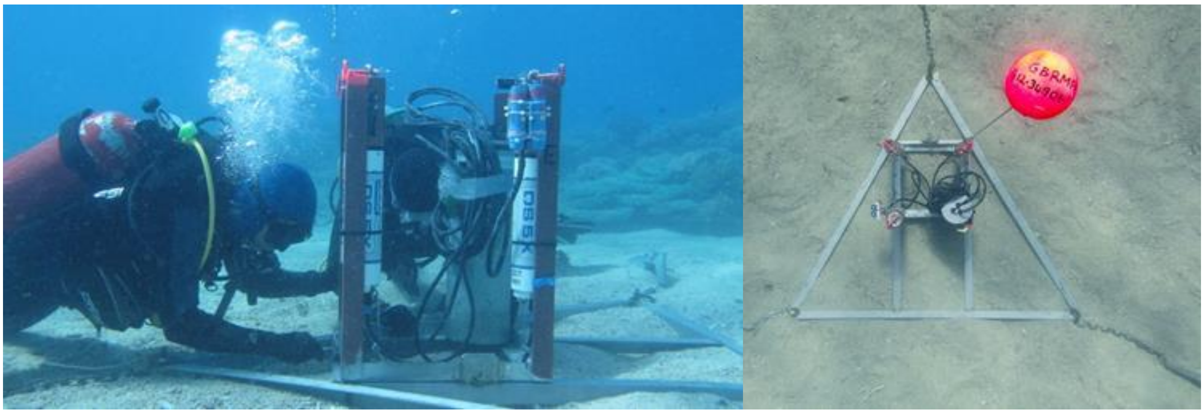

Figure 2 Benthic loggers deployed by SCUBA divers and fixed on deployment frames.

Figure 3 Excessive fouling of loggers occurred during deployments from October 2015 to May 2016.

Figure 4 Revised antifouling measures for continuous physicochemistry loggers.

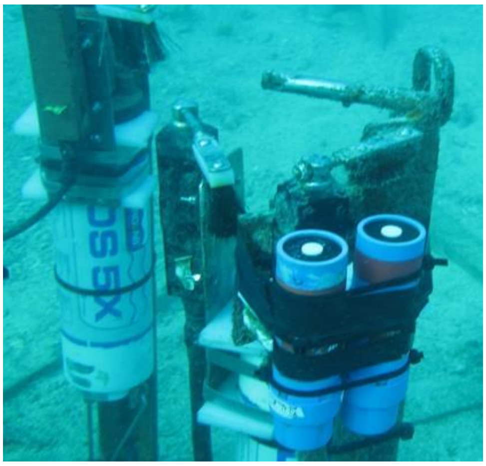

Figure 5 PAR loggers deployed adjacent to continuous physicochemistry loggers.

2.2.3 Altimeters

Traditional instruments such as sediment traps, which have been used in previous Abbot Point monitoring programs (Worley Parsons, 2014), measure the downward flux of sediment particles over any given time. However, determining the net flux or bed level change provides invaluable additional information to this traditional measure to better quantify sediment transport processes and confirm if there is overall deposition or erosion of sediments over a given time period within a local area. The use of traditional sediment traps assumes all captured particles are permanently deposited, whereas the altimeters provide a more detailed analysis of transport processes and demonstrate that it many cases sediments are transient in a system.

In contrast to traditional sediment-traps, acoustic real-time altimeters (Figure 6) have the ability to record the fine level changes of the sea bed by measuring altitude data from a known position over specified time intervals. An altimeter can measure both short and long term changes of bed elevation at locations where deposition and erosion of fine sediments occurs. Seabed monitoring using altimeters is superior to monitoring with sediment traps as continuous data is gained, with the ability to incorporate and identify resuspension events, thus calculating net, rather than total deposition or erosion over time. In addition it provides an invaluable insight into the primary drivers of these resuspension events and offers the potential ability to predict the extent of such, into the future.

Figure 6 ALTUS altimeters deployed adjacent to continuous physicochemistry and BPAR logger frames.

Continuous bed level measurements were obtained using ALTUS acoustic altimeters. The ALTUS altimeter (NKE instrumentation) is an autonomous instrument that obtains very high precision bed level measurements (millimetre scale) every 15 minutes, using a high frequency acoustic sensor and an inbuilt data logging device. Altimeters were mounted in duplicate, cross-current and adjacent to the physicochemistry and BPAR logger frames, between 200 and 600 mm above the seabed (Figure 6), at sites AMB1 and AMB2. External hydrowipers were installed to eliminate transducer interference caused by fouling. Altimeters were exchanged during the physicochemistry logger exchange and the recorded data downloaded at VE base.

2.3 Depth Profiling

Physicochemical parameters (temperature, conductivity, salinity, pH, turbidity and DO) were measured through the water column at 0.5 to 1.0 m depth intervals (depending on depth) to the benthos, using either a YSI 6820 or ProDSS (Figure 7) multi-parameter water meter. Down-welling PAR (measured in micromoles per square metre per second ($\mu mol/m^2/s$)) was measured concurrently using a LI-COR LI192SA Underwater Quantum Sensor in a lowering frame (Figure 7) and a LI-189 or LI1500 Quantum Radiometer Photometer, until the benthos was reached or light was <10 $\mu mol/s/m^2$.

2.4 Water Sampling

Water sampling was carried as per the Vision Environment HSEQ Management System protocols. Samples were collected in accordance with standard protocols derived from worldwide authorities, including:

- Australian and New Zealand Standards for water quality and sediment sampling (AS/NZS, 1998a, b, c);
- The American Public Health Association Standard Methods for the Examination of Water and Wastewater (APHA, 2005);
- Australian and New Zealand Water Quality Guidelines (ANZECC, 1992, 1998, ANZECC/ARMCANZ, 2000);
- The Queensland Water Quality Guidelines (DERM, 2009); and
- The Department of Environmental Resource Management Monitoring and Sampling Manual (DERM, 2010).

Water samples for analyses were collected at a depth of 0.5 m using a perspex pole sampler to which a 1 L Nalgene bottle was attached (Figure 8). Nalgene bottles were acid-washed with hydrochloric acid in the VE laboratory clean room prior to sampling, and triple rinsed in ambient water prior to sample collection at each site. Powder free gloves were worn to avoid contamination.

Samples which required filtration (dissolved metals and nutrients) were filtered, *in situ,* through a 0.45 µm sterile surfactant free cellulose acetate membrane syringe filter (Minisart 16555K) into an acid-washed sample bottle provided by the analysing laboratory (Figure 9). Each syringe was pre-rinsed in site water, and filters came pre-packaged from the supplier. For samples which did not require filtration (TSS, total nutrients, chlorophyll *a* and organics), water samples were decanted directly into the laboratory provided sample bottles.

Figure 7 Depth profiling using the YSI ProDSS and the LI-COR LI192SA Underwater Quantum Sensor.

Figure 8 Collection of water samples for analysis using an acid-washed Nalgene bottle in a perspex pole sampler.

Figure 9 Filtration of water samples.

Samples were stored on ice for transport to the analysing laboratory, with filtered nutrient samples frozen overnight in order to prolong sample holding times. In order to extend holding times for chlorophyll *a*, samples were pre-processed at VE through 0.45 µm glass fiber filters, using a manifold and vacuum pump, with the volume of water passed through the filter recorded (500 ml). Filter papers were folded in aluminum foil, placed in airtight plastic bags, then frozen to extend the holding period of these samples to 28 days, in accordance with APHA method 12000H (APHA, 2005). All water samples were analysed at ALS laboratories.

Duplicate water samples for all parameters were collected at 10% of sites as per established protocols, with a field and laboratory blank also collected. Analytical laboratory quality control measures included laboratory duplicates, laboratory blanks, analysis of certified reference material and matrix spikes.

2.5 Data Management

2.5.1 Physicochemistry Loggers

Management of physicochemistry logger data was undertaken as per VE HSEQ management system (MS) protocols, developed and peer reviewed during the three year Western Basin Dredge and Disposal Project (WBDDP), and Narrows Crossing projects (Vision Environment, 2013).

All continuous physicochemical data was manually uploaded to the VE cloud database, where it underwent SMART (Self-Monitoring Algorithm in Real Time) deconfounding. SMART was developed by VE as an initial automatic data deconfounding process in order to filter out erroneous raw real time data from multiple instruments, to provide a more accurate and instantly usable real time data set. However, SMART can also be used as an initial deconfounding tool for logged datasets.

Following the initial deconfounding, the SMART data was manually validated. In most cases, the SMART data did not need altering. However, there were some instances where data was removed from the dataset incorrectly, in which case it was inserted back into the dataset.

Erroneous data was identified using the following procedures as per VE HSEQ MS protocols:

- Turbidity
  - Continually increasing turbidity values, suggesting fouling, with no apparent environmental causes.
  - Intermittent, erratic values, either markedly higher or lower than the majority of values recorded at that time by that logger or adjacent loggers and inconsistent with previous trends.
- pH
  - pH values outside the typical lower estuarine and marine conditions (7.3 to 8.4). However, if both loggers were showing pH outside this range and environmental causes were indicated, these were considered a valid result.
  - SMART automatically moved the pH data from the dataset, when a logger had a conductivity result of zero (e.g. logger having been removed from the water during logger exchange).
- Conductivity
  - Conductivity values outside the typical lower estuarine and marine conditions (50 to 62 mS/cm), unless both loggers were showing conductivity outside this range and environmental causes were indicated (e.g. during a rain event).

  - If the difference between two of the loggers was 5 mS/cm or greater, the value closest to 55 mS/cm was kept, and the alternate values moved by SMART and identified as erroneous. However, this was manually checked and confirmed by VE personnel. Note that the 5 mS/cm difference was based on ± 10% difference between readings, which was higher than the Hydrolab DS5X sensor accuracy, which is reported at 1%.
- Dissolved oxygen
  - Oxygen values outside the typical lower estuarine and marine conditions (70 to 120% saturation), unless both loggers were showing DO outside this range and environmental causes are indicated.
  - If the difference between the loggers was 5% or greater, the value closest to 100 % saturation was kept, and the alternate values were moved by SMART and identified as erroneous. However, this was manually checked and confirmed by VE personnel. Note that the 5% difference was higher than the Hydrolab DS5X sensor accuracy, which is reported at 1% at concentrations <8 mg/L (or 100% saturation at 25ºC).
  - SMART automatically moved the dissolved oxygen data from the dataset, when a logger had a conductivity result of zero (e.g. logger having been removed from the water during logger exchange).
- Temperature
  - SMART automatically moved the temperature data from the dataset, when a logger had a conductivity result of zero (e.g. logger having been removed from the water during logger exchange).

Seasonal (Wet Season: 1 November to 30 April; Dry Season: 1 May to 31 October) statistics were calculated for each site using validated data, including means, medians, standard errors and percentiles. Data was plotted in conjunction with wave heights and rainfall.

One and two-way analyses of variance ($p < 0.05$, 95% confidence intervals) were used to determine statistical differences in water quality parameters among sites and seasons (wet season and dry season). Interactions between sites and season were also tested to determine if site patterns were consistent over seasons. Data were tested for homogeneity of variance and normality. Significance levels were increased ($p < 0.01$, 99% confidence intervals) where data did not meet that criterion (O'Neill, 2000, Underwood, 1997). Fisher's Least Significant Difference (LSD) Post hoc tests were used to determine any differences among sites.

2.5.2 BPAR Loggers

Management of BPAR logger data was undertaken as per VE HSEQ MS protocols. All BPAR data was manually uploaded to the VE cloud database. BPAR values from each logger during the non-daylight period (according to sunrise and sunset times reported by Geoscience Australia (2016)), were zeroed. Erroneous data was removed from the dataset. Subsequent calculations were based on the mean BPAR recorded from both loggers. The mean logger readings at 15 minute intervals were summed to calculate total daily BPAR in moles per square metre per day (mol/m^2/day). Once the data was deconfounded, monthly and seasonal statistics were calculated for each site, including means, medians, standard errors and ranges.

Erroneous data was identified by the two loggers differing by more than 20%. When this occurred, data from both loggers was flagged and examined. If the difference between the loggers persisted for a number of hours, or values were inconsistent with other BPAR sites, the data was considered erroneous. The 20% value was assigned assuming that a variance of ±10% is acceptable between loggers. Additionally, when the daily totals for each site were inconsistent with neighbouring sites and with previous trends, data was further investigated.

Similar to the physicochemistry loggers, seasonal statistics were calculated for each site using validated data, including means, medians, standard errors and percentiles. Benthic PAR data was plotted in conjunction with ambient PAR and rainfall. One and two-way analyses of variance ($p < 0.05$, 95% confidence intervals) were used to determine statistical differences in PAR among sites and seasons (wet season and dry season), and interactions between site and season. Data were tested for homogeneity of variance and normality. Significance levels were increased ($p < 0.01$, 99% confidence intervals) where data did not meet that criterion (O'Neill, 2000, Underwood, 1997). Fisher's LSD Post hoc tests were used to determine any differences among sites.

2.5.3 Altimeters

Altitude data was produced every 15 minutes, and the data used to examine surficial sediment deposition and erosion. Erroneous data was identified using the following procedures as per VE HSEQ MS protocols:

- Negative altitude values, indicating that insufficient echo was received from the seafloor to produce a valid reading.
- Instantaneous change value > 30 mm in 15 minutes. This data was flagged for further examination. Often only one or two variable readings were gained, indicating short-lived interference such as possible fauna activity.

Validated data was then used to calculate cumulative bed level change data (change from baseline point) at 15 minute intervals, which was then plotted. Data smoothing was carried out by calculating the daily mean cumulative change for each instrument and site, and plotting in conjunction with wave heights and rainfall. Seasonal bed level change was calculated for AMB1 and AMB2 using validated data from both deployed altimeters.

2.5.4 Depth Profiling and Water Analysis

Individual survey data were tabulated for each parameter at the sub-surface, mid-column, benthos and entire water column for each site. Data for the entire column was plotted to examine how well-mixed the water column was. The vertical light attenuation coefficient (K_d) was calculated in order to compare light attenuation through the water column at different sites and on different sampling occasions.

2.6 Water Quality Guidelines and Objectives

Water quality monitoring data from Abbot Point was compared to the Great Barrier Reef Water Quality Guidelines (GBRMPA, 2010), Queensland Water Quality Guidelines or QWQG (DERM, 2009), and Australian Water Quality Guidelines or AWQG (ANZECC/ARMCANZ, 2000). The Department of Environment and Resource Management (2009) state that the GBRMPA Guidelines are applicable inside the GBR Marine Park. Where there are no GBRMPA guidelines provided for a specific indicator, then the QWQG should be applied. Likewise, the QWQG takes precedence over the AWQG, due to their localised approach.

The GBRMPA guidelines used for comparison in this study were those derived for the Open Coastal area of the Burdekin (GBRMPA, 2010). The QWQG used for comparison were those derived for the Central Coast Queensland Region (which extends from the Burnett River basin near Bundaberg to the Black River Basin near Townsville) Open Coastal area. No GBRMPA Guidelines or QWQG are available for metals. Therefore, metal concentrations were compared to the AWQG (ANZECC/ARMCANZ, 2000). Trigger levels for varying levels of ecosystem protection (99%, 95%, 90% and 80% of species) have been derived for a number of metals. These guidelines refer to dissolved metals, which are those which pass through a 0.45 µm membrane filter (APHA, 2005), as these are considered to be the potential bioavailable fraction (ANZECC/ARMCANZ, 2000). The Abbot Point coastal environment can be described as slightly-to-moderately disturbed, therefore the 95% AWQG trigger value would be considered appropriate for comparison (DSITIA, 2014).

While localised water quality objectives (WQO) for the Mackay-Whitsundays Region (EHP, 2013b) have been completed by the Department of Environment and Heritage Protection (EHP) as per the Environmental Protection (Water) Policy 2009, these do not extend north to Abbot Point. Localised WQO for the Haughton, Burdekin and Don Basins region are currently under development by EHP. When the WQO have been finalised, they will take precedence over the current GBRMPA guidelines and QWQG due to their site-specific relevance.

3. RESULTS & DISCUSSION

3.1 Meteorological and Metocean Conditions

All loggers were originally deployed on 20 to 22 October 2015, prior to the commencement of the Wet Season on 1 November 2015.

3.1.1 Wet Season

Approximately 389 mm of rainfall (Figure 10) was recorded at Bowen Airport station (033327) from 1 November 2015 to 30 April 2016 (BOM, 2016), which is considerably lower than the long-term average of 774 mm during the wet season (between the 10th and 50th percentile) as recorded from 1987 to 2015.

Significant rain periods (> 45 mm total) included 3 to 4 January (71.4 mm), 4 to 6 February (82.2 mm), 4 to 7 March (97 mm) and 14 to 15 April (45.6 mm). Corresponding increases in river flow from the Don River, Elliot River and Euri Creek in the subsequent days were recorded (DNRM, 2016), particularly during January and February (Figure 10). Maximum daily flows from the Elliot River (5,355 ML/day) and Euri Creek (9,960 ML/day) were recorded on 6 February 2016, while at Don River, the maximum daily flow (4,644 ML/day) was recorded on 8 February 2016. Flows from Don River, Elliot River and Euri Creek during the Wet Season were 20,348 ML, 9,162 ML and 20,992 ML, respectively (DNRM, 2016), while average daily flow was 112, 50 and 116 ML/day, respectively.

From November 2015 to February 2016, daily winds were predominantly from the north-east, moving to be predominantly south-easterly during March and April. Strong winds (≥ 45 km/h) were found to be in a north-easterly or easterly direction in November and December 2015, but solely in a south-easterly direction from January to April 2016. Maximum daily wind gusts ranged from 19 km/h to 63 km/h, while mean daily significant wave heights ranged from 0.2 to 1.2 m (DSITIA, 2016), paralleling wind conditions. During the Wet Season, air temperatures ranged from 19.3 to 36.7ºC (BOM, 2016).

3.1.2 Dry Season

Approximately 249 mm of rainfall (Figure 11) was recorded at Bowen Airport station during the Dry Season (1 May to 31 October 2016), almost double the long-term dry season average of 129 mm (BOM, 2016).

Significant rain periods (> 45 mm total) included 19 to 20 June (82 mm) and 30 September (69 mm). Corresponding increases in river flow from the Don River, Elliot River and Euri Creek in the subsequent days were recorded (DNRM, 2016). Maximum daily flow from the Don River (2,113 ML/day) was recorded on 19 June, while maximum daily flow from Euri Creek (953 ML/day) was recorded on 20 June. The Elliot River exhibited maximum daily flow (425 ML/day) on the 30 September during the second significant rain period. Discharge from the three water bodies during the Dry Season was 4,500 ML, 536 ML and 1,885 ML respectively (DNRM, 2016), while average daily flow was 24, 3.0 and 10 ML/day, respectively, considerably lower than Wet Season flow.

Continuing on from the latter part of the Wet Season, daily winds were predominantly south-easterly from May to mid-September 2016 where winds then became predominantly from the north-east. Strong winds (≥ 45 km/h) were generally found to be in a south-easterly direction, with the exception of strong south-westerly winds on 19 June (57 km/h) and 3 August (46 km/h). Maximum daily wind gusts were similar to the Wet Season, ranging from 17 km/h to 65 km/h, as were mean daily significant wave heights, which ranged from 0.1 to 1.1 m (DSITIA, 2016). Air temperatures ranged from 6.3 to 32.1ºC (BOM, 2016).

3.1.3 Tidal Cycles During Sampling

Water samples for analysis were collected during January, May, July and October 2016. During January and May, sampling was undertaken during the lead-up to the new moon spring tide, with maximum tidal ranges of 3.07 m and 3.24 m during the respective surveys. During July, sampling was undertaken several days after a full moon spring tide, with a maximum tidal range of 2.12 m. In October, sampling was conducted in the days immediately prior to and after the new moon spring tide, with a maximum tidal range of 2.38 m.

3.2 Continuous Physicochemistry Loggers

3.2.1 Data Recovery

As mentioned in Section 2.2.1, data recovery during the initial two deployments, which encompassed the 2015/2016 Wet Season, was below expectation due to biofouling and sporadic logger failure; issues which could not be identified until logger retrieval. Benthic continuous logger data recovery rates are expected to be lower than that for telemetered loggers, due to the harsher environment and the ability to immediately identify and rectify faults for real time telemetered data. However, the use of additional antifouling measures during the 2016 Dry Season, improved the validated data recovery considerably, although benthic fouling will always be problematic.

Wet and Dry Season *validated* (i.e. after removal of erroneous values) data recovery rates for continuous physicochemistry loggers are listed in Tables 3 and 4.

The establishment of multiple individual log-files per logger (one per month) during the July to October deployment also assisted in reducing logger failure, which was prevalent during the earlier deployments. Previously, logging failure occurred randomly despite setting the same logging program for all sondes. Investigations by Hydrolab engineers in the USA determined that this was likely to be a component issue within the motherboard of the loggers. The problem only came to light because of the unusually large number of sondes being set to self-log for such a long period of time for this particular project. The issue has since been rectified.

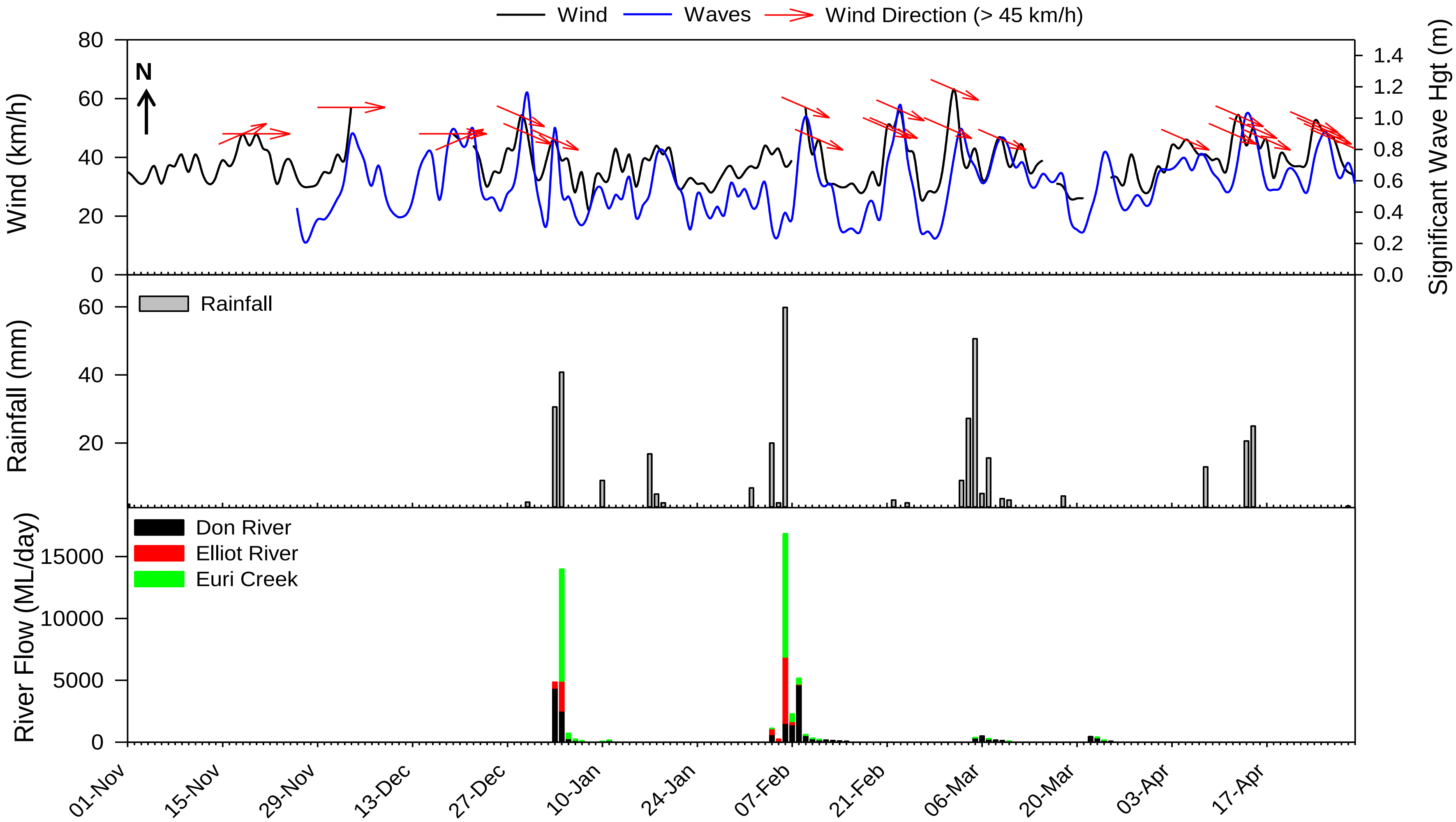

Figure 10 Port of Abbot significant wave heights, wind speed and rainfall as recorded at Bowen and river discharge from the Don River, Elliot River and Euri Creek, during the 2015/2016 Wet Season (1 November 2015 to 30 April 2016).
Note red arrows depict wind direction when winds > 45 km/h were recorded.

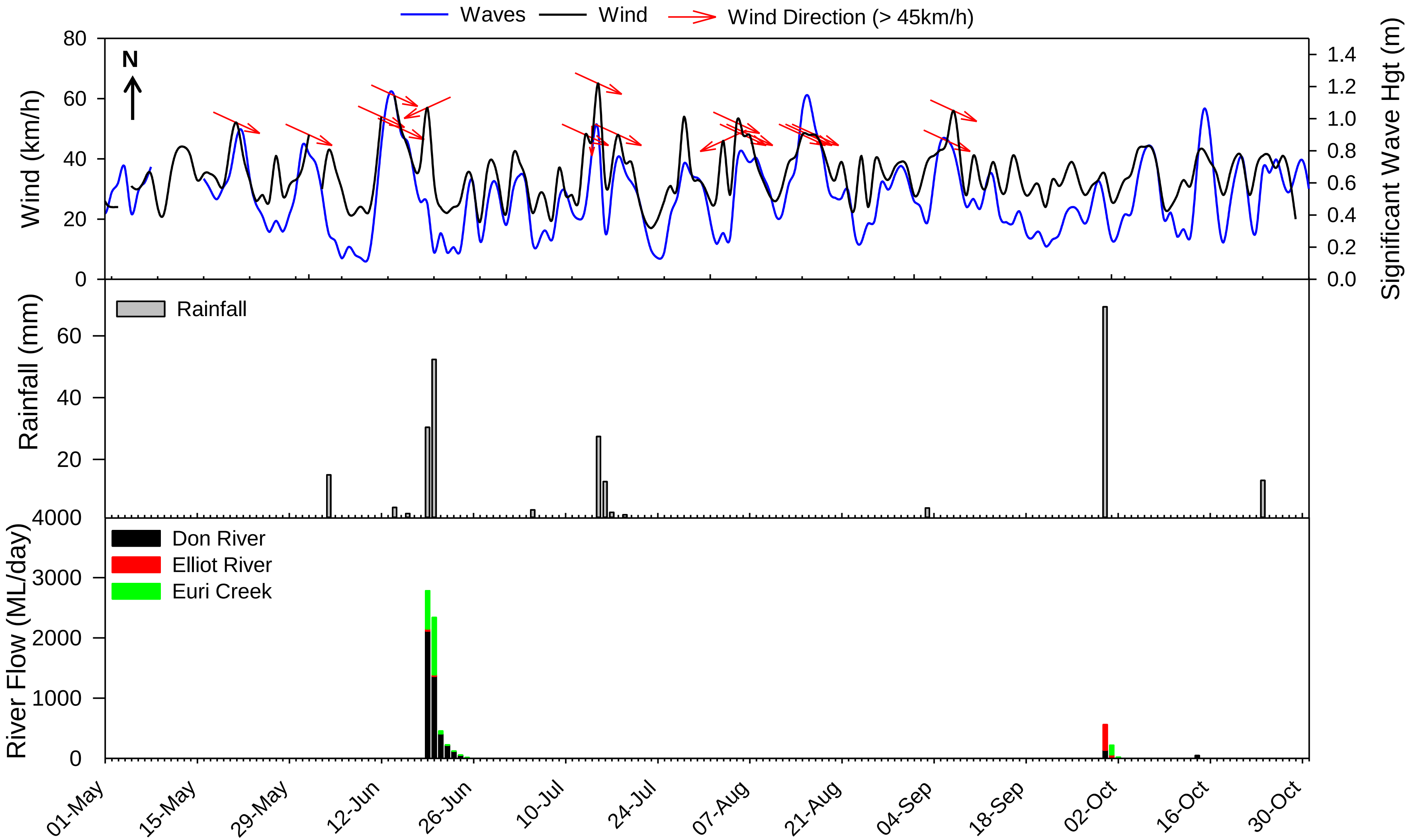

Figure 11 Port of Abbot significant wave heights, wind speed and rainfall as recorded at Bowen and river discharge from the Don River, Elliot River and Euri Creek, during the 2016 Dry Season (1 May 2016 to 31 October 2016).
Note red arrows depict wind direction when winds > 45 km/h were recorded.

Table 3 Validated data retention rates of continuous physicochemical data loggers during the Wet Season (1 November 2015 to 30 April 2016).

Site	% Data recovery				
	Temperature	pH	Conductivity/ salinity	Dissolved oxygen	Turbidity
AMB1	79	79	52	52	52
AMB2	100	91	71	71	100
AMB3	92	72	11	11	75
AMB4	93	93	74	74	64
AMB5	100	98	73	73	99
AMB6	54	54	53	53	35

Table 4 Validated data retention rates of continuous physicochemical data loggers during the Dry Season to date (21 October 2015 to 31 October 2015, 1 May to 31 October 2016).

Site	% Data recovery				
	Temperature	pH	Conductivity/ salinity	Dissolved oxygen	Turbidity
AMB1	98	57	98	98	73
AMB2	100	30	100	86	77
AMB3	70	32	68	41	55
AMB4	76	16	76	73	76
AMB5	57	9	57	31	57
AMB6	71	71	70	71	71

Note that 100% raw data recovery was gained for AMB1, AMB2, AMB5 and AMB6 during the July to October 2016 period. At AMB3 and AMB4, raw data recovery was lower due to water ingress. Low validated recovery rates for pH during the Dry Season was attributed to overzealous antifouling measures. Discussions with the manufacturers have led to reducing the level of antifouling on the pH reference probe, which was undertaken for the October 2016 to January 2017 deployment.

3.2.2 Turbidity

Turbidity statistics for the six sites for both the Wet and Dry season can be found in Table 5, and turbidity plotted in Figures 12 to 18. Note that validated turbidity data recovery was lower during the Wet Season, and therefore statistics for this season may not be an entirely accurate reflection of ambient conditions at the time.

Table 5 Turbidity statistics from data collected from loggers deployed October 2015 to October 2016. *N = 3334 to 15017 for wet season and 10117 to 14251 for dry season.*

Site	Wet Season turbidity (NTU)			Dry Season turbidity (NTU)		
	Mean ± se	Median	20^{th} to 80^{th} percentile range	Mean ± se	Median	20^{th} to 80^{th} percentile range
AMB1	3.1 ± 0.1	<1	<1 – 6.6	2.4 ± 0.0	2.5	<1 – 3.2
AMB2	11 ± 0	<1	<1 – 14	2.5 ± 0.0	1.3	<1 – 4.2
AMB3	1.9 ± 0.0	<1	<1 – 4.1	2.3 ± 0.0	1.5	<1 - 25
AMB4	9.3 ± 0.2	4.3	<1 - 12	<1	<1	<1 – 1.0
AMB5	2.5 ± 0.0	1.6	<1 – 4.8	3.6 ± 0.0	2.7	2.5 – 4.6
AMB6	4.2 ± 0.1	2.8	1.7 – 6.9	3.9 ± 0.0	3.3	<1 – 8.5

Overall, turbidity was significantly higher ($p < 0.05$) during the Wet Season (means: 1.9 to 11 NTU), than during the Dry Season (means: <1 to 3.9 NTU). Turbidity was significantly ($p < 0.05$) higher overall at AMB2, followed by AMB6, with AMB3 and AMB1 exhibiting significantly ($p < 0.05$) lower turbidity.

There was a significant interaction between sites and seasons, indicating that spatial patterns were not consistent across both the Wet and Dry Season. During the Wet Season, AMB2 (11 NTU) and AMB4 (9.3 NTU) exhibited significantly ($p < 0.05$) higher turbidity than remaining sites (1.9 to 4.2 NTU), but during the Dry Season, turbidity at AMB2 (2.5 NTU) and AMB4 (<1 NTU) was similar to, or lower than other sites (2.3 to 3.9 NTU). The 20th to 80th percentile ranges for all sites across both seasons indicate that the majority of turbidity values were found within a small range.

Turbidity at each of the sites appeared to be highly influenced by wave height, which was in turn influenced by wind conditions, whereas rainfall and tidal phases appeared to have little influence during this monitoring period. However it should be noted that lower than average rainfall was recorded during this monitoring period and that previous studies have noted large increases in turbidity following significant rainfall events of > 125 mm in one day (Worley Parsons, 2014). Periods of higher waves tended to result in short-lived increases in turbidity, due to resuspension of benthic sediments, although AMB5 was much less responsive than other sites, most likely due to its close proximity to and protection afforded by Holbourne Island. The close relationship was quite evident at AMB2 and AMB4 during February and March. During the 2016 Dry Season, this was also particularly evident in mid-June and mid-August at all sites where data was recorded. Previous monitoring at Abbot Point (GHD, 2009, 2010, 2012, Worley Parsons, 2014) in addition to Port of Mackay (NQBP, 2015) also found that increases in waves and wind resulted in higher turbidity.

There is no GBRMPA guideline for turbidity, therefore the QWQG should be used for comparison. Mean turbidity at all six sites during both seasons (with the exception of AMB4 during the Dry Season) was higher than the QWQG of 1 NTU, as found in previous monitoring programs (GHD, 2009, 2010, 2012, Worley Parsons, 2014). The QWQG, which apply to open coastal waters, could be considered conservative for the near shore Abbot Point sites, which can be influenced by adjacent river flows.

3.2.3 Temperature

During the monitoring period, water temperature at all sites exhibited a clear seasonal pattern, associated with ambient air temperatures. As expected, temperatures at all sites were significantly ($p < 0.05$) higher during the summer Wet Season (means: 28.1 to 29.0ºC) than during the winter Dry Season (means: 23.8 to 24.6ºC), paralleling ambient conditions (Table 6). Little variation was evident between sites, however of note were the small immediate decreases in temperature associated with rain events (Figures 19 and 20). Longer duration precipitation events generally resulted in more noticeable temperature declines. There appeared to be little relationship between temperature and site depth.

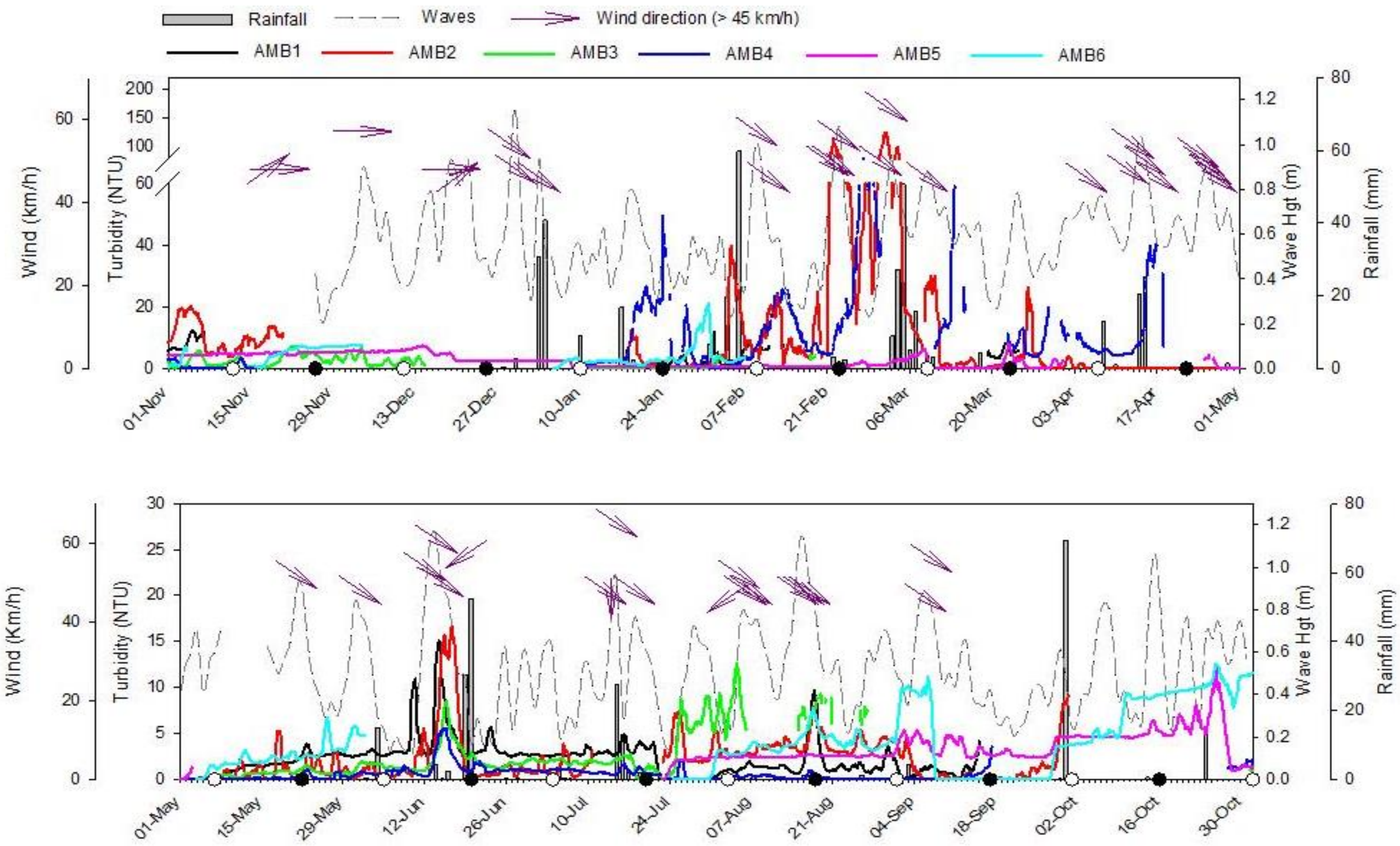

Figure 12 Turbidity 24h rolling average (RA), rainfall and wave height at AMB1 to AMB6 during the 2015/2016 Wet Season and 2016 Dry Season from November 2015 to October 2016.

Note purple arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively.

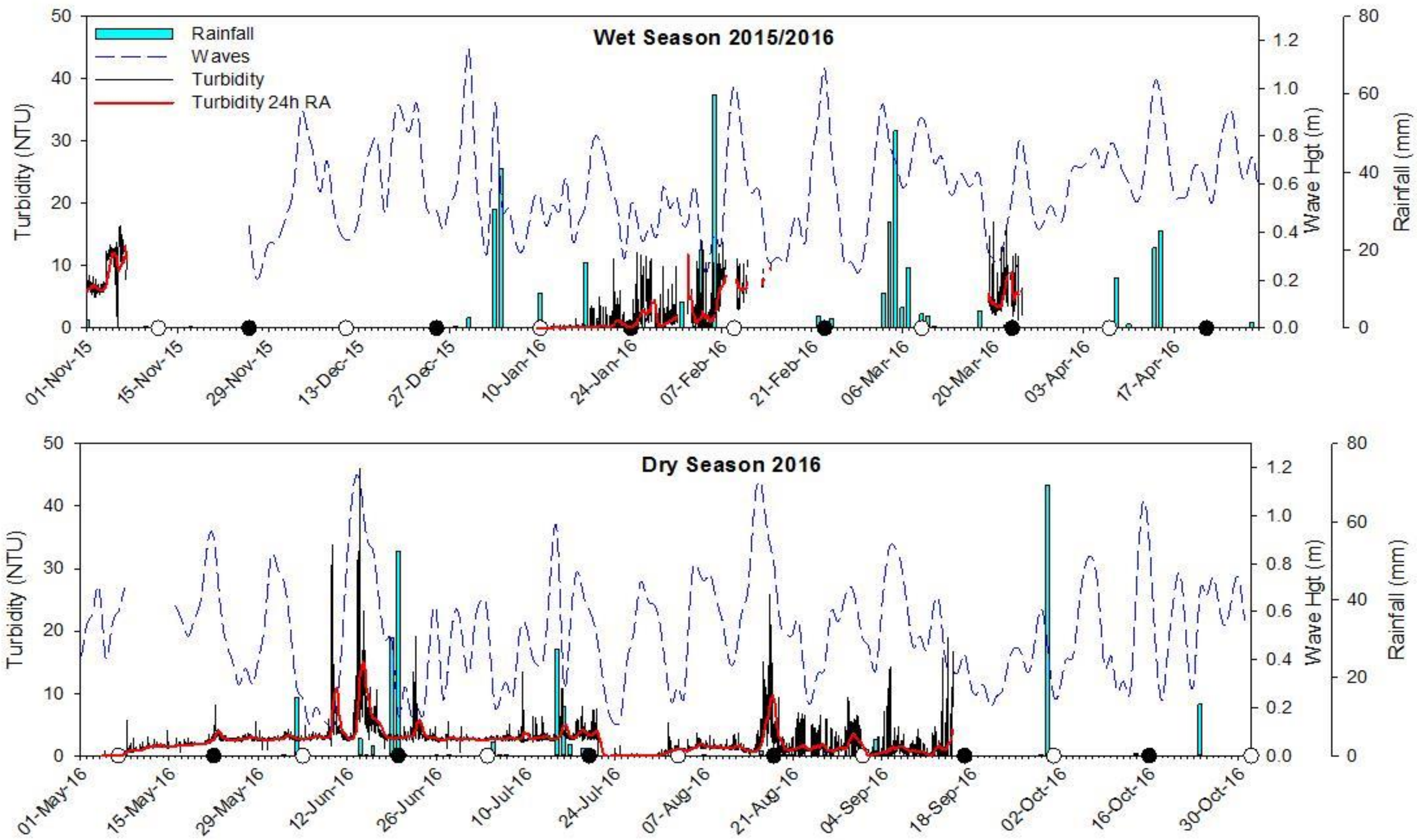

Figure 13 Mean benthic turbidity and 24h rolling average (RA), rainfall and wave height at AMB1 the 2015/2016 Wet Season and 2016 Dry Season from November 2015 to October 2016.
Open and closed circles indicate full and new moon periods, respectively.

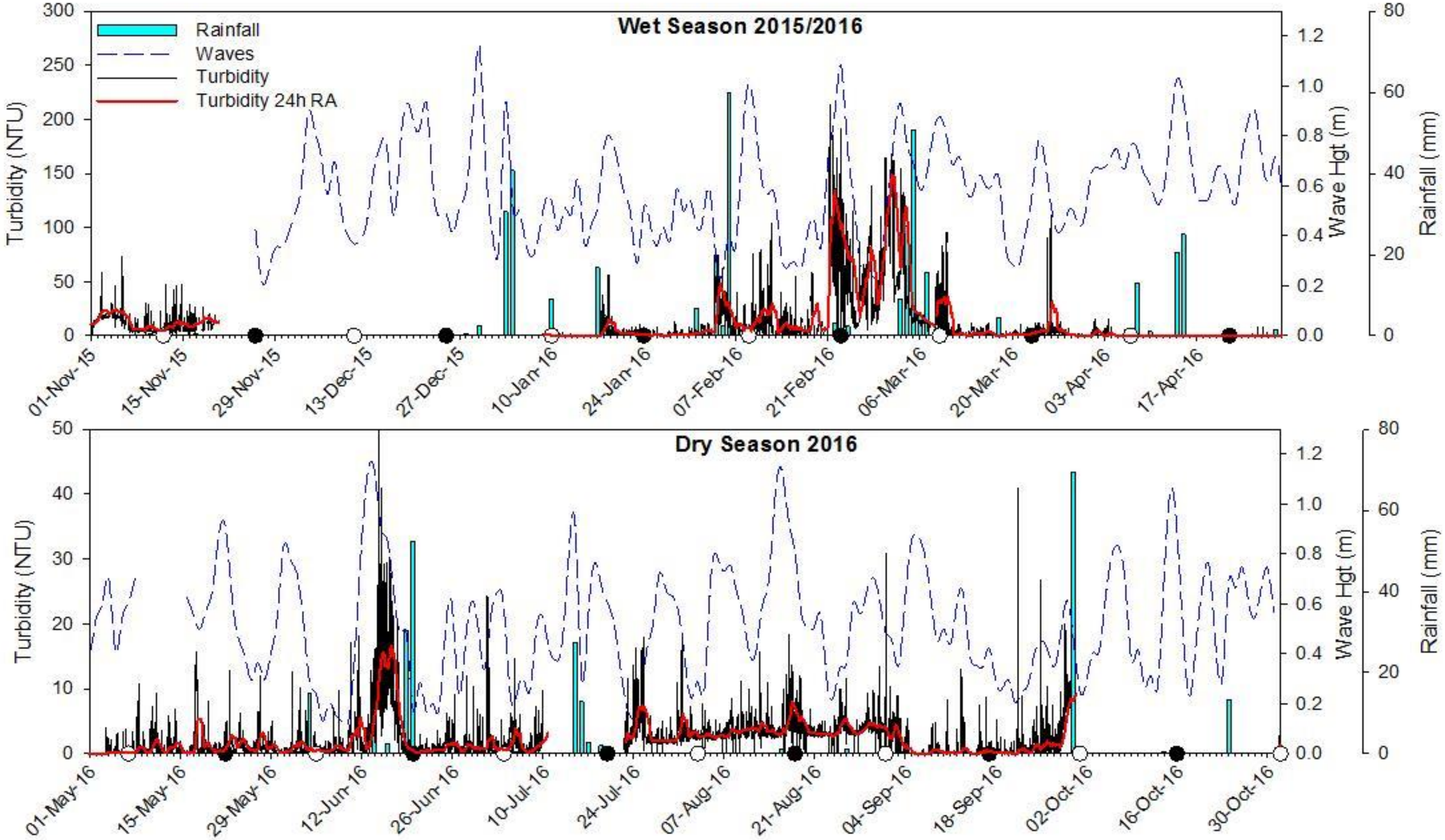

Figure 14 Mean benthic turbidity and 24h rolling average (RA), rainfall and wave height at AMB2 during the 2015/2016 Wet Season and 2016 Dry Season from November 2015 to October 2016.
Open and closed circles indicate full and new moon periods, respectively.

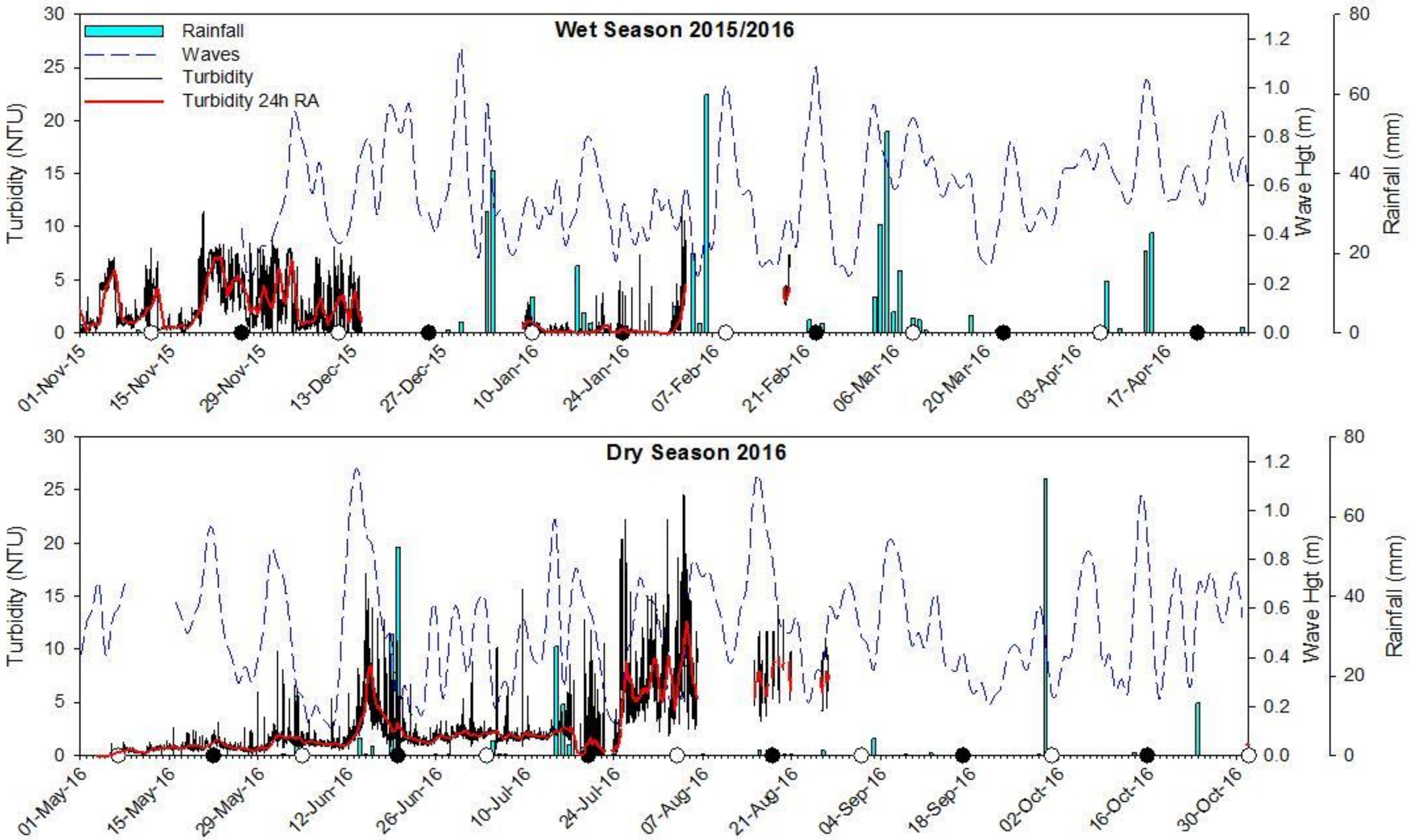

Figure 15 Mean benthic turbidity and 24h rolling average (RA), rainfall and wave height at AMB3 during the 2015/2016 Wet Season and 2016 Dry Season from November 2015 to October 2016.
Open and closed circles indicate full and new moon periods, respectively.

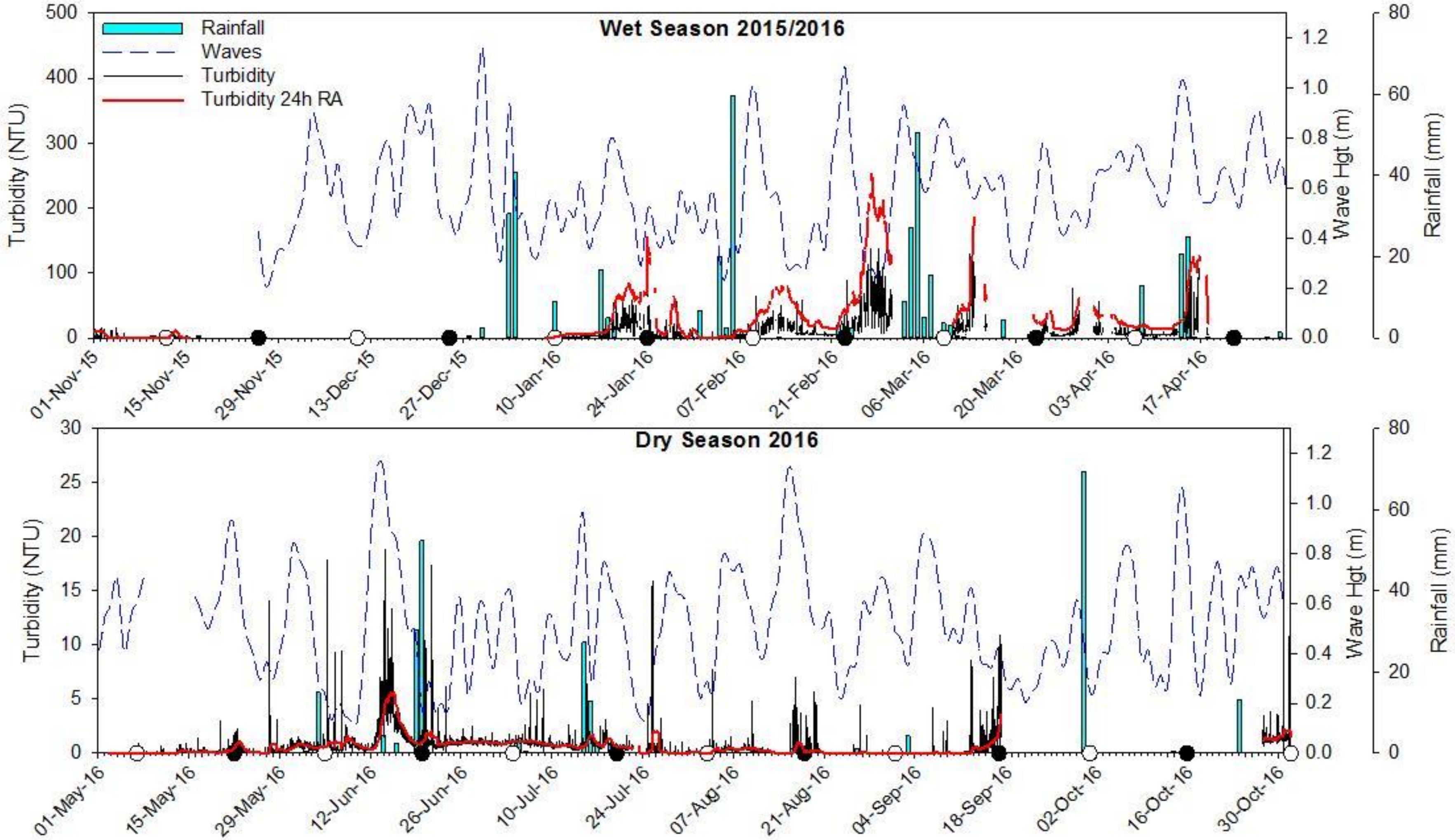

Figure 16 Mean benthic turbidity and 24h rolling average (RA), rainfall and wave height at AMB4 during the 2015/2016 Wet Season and 2016 Dry Season from November 2015 to October 2016.
Open and closed circles indicate full and new moon periods, respectively.

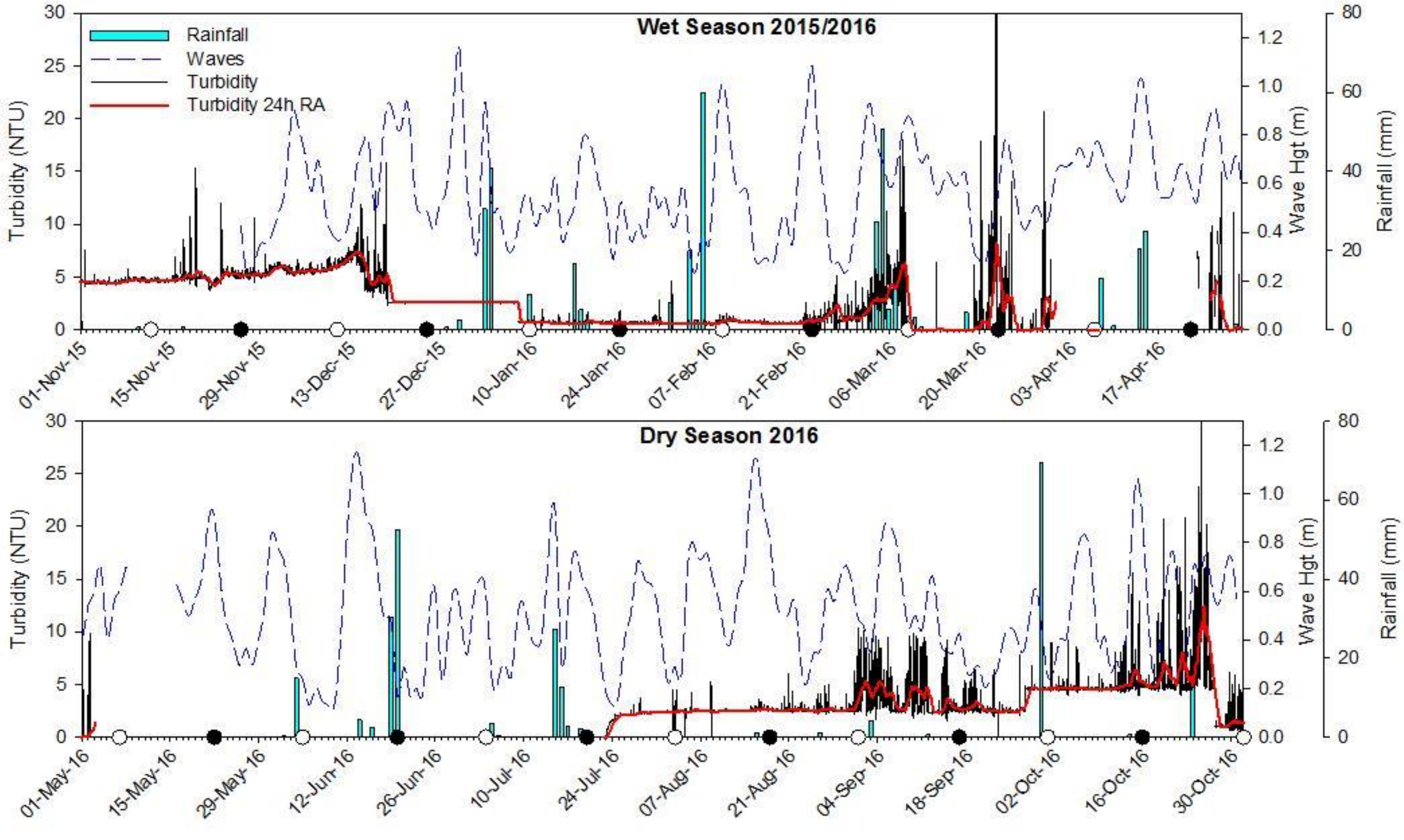

Figure 17 Mean benthic turbidity and 24h rolling average (RA), rainfall and wave height at AMB5 during the 2015/2016 Wet Season and 2016 Dry Season from November 2015 to October 2016.
Open and closed circles indicate full and new moon periods, respectively.

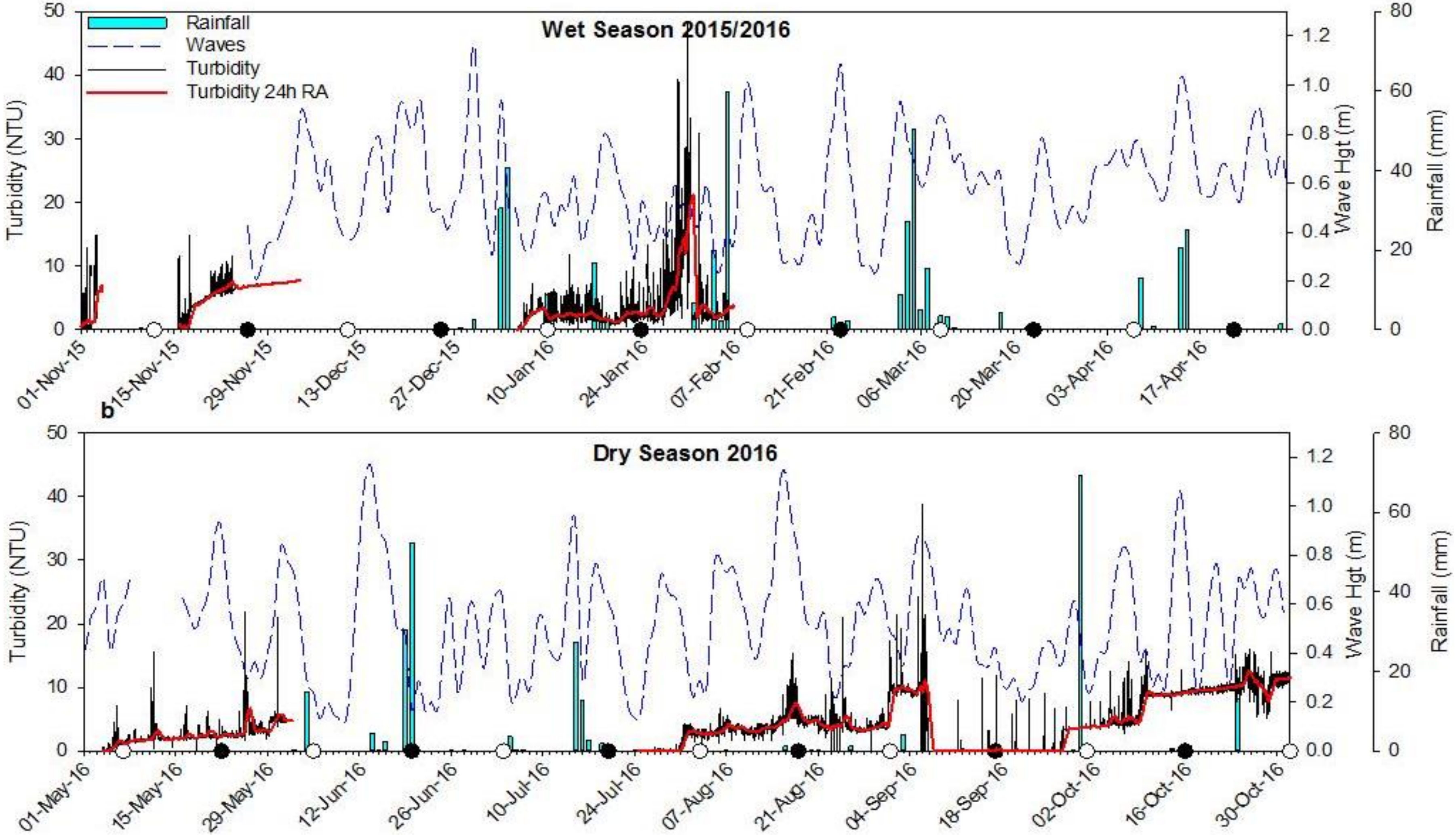

Figure 18 Mean benthic turbidity and 24h rolling average (RA), rainfall and wave height at AMB6 during the 2015/2016 Wet Season and 2016 Dry Season from November 2015 to October 2016.
Open and closed circles indicate full and new moon periods, respectively.

Table 6 Temperature statistics from data collected from loggers deployed October 2015 to October 2016.
N = 9487 to 17481 for wet season and 10363 to 18615 for dry season.

Site	Wet Season temperature (ºC)			Dry Season temperature (ºC)		
	Mean ± se	Median	20th to 80th percentile range	Mean ± se	Median	20th to 80th percentile range
AMB1	28.8 ± 0.0	28.7	28.1 – 29.8	24.3 ± 0.0	24.2	22.5 – 25.9
AMB2	28.5 ± 0.0	28.6	27.5 – 29.5	24.3 ± 0.0	24.2	22.7 – 25.9
AMB3	29.0 ± 0.0	28.9	28.2 – 29.9	23.8 ± 0.0	23.4	22.3 – 25.3
AMB4	28.8 ± 0.0	28.7	28.1 – 29.6	23.9 ± 0.0	23.6	22.5 – 25.3
AMB5	28.1 ± 0.0	28.3	27.3 – 28.9	24.3 ± 0.0	24.1	23.0 – 25.6
AMB6	28.4 ± 0.0	28.5	27.8 – 29.3	24.6 ± 0.0	25.2	22.7 – 26.0

3.2.4 pH

The pH at the majority of sites remained reasonably stable throughout the monitoring period (Figures 21 and 22, Table 7), with most values within, or marginally lower than the QWQG of 8.1 to 8.4. Limited pH data was available for the Dry Season due to interference from antifouling measures, as mentioned in Section 3.2.1 above.

Table 7 pH statistics from data collected from loggers deployed October 2015 to October 2016.
N = 9487 to 17199 for wet season and 1722 to 18697 for dry season.

Site	Wet Season pH			Dry Season pH		
	Mean ± se	Median	20th to 80th percentile range	Mean ± se	Median	20th to 80th percentile range
AMB1	8.0 ± 0.0	8.0	7.9 – 8.2	8.2 ± 0.0	8.2	8.1 - 8.3
AMB2	8.2 ± 0.0	8.3	8.1 – 8.3	8.2 ± 0.0	8.2	8.2 - 8.3
AMB3	8.1 ± 0.0	8.1	8.0 – 8.2	8.1 ± 0.0	8.0	8.0 - 8.2
AMB4	8.1 ± 0.0	8.1	8.0 – 8.2	8.2 ± 0.0	8.2	8.1 - 8.3
AMB5	8.3 ± 0.0	8.3	8.2 – 8.3	8.2 ± 0.0	8.2	8.1 - 8.3
AMB6	8.2 ± 0.0	8.2	8.1 – 8.3	8.3 ± 0.0	8.4	8.3 - 8.4

Of note was the diurnally fluctuating pH at AMB3 from February to April, which was not evident at other sites, nor was it evident during previous or subsequent deployments at AMB3. It is possible that the pH fluctuations were a result of potential runoff from nearby aquaculture facilities and wetlands during this period when rainfall was highest. Runoff from aquaculture facilities tends to be high in nutrients (Geoscience Australia, 2015), therefore a surface algal bloom and/or increase in benthic algae may have occurred in the vicinity of the AMB3 logger. Fluctuations in pH are evident when biological activity is high, with lower pH at night during respiration and increased pH during the day when photosynthesis is occurring (Geoscience Australia, 2015). Although only limited data was available for DO over this period, initial results indicate diurnal patterns occurred concurrently with pH.

The pH at AMB5 also exhibited consistent pH diurnal fluctuations concurrently with fluctuations in DO (Figures 22 and 26), with elevated pH and DO during the daytime periods. These fluctuations have been attributed to the adjacent coral reef and increased activity of coral associated, photosynthetic organisms.

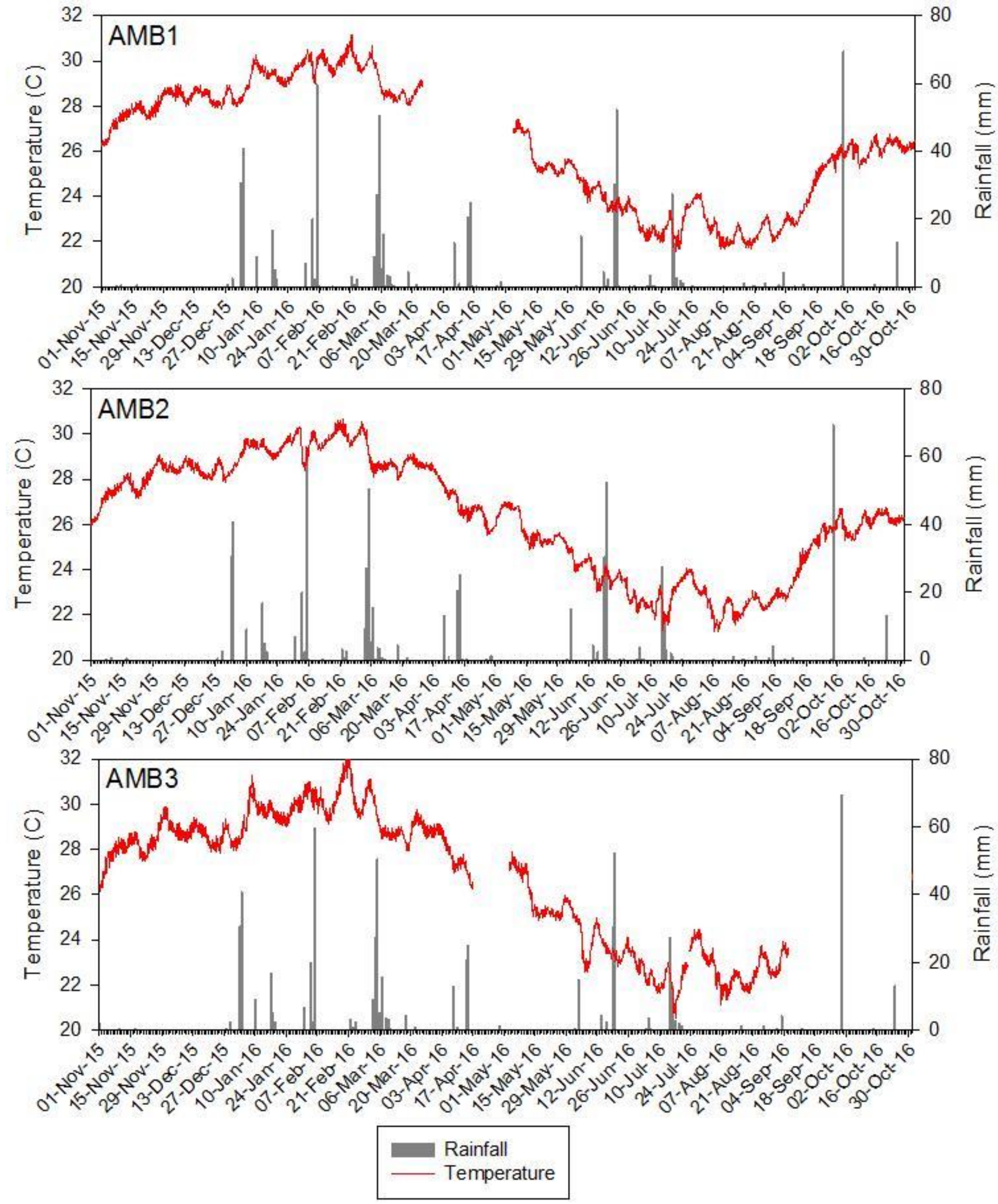

Figure 19 Temperature and rainfall at AMB1, AMB2 and AMB3 from November 2015 to October 2016.

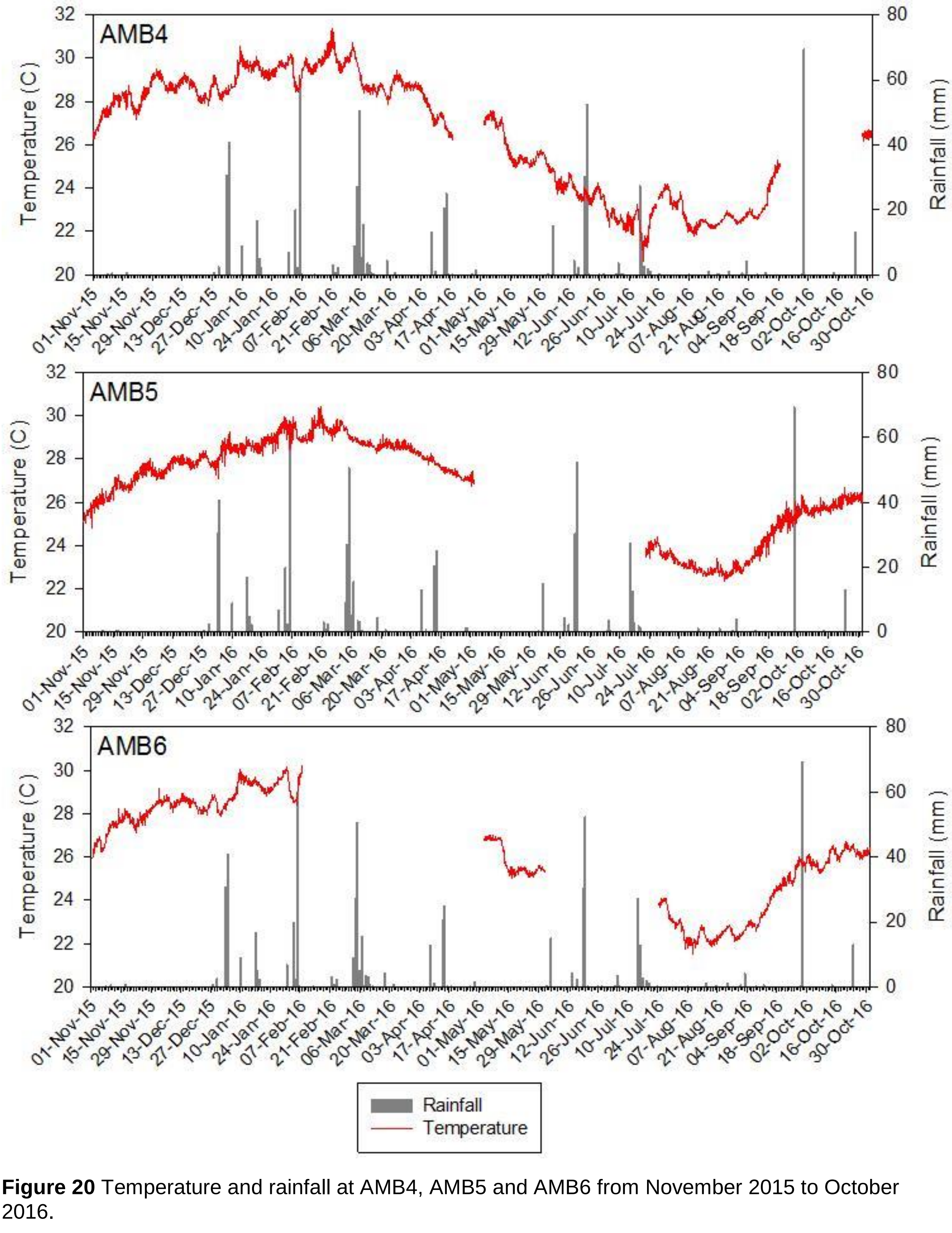

Figure 20 Temperature and rainfall at AMB4, AMB5 and AMB6 from November 2015 to October 2016.

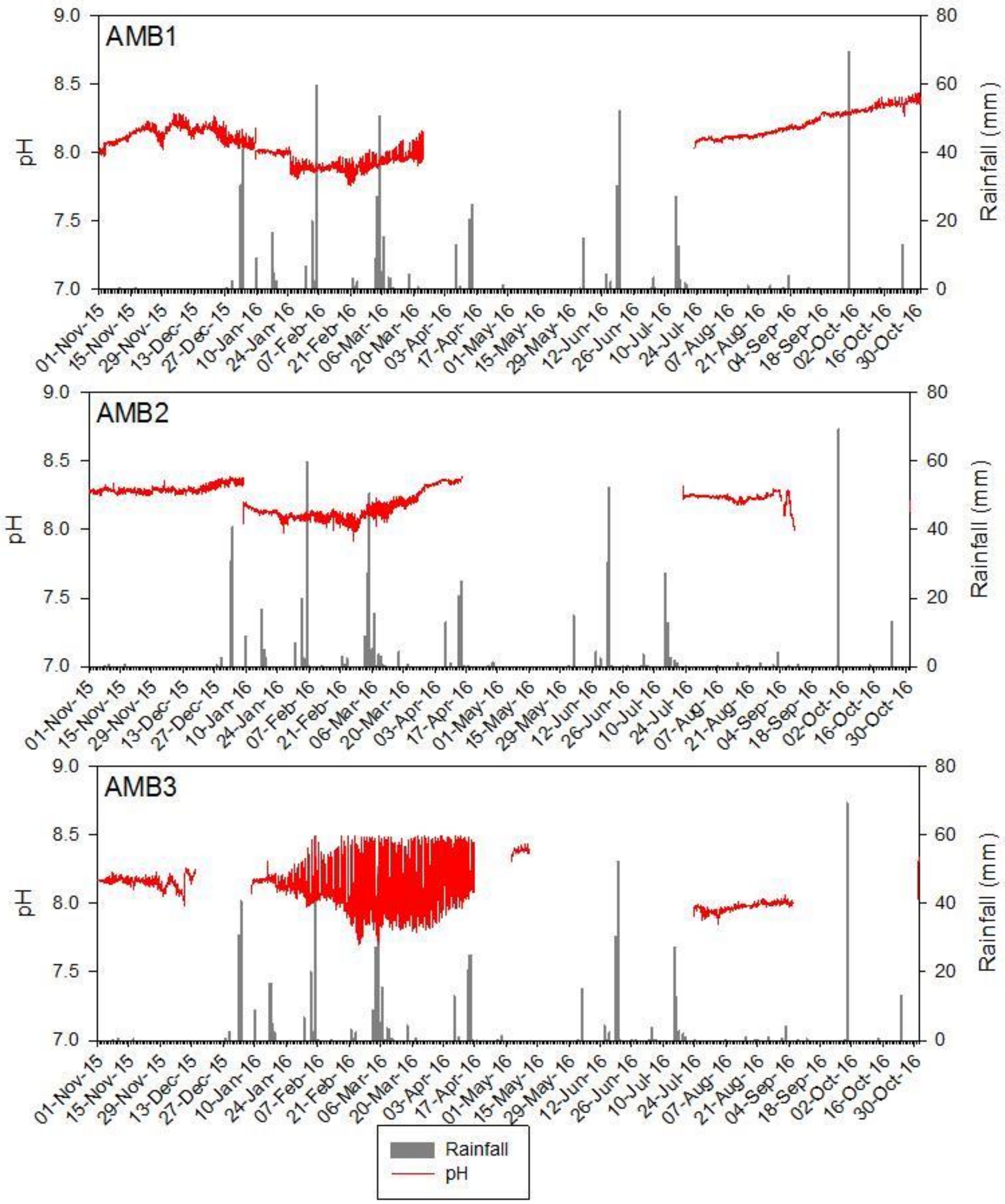

Figure 21 pH and rainfall at AMB1, AMB2 and AMB3 from November 2015 to October 2016.

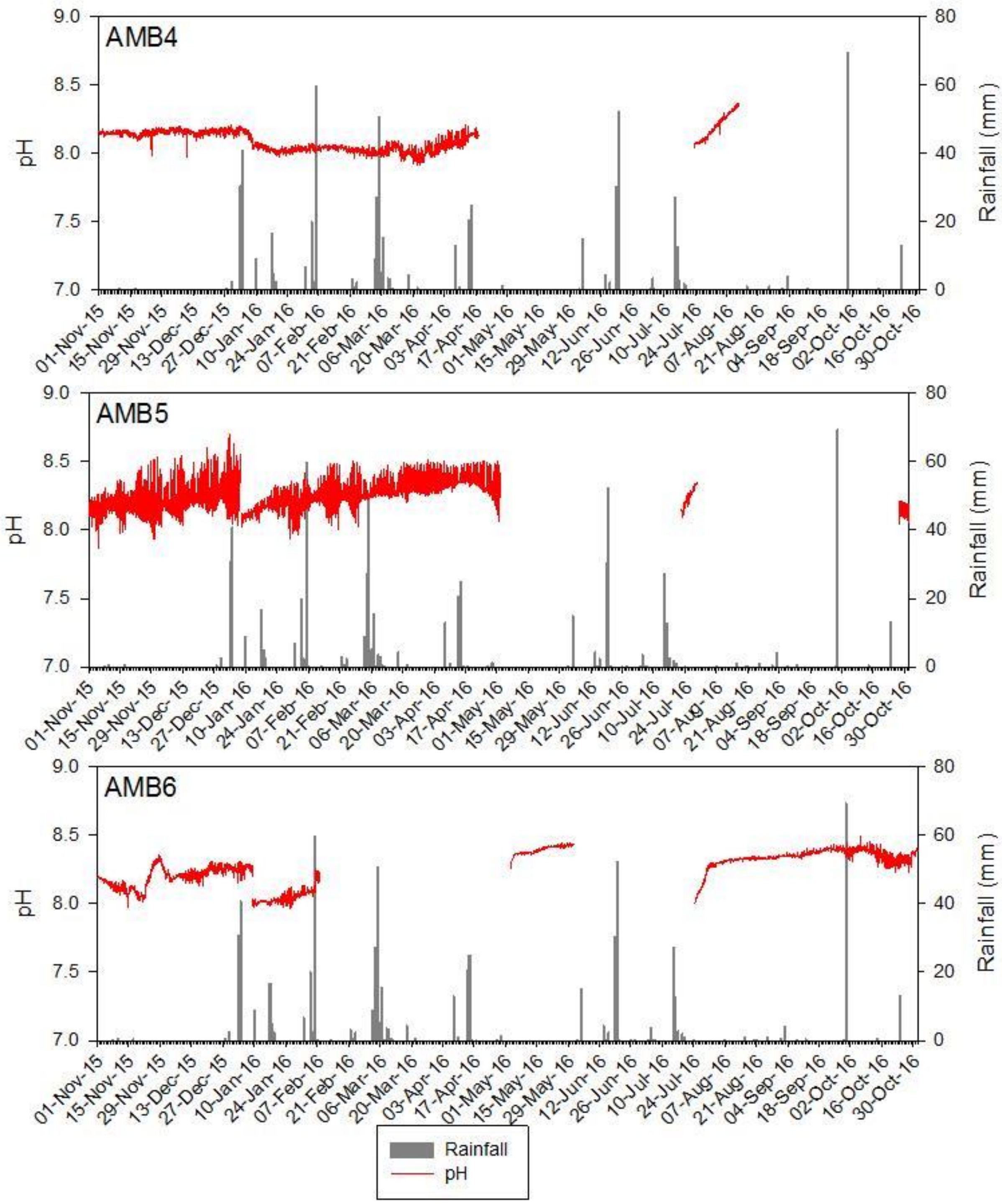

Figure 22 pH and rainfall at AMB4, AMB5 and AMB6 from November 2015 to October 2016.

3.2.5 Conductivity

Overall, conductivity was significantly ($p < 0.05$) higher during the Dry Season (means: 53.4 to 56.0 mS/cm) than during the Wet Season (means: 48.0 to 55.6 mS/cm), most likely due to the lower amount of rainfall and freshwater input into the marine environment surrounding Abbot Point (Tables 8, Figures 23 and 24).

During the Wet Season, both AMB1 and AMB2 exhibited a decrease in conductivity following large rain events (and associated river flows) in February and March 2016, respectively. AMB1 was likely influenced by the Don River and Euri Creek, while AMB2 potentially influenced by the Elliott River in conjunction with other nearby creeks. The declines in conductivity at AMB1 would be expected to be higher, due to the higher combined flows from the Don River and Euri Creek compared to the Elliott River. AMB4 and AMB5, located at Camp and Holbourne Islands did not appear to be directly affected by higher rainfall or river flows during the deployment periods, further supporting that river discharges have a localised and significant effect on inshore regions in close proximity to discharges. Limited Wet Season data is available for AMB3 and AMB6 and therefore mean wet season conductivity for these sites may be overestimated. Apart from the rainfall periods, conductivity tended to remain reasonably stable within and across the sites.

Table 8 Conductivity statistics from data collected from loggers deployed October 2015 to October 2016.
N = 1910 to 12987 for wet season and 10301 to 18615 for dry season.

Site	Wet Season conductivity (mS/cm)			Dry Season conductivity (mS/cm)		
	Mean ± se	**Median**	**20th to 80th percentile range**	**Mean ± se**	**Median**	**20th to 80th percentile range**
AMB1	48.0 ± 0.1	50.9	47.7 – 53.5	55.4 ± 0.0	52.7	52.1 – 59.8
AMB2	48.4 ± 0.0	48.7	43.5 – 53.9	56.0 ± 0.0	54.2	53.6 – 58.7
AMB3	54.8 ± 0.0	55.1	53.8 – 55.6	55.6 ± 0.0	57.1	52.3 – 57.8
AMB4	55.6 ± 0.0	55.9	54.5 – 56.9	56.0 ± 0.0	57.4	52.8 – 58.4
AMB5	52.8 ± 0.0	52.9	51.8 – 54.0	53.4 ± 0.0	53.7	53.5 – 53.8
AMB6	53.4 ± 0.0	53.1	52.4 – 54.8	54.7 ± 0.0	53.8	53.3 – 55.3

3.2.6 Dissolved Oxygen (DO)

Dissolved oxygen exhibited periods of high fluctuation at the majority of sites. Overall, dissolved oxygen was significantly ($p < 0.05$) higher during the Wet Season (means: 97 to 103% saturation) than during the Dry Season (means: 93 to 105% saturation). Throughout both seasons, mean DO values were within, or slightly below, the QWQG of 95 to 105% saturation (Table 9, Figures 25 and 26).

The largest fluctuations in DO were consistently recorded at site AMB5 particularly during the Wet Season, which also exhibited diurnal pH fluctuations (Figure 22). These fluctuations have been attributed to the adjacent coral reef and activity of coral associated, photosynthetic organisms, with lower DO (and pH) at night during respiration and increased DO (and pH) during the day when photosynthesis is occurring. Although limited data was available for DO at AMB3 from February to March, similar concurrent diurnal patterns in pH and DO were observed and attributed to possible surface algal blooms and/or benthic algae AMB3 and AMB5 are the two shallowest sites experiencing the highest benthic PAR values and therefore likely to exhibit higher levels of photosynthesis and diurnal fluctuations in DO, compared to deeper sites.

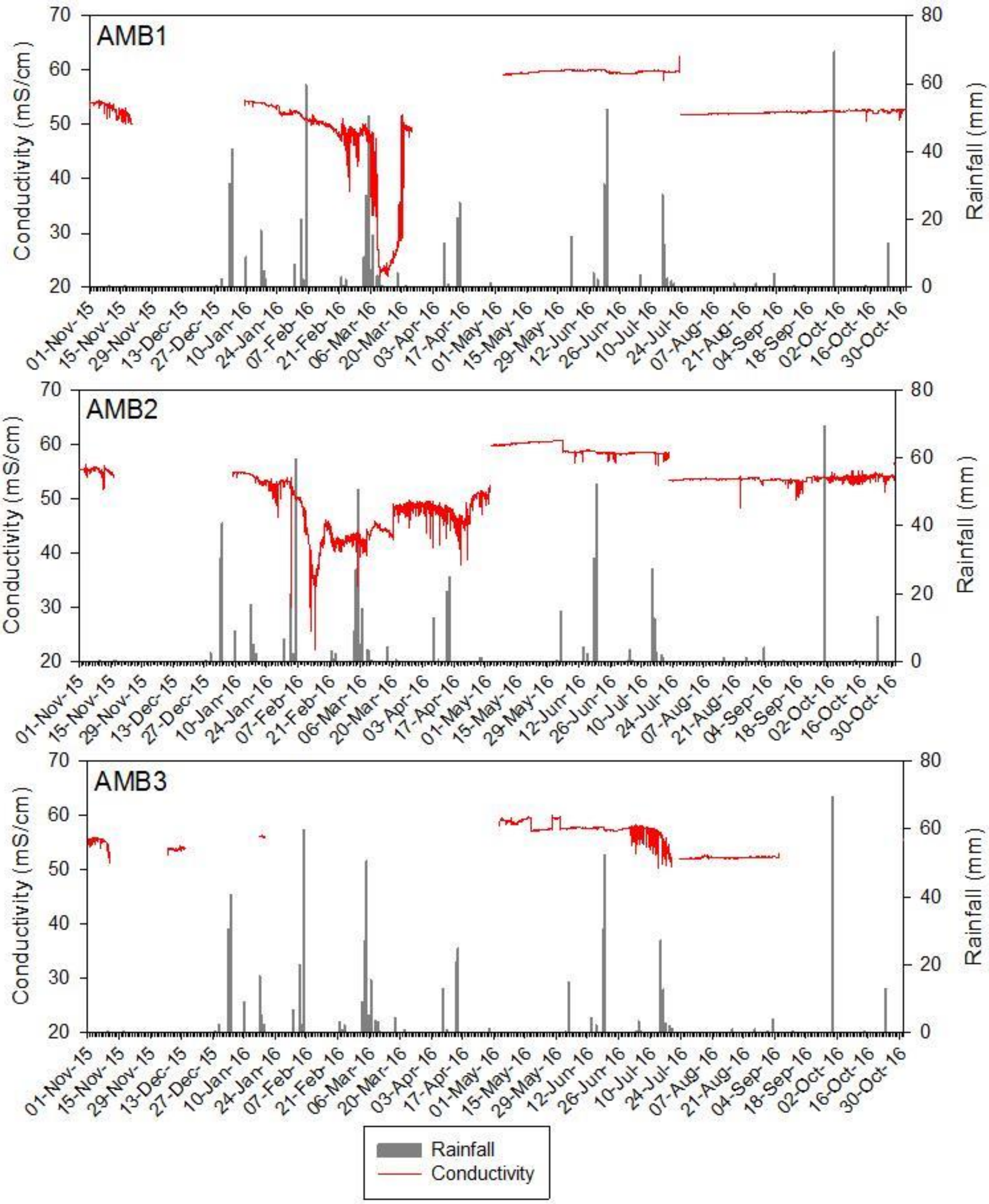

Figure 23 Conductivity and rainfall at AMB1, AMB2 and AMB3 from November 2015 to October 2016.

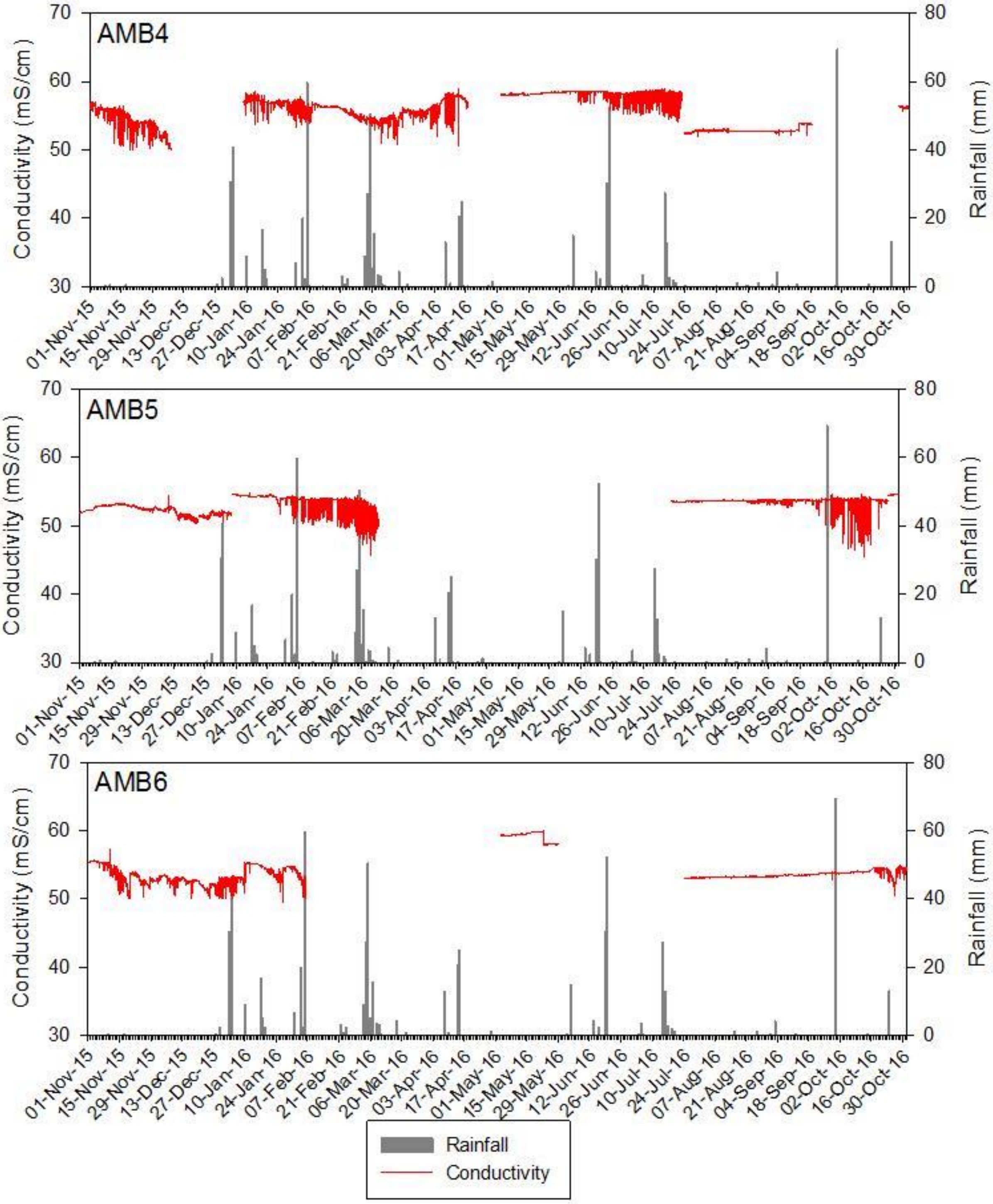

Figure 24 Conductivity and rainfall at AMB4, AMB5 and AMB6 from November 2015 to October 2016.

Table 9 Dissolved oxygen statistics from data collected from loggers deployed October 2015 to October 2016.
N = 6111 to 17465 for wet season and 5711 to 18308 for dry season.

Site	Wet Season dissolved oxygen (% sat.)			Dry Season dissolved oxygen (% sat.)		
	Mean ± se	**Median**	**20th to 80th percentile range**	**Mean ± se**	**Median**	**20th to 80th percentile range**
AMB1	97 ± 0	98	91 - 102	101 ± 0	101	96 - 106
AMB2	100 ± 0	100	92 - 102	94 ± 0	93	91 - 96
AMB3	100 ± 0	101	95 - 105	101 ± 0	102	95 - 106
AMB4	103 ± 0	103	96 - 111	99 ± 0	98	94 - 103
AMB5	101 ± 0	97	89 - 113	105 ± 0	107	101 - 110
AMB6	99 ± 0	100	97 - 102	93 ± 0	94	90 - 96

3.3 Physicochemistry Depth Profiling

While the continuous physicochemical loggers provided information about near benthos conditions, physicochemical depth profiling provided information in regards to the entire water column. Statistics, including means and standard errors, for depth profiled physicochemical parameters undertaken during January, May, July and October 2016 are tabulated in Tables 10 to 13. Light attenuation (K_d), or the rate at which light diminishes through the water column, was also calculated at each site and recorded. Depth profile plots comparing data across sampling events at each site are illustrated in Figures 27 to 32.

While depth profiling was undertaken at AMB1 in October/November and data logged appropriately, the data file was corrupted from the ProDSS water quality meter during data transfer. The ProDSS is a recently purchased and upgraded water quality meter, and therefore this issue had not been experienced previously. A recent software update to the ProDSS will ensure that data loss does not occur again. Minimal depth-profiling data for AMB1 however was manually recorded in the field sheet, which is always available for backup and validation.

As expected, clear seasonal patterns were evident for water temperature. Similar to the continuous loggers, warmest water temperatures were evident during the January sampling (26.5 to 30.0 ºC), and lowest temperatures were evident during the July sampling (23.2 to 24.3 ºC), with intermediate temperatures in May (26.5 to 27.3 ºC) and October (26.1 to 26.8 ºC). Conductivity was higher during the July survey than the other surveys, most likely due to the lower amount of rainfall experienced during the Dry Season conditions. High conductivity did not continue to the October survey likely attributable to the large rainfall experienced just prior to the survey. Previous monitoring programs also recorded lower conductivity during Wet Season monitoring (GHD, 2012, Worley Parsons, 2014).

Dissolved oxygen did not exhibit a clear seasonal pattern, with the majority of values remaining within the QWQG of 95 to 100% saturation. The exceptions to this were the highly oxygenated waters (107 – 110% saturation) at AMB5 in January, and the lower oxygen levels (89% saturation) at AMB5 in July 2016. However, this is likely to have been an artefact of sampling time, with January sampling undertaken during the afternoon and July sampling undertaken in the morning. This highlights the benefits of continuous loggers for which data is not biased due to sampling period. Values < 100% saturation were also recorded at AMB5 during April and October when sampling was also undertaken in the morning. As recorded by the continuous loggers, diurnal oxygen fluctuations due to respiration and photosynthesis of marine organisms were consistently higher at AMB5. The pH during the July sampling at AMB5 was also lower than typical.

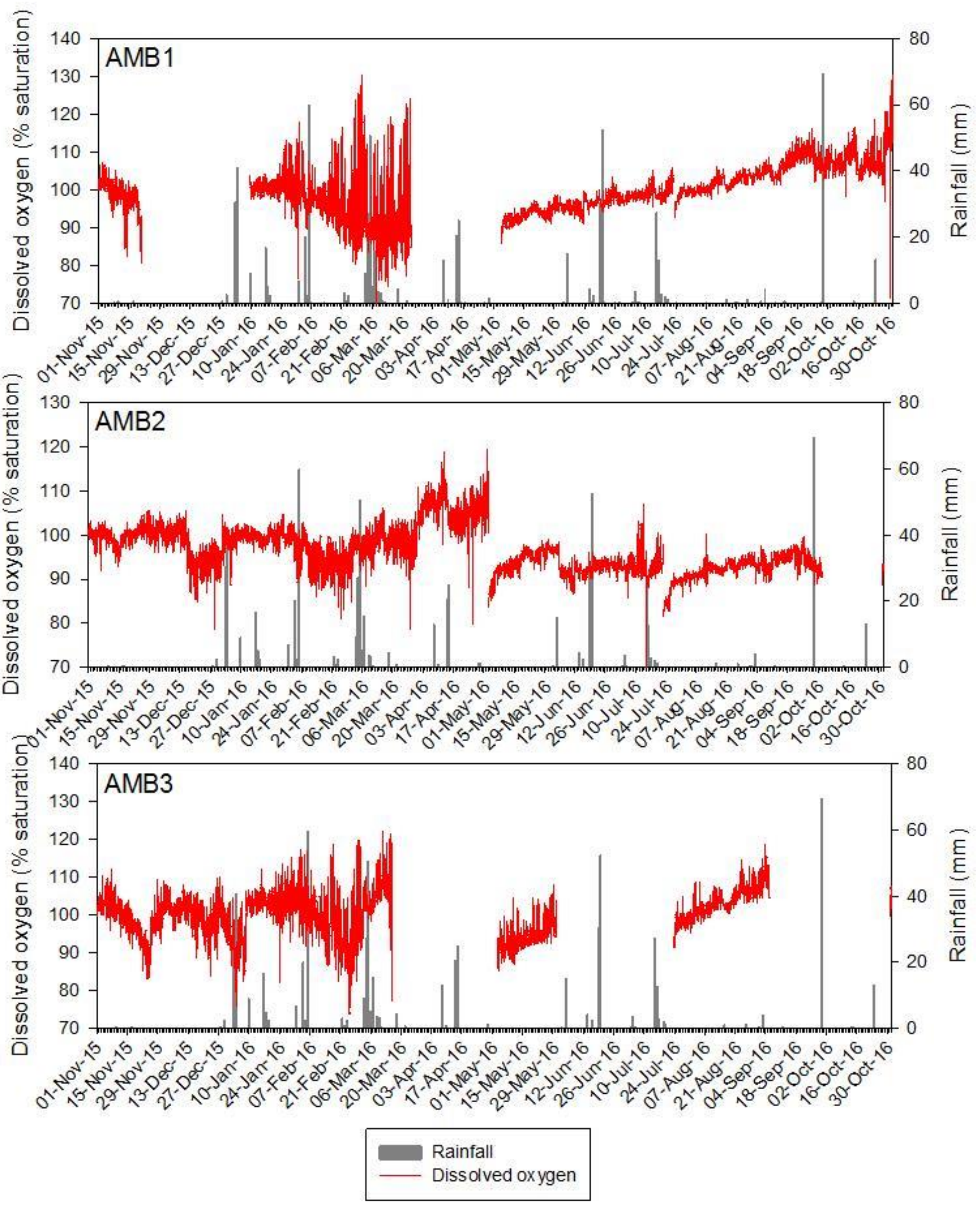

Figure 25 Dissolved oxygen and rainfall at AMB1, AMB2 and AMB3 from November 2015 to October 2016.

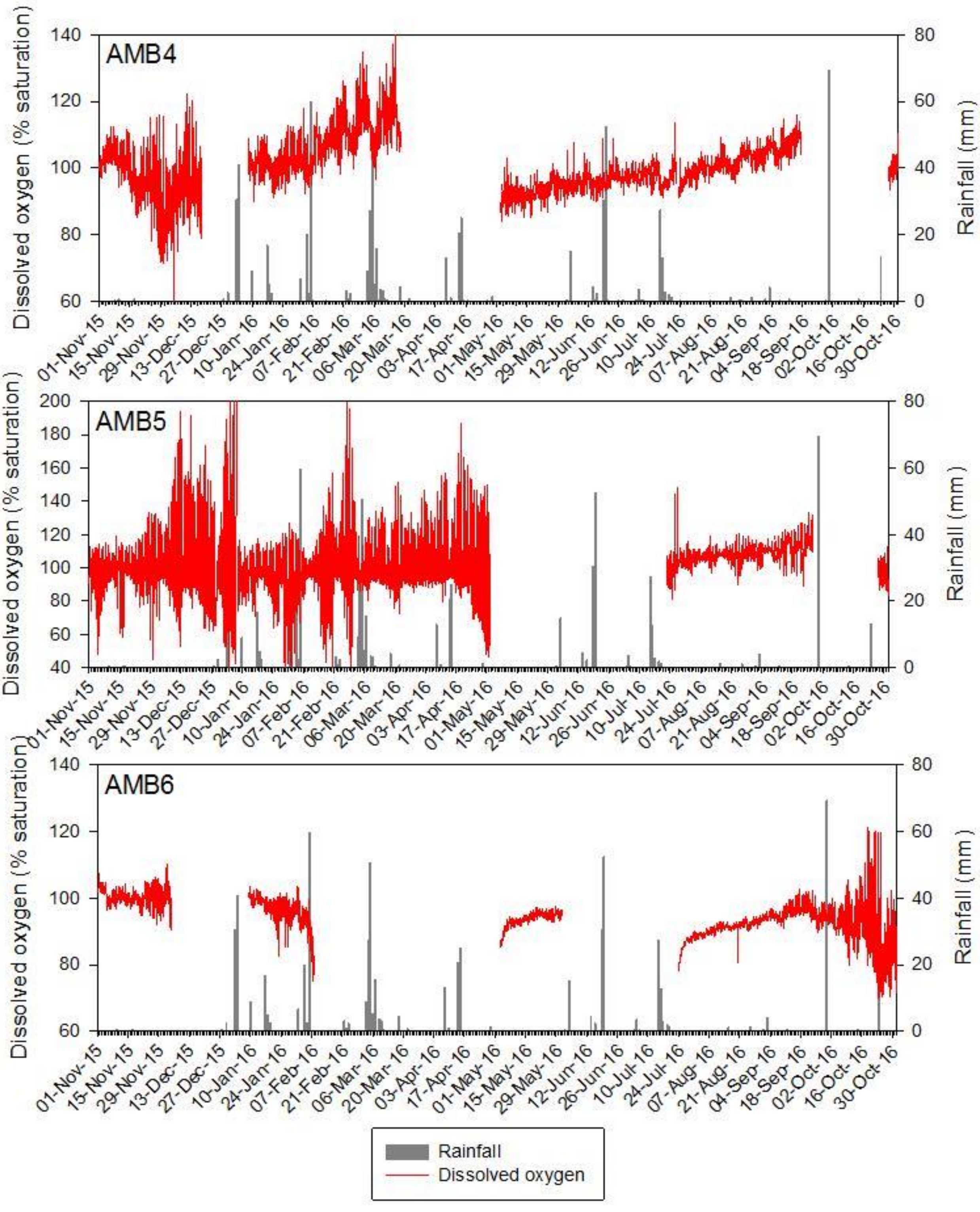

Figure 26 Dissolved oxygen and rainfall at AMB4, AMB5 and AMB6 from November 2015 to October 2016.

Table 10 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during January 2016 sampling event. *Values are means ± se (n = 3 for subsurface, mid and benthos, n = 15 to 26 for whole column). Values outside recommended QWQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Salinity (ppt)	Dissolved oxygen (% saturation)	Turbidity (NTU)	K_d
AMB1	9/01/2016 14:15	Sub-surface	30.0 ± 0.0	8.0 ± 0.0	54.8 ± 0.0	36.2 ± 0.0	102 ± 0	3.3 ± 0.0	0.20
		Mid	30.0 ± 0.0	8.0 ± 0.0	54.8 ± 0.0	36.2 ± 0.0	102 ± 0	8.6 ± 0.0	
		Benthos	29.9 ± 0.0	8.0 ± 0.0	54.8 ± 0.0	36.2 ± 0.0	102 ± 0	8.8 ± 0.0	
		Whole column	30.0 ± 0.0	8.0 ± 0.0	54.8 ± 0.0	36.2 ± 0.0	102 ± 0	6.1 ± 1	
AMB2	8/01/2016 18:00	Sub-surface	27.4 ± 0.0	8.3 ± 0.0	57.4 ± 0.0	38.2 ± 0.0	104 ± 0	12 ± 0.0	0.13
		Mid	27.4 ± 0.0	8.3 ± 0.0	57.3 ± 0.0	38.1 ± 0.0	103 ± 0	13 ± 0.0	
		Benthos	27.3 ± 0.0	8.3 ± 0.0	57.3 ± 0.0	38.1 ± 0.0	103 ± 0	13 ± 0.0	
		Whole column	27.4 ± 0.0	8.3 ± 0.0	57.3 ± 0.0	38.1 ± 0.0	103 ± 0	13 ± 0	
AMB3	8/01/2016 11:45	Sub-surface	28.8 ± 0.0	8.2 ± 0.0	57.0 ± 0.0	37.8 ± 0.0	100 ± 0	9.2 ± 0.1	0.28
		Mid	28.4 ± 0.1	8.2 ± 0.0	57.0 ± 0.0	37.8 ± 0.0	100 ± 0	10 ± 0.0	
		Benthos	28.0 ± 0.0	8.2 ± 0.0	57.0 ± 0.0	37.8 ± 0.0	99 ± 0	10 ± 0.0	
		Whole column	28.4 ± 0.1	8.2 ± 0.0	57.0 ± 0.0	37.8 ± 0.0	100 ± 0	10 ± 0	
AMB4	8/01/2016 9:00	Sub-surface	27.7 ± 0.0	8.2 ± 0.0	56.9 ± 0.0	37.8 ± 0.0	103 ± 0	8.4 ± 0.1	0.17
		Mid	27.5 ± 0.0	8.2 ± 0.0	57.0 ± 0.0	37.9 ± 0.0	103 ± 0	8.5 ± 0.0	
		Benthos	27.1 ± 0.0	8.1 ± 0.0	57.1 ± 0.0	37.9 ± 0.0	94 ± 0	9.2 ± 0.1	
		Whole column	27.5 ± 0.0	8.1 ± 0.0	57.0 ± 0.0	37.9 ± 0.0	101 ± 0	8.6 ± 0.1	
AMB5	7/01/2016 15:30	Sub-surface	26.7 ± 0.0	8.1 ± 0.0	56.7 ± 0.0	37.7 ± 0.0	110 ± 0	1.0 ± 0.0	0.22
		Mid	26.5 ± 0.0	8.1 ± 0.0	56.7 ± 0.0	37.7 ± 0.0	107 ± 0	1.0 ± 0.0	
		Benthos	26.5 ± 0.0	8.1 ± 0.0	56.7 ± 0.0	37.7 ± 0.0	107 ± 0	2.5 ± 1.5	
		Whole column	26.6 ± 0.0	8.1 ± 0.0	56.7 ± 0.0	37.7 ± 0.0	108 ± 0	1.3 ± 0.3	
AMB6	9/01/2016 7:30	Sub-surface	27.1 ± 0.0	8.2 ± 0.0	57.1 ± 0.0	38.0 ± 0.0	103 ± 0	4.0 ± 0.0	0.31
		Mid	27.1 ± 0.0	8.2 ± 0.0	57.1 ± 0.0	38.0 ± 0.0	102 ± 0	4.3 ± 0.1	
		Benthos	27.1 ± 0.0	8.2 ± 0.0	57.1 ± 0.0	38.0 ± 0.0	102 ± 0	8.3 ± 0.5	
		Whole column	27.0 ± 0.0	8.2 ± 0.0	57.1 ± 0.0	38.0 ± 0.0	102 ± 0	5.8 ± 0.4	
QWQG			**-**	**8.0 – 8.4**	**-**	**-**	**95 - 105**	**1**	

Table 11 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during May 2016 sampling event.
Values are means ± se (n = 3 for subsurface, mid and benthos, n = 14 to 28 for whole column). Values outside recommended QWQG are highlighted in blue.

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Salinity (ppt)	Dissolved oxygen (% saturation)	Turbidity (NTU)	K_d
AMB1	4/05/2016 10:30	Sub-surface	26.9 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.1 ± 0.0	101 ± 0	10 ± 0	0.24
		Mid	26.7 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.0 ± 0.0	100 ± 0	14 ± 1	
		Benthos	26.7 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.1 ± 0.0	100 ± 0	11 ± 0	
		Whole column	26.8 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.0 ± 0.0	100 ± 0	14 ±1	
AMB2	3/05/2016 8:00	Sub-surface	26.6 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.0 ± 0.0	100 ± 0	10 ± 0	0.17
		Mid	26.6 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.0 ± 0.0	99 ± 0	10 ± 1	
		Benthos	26.5 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.1 ± 0.0	99 ± 0	10 ± 0	
		Whole column	26.6 ± 0.0	8.2 ± 0.0	54.6 ± 0.0	36.0 ± 0.0	99 ± 0	10 ± 0	
AMB3	3/05/2016 12:30	Sub-surface	27.2 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	36.7 ± 0.0	103 ± 0	6.5 ± 0.0	0.29
		Mid	27.1 ± 0.0	8.2 ± 0.0	55.5 ± 0.0	36.7 ± 0.0	104 ± 0	6.5 ± 0.1	
		Benthos	27.1 ± 0.0	8.2 ± 0.0	55.6 ± 0.0	36.8 ± 0.0	107 ± 0	6.5 ± 0.1	
		Whole column	27.2 ± 0.0	8.2 ± 0.0	55.5 ± 0.0	36.7 ± 0.0	104 ± 0	6.0 ± 0.2	
AMB4	2/05/2016 13:15	Sub-surface	27.3 ± 0.0	8.2 ± 0.0	54.7 ± 0.0	36.2 ± 0.0	102 ± 0	4.5 ± 0.0	0.20
		Mid	26.9 ± 0.0	8.2 ± 0.0	54.7 ± 0.0	36.2 ± 0.0	99 ± 0	4.4 ± 0.1	
		Benthos	26.8 ± 0.0	8.2 ± 0.0	54.8 ± 0.0	36.3 ± 0.0	102 ± 0	4.3 ± 0.3	
		Whole column	27.0 ± 0.0	8.2 ± 0.0	54.8 ± 0.0	36.2 ± 0.0	101 ± 0	4.6 ± 0.0	
AMB5	2/05/2016 7:30	Sub-surface	26.9 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	36.3 ± 0.0	97 ± 0	11 ± 0	0.20
		Mid	26.9 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	36.3 ± 0.0	97 ± 0	10 ± 0	
		Benthos	26.9 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	36.3 ± 0.0	96 ± 0	10 ± 0	
		Whole column	26.9 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	36.3 ± 0.0	97 ± 0	10 ± 0	
AMB6	3/05/2016 15:45	Sub-surface	27.0 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	36.0 ± 0.0	102 ± 0	2.7 ± 0.0	0.22
		Mid	26.7 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	36.0 ± 0.0	102 ± 0	2.7 ± 0.1	
		Benthos	26.6 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	36.0 ± 0.0	102 ± 0	2.8 ± 0.0	
		Whole column	26.8 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	36.0 ± 0.0	102 ± 0	2.6 ± 0.0	
QWQG			**-**	**8.0 – 8.4**	**-**	**-**	**95 - 105**	**1**	

Table 12 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during July 2016 sampling event. *Values are means ± se (n = 3 for subsurface, mid and benthos, n = 17 to 51 for whole column). Values outside recommended QWQG are highlighted in blue.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Salinity (ppt)	Dissolved oxygen (% saturation)	Turbidity (NTU)	K_d
AMB1	22/07/2016 16:00	Sub-surface	23.8 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	102 ± 0	4.1 ± 0.0	0.23
		Mid	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	102 ± 0	4.4 ± 0.0	
		Benthos	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	102 ± 0	4.8 ± 0.1	
		Whole column	23.5 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	102 ± 0	4.4 ± 0.0	
AMB2	22/07/2016 12:15	Sub-surface	23.5 ± 0.0	8.1 ± 0.0	61.5 ± 0.0	41.4 ± 0.0	101 ± 0	1.4 ± 0.0	0.24
		Mid	23.3 ± 0.0	8.1 ± 0.0	61.5 ± 0.0	41.4 ± 0.0	101 ± 0	<1	
		Benthos	23.2 ± 0.0	8.1 ± 0.0	61.6 ± 0.0	41.4 ± 0.0	100 ± 0	<1	
		Whole column	23.4 ± 0.0	8.1 ± 0.0	61.6 ± 0.0	41.4 ± 0.0	101 ± 0	<1	
AMB3	23/07/2016 2:30	Sub-surface	23.6 ± 0.0	8.1 ± 0.0	61.3 ± 0.0	41.3 ± 0.0	102 ± 0	5.8 ± 0.0	0.27
		Mid	23.2 ± 0.0	8.1 ± 0.0	61.3 ± 0.0	41.3 ± 0.0	102 ± 0	5.9 ± 0.0	
		Benthos	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	103 ± 0	5.5 ± 0.3	
		Whole column	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	102 ± 0	5.9 ± 0.0	
AMB4	23/07/2016 10:30	Sub-surface	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	101 ± 0	<1	0.26
		Mid	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	102 ± 0	<1	
		Benthos	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	101 ± 0	<1	
		Whole column	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	101 ± 0	<1	
AMB5	22/07/2016 8:00	Sub-surface	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	41.4 ± 0.0	89 ± 0	6.6 ± 0.0	0.52
		Mid	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	41.4 ± 0.0	89 ± 0	7.1 ± 0.4	
		Benthos	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	41.4 ± 0.0	89 ± 0	7.5 ± 0.2	
		Whole column	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	41.4 ± 0.0	89 ± 0	7.2 ± 0.1	
AMB6	23/07/2016 16:15	Sub-surface	24.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	102 ± 0	1.0 ± 0.0	0.25
		Mid	23.6 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	101 ± 0	1.1 ± 0.1	
		Benthos	23.5 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	100 ± 0	1.4 ± 0.0	
		Whole column	23.8 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	41.3 ± 0.0	101 ± 0	1.1 ± 0.0	
QWQG			**-**	**8.0 – 8.4**	**-**	**-**	**95 - 105**	**1**	

Table 13 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during October/November 2016 sampling event. *Values are means ± se (n = 3 for subsurface, mid and benthos, n = 17 to 31 for whole column). Values outside recommended QWQG are highlighted in blue. AMB1 subsurface values only able to be reported due to ProDSS malfunction.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Salinity (ppt)	Dissolved oxygen (% saturation)	Turbidity (NTU)	Kd
AMB1	01/11/2016 09:15	Sub-surface	26.4	8.2	56.2	36.7	103	<1	0.16
		Mid	-	-	-	-	-	-	
		Benthos	-	-	-	-	-	-	
		Whole column	-	-	-	-	-	-	
AMB2	31/10/2016 13:45	Sub-surface	26.8 ± 0.0	8.1 ± 0.0	56.0 ± 0.0	37.2 ± 0.0	103 ± 0	1.0 ± 0.0	0.23
		Mid	26.2 ± 0.0	8.2 ± 0.0	56.1 ± 0.0	37.2 ± 0.0	102 ± 0	<1	
		Benthos	26.1 ± 0.0	8.2 ± 0.0	56.1 ± 0.0	37.2 ± 0.0	102 ± 0	<1	
		Whole column	26.4 ± 0.1	8.1 ± 0.0	56.1 ± 0.0	37.2 ± 0.0	102 ± 0	<1	
AMB3	27/10/2016 14:15	Sub-surface	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	37.6 ± 0.0	104 ± 0	<1	0.35
		Mid	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	37.6 ± 0.0	104 ± 0	<1	
		Benthos	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	37.6 ± 0.0	104 ± 0	<1	
		Whole column	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	37.5 ± 0.0	104 ± 0	<1	
AMB4	27/10/2016 11:30	Sub-surface	26.2 ± 0.0	8.1 ± 0.0	56.2 ± 0.0	37.3 ± 0.0	102 ± 0	1.1 ± 0.0	0.21
		Mid	26.2 ± 0.0	8.1 ± 0.0	56.3 ± 0.0	37.4 ± 0.0	102 ± 0	1.2 ± 0.0	
		Benthos	26.2 ± 0.0	8.1 ± 0.0	56.4 ± 0.1	37.5 ± 0.0	98 ± 2	1.1 ± 0.0	
		Whole column	26.2 ± 0.0	8.1 ± 0.0	56.3 ± 0.0	37.4 ± 0.0	101 ± 1	1.1 ± 0.0	
AMB5	27/10/2016 07:30	Sub-surface	25.9 ± 0.0	8.1 ± 0.0	55.6 ± 0.0	36.9 ± 0.0	97 ± 0	1.3 ± 0.0	0.19
		Mid	25.9 ± 0.0	8.2 ± 0.0	55.6 ± 0.0	36.9 ± 0.0	97 ± 0	1.3 ± 0.0	
		Benthos	25.9 ± 0.0	8.2 ± 0.0	55.6 ± 0.0	36.9 ± 0.0	97 ± 0	1.3 ± 0.0	
		Whole column	25.9 ± 0.0	8.1 ± 0.0	55.6 ± 0.0	36.9 ± 0.0	97 ± 0	1.3 ± 0.0	
AMB6	01/11/2016 06:30	Sub-surface	26.2 ± 0.0	8.1 ± 0.0	56.0 ± 0.0	37.2 ± 0.0	102 ± 0	<1	0.15
		Mid	26.2 ± 0.0	8.2 ± 0.0	56.0 ± 0.0	37.2 ± 0.0	101 ± 0	<1	
		Benthos	26.3 ± 0.0	8.2 ± 0.0	56.2 ± 0.0	37.3 ± 0.0	102 ± 0	<1	
		Whole column	26.2 ± 0.0	8.1 ± 0.0	56.1 ± 0.0	37.2 ± 0.0	102 ± 0	<1	
QWQG			**-**	**8.0 – 8.4**	**-**	**-**	**95 - 105**	**1**	

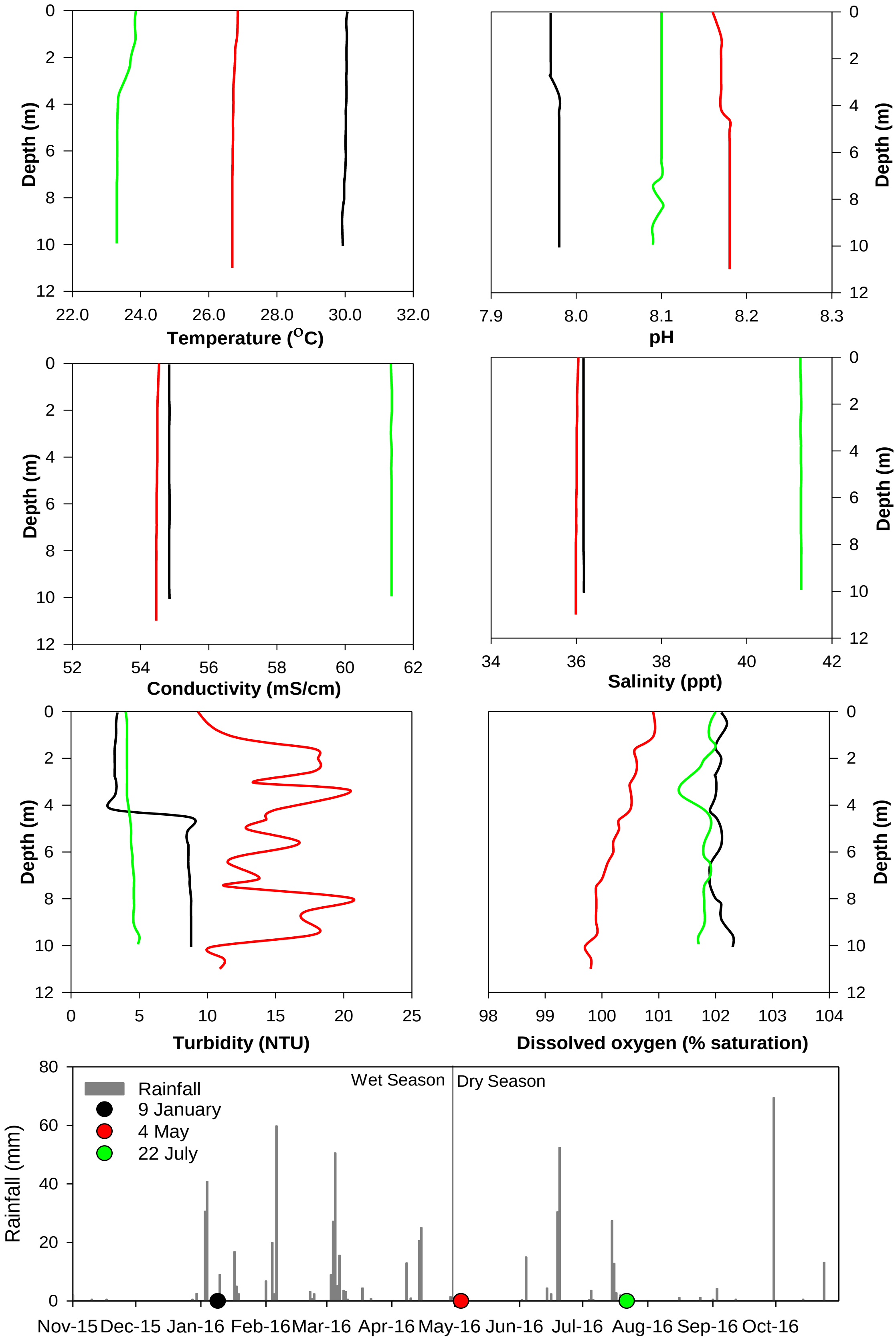

Figure 27 Depth-profiled physicochemical parameters and associated rainfall at AMB1 during January, May and July 2016.
Note no data available for October/November 2016 due to the malfunction of the ProDSS.

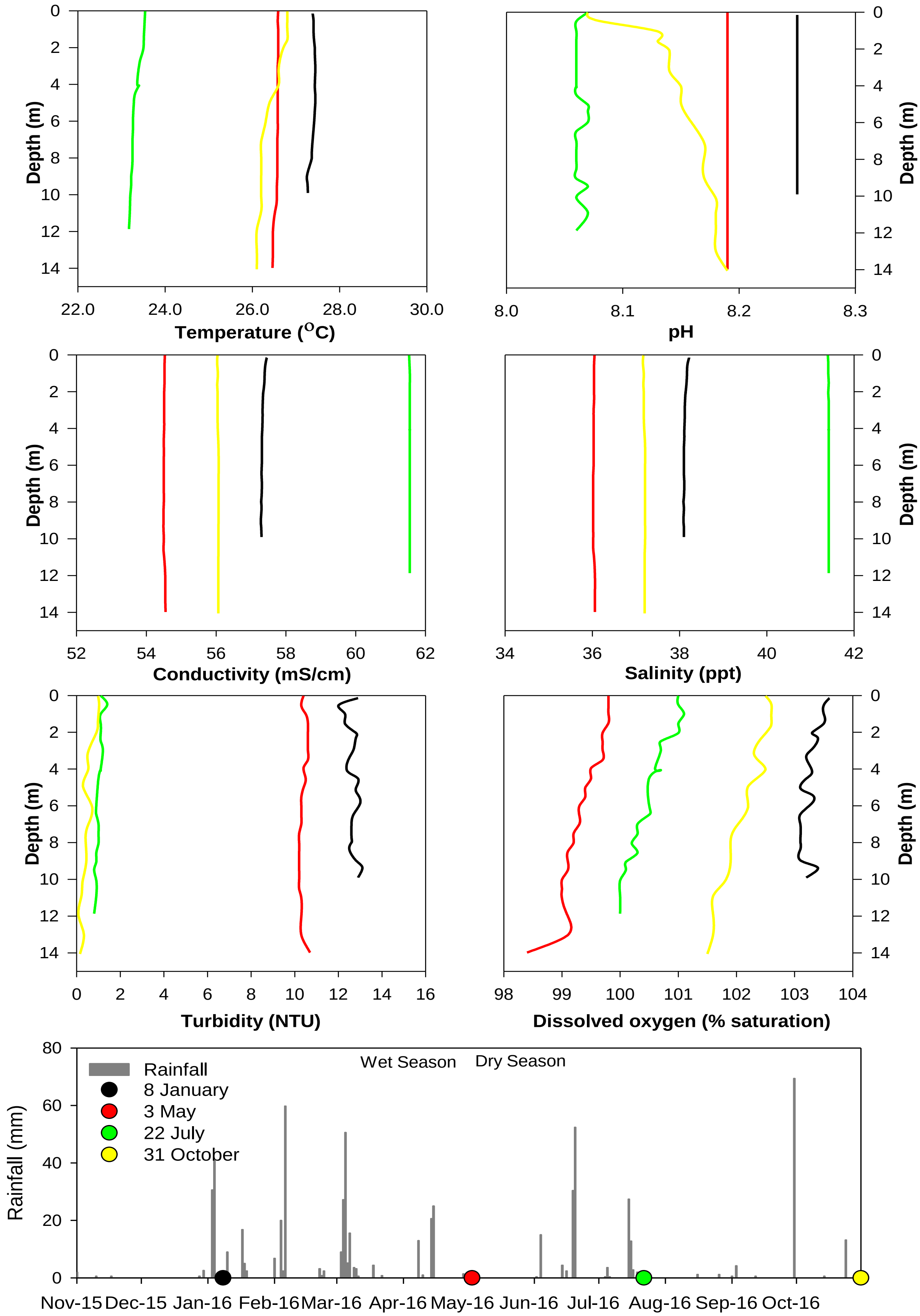

Figure 28 Depth-profiled physicochemical parameters and associated rainfall at AMB2 during January, May, July and October 2016.

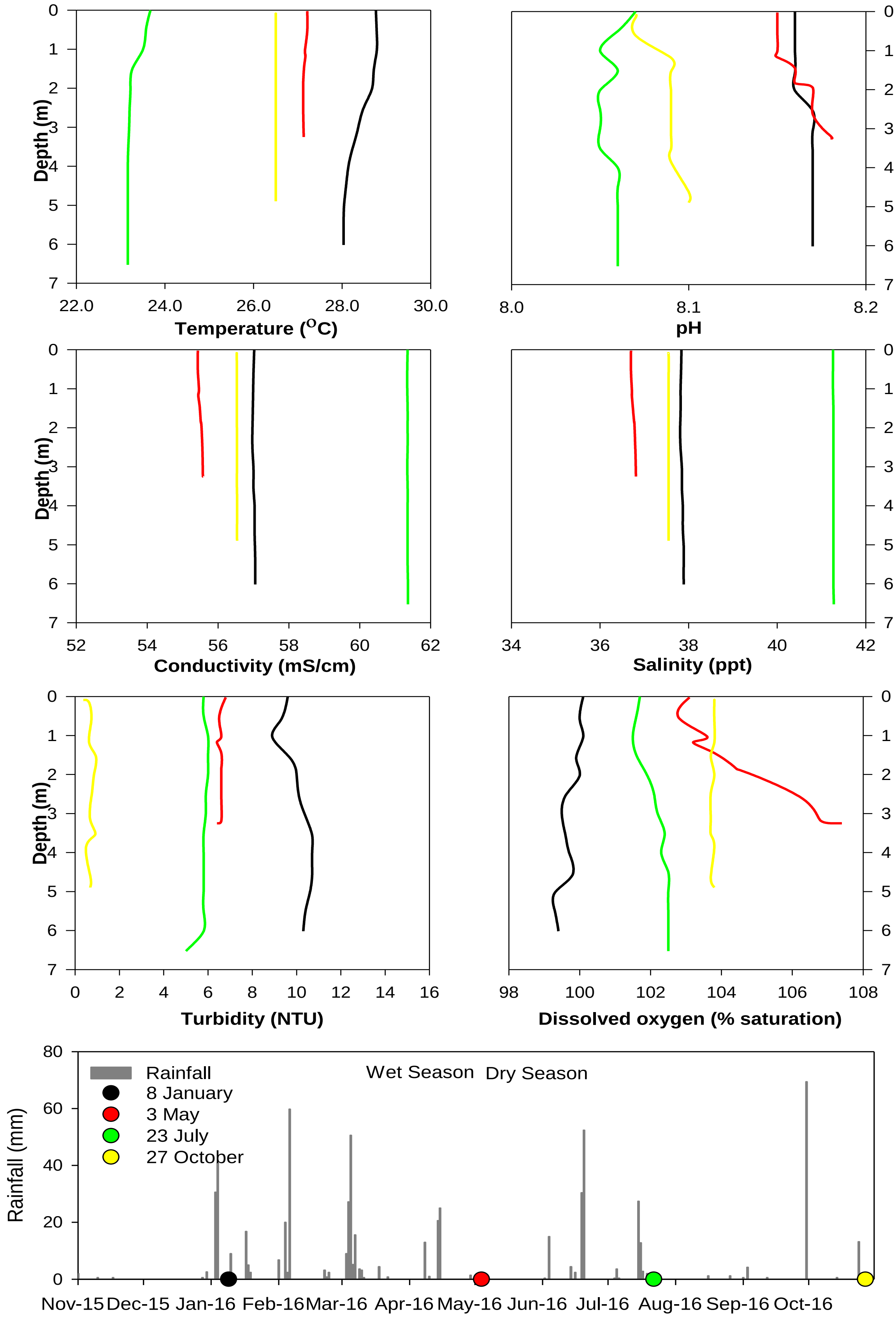

Figure 29 Depth-profiled physicochemical parameters and associated rainfall at AMB3 during January, May, July and October 2016.

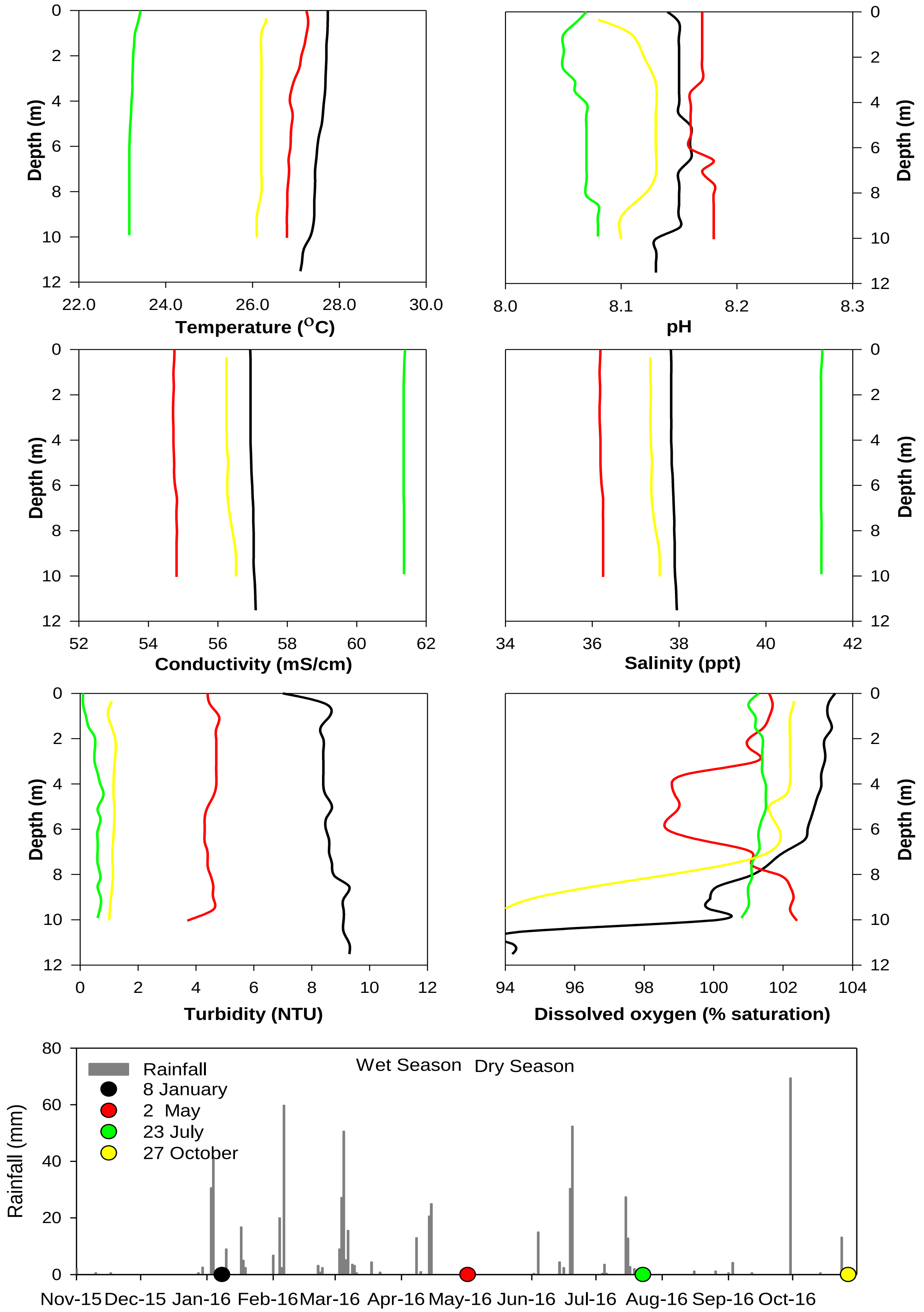

Figure 30 Depth-profiled physicochemical parameters and associated rainfall at AMB4 during January, May, July and October 2016.

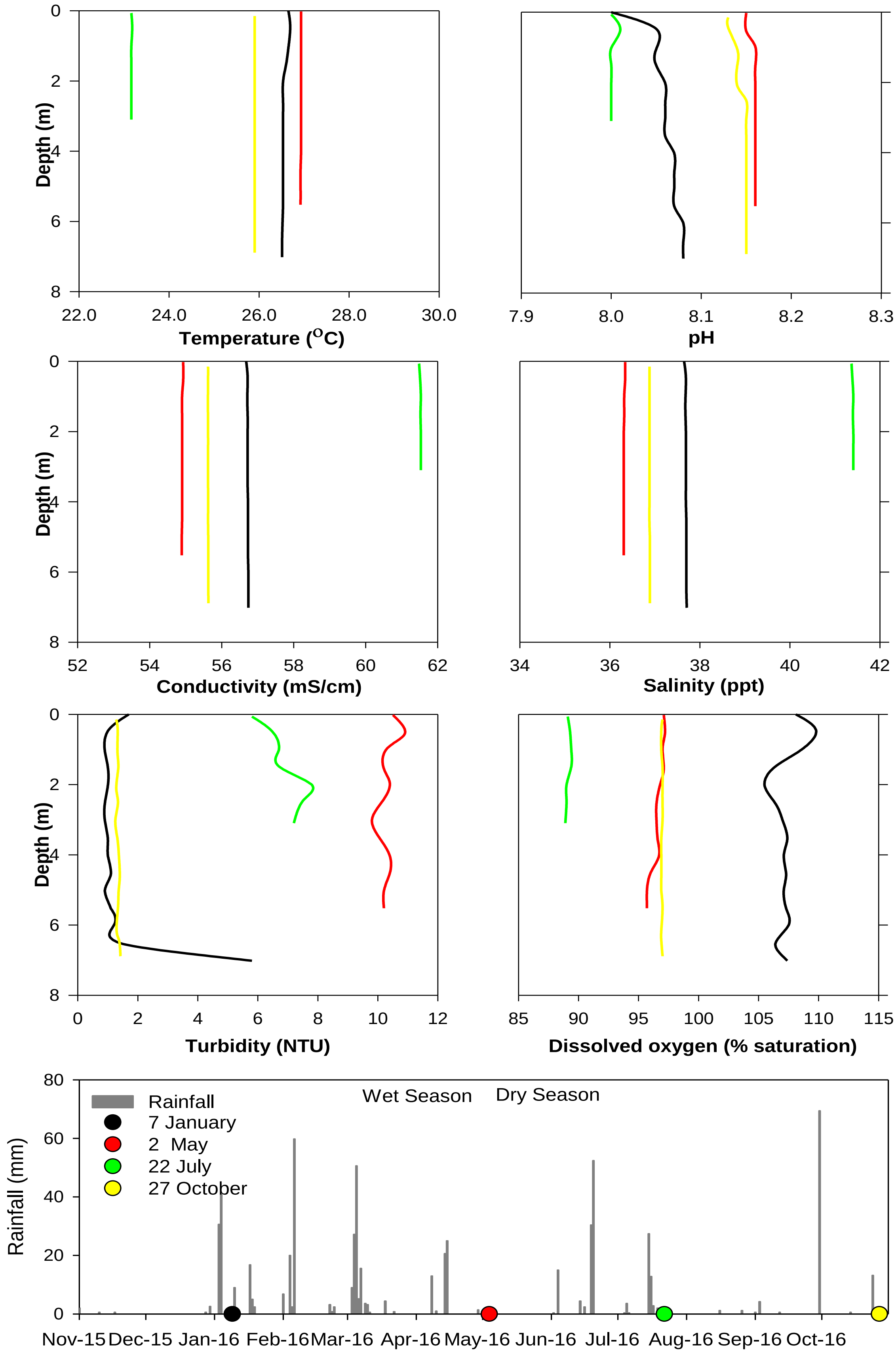

Figure 31 Depth-profiled physicochemical parameters and associated rainfall at AMB5 during January, May, July and October 2016.

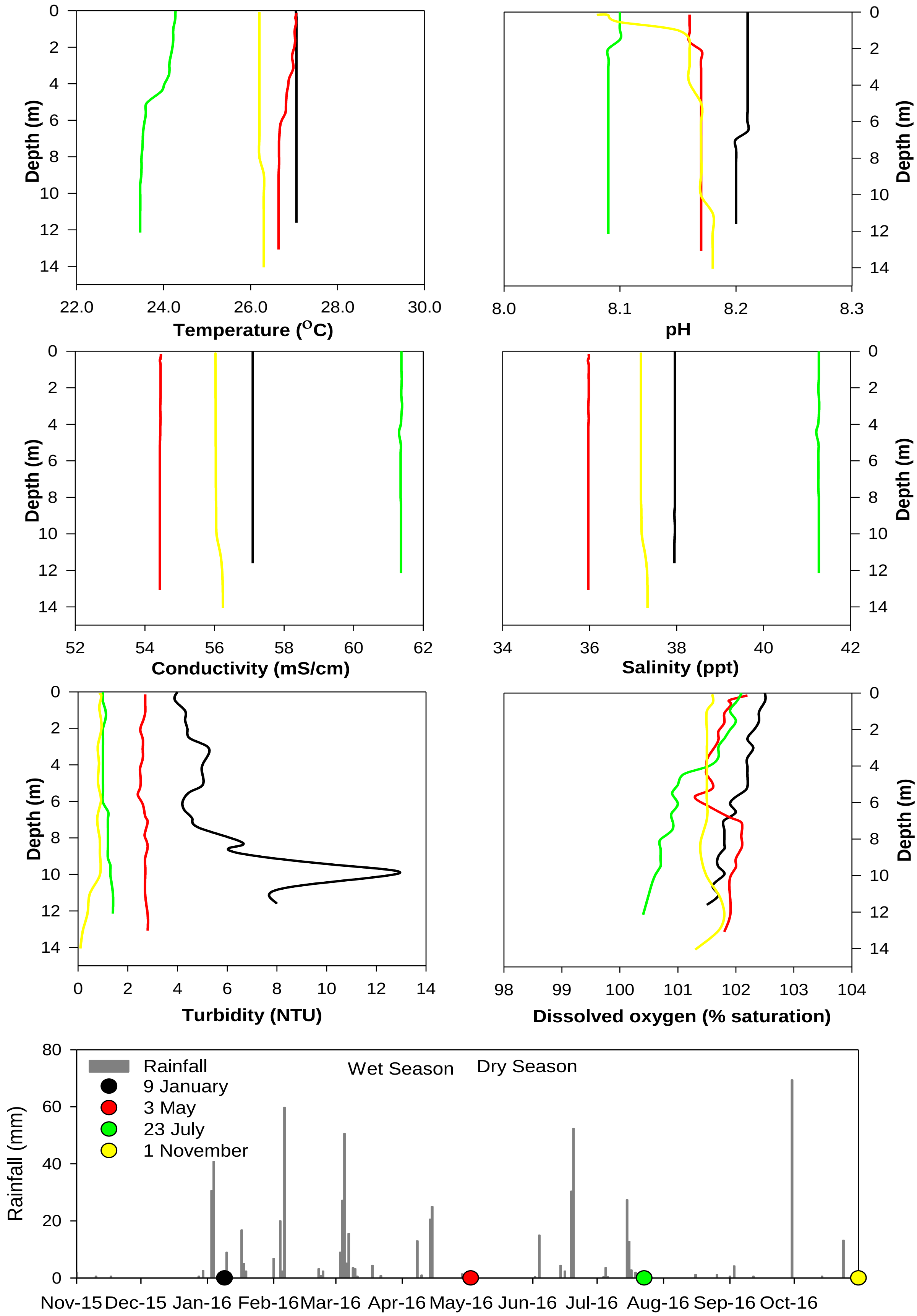

Figure 32 Depth-profiled physicochemical parameters and associated rainfall at AMB6 during January, May, July and October 2016.

Greater variation in pH between sites was evident during the January survey (8.0 to 8.3) in comparison with subsequent sampling. However, all pH values during all surveys were within, or marginally below, QWQG of 8.0 to 8.4. During the 2013/2014 monitoring of Abbot Point, pH values marginally lower than the QWQG range were also recorded (Worley Parsons, 2014), indicating that this is a common occurrence.

For most sites, turbidity was higher in January and April than during July and October. However, AMB5 exhibited a contrasting pattern with highest turbidity evident during July. Exceedances of the QWQG for turbidity (1 NTU) were found for all sites except AMB5 in January, AMB2 and AMB4 in July, and AMB1, AMB2, AMB3 and AMB6 in October. However, the QWQG which apply to open coastal waters could be considered conservative for the near shore Abbot Point sites, which are highly influenced by adjacent river flows. Light attenuation remained reasonably consistent across sites and monitoring events, generally ranging between 0.2 to 0.4.

Temperature, pH and conductivity remained consistent with water depth at all sites during all four sampling events. Some variation in turbidity and DO with water depth was evident at some sites during certain surveys; however no consistent pattern, nor vertical stratification, was detected. Previous monitoring programs had also found that Abbot Point coastal waters are well-mixed especially under non-flood conditions (GHD, 2009, 2010, 2012, Worley Parsons, 2014).

3.4 Continuous BPAR Loggers

There are three major environmental factors that can affect BPAR: the available ambient light, water depth and water clarity. Thus all three variables are considered in the following section. Mean seasonal ambient PAR and BPAR is reported as Total Daily PAR (TDP) in Figures 33 to 38, and Table 14.

TDP at Bowen Base was significantly ($p < 0.05$) higher in the Wet Season (79.2 mol/m^2/day) than in the Dry Season (72.8 mol/m^2/day). TDP was also significantly ($p < 0.05$) higher at each benthic site (except AMB6) during the Wet Season (mean 4.6, site seasonal means ranging from 1.3 to 9.3 mol/m^2/day), than during the Dry Season (mean 3.6, site seasonal means ranging from 0.7 to 8.7 mol/m^2/day), despite the significantly lower turbidity experienced during the latter season (see Table 5). The TDP at AMB6 did not differ significantly across the Wet (1.6 mol/m^2/day) and Dry (1.0 mol/m^2/day) seasons. Ambient PAR can typically be higher in the Wet Season due to the longer day lengths however this can often be offset by the higher number of cloudy days experienced over this period, with associated rainfall causing an increase in turbidity, thus reducing BPAR. A similar result was recorded in the previous monitoring program (Worley Parsons, 2014).

As would be expected, the shallowest sites (AMB3 and AMB5 at 3.9 and 6.5 m depth) exhibited significantly ($p < 0.05$) higher TDP in both the Wet Season (9.0 to 9.3 mol/m^2/day) and the Dry Season (5.8 to 8.7 mol/m^2/day) than all other sites. AMB2 and AMB6 are the deepest sites (12.2 and 13.1 m) and TDP at these sites was significantly ($p < 0.05$) lower than all other sites during both seasons (0.7 to 1.6 mol/m^2/day) due to light being diminished prior to reaching the benthic logger. Intermediate TDP was recorded at AMB1 and AMB4 which are located at 8.5 to 9.0 m depth. Similar seasonal and depth patterns of TDP have been recorded in previous monitoring programs (Worley Parsons, 2014).

Table 14 Total Daily PAR (TDP) statistics from data collected from loggers deployed October 2015 to October 2016.
N = 68 to 180 for wet season and 148 to 191 for dry season.

Site	Depth (m)	Wet Season TDP (mol/m^2/day)			Dry Season TDP (mol/m^2/day)		
		Mean ± se	Median	20th to 80th %ile range	Mean ± se	Median	20th to 80th %ile range
Base	-	79.2 ± 1.5	83.9	68.1 – 92.9	72.8 ± 1.0	5.0	63.1 – 84.1
AMB1	9.0	4.9 ± 0.2	4.6	2.4 – 7.2	2.6 ± 0.1	2.3	1.5 – 3.3
AMB2	12.2	1.3 ± 0.1	1.0	0.4 – 2.1	0.7 ± 0.1	0.5	0.2 – 1.2
AMB3	3.9	9.0 ± 0.4	9.0	6.7 – 11.9	5.8 ± 0.2	5.5	3.6 – 7.9
AMB4	8.5	2.9 ± 0.2	2.8	0.3 – 5.7	2.2 ± 0.1	2.1	1.2 – 2.7
AMB5	6.3	9.3 ± 0.4	9.0	5.0 – 14.3	8.7 ± 0.4	9.2	3.8 – 13.5
AMB6	13.1	1.6 ± 0.1	1.5	0.4 – 2.4	1.0 ± 0.1	0.8	0.1 – 1.8

Light requirement trigger values for intertidal seagrass species (*Zostera capricorni*) were utilised in the WBDDP as an ecological trigger on which management decisions could be made to inform the dredging operations (Vision Environment, 2013). Although *Zostera capricorni* has been identified in Abbot Point seagrass communities, the most common and widely distributed species is *Halodule uninervis* (McKenna and Rasheed, 2011). BPAR data collected at the offshore locations in Port Curtis has also been utilised to inform the current and existing light environment and growing conditions for subtidal seagrass species (Davies et al., 2015) in Port Curtis. While light requirements for certain species of seagrass in Port Curtis are now well established (Chartrand et al., 2012), little information exists on applicable light requirements for coral species.

3.5 Sedimentation

Sedimentation was measured at AMB1 and AMB2 using fixed deployment acoustic altimeters. Increased wave energy resulting from increased wind speeds, or stronger currents resulting from larger tidal ranges, has the potential to result in increased sediment resuspension. One of three outcomes occurs during such an event: deposition of sediment from another location, movement of sediment to another location, or resuspension with no net change. Two forms of information were provided by the altimeters:

- Instantaneous bed level change indicating the amount of sediment flux occurring at a set point in time; and
- Net cumulative change in bed level over a given period.

Sediment flux (in relation to baseline bed level) calculated every 15 minutes and daily mean cumulative bed level change are illustrated in Figures 39 and 40.

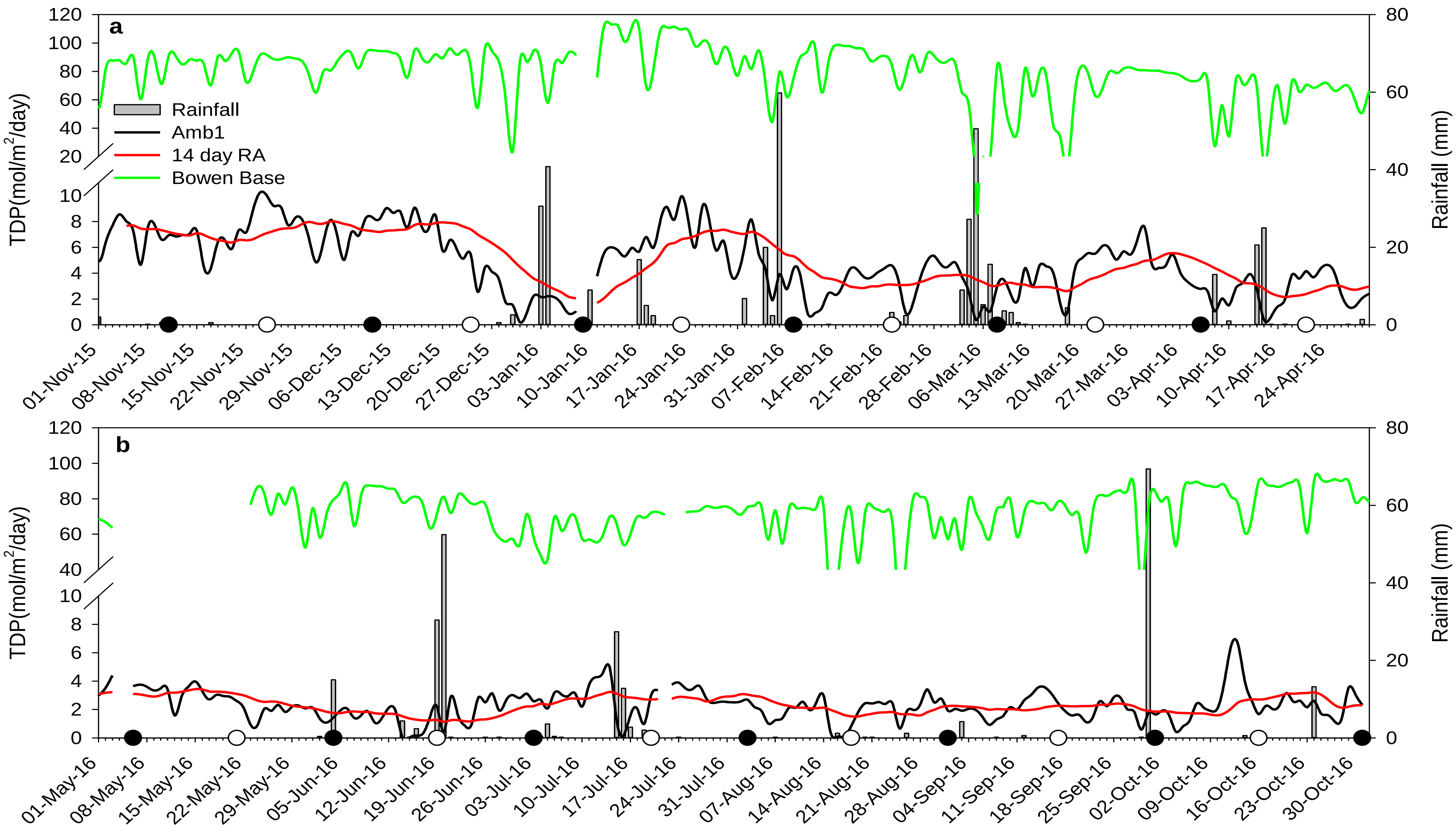

Figure 33 Benthic TDP and 14 day rolling average for BPAR at AMB1 and ambient (Bowen base) TDP during the a) Wet and b) Dry Seasons from November 2015 to October 2016 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively.

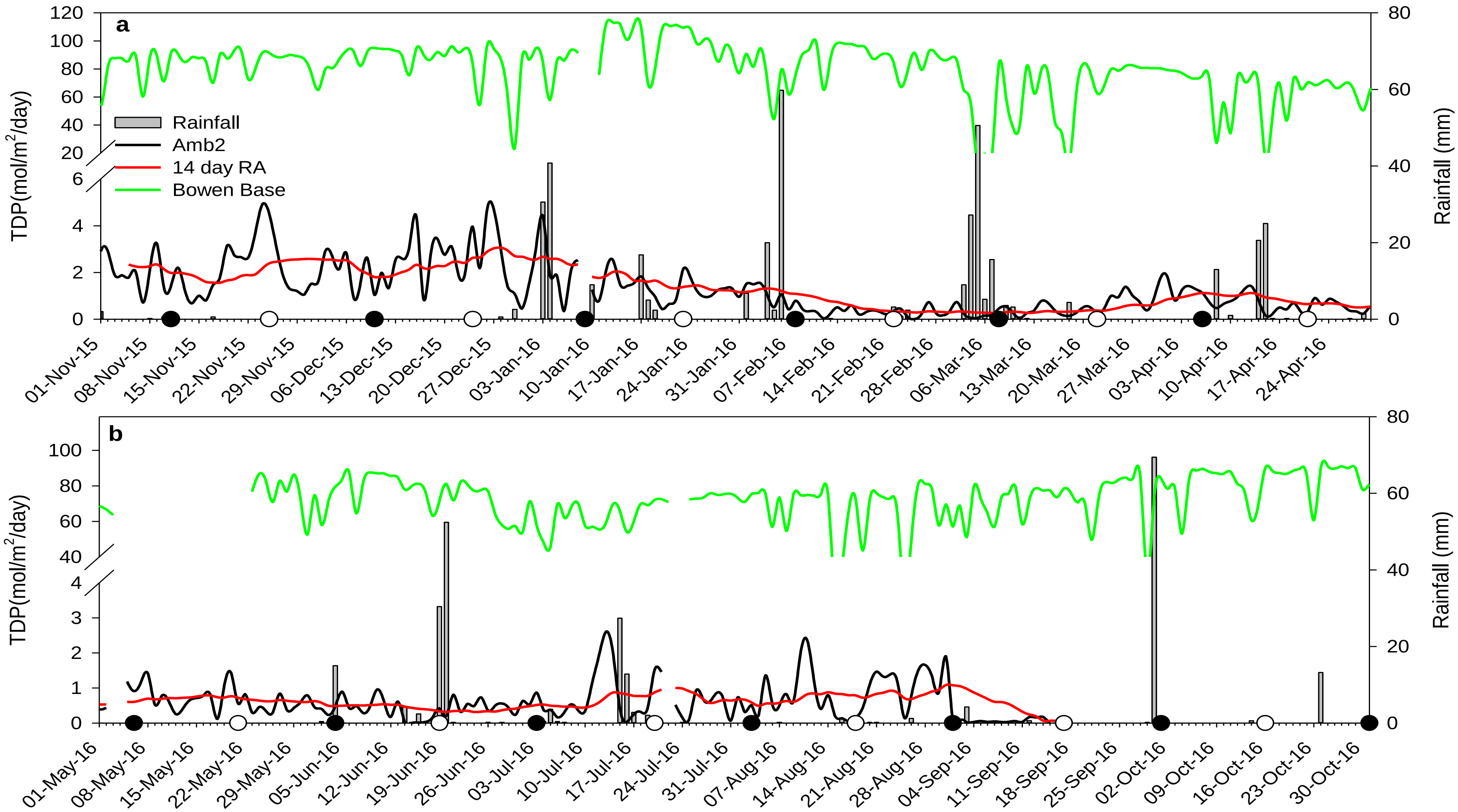

Figure 34 Benthic TDP and 14 day rolling average for BPAR at AMB2 and ambient (Bowen base) TDP during the a) Wet and b) Dry Seasons from November 2015 to October 2016 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively. Note that the loggers malfunctioned in mid-September 2016 and therefore no data is available from this date until end October 2016.

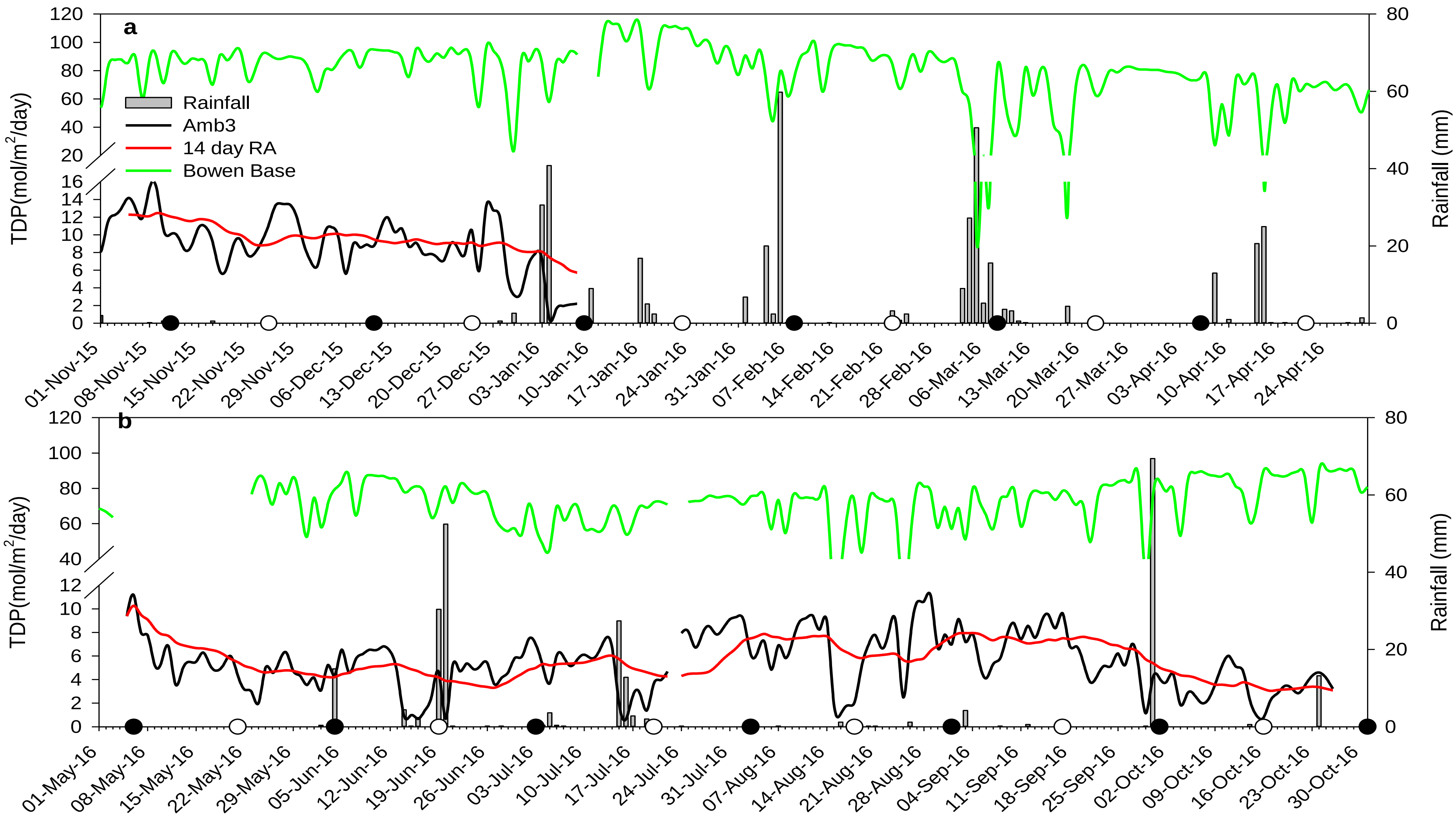

Figure 35 Benthic TDP and 14 day rolling average for BPAR at AMB3 and ambient (Bowen base) TDP during the a) Wet and b) Dry Seasons from November 2015 to October 2016 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively. Note that PAR loggers at AMB3 went missing during the January to May 2016 deployment and therefore no data is available for this time period at AMB3.

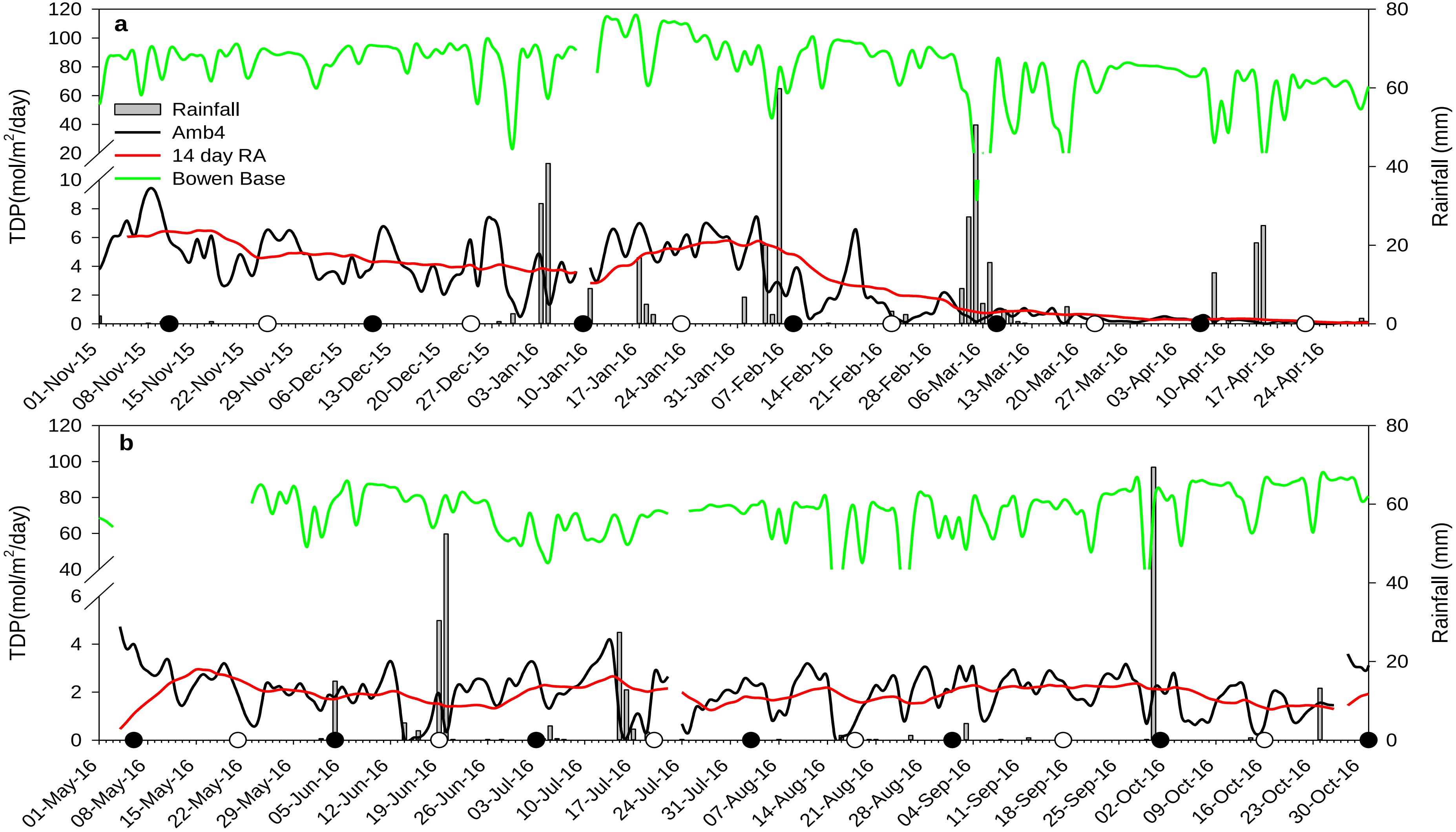

Figure 36 Benthic and ambient TDP and 14 day rolling average for benthic PAR at AMB4 during the a) Wet and b) Dry Seasons from November 2015 to October 2016 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively.

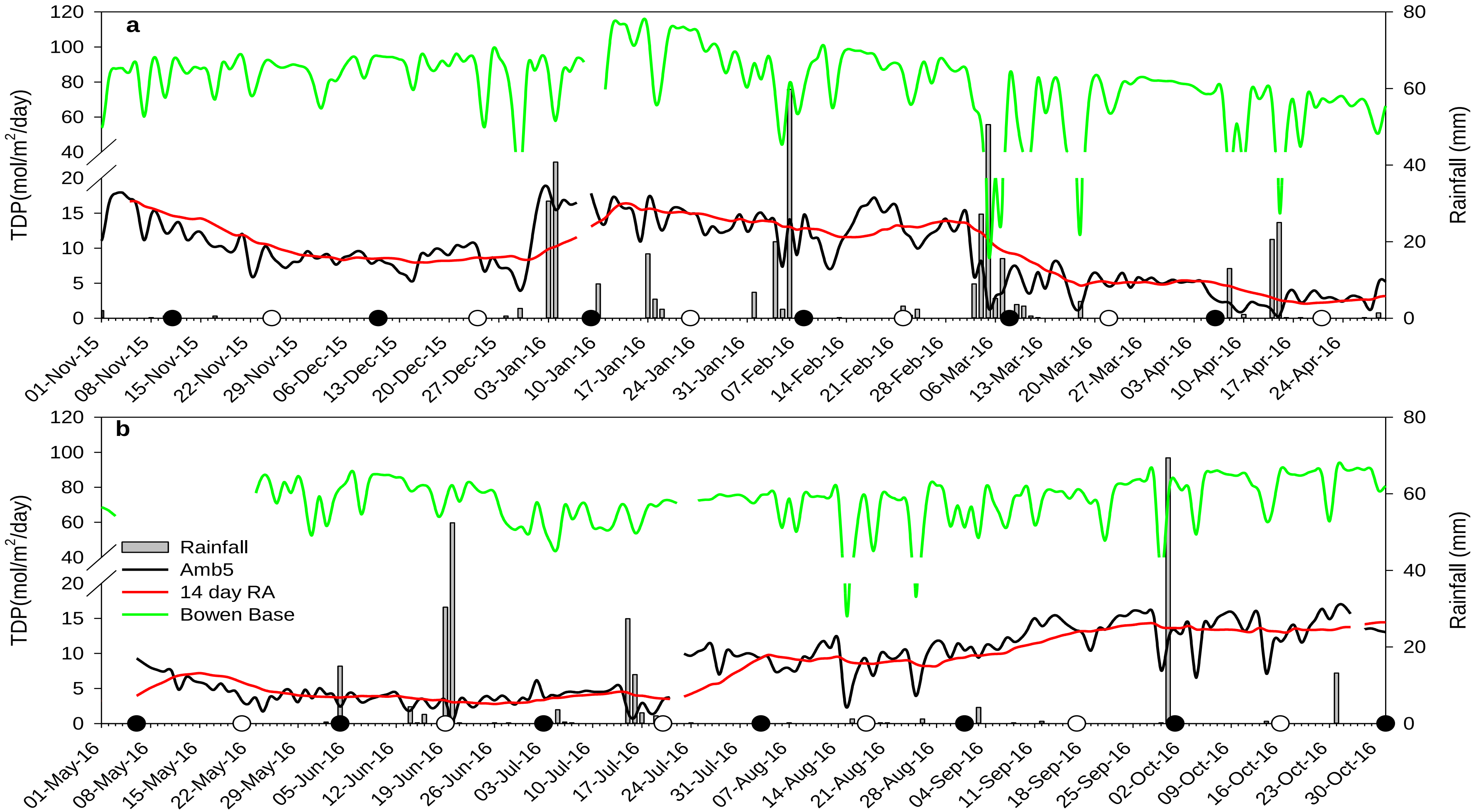

Figure 37 Benthic and ambient TDP and 14 day rolling average for benthic PAR at AMB5 during the a) Wet and b) Dry Seasons from November 2015 to October 2016 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively.

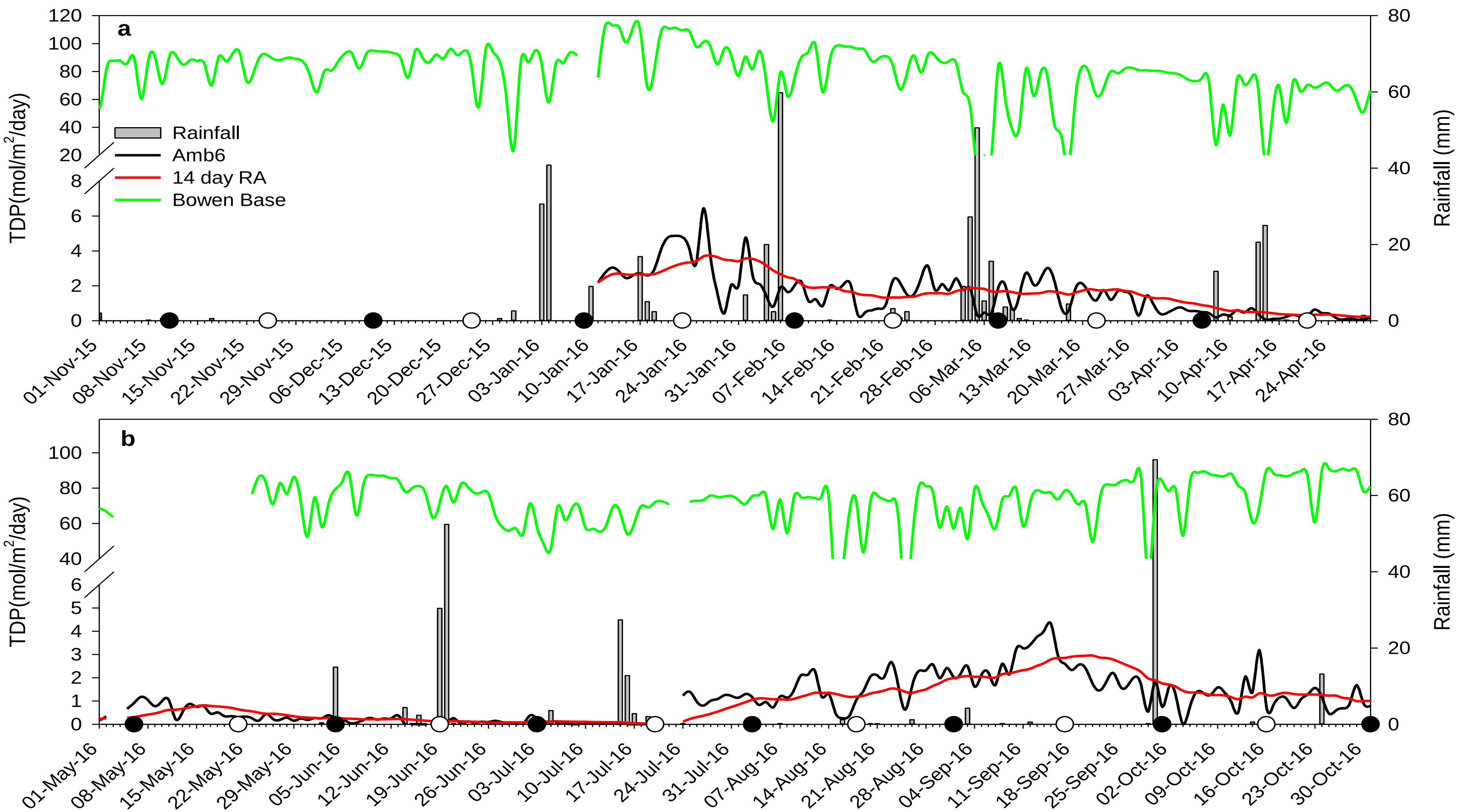

Figure 38 Benthic and ambient TDP and 14 day rolling average for benthic PAR at AMB6 during the a) Wet and b) Dry Seasons from November 2015 to October 2016 compared to ambient PAR measured at Bowen Base and rainfall.

Open and closed circles indicate full and new moon periods, respectively. Note that PAR loggers at AMB6 went missing during the November 2015 to January 2016 deployment, therefore no data is available for this time period at AMB6.

3.5.1 AMB1

At AMB1, bed levels increased (deposition) over time, increasing to between 5 and 10 mm higher than the baseline value recorded upon deployment on 21 October 2015, until late February. During late February/early March when the predominant daily wind direction changed from north-easterly to south-easterly, gradual erosion become apparent for a two week period (Figure 39).

Bed levels then remained reasonably stable (20 mm lower than baseline values) at AMB1 until the 8 to 10 June 2016, where the bed level decreased by approximately 50 mm. The rapid erosion was evident on both altimeters deployed at AMB1, and may be attributable to the change in wind direction which swung from south-easterly to south westerly on the 4 to 7 June, before changing to north-easterly on the 8 and 9 June. Wave heights were less than 0.2 m during this period (Figure 39) and therefore wind direction rather than wind speeds may be the driving factor resulting in either deposition or erosion at this site.

In the following days, the wind direction changed back to south-easterly and wave heights increased to 1.2 m. The bed levels increased for several days while wave heights remained above 0.8 m. Slow erosion of the beds continued for the most part from mid-June to the end of October 2016.

Sediment flux generally increased during periods of higher wave heights as observed on 31 December 2015, and 11 and 25 of February 2016, in addition to the 20 August and 16 October. Tidal phases did not appear to be highly influential in regards to sediment flux. Rainfall periods appeared to have little influence on sediment flux and bed level change for the most part, but results may have been overshadowed by wave heights and wind direction, which often occurred concurrently.

3.5.2 AMB2

At AMB2, data was only able to be gained until early September 2016 due to the benthic unit being tipped over and dragged several meters from its position, most likely due to a fishing trawler, resulting in the loss of one altimeter.

Sediment flux at AMB2 was much less volatile than at AMB1 and appeared mostly unresponsive to rainfall, tidal fluctuations or wave heights. AMB2 is approximately 3 to 4 m deeper than AMB1, and thus may not respond to weather and metocean conditions as strongly as the shallower site. Additionally AMB1 may have a more unstable surficial sediment layer compared to AMB2, due to its close proximity to the Don and Euri Rivers.

Overall, the bed levels at AMB2 exhibited erosion, with lower bed levels compared to 21 October 2015 baseline values over the entire monitoring period. Three periods of rapid erosion were apparent: The first 10 days of the monitoring period (21 to 31 October 2015) in which 40 mm of erosion occurred, the first fortnight of April 2016, where an additional 70 mm of erosion was observed, and the start of August where 40 mm of erosion was recorded over six days. Only one altimeter was fully functional during all three erosion periods, with insufficient echo return for the alternate altimeters on the first two occasions, and the alternate altimeter missing for the last erosion period. As the erosion was gradual during all three periods and did not align with weather events, faunal activity may be responsible for the erosion. Fauna and associated activity has been recorded by divers previously at the AMB2 site.

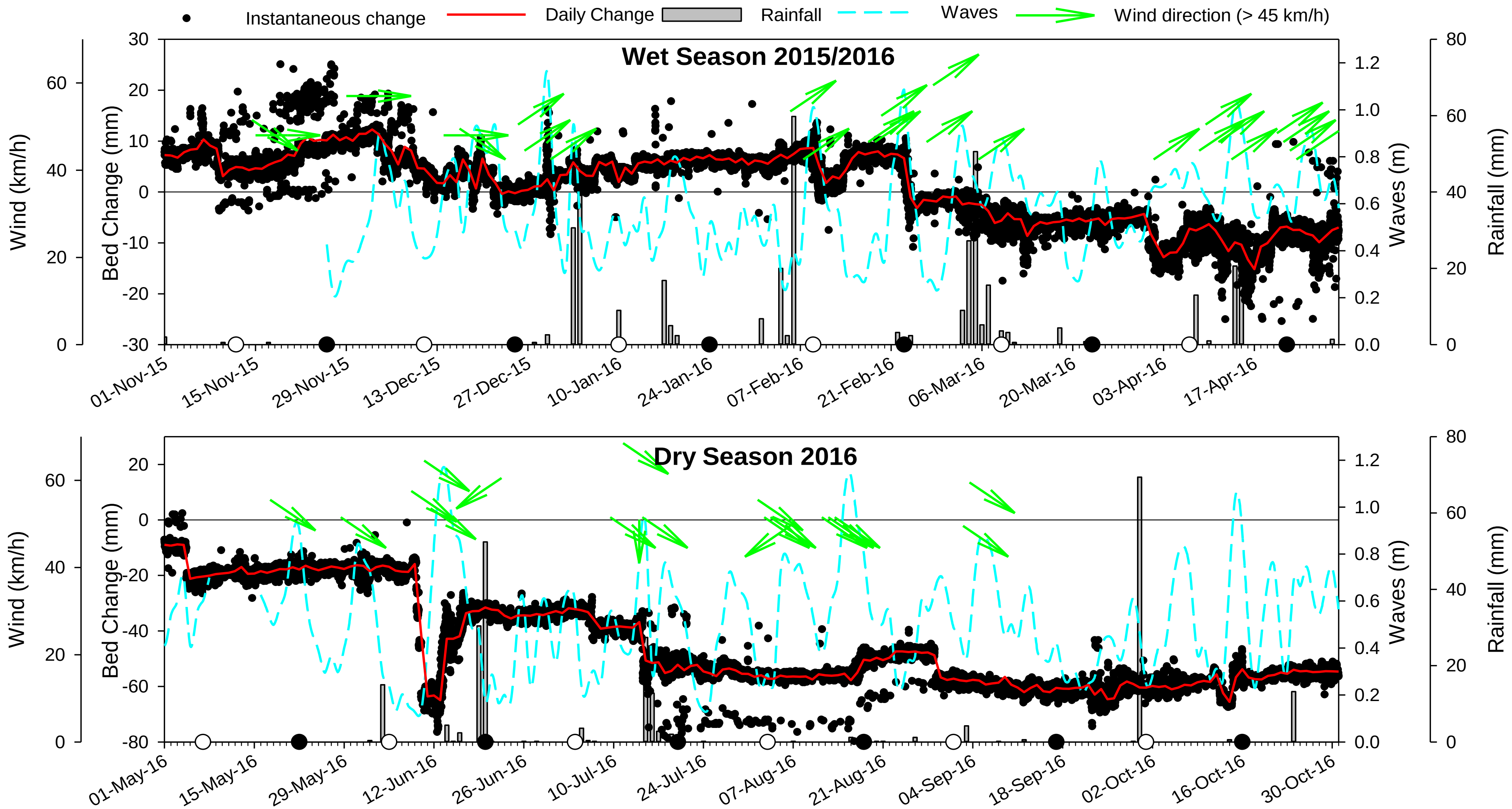

Figure 39 Mean instantaneous bed level change and daily cumulative bed level change at AMB1 during the 2015/2016 Wet and 2016 Dry Seasons from November 2015 to October 2016 compared to wave heights and rainfall.

Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods respectively.

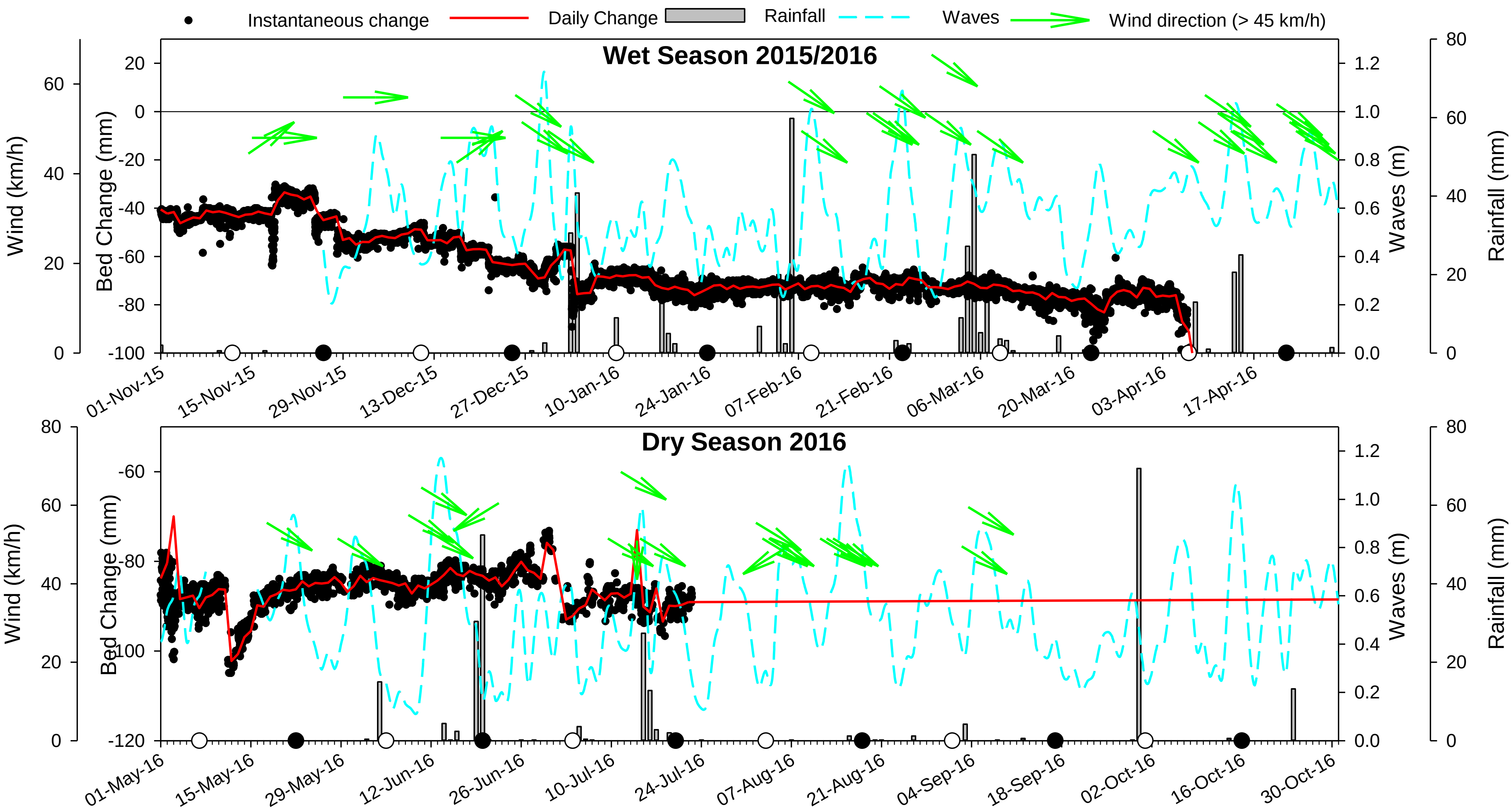

Figure 40 Mean instantaneous bed level change and daily cumulative bed level change at AMB2 during the 2015/2016 Wet and 2016 Dry Seasons from November 2015 to October 2016 compared to wave heights and rainfall.
Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods respectively.

3.5.3 Cumulative Bed Level Change

The cumulative changes in bed level over the Wet Season and the Dry Season have been calculated (Table 15). Seasonal values were calculated using the last value of the previous season (e.g. 31 October 2015 and 30 April 2016) and subtracting from the last value of the season in question. As two altimeters were deployed at each site, means and standard errors were calculated where available. At both AMB1 and AMB2 sites, erosion was recorded during each season. Erosion was highest during the Wet Season at AMB2, and Dry Season at AMB1.

Table 15 Net Bed Level Change statistics from data collected from altimeters deployed AMB1 and AMB2 from October 2015 to October 2016.
Values are means ± se (n = 182 for wet season and 184 for dry season.) Note Wet Season bed level changes used 31 October 2015 bed level values as Baseline for calculations. Dry Season bed level changes used 30 April 2016 bed level values as Baseline for calculations.

Site	Net bed level change (mm)	
	Wet Season	**Dry Season**
AMB1	-17 ± 10	-47 ± 9
AMB2	-112 ± 2	-5 ± 0

GRBMPA have provided a sedimentation guideline trigger value of a maximum mean annual value of 3 mg/cm^2/day and a daily maximum of 15 mg/cm^2/day, based on sediment traps used in experimental and field conditions (De'ath and Fabricius, 2008, GBRMPA, 2010), which are likely not very applicable to altimeter data. However, as net erosion has been recorded at AMB1 and AMB2 to date and the trigger value is applicable to deposition data only, the GBRPMA trigger values have not been exceeded.

3.6 Water Sampling

Water sampling was undertaken during the January, May, July and October 2016 surveys. A summary of QA/QC across the four surveys can be found in the Appendix. Nutrient and chlorophyll *a* concentrations from all four surveys are listed in Table 16, and depicted in Figure 41.

Concentrations of nutrients during the January 2016 sampling were generally not quantified due to the high limits of reporting (LOR) provided by the analytical laboratory during this occasion. The LOR were lowered during subsequent surveys at VE request.

With the exception of AMB5 during January 2016, phosphorus forms at all sites during all surveys were below laboratory LOR. The anomalously high total phosphorus at AMB5 during January may be due to sample contamination or a laboratory error, as subsequent results were consistently low.

When laboratory LOR were lower in May and July 2016, total nitrogen was detected at concentrations lower than the QWQG of 140 µg/L at all sites, similar to previously recorded concentrations (Worley Parsons, 2014). However, concentrations during October were higher than the QWQG at all sites. Monitoring in January 2017 will determine whether elevated nitrogen during the wet season occurs at Abbot Point. Total Kjeldahl Nitrogen (TKN) concentrations were similar to total nitrogen concentrations, indicating that nitrogen was predominantly in an organic form, thus not readily bioavailable.

Ammonia was recorded at very high concentrations (at least five times the QWQG) at all sites (excluding AMB5 – no value obtained) during January 2016. As ammonia concentrations in April and July 2016 were < 5 µg/L, these results should be treated with caution. The January 2016 concentrations may have been erroneous due to sample contamination or a laboratory error, although it has been noted that several ammonia concentrations recorded in a previous monitoring program in January 2014 reached concentrations as high as 200 µg/L (Worley Parsons, 2014). Generally concentrations of this magnitude across all sites, indicates laboratory error. October 2016 results ranged from <5 to 18 µg/L, suggesting along with the total nitrogen results, that elevated nitrogen may be present during the Wet Season. A similar result was evident for nitrogen oxide (NOx) concentrations. Continued monitoring in January 2017 will determine whether this is the case.

Chlorophyll *a* was detected at all sites during the latter three surveys when LOR were lowered. Concentrations were highest during October 2016, with concentrations at AMB2 and AMB4 exceeding the QWQG of 0.45 µg/L. Chlorophyll *a* concentrations are generally stimulated by increased temperature, light and nutrients (Popovich and Marcovecchio, 2008), with elevated concentrations usually found in the summer months. Concentrations during the January 2017 survey are predicted to be higher than the October 2016 concentrations. Despite its close proximity to potential run off from aquaculture facilities and wetlands, concentrations of nutrients at AMB3 were within range of other sites.

Water sampling for TSS, dissolved metals and organics was undertaken during the January and July 2016 surveys (Table 17). With the exception of TSS concentrations at AMB1 and AMB4 in January (3 mg/L), concentrations were less than or equal to the QWQG of 2 mg/L.

Of the dissolved metals, only arsenic was detected across the sites during both surveys. Concentrations (1.2 to 2 µg/L) were similar to previously recorded concentrations (Worley Parsons, 2014), suggesting perhaps a regionally specific natural geological dominance. All other dissolved metal concentrations were below LOR, and therefore well below the 95% AWQG trigger level.

All concentrations of hydrocarbons, BTEXN and herbicides were below LOR at each site where monitored during each survey (Table 18), similar to previously recorded concentrations (Worley Parsons, 2014).

Table 16 Concentrations of nutrients and chlorophyll *a* at AMB1 to AMB6 during January, May, July and October 2016.
Values exceeding the QWQG are highlighted in blue. Note that no results were available for certain nitrogen parameters at AMB5 in January due to bottle breakages during transit to the laboratory. Note the higher LOR provided by the laboratory during the January 2016 sampling.

Parameter	Month	Site						QWQG
		AMB1	AMB2	AMB3	AMB4	AMB5	AMB6	
Total Phosphorus (µg/L)	January	<50	<50	<50	<50	180	<50	20
	May	<5	<5	<5	<5	<5	<5	
	July	<5	<5	<5	<5	<5	<5	
	October	<5	<5	<5	<5	<5	<5	
Orthophosphate (µg/L)	January	<10	<10	<10	<10	<10	<10	6
	May	<1	<1	<1	<1	<1	<1	
	July	<1	<1	<1	<1	<1	<1	
	October	<1	<1	<1	<1	<1	<1	
Total Nitrogen (µg/L)	January	<500	<500	<500	<500	-	<500	140
	May	120	100	130	120	130	130	
	July	90	110	80	110	100	120	
	October	260	230	230	260	280	180	
Total Kjeldahl Nitrogen (TKN) (µg/L)	January	<500	<500	<500	<500	<1000	<500	-
	May	120	100	130	120	120	130	
	July	90	110	80	110	100	120	
	October	260	230	220	260	270	180	
Ammonia (µg/L)	January	50	50	20	40	-	90	4
	May	<5	<5	<5	<5	<5	<5	
	July	<5	<5	<5	<5	<5	<5	
	October	<5	8	14	<5	18	5	
NOx (Nitrite + Nitrate) (µg/L)	January	<10	<10	<10	<10	-	<10	3
	May	2	3	2	2	5	<2	
	July	<2	<2	<2	<2	3	<2	
	October	4	4	8	4	10	5	
Chlorophyll *a* (µg/L)	January	<1	<1	<1	<1	<2	<4	0.45
	May	0.19	0.18	0.25	0.30	0.45	0.22	
	July	0.20	0.26	0.32	0.32	0.10	0.21	
	October	0.34	0.61	0.41	0.50	0.18	0.28	

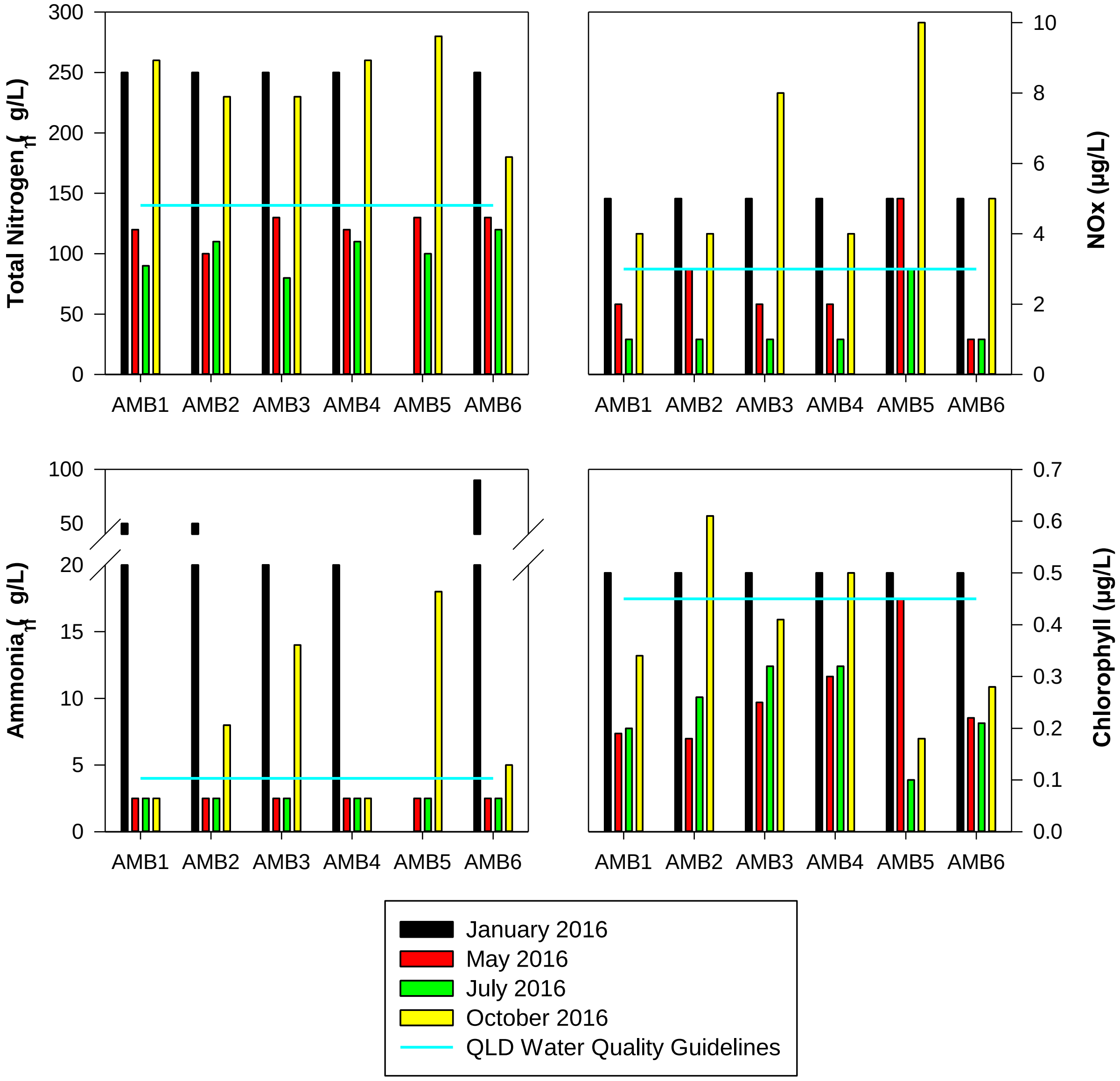

Figure 41 Concentrations of nutrients and chlorophyll *a* at AMB1 to AMB6 during January, May, July and October 2016.

Phosphorus forms not plotted as the majority of reliable results were < LOR. Values which were < LOR, were plotted as ½ LOR. Note that higher LOR were applicable for chlorophyll a concentrations in January 2016.

Table 17 Concentrations of TSS and dissolved metals at AMB1 to AMB6 during January and July 2016.
Values exceeding the QWQG or 95% AWQG are highlighted in blue. Note that no results available for certain TSS at AMB5 in January due to bottle breakages during transit to the laboratory.

Parameter	Month	Site						QWQG/ AWQG
		AMB1	AMB2	AMB3	AMB4	AMB5	AMB6	
Total suspended solids (mg/L)	January	3	2	<1	3	-	2	2
	July	<1	1	1	<1	<1	1	
Arsenic (µg/L)	January	1.6	1.6	1.6	2.4	2	1.7	-
	July	1.3	1.2	1.2	1.3	1.2	1.3	
Cadmium (µg/L)	January	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	July	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Chromium (µg/L)	January	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	Cr(III) 27.4 Cr(VI) 4.4
	July	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Copper (µg/L)	January	<1	<1	<1	<1	<1	<1	1.3
	July	<1	<1	<1	<1	<1	<1	
Lead (µg/L)	January	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	4.4
	July	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Mercury (µg/L)	January	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.4
	July	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	
Nickel (µg/L)	January	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	70
	July	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Zinc (µg/L)	January	<5	<5	<5	<5	<5	<5	15
	July	<5	<5	<5	<5	<5	<5	

Table 18 Concentrations of hydrocarbons, BETXN and herbicides at AMB1, AMB2 and AMB4 during January and July 2016.

Parameter (µg/L)	Month	Site		
		AMB1	AMB2	AMB4
Total Recoverable Hydrocarbons				
C6 - C9 Fraction	January	<20	<20	<20
	July	<20	<20	<20
C10 - C14 Fraction	January	<50	<50	<50
	July	<50	<50	<50
C15 - C28 Fraction	January	<100	<100	<100
	July	<100	<100	<100
C29 - C36 Fraction	January	<50	<50	<50
	July	<50	<50	<50
C10 - C36 Fraction (sum)	January	<50	<50	<50
	July	<50	<50	<50
C6 - C10 Fraction	January	<20	<20	<20
	July	<20	<20	<20
C6 - C10 Fraction minus BTEX (F1)	January	<20	<20	<20
	July	<20	<20	<20

Parameter (µg/L)	Month	Site		
		AMB1	AMB2	AMB4
>C10 - C16 Fraction	January	<100	<100	<100
	July	<100	<100	<100
>C16 - C34 Fraction	January	<100	<100	<100
	July	<100	<100	<100
>C34 - C40 Fraction	January	<100	<100	<100
	July	<100	<100	<100
>C10 - C40 Fraction (sum)	January	<100	<100	<100
	July	<100	<100	<100
>C10 - C16 Fraction minus Naphthalene (F2)	January	<100	<100	<100
	July	<100	<100	<100
BETXN				
Benzene	January	<1	<1	<1
	July	<1	<1	<1
Toluene	January	<2	<2	<2
	July	<2	<2	<2
Ethylbenzene	January	<2	<2	<2
	July	<2	<2	<2
meta- & para-Xylene	January	<2	<2	<2
	July	<2	<2	<2
ortho-Xylene	January	<2	<2	<2
	July	<2	<2	<2
Total Xylenes	January	<2	<2	<2
	July	<2	<2	<2
Sum of BTEX	January	<1	<1	<1
	July	<1	<1	<1
Naphthalene	January	<5	<5	<5
	July	<5	<5	<5
Herbicides				
Hexazinone	January	<0.20	<0.20	<0.20
	July	<0.02	<0.02	<0.02
Metribuzin	January	<0.20	<0.20	<0.20
	July	<0.02	<0.02	<0.02
Diuron	January	<0.20	<0.20	<0.20
	July	<0.02	<0.02	<0.02
Fluometuron	January	<0.10	<0.10	<0.10
	July	<0.01	<0.01	<0.01
Tebuthiuron	January	<0.20	<0.20	<0.20
	July	<0.02	<0.02	<0.02
Bromacil	January	<0.20	<0.20	<0.20
	July	<0.02	<0.02	<0.02
Chlorsulfuron	January	<2.0	<2.0	<2.0
	July	<0.20	<0.20	<0.20
Ametryn	January	<0.10	<0.10	<0.10
	July	<0.01	<0.01	<0.01
Atrazine	January	<0.10	<0.10	<0.10
	July	<0.01	<0.01	<0.01
Cyanazine	January	<0.20	<0.20	<0.20
	July	<0.02	<0.02	<0.02
Cyromazine	January	<0.50	<0.50	<0.50
	July	<0.05	<0.05	<0.05

Parameter (µg/L)	Month	Site		
		AMB1	AMB2	AMB4
Prometryn	January	<0.10	<0.10	<0.10
	July	<0.01	<0.01	<0.01
Propazine	January	<0.10	<0.10	<0.10
	July	<0.01	<0.01	<0.01
Simazine	January	<0.20	<0.20	<0.20
	July	<0.02	<0.02	<0.02
Terbuthylazine	January	<0.10	<0.10	<0.10
	July	<0.01	<0.01	<0.01
Terbutryn	January	<0.10	<0.10	<0.10
	July	<0.01	<0.01	<0.01

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5. Appendix

Table 19 Summary of water sampling QA/QC.

Report number	**EB1600614**	**EB1611709**	**EB1618732**	**EB1626176**
Date samples collected	7 to 9 January	2 to 4 May 2016	22 to 23 July	27 & 31 October, 1 November
Date of Sample Analysis	12 to 19 January 2016 *Note that nutrient samples were frozen prior to dispatch to the laboratory, thus prolonging their holding period.*	9 to 10 May 2016 *Note that nutrient samples were frozen prior to dispatch to the laboratory, thus prolonging their holding period.*	28 July to 1 August *Note that nutrient samples were frozen prior to dispatch to the laboratory, thus prolonging their holding period.*	*Note that nutrient samples were frozen prior to dispatch to the laboratory, thus prolonging their holding period*
Laboratory blank concentration	Acceptable *Note that detectable concentrations of TSS were found in both the field and laboratory blank, indicating suspended particles were present in the freshwater solution provided for analysis (VE MilliRO® unit). Although not due for exchange at the time the unit filter has since been changed. Results were not affected.*	Acceptable *Except for the detectable concentrations of total nitrogen and total kjeldahl nitrogen*	Acceptable	Acceptable
Field blank concentration	Acceptable *Note that detectable concentrations of TSS were found in both the field and laboratory blank, indicating suspended particles were present in the freshwater solution provided for analysis (VE MilliRO® unit). Although not due for exchange at the time the unit filter has since been changed. Results were not affected.*	Acceptable	Acceptable	Acceptable *Except for detectable concentrations of total nitrogen and total kjeldahl nitrogen*

Report number	EB1600614	EB1611709	EB1618732	EB1626176
Relative Percent Deviation (RPD) for duplicate field sample	Acceptable *Except for ammonia concentrations which varied markedly between the duplicate samples indicating heterogeneity of the ambient water samples.*	Acceptable	Acceptable	Acceptable *Except for ammonia concentrations which varied markedly between the duplicate samples indicating heterogeneity of the ambient water samples.*
Laboratory method blanks	Acceptable	Acceptable	Acceptable	Acceptable
RPD Laboratory duplicate	Acceptable	Acceptable	Acceptable	Acceptable
Recovery from laboratory control sample (LCS)	Acceptable	Acceptable	Acceptable	Acceptable
Recovery from matrix spike (MS) sample	Acceptable	Acceptable	Acceptable	Acceptable