Tionscadal Soláthair Uisce
Water Supply Project

Environmental Impact Assessment Report (EIAR)

Volume 6 of 6: Appendices

(Appendix A9.1) Abstraction Assessment

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Acronyms and Abbreviations

Abbreviation	Meaning
AWB	Artificial Water Body
BOD	Biochemical Oxygen Demand
BPS	Booster Pumping Station
CHL	Chlorophyll-*a*
DHLGH	Department of Housing, Local Government and Heritage
DO	Dissolved Oxygen
DWPA	Drinking Water Protected Area
EDEN	Environmental Data Exchange Network
EIAR	Environmental Impact Assessment Report
EPA	Environmental Protection Agency
EQS	Environmental Quality Standard
ESB	Electricity Supply Board
HMWB	Heavily Modified Water Body
mAOD	Metres Above Ordnance Datum
NH3-N	Ammonia
NO3-N	Nitrate
NOB	Normal Operating Band
NWRP	National Water Resources Plan
ORS	Old River Shannon
PoMs	Programme of Measures
PO4-P	Orthophosphate
RBMP	River Basin Management Plan
RWI&PS	Raw Water Intake and Pumping Station
SAC	Special Area of Conservation
SPA	Special Protection Area
UKTAG	UK Technical Advisory Group
WFD	Water Framework Directive
WQMS	Water Quality Monitoring Station
WTP	Water Treatment Plant

1. Introduction

1. This appendix assesses the potential likely significant effects of the Operational Phase impacts of the Proposed Project on the surface water environment because of the proposed abstraction at Derg Heavily Modified Water Body (HMWB). No construction impacts or maintenance related impacts are considered in this appendix. Any likely significant effects of the impacts as a result of abstraction during the Construction or Commissioning Phases of the Proposed Project are addressed in the Water Status Impact Assessment Report.

2. The likely significant effects of the construction of the Proposed Project at the Raw Water Intake and Pumping Station (RWI&PS) are considered in Appendix A9.3 (Non-Linear Principal Infrastructure and 38 kV Uprate Works Assessment). These effects are also examined in the Water Status Impact Assessment Report.

3. Section 5 of this appendix details any mitigation measures to avoid, reduce or mitigate likely significant effects related to the operational impacts of the proposed abstraction at Derg HMWB (Parteen Basin).

4. This appendix forms part of, and is intended to be read alongside, Chapter 9 (Water). Other appendices associated with Chapter 9 include:
    - Appendix A9.2 (Pipeline Assessment)
    - Appendix A9.3 (Non-Linear Principal Infrastructure and 38 kV Uprate Works Assessment)
    - Appendix A9.4 (Flood Risk Assessment)
    - Appendix A9.5 (Baseline)
    - Appendix A9.6 (Laboratory Analysis and In Situ Results)
    - Appendix A9.7 (EPA Monitoring Information).

5. This appendix should also be referred to alongside the Water Status Impact Assessment Report.

6. The Proposed Project involves a projected peak raw water abstraction of 300Mld (with a maximum flow of 3.47m^3/s) at the year 2050. This peak abstraction rate is only envisaged to be approached during periods of major drought in the east, which may or may not coincide with major drought in the Shannon Basin.

7. Further details of the Proposed Project are provided in Chapter 4 (Proposed Project Description) and Appendix A4.1 (Operational Strategy).

2. Study Area

8. This assessment is limited to surface water receptors only. For the purposes of this assessment, a water environment receptor is any surface water receptor, regardless of designation, that is potentially affected by operation of the abstraction regime. Groundwater is assessed separately in Chapter 10 (Soils, Geology & Hydrogeology) of this Environmental Impact Assessment Report (EIAR) and in the Water Status Impact Assessment Report.

9. The study area is shown in A9.1 Figure 1 and the WFD-designated water bodies are listed in Table 3.1.

10. The 'upstream limit' of the study area is determined to be Meelick Weir, which acts as a boundary by virtue of its hydraulic control, with the upstream and downstream reaches of the Shannon. The Meelick Weir and the Corclough Bridge on Incherky are points of hydraulic control, which entirely partition the whole Shannon upstream from activities at the Derg TN (Lough Derg) and the Derg HMWB (Parteen Basin). It should be noted that the Derg TN is hydrologically connected upstream of the Derg HMWB and they are effectively part of the same lake but are divided under the WFD.

11. The Shannon (Lower)_030 at Meelick is regulated by a long weir on the Main Channel operated by Waterways Ireland, to maintain minimum navigation levels between Athlone and Meelick. Navigation around this weir is managed via the Victoria Lock which is served by a side channel of Shannon (Lower)_030 from the upstream side of Meelick Weir, returning to the main channel downstream where it converges with Incherky_010. Incherky_010 is crossed by a bridge at Corclough which also incorporates sluice gates at Clonahenoge. That channel is divided into smaller channels upstream, fed by Shannon (Lower)_020. Examination of these points has shown that flow and water level at these locations is determined only by conditions upstream, and not those occurring downstream.

12. There is free fall of water over Meelick Weir at medium and low flows, and so changes to the water levels of Lough Derg (Derg TN) have no influence on water levels upstream of Meelick Weir. This therefore sets the upper limit of physical influence for water levels in Lough Derg (Derg TN) (i.e. it is not physically possible for water levels in Lough Derg (Derg TN), in low and medium flows, to influence water levels upstream of Meelick Weir).

13. The 'downstream limit' of the study area is the confluence of the Shannon (Lower)_060 (Limerick Dock) and the Ardnacrusha Tailrace (North Ballycannan_010) at Limerick Dock. The diurnal tidal influence on water levels and flows at this point mean that any change in the Tailrace flow would be imperceptible in Limerick Dock at the confluence.

14. Between the up and downstream limits, the study area includes a number of WFD water bodies, including:

    - Shannon (Lower)_030 (which feeds into the Derg TN): as far as Meelick Weir
    - Derg TN (Lough Derg): the whole lake is included
    - Derg HMWB (Parteen Basin): the whole water body is included
    - Numerous tributaries feed into the Derg TN and the Derg HMWB: for the purposes of this assessment, the upstream limits of these tributaries has been determined to be immediately upstream of their confluence with the lakes. This is because the water level at their confluence with the Derg TN and the Derg HMWB is determined by the water levels in the respective lakes and there would be no impacts further upstream. There would also be no impact on the watercourses that feed into the Derg HMWB above the upper water level limit of the Normal Operating Band (NOB) (described in Section 3.2.2)
    - The Ardnacrusha Canal: the Headrace and the Tailrace (North Ballycannan_010)
    - Shannon (Lower)_050, Shannon (Lower)_060 (River Shannon downstream of Parteen Weir) and Limerick Dock, to its confluence with the Tailrace (North Ballycannan_010)
    - Bridgetown (Clare)_010 and Kilmastulla_050, which feed into the Tailrace and Shannon (Lower)_050 respectively.

3. Baseline Environment

3.1 Overview of Surface Water Receptors

15. The River Shannon is divided into the Upper Shannon and Lower Shannon, for the purposes of the Water Action Plan 2024 – A River Basin Management Plan (RBMP) for Ireland (Department of Housing, Local Government and Heritage (DHLGH) 2024) and Water Framework Directive (WFD) reporting. The Upper Shannon extends generally north from Shannonbridge; the Lower Shannon extends generally south from Shannonbridge to Limerick.

16. Within the Lower Shannon area, there are four catchments: Lower Shannon 25A to 25D. The study area for the Abstraction Assessment includes water bodies from three of these catchments: the Lower Shannon 25B, 25C and 25D. Lower Shannon 25A is not included in the study area as none of the water bodies within that catchment feed into the Derg TN or Derg HMWB.

17. The baseline conditions of relevant water bodies within these catchments are described in this section and include a catchment overview, and descriptions for water levels and flows where available, water quality and hydromorphology. The WFD ecological status (or potential) and the details of this status are also provided.

18. As part of the RBMP process, water bodies are assessed as to whether they are 'At Risk' of not meeting the WFD objectives by the end of the RBMP cycle. This assessment includes the identification of the significant pressures which contribute to current and future status of the water body sourced from their catchment assessments. These significant pressure categories include agriculture, hydromorphological changes, urban wastewater, forestry, domestic wastewater, urban runoff, peat and other extractive industries and mines and quarries.

19. There are two Nutrient Sensitive Areas (NSAs) within the study area (Lough Derg on the River Shannon (Lake) and Nenagh (River)). Of most relevance to the assessment is the Lough Derg on the River Shannon NSA, which encompasses both the Derg TN (Lough Derg) and Derg HMWB (Parteen Basin).

20. There are 28 WFD Water Bodies (including the Derg TN and the Derg HMWB) in the Lower Shannon 25B, 25C and 25D catchments (see A9.1 Figure 1), 24 of which discharge into the Derg TN or Derg HMWB. Table 3.1 provides a baseline overview of each of these based on information from the Environmental Protection Agency's (EPA's) catchments.ie website and the Environmental Data Exchange Network (EDEN). These details are drawn from the full list of surface water receptors potentially affected by the Proposed Project which is provided in Appendix A9.5 (Baseline).

Table 3.1: WFD Status and Significant Pressures of Sub-Catchment Water Bodies within the Study Area

Catchment (WFD Catchment Code)	Sub-Catchment Name (Code)	WFD Water Body Name	WFD Ecological Status (2019-2024)	Sub-Catchment Pressure Category	Receiving Water Body
Lower Shannon (25B)	25B_4 Shannon[Lower]_SC_050 25B_5 Shannon[Lower]_SC_060	Shannon (Lower)_030	Moderate	Anthropogenic Pressures	Derg TN
Lower Shannon (25C)	25C_10 Shannon[Lower]_SC_070 25C_11 Nenagh_SC_020 25D_6 Shannon[Lower]_SC_080	Derg TN	Moderate	Agriculture Hydromorphology Invasive Species	Derg HMWB
	25C_10 Shannon[Lower]_SC_070	Shannon (Lower)_040	Good	Pressures	Shannon (Lower)_050, Derg TN and Derg HMWB

Catchment (WFD Catchment Code)	Sub-Catchment Name (Code)	WFD Water Body Name	WFD Ecological Status (2019-2024)	Sub-Catchment Pressure Category	Receiving Water Body
Lower Shannon (25C)	25C_1 Youghal[Tipperary]_SC_010	Newtown_010	Good	No Pressure Impacts listed	Derg TN
		Youghal (Tipperary)_010	Moderate	Agriculture	Derg TN
		Ardgregane Stream_020	Moderate	Hydromorphology Agriculture Urban Run-off	Derg TN
	25C_11 Nenagh_SC_020	Nenagh_070	Moderate	Hydromorphology	Derg TN
		Clonmakilladuff_010	Moderate	Agriculture	Derg TN
	25C_9 Ballyfinboy_SC_010	Ballyfinboy_070	Poor	Agriculture Hydromorphology	Derg TN
	25C_7 Bow_SC_010	Woodford (Galway)_030	Moderate	Anthropogenic Pressures	Derg TN
		Derrainy_010	Good	Forestry	Derg TN
		Bow_010	Moderate	Hydromorphology	Derg TN
		Coos_010	Moderate	Agriculture	Derg TN
		Moannakeeba_East _010	Good	Agriculture Extractive Industry Forestry Domestic Wastewater	Derg TN
		Lower Village Trib_010	Good	Agriculture Forestry Domestic Wastewater	Derg TN
		South Boleynagoagh_010	Moderate	Anthropogenic Pressures	Derg TN
		Kilrateera_Upper_010	Good	Agriculture Forestry	Derg TN
	25C_3 Graney [Shannon]_SC_010	Graney (Shannon)_050	Moderate	Forestry Hydromorphology Urban Run-off	Derg TN
	25C_2 LorrhaStream_SC_010	Lorrha Stream_020	Poor	Agriculture Extractive Industry Invasive Species Hydromorphology	Derg TN
		Carrigahorig Stream_010	Poor	Agriculture	Derg TN
		Terryglass_010	Moderate	Agriculture	Derg TN
	25C_12 Kilcrow_SC_010	Kilcrow_070	Poor	Anthropogenic Pressures	Derg TN

Catchment (WFD Catchment Code)	Sub-Catchment Name (Code)	WFD Water Body Name	WFD Ecological Status (2019-2024)	Sub-Catchment Pressure Category	Receiving Water Body
Lower Shannon (25D)	25D_6 Shannon [Lower]_SC_080	Derg HMWB	Good	Agriculture	Shannon (Lower)_050
		Shannon (Lower)_050	Poor	Hydromorphology Anthropogenic Pressures	Derg HMWB and Shannon (Lower)_060
		Ardcloony_010	Good	Anthropogenic Pressures	Shannon (Lower)_050
		Grange (Tipperary)_010	Moderate	Hydromorphology Urban Wastewater	Derg HMWB
		Bridgetown (Clare)_010	Moderate	Hydromorphology Extractive Industry	Shannon (Lower)_050
		Kilmastulla_050	Moderate	Anthropogenic Pressures	Shannon (Lower)_050

3.2 Derg TN and Derg HMWB (Lower Shannon 25C and 25D)

3.2.1 Overview

21. The Derg TN (25C) and the Derg HMWB (25D) are described in this section of the appendix to provide a comprehensive understanding of lake management under the Electricity Supply Board (ESB). This is a critical aspect controlling baseline conditions.

22. The Lower Shannon (25C) catchment covers an area of 1,820km² and comprises the Derg TN and its catchment (see A9.1 Figure 1). It is characterised by flat limestone plains to the east of the Derg TN, the uplands of the Devil's Bit Mountain in the south-east, the Slieve Aughty Mountains in the west and the Slieve Bearnagh and Arra Mountains in the south. The Derg TN narrows at Ballina and Killaloe and flows into the Derg HMWB and into the Shannon (Lower)_050 and _060 (Old River Shannon).

23. The Derg HMWB (see Image 3.1) lies immediately downstream of Derg TN. It is connected to Derg TN by a narrow channel between the towns of Killaloe and Ballina.

24. The Derg HMWB, also known locally as the Parteen Basin or 'Lower Lake', was constructed under the River Shannon Hydro-Electric Scheme in the late 1920s. It floods an area through which the River Shannon once flowed as a river, and the old channel is still recognisable in bathymetric/depth surveys of the bed of the flooded basin. More information on this is available in A9.1 Annex B (Water Quality Modelling Report).

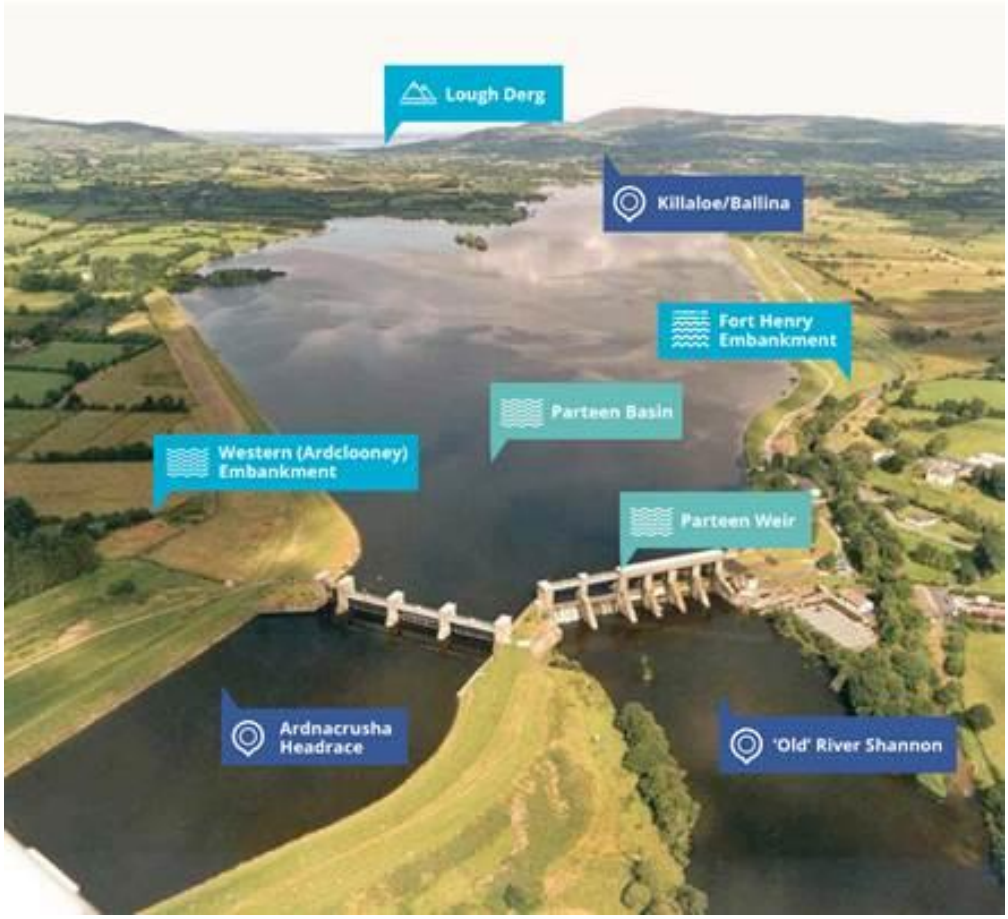

Image 3.1: Derg HMWB (Parteen Basin) (Photo Courtesy of ESB)

25. The entirety of the Derg TN is located within a designated Drinking Water Protected Area (DWPA) and both the Derg TN and the Derg HMWB are classified as NSAs. This Appendix assesses the effects of the abstraction on DWPAs and NSAs (see Section 6.2.2). A separate WFD compliance assessment of the effects of the proposed abstraction on DWPAs and NSAs is presented in the Water Status Impact Assessment Report. The WFD status of the Derg TN (2019 to 2024) is Moderate and of the Derg HMWB is Good. For an assessment of the impacts on these WFD designations, please refer to the Water Status Impact Assessment Report. In addition, the Derg TN falls within the Derg TN (Shannon) Special Protection Area (SPA) with the Derg HMWB and the Kilmastulla_050 forming part of the Lower River Shannon Special Area of Conservation (SAC) [002165].

26. The Derg TN and the Derg HMWB are fed by numerous WFD water bodies of varying sizes, the largest of which is the Shannon (Lower)_030 which enters the Lough at its most northerly point near Portumna. The network is complex. A number of settlements are present along the shores of the Derg TN, notably Portumna, Dromineer, Mountshannon, Ballina and Killaloe. Land use adjacent to the Lough is predominantly agricultural.

27. The Derg TN has Moderate WFD Status and is At Risk of not achieving good status due to significant pressures including agriculture, hydromorphology, invasive species and urban wastewater.

28. The Derg HMWB is currently achieving Good Ecological Status, but this has fallen from High Ecological Status in the last decade. The Derg HMWB has an objective to achieve (maintain) Good Ecological Potential. The water body is not at risk of not achieving its environmental objectives and no significant pressures have been identified.

29. The Parteen Weir, located at the southernmost extent of Lough Derg, controls the Lough outlet for the purpose of hydroelectricity production. Outflows from the Lough are those that flow into the Old River Shannon (ORS) channel (comprising a statutory minimum compensation flow of 10m^3/s (made up of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates) and flood releases/spills during periods of high flow), including the water that travels down the Ardnacrusha headrace to be used for electricity power generation and a small allowance (0.5m^3/s) for the Ardnacrusha fish pass.

3.2.2 Hydrological Baseline, ESB Operating Principles and the Hydrological Model

30. The current water levels and flows of Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) have been analysed and are described in detail in Annex A (Hydrological Modelling Report). The ESB operating regime for the Ardnacrusha Generating Station and Parteen Weir controls the levels and flows within both water bodies.

31. The ESB work to the Poolbeg datum, whilst the Hydrological Model developed for the Proposed Project has been set up to work to the Malin Head datum. Therefore, all lake water levels given here are with respect to Malin Head[1].

32. The ESB manage the water levels on Lough Derg (Derg TN) within the NOB. This band is defined using the following water levels:

    - Lough Derg (Derg TN) top of NOB level = 30.86mAOD (Above Ordnance Datum)
    - Lough Derg (Derg TN) bottom of NOB level = 30.40mAOD

33. On Parteen Basin (Derg HMWB) ESB keep water levels within an upper and lower water level, for dam safety purposes. These water levels are as follows:

    - Parteen Basin (Derg HMWB) upper water level = 30.86mAOD
    - Parteen Basin (Derg HMWB) lower water level = 30.00mAOD.

34. Parteen Weir acts as the downstream control structure for water levels in the system. Water levels in Parteen Basin are maintained within the upper and lower levels at all times. During low flow conditions, the lower water level at Parteen Basin (30.0mAOD Malin), must be maintained for dam safety purposes and in doing this ESB ensures that water levels on Lough Derg are within the NOB as the waterbodies broadly operate as a combined system, in these conditions.

35. The key ESB principles/rules governing the water level management of Derg TN and Derg HMWB are provided in Table 3.2. For a fuller description refer to Annex A (Hydrological Modelling Report).

Table 3.2: Key ESB Principles or Rules Governing the Management of Water Levels at Derg TN and Derg HMWB

General Principle or Rule	Description
Water level to be kept within the Lough Derg Normal Operating Band (NOB)	The ESB manages the water levels (as monitored at Killaloe) to be within the Lough Derg (Derg TN) NOB between 30.40 metres Above Ordnance Datum (mAOD Malin) and 30.86mAOD. During sufficiently big floods, the level of Lough Derg (Derg TN) cannot be prevented from exceeding the top of the NOB and the Flood Rule (see last row of this table) comes into effect.
Early summer Lough Derg level	A guide rather than a strict rule. It is understood that the ESB does not aim to be at 30.86mAOD at Killaloe but tend to the upper end around 30.80mAOD average[2] Lough Derg (Derg TN) level. This is subject to operational requirements which can mean, when there is sufficient water available, that they utilise the full operating band. It is understood ESB seek to have Derg water levels towards the upper end of the NOB in late spring/ early summer.

[1] To convert levels recorded to the Malin Head datum to the Poolbeg datum (in the vicinity of Lough Derg and Parteen Basin) a value of 2.70m needs to be added to the Malin Head level.

[2] Whilst the ESB Lough Derg top and bottom NOB levels are with respect to the levels monitored at Killaloe, the WSP hydrological model is based on the Lough Derg average water level calculated as the average of the levels recorded at Portumna and Killaloe.

General Principle or Rule	Description
Autumn and winter Derg level	A guide rather than a strict rule. ESB seek to have Lough Derg (Derg TN) water levels towards the lower end of the band in autumn and winter to allow ESB to have lake storage available to accommodate flood flows into the system.
Low flow regime	A guide rather than a strict rule. Lough Derg inflow of 100m^3/s on a falling hydrograph is a trigger to commence retaining water towards the upper end of the NOB.
Compensation flow	Statutory compensation flow of 10m^3/s is released to the Old River Shannon[3], and 0.5m^3/s is also released at the Ardnacrusha fish pass.
Flood rule	When Lough Derg (Derg TN) is greater than the top of the NOB (30.86mAOD) and inflow is greater than the maximum capacity of Ardnacrusha (i.e. greater than about 400m^3/s), then excess is released down the Old Shannon until the Parteen Basin (Derg HMWB) level does not go below 30.00mAOD.

3.2.3 Water Quality Baseline and Modelling

36. From 2015 to December 2023, monitoring took place at 15 locations across the Derg TN, the Derg HMWB and their tributaries, as part of the Lough Derg Monitoring Project, commissioned by Uisce Éireann. Automatic monitoring was carried out on water flows, levels and quality (specifically, nutrients and chlorophyll levels). Spot sampling was also carried out monthly to determine the treatability of the water. In July 2018, 11 of the automatic monitoring stations were decommissioned; these were largely measuring levels and water quality. From July 2018, there remains two nutrient analysers, one at Parteen Basin (Derg HMWB) and one at Portumna Bridge, and two weather stations, one at Balinderry and one at Whitegate. The majority of the automatic monitoring stations were decommissioned because the data they produced were mainly used to calibrate the water quality modelling being carried out for the Proposed Project; this was based on 2016 data and re-calibrated using 2018 data.

37. The monthly spot sampling continues for water treatability, and this is considered by the Design Team to ensure the RWI&PS and Water Treatment Plant (WTP) are designed appropriately to treat the abstracted water to the required drinking water standards. A9.1 Figure 2 details the locations of these 14 river monitoring locations which are labelled ‘WQMS_1’ to ‘WQMS_14’.

38. The quarterly (to 2017) and annual (2018-2023) reports are provided in Annex D (Summary Reports of Lough Derg Water Quality Monitoring May 2015 to December 2023) of this appendix. Details of the water quality modelling are provided in Section 4.3.

39. The results from the Lough Derg water quality monitoring were used to inform a water quality model and subsequent reporting to determine the potential environmental impacts of the Proposed Project on the water quality of the Derg TN and the Derg HMWB under extreme drought conditions. The model uses the summer of 2018 as its baseline water level as this has been identified as one of the most extreme drought periods experienced in Lough Derg (Derg TN) across historical records. Five scenarios were considered including the 2018 baseline scenario, against which the addition of the proposed abstraction could be measured. This approach is further described in summary in Section 4.3.2; the results are summarised in Section 6.2.1. Full details of the baseline monitoring and results are provided in Annex B (Water Quality Modelling Report) to this appendix.

40. Drought related risks are important in the context of WFD compliance as drought can lead to temporary deterioration in water body status. The drought modelling serves to understand the resilience of the water body and potential short-term risks posed by the Proposed Project under extreme hydrological stress. It is usual practice for Water Framework Directive (WFD) compliance to be based on long-term hydrological conditions and the use of Environmental Quality Standards (EQS) – typically expressed as mean or 95%ile concentrations – as metrics that are designed to reflect average or near worst-case conditions over extended periods of time. Drought conditions, such as those modelled here, fall outside of the conventional WFD hydrological assumptions and are not expected to meet EQS targets during such events. In order to contextualise the potential impact of a drought, water quality modelling results have

[3] Formed of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates

been presented using the 95%ile metrics for reference only and are not intended to imply that compliance with WFD standards is expected or required under drought conditions. WFD EQS are based on long-term average and percentile concentrations, and while drought conditions may influence mean values, 95%ile thresholds are typically less impacted.

3.2.4 Hydromorphology

41. Much of the Derg TN and the Derg HMWB are bordered by woodland. Around urban areas, private jetties and quays are present, as well as marinas, harbours and artificially reinforced banks, particularly at Ballina and Killaloe. Towards the south of Derg TN, a significant portion of the shore is managed, particularly around Parteen Weir where the shoreline has been artificially straightened and is covered by grasses.

42. Hydrographic baseline data for Derg TN (Water body IE_SH_25_191a) are provided in Annex E (Lough Derg Hydrographic Survey). Greatest depths were located 2.7km north-west of Garrykennedy. In general, the northern portion of the lake from Portumna to Mota was shallower and gently sloping. In contrast, a deep channel with steeply dipping sides is evident north of Killaloe and continuing to Garrykennedy. The 'drowned landscape' of the Derg HMWB, south of Killaloe, is evident, showing the 1929 river channel and Killaloe Canal. Bathymetric data from the survey were used to create a lakebed elevation for the Derg TN; elevations were found to range from 29.8mAOD to -6.0mAOD (levels in metres Above Ordnance Datum refer to the Malin Head Ordnance Datum, unless otherwise stated).

3.3 Inflow – Tributaries to Derg TN and Derg HMWB (Lower Shannon 25B, 25C and 25D)

3.3.1 Shannon (Lower)_030 (25B)

43. The Shannon (Lower)_030 at Meelick Weir represents the 'upstream limit' of the study area. From Meelick Weir, the river flows south-west for approximately 15km into the Derg TN at Portumna.

44. This catchment covers an area of 982km² and is characterised by a wide flat plain underlain by mostly impure limestones with a band of purer karstified limestone running from Fivealley to Ballingarry and an upland region in the east comprising the western slopes of the Slieve Bloom Mountains and the low hills to the south-west of Roscrea. There are extensive sand and gravel deposits around Roscrea and Birr that form productive groundwater aquifers.

45. Water levels and flows in Shannon (Lower)_030 are controlled by ESB management of sluices upstream in Athlone.

46. Water levels at Portumna Bridge immediately upstream of the Derg TN are monitored by ESB. This monitoring station has been in place for many years. Data from 1932 to 2023 have been obtained from ESB and used to model the impacts of the Proposed Project on the water body.

47. Using these data, the inflow to the Derg HMWB has been calculated. The calculated inflows include a number of variables and water body inflows, and so cannot be attributed to a single water body. To address this, the calculated inflows are collectively provided under the baseline for the Derg TN and the Derg HMWB.

48. The Shannon (Lower)_030 has 'Moderate' ecological status (2019 to 2024) and its at risk status is currently 'under review' by the EPA to determine its ecological status as well as if any anthropogenic pressures are present.

49. Shannon (Lower)_030 is in the Shannon Callows SPA, River Shannon Callows SAC and the River Shannon Callows Proposed Natural Heritage Area.

50. The catchment of the Shannon (Lower)_030 is rural with predominant land uses being pasture and peat cutting. It has a wide floodplain regularly inundated by flood water during high intensity or prolonged rainfall events. Flooding across the floodplain is more extensive and more frequent in vicinity to and upstream of Banagher. Whilst inundated, multiple secondary channels and backwaters to the Shannon (Lower)_030 are in use.

51. The planform of the water body is meandering and commonly splits into multiple threads separated by river islands and large vegetated mid-channel bars. The main channel has been heavily modified for navigation, with weirs, sluices and locks present along artificially straightened reaches. Large weirs, sluices and locks are present along the straightened channels between the Derg TN and Shannonbridge.

52. Consequently, the main channel has limited morphological features within the current channel. It has a uniform cross-section and simple vegetated riparian zones. A range of morphological features is present within the secondary channels. Features such as mid-channel bars, river islands, small point bars and backwaters have been noted and provide morphological diversity and a variation in channel dimensions and to the cross-sectional shape. The riparian zone with secondary channels is vegetated by a similar assemblage of grass, shrubs and trees. Trees were recorded as occupying a greater area of the riparian zone close to the secondary channels.

53. Analysis of historical maps from 1837 shows short lengths of modification, particularly along artificial canal sections. There is evidence of small multiple islands where larger islands are currently present, suggesting growth and/or merger of islands. Significant modifications have been made since 1837 to the channel downstream of Banagher where an approximately 327m wide weir has been constructed across the main channel of the water body as well as a 750m navigation canal with locks.

3.3.2 Other Tributaries of Derg TN and Derg HMWB

54. There are numerous WFD water bodies which are direct tributaries to either Derg TN or Derg HMWB (see Table 3.1).

55. The Bridgetown (Clare)_010 and Kilmastulla_050 do not flow into Derg TN or Derg HMWB; they flow directly into the Tailrace (North Ballycannan_010) and Shannon (Lower)_050 respectively. Shannon (Lower)_050 is both a tributary to Derg HMWB and the receiving water body, due to the historical hydromorphological changes of the lower Shannon River. Therefore, it is considered in both the inflow and downstream flow sections.

56. With the exception of Kilmastulla_50 and Clare_10, these water bodies contribute to the water levels and flows of Derg TN and Derg HMWB. Equally, the water levels of Derg TN and Derg HMWB influence the water level and flow of these inputting water bodies as the water levels at the confluences of the tributaries of the Derg TN and the Derg HMWB are controlled by the level of Derg TN and Derg HMWB either directly or indirectly.

57. Whilst the water quality of these inputting water bodies has the potential to influence water quality of Derg TN and Derg HMWB, there is limited potential for alterations in water quality of Derg TN and Derg HMWB to impact the water quality of these inputting water bodies. This is because these contributing tributaries are upstream of the Derg TN and Derg HMWB but there may be some interactions at the confluences where these tributaries meet the Derg TN and Derg HMWB.

58. The WFD status of each of these various tributaries are outlined in Table 3.1. The significant pressures listed on the EPA's EDEN Portal and catchments.ie website which are potentially contributing to the water bodies not achieving their environmental objectives are also listed. In terms of assigning sensitivities, as Derg HMWB and Kilmastulla_050 are within the Lower River Shannon SAC, all water bodies are considered to be hydrologically connected to this SAC.

59. A hydromorphology baseline has been developed for these tributaries as part of a desktop study. Table 3.3 provides a high-level overview of the hydromorphological baseline based on water bodies which have been grouped together with similar characteristics as outlined in the desk study. A separate walkover has been undertaken to support data obtained in desk studies for a selection of water bodies.

Table 3.3: Summary of Hydromorphological Characteristics of Water Bodies Feeding into Derg TN and Derg HMWB

WFD Water Body Name	Baseline Summary
Newtown_010, Kilrateera_Upper_010	The Newton_010 and Kilrateera_Upper_010 are WFD designated water bodies of Good status. The water bodies form a low to moderately sinuous planform flowing from west to east prior to discharge to the Derg TN. The channels vary in width over their length. Riparian vegetation is present on both banks over most of the length which makes further characterisation from imagery difficult. However, the sinuous planform and variation in channel widths indicate morphologically active water bodies. Modifications include existing road crossings and potential realignment/straightening in sections to follow field boundaries.
Youghal (Tipperary)_010, Bow_010	The Youghal (Tipperary)_010 and Bow_010 are WFD designated water bodies of Moderate status. They form a low to moderately sinuous planform flowing from west to east prior to discharge to the Derg TN. Both channels vary in width over their length. Riparian vegetation is present on both banks over most of the channel length which makes further characterisation from imagery difficult. However, the sinuous planform and variation in channel width indicates morphologically active water bodies. Modifications include existing road crossings and potential realignment/straightening in sections to follow field boundaries.
Clonmakilladuff_010, South Boleynagoagh_010	The Clonmakilladuff_010 and South Boleynagoagh_010 are WFD designated water bodies of Moderate status. The water bodies form a straight and narrow platform, with no distinct morphological features or process, flowing east to west prior to discharge to the Derg TN. Modifications include existing road crossings and realignment/straightening in sections to follow field boundaries.
Coos_010	The Coos_010 is a WFD designated water body of Moderate status. The water body forms a low to moderately sinuous planform flowing from west to east prior to discharge to the Derg TN. Multiple tributaries feed into the main stem channel within the catchment. The channel varies in width over its length. Riparian vegetation is present on both banks over most of the channel length which makes further characterisation from imagery difficult. However, the planform and variation in channel width indicate a morphologically active water body. Modifications include existing road crossings and potential realignment/straightening in sections to follow field boundaries.
Moannakeeba_East_010, Lower Village Trib_010	The Moannakeeba_East_010 and Lower_Village_Trib_010 are WFD designated water bodies of Good status. The water bodies form a straight and narrow planform with limited morphological features and processes visible, flowing from west to east prior to discharge to the Derg TN. Riparian vegetation is present on both banks over most of the channel length. Modifications include existing road crossings and likely realignment/straightening in sections to follow field boundaries.
Graney (Shannon)_050	The Graney (Shannon)_050 a WFD designated water body of Moderate status. The water body forms a low sinuosity and narrow planform with limited morphological features and processes visible, flowing from west to east prior to discharge to the Derg TN. Within the upper catchment the water body discharges to a small lake from which it flows from the southern extents towards Lough Derg. Riparian vegetation is present on both banks over most of the channel length. Modifications include existing road crossings, offtake to form a small harbour for pleasure craft, and likely realignment/straightening in sections to follow field boundaries.
Lorrha Stream_020, Carrigahorig Stream_010	The Lorrha Stream_020 and Carrigahorig Stream_010 are WFD designated water bodies of Poor status. The water bodies form a straight and narrow planform with limited morphological features and processes visible, flowing from east to west prior to discharge to the Derg TN. Riparian vegetation is present on both banks over most of the channel length. Modifications include existing road crossings and likely realignment/straightening in sections to follow field boundaries.
Shannon (Lower)_030, Ardgregane_020, Nenagh_070, Woodford_030, Terryglass_010, Grange (Tipperary)_010	The listed water bodies are WFD designated water bodies of Moderate status. The water bodies display a low to moderately sinuous planform and vary their channel width over their length. Riparian vegetation lines both banks of each watercourse; where riparian vegetation thins, small reaches of active bank erosion are visible. This, alongside the sinuosity and width variations, suggest morphologically active water bodies.
Ballyfinboy_070, Kilcrow_070	The listed water bodies are WFD designated water bodies of Poor status. The water bodies display a low to moderately sinuous planform and vary their channel width over their length. Riparian vegetation lines both banks of each watercourse; where riparian vegetation thins, small reaches of active bank erosion are visible. This, alongside the sinuosity and width variations, suggest morphologically active water bodies.
Shannon (Lower)_040, Derrainy_010, Ardcloony_010	The listed water bodies are WFD designated water bodies of Good status. The water bodies display a low to moderately sinuous planform and vary in channel width over their length. Riparian vegetation lines both banks of each watercourse; where riparian vegetation thins, small reaches of active bank erosion are visible. This, alongside the sinuosity and width variations, suggest morphologically active water bodies.

WFD Water Body Name	Baseline Summary
Shannon (Lower)_050	The Shannon (Lower)_050 is a WFD designated water body of Poor status. The main stem of the Shannon (Lower)_050 starts downstream of Parteen Weir (the mechanism which controls outflows from the Derg HMWB). From here it flows south and is modified to form the Ardnacrusha Headrace which feeds a hydroelectric plant. Displays a low sinuosity planform with limited morphological features and processes.

3.4 Forward Flow – Downstream of Parteen Weir and Tributaries to Derg HMWB

3.4.1 Shannon (Lower)_050 and Shannon (Lower)_060 (Lower Shannon 25D) (The Old River Shannon)

60. Lower Shannon 25D is predominantly a rural catchment, covering an area of 1,820km². Land use is a mixture of pasture and unimproved grasslands, with occasional coniferous plantations also present. Wet flood meadows, rough pasture and bogs are found in the west and south of the catchment. The Lower Shannon 25D also includes the Shannon (Lower)_050 and the Shannon (Lower)_060, tributaries of the Kilmastulla River as well as tributaries to Derg HMWB (a number of which are classified as part of the Shannon (Lower)_050 water body). The two water bodies Shannon (Lower)_050 and Shannon (Lower)_060 are collectively known as the 'Old River Shannon' locally and referred to as such in this appendix when both lengths of the river are discussed simultaneously.

61. ESB provided flow records from 1932-2023 from Ardnacrusha Generating Station and over Parteen Weir into the Shannon (Lower)_050. The river here receives a statutory compensation flow of 10m^3/s including 0.7m^3/s which passes through the fish pass at Parteen Weir; 0.5m^3/s is also released at the fish pass at Ardnacrusha. The flow over Parteen Weir typically remains at this value until the Ardnacrusha Generating Station reaches capacity at or near 400m^3/s. Once the total flow entering the Derg HMWB exceeds 400m^3/s, and the water level is continuing to rise above 30.0mAOD (minimum level in Parteen Basin (Derg HMWB)), any excess water is released over Parteen Weir and down the Shannon (Lower)_050 and Shannon (Lower)_060. Further details on flows over Parteen Weir are provided in Annex A (Hydrological Modelling Report).

62. Currently, the Shannon (Lower)_050 is classified as achieving Poor status and fails to achieve Good status due to various anthropogenic pressures. The Shannon (Lower)_060 is classified as having Moderate status.

63. The Shannon (Lower)_050 and Shannon (Lower)_060 (Old River Shannon) water bodies form a large meandering watercourse which begins at Parteen Weir and discharges into the tidal Limerick Dock. The catchment is typically rural with four larger urban areas alongside the channel banks: Castleconnell, Castletroy, Westbury and Limerick. Land use consists predominantly of pasture with woodland plantations and peat cuttings occupying a small area north of Castleconnell.

64. The water body has been highly modified to include the construction of Ardnacrusha Headrace in 1922 and the construction of weirs upstream of Limerick (date unknown). The water bodies are impacted by controlled flow regimes but have enough flow to maintain morphological diversity. Vegetated mid-channel bars and river islands are present along lengths of the channel in both water bodies. The former is especially common in the Shannon (Lower)_060, to the south of Doonass and north-west of Castletroy. These features, indicated by the colonisation by vegetation, suggests the channel has stabilised and is in equilibrium with the flow and sediment regime dictated by the statutory minimum compensation flow volume. In these areas, alluvial woodland has developed across the width of the channel section including growth on and between the river islands and bar forms.

65. Analysis of aerial imagery of reaches upstream and downstream of Doonass and Castleroy shows limited or no morphological features. The Shannon (Lower)_060 channel appears uniform and likely has a trapezoidal cross-section along these lengths. Short lengths of bank reinforcement at bridges and small structures such as jetties are also noted.

66. The riparian zone is vegetated by a semi-continuous woodland from Castleconnell to a point approximately 5km downstream. Trees are otherwise present through a narrow buffer, either as limited stands or as individual trees. Shrubs and grass are present in the absence of trees.

67. Analysis of the historic map from 1837 shows little evidence of channel adjustment or of significant channel modification. The islands and bars identified in aerial imagery south of Doonass and north-west of Castleroy are not depicted on the historical map, suggesting channel modification or deposition of material in these reaches. In 1837 a small area of Castleconnell is depicted as being an island separated from Castleconnell by an anabranch[4] of the ORS. Present day mapping shows a small stream passing along the old course of the anabranch.

68. In March 2022, the EPA published a Review of Ireland's Heavily Modified Water Body Designations for the Third Cycle RBMP (EPA 2022b). This document sets out the outcomes of a review of 466 water bodies to determine whether they meet the criteria for designation as HMWBs. Through this review, the Shannon (Lower)_050 and Shannon (Lower)_060 were identified in a provisional list of water bodies to be designated as heavily modified, as there are no measures available that can restore ecological status conditions without impacting water storage and regulation. This process/discussion is ongoing with the outcomes to the HMWB designation to be decided.

69. If the proposed designations were to be approved, the next steps would be to support the water bodies in achieving Good Ecological Potential through the River Basin Management Plan governance and WFD compliance. The current Water Action Plan 2024 identifies 11 different significant pressure categories for surface water bodies, one of these being pressures on Hydromorphology, which includes physical modifications to the flow, form or function of natural surface water bodies. The Water Action Plan 2024 sets out the following action for an existing Hydromorphology significant pressure on the Lower River Shannon:

    "Hymo 7: Implementation of the roadmap of actions, including the use of state-of-the-art technical solutions, to improve fish migration in the lower Shannon at the Hydroelectric scheme located around Parteen and Ardnacrusha. The pilot project will initially examine the feasibility of mitigation and will progress to the next stages, as appropriate"

70. The Water Action Plan 2024 roadmap of actions to improve fish migration in the Lower River Shannon and the Hydroelectric scheme located around Parteen and Ardnacrusha includes the following components:

    i) New fish pass at Parteen Weir

    ii) Environmental (Eflow) study programme

    iii) Tailrace barrier feasibility study

    iv) Downstream fish pass feasibility study

    v) New fish pass at Ardnacrusha Power Station feasibility study

    vi) Lower River Shannon Management Plan.

[4] An anabranch is a section of a river or stream that diverts from the main channel or stem of the watercourse and rejoins the main stem downstream.

71. In relation to step (ii), an outline Eflows[5] approach has been developed by a CDM Smith study[6]. The study proposes the use of a variable Eflows regime for the flows released down the ORS at Parteen Weir.

72. As part of the WSP hydrological modelling scope, a sensitivity analysis has been undertaken to test how the inclusion of the proposed Eflows regime to the ORS at Parteen Weir would be likely to impact the viability of the proposed WSP abstraction. To do this the WSP hydrological model has been codified to represent the proposed Eflows release regime rules from the CDM Smith study. Further details are provided in Annex A (Hydrological Modelling Report).

3.4.2 Ardnacrusha Canal – the Headrace and Tailrace (North Ballycannan_010)

73. The Ardnacrusha Canal was constructed in 1922. The Ardnacrusha Canal (both Headrace and Tailrace), like all canals in Ireland, is designated as an Artificial Water Body (AWB)[7]. It is therefore not classed as a HMWB.

74. Ardnacrusha Headrace is 'unmonitored' and so was omitted from the 2018 Catchment Summary for the Lower Shannon 25D, which states that there are no AWBs in the catchment[8].

75. The Tailrace section of Ardnacrusha Canal incorporates a WFD water body, North Ballycannan_010. The Tailrace flows from Ardnacrusha Generating Station into Limerick Dock. This confluence is tidally influenced.

76. The Headrace feeds approximately 90-95% of the average long-term flow from the River Shannon to the Ardnacrusha Generating Station. Further details of the flow regime at Ardnacrusha are provided in Annex A (Hydrological Modelling Report) which describes in detail the ESB Operating Principles for this power station.

77. The Headrace is a man-made canal and is managed for operation of the Ardnacrusha Generating Station. The Headrace is not identified as a WFD water body. The Headrace is unmonitored. The Tailrace (North Ballycannan_010) has a Poor WFD ecological status. North Ballycannan_010 is identified as being 'At Risk' due to various anthropogenic pressures.

78. From a hydromorphological perspective, the margins of the Headrace and Tailrace (North Ballycannan_010) are vegetated with trees, shrubs and tall grasses, and the canal is a man-made (heavily modified) water body. As described in detail above, the water levels in the canal are artificially controlled by ESB Ardnacrusha Generating Station.

3.4.3 Limerick Dock

79. Limerick Dock (IE_SH_060_0900) is a transitional water body designated as a HMWB between Corbally Road Bridge and the N18 bridge in Limerick. It includes Abbey River and Ballynaclough Creek.

80. Hydrological flow at Limerick Dock is seasonal, receiving an average of 180m^3/s from the Lower River Shannon.

[5] Environmental flows (Eflows) are considered within the context of the WFD as a hydrological flow regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies.

[6] CDM Smith (2025). Roadmap for the Lower River Shannon Report 2021. Provision of Expert Advisory Services Regarding Fish Migration in the Lower River Shannon Catchment. Prepared by CDM Smith for the Department of Housing, Local Government and Heritage (CDM Smith (2025). Fish Pass Feasibility Study)

[7] Water Action Plan 2024. A River Basin Management Plan for Ireland (DHLGH 2024)

[8] Confirmed by Email from EPA Catchment Team April 2019.

81. The WFD status of Limerick Dock is Poor (2019 to 2024), a reduction from moderate status in the last iteration. The EPA has determined Limerick Dock to be 'At Risk' of not achieving its environmental objectives under the WFD, due to hydromorphological pressures as a result of the port facilities bank reinforcement and the presence of weirs.

82. Limerick Dock is heavily modified with artificial banks along much of the reach upstream of Limerick. Limerick Dock is surrounded by urban land use.

83. The reach downstream of Limerick, except for Limerick Dock, is natural and bordered by tidal marsh. The presence of the tidal marsh is more extensive along the southern shoreline compared with the northern shoreline.

84. During low tides, morphologically valuable bedrock features downstream of Thomond Weir, side bars and a point bar composed of gravels, sand and silt (along the west bank at Clancy's Strand) are exposed. The exposure/development of these features is likely to be influenced by a reduction in sediment delivery due to channel regulation by Parteen Weir and other structures, as well as the diurnal tidal cycle. Much of the intertidal zone within Limerick is urbanised, with reinforcements present along both banks of the watercourse. West of Limerick, low tides expose estuarine muds within the intertidal area, primarily alongside the right bank of the channel. A number of smaller channels are exposed across this area at low tide. At the edge of the tidal muds are areas of marshy and estuarine vegetation which are regularly inundated. Within these areas, and at the edge of the intertidal zone, vegetation is dominated by large trees and shrubs.

85. West of Limerick, the intertidal area exposes estuarine muds primarily found alongside the right bank of the channel. A number of smaller channels are exposed across this area at low tide. At the edge of the tidal muds are areas of marshy and estuarine vegetation which are regularly inundated. Within these areas, and at the edge of the intertidal zone, vegetation is dominated by large trees and shrubs.

86. Analysis of historical map records from 1837 shows significant changes to the channel and riparian zone through Limerick Dock. Modifications include the construction of a railway bridge, Thomond Bridge, a weir between the Ennis Road bridge and Merchants Quay with a sluice between Honan's Quay and the 1916 Memorial Island, the R527 bridge and Limerick Dock.

4. Appraisal Method for the Assessment of Likely Significant Effects

4.1 Overview

87. The method for the assessment of likely significant effects is set out in Section 9.2.5 of Chapter 9 (Water), and this assessment has been undertaken in accordance with the information provided there. The overall effect of changes as a result of the Proposed Project is determined by a set of criteria including their relative sensitivity or 'value' (e.g. whether features are of national, regional or local value). Table 9.5 of Chapter 9 (Water) outlines the criteria for estimating the sensitivity of receptors and their attributes.

88. Each receptor is assigned a sensitivity for three separate water environment attributes:
    - Hydrology and surface water quality
    - Hydromorphology
    - Surface water supply.

89. Sensitivity categories include negligible, low, medium, high and very high.

90. The magnitude of impacts on receptors (for each of the three surface water attributes) is then determined in accordance with Table 9.6 of Chapter 9. Magnitude of impact categories include negligible, low, medium and high.

91. Once the magnitude is determined, the significance of an effect on water bodies (for each of the three surface water attributes) is then assigned by combining the sensitivity of the receptor with the predicted magnitude of impact, as shown in Table 9.7 of Chapter 9 and replicated in Table 4.1 below.

Table 4.1: Significance of Environmental Effect (EPA Guidelines (EPA 2022a))

Magnitude of Impacts	Sensitivity of Receptor				
	Negligible	Low	Medium	High	Very High
Negligible	Imperceptible	Not Significant	Not Significant	Not Significant	Not Significant
Low	Not Significant	Slight	Slight	Moderate	Significant
Medium	Not Significant	Slight	Moderate	Significant	Very Significant
High	Not Significant	Moderate	Significant	Very Significant	Profound

92. The assessment of likely significant effects on the surface water environment as a result of the proposed abstraction has been carried out in two steps:
    - Step 1: an assessment of the potential changes to lake levels and river flows and can be considered to describe the direct impacts
    - Step 2: an assessment of the impacts that the changes assessed in Step 1 might have on other attributes of surface water receptors, specifically water quality, water levels and hydromorphology. As such, these can be considered to be indirect impacts.

93. Step 1 of the assessment considered the hydrology of the catchments within the study area together. To determine the changes to the levels and flows to receptors within these catchments, a hydrological model was constructed. A summary of the modelling approach is provided in Section 4.3.1; full details of the methods employed and outcomes of the modelling are provided in Annex A (Hydrological Modelling Report) of this appendix. The model examined the historical record (supplied by ESB) and compares these recorded levels with simulated levels, as if the proposed water supply abstraction of 154Mld (under normal demand conditions) and 300Mld (during short peak demand periods) was in place at that time.

94. Step 2 of the assessment considered the impacts on other receptor attributes as a result of any changes in levels and flows, specifically water quality and hydromorphology. Ecological impacts are considered in Chapter 8 (Biodiversity) of the EIAR. For water quality in Derg TN and Derg HMWB, a water quality model was constructed. This model uses the outputs of the hydrological model as well as other data such as depth and water quality, gathered to determine a baseline (see Section 3.2.2 to Section 3.2.4), to examine the water circulation and water quality within Derg TN and Derg HMWB. A summary of the methods employed in this modelling is provided in Section 4.3.2; full details are provided in Annex B (Water Quality Modelling Report) of this appendix.

4.2 Sensitivity of Baseline Receptors

95. The sensitivity to change must be determined to assess the significance of effects. Each water receptor is allocated a sensitivity[9] for three separate water environment attributes: hydrology and surface water quality, hydromorphology, and surface water supply. Sensitivities range from low to very high.

96. Table 4.2 details the sensitivity of each of the receptors in the study area against the three attributes.

[9] Sensitivity has been determined by the experts who have contributed to this appendix. It is based on guidance documents from the EPA and best-practice and industry standards.

Table 4.2: Sensitivity of Water Bodies Within the Study Area

WFD Catchment (Code)	WFD Sub-Catchment Name (Code)	Receptor (WFD Water Body Name)	WFD Status (2019-2024)	Sensitivity		
				Hydrology & Surface Water Quality	Hydromorphology	Surface Water Supply
LOWER SHANNON (25B)	25B_4 Shannon[Lower]_SC_050	SHANNON (LOWER)_030	Moderate	Very high	Medium	Low
LOWER SHANNON (25C)	25C_10 Shannon[Lower]_SC_070	SHANNON (LOWER)_040	Good	High	Medium	Low
		Derg TN	Moderate	Very high	Very high	Low
	25C_1 Youghal [Tipperary]_SC_010	NEWTOWN_010	Good	High	Low	Low
		YOUGHAL (TIPPERARY)_010	Moderate	High	Low	Low
		ARDGREGANE STREAM_020	Moderate	High	Medium	Low
	25C_11 Nenagh_SC_020	NENAGH_070	Moderate	High	Medium	Low
		CLONMAKILLADUFF_010	Moderate	High	Low	Low
	25C_9 Ballyfinboy_SC_010	BALLYFINBOY_070	Poor	High	Medium	Low
	25C_7 Bow_SC_010	WOODFORD (GALWAY)_030	Moderate	High	Medium	Low
		DERRAINY_010	Good	High	Medium	Low
		BOW_010	Moderate	High	Low	Low
		COOS_010	Moderate	High	Low	Low
		MOANNAKEEBA_EAST_010	Good	High	Low	Low
		LOWER VILLAGE TRIB_010	Good	High	Low	Low
		SOUTH BOLEYNAGOAGH_010	Moderate	High	Low	Low
		KILRATEERA_UPPER_010	Good	High	Low	Low
	25C_3 Graney[Shannon]_SC_010	GRANEY (SHANNON)_050	Moderate	High	Low	Low
	25C_2 LorrhaStream_SC_010	LORRHA STREAM_020	Poor	High	Low	Low
		CARRIGAHORIG STREAM_010	Poor	High	Low	Low
		TERRYGLASS_010	Moderate	High	Medium	Low
	25C_12 Kilcrow_SC_010	KILCROW_070	Poor	High	Medium	Low
LOWER SHANNON (25D)	25D_6 Shannon[Lower]_SC_080	ARDCLOONY_010	Good	High	Medium	Low
		BRIDGETOWN (CLARE)_010	Moderate	High	Low	Low
		KILMASTULLA_050	Moderate	Very high	Medium	Low
		GRANGE (TIPPERARY)_010	Moderate	High	Medium	Low
		DERG HMWB (Parteen Basin)	Good	Very high	Low	Low
		SHANNON (LOWER)_050	Poor	Very high	High	Low

4.3 Modelling

97. The complexity of the hydrological processes being assessed requires the use of models to determine potential impact on hydrology and water quality. An overview of the two models used is provided here and full details of the models are provided in Annex A (Hydrological Modelling Report) and Annex B (Water Quality Modelling Report) of this appendix.

4.3.1 Hydrological Model

98. A hydrological model was developed to assess the impact of the proposed abstraction on the water levels of Derg TN and Derg HMWB and the pass forward flows released to the ORS. Full details of the approach to modelling are provided in Annex A (Hydrological Modelling Report). A summary is provided here for ease of reference.

99. Two constant rates of abstraction have been investigated: i) 154Mld – taken to be representative of normal operation demand by the year 2050, and ii) 300Mld – projected peak need/demand at year 2050.

100. The model was run using data from the period 1 January 1972 to 31 October 2023, allowing the simulation of daily levels and daily flows across this 52-year period with and without the proposed abstraction in place. Runs of the model on earlier periods have not been undertaken as the water resources management practices differed then: precluding the derivation of representative hydrological inflows.

101. The model was further developed to incorporated future climate change scenarios to also allow a simulation of the impact with the Proposed Project in place and including the effects of future climate change on flows on the River Shannon.

102. As a separate exercise, in order to test whether WFD mitigation measures and / objectives to restore the favourable conservation status of the qualifying interests of the Lower River Shannon SAC would be impeded by the Proposed Project, a sensitivity analysis was undertaken to apply an outline Eflows approach proposed in a recent study (CDM Smith, 2025) to the model and investigate the potential impacts of future changes in the compensation flow regime.

103. The ESB monitors the daily lake water levels in metres Above Ordnance Datum (mAOD) (Poolbeg) at three different locations:

    i) Portumna Bridge – at the top of Lough Derg (Derg TN)

    ii) Killaloe – at the bottom of Lough Derg (Derg TN)

    iii) Parteen Weir – at the bottom of Parteen Basin (Derg HMWB), on the upstream of Parteen Weir.

104. The ESB work to the Poolbeg datum, whilst the Hydrological Model developed for the Proposed Project has been set up to work to the Malin Head datum. Therefore, recorded ESB lake water levels were converted from Poolbeg to Malin Head via the subtraction of 2.70m.

105. The ESB also keep daily flow records in cubic metres per second (m^3/s) for flows going through the Ardnacrusha Generating Station and the total amount of water leaving Derg HMWB (i.e. the total combined flow going downstream to both the ORS channel and Ardnacrusha Headrace canal).

106. The Proposed Project impact assessment needs to be representative of the hydrological conditions going forward. Whilst ESB level and flow records extend back to 1932, prior to 1972 the management of the River Shannon was significantly different to that of today. Active management of upstream storages Lough Ree and Allen occurred to supplement flows to Lough Derg (Derg TN). After 1971 this ceased and the upstream Shannon management regime (which follows prescribed actions to meet navigation and flood management requirements) has since been, it is understood, applied in a consistent manner. The derived inflows to Lough Derg (Derg TN) prior to 1972 are therefore judged to be potentially unrepresentative of the post 1971 hydrological conditions and for this reason are not included in the analysis.

107. The lake levels provided by the ESB for use within the Proposed Project models have undergone visual quality control and verified as part of the hydrological modelling assessment. Where occasional daily gaps or incongruous spikes were identified, they were graphically inspected and infilled based upon a combination of inter-site relationships and interpretation of the hydrograph immediately before and after the missing data.

108. The hydrological model simulations provide an understanding of the impacts on lake levels and forward flows required to inform the Chapter 9 (Water) of the EIAR. The simulations also provide the information required to apply the UK Technical Advisory Group (UKTAG) WFD lake level test, which has been discussed with the EPA as being an appropriate test in the absence of an Irish WFD lake level test. This report describes the application of this test on both Derg TN and Derg HMWB.

109. Initial modelling of the water levels of the Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) system was based upon reproducing the baseline historical observed level and then simulating the effect of introducing the Proposed Project abstraction. This was achieved by proportionally reducing the flow going to Ardnacrusha (when it is operating) by the amount of water abstracted by the Proposed Project. During drought periods, when power generation at Ardnacrusha is no longer occurring, this adjustment of the Ardnacrusha flow can no longer occur and the WSP flow is provided by a reduction in the lake level and storage volume. The level of Lough Derg (Derg TN) is controlled by the balance between the lake inflow minus the outflow (comprising compensation flow to the ORS, fish pass flows at Parteen Weir and Ardnacrusha; together with or without the WSP flow). When the lake storage is in deficit, it is then preferentially replenished over Ardnacrusha hydropower generation once the drought ceases and inflows recover. This model is referred to as the ‘Historical Model’.

110. The Historical Model uses the historical recorded Ardnacrusha flows controlled by the ESB in response to the historical inflows entering the Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) system at the time. Therefore, these historical Ardnacrusha flows may not be appropriate for future scenarios when projected climate change impacts will alter the lake inflow regime, i.e. in future wetter periods when Ardnacrusha is likely to use more water and in future drier periods when ESB may need to reduce the flows going to the power station. To model the future impact of the Proposed Project therefore requires a rules-based modelling approach using the best understanding of ESB’s operational rules to determine how much water would flow to Ardnacrusha based upon the changed inflow hydrology whilst still meeting the required compensation and fish pass flows and keeping the lake levels within the Lough Derg NOB and within the upper and lower water levels that ESB applies to Parteen Basin.

111. The ESB operational principles used in the final WSP hydrological model build[10] are based on discussions with ESB to understand how ESB typically aim to manage both the Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) system levels and the pass forward flows to the Ardnacrusha power station and ORS. The operational guiding principles received from ESB were then codified into the model for a rules-based modelling approach.

[10] This final version of the WSP hydrological model build has previously been referred to as the ‘Operational Principles Model’ to differentiate it from the initial ‘Historical Model’ build.

112. The WSP hydrological model was run including the Proposed Project constant abstraction rates of 154Mld (normal) and 300Mld (peak). It was also run with consideration for climate change impacts (using a reasonable worst case in terms of potential climate change scenarios) and for proposed Eflow releases at Parteen Weir, to take account of the proposed RBMP measures for the Shannon (Lower)_050 and Shannon (Lower)_060 candidate HMWBs.

113. In determining the impacts as a result of any changes due to the Proposed Project, as WFD lake standards for the management of abstraction impacts are yet to be finalised by the EPA for Ireland, two different kinds of lake standards tests have been applied:

    i) A screening test based upon the proposed abstraction being within a proportion of the lake inflow, that has been previously used by Uisce Éireann in consultation with the EPA in the development of the Uisce Éireann National Water Resources Plan (NWRP) (Irish Water 2021)[11]

    ii) The WFD lake level standards test UK approach as documented in the UKTAG River Basin Management (2015-21) report[12].

114. After discussing the matter with the EPA, it was decided to adopt the (ii) UKTAG WFD lake level test approach as it was considered the more complex and sophisticated target used in the UK, and therefore the most appropriate for the Proposed Project. Details of the application of these tests are provided in Annex A (Hydrological Modelling Report).

4.3.2 Hydrodynamic Model

115. This section summarises the approach to the water quality modelling. Full details are provided in Annex B (Water Quality Modelling Report) and Annex C (Water Quality Modelling Calibration Report) of this appendix. The modelled study area extends from Portumna Bridge at the north of Derg TN to Parteen Weir/Ardnacrusha Headrace in the south. The bathymetry of the study area was provided by Geomara who completed a bathymetric survey of Derg TN and Derg HMWB in 2015; a copy of the bathymetry report is provided in Annex E (Lough Derg Hydrographic Report) of this appendix.

116. The boundaries of the model include the main inflow to Derg TN from the Shannon (Lower)_030 and the tributaries which input to Derg TN and Derg HMWB. The outflow considered a combined outflow via Parteen Weir to Shannon (Lower)_050 and to Ardnacrusha Headrace. The model also includes recorded meteorological conditions, and water quality data for the tributaries which feed into the lakes.

117. The model was calibrated using 2016 recorded data as a baseline and point of verification; details of the data used in this process are provided in quarterly and annual reports of the Lough Derg Monitoring Project, in Annex D (Summary Reports of Lough Derg Water Quality Monitoring May 2015 to December 2023) of this appendix. As the period 1 March 2016 to 31 December 2016 yielded a full set of data from instruments deployed within Lough Derg as part of the hydrographic survey campaign, the water quality model predictions were able to be compared against this recorded dataset in order to verify the model. The model was subsequently re-calibrated using 2018 recorded data for the period 1 October 2017 to 31 December 2018 with the new model predictions compared against the appropriate recorded dataset. The Water Quality Modelling Report uses 2018 as its baseline water level as this has been identified as one of the most extreme drought periods experienced in Lough Derg (Derg TN) across historical records. Full details of the baseline modelling are provided in Annex B (Water Quality Modelling Report). Full details of the calibration of the model are provided in Annex C (Water Quality Modelling Calibration Report) of this appendix.

[11] Irish Water (2021). National Water Resources Plan – Appendix C.

[12] UKTAG (2013). Updated recommendations on Environmental Standards, River Basin Management (2015-21). http://www.wfduk.org/sites/default/files/Media/Environmental%20standards/UKTAG%20Environmental%20Standards%20Phase%203%20Final%20Report%2004112013.pdf

118. Using 2018 as a baseline year, a number of scenarios were run for the model:

- Scenario 1: Baseline
- Scenario 2: Proposed abstraction at constant 154Mld
- Scenario 3: Proposed abstraction at constant 300Mld
- Scenario 4: Proposed abstraction at constant 154Mld including climate change effects
- Scenario 5: Proposed abstraction at constant 300Mld including climate change effects.

119. Regarding the hydrological model Eflows sensitivity analysis, this was a separate exercise to test whether WFD mitigation measures and / objectives to restore the favourable conservation status of the qualifying interests of the Lower River Shannon SAC would be impeded by the Proposed Project. The sensitivity analysis found that similar water level differences were simulated during the 2018 drought with or without the Eflows regime included because during droughts the required minimum baseflow would still be set to $10m^3/s$ and there would be no need for freshet releases[13]. Therefore, as the water quality modelling is focussed on the 2018 drought, there was no need to include the Eflows scenario.

4.4 Mitigation

120. In general, a hierarchical approach to mitigation has been adopted for the Proposed Project, which seeks to avoid adverse effects in the first instance through an iterative approach to design. This is 'embedded mitigation' and is assumed to be in place during the assessment of likely significant effects.

121. Where avoidance is not possible, and where significant adverse effects are identified during the impact assessment, mitigation measures are proposed to prevent or reduce those effects.

122. As discussed in Section 9.5.1 of Chapter 9 (Water), there are two types of mitigation: generic mitigation measures and site-specific mitigation measures. Each potentially significant adverse effect requires mitigation, but many effects can and will be addressed using generic mitigation including the application of best practice in the construction of the Proposed Project. These are set out in Annex B (Surface Water Management Plan) of Appendix A5.1 (Construction Environmental Management Plan).

123. Site-specific mitigation has been developed where generic mitigation would be inappropriate, ineffective, or insufficient to avoid or minimise effects from a specific project element.

[13] Within the hydrological modelling Eflows sensitivity analysis, freshets are not released during drought periods. The basis of this assumption is that if the Eflow is an attempt to mimic the natural flow regime then artificially releasing standard freshets over this period would seem to be introducing a non-natural characteristic to the flow regime.

5. Design Phase/Embedded Mitigation

124. Permanent features which result in the avoidance or reduction of impacts during the lifetime of the Proposed Project are considered to be part of the design of the Proposed Project (also known as embedded mitigation) and as such are included in the initial assessment of impacts. Chapter 4 (Proposed Project Description) of the EIAR provides the details of the permanent design features which will result in impacts being avoided or reduced.

125. This includes the proposed abstraction rates from Derg HMWB; these have been determined based upon the need for water supply and also the requirements to ensure there will be no deterioration in WFD status or impediment to the achievement of the objectives of impacted water bodies. The extensive hydrological and water quality modelling work that accompanies this appendix provides full details of the range of abstraction rates modelled, with accompanying sensitivity tests for climate change and RBMP mitigation measures.

126. A number of permanent features have been incorporated into the design of the Raw Water Intake to minimise impacts on the water environment as a result of the proposed abstraction. These are detailed and considered in Appendix A9.3 (Non-Linear Principal Infrastructure and 38 kV Uprate Works Assessment).

127. Chapter 4 (Proposed Project Description) also details design embedded mitigation incorporated to minimise impacts on biodiversity and risks from invasive species. The assessment of these impacts and risks can be found in Chapter 8 (Biodiversity).

128. The proposed location for the Raw Water Intake has been carefully selected by carrying out a Multi-Criteria Analysis of the impacts on environmental criteria including the surface water environment.

129. Details of alternatives considered are provided in Chapter 3 (Consideration of Reasonable Alternatives) of the EIAR. This sets out how the locations for raw water intake have been selected with the aim of reducing proximity to sensitive surface water receptors. With the exception of the RWI&PS, the WTP access road, and the Booster Pumping Station (BPS) (including the power connection from Birr to the BPS site), none of the Infrastructure Sites contains, or is in close proximity to, surface water receptors of a medium or higher sensitivity.

6. Potential Operational Effects of the Proposed Project

130. As set out in Section 1 of this appendix, this assessment considers the likely significant effects of the operation of the proposed abstraction only. Construction effects associated with the Raw Water Intake are detailed in Appendix A9.3 (Non-Linear Principal Infrastructure and 38 kV Uprate Works Assessment).

131. A summary of mitigation and residual effects for each of the relevant water bodies is provided throughout this section.

6.1 Step 1 Assessment: Levels and Flows

132. As described in Section 4, the assessment of likely significant effects has been carried out in two 'steps': Step 1 assesses the impacts of the abstraction on water levels and flows, and Step 2 assesses the impacts that those changes might have on other attributes of surface water receptors, specifically water quality and hydromorphology.

6.1.1 Summary of Findings from the Hydrological Model

133. Annex A (Hydrological Modelling Report) provides full details of the findings of the hydrological modelling study. A summary is provided here for ease of reference.

6.1.1.1 General Findings

134. The impacts to lake levels and forward flows to the ORS due to the modelled inclusion with the Proposed Project abstraction (as a constant flow of either 154Mld or 300Mld) were found to be barely distinguishable from the baseline case when viewed on level/flow duration curves (a standard hydrological method for comparing long-term data series).

135. The level regimes of both the Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) are only simulated to be affected by the Proposed Project abstraction during extreme drought periods and in the days immediately after the drought (up to a week) when inflow is needed to replenish any deficit in storage caused by the Proposed Project abstraction. From the 52-year model simulation period (1972-2023), the simulated lake levels are only found to be notably affected by the inclusion of the Proposed Project during the 1995 and 2018 drought events, with all other years showing no perceptible impacts. Therefore, for approximately 99% of the 52-year model simulation period, there are no perceptible impacts to simulated lake levels as a result of the Proposed Project.

136. The model demonstrates that the required ORS compensation and fish pass flows can always be met, either with or without the simulated Proposed Project abstraction in place within the modelling undertaken.

137. ESB will facilitate the proposed abstraction of water by the Proposed Project within its current operating practices. As part of an overall agreement with ESB, water will be diverted to the Proposed Project abstraction from the flow that would otherwise have been used for electricity generation on a continuous year round basis. At a practical level, this will mean that ESB, in keeping the water level within the NOB on Lough Derg and within the upper and lower water level on Parteen Basin, will take account of, and respond to, the volume of water abstracted for the Proposed Project, alongside other relevant considerations such as, maintaining statutory compensation flow of 10m^3/s down the old Shannon channel, predicted rainfall, the demand for power and operating practices. ESB will maintain the water levels within the NOB on Lough Derg and within the upper and lower water levels on Parteen Basin, as it does currently. Over longer periods there would be a generalised adjustment of the flow going to Ardnacrusha by ESB to respond to the volume of water used

by the Proposed Project. However, the operation of Lough Derg, post works, will feel and look very similar to the way it currently operates, and there will not be a visible day to day difference.

138. During flood flows, when the ESB can no longer keep the water level below the top of the Lough Derg NOB, the ESB can operate Ardnacrusha at full capacity and allow the excess flow down the ORS as they have done in the past, and the Proposed Project abstraction would be provided from a minor depletion in the simulated lake storage.

139. The simulated forward flows to the ORS remain unchanged by the inclusion of the Proposed Project abstraction. The proportion of days (to the nearest whole percent) when the ORS is receiving the minimum required compensation and fish pass flows is simulated to be unchanged by the inclusion of the Proposed Project abstraction, as does the timing of the spill flows down ORS when Ardnacrusha is at full capacity.

6.1.1.2 Drought Impacts

140. From the 52-year model simulation period (1972-2023), it was decided to look closer at the specific 1995 and 2018 drought events that the Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) system was proven to be the most sensitive to. The 2018 drought shows the biggest impact of the WSP scenarios on the simulated lake levels, and the 1995 drought shows the second biggest impact. Other candidate droughts such as 1976, 1989, 2006, and 2010 were simulated to have negligible simulated lake level differences that were much less significant.

141. For the 2018 drought event (most impactful), with the inclusion of the Proposed Project 154Mld abstraction scenario, the maximum difference in simulated lake level from the baseline at the lowest point of the drawdown is 65mm. For the Proposed Project 300Mld abstraction scenario, the maximum difference lake level difference at the lowest point of the drawdown is 134mm. Even during the worst modelled drought event (2018) from the 52-year model simulation period, the size and rate of simulated lake level change fits within the range of ESB normal observed lake level fluctuations seen within the 52-year period of historical recorded levels. Furthermore, the simulated lake levels with the inclusion of the Proposed Project abstraction are still within the Lough Derg NOB, and within the upper and lower water levels that ESB applies on Parteen Basin, without a change to the ORS compensation and fish pass flows, which would always be met.

6.1.1.3 Climate Change

142. Climate change simulations for a ‘reasonable worst case’ scenario for the 2080s epoch indicate that simulated lake levels would still remain within the Lough Derg NOB when including the Proposed Project abstraction. The simulated lake levels with Proposed Project included only drop close to the bottom of the Lough Derg NOB once within the 52-year model simulation period – during the modelled 2018 drought event.

143. During the modelled 2018 drought event, with the inclusion of the 2080s Lower (reasonable worst case) climate change scenario, the difference in simulated lake level between the Proposed Project 300Mld abstraction scenario and baseline at the lowest point of the drawdown is 168mm. Therefore, even when applying a precautionary approach to consider the reasonable worst case 2080s climate change projections to the most impactful drought event (2018) in the 52-year model simulation period, the additional simulated lake level drawdown caused by the inclusion of Proposed Project is still fitting within the range of ESB normal observed lake level fluctuations, resulting in levels still within Lough Derg NOB, and within the upper and lower water levels that ESB applies on Parteen Basin with no change to the ORS compensation and fish pass flows, which would always be met.

6.1.1.4 Eflows

144. The Water Action Plan 2024 (DHLGH 2024) sets out a roadmap of actions aimed to improve fish migration in the Lower River Shannon around Parteen Weir and the Ardnacrusha power station. An outline Eflow approach has been developed by a CDM Smith study to provide proposed variable compensation flows to be released down the ORS from Parteen Weir. As part of the WSP hydrological modelling scope, a sensitivity analysis has been undertaken to test how the inclusion of this proposed Eflow regime would be likely to impact the viability of the proposed WSP abstraction.

145. To do this the WSP hydrological model has been codified to represent the proposed Eflow regime rules from the CDM Smith study. The application of the proposed Eflow regime involved replacing the existing ORS 10m^3/s compensation and fish pass flow with a variable baseflow compensation flow and the inclusion of seasonal freshets (periodic increases in flow over Parteen Weir, with the frequency and volumes of these varying seasonally throughout the year) to assist migratory fish up the ORS and into Parteen Basin (Derg HMWB).

146. The sensitivity analysis found that similar lake water level differences were simulated during the droughts when the WSP abstractions were included in the Eflow scenario as were simulated for the case for the baseline constant 10m^3/s compensation flow. This relies on the assumption that freshets would not be released during droughts.

6.1.1.5 WFD Lake Tests

147. As WFD lake standards for the management of abstraction impacts are yet to be finalised by the EPA for Ireland, two different kinds of lake standards tests have been applied for the purpose of assessing the Proposed Project: i) the NWRP screening test based upon the proposed abstraction being within a proportion of the lake inflow, and ii) the UKTAG WFD lake level standards test based on changes in the extent of the littoral zone due to the activity being assessed (in this case the Proposed Project abstraction).

148. The Proposed Project passes the (i) NWRP screening test as the proposed peak 300Mld abstraction is comfortably within the 10% of the lake inflow Q50 threshold. After discussing the matter with the EPA, it was decided to adopt the (ii) UKTAG WFD lake level test approach as it was considered the more complex and sophisticated target used in the UK, and therefore the most appropriate for the Proposed Project.

149. Based on the UKTAG WFD lake level test the following standards are met for the two WSP abstraction rates:

- A constant proposed abstraction of 154Mld results in both the Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
- A constant proposed abstraction of 300Mld results in both the Lough Derg (Derg TN) and Parteen Basin (Derg HMWB) water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
- Inclusion of the future ‘reasonable worst case’ 2080s climate change impacts and/or proposed ORS Eflows regime sensitivity analyses results in both the water bodies still meeting the lake level requirements for the WFD Good status (Potential) standard for a constant WSP abstraction of 154Mld or 300Mld.

6.2 Step 2: Likely Significant Effects on the Surface Water Environment

6.2.1 Outputs from the Hydrodynamic Model

150. Summary outputs of the water quality model are provided below with full details, including temporal graphs, provided in Annex B (Water Quality Modelling Report) with A9.1 Figure 2 detailing the monitoring locations.

151. Three Water Quality Monitoring Stations are used to spatially represent the Lough Derg (Derg TN) as follows:

- Water Quality Monitoring Station 2 (WQMS-2)
- Water Quality Monitoring Station 5 (WQMS-5)
- Water Quality Monitoring Station 8 (WQMS-8).

152. Analysis of the water quality modelling, summarised below, has focussed on comparing predicted differences in average concentrations per location per scenario (outlined in Section 4.3.2) against the drought baseline. As noted in Section 3.2.3, this modelling was undertaken to assess potential impacts under extreme drought conditions. To help contextualise the potential impacts, water quality modelling results have been presented using the 95%ile metrics. These are provided for reference only and are not intended to imply that compliance with WFD Environmental Quality Standards (EQSs) is expected nor required under drought conditions. Although the Derg TN is currently classified as Moderate status, all parameters have been assessed against Good status EQS values for consistency and to provide a clearer understanding of potential impacts.

6.2.1.1 Biochemical Oxygen Demand

153. Table 6.1 shows the predicted Biochemical Oxygen Demand (BOD) concentrations under the various scenarios (see Section 4.3.2) set against the 2018 drought baseline scenario. As there is no 95%ile EQS for BOD in lakes of Moderate status, the 95%ile EQS for BOD in rivers of Good status (≤2.6mg/l) (European Communities Environmental Objectives (Surface Water) Regulations 2009) is used to help contextualise the potential impacts under extreme drought conditions and is provided for reference only. EPA chemistry monitoring data captured at Lough Derg (Derg TN) for WFD operational, surveillance and investigative stations has a Limit of Detection of 1mg/l with results recorded to zero decimal places. The predicted differences in concentration calculated as part of the water quality modelling are provided to three decimal places. This is more decimal places than the available water quality data for Lough Derg (Derg TN).

Table 6.1: Predicted Differences in Average BOD Concentration per Location per Scenario

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	Scenario 300 Ml/d	Scenario 154 Ml/d +CC	Scenario 300 Ml/d +CC
BOD (mg/)	Average	**WQMS-2**	**1.780 mg/l**	1.779 mg/l	1.779 mg/l	1.744 mg/l	1.742 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*-0.001 mg/l*	*-0.036 mg/l*	*-0.038 mg/l*
		% Difference from Baseline		*0.0%*	*-0.1%*	*-2.0%*	*-2.1%*
		WQMS-5	**1.521 mg/l**	1.521 mg/l	1.521 mg/l	1.492 mg/l	1.491 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*-0.029 mg/l*	*-0.029 mg/l*
		% Difference from Baseline		*0.0%*	*0.0%*	*-1.9%*	*-1.9%*
		WQMS-8	**1.368 mg/l**	1.366 mg/l	1.366 mg/l	1.356 mg/l	1.355 mg/l
		Difference from Baseline (mg/l)		*-0.001 mg/l*	*-0.002 mg/l*	*-0.012 mg/l*	*-0.012 mg/l*
		% Difference from Baseline		*-0.1%*	*-0.1%*	*-0.9%*	*-0.9%*

154. Average drought baseline BOD concentrations are between 1.368mg/l and 1.780mg/l. The model predicted miniscule decreases (to the second decimal place) of between -2.1% and -0.1% with respect to the drought baseline (Scenario 1) in the average BOD concentrations over the course of the simulation period at locations WQMS-2, WQMS-5 and WQMS-8 for all four abstraction scenarios.

6.2.1.2 Dissolved Oxygen

155. Table 6.2 shows the predicted Dissolved Oxygen (DO) concentrations under the various scenarios (see Section 4.3.2) set against the 2018 drought baseline scenario. In the absence of applicable standards in Ireland, the 95%ile EQS for DO in lakes of Good status (≥5mg/l for measurements taken in July and August) (Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015) is used to help contextualise the potential impacts under extreme drought conditions and is provided for reference only. EPA chemistry monitoring data captured at Lough Derg (Derg TN) for WFD operational, surveillance and investigative stations has a Limit of Detection of 0.1mg/l with results recorded to two decimal places. The predicted differences in concentration calculated as part of the water quality modelling are provided to three decimal places. This is more decimal places than the available water quality data for Lough Derg (Derg TN).

Table 6.2: Predicted Differences in Average DO Concentration per Location per Scenario

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
DO (mg/)	Average	**WQMS-2**	**11.052 mg/l**	11.051 mg/l	11.049 mg/l	11.003 mg/l	11.001 mg/l
		Difference from Baseline (mg/l)		*-0.002 mg/l*	*-0.003 mg/l*	*-0.050 mg/l*	*-0.051 mg/l*
		% Difference from Baseline		*0.0%*	*0.0%*	*-0.5%*	*-0.5%*
		WQMS-5	**10.812 mg/l**	10.813 mg/l	10.814 mg/l	10.798 mg/l	10.801 mg/l
		Difference from Baseline (mg/l)		*0.002 mg/l*	*0.003 mg/l*	*-0.014 mg/l*	*-0.011 mg/l*
		% Difference from Baseline		*0.0%*	*0.0%*	*-0.1%*	*-0.1%*
		WQMS-8	**10.854 mg/l**	10.859 mg/l	10.863 mg/l	10.930 mg/l	10.937 mg/l
		Difference from Baseline (mg/l)		*0.005 mg/l*	*0.009 mg/l*	*0.076 mg/l*	*0.083 mg/l*
		% Difference from Baseline		*0.0%*	*0.1%*	*0.7%*	*0.8%*

156. Average drought baseline DO concentrations are between 10.812mg/l and 11.052mg/l. The model predicted miniscule variations (increases and decreases to the second decimal place) of between -0.5% to +0.8% with respect to the drought baseline (scenario 1) in the average DO concentrations over the course of the simulation period at locations WQMS-2, WQMS-5 and WQMS-8 for all four abstraction scenarios.

6.2.1.3 Chlorophyll-*a*

157. Table 6.3 shows the predicted Chlorophyll-*a* (CHL) concentrations under the various scenarios (see Section 4.3.2) set against the 2018 drought baseline scenario. In the absence of applicable standards in Ireland, the 95%ile EQS for CHL (≤10µg/l) (Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015) is used to help contextualise the potential impacts under extreme drought conditions and is provided for reference. EPA chemistry monitoring data captured at Lough Derg (Derg TN) for WFD operational, surveillance and investigative stations has a Limit of Detection of 1µg/l with results recorded to one decimal place. The predicted differences in concentration calculated as part of the water quality modelling are provided to three decimal places. This is more decimal places than the available water quality data for Lough Derg (Derg TN).

Table 6.3: Predicted Differences in Average CHL Concentration per Location per Scenario

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
CHL (ug/)	Average	**WQMS-2**	**1.535 ug/l**	1.531 ug/l	1.526 ug/l	1.522 ug/l	1.512 ug/l
		Difference from Baseline (mg/l)		*-0.004 ug/l*	*-0.009 ug/l*	*-0.014 ug/l*	*-0.024 ug/l*
		% Difference from Baseline		*0%*	*-1%*	*-1%*	*-2%*
		WQMS-5	**1.714 ug/l**	1.712 ug/l	1.711 ug/l	1.698 ug/l	1.694 ug/l
		Difference from Baseline (mg/l)		*-0.002 ug/l*	*-0.003 ug/l*	*-0.016 ug/l*	*-0.020 ug/l*
		% Difference from Baseline		*0%*	*0%*	*-1%*	*-1%*
		WQMS-8	**1.943 ug/l**	1.946 ug/l	1.947 ug/l	1.969 ug/l	1.969 ug/l
		Difference from Baseline (mg/l)		*0.003 ug/l*	*0.004 ug/l*	*0.026 ug/l*	*0.026 ug/l*
		% Difference from Baseline		*0%*	*0%*	*1%*	*1%*

158. Average baseline CHL concentrations are between 1.535µg/l and 1.943µg/l. The model predicted miniscule variations (increases and decreases to the second decimal place) of between -2% to +1% with respect to the drought baseline (scenario 1) in the average CHL concentrations over the course of the simulation period at locations WQMS-2, WQMS-5 and WQMS-8 for all four abstraction scenarios.

6.2.1.4 Nitrate

159. Table 6.4 shows the predicted Nitrate (NO3-N) concentrations under the various scenarios (see Section 4.3.2) set against the 2018 drought baseline scenario. In the absence of an applicable 95%ile EQS, for NO3-N, the Nitrates Directive (91/676/EEC) can be used as a proxy. It considers ≤50mg/l as a threshold for risk of nitrate vulnerability and is used to help contextualise the potential impacts under extreme drought conditions and is provided for reference only. EPA chemistry monitoring data captured at Lough Derg (Derg TN) for WFD operational, surveillance and investigative stations has a Limit of Detection of 0.1mg/l with results recorded to one decimal place. The predicted differences in concentration calculated as part of the water quality modelling are provided to three decimal places. This is more decimal places than the available water quality data for Lough Derg (Derg TN).

Table 6.4: Predicted Differences in Average NO3-N Concentration per Location per Scenario

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
NO3-N (mg/)	Average	**WQMS-2**	**0.908 mg/l**	0.907 mg/l	0.906 mg/l	0.879 mg/l	0.877 mg/l
		Difference from Baseline (mg/l)		*-0.001 mg/l*	*-0.001 mg/l*	*-0.029 mg/l*	*-0.031 mg/l*
		% Difference from Baseline		*-0.1%*	*-0.2%*	*-3.2%*	*-3.4%*
		WQMS-5	**0.804 mg/l**	0.804 mg/l	0.805 mg/l	0.760 mg/l	0.761 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.001 mg/l*	*-0.043 mg/l*	*-0.043 mg/l*
		% Difference from Baseline		*0.1%*	*0.1%*	*-5.4%*	*-5.3%*
		WQMS-8	**0.646 mg/l**	0.647 mg/l	0.647 mg/l	0.613 mg/l	0.613 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*-0.033 mg/l*	*-0.033 mg/l*
		% Difference from Baseline		*0.0%*	*0.1%*	*-5.1%*	*-5.1%*

160. Average baseline NO3-N concentrations are between 0.646mg/l and 0.908mg/l. The model predicted small decreases (to the second decimal place) of between -5.4% to +0.1% with respect to the drought baseline (scenario 1) in the average NO3-N concentrations over the course of the simulation period at locations WQMS-2, WQMS-5 and WQMS-8 for all four abstraction scenarios.

6.2.1.5 Orthophosphate

161. Table 6.5 shows the predicted Orthophosphate (PO4-P) concentrations under the various scenarios (see Section 4.3.2) set against the 2018 drought baseline scenario. As there is no 95%ile EQS for PO4-P in lakes of Moderate status, the 95%ile EQS for PO4-P in rivers of Good status (≤0.075mg/l) (European Communities Environmental Objectives (Surface Water) Regulations 2009) is used to help contextualise the potential impacts under extreme drought conditions and is provided for reference only. EPA chemistry monitoring data captured at Lough Derg (Derg TN) for WFD operational, surveillance and investigative stations has a Limit of Detection of 0.01mg/l with results recorded to two decimal places. The predicted differences in concentration calculated as part of the water quality modelling are provided to three decimal places. This is more decimal places than the available water quality data for Lough Derg (Derg TN).

Table 6.5: Predicted Differences in Average PO4-P Concentration per Location per Scenario

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
PO4-P (mg/)	Average	**WQMS-2**	**0.007 mg/l**	0.007 mg/l	0.007 mg/l	0.007 mg/l	0.007 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*
		% Difference from Baseline		*-0.2%*	*-0.4%*	*-4.9%*	*-5.2%*
		WQMS-5	**0.008 mg/l**	0.008 mg/l	0.008 mg/l	0.008 mg/l	0.008 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*
		% Difference from Baseline		*-0.2%*	*-0.4%*	*-3.4%*	*-3.8%*
		WQMS-8	**0.011 mg/l**	0.011 mg/l	0.011 mg/l	0.011 mg/l	0.011 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*
		% Difference from Baseline		*-0.6%*	*-1.1%*	*-1.3%*	*-2.1%*

162. Average baseline PO4-P concentrations are between 0.007mg/l and 0.011mg/l. The model predicted small decreases (to the second decimal place) of between -5.2% to -0.2% with respect to the drought baseline (scenario 1) in the average PO4-P concentrations over the course of the simulation period at locations WQMS-2, WQMS-5 and WQMS-8 for all four abstraction scenarios.

6.2.1.6 Ammonia

163. Table 6.6 shows the predicted Ammonia (NH3-N) concentrations under the various scenarios (see Section 4.3.2) set against the 2018 drought baseline scenario. As there is no 95%ile EQS for NH3-N in lakes of Moderate status, the 95%ile EQS for NH3-N in rivers of Good status (≤0.14mg/l) (European Communities Environmental Objectives (Surface Water) Regulations 2009) is used to help contextualise the potential impacts under extreme drought conditions and is provided for reference only. EPA chemistry monitoring data captured at Lough Derg (Derg TN) for WFD operational, surveillance and investigative stations has a Limit of Detection of 0.01mg/l with results recorded to two decimal places. The predicted differences in concentration calculated as part of the water quality modelling are provided to three decimal places. This is more decimal places than the available water quality data for Lough Derg (Derg TN).

Table 6.6: Predicted Differences in Average NH3-N Concentration per Location per Scenario

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
NH3-N (mg/)	Average	**WQMS-2**	**0.083 mg/l**	0.083 mg/l	0.083 mg/l	0.080 mg/l	0.080 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*-0.003 mg/l*	*-0.003 mg/l*
		% Difference from Baseline		*0.3%*	*0.0%*	*-3.6%*	*-4.0%*
		WQMS-5	**0.069 mg/l**	0.069 mg/l	0.069 mg/l	0.067 mg/l	0.067 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*-0.001 mg/l*	*-0.002 mg/l*	*-0.002 mg/l*
		% Difference from Baseline		*-0.6%*	*-0.7%*	*-2.8%*	*-3.1%*
		WQMS-8	**0.071 mg/l**	0.071 mg/l	0.070 mg/l	0.069 mg/l	0.069 mg/l
		Difference from Baseline (mg/l)		*-0.001 mg/l*	*-0.001 mg/l*	*-0.002 mg/l*	*-0.002 mg/l*
		% Difference from Baseline		*-0.9%*	*-1.1%*	*-2.8%*	*-3.1%*

164. Average baseline NH3-N concentrations are between 0.069mg/l and 0.083mg/l. The model predicted miniscule variations (to the third decimal place) of between -4% to +0.3% with respect to the drought baseline (scenario 1) in the average NH3-N concentrations over the course of the simulation period at locations WQMS-2, WQMS-5 and WQMS-8 for all four abstraction scenarios.

6.2.1.7 Summary of Modelling Results

165. Based on the predictions from the calibrated and verified water quality model, it has been shown both spatially and temporally that there would be a neutral effect on the water quality of Lough Derg (Derg TN).

166. The impact has been classed as neutral as the computational modelling exercise predicted miniscule positive and negative differences in water quality concentrations between different scenarios. The predicted differences between scenarios have been shown to be less than the natural variability of the system. The magnitude of the differences between scenarios at the locations assessed would be within the normal bounds of variation of laboratory analysis results from coincident physical samples.

167. Algae blooms have been reported on Lough Derg (Derg TN), as recently as September 2025, as a result of blue-green algae (cyanobacteria). Occurring in specific temperature, light, nutrient, wind speed and direction conditions, the algae can evolve to produce toxins from a non-toxic state. Blue-green algae develop populations relatively slowly during the year, appearing in low numbers in late spring before evolving during the summer and peaking in early autumn. Predictions from the calibrated and verified water quality model for Chlorophyll-a, during the drought scenarios, do not indicate the presence of algal blooms – see Section 6.2.1.3 for further information. Furthermore, EPA Report "Investigating the likelihood of a Lough Neagh bloom scenario happening in the Republic of Ireland" (EPA, 2023) tested 35 lakes, including Lough Derg (Derg TN) and Derg HWMB (Parteen Basin) concluding that neither faced a high potential threat of experiencing serious Harmful Algal Bloom events due to a combination of factors like those that implicated in the Lough Neagh bloom.

6.2.2 Derg TN and Derg HMWB

168. Step 1 of this assessment demonstrated no likely significant effects on the water level regimes in the Derg TN and the Derg HMWB water bodies. The hydrological modelling analysis only simulated perceptible effects from the inclusion of Proposed Project during extreme drought periods (1995 and 2018) and in the days immediately after these drought events (up to a week). Therefore, for approximately 99% of the 52-year model simulation period (1972-2023), there are no perceptible impacts as a result of the Proposed Project. The maximum difference in simulated levels from the baseline at the lowest point of the 2018 drought event (most impactful) drawdown is 134mm at the 300Mld abstraction rate and 65mm at the 154Mld abstraction rate. The

size and rate of simulated lake level change fits within the range of ESB normal observed lake level fluctuations seen within the received 52-year period of historical recorded levels.

169. When applying a precautionary approach to consider the 'reasonable worst case' 2080s climate change scenario for the 2018 drought, simulated lake levels with the Proposed Project drop lower but remain within the NOB on Lough Derg and within the upper and lower water levels that ESB applies on Parteen Basin. The maximum difference in simulated levels from baseline (with climate change) at the lowest point of the 2018 drought event is 168mm at the 300Mld abstraction rate. The size and rate of simulated lake level change still fits within the range of ESB normal observed lake level fluctuations seen within the received 52-year period of historical recorded levels.

170. Based on the application of the UKTAG WFD lake level test, a Proposed Project constant abstraction of both 154Mld and 300Mld meets the WFD lake level requirements for Good status standards at both Derg TN and Derg HMWB water bodies. The Derg TN is at Moderate status currently, and the Derg HMWB is at Good Ecological Potential. Changes in the levels of the lakes as a result of the proposed abstraction would not result in a deterioration of status nor prevent the achievement and/or maintenance of Good Ecological Potential. Changes are simulated to be long term but only to occur during extreme drought periods (1995 and 2018) within the 52-year model simulation period; the magnitude is negligible. Effects on lake levels in both the Derg TN and the Derg HMWB would be Not Significant. Impacts on flows are discussed within the assessment of likely significant effects for Shannon (Lower)_050 in Section 6.2.4.

171. Based upon the outputs of the water quality modelling for the Derg TN and the Derg HMWB, impacts of a negligible magnitude are predicted as a result of the Proposed Project. As a result, effects on water quality in both Derg TN and Derg HMWB would be Not Significant. In addition, the Step 2 assessment was carried out under drought conditions, which is a conservative scenario, and determined no discernible impacts modelled in support of this.

172. Due to the Not Significant impacts on both the lake levels and water quality within the Derg TN and the Derg HMWB, it is anticipated that effects on the Lough Derg on the River Shannon NSA will also be Not Significant. Sections 5 and 5.4 of the Water Status Impact Assessment Report also provide an assessment of the impacts of the proposed abstraction on NSAs in. This assessment concluded that the operation of the RWI&PS would have no impact on NSAs during operation.

173. Based upon the negligible impacts on lake levels, effects on the hydromorphology of the lakes are also considered to be negligible and therefore Not Significant. Given the size of the lake, and the parameters tested, the general chemical condition quality element suggests that there would be negligible impact. This is referenced in the Water Status Impact Assessment Report.

6.2.3 Inputting Tributaries to Derg TN and Derg HMWB

174. There are over 20 water bodies feeding into the two lakes. Individual assessments against each of these are summarised in Table 6.7.

175. The negligible impacts predicted for Derg TN and Derg HMWB in terms of levels, water quality and hydromorphology mean that any effects on inputting water bodies would also be negligible at most and therefore Not Significant.

6.2.4 Shannon (Lower)_050

176. The hydrological modelling demonstrated that existing compensation and fish pass flows are always met with or without the Proposed Project. There is a statutory requirement for the ESB to maintain these flows and so any impacts as a result of the Proposed Project would not be on these flows but on the lake levels, as flows would be maintained through the release of stored water. Impacts on lake levels are discussed under Section 6.2.2. The proportion of days (to the nearest whole percent) when the Shannon (Lower)_050 is receiving just the compensation and fish pass flows is predicted to be unchanged by the inclusion of the proposed abstraction, as is the timing of the spills. As a result, there would be no impact on compensation and fish pass flows resulting from the Proposed Project.

177. The hydrological model also included a sensitivity analysis to determine if the proposed abstraction would impact on an outline Eflow regime proposed in a recent study currently being considered for the Shannon (Lower)_050. The proposed variable Eflow regime includes the release of 'freshets'. It has been assumed these would not be released during a drought scenario. The model found that the released flows to the ORS during periods of spill are virtually the same for the Proposed Project abstraction rate of 300Mld with either a compensation flow of 10m^3/s or the variable Eflows regime. The Proposed Project would therefore have a negligible impact on the operation of the Eflow regime and would not prevent the use of this mitigation measure to help achieve Good Ecological Status for the Shannon (Lower)_050. In addition, the Shannon (Lower)_050 is a candidate HMWB and is included on the list under the Water Action Plan 2024. Therefore, effects would be Not Significant.

178. As the abstraction will have a negligible impact on the Eflows regime, there would be no reduction in flows in the Shannon (Lower)_050. This means that there would be no potential for reduced flushing in the channel and therefore no knock-on impacts on sediment transport, wetland habitats and alluvial woodland.

179. No likely impacts on flow as a result of the Proposed Project mean that there would be no likely significant direct or indirect significant effects on water quality or hydromorphology.

6.2.5 Shannon (Lower)_060 and Limerick Dock

180. The Shannon (Lower)_060 is immediately downstream of the Shannon (Lower)_050. As there are no impacts on the Shannon (Lower)_060, there would be no significant effects on this water body.

181. Similarly, there would be no significant effects on Limerick Dock.

182. As the abstraction will have a negligible impact on the Eflows regime, there would be no reduction in flows in the Shannon (Lower)_060 and Limerick Dock water bodies. This means that there would be no potential for reduced flushing in the channel and therefore no knock-on impacts on sediment transport, wetland habitats and alluvial woodland.

6.3 Summary of Likely Significant Effects

183. Table 6.7 summarises the likely significant effects arising from the proposed abstraction to hydrology and surface water quality, and hydromorphology. There are no known surface water abstractions within 50m of the proposed works or rivers within DWPAs or Lakes hydrologically connected within 2km downstream of the receptors for this assessment. Therefore, surface water supply has not been assessed for likely significant effects arising from the proposed abstraction.

Table 6.7: Summary of Operational Effects for the Proposed Abstraction

WFD Surface Water Body Receptors (WFD Name)	Potential Impact	Receptor Attributes	Sensitivity	Magnitude of Impact	Significance of Environmental Effect	Overall Significance of Effect
Derg TN and Derg HMWB (Parteen Basin)	Changes in water levels	Hydrology and surface water quality	Very high	No Impact	No Impact	Not Significant
	Changes in water levels (climate change scenario)		Very high	No Impact	No Impact	
	Changes in water levels (drought scenario)		Very high	Negligible	Not Significant	
	Changes in water quality as a result of changing water levels		Very high	Negligible	Not Significant	
	Impacts on Lough Derg on the River Shannon NSA		Very high	Negligible	Not Significant	
	Changes to hydromorphology (Derg HMWB)	Hydromorphology	Low	Negligible	Not Significant	
	Changes to hydromorphology (Derg TN)		Very high	Negligible	Not Significant	
Rivers flowing into Derg TN/Derg HMWB	Changes in water levels	Hydrology and surface water quality	Very high	Negligible	Not Significant	Not Significant
	Changes in water quality as a result of changing water levels		Very high	Negligible	Not Significant	
	Changes to hydromorphology	Hydromorphology	Low	Negligible	Not Significant	
Shannon (Lower)_050	Changes in water levels	Hydrology and surface water quality	Very high	Negligible	Not Significant	Not Significant
	Changes in water levels (flood conditions)			Negligible	Not Significant	
	Changes in water quality as a result of changing water levels		Very high	Negligible	Not Significant	
	Changes to hydromorphology	Hydromorphology	High	Negligible	Not Significant	
Shannon (Lower)_060	Changes in water levels	Hydrology and surface water quality	Very high	Negligible	Not Significant	Not Significant
	Changes in water levels (flood conditions)			Negligible	Not Significant	
	Changes in water quality as a result of changing water levels		Very high	Negligible	Not Significant	
	Changes to hydromorphology	Hydromorphology	Medium	Negligible	Not Significant	
Headrace	Changes in water levels	Hydrology and surface water quality	Medium	Negligible	Not Significant	Not Significant
	Changes in water quality as a result of changing water levels		Medium	Negligible	Not Significant	
	Changes to hydromorphology	Hydromorphology	Low	Negligible	Not Significant	

WFD Surface Water Body Receptors (WFD Name)	Potential Impact	Receptor Attributes	Sensitivity	Magnitude of Impact	Significance of Environmental Effect	Overall Significance of Effect
Tailrace (North Ballycannan_010)	Changes in water levels	Hydrology and surface water quality	High	Negligible	Not Significant	Not Significant
	Changes in water quality as a result of changing water levels		High	Negligible	Not Significant	
	Changes to hydromorphology	Hydromorphology	Low	Negligible	Not Significant	
Limerick Dock	Changes in water levels	Hydrology and surface water quality	Very high	Negligible	Not Significant	Not Significant
	Changes in water quality as a result of changing water levels		Very high	Negligible	Not Significant	
	Changes to hydromorphology	Hydromorphology	Low	Negligible	Not Significant	

7. Mitigation and Residual Effects

184. The level of abstraction proposed has been assessed through the use of sophisticated models for hydrology and water quality, and no significant effects are predicted. As a result, no mitigation measures beyond the embedded design measures are proposed.

185. Likely significant effects arising from the proposed abstraction to the water environment will be addressed using embedded mitigation measures within the Proposed Project design.

186. From the assessment presented in this appendix, it is expected that residual effects will be Not Significant and will therefore remain at the significance level as those presented in Table 6.7.

References

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Figures

A9.1 Figure 1: Abstraction Study Area

A9.1 Figure 2: Water Monitoring Locations

N

Loughrea
Rea
ROOAUNMORE (DUNKELLIN BY)
Cregaclare Demesne
Kilcrow_SC_010
N65
Shannon[Lower]_SC_050
Shannon[Lower]_SC_030
Banagher
Frankford
R355
N52
Shannon[Lower]_SC_040
252 m
Cappagh[Galway]_SC_010
Shannon[Lower]_SC_060
296 m
Derry
N66
365 m
R353
Gort
R352
Camcor_SC_010
LorrhaStream_SC_010
LittleBrosna_SC_020
R421
Cutra
100 m
Slieve Aughty Mountains
Atorick
212 m
213 m
302 m
Bow_SC_010
Graney[Shannon]_SC_020
373 m
Graney
342 m
Alewnaghta
Shinrone
Ballyfinboy_SC_010
R462
Ardcrony
Townfields
LittleBrosna_SC_010
N62
Feakle
Shannon[Lower]_SC_070
Ollycraggan
Graney[Shannon]_SC_010
Scarriff
Drewsborough
Derg TN
Garraunfadda
177 m
Garrykennedy
Nenagh_SC_020
228 m
R462
R352
Bridget
R420
Youghal[Tipperary]_SC_010
N52
Ollatrim_SC_010
455 m
205 m
176 m
Cullaunyheeda
Terronea
Duin CE
Killaloe
480 m
Clonmore
Shannon[Lower]_SC_080
Nenagh_SC_010
403 m
Derg HMWB
Manna South
Longorchard
Finn CE
Castle CE
Rosroe
R463
R498
R497
699 m
Shannon[Lower]_SC_100
Newport[Tipperary]_SC_010
Ballyliddan
Cappaghwest
127 m
Moyne Temple
96 m
Castlebank
Newport
543 m
N18
R503
Kileengarrif_SC_010
R494
195 m
427 m
Thurles
Limerick
Bilboa_SC_010
Shannon[Lower]_SC_090
Bleach
Farnane
Drumbane
Mulkear_SC_020
N24
433 m
Dromsally
Mulkear_SC_010

0 2.5 5 10 15 20 25 Kilometres

Note :-
Planning Application Boundary is for information purposes only and title will be reflected in acquisition mapping'

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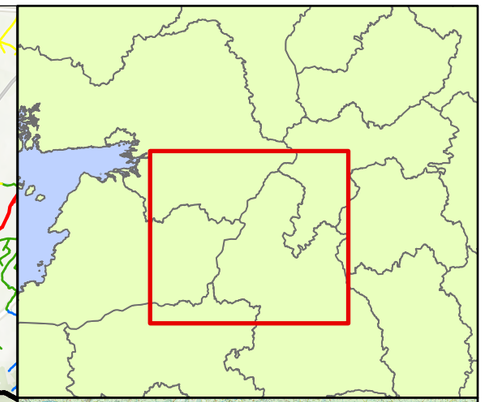
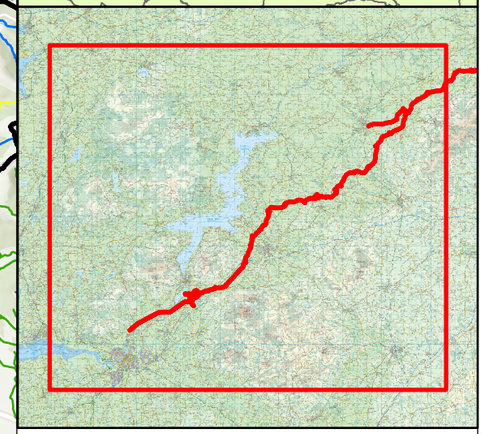
World Hillshade: Esri, Ordnance Survey, NASA, NGA, USGS
World Topographic Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS; © OpenStreetMap contributors, and the GIS User Community





Legend

- Planning Application Boundary
- Catchment Boundaries
- Subcatchment Boundaries

River Waterbody WFD Status 2019-2024
WFD Ecological Status

- High
- Good
- Moderate
- Poor

Lake Waterbody WFD Status 2019-2024
WFD Ecological Status

- Good
- Moderate
- Bad

Rev.	Date	RLB	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
F02	05/12/202	16	FINAL - PLANNING PERMISSION	EA	PG	KK	SW
F01	10/10/2025	14	FOR APPROVAL	JL	PW	HS	SW

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Client: Uisce Éireann Irish Water; Tionscadal Soláthair Uisce Water Supply Project

Project
Water Supply Project
Eastern and Midlands Region

Drawing Title
A9.1 Figure 1
Abstraction Study Area

Drawing Status: **FINAL – PLANNING APPLICATION**

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Drawing No.
32105801/700/12106

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WQMS_11A
ADCP_1
WLR_HS_1
MSSNA_1
WQMS_4
WQMS_10
WTMS_1
WQMS_1
WQMS_9
WLR_HS_2
ADCP_2
WQMS_2
MSSNA_2
WLR_HS_3
WLR_HS_6
WQMS_3
WQMS_12
ECO4
WTMS_2
ADCP_3
MSSNA_3
WQMS_5
WQMS_13
ECO3
WTMS_3
WQMS_6
WLR_HS_4
WQMS_14
ECO2
ADCP_4
MSSNA_4
WQMS_7
ECO1
WLR_HS_5
MSSNA_5
WQMS_8
WTMS_4

Abbey
Ballynakill
Portumna
Lorrha
Birr
Woodford
Terryglass
Carrig
Aglish
Rosmore
Ulicksmountain
Ballinderry
Gorteeny
Ballingarry
Pollagoona Mountain
Borrisokane
Newchapel
Coolbaun
Shinrone
Turkenagh Mountain
Cappaghabaun Mountain
Kilcomin
Whitegate
Cloghjordan
Ardcrony
Mountshannon
Puckaun
Dromineer
Scarriff
Tuamgraney
Dunkerrin
Bodyke
Mountain Park
Ogonnelloe
Portroe
Ballycommon
Newtown
Ballymackey
Moneygall
Nenagh
Toomyvara
Carrigatogher
Arra Mountains
Feenlea Mountain
Glenvagalligh Mountain
Ballykildea Mountain
Capparoe
Borrisnoe Mountain
Kilduff Mountain
Devilsbit Mountain
Ballina
Kilbane
Lackareagh Mountain
Silvermines
Dolla
Templederry
Mountains
Ballinahinch
Killoscully
Birdhill
Bridgetown
Kilmore
O'Briensbridge

N52 N65 N62 M7 M6 R445

0 0.5 1 2 3 4 5 Kilometres

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Note :-
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Legend

- Planning Application Boundary
- Acoustic Doppler Current Profiler
- Moored Sampling Station & Nutrient Analysers
- Lake Water Level Recorder
- Lake Monitoring Location
- River Monitoring Location

Rev.	Date		Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
F02	27/11/2025	16	FINAL - PLANNING PERMISSION	EA	PG	KK	SW
F01	10/10/2025	14	FINAL – PLANNING PERMISSION	JL	SM	SM	SW

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Project
Water Supply Project
Eastern and Midlands Region

Drawing Title
A9.1 Figure 2
Water Monitoring Stations

Drawing Status: FINAL – PLANNING APPLICATION

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Drawing No.	32105801/700/12106		

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Annexes

Annex A: Hydrological Modelling Report

Annex B: Water Quality Modelling Report

Annex C: Water Quality Modelling Calibration Report

Annex D: Summary Reports of Lough Derg Water Quality Monitoring May 2015 to December 2023

Annex E: Lough Derg Hydrographic Survey

Tionscadal Soláthair Uisce
Water Supply Project

Environmental Impact Assessment Report (EIAR)

Volume 6 of 6: Appendices

(Appendix A9.1 Annex A) Hydrological Modelling Report

Document no: 32105801/EIARA9.1
Version: Final

December 2025

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Acronyms and Abbreviations

Abbreviation	Meaning
CC	Climate change
CFRAM	Catchment-based Flood Risk Assessment and Management
DERG HMWB	The name given by the River Basin Management Plan process to Parteen Basin
DERG TN	The name given by the River Basin Management Plan process to Lough Derg
EIAR	Environmental Impact Assessment Report
ESB	Electricity Supply Board
EPA	Environmental Protection Agency
GEP	Good Ecological Potential
GES	Good Ecological Status
HMWB	Heavily Modified Water Body
m^3/s	Cubic metres per second
mAOD	Metres Above Ordnance Datum
Mld	Million litres per day
NOB	Normal Operating Band
NWRP	National Water Resources Plan
OPW	Office of Public Works
ORS	Old River Shannon
PE	Potential Evaporation
UKTAG	UK Technical Advisory Group
WFD	Water Framework Directive
WSP	Water Supply Project: Eastern & Midlands Region

1. Introduction

1. This report provides a summary of the hydrological modelling that has been undertaken for the Proposed Project.

2. A hydrological model was developed in order to assess the impact of the proposed abstraction on the water levels of Lough Derg and Parteen Basin and the pass forward flows released to the Old River Shannon (ORS).

3. Two constant rates of abstraction have been investigated: i) 154Mld – taken to be representative of normal operation demand by the year 2050, and ii) 300Mld – projected peak demand at year 2050. Constant abstraction rates have been used since future transfer rates on a day-by-day basis are not known. Applying an abstraction rate of 154Mld across the entire period of simulation allows the impact of that typical abstraction to be assessed every day. The projected peak of 300Mld is only envisaged to be approached at times of major drought in the east which may or may not coincide with major drought in the Shannon basin. To apply this peak abstraction rate across all days in the simulation is very much a precautionary assessment of the impact that the abstraction could have.

4. The model was run using data from the period 1 January 1972 to 31 October 2023, allowing the simulation of daily levels and daily flows across this 52-year period with and without the proposed abstraction in place. Runs of the model on earlier periods have not been undertaken as the water resources management practices differed to those of today: precluding the derivation of representative hydrological inflows.

5. The model was further developed to incorporated future climate change scenarios to also allow a simulation of the impact with the Proposed Project in place and including the effects of future climate change on flows on the River Shannon.

6. As a separate exercise, in order to test whether WFD mitigation measures and / objectives to restore the favourable conservation status of the qualifying interests of the Lower River Shannon SAC would be impeded by the Proposed Project, a sensitivity analysis was undertaken to apply an outline Eflows[1] approach proposed in a recent study to the model and investigate the potential impacts of future changes in the compensation flow regime.

7. The simulations provide an understanding of the change in lake levels and forward flows required to inform the Environmental Impact Assessment Report (EIAR) for the Proposed Project. The simulations also provide the information required to apply the UK Technical Advisory Group (UKTAG) Water Framework Directive (WFD) lake level test, which has been discussed with the Environmental Protection Agency (EPA) as being an appropriate test in the absence of an Irish WFD lake level test.

[1] Environmental flows (Eflows) are considered within the context of the WFD as a hydrological flow regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies

2. Hydrological Modelling

2.1 Description of the Hydrological System

8. Image 2.1 provides a schematic of the hydrological components of the combined Lough Derg and Parteen Basin system. The inflow from the catchment is dominated by the Shannon flow, though smaller rivers and areas of land downstream of where the Shannon joins Lough Derg also provide water. Direct precipitation to and evaporation from Lough Derg and Parteen Basin constitute the direct surface fluxes. Outflows from the system are those that flow into the ORS channel (comprising a compensation flow of 10m^3/s [made up of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates] and flood releases/spills during periods of high flow), and the water that travels down the Ardnacrusha headrace to be used for electricity power generation and a small allowance (0.5m^3/s) for the Ardnacrusha fish pass.

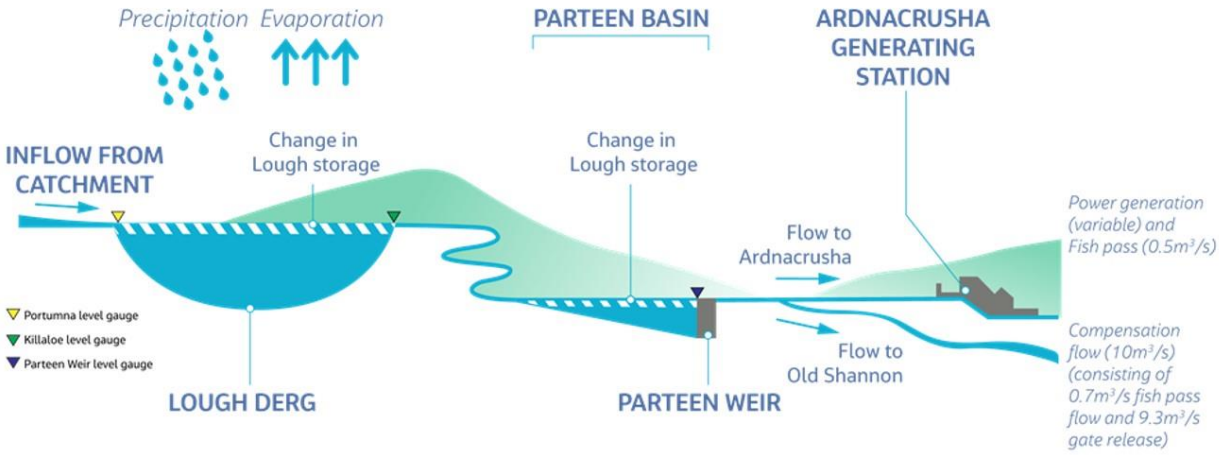


Image 2.1: Water Balance Schematic of the Lough Derg and Parteen Basin System

9. The Electricity Supply Board (ESB) monitor the outflows from the system, keeping daily records of flow through Ardnacrusha and the total amount of water leaving Parteen Basin. They also monitor the daily level of Lough Derg at Portumna and Killaloe as well as the level in Parteen Basin (Image 2.1). All records extend back to the beginning of 1932. Uisce Éireann also installed continuous monitoring level gauges in 2015 on Lough Derg, allowing cross checks to be made against the ESB level data. Refer to Attachment A for a description of the various gauges and the cross checks undertaken.

2.2 Model Build

2.2.1 Modelling Approach

10. A hydrological model representing the combined Lough Derg and Parteen Basin system has been built using a standard water balance modelling approach to simulate average lake water levels and flows at a daily time step. The daily change in the volume of water within the lake system is calculated according to the difference between inflows and outflows. This daily change in lake volume is converted to a change in average water level and added to the existing lake level. Water above the lake top water level is spilt in the next daily time step.

11. Initial modelling of the Lough Derg and Parteen Basin system lake levels was based upon reproducing observed levels and then simulating the effect of introducing the WSP (Water Supply Project Eastern and Midlands, i.e. the Proposed Project) abstraction. This initial model build is referred to as the 'Historical Model' and is described in Attachment B.

12. The Historical Model used the historical recorded Ardnacrusha flows controlled by the ESB in response to the historical inflows entering the Lough Derg and Parteen Basin system at the time, therefore offers an appropriate means for estimating what the impact of the WSP abstraction scenarios would have been on the observed Lough Derg and Parteen Basin system levels of the past (based upon the Ardnacrusha flows of the past). However, it does rely on the historical Ardnacrusha flows being appropriate for the inflows into the system.

13. Investigating the likely future WSP impacts needs an approach in which the Ardnacrusha flows can be estimated since the inflows into the system are projected to change due to climate change: with winters likely to become wetter and summers drier. Use of the historical Ardnacrusha flows in such a future will not be appropriate since in future wetter periods Ardnacrusha is likely to use more water and in drier periods the flows will need to be reduced. There is therefore a need for a rules-based approach for simulating the Ardnacrusha flows and the management of the system.

14. To model the future impact of WSP abstractions requires the inclusion of the ESB operational rules that determine how much water will flow to Ardnacrusha based upon the changed lake inflow hydrology whilst still meeting the required compensation and fish pass flows and keeping the lake levels within ESB's Normal Operating Band (NOB) for Lough Derg and within the upper and lower water levels that ESB applies to Parteen Basin. The ESB operational principles used in the final WSP hydrological model build are based on discussions with ESB to understand how ESB typically aim to manage both the Lough Derg and Parteen Basin system levels and the pass forward flows to the Ardnacrusha power station and ORS. Operational guiding principles received from ESB (as described in Section 2.2.3) were codified into the WSP hydrological model for a rules-based modelling approach.

2.2.2 Derivation of the Net Inflow Time Series

15. Coverage of river flow gauging stations monitoring the flow directly into the lake is poor and this prevents a direct measurement of the total daily inflow from the catchment. For example, the first upstream Shannon flow gauging station to monitor the full flow regime (low flows as well as high flows) is at Athlone (Athlone D/S Weir - station number 26027). That gauge monitors only 43% of the Lough Derg and Parteen Basin system catchment and has a short record only dating back to 2007. Consequently, its possible use in the derivation of a long-term inflow series to Lough Derg is rendered highly restricted. Other tributary gauges exist downstream, but large portions of the Lough Derg/Parteen Basin inflow catchment remain ungauged.

16. Therefore, to estimate the daily inflow, a back calculation of the water balance of the joint Lough Derg and Parteen Basin system is used. Daily net inflow is calculated from the recorded outflows and changes in lake storage using the following equation:

$$Q_{Inflow} = Q_{ParteenWeir} + Q_{Ardnacrusha} + \Delta S_{ParteenBasin} + \Delta S_{LoughDerg}$$

where:

Q_{Inflow}	Estimated net inflow
$Q_{ParteenWeir}$	Flow to the Old River Shannon channel
$Q_{Ardnacrusha}$	ESB headrace flow
$\Delta S_{LoughDerg}$	Change in storage on Lough Derg. Estimated from the daily average of the Portumna and Killaloe levels, and using a constant lake area = 116.5km^2 (EPA 2024[2])
$\Delta S_{ParteenBasin}$	Change in storage on Parteen Basin. Estimated from the daily Upper Parteen Basin level, and using a constant lake area = 3.6km^2 (EPA 2024[3])

[2] EPA (2024). EPA Water Environment Maps [Online]. Available at: gis.epa.ie/EPAMaps/Water [Accessed August 2024].

[3] Ibid

17. The resulting inflow is the net inflow of the catchment inflows and the direct rainfall to and evaporation from the lake surfaces. This is to say the inflow series implicitly includes the evaporation from and the direct rainfall to the lake surfaces.

18. The inflow series relies on ESB monitored outflows and ESB water level data from Portumna, Killaloe and Parteen Basin. The variation of water level between these three gauging locations is primarily affected by two factors. In the first instance the water surface profile from Portumna to Parteen Basin is dictated by the hydraulic gradient required to move water through Lough Derg, the Killaloe channel and Parteen Basin. In addition, the impact of a prevailing south-westerly wind can also result in noticeable differences between water levels at each of these gauging locations.

19. Furthermore, Parteen Basin can experience localised drawdown during periods when outflows to Ardnacrusha and the ORS channel temporarily exceed the conveyance of the incoming Killaloe channel which links Lough Derg to Parteen Basin.

20. The inflow time series calculated in this way has 'noise' in it, arising from the sensitivity of low flows to water level measurement, and the sensitivity of water level in turn to wind effects. Overall, the cumulative volume is faithfully reproduced by the calculated inflows, but variation in day-to-day calculated inflows is evident in the data. A 3-day moving average[4] time series removes the worst of this 'noise' and gives a better indication of inflow during low flows (Image 2.2).

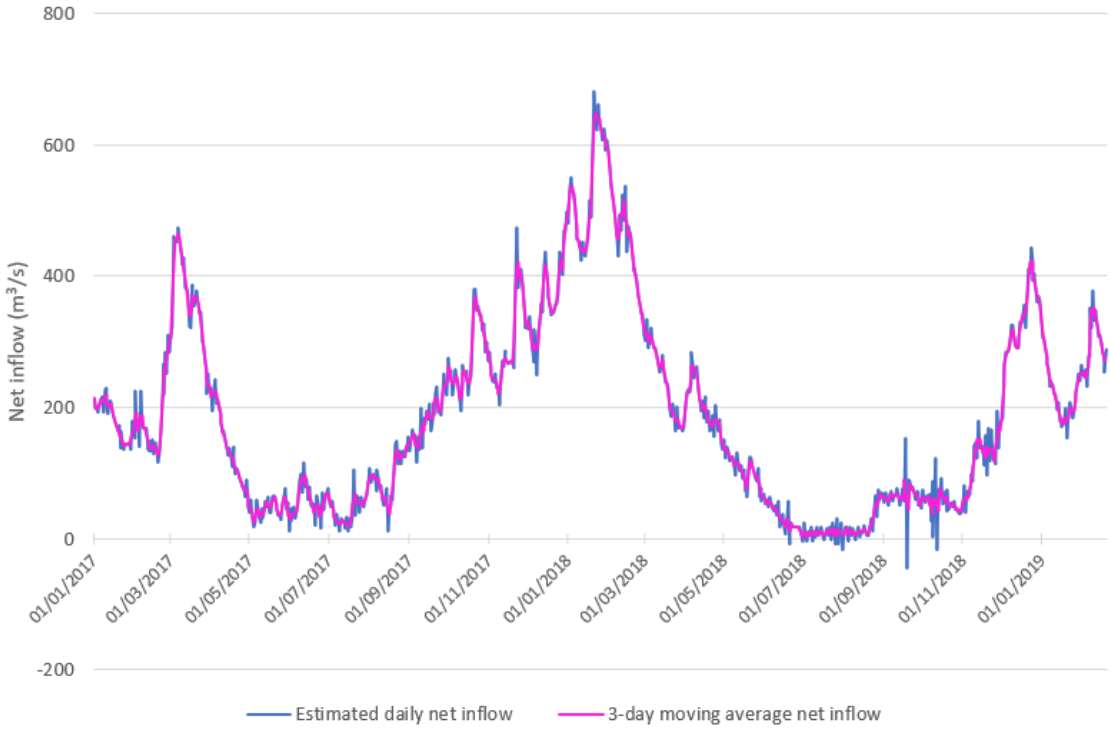


Image 2.2: Example Daily Net Inflow Smoothed Using a 3-Day Running Mean

21. Analysis of the ESB records shows that there are gaps in flow data for the periods 07/11/1991 to 14/12/1991, and 5/11/1999 and 19/11/1999. These occur during the wet early winter periods when inflows are elevated (as evidenced by the estimated flows either side of the gaps) and can be reasonably judged not to include low flows of importance to the analysis.

[4] The use of a moving average for presenting flows or levels is a commonly used approach within hydrology to remove the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends. Within this report, both a 2-day and 3-day moving average approach have been used for different hydrological datasets, based on the noise of the specific flow or level time series.

22. The 99-percentile flow (Q99) calculated from the 3-day moving average series is estimated to be 12.3m^3/s for the full 52-year model net inflow period 01/01/1972 to 31/10/2023. The 95-percentile flow (Q95) is estimated to be 25.6m^3/s; and the 50-percentile flow to be 159.0m^3/s.

23. The 2018 and 1995 summer drought events were the most significant in terms of the duration and frequency of extremely low inflows to the Lough Derg and Parteen Basin system. The back-calculated inflow for 2018 was less than 15m^3/s on 54 days and less than 10m^3/s on 33 days. By comparison, the back-calculated inflow for 1995 was less than 15m^3/s on 31 days and less than 10m^3/s on 16 days.

24. The WSP impact assessments need to be representative of the hydrological conditions going forward. Prior to 1972 the management of the Shannon was significantly different to that of today. Active management of upstream storages in Lough Ree and Allen occurred to supplement flows to Lough Derg. After 1971 this ceased and the upstream Shannon management regime (which follows prescribed actions to meet navigation and flood management requirements) has since been, it is understood, applied in a consistent manner. The derived inflows to Lough Derg prior to 1972 are therefore judged to be potentially unrepresentative of the post 1971 hydrological conditions and for this reason are not included in the analysis.

25. The net lake inflow time series (1972–2023) used in the WSP hydrological model is a function of catchment inflows, precipitation falling directly on the lake surface and evaporation losses from the lake system. While these components are combined in the inflow time series, in the context of climate change each of these hydrological components will experience different climate change effects. Given the hydrological model has been built to understand future impacts, these hydrological components have been separated out to facilitate assessment under different climate change scenarios.

26. The following equation allows the catchment inflow to be estimated from the net inflow series:

$$Q_{\text{Catchment Inflow}} = Q_{\text{Net Inflow}} - P_{\text{Lake}} + E_{\text{Lake}}$$

where:

$Q_{\text{Catchment Inflow}}$ Fluvial inflow from the upstream catchment

$Q_{\text{Net Inflow}}$ Net inflow as described above

P_{Lake} Precipitation to the lake surface

E_{Lake} Evaporation from the lake surface

27. The precipitation daily series was derived from Met Éireann data from the following gauges: Portumna O.P.W. and Killaloe Docks, supplemented by the Ardnacrusha (Gen.Stn.No.2) gauge to fill gaps in the Killaloe gauge.

28. The long-term evaporation series for the lake surface was derived by scaling a long-term potential evaporation (PE) series (derived from gridded daily temperature using the Oudin formula[5]) to that of the measured PE record (2008–2023) at the Met Eireann Gurteen weather station (located between Borrisokane and Birr). The resulting PE series 1972–2023 was then converted to an open water estimate using the Finch formula following guidance given in Environment Agency (2001)[6]. It is recognised that the Finch formula may have limitations in its application in Ireland as it was developed for UK hydrological modelling, based on empirical relationships derived from UK open water evaporation data. However, it

[5] Oudin *et al.* (2005). Which potential evapotranspiration input for a lumped rainfall-runoff model? Part 2 - Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling. Journal of Hydrology. 303(1-4). 290-306.

[6] Environment Agency (2001). Estimation of Open Water Evaporation – A review of methods, R&D Technical Report W6-043/TR.

was deemed the best approach based on experience and professional judgment in the absence of available Ireland-specific methods.

2.2.3 ESB Operational Principles

29. The ESB work to the Poolbeg datum, whilst the WSP hydrological model has been set up to work to the Malin Head datum. All levels given here are with respect to Malin Head, though equivalent Poolbeg values are given in italics[7].

30. The ESB manage the water levels on Lough Derg (Derg TN) within the NOB. This band is defined using the following water levels:

- Lough Derg top of NOB = 30.86mAOD *[33.56mAOD Poolbeg]*
- Lough Derg 'Black Start' reserve level = 30.50mAOD *[33.20mAOD Poolbeg]*
- Lough Derg bottom of NOB = 30.40mAOD *[33.10mAOD Poolbeg].*

31. On Parteen Basin (Derg HMWB) ESB keep water levels within an upper and lower water level, for dam safety purposes. These water levels are as follows:

- Parteen Basin upper water level = 30.86mAOD *[33.56mAOD Poolbeg]*
- Parteen Basin lower water level = 30.00mAOD *[32.70mAOD Poolbeg]*.

32. Parteen Weir acts as the downstream control structure for water levels in the system. Water levels in Parteen Basin are maintained within the upper and lower levels at all times. During low flow conditions, the lower water level at Parteen Basin (30.0mAOD Malin), must be maintained for dam safety purposes and in doing this ESB ensures that water levels on Lough Derg are within the NOB as the waterbodies broadly operate as a combined system, in these conditions.

> Note upon Lough Derg levels:
> The Lough Derg operating band referred to above are with respect to the levels as monitored at Killaloe (Pier Head). However, the water balance modelling work is based upon the average Lough Derg water level – calculated as the average of the levels recorded at Portumna and at Pier Head, Killaloe (refer to Section 2.2.2). The Portumna and Killaloe levels can differ due to wind and flow effects through the lake, and the range of difference is about 0 to 0.4m. These differences are a function of flow magnitude and wind direction and speed. When Ardnacrusha is operating at near full capacity there is on average about a 0.2m difference in the levels (meaning that in these conditions there is approximately a 0.1m difference between the Killaloe level and the average lake level). During the summer period (when inflows are low) the recorded Killaloe level equates more closely to the average lake level.

33. The received ESB key principles/rules governing the level management of Lough Derg and Parteen Basin are provided in Table 2.1. For a fuller description refer to Attachment C.

Table 2.1: Key Principles and Rules Governing the Management of the Levels in the Lough Derg and Parteen Basin System

General Principle or Rule	Description
Water level to be kept within the Lough Derg Normal Operating Band (NOB)	The ESB manage the water levels (as monitored at Killaloe) to be within the Lough Derg Normal Operating Band (NOB) between 30.40mAOD and 30.86mAO. During sufficiently big floods the level of Lough Derg cannot be prevented from exceeding the top of the NOB and the Flood Rule comes into effect. The NOB is further refined by the presence of the 30.50mAOD 'Black Start' reserve level for water that is reserved by ESB in case of a supply emergency upon the electricity network necessitating power to be supplied by Ardnacrusha. Whilst it is acknowledged that ESB may manage lake water levels not to encroach upon the Black Start reserve, the WSP hydrological models do not use the Black Start as a minimum threshold level, and are only concerned with simulated levels being maintained within the NOB.

[7] To convert levels recorded to the Malin Head datum to the Poolbeg datum (in the vicinity of Lough Derg and Parteen Basin) a value of 2.7m needs to be added to the Malin Head level.

General Principle or Rule	Description
Early summer Lough Derg level	A guide rather than a strict rule. The ESB do not aim to be at 30.86mAOD at Pier Head, but tend to the upper end around 30.80mAOD average Lough Derg level, subject to operational requirements which can, when there is sufficient water available, mean that they utilise the full operating band. ESB seek to have Derg water levels towards the upper end of the NOB in late spring/ early summer.
Autumn and winter Lough Derg level	A guide rather than a strict rule. ESB seek to have Lough Derg water levels towards the lower end of the NOB in autumn and winter to allow ESB to have lake storage available to accommodate flood flows into the system.
Low flow regime	A guide rather than a strict rule. Lough Derg inflow of 100m^3/s on a falling hydrograph is a trigger to commence retaining water towards the upper end of the NOB.
Compensation flow	Statutory compensation flow of 10m^3/s is released to the Old River Shannon[8], and 0.5m^3/s is also released at the Ardnacrusha fish pass.
Flood rule	When Lough Derg levels are greater than the top of the NOB (30.86mAOD) and inflow is greater than the maximum capacity of Ardnacrusha power station (i.e. greater than about 400m^3/s), then excess water is released down the Old River Shannon until the Parteen Basin level does not go below 30.00mAOD.

34. Based on the above information and interpretation of the level and flow time series, an algorithm for simulating the day-by-day abstraction rate to Ardnacrusha was developed. The algorithm is based upon: i) the net inflow from the previous day, ii) the size of the compensation flow, iii) and a 20m^3/s inflow threshold below which the Ardnacrusha flow is switched to zero. Refer to Attachment C for more detail and performance assessment of the algorithm.

35. An exact match between simulated and actual flows used for Ardnacrusha power generation is not expected to be possible since this is in part dictated by power generation commercial factors on the day-to-day ESB abstraction. The available description of the level management does not explicitly describe the rules governing this aspect. However, the resource is finite and Ardnacrusha abstraction on one day (or several consecutive days) will need to be balanced out within subsequent abstractions to keep the levels within the Lough Derg NOB (outside of flood periods). In this way the abstraction possible from a longer period is quite tightly constrained by the amount of water entering the system and the need to keep the level within the Lough Derg NOB, though there is flexibility on a day or short sequence of days for power generation optimisation.

36. An important aspect to recognise is that the level of the Lough Derg and Parteen Basin system is quite sensitive to the amount of water flowing to Ardnacrusha. For example: with an average daily inflow of 100m^3/s and allowing for 10m^3/s compensation flows to the ORS, the lake level will rise by 65mm with no generation in a 24-hour period. For context the level difference between the top and bottom of the Lough Derg NOB is only 460mm. This suggests that the ESB have a reasonable degree of control on lake levels outside of flood and drought periods. This gives the ESB some freedom to vary their abstraction rates (outside of drought periods) to meet their short-term power generation requirements safe in the knowledge that there is sufficient near-term future inflow such that the lough levels can be restored. Only when the inflow reduces towards low flow/drought flow does this flexibility reduce and is presumed to be the reason why the level is managed towards the upper end of the Lough Derg NOB during low flow periods so that if a drought does occur there is adequate storage within the Lough Derg NOB to meet the compensation and fish pass flow requirements.

37. The level of the Lough Derg and Parteen Basin system is sensitive to the Ardnacrusha abstraction. For example: minor differences in abstraction and/or compensation flow over several days/weeks will result in an additive displacement of the lake level. These adjustments can make the water balance modelling difficult as they result in inappropriate starting levels being simulated at the onset of a drought. If the simulated starting level were inappropriately too low, then it is more likely that the simulated drought level will drop towards the bottom of the Lough Derg NOB. To counter this within the model, a simple routine has been added that ‘hunts’ to set the lake level either towards the upper end of the Lough Derg NOB

[8] Formed of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates

during low inflow periods (net inflows <100m^3/s) or towards the lower end of the Lough Derg NOB outside of the low inflow periods (as indicated in Table 2.1).

38. The 'hunting' routine takes the simulated Ardnacrusha flow and adds a small additional amount on if the lake level is above the targeted level. Conversely a small amount is subtracted from the simulated Ardnacrusha flow if the lake level is below the targeted level. This is continually applied on subsequent time steps and the simulated level will tend towards the target level whilst maintaining the water balance of the system. However, in flood periods the hunting routine is swamped, and the level will move above the targeted level. During drought periods (net inflows <20m^3/s) when the Ardnacrusha flow is switched off, the hunting routine is also switched off and the level will (if the outflow is greater than the net inflow) drawdown away from the targeted level.

39. The WSP hydrological model uses two average lake 'target' levels based on the operating guiding principles information received on when ESB seek to have lake water levels towards the upper or lower end of the Lough Derg NOB (see Table 2.1). The upper target level is taken to be 30.80mAOD *[33.50mAOD Poolbeg]*. The lower target level is taken to be 30.70mAOD *[33.40mAOD Poolbeg]* (which is approximately equivalent to 30.60mAOD *[33.30mAOD Poolbeg]* when viewed from the perspective of the Pier Head gauge at Killaloe once the gradient of the lake's surface is allowed for during high flow periods).

40. The selection of which target level the model aims to manage levels to is based upon the size of the back simulated lake net inflow. The inflow trigger threshold is set at 100m^3/s with the upper target level (30.80mAOD) chosen when the inflow is below 100m^3/s, and the lower target level (30.70mAOD) chosen when the inflow is greater than 100m^3/s. Refer to Attachment C for more detail and performance assessment of the model hunting routine.

2.2.4 Incorporating the Proposed WSP Abstraction

41. The model is set up as a standard water balance model run on a daily time step with excess water above the top of the Lough Derg NOB being spilled to the ORS. The daily change in the volume of water within the Lough Derg and Parteen Basin system is calculated according to the difference between inflows and outflows, where the proposed WSP abstraction is represented as an additional outflow component that removes a fixed constant daily volume (either 154Mld or 300Mld scenario) from the system simulated storage volume calculation.

42. The WSP hydrological model total outflow is given by:

    Outflows = Ardnacrusha flow + Ardnacrusha fish pass flow + compensation flow[9] to the ORS + flood release/spill to the ORS + WSP abstraction

43. This daily change in simulated lake volume is converted to a change in simulated lake water level and added to the existing lake level.

44. The WSP hydrological model calculates daily simulated outflows based on using the following three different lake inflow conditions scenarios:

    i) Flood conditions:

45. If the lake inflow is greater than the 390m^3/s maximum generation capacity of Ardnacrusha power station[10], then the Ardnacrusha flow is set to 390m^3/s. The model hunting routine to adjust Ardnacrusha flows to manage lake level towards the Lough Derg NOB upper or lower target level is switched off. The compensation, fish pass and flood release/spill flows to the ORS are maintained as they would normally without the WSP abstraction in place. Water above the top of the Lough Derg NOB is spilt in the next time

[9] The compensation flow consists of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates

[10] 390m^3/s is based on the observed average historical performance received

step. The WSP abstraction is provided from a minor reduction in the simulated lake storage. The model assumes that depletion of lake storage results in a drop in water level which is evenly distributed across the entire surface area of Lough Derg and Parteen Basin system.

ii) Normal conditions (non-flood and non-drought):

46. If the lake inflow is between 20m^3/s and 390m^3/s, the Ardnacrusha flow is firstly set to the difference between the inflow and the required compensation and fish pass outflows, then adjusted by the hunting routine to manage lake level towards the Lough Derg NOB upper or lower target level. The compensation and fish pass flows to the ORS are maintained as they would normally without the WSP abstraction in place. The WSP abstraction is provided from a minor reduction in the simulated lake storage. The model assumes that depletion of lake storage results in a drop in water level which is evenly distributed across the entire surface area of Lough Derg and Parteen Basin system.

iii) Drought conditions:

47. If the lake inflow is less than 20m^3/s then the flow to Ardnacrusha is set to zero as power generation is ceased (a threshold based upon observed recent management practice). The model hunting routine to adjust Ardnacrusha flows to manage lake level towards the Lough Derg NOB upper or lower target level is switched off. The compensation and fish pass flows to the ORS are maintained as they would normally without the WSP abstraction in place. The WSP abstraction is provided from a reduction in the simulated lake storage. The model assumes that depletion of lake storage results in a drop in water level which is evenly distributed across the entire surface area of the Lough Derg and Parteen Basin system. Once the drought ceases and lake inflows recover the lake storage deficit is preferentially replenished before ESB hydropower generation is permitted to begin. Once the lake level has recovered towards the target level then the normal conditions rules apply.

2.3 Model Simulations

48. This section provides the findings from the WSP hydrological model simulations testing the impacts of the inclusion of the proposed WSP abstraction (as a constant flow of either 154Mld or 300Mld) to the Lough Derg and Parteen Basin system lake levels and forward flows to the ORS and ESB Ardnacrusha headrace channel.

49. The model was run using data from the period 1 January 1972 to 31 October 2023, allowing the simulation of daily levels and daily flows across this 52-year period with and without the proposed abstraction in place.

50. The model was further developed to incorporated future climate change scenarios to also allow a simulation of the impact with the Proposed Project in place and including the effects of future climate change on flows on the River Shannon.

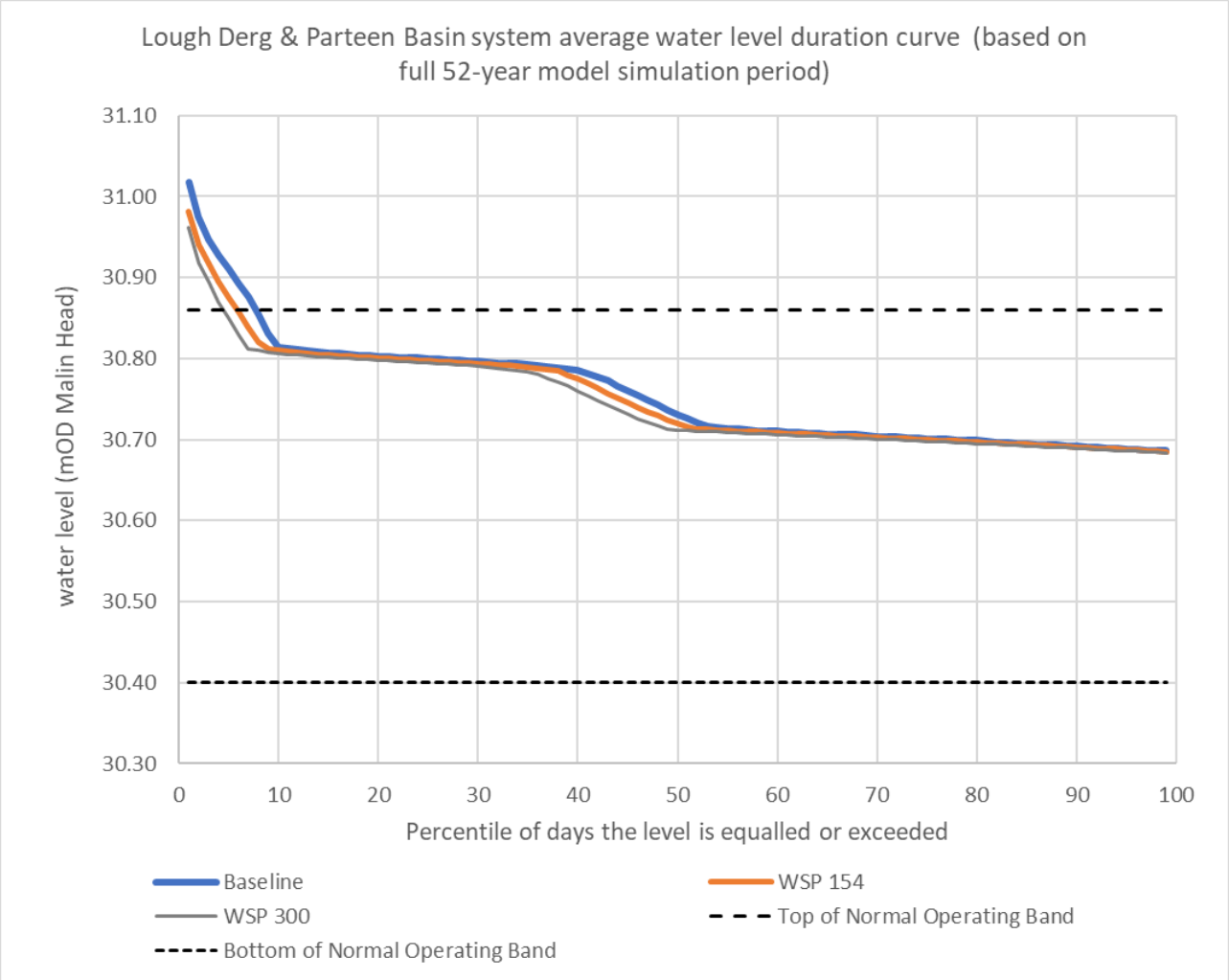
51. As a separate exercise, in order to test whether WFD mitigation measures and / objectives to restore the favourable conservation status of the qualifying interests of the Lower River Shannon SAC would be impeded by the Proposed Project, a sensitivity analysis was undertaken to apply an outline Eflows approach proposed in a recent study the model and investigate the potential impacts of future changes in the compensation flow regime.

52. Regarding lake water levels, the ESB work to the Poolbeg datum; however, the WSP hydrological model has been set up to work to the Malin Head datum. Therefore, all water level graphs in this report are given as metres Above Ordnance Datum (mAOD) with respect to Malin Head. To convert levels recorded to the Malin Head datum to the Poolbeg datum (in the vicinity of Lough Derg and Parteen Basin) a value of 2.7m needs to be added to the Malin Head level.

2.3.1 With the Proposed WSP Abstraction

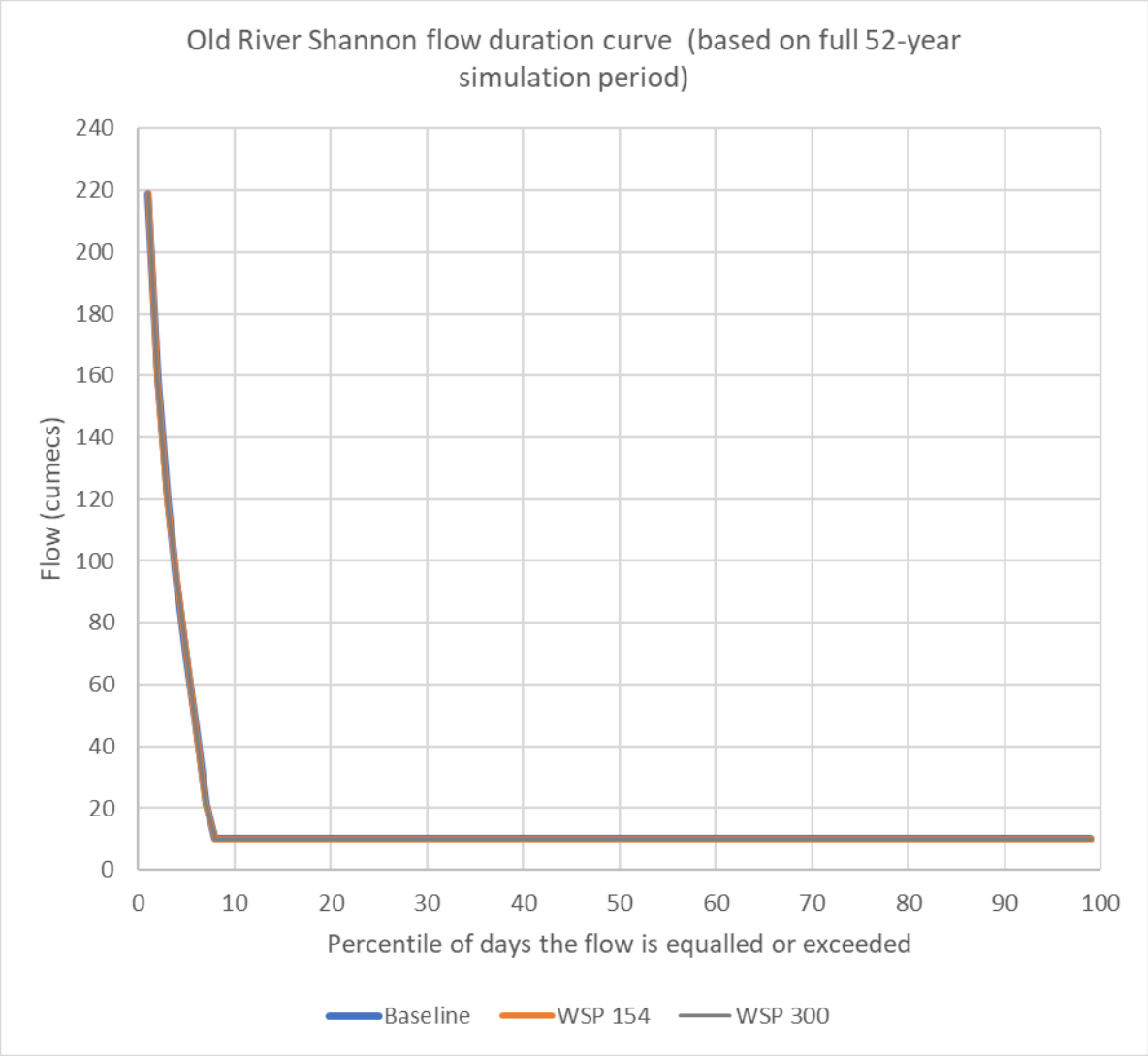
53. The full 52 years of model simulation (1972–2023), comparing the simulated time series of the Lough Derg and Parteen Basin system average water levels and the forward flows down the ORS, with and without the WSP abstraction in place, are provided in Attachment D. Image 2.3 presents the lake level results in the form of a level duration curve, and Image 2.4 and Image 2.5 present the ORS and the Ardnacrusha flows in the form of flow duration curves.

54. Level and flow duration curves are a commonly used means within hydrology of presenting level and flow regime characteristics in the form of the percentage of time a flow is equalled or exceeded. Flow duration curves are the basis of commonly referred to flows such as the Q95 flow (a low flow index that means the flow that is equalled or exceeded for 95% of the time) or Q50 flow (the flow that is equalled or exceeded for 50% of the time). As such the flow and level duration curves offer a succinct means of comparing flow and level regimes derived from long time series of data.



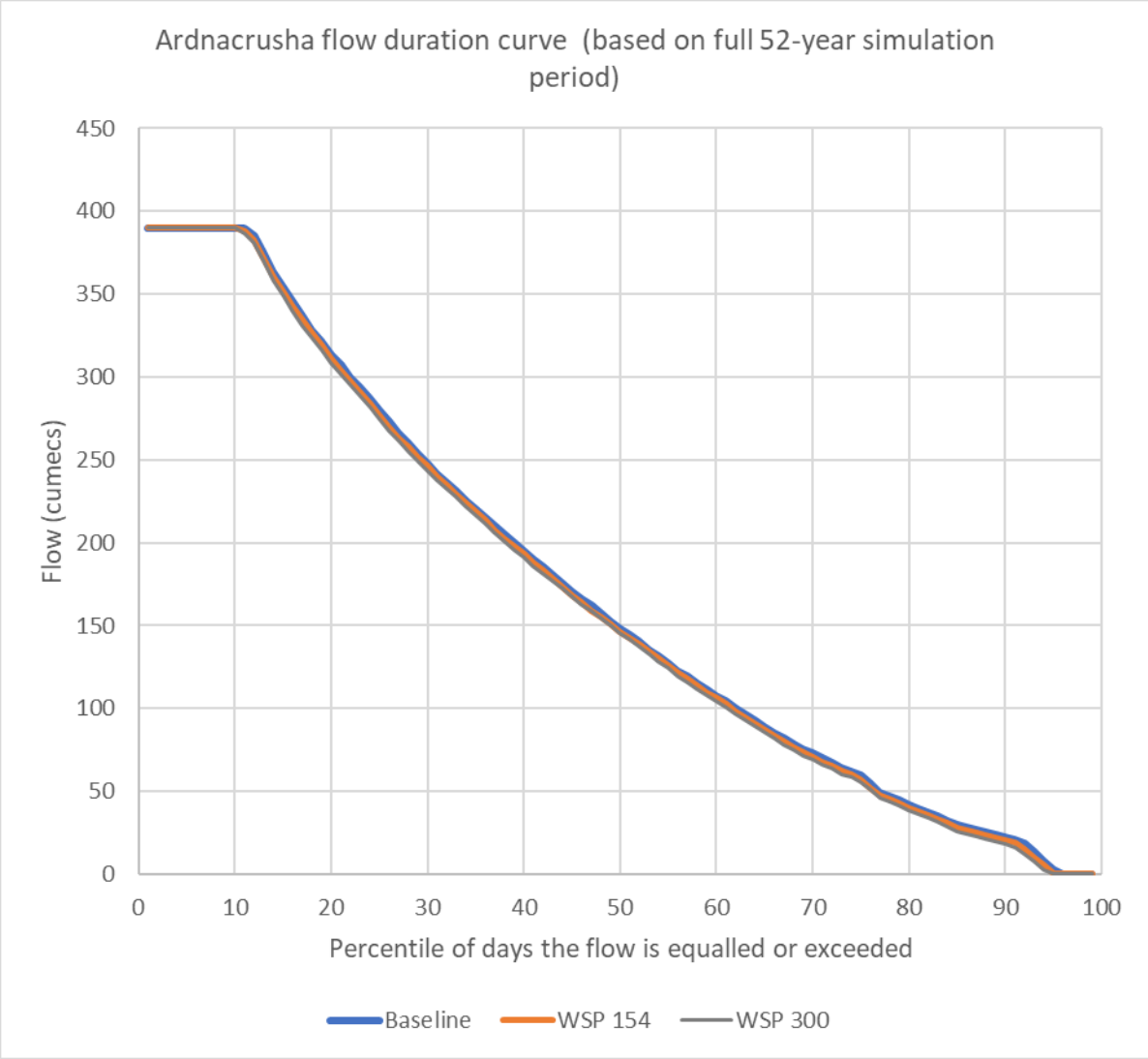
Note: The overlapping of the curves causes the individual colours to be difficult to distinguish

Image 2.3: WSP Hydrological Model: Simulated Impact of WSP Abstraction on the Lough Derg & Parteen Basin System Level Duration Curve



Note: The overlapping of the curves causes the individual colours to be difficult to distinguish

Image 2.4: WSP Hydrological Model: Simulated Impact of WSP Abstraction on the Flow to the Old River Shannon Flow Duration Curve



Note: The overlapping of the curves causes the individual colours to be difficult to distinguish

Image 2.5: WSP Hydrological Model: Simulated Impact of WSP Abstraction on the Ardnacrusha Flow Duration Curve

55. Image 2.3 to 2.5 demonstrate that the impact to the Lough Derg and Parteen Basin system water level, ORS flow and Ardnacrusha flow regimes due to the inclusion of the proposed WSP abstraction are barely distinguishable across the 52-year model simulation period. This is because the proposed peak WSP abstraction (300Mld) represents less than 2% of the long-term average daily inflow to Lough Derg.

56. The flows into the ORS are simulated in the baseline (no WSP) case to be greater than the required compensation flow[11] of 10m^3/s for only 7% of the time. The percentage of days is not simulated to change in the two WSP scenarios modelled (as a constant flow of either 154Mld or 300Mld).

57. Image 2.3 shows minor simulated lake level differences only between the baseline (without WSP) and WSP scenarios because the WSP hydrological model is set up to provide the proposed WSP abstraction from a marginal depletion in the simulated lake storage on a daily basis across the model simulation period (1972–2023). The graph shows the minor level differences to occur in the higher simulated lake levels only. This is because during model flood conditions, the Ardnacrusha flow is fixed to its maximum capacity (390m^3/s) and the model hunting routine which adjusts Ardnacrusha flows to manage lake levels towards a Lough Derg NOB target level is switched off (as described in Section 2.2.4). For context on the

[11] Consisting of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates

scale of different modelled lake outflows, the proposed WSP abstraction peak flow of 3.47m³/s (300Mld) equates to less than 1% of the 390m³/s Ardnacrusha peak flow. Therefore, the proposed WSP abstraction has a negligible impact to lake levels when compared to the Ardnacrusha lake outflows.

58. Whilst Image 2.5 shows minor lake level differences to occur in the higher simulated lake levels only when viewed as the level duration curve for the full long-term 52-year analysis, there can be some notable differences occurring during specific extreme drought events within the simulation period. Therefore, it was decided to look closer at specific drought events that the Lough Derg and Parteen Basin system was proven to be the most sensitive to. The 2018 drought event shows the biggest impact of the WSP scenarios on the simulated lake levels, and the 1995 drought shows the second biggest impact.

59. Attachment D provides the WSP hydrological model simulation full long-term 52-year (1972–2023) time series. Image 2.6 and Image 2.7 present a closer look of the time series simulations for these two extreme droughts 1995 and 2018. The graphs provide simulated lake levels (with and without WSP) on the first Y-axis, and simulated flows on the second Y-axis. A 2-day running mean is applied to the simulated lake water levels to remove the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends in levels. The flows include the back-calculated daily net lake inflows to the Lough Derg and Parteen Basin system (discussed in Section 2.2.2), and the simulated Ardnacrusha flows to the power station (with and without WSP). To note the overlapping of the lines can cause the individual colours to be difficult to distinguish. A drought indicator[12] is provided at the top of the graphs as a guide to when the lake daily net inflows dropped significantly for a certain period of time.

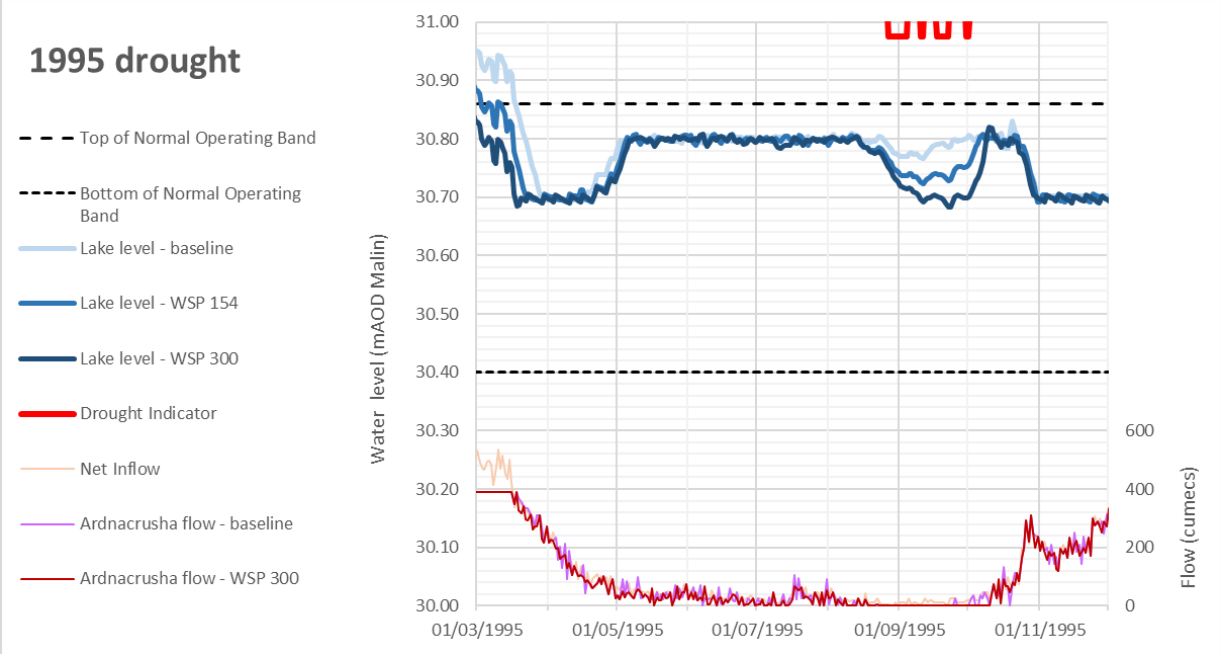


Image 2.6: WSP Hydrological Model: Simulation of the 1995 Drought Event: i) Baseline (Without WSP), ii) WSP = 154Mld, and iii) WSP = 300Mld

[12] The drought indicator is specific for the sensitivity of this system and is based upon flagging the occurrence of five consecutive days when the net inflow is less than 20m³/s

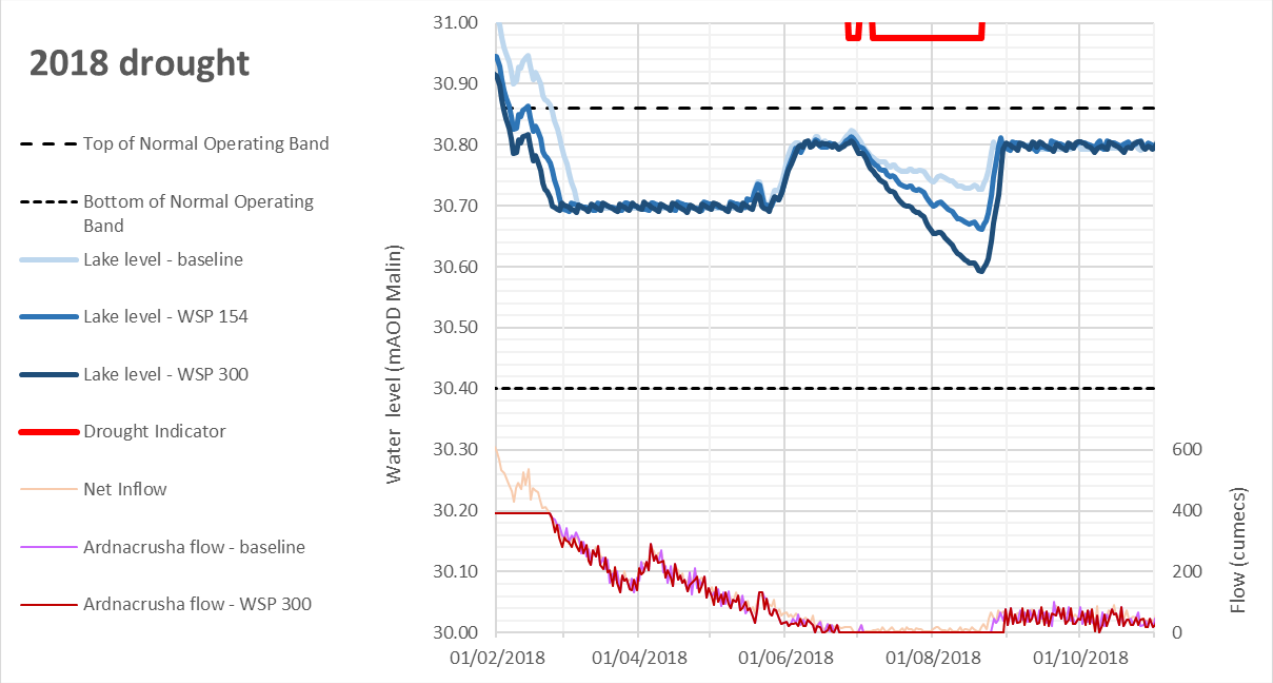


Image 2.7: WSP Hydrological Model: Simulation of the 2018 Drought Event: i) Baseline (Without WSP), ii) WSP = 154Mld, and iii) WSP = 300Mld

60. From the long-term 52-year model simulation period, the 2018 drought event shows the biggest difference in simulated lake levels between the baseline (without WSP) and with WSP scenarios. Image 2.7 shows how during the modelled 2018 drought event, an extended period of severely low summer lake inflows (<20m^3/s) triggers the model drought conditions scenario rules, meaning the flow to the Ardnacrusha power station is switched off for several weeks. However, the lake outflows still outweigh the severely low lake inflows as the model must still maintain the ORS compensation and fish pass flows, resulting in a drawdown in simulated lake storage and levels. The inclusion of the proposed WSP abstraction as an additional lake outflow that must be maintained results in a deeper drawdown than the baseline (without WSP) scenario.

61. For the modelled 2018 drought, the WSP 154Mld scenario results in a simulated lake level drawdown low point 65mm below the baseline (without WSP) scenario. For the peak WSP 300Mld scenario the difference at the lowest point of the drawdown is 134mm below the baseline. This size and rate of change easily fits within the commonly observed level changes seen within the 52-year period of observed levels (refer to Image B.1 within Attachment B to see the fluctuations in the observed historical levels recorded by ESB). As Image 2.7 demonstrates, even during the most impactful drought event in the 52-year model simulation period, the additional simulated lake level drawdown caused by the inclusion of WSP is still within the Lough Derg NOB and within the upper and lower water levels that ESB applies to Parteen Basin.

2.3.2 With Future Climate Change Impacts

62. The WSP hydrological model includes the required flexibility to assess the impacts of the WSP abstraction in the future, by using a rules-based modelling approach to adjust to the projected changes to the lake inflow hydrology from future climate change impacts.

63. A precautionary approach to the consideration of climate change and a ‘reasonable worst case’ for the 2080s epoch has been used for the Proposed Project EIAR.

64. Two sources of climate change information regarding how Irish fluvial flows are projected to change were used and the results compared.

i) Maynooth, 2008. Climate Change – Refining the Impacts for Ireland (2001-CD-C3-M1) STRIVE Report

ii) ICARUS, 2020. Identification of climate sensitive catchments: Water Resources and Climate Change Adaptation. CRU Report.

65. The Maynooth (2008) report supplies river flow monthly change allowances for the 2080s epoch together with an indication of uncertainties for nine catchments across Ireland. In the Uisce Éireann National Water Resources Plan (NWRP) (Irish Water 2021)[13] these climate change allowances were used to derive an Ireland-wide set of monthly river flow change allowances together with Upper and Lower values[14] (refer to Attachment E for more detail). These allowances matched closely with the average values of a subset of central and western catchments. The Ireland-wide set of allowances formed one means of adjusting the catchment inflows to Lough Derg and Parteen Basin and are referred to as the NWRP allowances. The Lower allowances are used to provide the reasonable worst case scenario.

66. The ICARUS (2020) study provides a more up to date appraisal of how climate change is projected to alter river flows. It supplies a means of selecting climate change allowances dependent on catchment characteristics for any location in Ireland. Allowances for the 2080s epoch are supplied for two representative concentration pathways (RCP4.5 & RCP8.5)[15] for a 2-degree Celsius rise in annual mean temperature. The allowances supplied sample the probabilistic nature of the projections such that Upper and Lower estimates around a Central projection can be considered. Unlike the Maynooth (2008) monthly allowances the ICARUS allowances are supplied only for the low flow statistic Q95 (the flow that is equalled or exceeded for 95% of the time). This prevents a perturbation of the full flow regime which is likely to be of importance when considering a system with lake or reservoir storage[16].

67. To apply the ICARUS allowances a variant of the NWRP approach has been followed in which the NWRP allowances are applied throughout the calendar year, with the exception of during drought periods when the ICARUS allowance is applied instead. The applicability of the ICARUS Q95 allowances for rarer drought events has been investigated and found likely to provide a reasonable first-order estimate of allowances for low flows as rare as the 1 in 25-year low flow (though with the caveat that greater uncertainties, and hence lower confidence, apply to those flows at the rarer end of the scale). This approach to applying climate change to the inflows is referred to as the ICARUS Variant method. See Attachment F for more details on the study undertaken by this project to investigate the applicability of the ICARUS climate change allowances for Q95 to rarer low flows.

68. A range of allowances are supplied by the ICARUS study based upon the probabilistic nature of the underlying projection data. To supply a reasonable worst case scenario for the 2080s the RCP8.5 Upper 75th allowance was selected[17] (in the results it is also referred to as the Lower Scenario to be consistent with the nomenclature of the NWRP approach). For comparison the results, from the Central 50th (2080s, RCP8.5) climate change allowance, are also presented to provide context.

[13] Irish Water (2021). National Water Resources Plan – Appendix F.

[14] The 2080s Lower Scenario factors have been taken to represent the reasonable worst case scenario. The numerical values are lower in comparison to the Central Scenario values and result in larger reductions of flow. For example: the Lower Scenario August percentage change in flow is -25.4%, whereas the central Scenario value is -11.4%.

[15] A Representative Concentration Pathway is a greenhouse gas concentration trajectory adopted by the IPCC. The RCP8.5 pathway is considered to be at the upper end of what could occur whilst the RCP4.5 is a more central pathway.

[16] The level of a reservoir or raised lake depends not only on the balance between the inflows and outflows during the drought period but also on the antecedent water level. The antecedent water level is dependent on the inflows prior to the drought. It is therefore generally necessary to consider how climate change is likely to affect the inflows outside of the low flow period as well.

[17] The Upper 75th means that from the ensemble of possible projections 75% of them have estimates that are less worse, and 25% have estimates that are worse than the value being used.

69. Climate change was incorporated into the projection of evaporation using the +2°C increase in mean temperature approach used in the ICARUS (2020) study, which uses the Oudin formula to estimate the change in evaporation. Sensitivity analysis to a +/-0.5°C uncertainty to the +2°C increase in mean temperature suggested only marginal differences in the simulated levels and was not therefore included in the analysis.

70. Seasonal rainfall allowances were obtained from an interpretation of various sources of Ireland specific climate change analyses (Maynooth 2008[18]; Maynooth 2018[19]; Nolan *et al*. 2017[20]; Nolan & Flanagan 2020[21]) which suggests for the 2080s that summer rainfall depth may be reduced by -21% (+/- 7) and winter rainfall increased by +16% (+/- 7) (see Attachment E).

71. Image 2.8 and Image 2.9 present the modelling results with the reasonable worst case 2080s climate change impacts (CC 2080s Lower) included for the baseline (without WSP) and with WSP scenarios for the 1995 and 2018 drought events respectively. The graphs also provide the simulated lake levels without future climate change allowances (shown previously in Image 2.6 and 2.7). Therefore, Image 2.8 and Image 2.9 show the combined effects of both projected future climate change and WSP on simulated lake levels for the two most impactful modelled drought events 1995 and 2018.

72. As previously, the graphs provide simulated lake levels on the first Y-axis, and simulated flows on the second Y-axis. A 2-day running mean is applied to the simulated lake water levels to remove the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends in levels. Regarding flows, the graphs include the back-calculated daily net lake inflows to the Lough Derg and Parteen Basin system with and without including climate change allowances, and the simulated Ardnacrusha flows to the power station with and without climate change. To note the overlapping of the lines can cause the individual colours to be difficult to distinguish. A drought indicator[22] is provided at the top of the graphs as a guide to when the lake daily net inflows dropped significantly for a certain period of time.

73. Slight level differences between the baseline and climate change scenarios are simulated during the transitions between the upper and lower target levels. This is due to the seasonal change of more water in the winter and less water in the summer resulting in a difference in timing of when the 100m^3/s net inflow threshold flow occurs. This is a function of the climate change scenario rather than an impact of the WSP abstraction. As discussed in Section 2.2.3, the selection of which target level the model aims to manage levels to is based upon the size of the simulated inflow: the inflow trigger threshold is set at 100m^3/s with the upper target level (30.80mAOD) chosen when the inflow is below 100m^3/s, and the lower target level (30.70mAOD) chosen when the inflow is greater than 100m^3/s.

[18] Maynooth (2008). Climate change – Refining the impacts for Ireland, Report for the EPA STRIVE Programme 2007 – 2013.

[19] Maynooth (2018). Regional Climate Model Simulations for Ireland for the 21st Century (2011-CCRP-MS-2.2) EPA Research Report (EPA Research Programme 2014-2020).

[20] Nolan P. O'Sullivan J, McGrath R (2017). Impacts of climate change on mid-twenty-first-century rainfall in Ireland: high resolution regional climate model ensemble approach. International Journal of Climatology, 4347 – 4363.

[21] Nolan P & Flanagan J (2020). High-resolution Climate Projections for Ireland – A Multi-model Ensemble Approach, EPA Research Report, (2014-CCRP-MS.23).

[22] The drought indicator is specific for the sensitivity of this system and is based upon flagging the occurrence of five consecutive days when the net inflow is less than 20m^3/s.

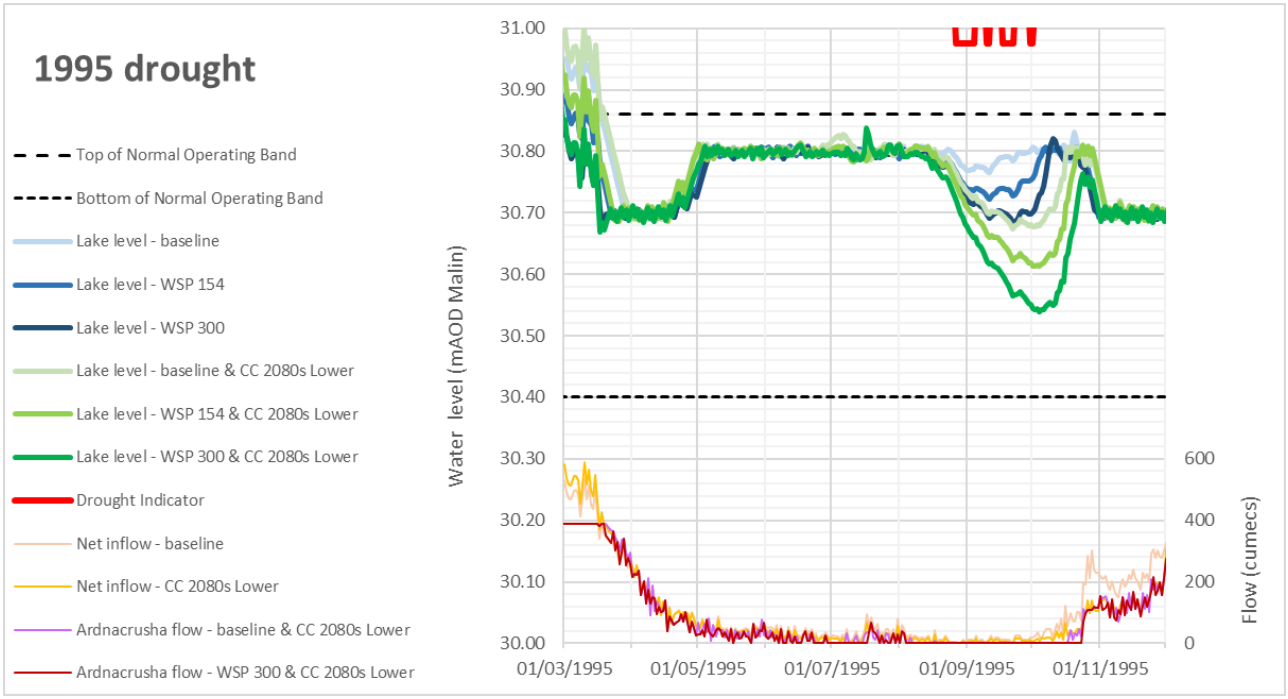


Image 2.8: WSP Hydrological Model: Simulation of the 1995 Drought Including Climate Change: i) Without WSP, ii) WSP = 154Mld, iii) WSP = 300Mld

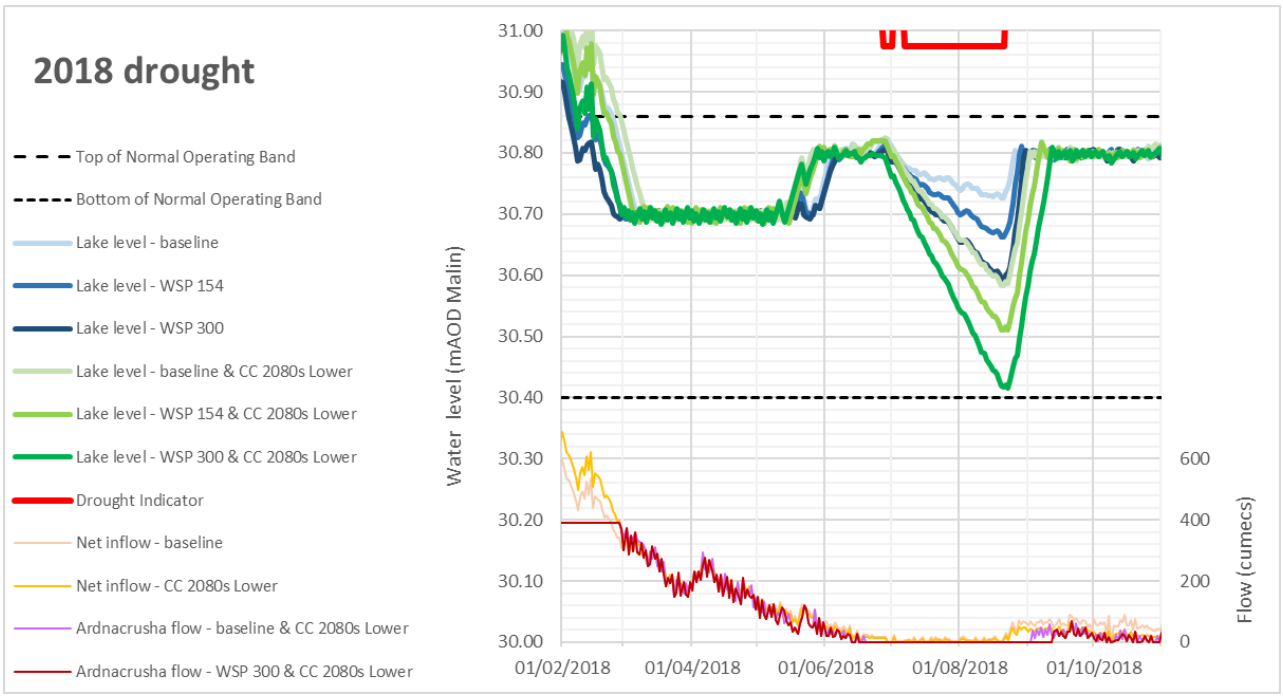


Image 2.9: WSP Hydrological Model: Simulation of the 2018 Drought Including Climate Change: i) Without WSP, ii) WSP = 154Mld, iii) WSP = 300Mld

74. As with the previous model scenarios, from the long-term 52-year model simulation period, the 2018 drought event shows biggest difference in simulated lake levels between the baseline (without WSP) and with WSP scenarios when applying the potential effects of projected future climate change for the 2080s epoch.

75. When simulating the 2018 drought event with the reasonable worst case 2080s climate change allowances (CC 2080s Lower), the WSP 154Mld scenario results in a simulated lake level drawdown low point 73mm below the baseline. For the peak WSP 300Mld scenario the difference at the lowest point of the drawdown is 168mm below the baseline. This size and rate of change easily fits within the commonly observed level changes seen within the 52-year period of observed levels (refer to Image B.1 within Attachment B to see the fluctuations in the observed historical levels recorded by ESB. As Image 2.9 demonstrates, even when applying a precautionary approach to consider the reasonable worst case 2080s climate change projections to the most impactful drought event in the 52-year model simulation period, the additional simulated lake level drawdown caused by the inclusion of WSP is still within the Lough Derg NOB and within the upper and lower water levels that ESB applies to Parteen Basin.

2.3.3 Sensitivity to a Proposed Eflows Regime at Parteen Weir

76. The Water Action Plan 2024[23] identifies 11 different significant pressure categories for surface water bodies, one of these being pressures on Hydromorphology, which includes physical modifications to the flow, form or function of natural surface water bodies. The Water Action Plan 2024 sets out the following action for an existing Hydromorphology significant pressure on the Lower River Shannon:

> *"Hymo 7: Implementation of the roadmap of actions, including the use of state-of-the-art technical solutions, to improve fish migration in the lower Shannon at the Hydroelectric scheme located around Parteen and Ardnacrusha. The pilot project will initially examine the feasibility of mitigation and will progress to the next stages, as appropriate"*

77. The Water Action Plan 2024 roadmap of actions to improve fish migration in the Lower River Shannon and the Hydroelectric scheme located around Parteen and Ardnacrusha includes the following components:

    i) New fish pass at Parteen Weir
    ii) Environmental (Eflow) study programme
    iii) Tailrace barrier feasibility study
    iv) Downstream fish pass feasibility study
    v) New fish pass at Ardnacrusha Power Station feasibility study
    vi) Lower River Shannon Management Plan.

78. In relation to step (ii), an outline Eflows approach has been developed by a CDM Smith study[24]. The study proposes the use of a variable Eflows regime for the flows released down the ORS at Parteen Weir.

79. As part of the WSP hydrological modelling scope, a sensitivity analysis has been undertaken to test how the inclusion of the proposed Eflows regime to the ORS at Parteen Weir would be likely to impact the viability of the proposed WSP abstraction. To do this the WSP hydrological model has been codified to represent the proposed Eflows release regime rules from the CDM Smith study.

[23] Water Action Plan 2024: A River Basin Management Plan for Ireland (DHLGH 2024).

[24] CDM Smith (2025). Roadmap for the Lower River Shannon Report 2021. Provision of Expert Advisory Services Regarding Fish Migration in the Lower River Shannon Catchment. Prepared by CDM Smith for the Department of Housing, Local Government and Heritage (CDM Smith (2025). Fish Pass Feasibility Study).

80. The proposed Eflows regime comprises of a variable baseflow compensation flow and a seasonal series of freshets[25]. The study proposed the following rules to govern the Eflow releases:

    a) Minimum baseflow of 10m^3/s if net inflow to the combined Lough Derg/Parteen Basin is ≤ 65m^3/s (irrespective of season)

    b) Raised baseflow of 17m^3/s if net inflow to the combined Lough Derg/Parteen Basin is > 65m^3/s (irrespective of season)

    c) The estimated freshet daily volumes over and above the baseflow, as a function of the baseflow compensation flow, are as given in Table 2.2

Table 2.2: Freshet Volumes and Frequency Throughout the Year

Period	Freshet Daily Volume (m^3)		Frequency of Freshet Release
	10m^3/s Baseflow	17m^3/s Baseflow	
March - May	948,000	343,200	1 per week
June - September	1,044,600	439,800	1 per week unless net inflow < 20m^3/s
October - December	1,642,950	1,038,150	1 every 2 weeks
January - February	0	0	None

    d) The freshets are released at the frequency indicated in the Table 2.2. The representation of this in the model has assumed a freshet occurs on the same day each week between March and September (with the first one being released on 1 March). During the October to December period the releases are also released a constant time apart (i.e. every 14 days)

    e) Total daily Eflows from Parteen Weir to the ORS on any day is calculated as the baseflow plus the freshet (if there is one timed for that day), and subject to the qualifications in the following assumptions concerning spill and drought.

81. The following assumptions form the basis of the proposed representation of the Eflows regime:

    i. During periods of spill from the Parteen Basin to the ORS (i.e. when the Ardnacrusha capacity is exceeded) no freshets will be required

    ii. During drought periods freshets will not be released. The basis of this assumption is that if the Eflow is an attempt to mimic the natural flow regime then artificially releasing standard freshets over this period would seem to be introducing a non-natural characteristic to the flow regime. (Drought in terms of the WSP modelling has been taken to be when net inflows to the combined Lough Derg/Parteen Basin water body are < 20m^3/s)

    iii. The existing provision of a fish pass flow at Ardnacrusha (equivalent to 0.5m^3/s) continues to be released.

82. Image 2.10 and Image 2.11 compare the simulated lake levels and ORS flows with and without the inclusion of the proposed Eflows regime rules for different scenarios for the 2018 drought event (i.e. the most impactful within the 52-year model simulation period). As previously, the graphs provide simulated lake levels on the first Y-axis, and simulated flows on the second Y-axis. A 2-day running mean is applied to the simulated lake water levels to remove the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends in levels. The graphs do not show the lake net inflows but a drought indicator[26] is provided at the top of the graphs as a guide to when the lake daily net inflows dropped significantly for a certain period of time. To note the overlapping of the lines can cause the individual colours to be difficult to distinguish.

[25] Freshets are periodic increases in flow releases over Parteen Weir to assist migratory fish up the ORS and into Parteen Basin. Their frequency and volume varies seasonally throughout the year.

[26] The drought indicator is specific for the sensitivity of this system and is based upon flagging the occurrence of five consecutive days when the net inflow is less than 20m^3/s

83. Image 2.10 shows the modelled effects on the simulated lake levels and ORS flows due to the introduction of the proposed Eflows regime for the 2018 drought, for the baseline (without WSP) scenario. During model flood conditions, when the Ardnacrusha flow is set to maximum capacity (390m^3/s), the excess water being released down the ORS as flood release/spill flows is virtually the same with or without the proposed Eflows regime in place. However, as Image 2.10 shows, during normal conditions the Eflows regime means more total water being released and a greater flow variability based on variable minimum baseflows (either 10m^3/s or 17m^3/s dependent on lake net inflow) combined with a seasonal series of freshets (based on the volume/ frequency regime described in Table 2.2). The graph shows the Eflows regime in comparison to the uniform minimum 10m^3/s compensation flows of the baseline ORS regime.

84. Image 2.10 shows that whilst the ORS simulated flows would differ when applying the proposed Eflows regime, there is no perceptible impact on simulated lake levels with or without the Eflows in place. This is because during model normal conditions, the WSP hydrological model hunting routine adjusts the Ardnacrusha flow to manage the lake level towards a Lough Derg NOB target level (as described in Section 2.2.4). During model drought conditions, Ardnacrusha flows are not operating (therefore cannot be adjusted), and both compensation flow regime scenarios (with and without the proposed Eflows regime) maintain the same constant 10m^3/s baseflow release. Furthermore, during drought conditions, the proposed Eflows regime assumes that freshets would not be released as Eflows are an attempt to mimic the natural flow regime. This results in similar simulated lake level drawdown low points with or without the inclusion of the proposed Eflows regime.

85. Image 2.11 shows the proposed Eflows regime sensitivity analysis for the 2018 drought, but with the combined effects of both the proposed WSP abstraction (peak 300Mld) and the projected future ‘reasonable worst case’ climate change impacts (2080s Lower). As seen previously, whilst the graph shows how the ORS simulated flows differ during normal conditions, there would be the same constant minimum 10m^3/s baseflows (and no freshet releases) released during drought conditions, and there are no perceptible changes to the simulated 2018 drought lake levels and drawdown low point when modelled for the proposed WSP abstraction with climate change scenario, from the inclusion of the proposed Eflows regime.

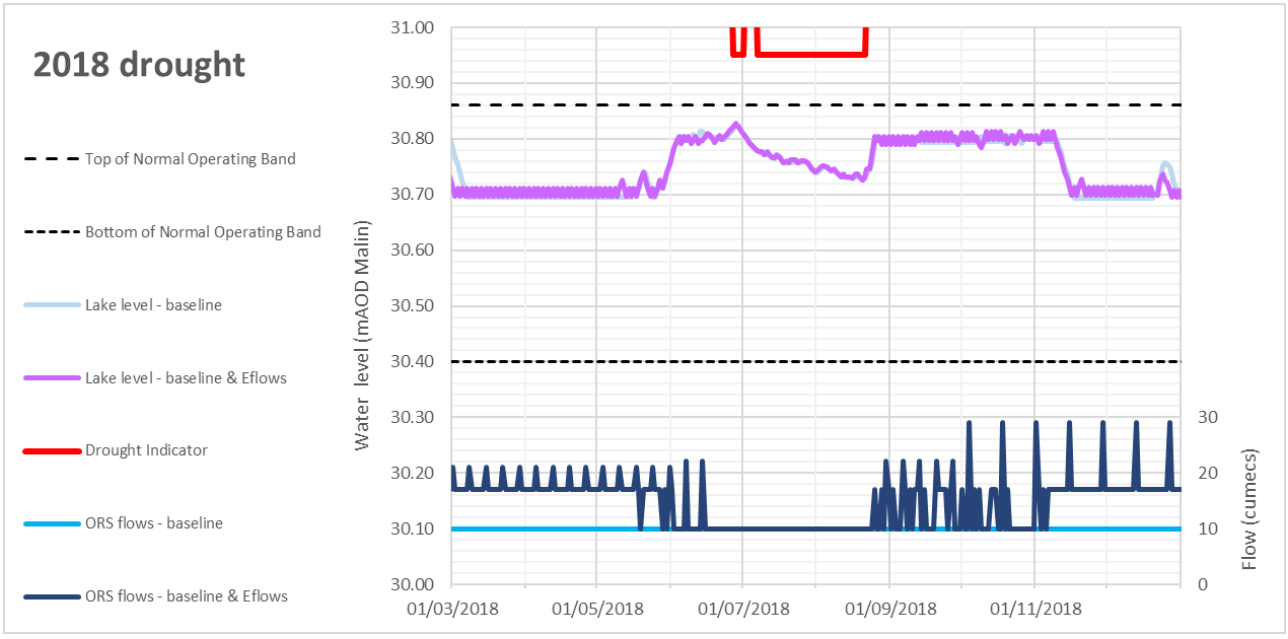


Image 2.10: WSP Hydrological Model: Simulation of the 2018 Drought Event with the Proposed Eflow Release Regime to the Old River Shannon for Baseline (Without WSP)

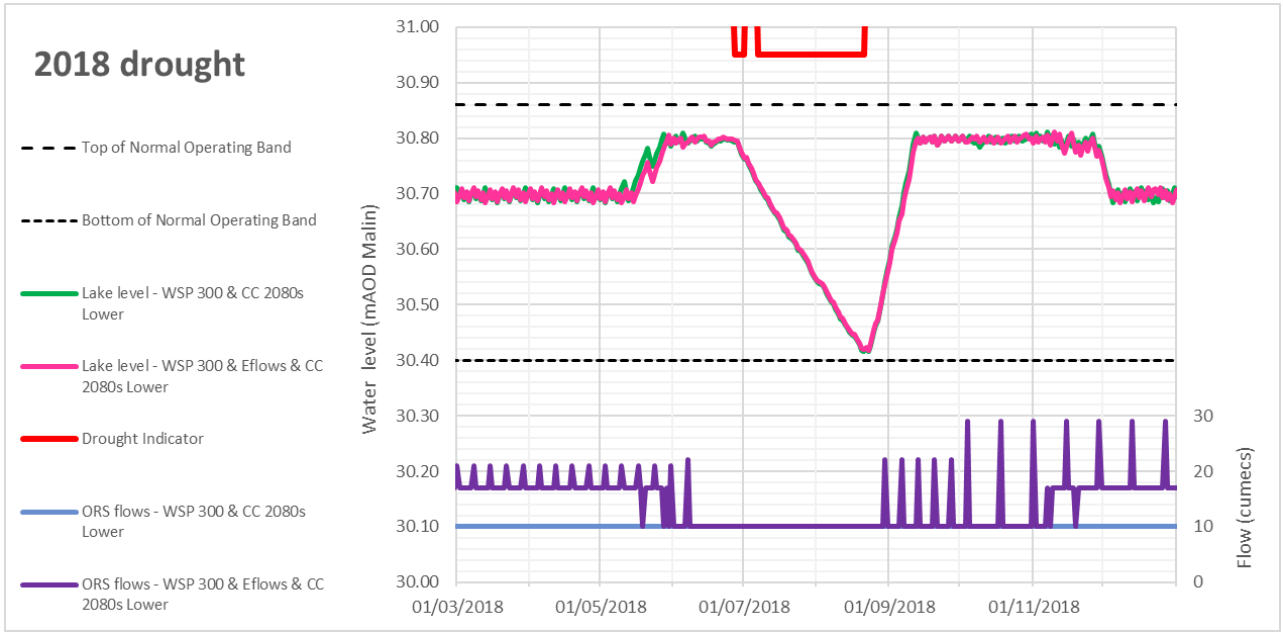


Image 2.11: WSP Hydrological Model: Simulation of the 2018 Drought Event With the Proposed Eflow Release Regime to the Old River Shannon for the WSP 300Mld and Climate Change Scenarios

3. Parteen Basin

3.1 Introduction

86. Parteen Basin, also known locally as the 'Lower Lake', was formed as part of the Shannon Hydro-Electric Scheme in the late 1920s. Parteen Basin floods an area through which the River Shannon once flowed as a river, and much of the perimeter of Parteen Basin is formed by high linear engineered embankment dams constructed as part of the scheme. Parteen Basin is regulated both by the discharge through Parteen Weir to the ORS channel, and by the flow abstracted by ESB through to the Ardnacrusha power station headrace to be used for electricity power generation. Parteen Basin is linked to Lough Derg by the narrow Killaloe channel.

87. The Shannon, including Parteen Basin has historically a number of users/activities associated with it including navigation, hydropower generation, farming, environmental aspects and flood risk. There have been several studies in respect of flood risk, including the Shannon Catchment-based Flood Risk Assessment and Management (CFRAM) study, delivered by the Office of Public Works (OPW) under government policy. As part of the CFRAM study, research was undertaken to understand current operations of structures (e.g. weirs) along the River Shannon to establish how they impact on flood risk management. The 2011 CFRAM study report[27] noted through the literature review that a 2001 study by Kirk McClure Morton[28], looked at the current management of the water levels of the River Shannon and recognised that the Shannon system has a history of severe flooding especially downstream of Lough Allen to Parteen Weir. It was also noted in the study that the operational controls by ESB and Waterways Ireland were not seen as contributing to flooding problems. It stated that simulations undertaken as part of the study "*indicate that even if Ardnacrusha Power Station was not in operation during the most recent flood event this would have no impact on water levels in the worst hit flooded areas, however such a scenario would most likely result in severe flooding downstream of Parteen Weir to Limerick*". Therefore, based on the Shannon CFRAM study, it could be said that the operational regime of Ardnacrusha and the controls undertaken at Parteen Weir act indirectly as a flood protection measure for downstream sections.

88. The Parteen Basin recorded level shows greater variation than the recorded Lough Derg levels. This is a function of the management regime and the hydraulic characteristics of Parteen Basin and its connection to Lough Derg. During low flow/drought periods, when flows to Ardnacrusha are much reduced or stopped, the levels recorded at Killaloe and Parteen Basin balance out (Image 3.1).

89. Outside of the low flow periods there are greater flows going to Ardnacrusha and this causes the Parteen Basin water levels to become drawn down lower relative to levels at Killaloe. The Parteen Basin level is then determined by the hydraulic characteristics of the Parteen Basin system up to Lough Derg and its efficiency at transferring the flow (Ardnacrusha + compensation/fish pass flow) along the resulting hydraulic gradient. This is further exacerbated during flood conditions when the gates on Parteen Weir are managed to release additional water down the ORS channel to allow the flood to pass safely through the system. This level behaviour is evident in Image 3.1.

3.2 Simulation of Levels

90. Section 2.1 describes the lake level modelling undertaken for the Lough Derg and Parteen Basin system. Flowing into the model is the net inflow which is calculated from the water balance of both Lough Derg and Parteen Basin, though the influence of the much smaller Parteen Basin (surface area 3.6km^2) in the storage calculations of the overall water balance is slight compared to that of the much larger Lough Derg (surface area 116.5km^2).

[27] OPW (2011). Shannon CFRAM Study – River Shannon Level Operation Review

[28] Kirk McClure Morton (2001). Study of the Current Management of the Water Levels of the River Shannon

91. The simulation assumes that any increase in the cumulative volume of water abstracted during drought periods (to maintain abstraction and compensation/fish pass flows) results in a drop in water level which is evenly distributed across the entire combined surface area of the Lough Derg and Parteen Basin system. This is based on the assumption that the influence of any additional abstraction on the hydraulic gradient is imperceptible.

92. Outside of the low flow/drought period the quantities of water leaving Parteen Basin are simulated to be the same whether it is the Baseline case (without WSP abstraction) or the case with WSP abstraction. As described in Section 2.2, the proposed WSP abstraction will be provided from a minor depletion in the Lough Derg and Parteen Basin system simulated lake storage, meaning outside of flood and drought conditions the Ardnacrusha flow will need to be adjusted to manage the lake levels within the Lough Derg NOB. It is assumed that, during the non-drought periods, the same decisions regarding the management of the Parteen Basin levels will result whether the WSP abstraction is included or not. It is expected that the Parteen Basin level regime (with and without WSP) will also only differ during the drought periods, and that as the levels of the two water bodies balance out during low flow periods the changes in level during droughts will be the same in both water bodies.

93. As described in Section 2, the inclusion of the WSP abstraction only results in perceptible changes to the Lough Derg and Parteen Basin combined system lake level regime during infrequent extreme drought events (1995 and 2018). However, these simulated changes in levels fall within the normal range of level variation seen within the observed historical levels record (1972–2023). Likewise, this is also the case for the simulated changes for Parteen Basin. As described in Section 2.2 and Attachment C the ESB have some freedom in the level management of the lakes for short-term income optimisation (i.e. commercial factors having a bearing on the ESB day-to-day abstraction). The associated changes in level due to this appear to be frequent and of similar size to that simulated in the rare droughts to be caused by inclusion of the WSP abstraction.

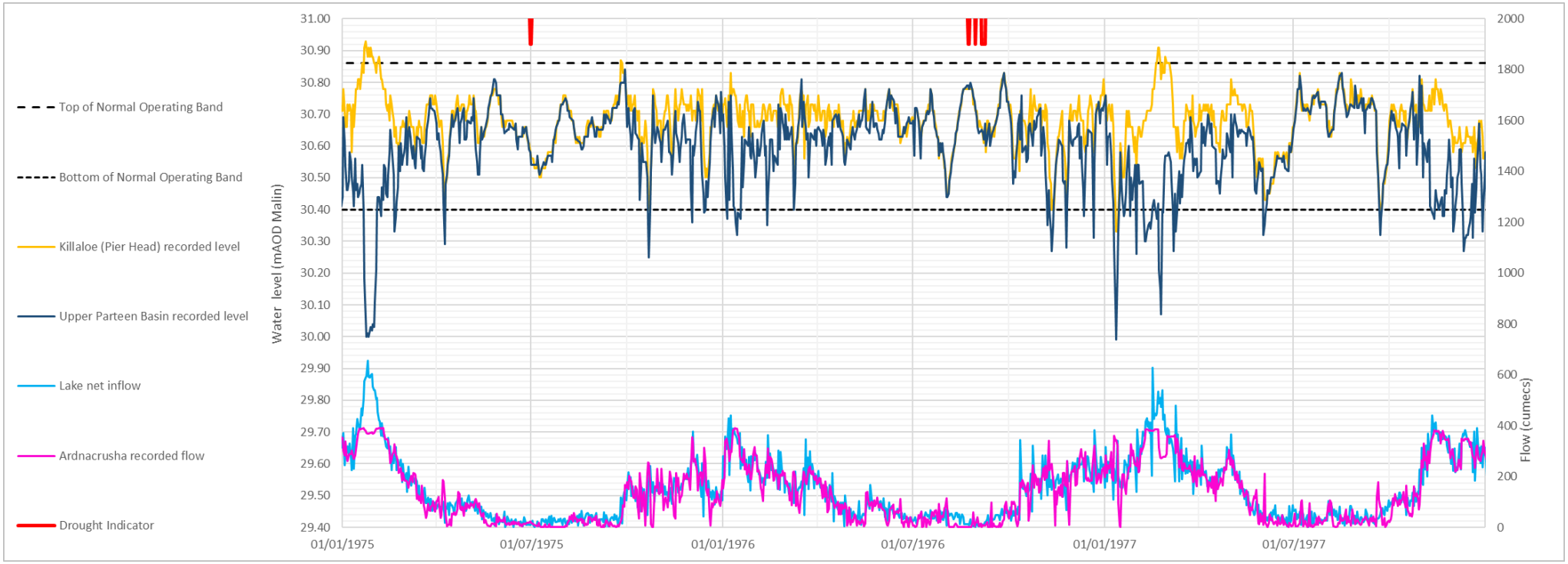


Image 3.1: Comparison of the Recorded Water Levels of Lough Derg and Parteen Basin

4. WFD Lake Tests

4.1 Introduction

94. The WFD sets out objectives for rivers, lakes, groundwater, estuaries and coastal waters. Objectives are set for water bodies and expressed in terms of status. The objectives include,

    - Preventing deterioration in status
    - Restoring water bodies to Good status.

95. Standards are matched to the objectives of the Directive. Environment agencies use standards to set limits on the amount of water that can be abstracted, or how much pollutant can enter the environment, to either improve environmental quality or to prevent it from deteriorating.

96. Surface water bodies are assigned to one of five classes: High, Good, Moderate, Poor or Bad status. To assign a class the achievement of environmental standards is taken into account. For example, if a lake level identified for Good status is not met, the status will be moderate or worse. The Directive requires that the overall status of the water body is determined by the lowest status from all the standards that are assessed.

97. The Water Environment (Abstractions and Associated Impoundments) Act 2022 [29] and the Water Environment (Abstractions and Associated Impoundments) Regulations 2024 [30] came into operation on 28 August 2024. The purpose of the legislation is to provide for the regulation (registration, licensing and control) of water abstractions and their associated impoundments and to give effect to the EU WFD. The Water Environment (Abstractions and Associated Impoundments) Regulations 2024 outlines that the EPA shall establish ecology-based hydrological limits to sustain the surface water status of bodies of surface water.

98. As WFD lake standards for the management of abstraction impacts are yet to be finalised by the EPA for Ireland, two different kinds of lake standards tests have been applied for the purpose of assessing the Proposed Project:

    i) A screening test based upon the proposed abstraction being within a proportion of the lake inflow, that has previously been used by Uisce Éireann in consultation with the EPA in the development of the Uisce Éireann NWRP (Irish Water 2021)[31]

    ii) The WFD lake level standards test UK approach as documented in the UKTAG River Basin Management (2015 – 21) report[32].

99. After discussing the matter with the EPA, it was decided to adopt the (ii) UKTAG approach as it was considered the more complex and sophisticated target used in the UK, therefore the most appropriate for the Proposed Project. However, this section describes the application of both tests to the Lough Derg and Parteen Basin system.

4.2 Application of the NWRP Screening Test

100. The screening test criteria is that the abstraction from a lake should be less than 10% of the inflow Q50 (Q50 is the median daily inflow).

[29] https://www.irishstatutebook.ie/eli/2022/act/48/enacted/en/html?q=Abstractions.

[30] https://www.irishstatutebook.ie/eli/2024/si/419/made/en/print?q=Abstractions.

[31] Irish Water (2021). National Water Resources Plan – Appendix C.

[32] UKTAG (2013). Updated recommendations on Environmental Standards, River Basin Management (2015-21) [http://www.wfduk.org/sites/default/files/Media/Environmental%20standards/UKTAG%20Environmental%20Standards%20Phase%203%20Final%20Report%2004112013.pdf].

101. Based on the daily inflow sequence (described in Section 2.2.2), Table 4.1 and Table 4.2 provide the outcome of the screening test separately applied to Lough Derg and Parteen Basin respectively. Both pass the test with the maximum WSP abstraction flow being less than a quarter of the maximum amount the test requires.

102. The abstraction physically takes place from Parteen Basin and not from Lough Derg, perhaps raising questions about the applicability of this test to Lough Derg. However, during low flow periods the two water bodies act as one with levels balancing out between them. Therefore, for completeness, the test has been applied separately to the separately classified Lough Derg water body.

Table 4.1: Lough Derg Screening Test Results

Period Record	Combined Catchment* Q50 (m^3/s)	Lough Derg Q50† (m^3/s)	10% of Q50 (m^3/s)	WSP Abstraction Flow Max‡ (m^3/s)	Pass/Fail?
1972-2023 [52 years]	155.5	154.6	15.5	3.47	Pass
2004-2023 [last 20 years]	168.8	167.8	16.8	3.47	Pass

* Combined catchment – the combined Lough Derg and Parteen Basin catchment for which the net inflow series was calculated.

† Lough Derg Q50 = the combined catchment Q50 linearly scaled in line with the relative catchment areas of the Derg catchment and the combined catchment. Catchment areas were derived from the OPW FSU (Flood Studies Update) catchment descriptors with the Kilmastulla River catchment area removed since this river has been diverted to join with the ORS immediately below Parteen Weir.

‡ Equivalent to 300Mld

Table 4.2: Parteen Basin Screening Test Results

Period Record	Combined Catchment* Q50 (m^3/s)	Parteen Basin Q50†† (m^3/s)	10% of Q50 (m^3/s)	WSP Abstraction Flow Max (m^3/s)	Pass/Fail?
1972-2023 [52 years]	155.5	155.5	15.6	3.47	Pass
2004-2023 [last 20 years]	168.8	168.8	16.9	3.47	Pass

* Combined catchment – the combined Lough Derg and Parteen Basin catchment for which the net inflow series was calculated.

†† Inflow to Parteen Basin is taken to be equal to the inflow to the combined catchment

103. Application of the 'reasonable worst case' 2080s climate change impacts to the 1972 – 2023 inflow data gives a Q50 value of $125m^3/s$. Therefore, 10% of this value is still much greater than the proposed maximum WSP abstraction flow of $3.47^3/s$, and it is concluded that the WSP abstractions will also pass the NWRP screening test with climate change to the 2080s included.

4.3 Application of the UKTAG WFD Lake Level Standard

104. The UKTAG is a working group of experts drawn from UK environment agencies and conservation agencies. It also includes representatives from Ireland. The UKTAG develops technical advice on the Environmental standards for achieving different WFD status and how they may be used for river basin planning. In using the term 'standard' the UKTAG means numerical limits on things like the concentration of chemicals, river flow or water levels, or measurements of biological communities.

105. The UKTAG WFD lake level standard considers changes in the extent of the littoral zone (which is the shallow near-shore zone where maximum ecological activity occurs) due to the activity being assessed (in this case abstraction). The precise measure that is considered is somewhat confusingly called 'lake surface area' and is defined as meaning for any day, (a) the area under the reference conditions of the lake's surface that would overly water from the shore out to 5 metres deeper than the depth to which light penetration to the lakebed would be sufficient, under those conditions, to enable the growth of rooted plants or bottom-living algae.

106. This definition requires an understanding of the depth to which light penetration to the lakebed would be sufficient to enable the growth of rooted plants or bottom-living algae. This is also known as the euphotic depth. For Lough Derg and Parteen Basin the euphotic depth has been established[33], from direct monitoring of the depths of aquatic plants and charophytes (green algae), to be a depth of 5m (Attachment H).

107. Reference conditions are defined, in the guidance, as meaning in the absence of any abstractions or discharges that could affect the surface area of the lake. For lakes designated as heavily modified for water storage, 'reference conditions' may be taken to mean the regime as (a) altered by the use for which the lake has been designated; and (b) with all mitigation measures that can be put in place without a significant adverse impact on the use or the wider environment.

108. To undertake the assessment requires both an understanding of the bathymetry of the water bodies and a daily lake level series of the reference condition together with a corresponding lake level series with the abstraction pressure included. With these components the 'lake surface area' can be determined for each day of the reference period, and the change in extent calculated from a comparison on each day to where the abstraction affected level falls upon the shoreline. The detail of how this has been accomplished in separate analyses for Lough Derg and for Parteen Basin is presented in Attachment I.

109. The outputs from the WSP hydrological model[34] have been used to supply the necessary daily lake level series of the reference condition and the corresponding lake level series with the abstraction pressure included. Both constant WSP abstraction flows of 154Mld and 300Mld were assessed.

110. Table 4.3 provides the UKTAG WFD status criteria of the lake level standard. The standards effectively stipulate the percentage reduction in lake surface area that may not be exceeded for more than 1% of days in any one year and are recommended to be applied over a 30-year period in order to account for unusually wet and dry years.

111. Lough Derg (Derg TN) has Moderate WFD status and Parteen Basin (Derg HMWB) has Good WFD status (2016-2021). As Parteen Basin is classified as a heavily modified water body (HMWB), the water body has an objective to achieve Good Ecological Potential (GEP) rather than Good Ecological Status (GES). For the purpose of presenting the application of the UKTAG test on the two water bodies, the results focus on achieving the WFD Good status lake standard. See Appendix A9.1 (Abstraction Assessment) for more details on the ongoing HMWB designation process in Ireland and GEP requirements.

[33] Minchin, D (2021). Water transparency in Lough Derg and Parteen Reservoir, Shannon River. Lough Derg Science Group, Unpublished Report.

[34] The final version of the WSP hydrological model build has previously been referred to as the 'Operational Principles Model' to differentiate it from the initial 'Historical Model' build.

Table 4.3: UKTAG WFD Lake Standards for the Effect of Water Level Changes on Lake Surface Area

Daily Maximum Percentage Reductions in Lake Surface Area in 99 Percent of Days in Any Year			
High	Good	Moderate	Poor
1	5	10	20

112. Table 4.4 summarises the lake level standard results for Lough Derg (Derg TN), and Table 4.5 summarises the results for Parteen Basin (Derg HMWB). Attachment I provides more details on the test results.

Table 4.4: Summary Results of the UKTAG WFD Lake Level Test Applied to Lough Derg (Derg TN)

WSP Abstraction Flow (Mld)	Year(s)	% Reduction in Lake Surface Area Equalled or Exceeded for 1% of the Days in the Year	WFD Status Achieved From UKTAG Lake Level Standards Test
154	All 52 years (1972-2023)	<1%	High
300	All 52 years (1972-2023)	<5%	Good

Table 4.5: Summary Results of the UKTAG WFD Lake Level Test Applied to Parteen Basin (Derg HMWB)

WSP Abstraction Flow (Mld)	Year(s)	% Reduction in Lake Surface Area Equalled or Exceeded for 1% of the Days in the Year	WFD Status Achieved From UKTAG Lake Level Standards Test
154	All 52 years (1972-2023)	<5%	Good
300	All 52 years (1972-2023)	<5%	Good

113. The recommended standards (Table 4.3) stipulate the percentage reduction in area that may not be exceeded for more than 1% of days in any one year. The test results show that the 5% change in lake surface area threshold for WFD Good status standards is not exceeded for either the Lough Derg (Derg TN) or Parteen Basin (Derg HMWB) lake water bodies in any scenario across the 52-year simulation period.

114. Based on the UKTAG WFD criteria the following standards are met for the two WSP abstraction rates:

- A constant WSP abstraction of 154Mld results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
- A constant WSP abstraction of 300Mld results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard.

115. It is noted that the amount by which the 300Mld abstraction breaks the 1% change in lake surface area threshold is small, i.e. the Good status range is from 1% to 5% reduction in lake surface area and the results only reach up to a reduction of 2.37% (see Table I.4 within Attachment I).

116. Similar analysis is also presented in Attachment I for the sensitivity scenarios in which the 'reasonable worst case' 2080s climate change and/or the proposed ORS Eflows regime are applied. These scenarios still resulted in both water bodies meeting the UKTAG WFD lake level test requirements for the WFD Good status (Potential) standard for a constant WSP abstraction of 154Mld or 300Mld.

5. Summary of Findings

5.1 General Findings

117. The impacts to Lough Derg and Parteen Basin lake levels and forward flows to the ORS due to the modelled inclusion of the WSP abstraction (as a constant flow of either 154Mld or 300Mld) are barely distinguishable from the baseline case when viewed on level/flow duration curves (a standard hydrological method for comparing long-term data series).

118. The level regimes of both Lough Derg and Parteen Basin are only simulated to be affected by the WSP abstraction during rare extreme drought events and in the days immediately after the drought (up to a week) when inflow is needed to replenish any deficit in storage caused by the WSP abstraction. From the 52-year model simulation period (1972–2023), the simulated lake levels are only found to be notably affected by the inclusion of WSP during the 1995 and 2018 drought events, with all other years showing no perceptible impacts. Therefore, for approximately 99% of the 52-year model simulation period, there are no perceptible impacts to simulated lake levels as a result of the proposed WSP abstraction.

119. The model demonstrates that the required ORS compensation and fish pass flows can always be met, either with or without the WSP abstraction in place.

120. The model demonstrates that the WSP abstraction volume is provided from a marginal reduction in the simulated lake storage on a daily basis across the 52-year simulation period. The model assumes that depletion of lake storage results in a drop in water level which is evenly distributed across the entire surface area of the Lough Derg and Parteen Basin system.

121. ESB will facilitate the proposed abstraction of water by the Proposed Project within its current operating practices. As part of an overall agreement with ESB, water will be diverted to the Proposed Project abstraction from the flow that would otherwise have been used for electricity generation on a continuous year round basis. At a practical level, this will mean that ESB, in keeping the water level within the Normal Operating Band on Lough Derg and within the upper and lower water level on Parteen Basin, will take account of, and respond to, the volume of water abstracted for the Proposed Project, alongside other relevant considerations such as, maintaining statutory compensation flow of 10m^3/s down the old Shannon channel, predicted rainfall, the demand for power and operating practices. ESB will maintain the water levels within the Normal Operating Band on Lough Derg and within the upper and lower water levels on Parteen Basin, as it does currently. Over longer periods there would be a generalised adjustment of the flow going to Ardnacrusha by ESB to respond to the volume of water used by the Proposed Project. However, the operation of Lough Derg, post works, will feel and look very similar to the way it currently operates, and there will not be a visible day to day difference.

122. During flood flows, when the ESB can no longer keep the water level below the top of the Lough Derg NOB, the ESB can operate Ardnacrusha at full capacity as they have done in the past, and the proposed WSP abstraction would be provided from a minor depletion in the simulated lake storage.

123. The simulated forward flows to the ORS remain unchanged by the inclusion of the Proposed Project abstraction. The proportion of days (to the nearest whole percent) when the ORS is receiving the minimum required compensation and fish pass flows is simulated to be unchanged by the inclusion of the Proposed Project abstraction, as does the timing of the spill flows down ORS when Ardnacrusha is at full capacity.

5.2 Drought Impacts

124. From the 52-year model simulation period (1972–2023), it was identified that the 1995 and 2018 drought events were the most severe on record for the Lough Derg and Parteen Basin system. The 2018 drought shows the biggest impact of the WSP scenarios on the simulated lake levels, and the 1995 drought shows the second biggest impact. Other candidate droughts such as 1976, 1989, 2006, and 2010 were simulated to have negligible simulated lake level differences that were much less significant.

125. For the 2018 drought event (most impactful), with the inclusion of the WSP 154Mld scenario, the maximum difference in simulated lake level from the baseline (no WSP) at the lowest point of the drawdown is 65mm. For the WSP 300Mld scenario, the maximum difference lake level difference at the lowest point of the drawdown is 134mm. Even during the worst modelled drought event (2018) from the 52-year model simulation period, the size and rate of simulated lake level change fits within the range of ESB normal observed lake level fluctuations seen within the 52-year period of historical recorded levels. Critically, the simulated lake levels with the inclusion of the proposed WSP abstraction are still within the Lough Derg NOB and within the upper and lower water levels that ESB applies on Parteen Basin without a change to the ORS compensation and fish pass flows, which would always be met.

5.3 Climate Change

126. Climate change simulations for a ‘reasonable worst case’ scenario for the 2080s epoch indicate that simulated lake levels would remain within the Lough Derg NOB when including the proposed WSP abstraction. The simulated lake levels with WSP only drop close to the bottom of the Lough Derg NOB once within the 52-year model simulation period – during the modelled 2018 drought event.

127. During the modelled 2018 drought event, with the inclusion of the 2080s Lower (reasonable worst case) climate change scenario, the difference in simulated lake level between the WSP 300Mld scenario and baseline (without WSP) at the lowest point of the drawdown is 168mm. Therefore, even when applying a precautionary approach to consider the reasonable worst case 2080s climate change projections to the most impactful drought event (2018) in the 52-year model simulation period, the additional simulated lake level drawdown caused by the inclusion of WSP is still fitting within the range of ESB normal observed lake level fluctuations, resulting in levels still within the Lough Derg NOB and within the upper and lower water levels that ESB applies on Parteen Basin with no change to the ORS compensation and fish pass flows, which would always be met.

5.4 Eflows

128. The Water Action Plan 2024 sets out a roadmap of actions aimed to improve fish migration in the Lower River Shannon around Parteen Weir and the Ardnacrusha power station. An outline Eflows approach has been developed by a CDM Smith study to provide proposed variable compensation flows to be released down the ORS from Parteen Weir. As part of the WSP hydrological modelling scope, a sensitivity analysis has been undertaken to test how the inclusion of this proposed Eflows regime would be likely to impact the viability of the proposed WSP abstraction.

129. To do this the WSP hydrological model has been codified to represent the proposed Eflows regime rules from the CDM Smith study. The application of the proposed Eflows regime involved replacing the existing ORS 10m^3/s compensation and fish pass flow with a variable baseflow compensation flow and the inclusion of seasonal freshets to assist migratory fish up the ORS and into Parteen Basin.

130. The sensitivity analysis found that similar lake water level differences were simulated during the droughts when the WSP abstractions were included in the Eflows scenario as were simulated for the case for the baseline constant 10m^3/s compensation flow. This relies on the assumption that freshets would not be released during droughts.

5.5 Water Framework Directive Lake Tests

131. As WFD lake standards for the management of abstraction impacts are yet to be finalised by the EPA for Ireland, two different kinds of lake standards tests have been applied for the purpose of assessing the Proposed Project: i) the NWRP screening test based upon the proposed WSP abstraction being within a proportion of the lake inflow, and ii) the UKTAG WFD lake level standards test based on changes in the extent of the littoral zone due to the activity being assessed (in this case the proposed WSP abstraction).

132. The Proposed Project passes the (i) NWRP screening test as the proposed WSP peak 300Mld abstraction is comfortably within the 10% of the lake inflow Q50 threshold. After discussing the matter with the EPA, it was decided to adopt the (ii) UKTAG WFD lake level test approach as it was considered the more complex and sophisticated target used in the UK, and therefore the most appropriate for the Proposed Project.

133. Based on the UKTAG WFD lake level test the following standards are met for the two WSP abstraction rates:

- A constant WSP abstraction of 154Mld results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
- A constant WSP abstraction of 300Mld results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
- Inclusion of the future ‘reasonable worst case’ 2080s climate change impacts and/or proposed ORS Eflows regime sensitivity analyses results in both the water bodies still meeting the lake level requirements for the WFD Good status (Potential) standard for a constant WSP abstraction of 154Mld or 300Mld.

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Attachment A. Hydrometric Data Checks and Validation

1. The following hydrometric data were obtained from ESB for the hydrology modelling (Table A.1):

Table A.1: Hydrometric data from ESB

Data	Units	Period	Time step
Portumna level	metres (above Poolbeg datum)	Jan 1932 – Oct 2023	Daily
Killaloe (Pier Head) level	metres (above Poolbeg datum)	Jan 1932 – Oct 2023	Daily
Ballyvalley level	metres (above Poolbeg datum)	Feb 1997 – Oct 2023	Daily
Parteen Weir Upstream level	metres (above Poolbeg datum)	Jan 1932 – Oct 2023	Daily
Total flow at Parteen	m^3/s	Jan 1932 – Oct 2023	Daily
Ardnacrusha Station discharge	m^3/s	Jan 1932 – Oct 2023	Daily
Lough Derg inflow	m^3/s	Jan 1932 – Oct 2023	Daily

2. Each of the level series were converted to the Malin Head datum via the subtraction of 2.7m. The level data underwent visual quality control and where the occasional daily gap or incongruous spike were identified they were graphically inspected and infilled based upon a combination of inter-site relationships and interpretation of the hydrograph immediately before and after the missing data. In the period of data (1972 – 2023) just one longer gap existed, viz: 5 November 1999 to 19 November 1999. This was of no relevance to the investigation into the impacts of the WSP abstraction since the impacts are only simulated to occur during drought periods. The gap was therefore infilled using typical level data of that period.

3. Within the supplied flow data there was just one period identified (7 Nov 1991 – 14 Dec 1991), over and above the above-mentioned gap, where inconsistent data existed. As for the level data gap, this winter period was of no significance to the impact assessment. The missing data were therefore infilled using typical level data of that period.

4. The ESB calculated Lough Derg inflow data does not account for the change in storage associated with the changing level in Parteen Basin. This was therefore replaced within the study by the net inflow (as described in Section 2.2.2) which does include accounting for the Parteen Basin change in storage. Comparison to the ESB calculated inflows was however undertaken as a check. This showed very close agreement, with only very minor day-to-day differences that, as expected, balanced out over time.

5. Uisce Éireann installed additional water level recorders around Lough Derg (Image A.1) (period of record: 2015 – 2017). This allows cross-checks upon the ESB level measurements to be made. Image A.2 compares the Uisce Éireann levels recorded between 2015 and 2017. During the wet winter periods a slight level gradient establishes itself from north to south as high flows pass through the system (when Ardnacrusha operates at high flows and the Parteen Weir gates are lowered to safely pass the flood flows through Parteen Basin). During the dry periods the levels of the various gauges are much closer. Some variation is evident in the relative levels during the drier periods, as is evident for the Portumna level during 2015 compared with the levels after May 2016. The change commences after what is believed to have been an accidental movement of the sensor in the early 2016 summer, and the sensor not being re-surveyed back to the same level. This was allowed for in the Hydrodynamic Modelling (refer to the A9.1 Annex B Water Quality Modelling Report).

6. Image A.3 and Image A.4 compare the Uisce Éireann recorded levels to those obtained from the ESB equivalent sites. The day-to-day pattern of variation closely agree giving confidence in the daily level changes recorded by the ESB level sensors. Both comparisons show the Uisce Éireann gauges to have recorded slightly lower absolute levels – i.e. they are offset. This, however, does not affect the calculation of the daily net inflows to the system because that calculation relies on an estimation of the day-to-day change in storage. A systematic offset to the level does not affect this. This was tested in the modelling by systematically offsetting the Portumna level record and comparing the resulting net inflows calculated. The only daily inflow that is changed is the day when the offset is applied; all other days return the same numerical values for the inflow.

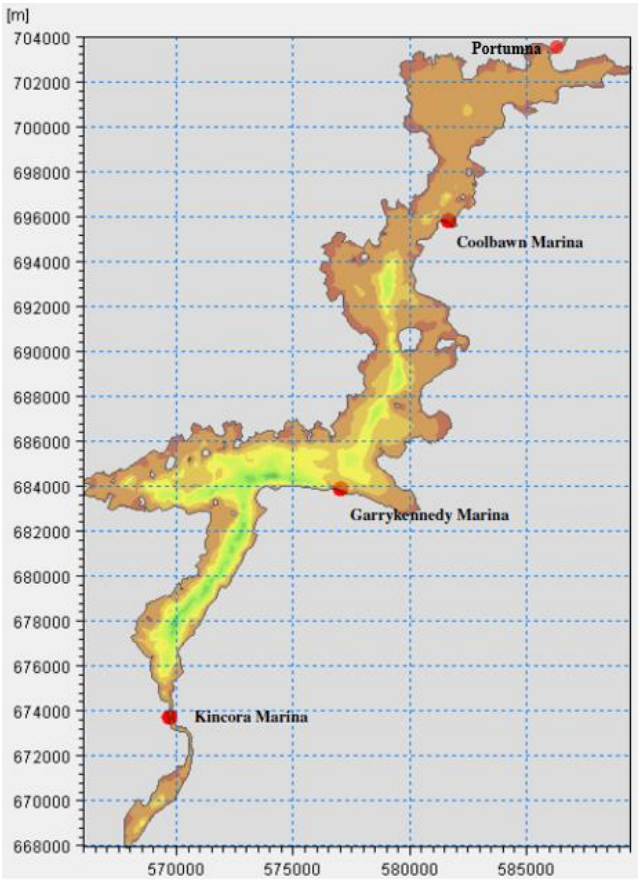


Image A.1: Uisce Éireann Continuous Water Level Monitors Installed in 2015.

7. It was also observed that the ESB Killaloe and Portumna level datasets incorporate a systematic offset relative to each other of about 0.08m that occurred during the 1983/84 winter. Image A.5 and Image A.6 provide comparisons of Portumna and Killaloe levels from periods before and after the occurrence of the offset. During the dry summers the Portumna and Killaloe levels match (prior to the offset), whilst after the offset the levels during dry periods differ by about 0.08m. However, as indicated above the inclusion of the offset does not alter the calculated net inflow series (apart from on the day that the change was made).

8. Output from the Hydrodynamic modelling (A9.1 Annex B Water Quality Modelling Report) for 2016 is shown in Image A.7. This detailed modelling predicts that during the drier summer period the levels in the north almost equal the levels in the south.

9. Direct checks upon the validity of the daily flows provided by ESB was not straightforward. The approach taken by the project was therefore to undertake modelling sensitivity analysis in which the Ardnacrusha flows and the ORS flows (calculated by subtracting the Ardnacrusha flows from the Total flow at Parteen) were reduced by 10% and 20% (both independently and jointly) to represent possible underestimation of the observed flows. These reduced flows were included in the derivation of revised Net Inflow series and used as input into the modelling exercise to assess whether this would change the simulated impact of the WSP abstractions. This sensitivity analysis is described in Attachment G.

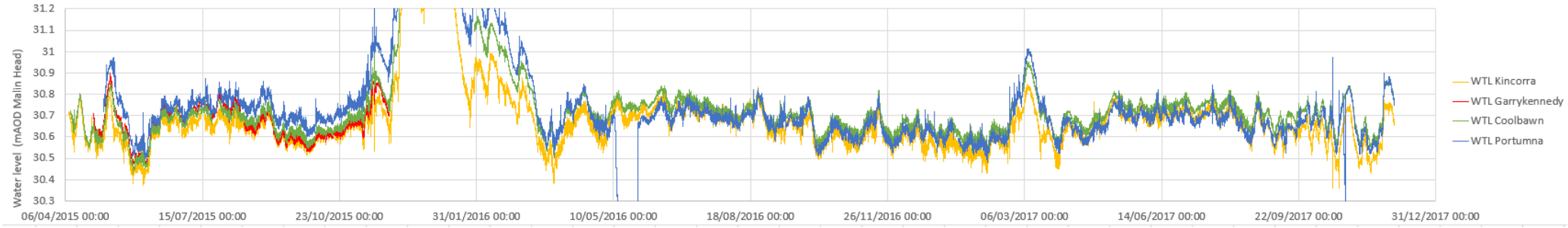


Image A.2: Lough Derg Water Level Recorded by the Uisce Éireann Gauges (Garrykennedy Gauge Malfunctioned in the Beginning of 2016)

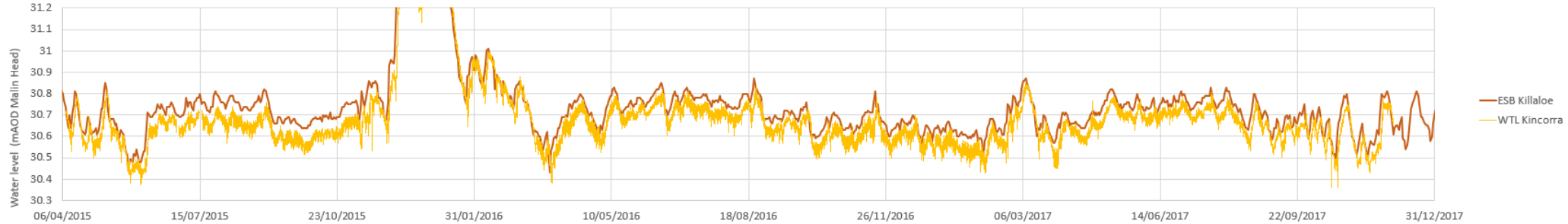


Image A.3: Comparison of the Levels Recorded by the ESB Killaloe Gauge and Uisce Éireann Kincorra (Killaloe) Gauge

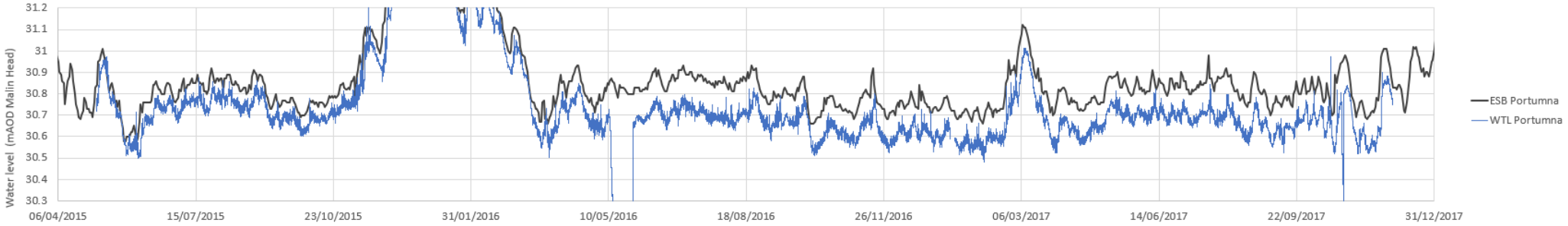


Image A.4: Comparison of the Levels Recorded by the ESB Portumna Gauge and Uisce Éireann Portumna Gauge

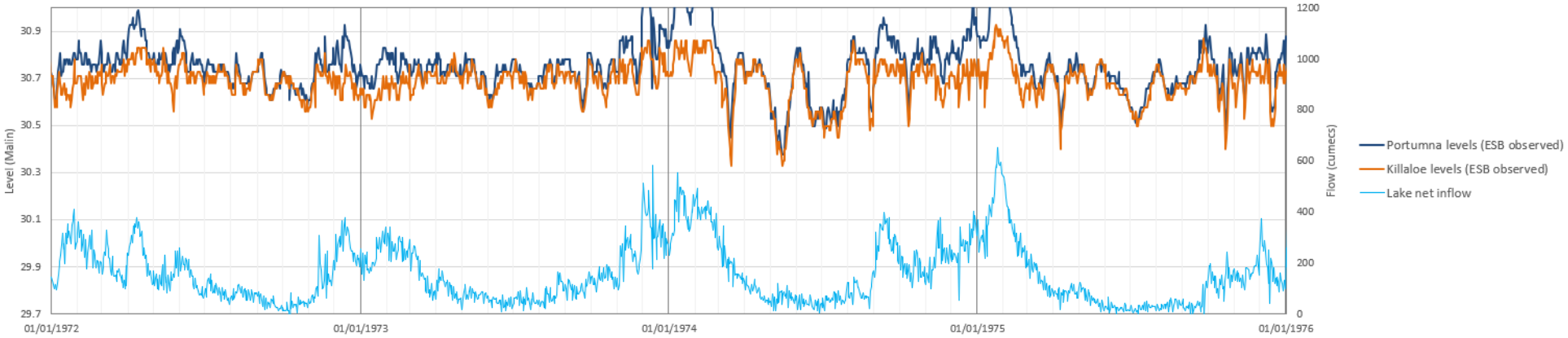


Image A.5: Example Portumna and Killaloe ESB Levels from the Period Prior to the 1983/1984 Offset

(Note matching levels during the low flow dry periods)

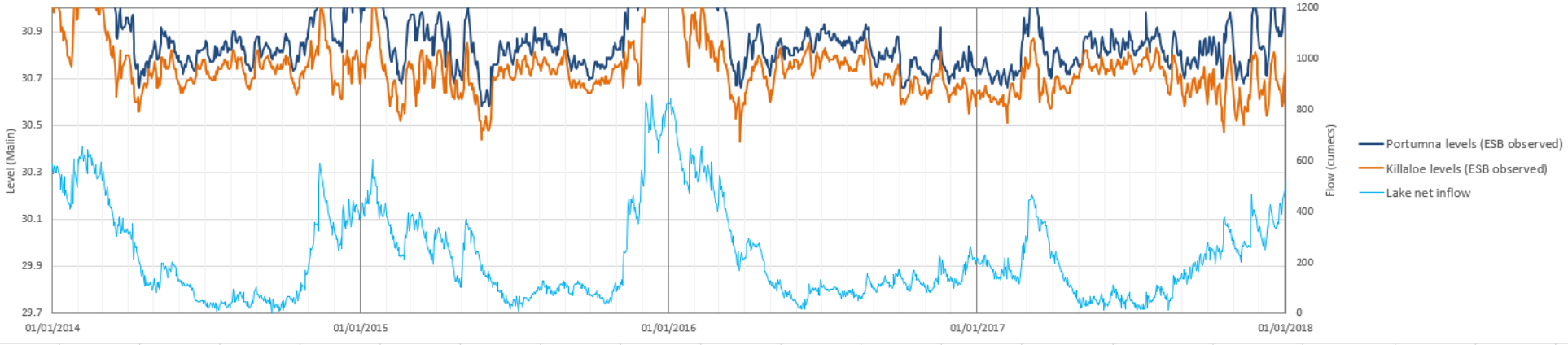


Image A.6: Example Portumna and Killaloe ESB Levels from the Period after the 1983/1984 Offset. (Note levels during the low flow dry periods are offset)

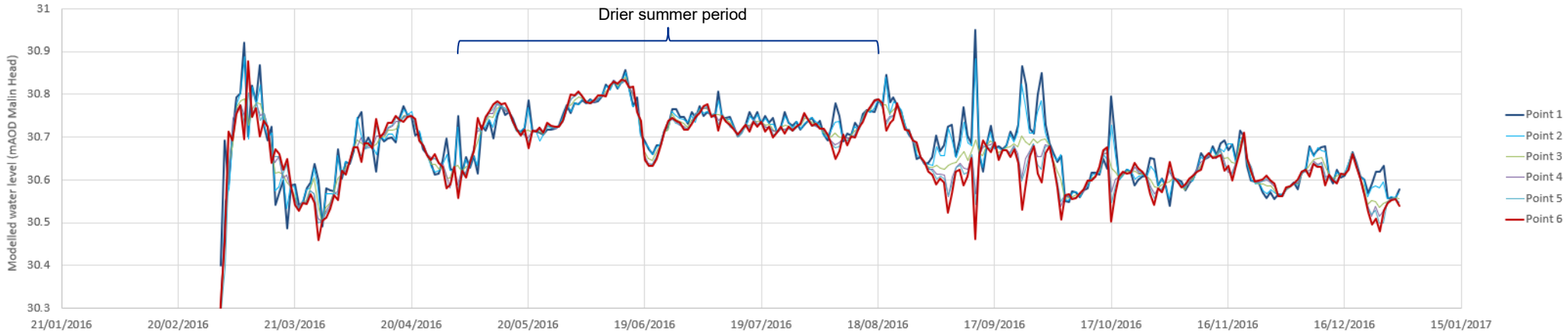


Image A.7: Hydrodynamic Model Simulation of the Level of Lough Derg at 6 Locations Along the Length of the Lake

Image note: During the drier summer period the level of the lake is simulated as becoming almost the same along its length. During the wetter periods a greater variation is simulated

Attachment B. Historical Model

B.1 Introduction

1. Initial hydrological modelling undertaken for the Proposed Project involved simulating the Lough Derg and Parteen Basin system lake levels based upon reproducing the baseline historical observed levels and then simulating the effect of introducing the WSP abstraction. This initial model build was referred to as the "Historical Model".

2. The Historical Model used the historical recorded Ardnacrusha flows controlled by the ESB in response to the historical inflows entering the Lough Derg and Parteen Basin system at the time, therefore offers an appropriate means for estimating what the impact of the WSP abstraction scenarios would have been on the observed Lough Derg and Parteen Basin system levels of the past (based upon the Ardnacrusha flows of the past), however, it does rely on the historical Ardnacrusha flows being appropriate for the inflows into the system.

3. Investigating the likely future WSP impacts needs an approach in which the Ardnacrusha flows can be estimated since the inflows into the system are projected to change due to climate change: with winters likely to become wetter and summers drier. Use of the historical Ardnacrusha flows in such a future will not be appropriate since in future wetter periods Ardnacrusha is likely to use more water and in drier periods the flows will need to be reduced. It was recognised that there was a need for a rules-based approach for simulating the Ardnacrusha flows and the management of the system.

4. The Historical Model build was superseded by the development of the rules-based Operational Principles Model build (simply referred to as the final WSP hydrological model in the main report). This Attachment serves to provide details on the Historical Model build and results.

B.2 Description of the Historical Model

5. The Historical Model was based upon reproducing the Lough Derg and Parteen Basin system historical observed water levels and then simulating the effect of introducing the WSP abstraction. This is achieved by providing the amount of water abstracted by WSP by proportionally reducing the flow going to Ardnacrusha (when it is operating). During drought periods, when power generation at Ardnacrusha is no longer occurring, this adjustment of the Ardnacrusha flow can no longer occur and the WSP abstraction is provided by a reduction in the lake level and storage volume.

6. The level of Lough Derg and Parteen Basin system is controlled by the balance between the lake inflow minus the outflow (comprising compensation flow to the ORS, fish pass flows at Parteen Weir and Ardnacrusha; together with or without the WSP abstraction). When the lake storage is in deficit, it is then preferentially replenished over Ardnacrusha hydropower generation once the drought ceases and inflows recover.

7. The Historical Model for the simulation of Lough Derg levels is built from the water balance model used to derive the net inflow series. To accommodate the proposed WSP abstraction the following three rules are used, the daily flow abbreviations for which are as follows:

Q_{WSP}	Proposed WSP abstraction flow
$Q_{Ardnacrusha\ Historical}$	The historical recorded Ardnacrusha flow
$Q_{Ardnacrusha\ (WSP)}$	The simulated Ardnacrusha flow that would occur when the WSP abstraction is in place

$Q_{Spill\ Historical}$ The historical spill to the Old River Shannon (over and above the required compensation and fish pass flow)

$Q_{Spill\ (WSP)}$ The spill to the Old River Shannon (over and above the required compensation and fish pass flow) that would occur when the WSP abstraction is in place

Rule 1 (Flood conditions)

$$\text{If } Q_{Spill\ Historical} > Q_{WSP} \text{ then } Q_{Ardnacrusha\ (WSP)} = Q_{Ardnacrusha\ Historical} \text{ and } Q_{Spill\ (WSP)} = Q_{Spill\ Historical} - Q_{WSP}$$

8. This rule means that during flood episodes, when there is more water flowing through the Lough Derg and Parteen Basin system than can be used for electricity generation, Ardnacrusha will operate to the maximum as it did in the past, and due to the additional presence of the WSP abstraction the ORS spill flow will be marginally reduced by an amount equal to the WSP abstraction. The result is that the water removed from Parteen Basin is the same as it was historically.

Rule 2: (Normal operating conditions)

$$\text{If } Q_{Ardnacrusha\ Historical} - Q_{WSP} > 0 \text{ then } Q_{Ardnacrusha\ (WSP)} = Q_{Ardnacrusha\ Historical} - Q_{WSP}$$

9. This rule means that to accommodate the presence of the WSP abstraction the Ardnacrusha flow will be reduced by an amount equal to the WSP abstraction. This amount would not have to be taken strictly on the same day, but the ESB would need to continue to carefully manage the levels to be within the Lough Derg NOB and within the current upper and lower water levels on the Parteen Basin. The result is that the water removed from Parteen Basin is the same as it was historically whilst also still meeting the required ORS compensation flows and fish pass flows.

Rule 3 (Drought conditions)

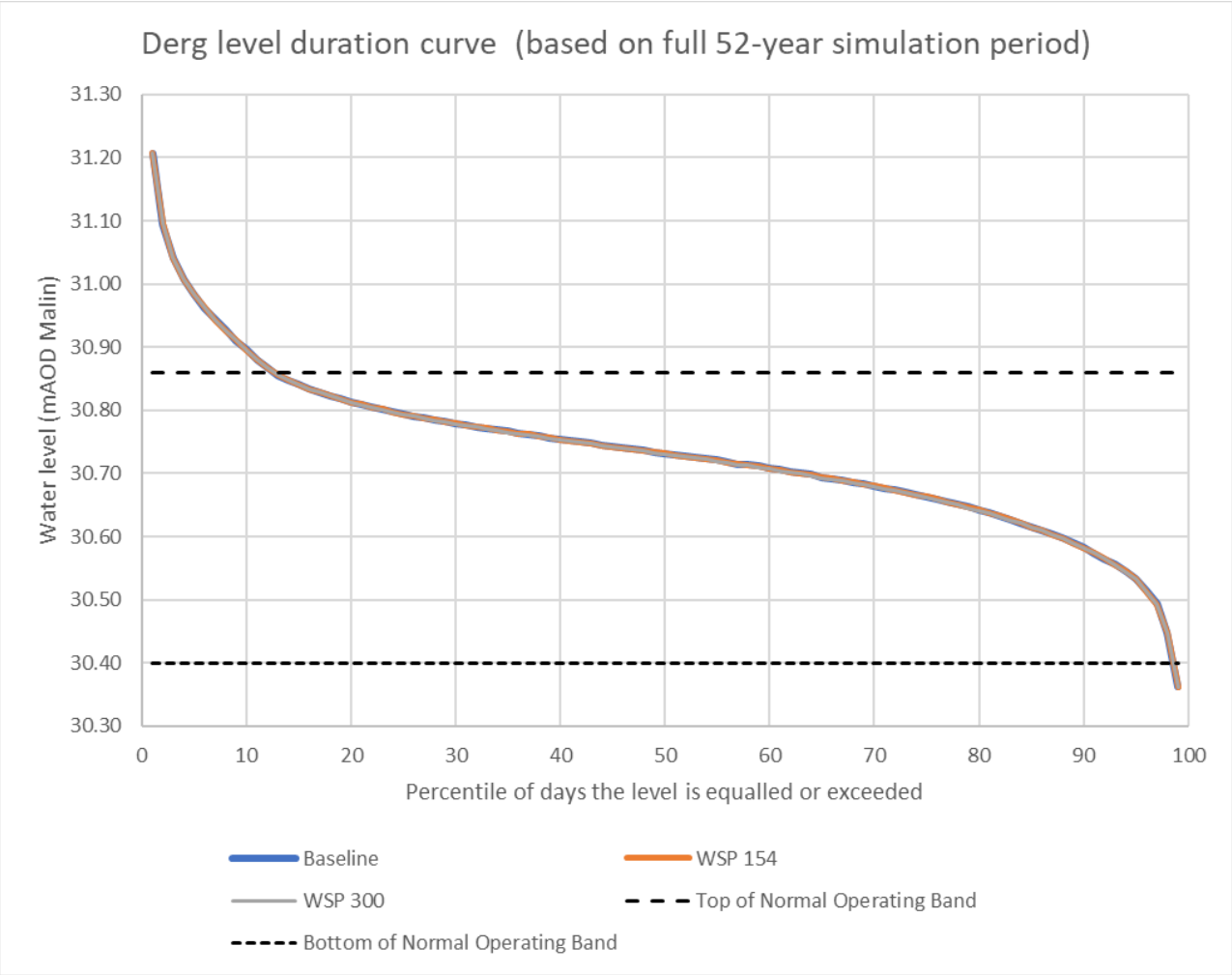
$$\text{If } Q_{Ardnacrusha\ Historical} - Q_{WSP} \leq 0 \text{ then } Q_{Ardnacrusha\ (WSP)} = 0$$

10. This rule comes into play during drought periods when the inflows are particularly low. During this period the water required to meet the WSP abstraction (as well as the required compensation and fish pass flows) shall be met through a combination of the meagre drought inflows and when necessary, a depletion of the lake storage. The model assumes that depletion of lake storage results in a drop in water level which is evenly distributed across the entire surface area of Lough Derg and Parteen Basin. Once the drought ceases and inflows recover the lake storage deficit due to the inclusion of the WSP abstraction is modelled as being preferentially replenished before any hydropower generation is permitted to begin. Once the level has recovered to the historical level then Rule 2 comes into effect.

B.3 Historical Model Simulated Impact of Proposed WSP Abstraction

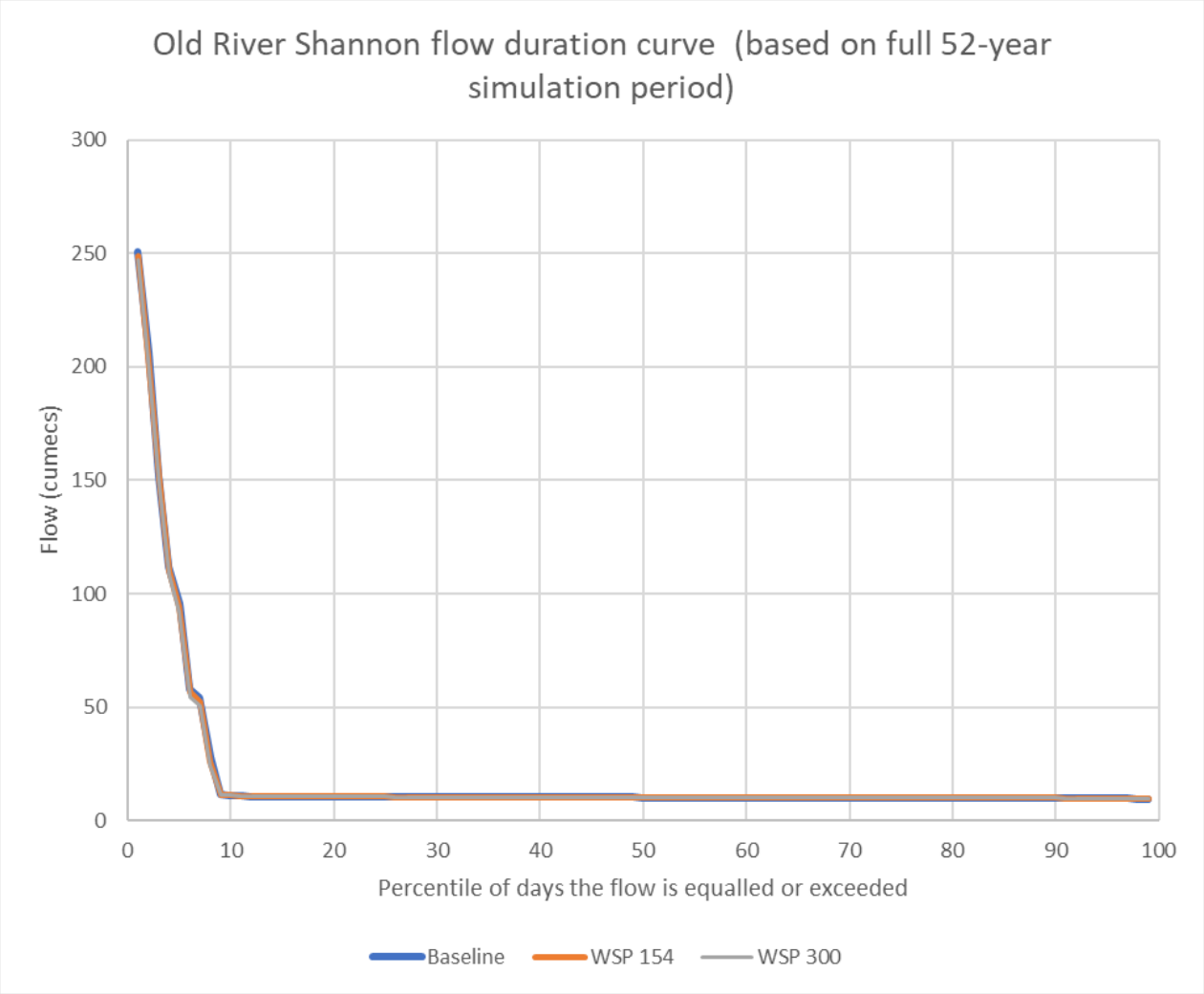
11. The full 52 years of simulation, comparing the simulated Lough Derg levels and the forward flows down the ORS, with and without the WSP abstraction, are provided in Image B.8 – B.20. Image B.1 presents the level results in the form of a level duration curve, and Image B.2 and B.3 present the ORS and the Ardnacrusha flows in the form of flow duration curves. Flow duration curves are a commonly used means within hydrology of presenting flow regime characteristics in the form of the percentage of time a flow is equalled or exceeded; and is the basis of commonly referred to flows such as the Q95 flow (a low flow index that means the flow that is equalled or exceeded for 95% of the time). Likewise, the Q50 is the flow that is equalled or exceeded for 50% of the time. As such the flow duration curve offers a succinct means of comparing flow regimes derived from long time series of data.

12. Regarding lake water levels, the ESB work to the Poolbeg datum, however the WSP hydrological models have been set up to work to the Malin Head datum. Therefore, all water level graphs in this report are given as metres Above Ordnance Datum (mAOD) with respect to Malin Head. To convert levels recorded to the Malin Head datum to the Poolbeg datum (in the vicinity of Lough Derg and Parteen Basin) a value of 2.7m needs to be added to the Malin Head level.



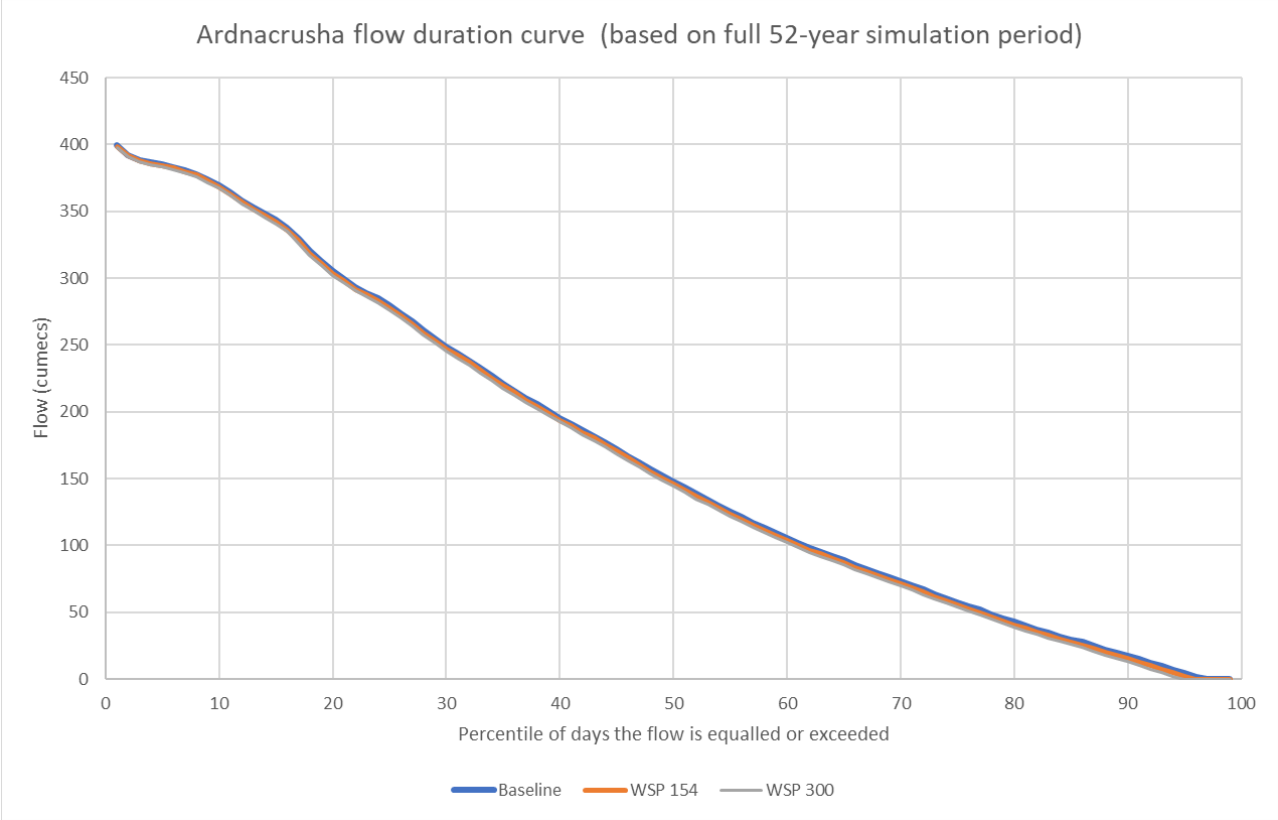
Note: The overlapping of the curves causes the individual colours to be difficult to distinguish

Image B.1: Historical Model: Simulated Impact of WSP Abstraction on the Lough Derg & Parteen Basin System Level Duration Curve



Note: The overlapping of the curves causes the individual colours to be difficult to distinguish

Image B.2: Historical Model: Simulated Impact of WSP Abstraction on the Flow to the Old River Shannon Flow Duration Curve

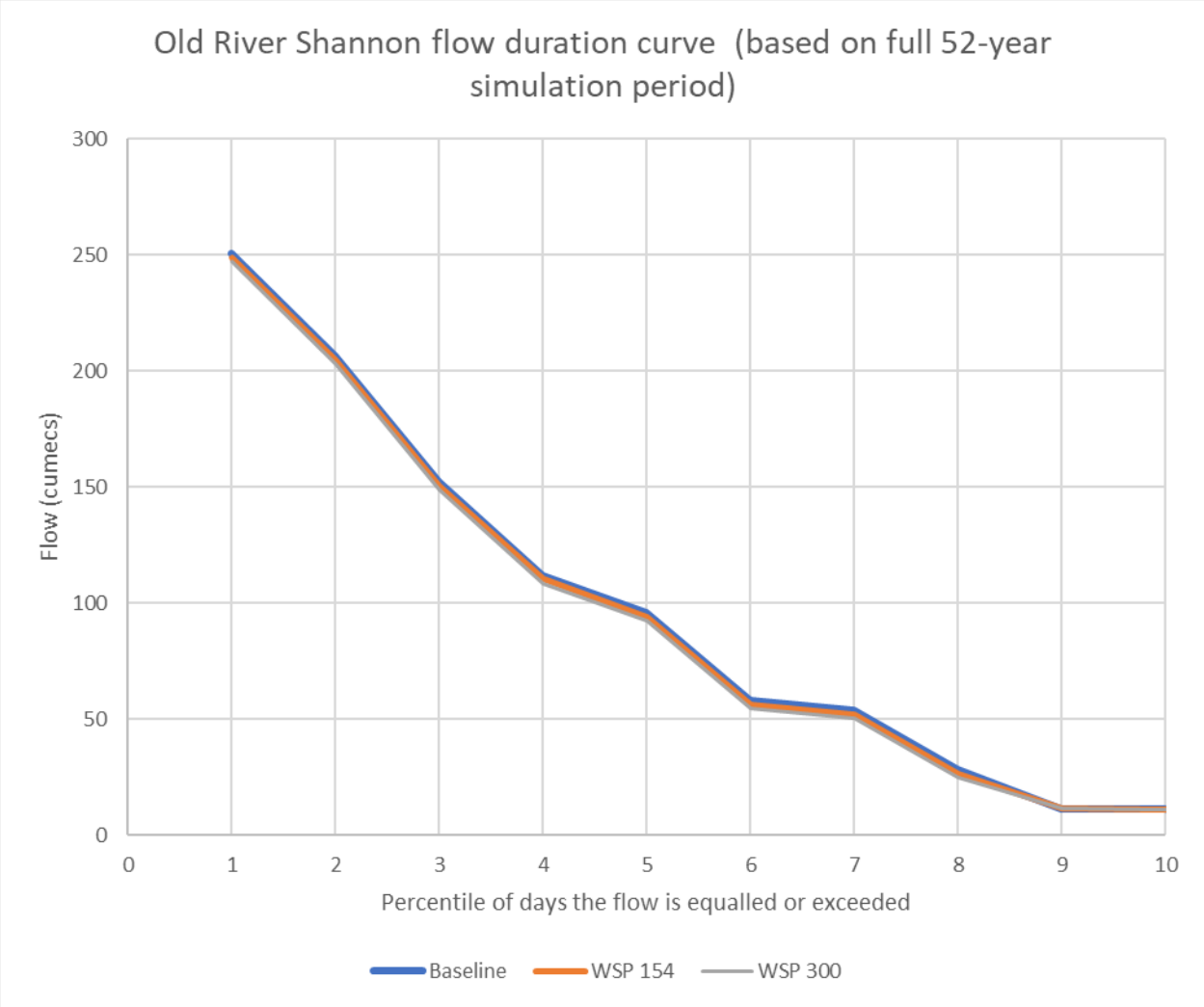


Note: The overlapping of the curves causes the individual colours to be difficult to distinguish

Image B.3: Historical Model: Simulated Impact of WSP Abstraction on the Ardnacrusha Flow Duration Curve

13. The Historical Model demonstrates that there will no perceptible impact on Lough Derg and Parteen Basin water levels arising from the introduction of the proposed WSP abstraction. This is because the peak daily proposed WSP abstraction flow (300Mld) represents less than 2% of the long-term average daily inflow to Lough Derg. Image B.4 expands the left-hand end of the ORS flow duration curve to focus in upon the high flows that occur during flood periods. In the historical period investigated (1972 – 2023), the observed ORS flows were greater than the 10m³/s obligatory minimum compensation flow for 61% of the 52-year period. With the two WSP abstraction scenarios included (154Mld and 300Mld), the percentage of days above minimum compensation flow does not change.

14. There is a minor reduction in the ORS high flows during flood conditions equivalent to the size of the WSP abstraction, when the Ardnacrusha flows are set to equal what was taken in the past and therefore the spill flow going down the ORS must be marginally reduced by an amount equal to the WSP abstraction.



Note: The overlapping of the curves causes the individual colours to be difficult to distinguish

Image B.4: Same as Image B.2, but X-axis Expanded to Focus Upon the High Flows that Occur During Flood Periods

15. The presence of the WSP abstraction is more evident in the Ardnacrusha flow-duration curve, which shows water going through the power station, since for most of the time this is being reduced by an amount equivalent to the WSP abstraction to compensate for the WSP abstraction. Were the Ardnacrusha flow not to be adjusted in line with the WSP abstraction the level would drop and drop below the bottom of the Lough Derg NOB. Evidence for this is shown in Image B.5 were the Historical Model has been rerun for the WSP = 154Mld (1.78m^3/s) scenario but without the adjustment to the Ardnacrusha flow to compensate the WSP abstraction. As can be seen, the system is quite sensitive, and the level is simulated to drop below the bottom of the NOB within a matter of months. The Ardnacrusha flow adjustment does not necessarily need to be done on the same day. There is some short-term flexibility within the system as to the timing, but the ESB need to carefully manage the level to be within the Lough Derg NOB within the finite amount of water that is passing through the system, as they currently do. To do otherwise (as shown in Image B.5) results in the level quickly falling.

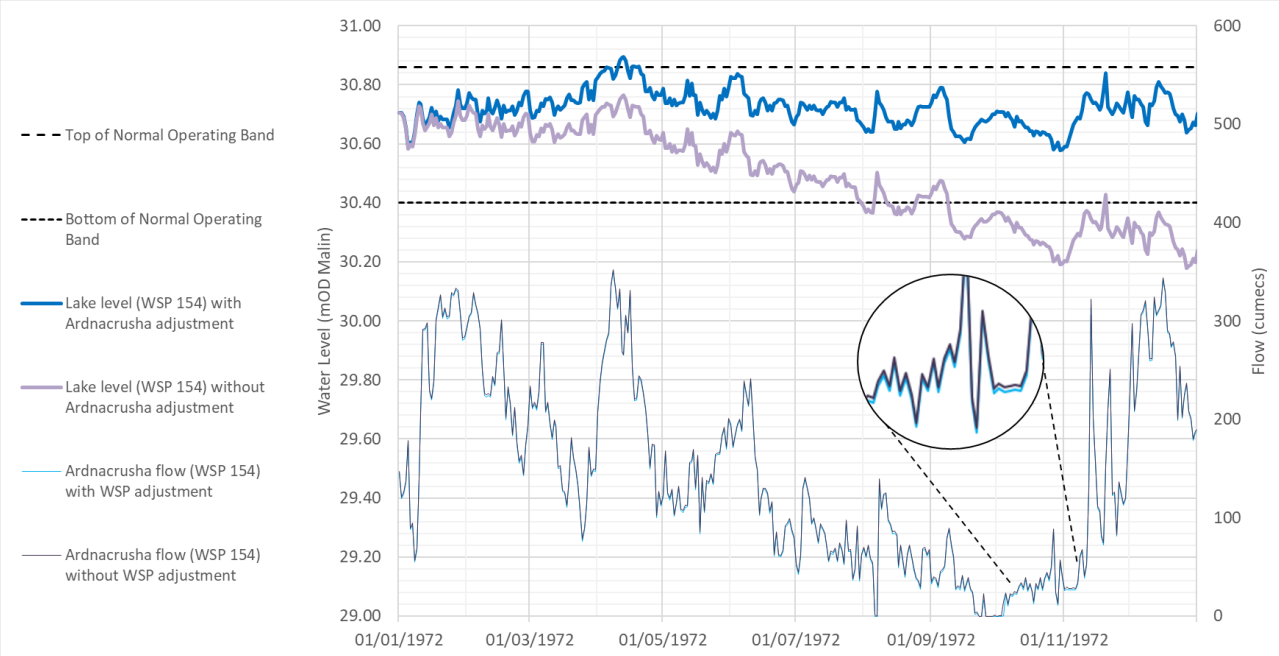


Image B.5: Historical Model: Simulation of the Impact of WSP = 154Mld on Lough Derg Level with and without the Ardnacrusha Flow Adjustment to Compensate for the Presence of the WSP Abstraction. [Insert shows the adjusted Ardnacrusha flow to be marginally lower by 1.78m^3/s (154Mld)]

16. Although Image B.1 shows barely a perceptible difference in lake levels between the long-term 52-year analysis of the baseline (without WSP) and with WSP scenarios, there can be notable simulated level differences occurring during specific extreme drought events within the simulation period. Therefore, it was decided to look closer at specific drought events that the Lough Derg and Parteen Basin system was proven to be the most sensitive to. The 2018 drought shows the biggest impact of the WSP scenarios on the simulated lake levels. The 1995 drought shows the second biggest impact.

17. Whilst Image B.8 – B.20 provides the full 52-year model simulation period, Image B.6 and Image B.7 present the time series simulations for these two drought events 1995 and 2018. The graphs provide simulated lake levels (with and without WSP) on the 1st Y-axis, and simulated flows on the 2nd Y-axis. A 2-day running mean is applied to the simulated lake water levels to remove the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends in levels. The flows include the back-calculated daily net lake inflows to the Lough Derg and Parteen Basin system (discussed in Section 2.2.2 of the main report), and the simulated Ardnacrusha flows to the power station (with and without WSP). To note the overlapping of the lines can cause the individual colours to be difficult to distinguish. A drought indicator[35] is provided at the top of the graphs as a guide to when the lake daily net inflows dropped significantly for a certain period of time.

[35] the drought indicator is specific for the sensitivity of this system and is based upon flagging the occurrence of five consecutive days when the net inflow is less than 20m^3/s

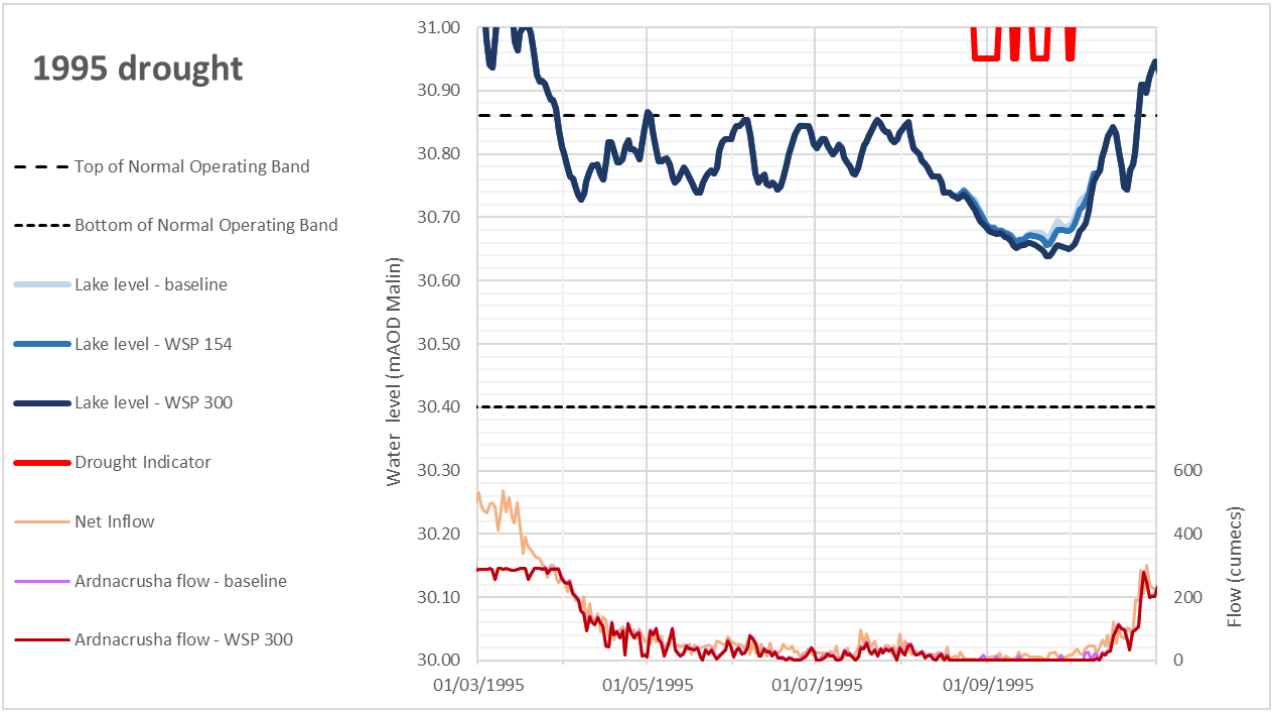


Image B.6: Historical Model: Simulation of the Lough Derg & Parteen Basin System Level for the 1995 Drought Event: i) without WSP (baseline), ii) WSP = 154Mld, and iii) WSP = 300Mld

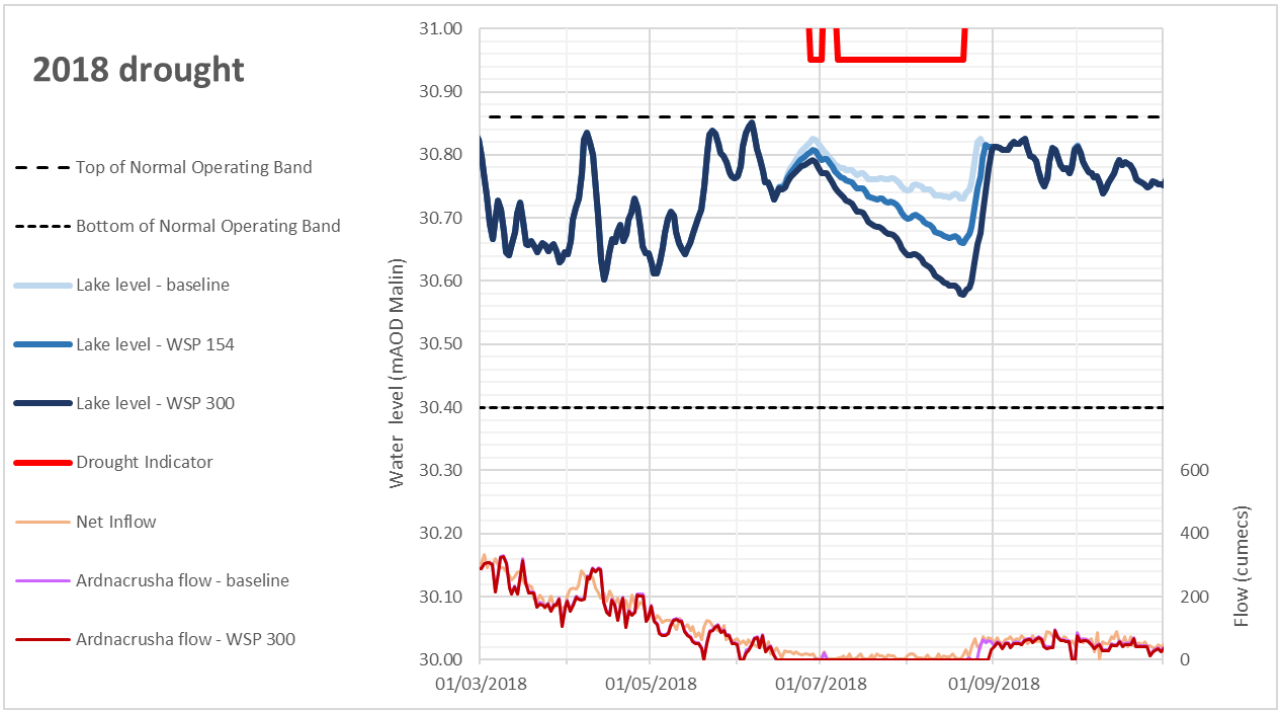


Image B.7: Historical Model: Simulation of the Lough Derg & Parteen Basin System Level for the 2018 Drought Event: i) without WSP (baseline), ii) WSP = 154Mld, and iii) WSP = 300Mld

18. The 1995 and 2018 drought events are the only years within the 52-year model simulation period where there is a notable difference in simulated lake levels between the baseline (without WSP) and with WSP scenarios. For all other model simulation years, the simulated levels are traced over each other since the WSP abstraction is balanced out by either a reduction in Ardnacrusha flow or by a reduction in release/spill to the ORS during periods of flood. During the 2018 drought event (most impactful), an extended period of severely low summer flows to the lake (use the graph drought indicator) resulted in the flow to the Ardnacrusha power station being switched off, and a notable drawdown in simulated lake levels from lake storage depletion as the model must push water out to meet the required ORS compensation flows and WSP abstraction.

19. In Image B.7, the storage deficit due to the presence of the WSP abstraction can be seen to be replenished slightly later than the baseline, and that the flow to Ardnacrusha begins slightly later because when the drought ends, and inflow begins to recover, these flows are first used to replenish the storage deficit caused by the WSP abstraction, and hence the flow to Ardnacrusha begins later. The biggest difference between the baseline (without WSP) and with WSP simulated levels in the full 52-year period of simulation occurs in the 2018 drought. For the WSP 154Mld scenario the difference in lake level from the baseline at the lowest point of the drawdown is 70mm. Similarly, for the WSP 300Mld scenario the difference in level from the baseline at the lowest point of drawdown is 152mm. This size and rate of change easily fits within the commonly observed level changes seen within the 52-year period of observed levels (refer to the Baseline levels in Image B.8 – B.20).

20. The initial Historical Model and the final WSP Hydrological Model (applying ESB operational principles) simulate slightly different departures from their respective baselines during the 2018 drought simulation. The reason for this is that the final model maintains the simulated lake levels close to the upper target level up until the end of June 2018. As the drought deepens at the start of July the levels descend and diverge from this almost same starting level. In contrast to this the Historical Model is dependent on the Ardnacrusha historical pattern of abstraction which ceased 8 days earlier than simulated in the final model. From this earlier time the Historical Model starts to drawdown the levels due to the WSP abstraction and the simulated levels begin to diverge. By the time it reaches the end of June there is already a level difference between the scenarios, and as the drought deepens the levels further diverge. This leads to the slight difference in the comparisons.

21. In conclusion, the Historical Model found the impacts to simulated Lough Derg and Parteen Basin average lake levels and forward flows (to both the ORS and Ardnacrusha power station) to be barely distinguishable when comparing the baseline (without WSP) and with WSP scenarios (154Mld or 300Mld). This has been shown when viewed on level and flow duration curves for comparing the 52-year long-term data time series. The simulated lake levels are only found to be notably affected by the inclusion of WSP during the 1995 and 2018 drought events, with all other years showing no perceptible impacts. However, even during 2018 (the most impactful drought), the size of simulated level change (152mm) is still within the range of ESB normal observed level fluctuations, and critically still within the Lough Derg Normal Operating Band (NOB), and within the upper and lower water levels that it applies on Parteen Basin. The ORS compensation and fish pass flows are always met with or without the WSP abstraction in place within the modelling undertaken.

B.4 Historical Model Long-term Simulation Time Series

22. Image B.8 – B.20 gives a series of graphs to provide the Historical Model simulated Lough Derg and Parteen Basin system average lake levels and pass forward flows to the Old River Shannon (ORS) for the full 52-year simulation period for three scenarios:

    Baseline – the observed historical levels without WSP abstraction (this provides the ESB recorded levels)

    WSP 154 included – the same as the Baseline but with a WSP constant abstraction of 154Mld (1.78m^3/s)

    WSP 300 included – the same as the Baseline but with a WSP constant abstraction of 300Mld (3.47m^3/s)

23. A 2-day running mean is applied to the simulated lake water levels to remove the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends in levels. The graphs are split between lake level information on the 1st Y-axis and flow information on the 2nd Y-axis. To note the overlapping of the lines can cause the individual colours to be difficult to distinguish. To help see where significant level differences occur use the drought indicator[36] at the top of the graph as a guide – for example go to 1995 and 2018 during which the two most significant droughts to the system occurred.

24. Although simulated level differences between scenarios are distinguishable during the worst droughts (1995 and 2018), the changes in forward flow to the ORS cannot be distinguished. A minor reduction to forward flows to the ORS (equivalent to the WSP abstraction) does occur during flood flows, but this is too small to be distinguished on the graphs at this scale. Outside of these flood periods the forward flow traces are the same showing that the fish pass and compensation flows to the ORS are always met regardless of scenario considered.

[36] the drought indicator is specific for the sensitivity of this system and is based upon flagging the occurrence of five consecutive days when the net inflow is less than 20m^3/s

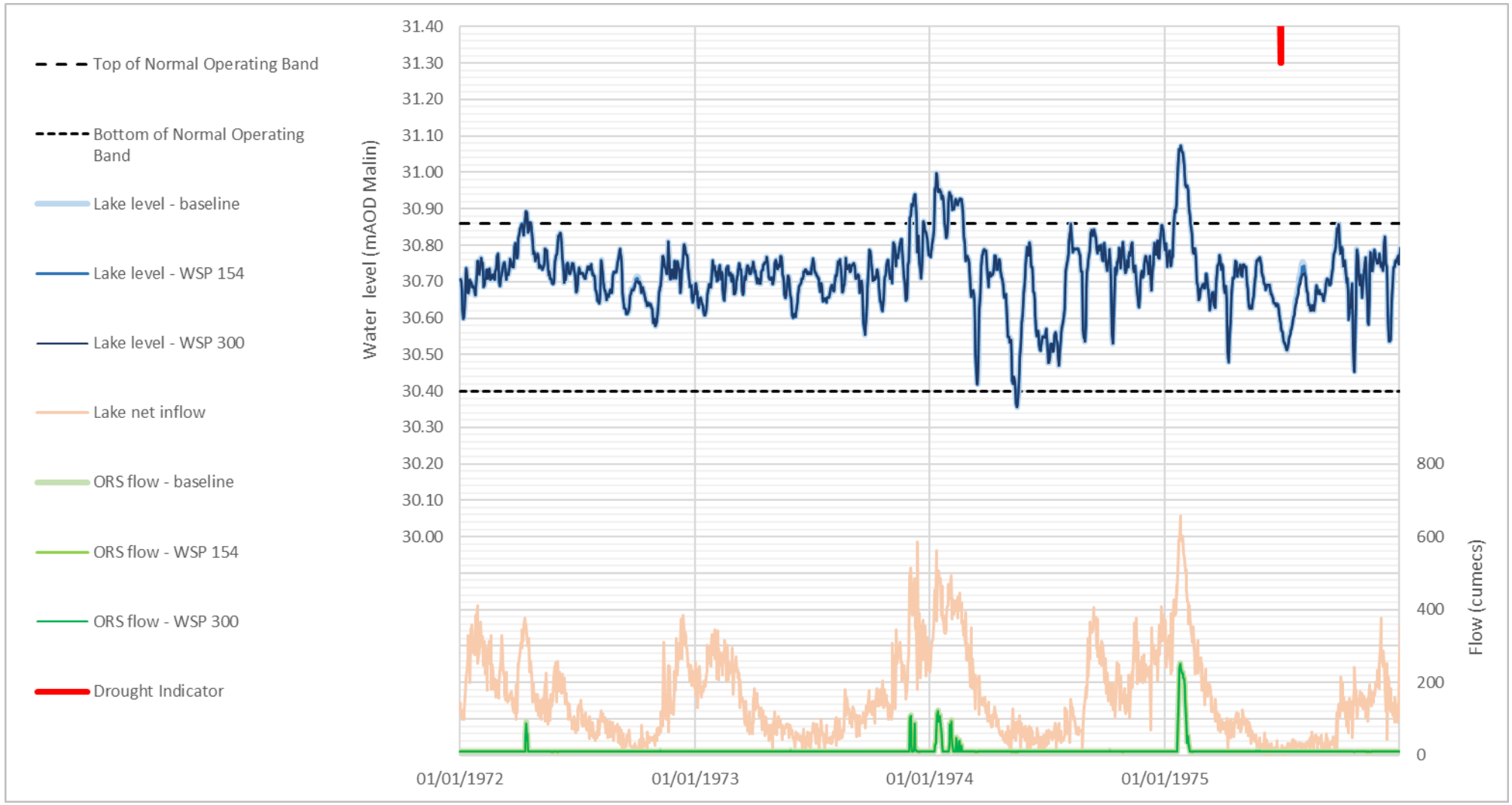


Image B.8: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (1972-1975)

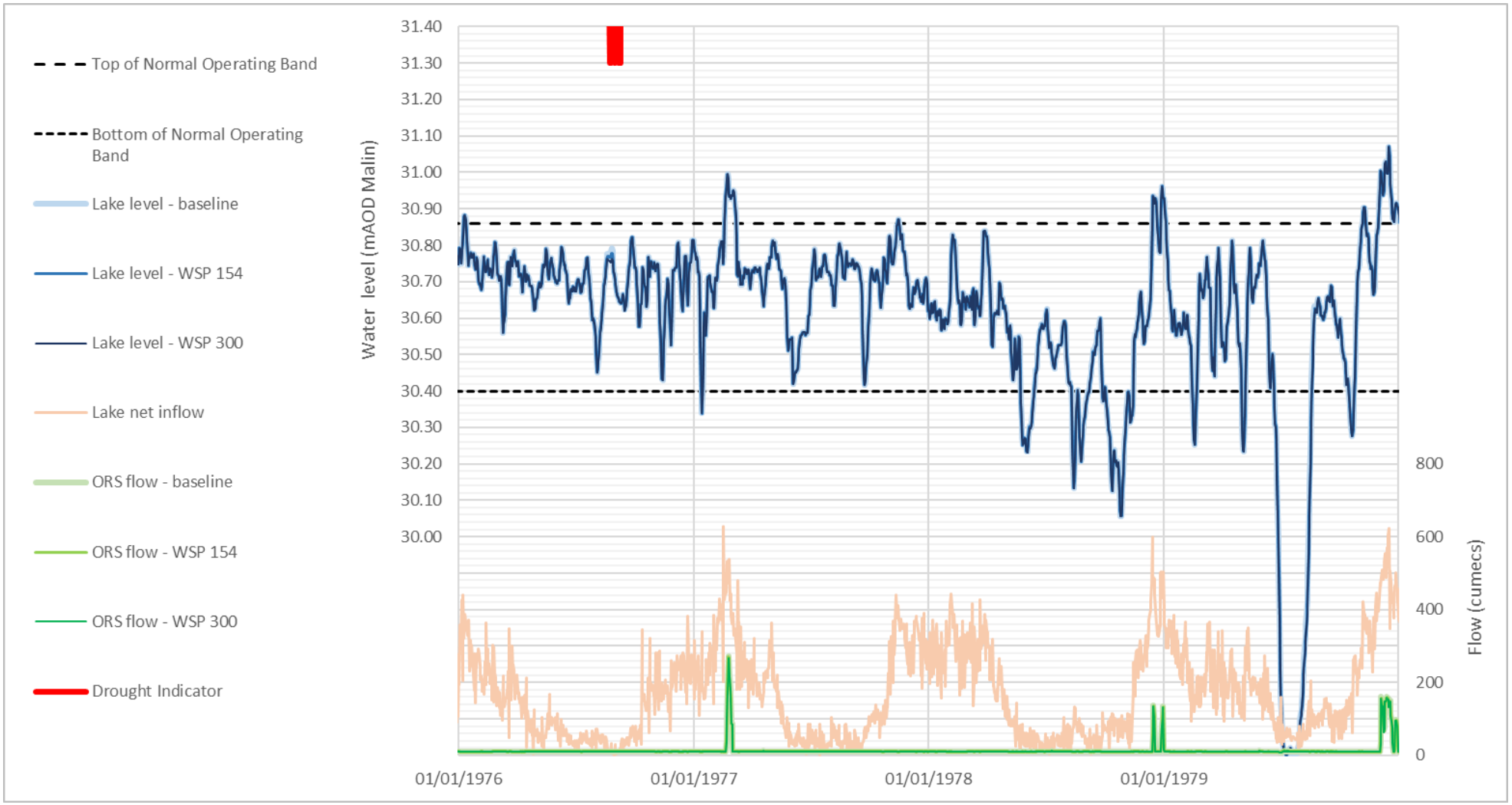


Image B.9: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (1976-1979)

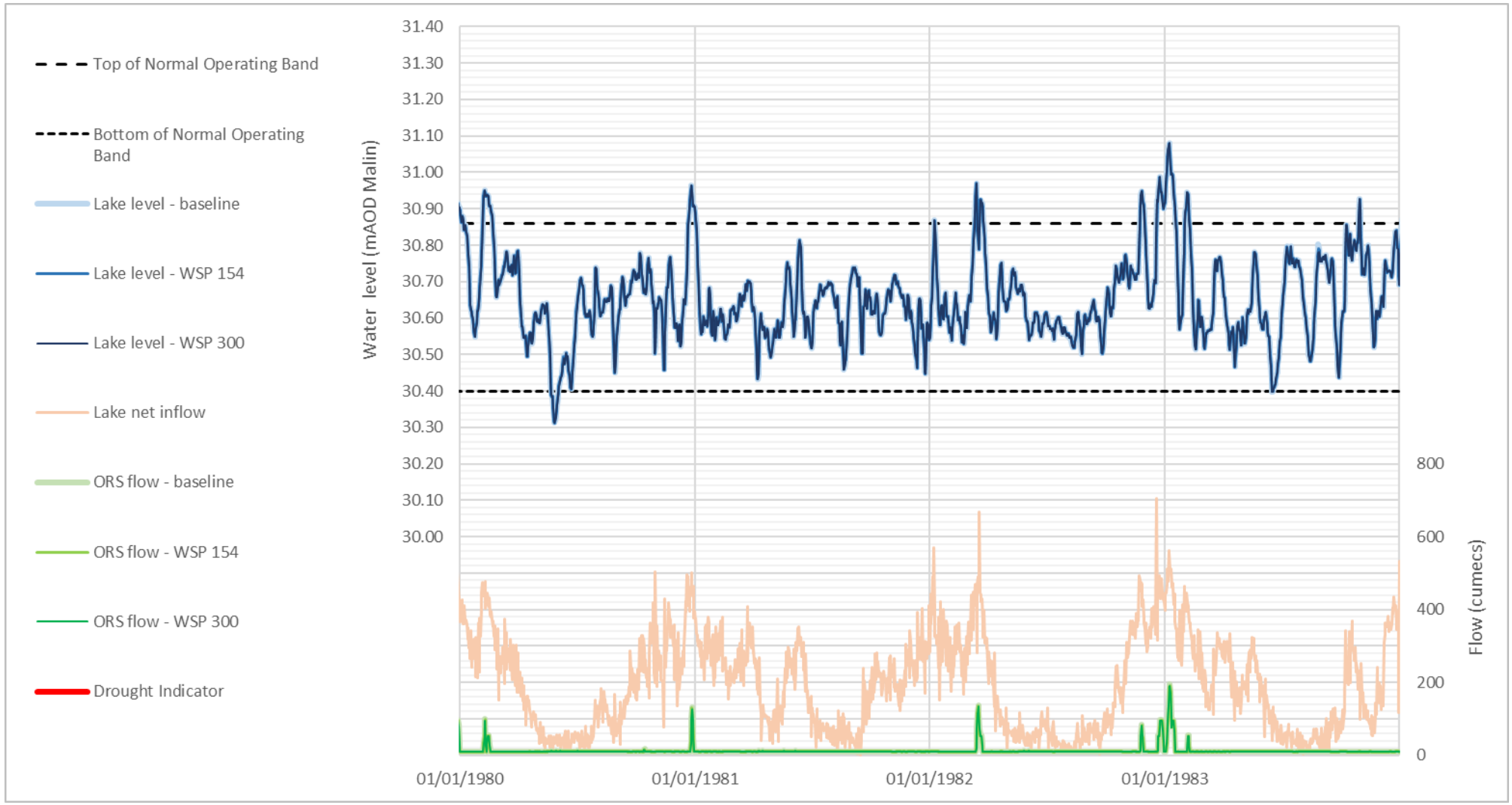


Image B.10: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (1980-1983)

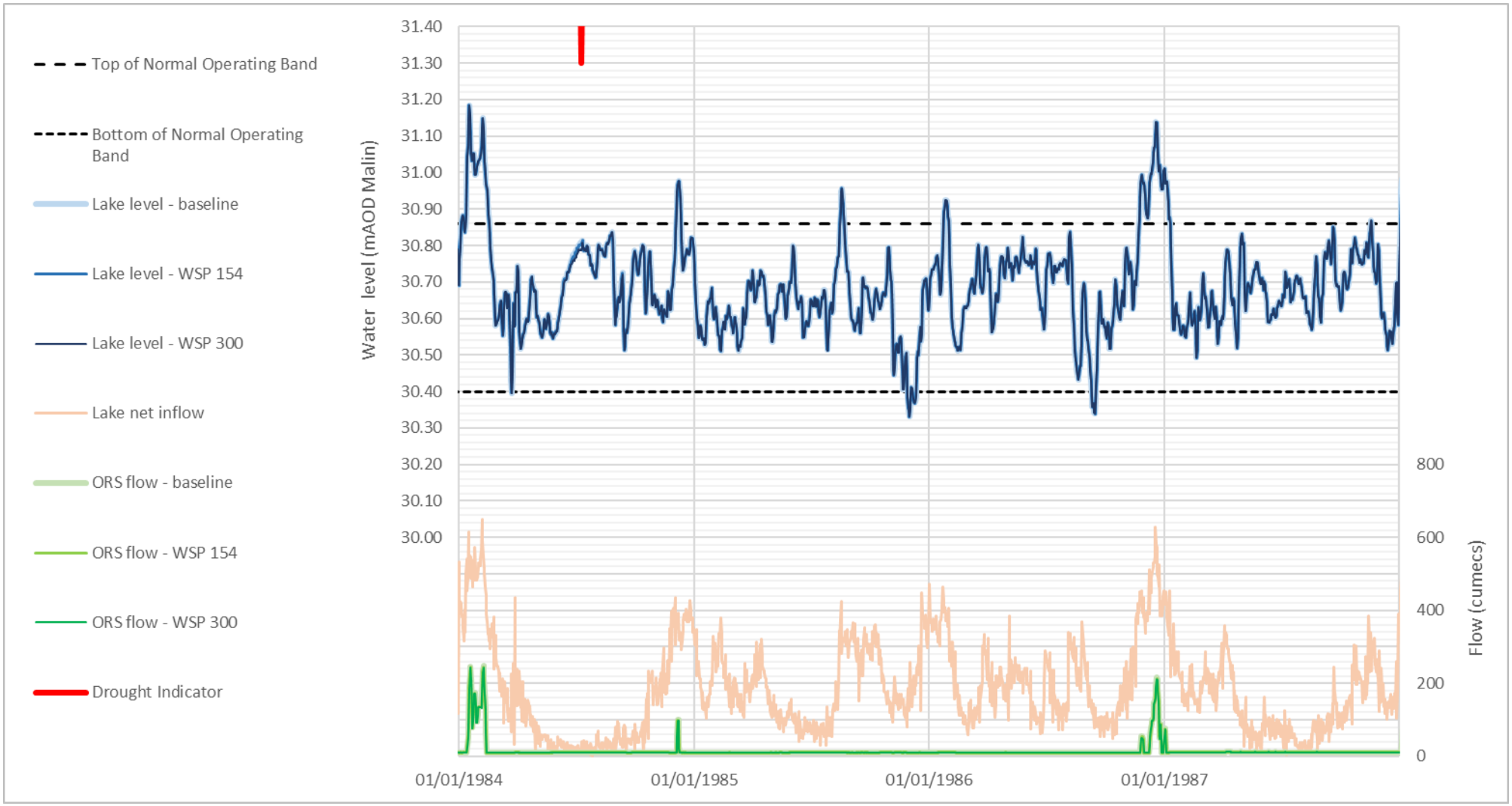


Image B.11: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (1984 - 1987)

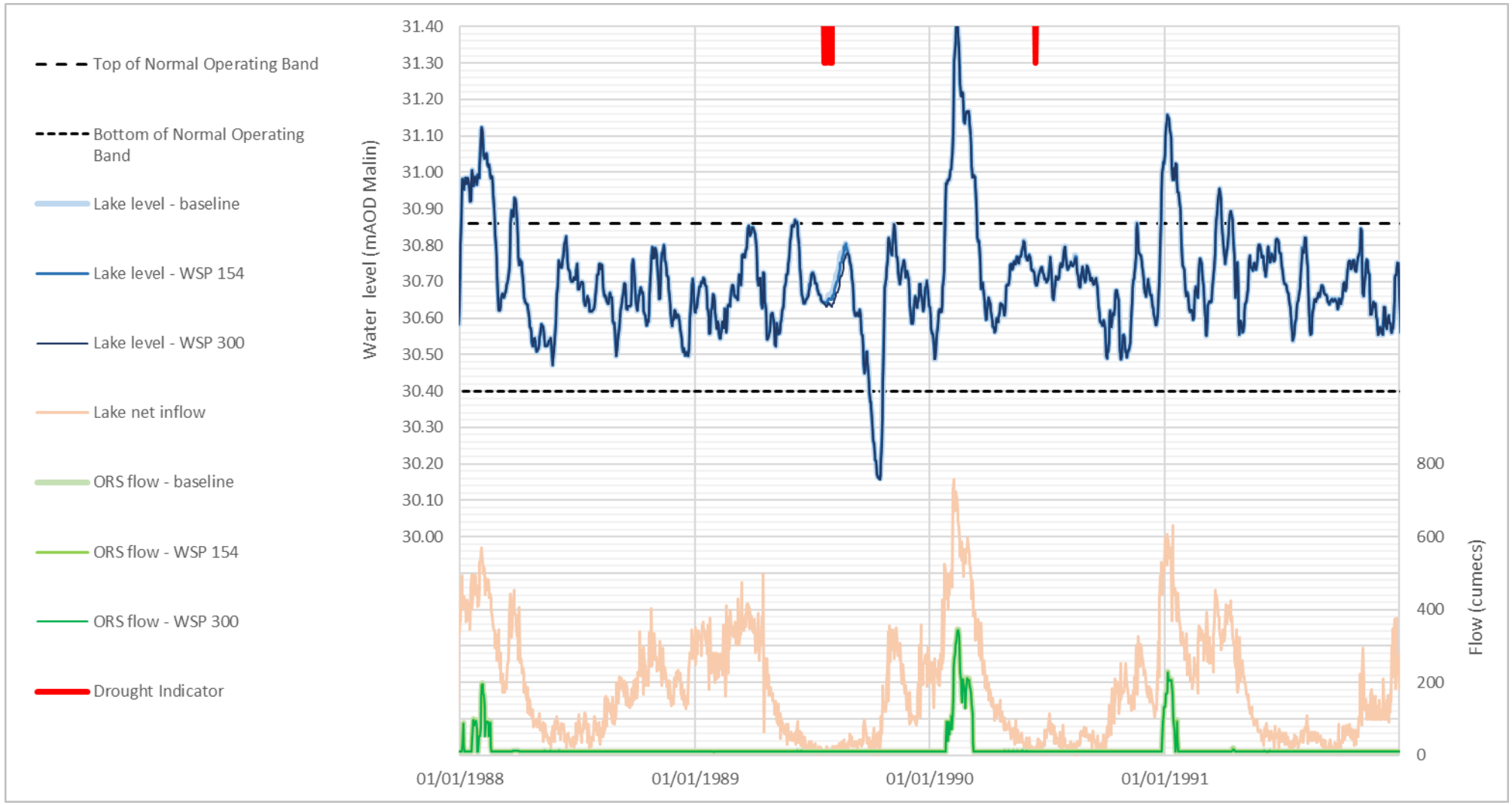


Image B.12: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (1988-1991)

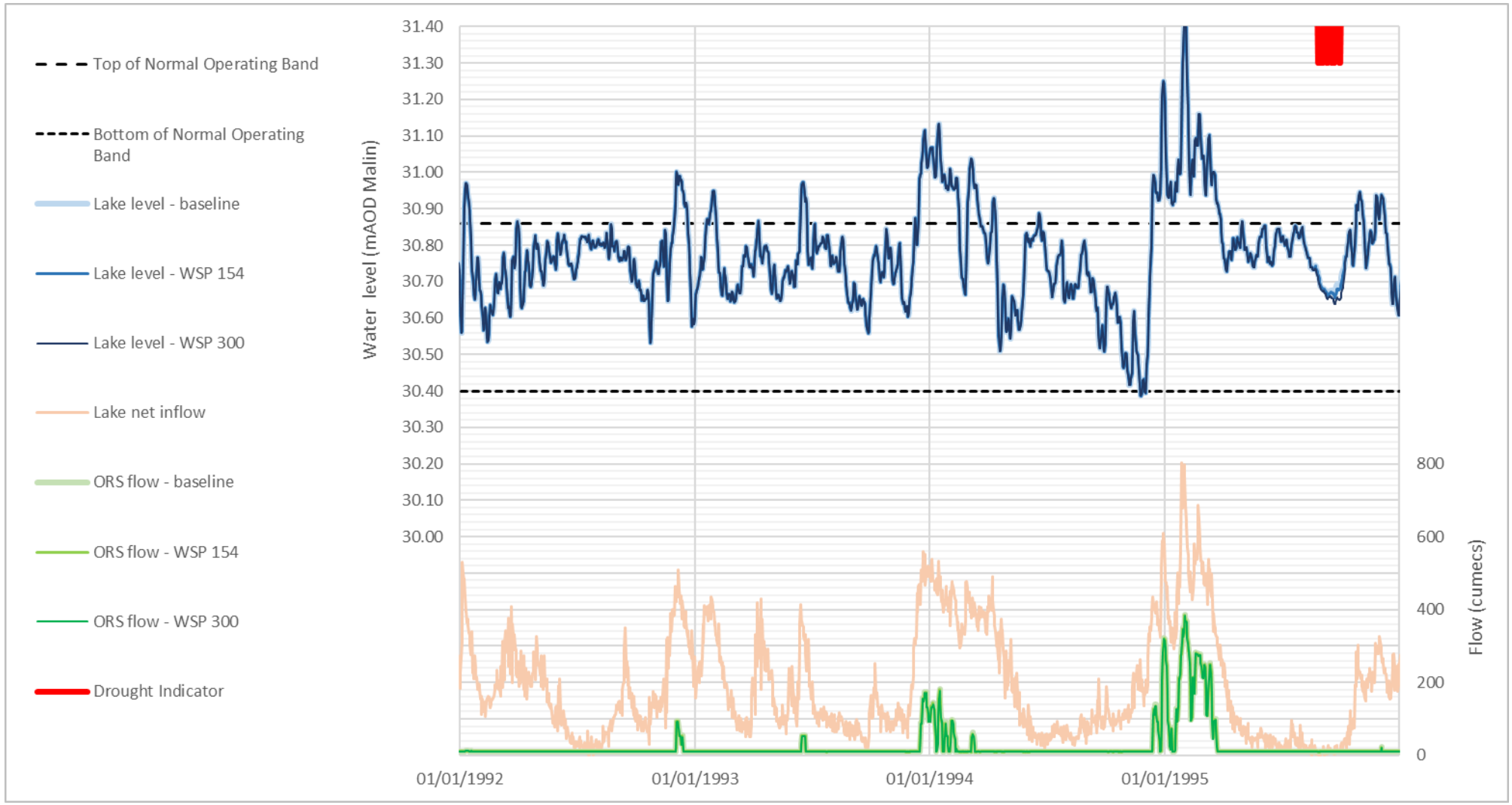


Image B.13: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (1992-1995)

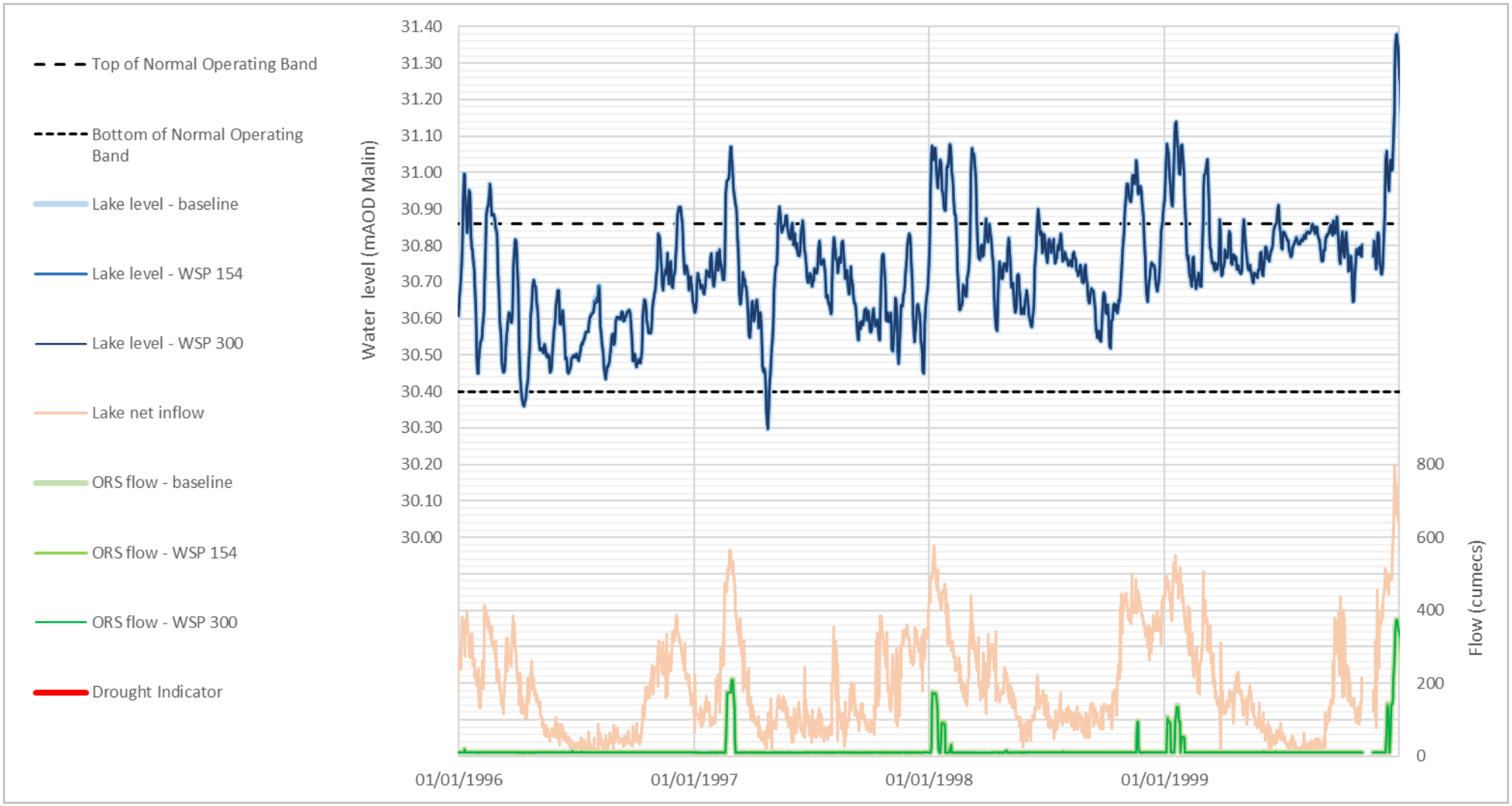


Image B.14: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (1996-1999)

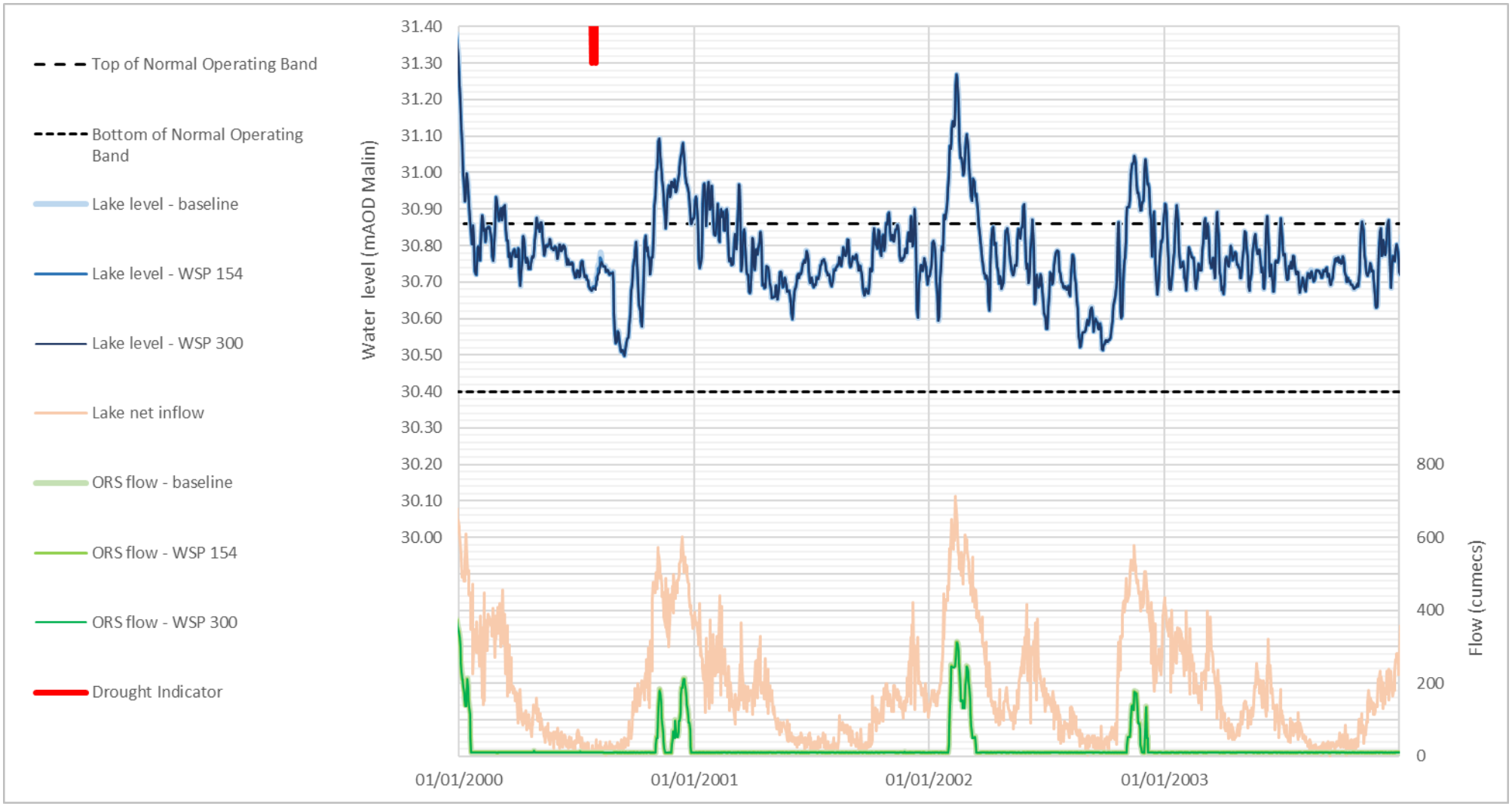


Image B.15: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (2000-2003)

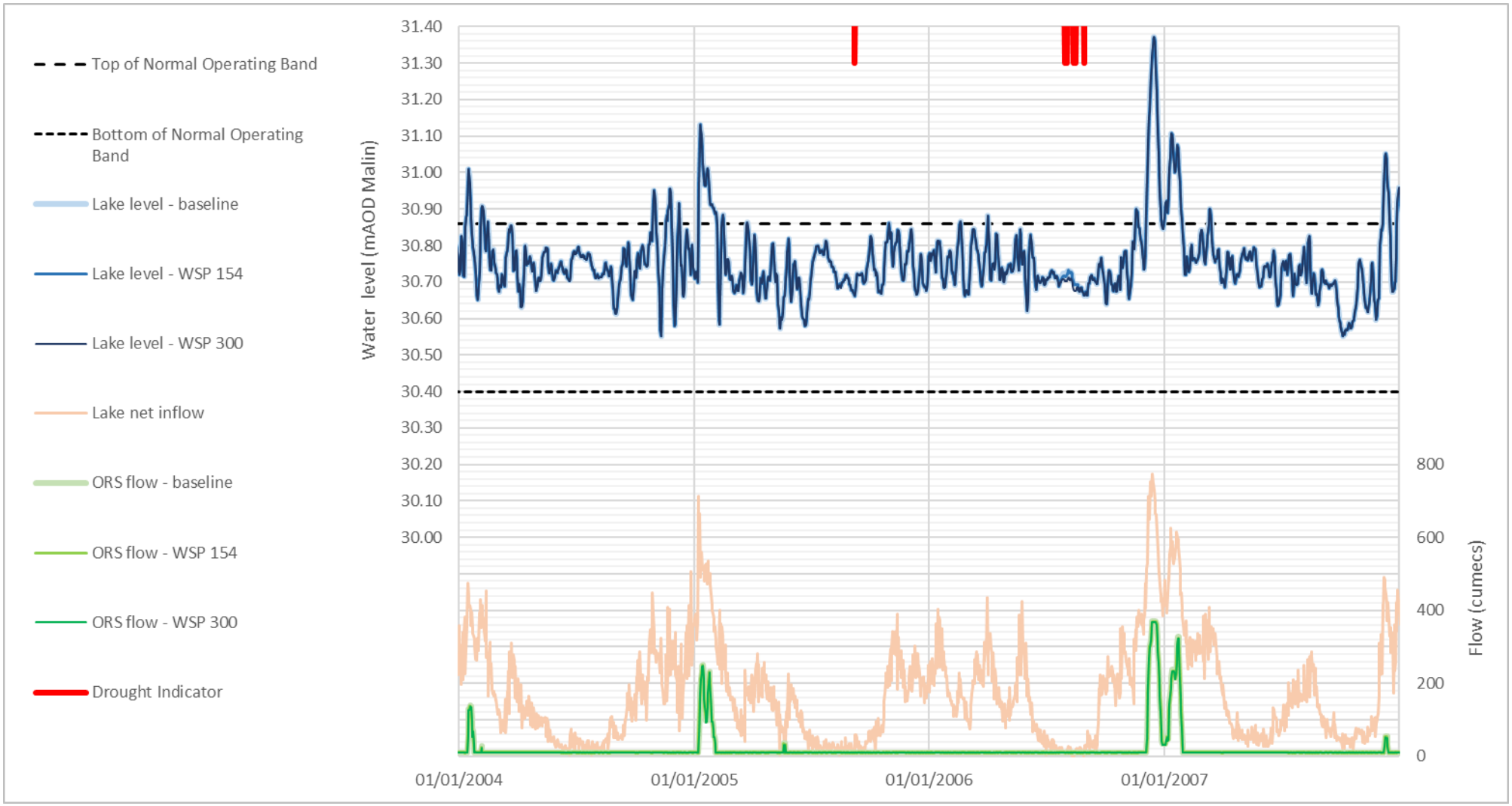


Image B.16: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (2004-2007)

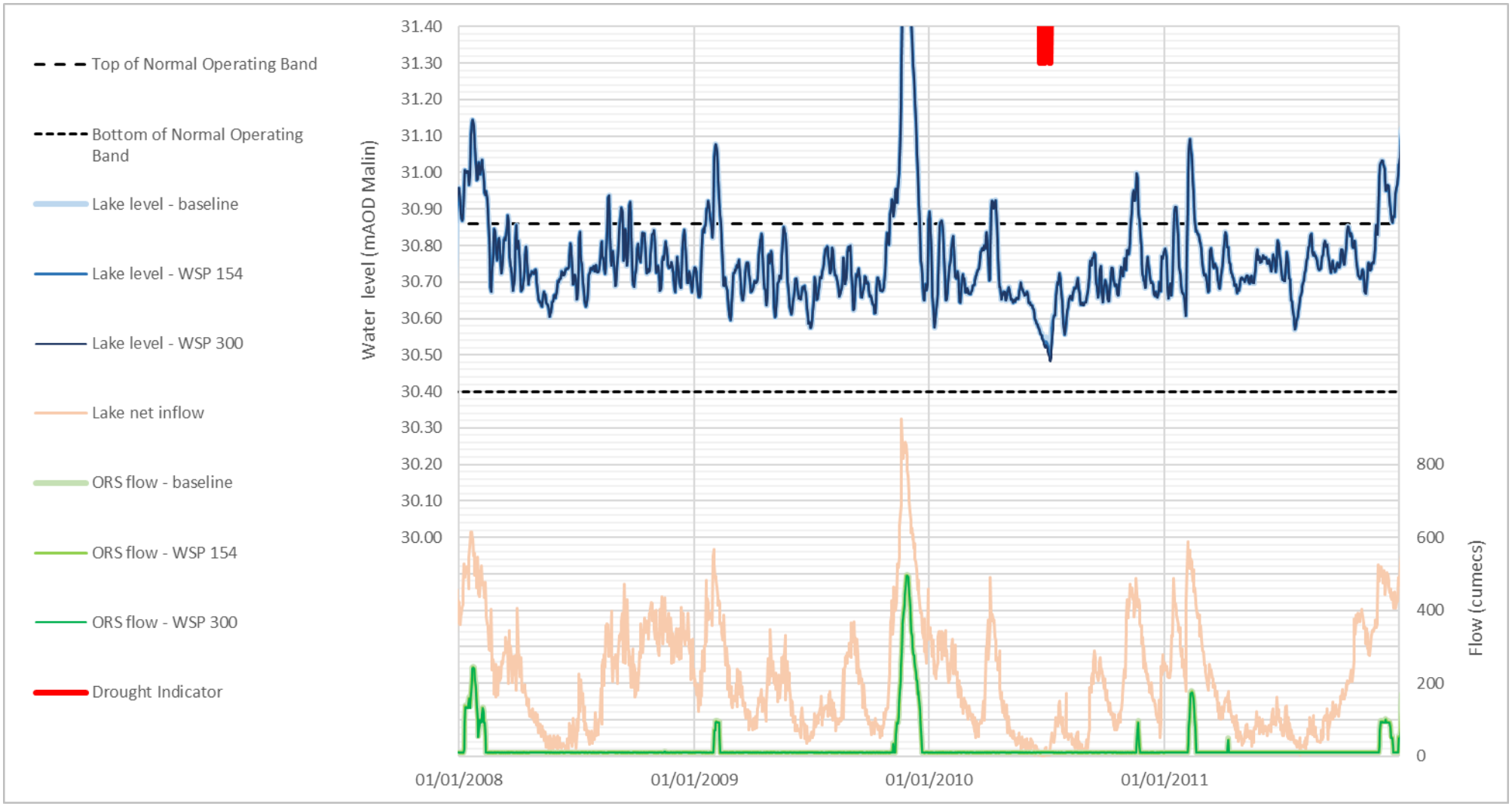


Image B.17: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (2008 - 2011)

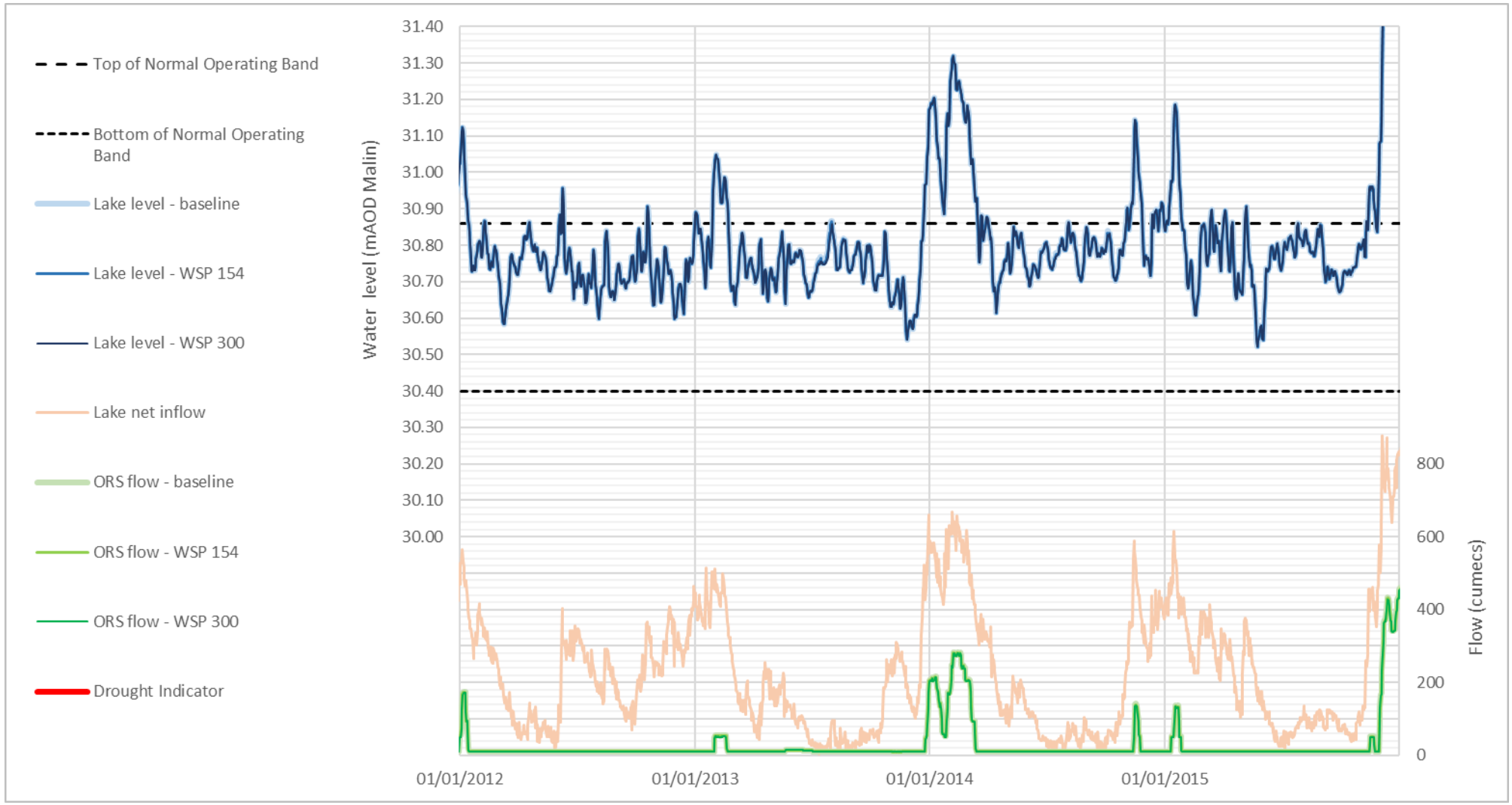


Image B.18: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (2012-2015)

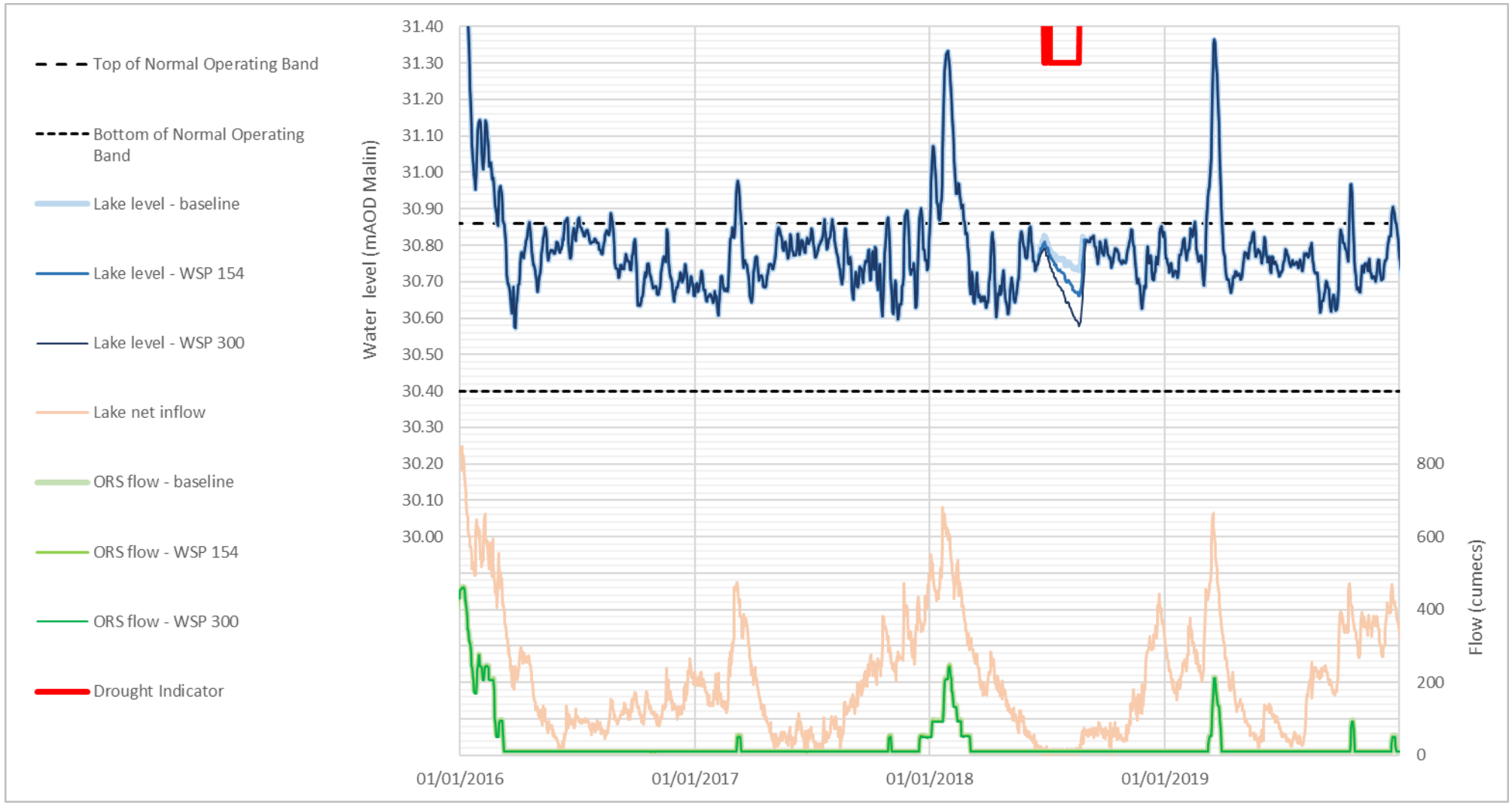


Image B.19: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (2016-2019)

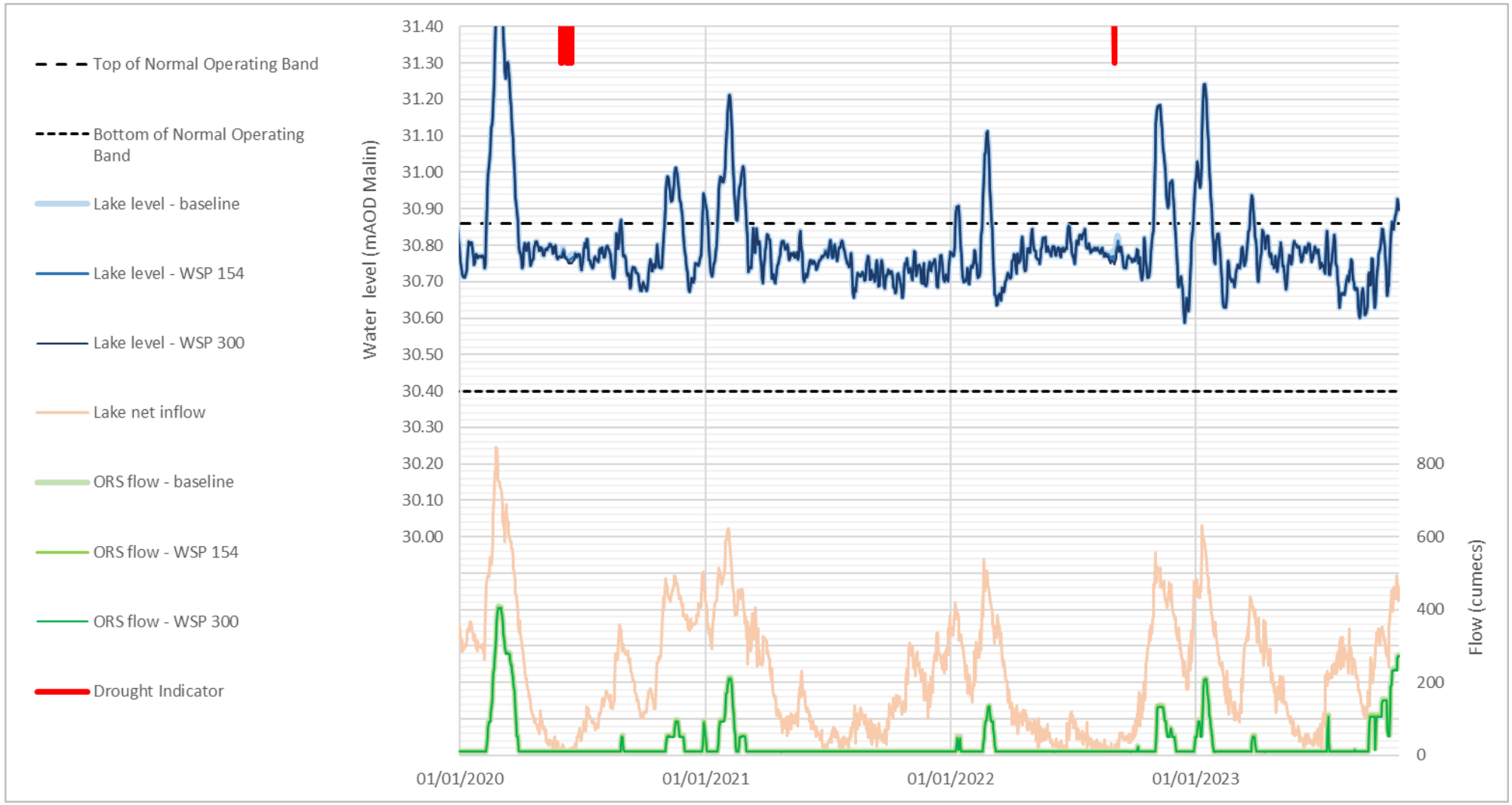


Image B.20: Historical Model: Simulated Lough Derg and Parteen Basin system lake levels and Old River Shannon flows long-term time series (2020-2023)

Attachment C. Codification of the ESB Operational Principles

C.1 Introduction

1. The Historical Model offers an appropriate means for estimating what the impact of the WSP abstraction scenarios would have been on the observed Lough Derg and Parteen Basin system levels of the past (based upon the Ardnacrusha flows of the past). However, it does rely on the historical Ardnacrusha flows being appropriate for the inflows into the system. Investigating the likely future WSP impacts needs an approach in which the Ardnacrusha flows can be estimated since the inflows into the system are projected to change due to climate change: with winters likely to become wetter and summers drier. Use of the historical Ardnacrusha flows in such a future will not be appropriate since in future wetter periods Ardnacrusha is likely to use more water and in drier periods the flows will need to be reduced. There is therefore a need for a rules-based approach for simulating the Ardnacrusha flows and the management of the system.

2. The ESB operational principles rules used in the final WSP hydrological model build[37] are based on discussions with ESB to understand how ESB typically aim to manage both the Lough Derg and Parteen Basin system levels, and the pass forward flows to the Ardnacrusha power station and ORS. The operational guiding principles received from ESB were then codified into the WSP hydrological model for a rules-based modelling approach.

C.2 Operational Information

3. The ESB work to the Poolbeg datum, whilst the WSP hydrological models have been set up to work to the Malin Head datum. All levels given here are with respect to Malin Head, though equivalent Poolbeg values are given in italics[38].

4. The ESB manage the water levels on Lough Derg (Derg TN) within the NOB. This band is defined using the following water levels: :
    - Lough Derg top of NOB = 30.86mAOD *[33.56mAOD Poolbeg]*
    - Lough Derg 'Black Start' reserve level = 30.50mAOD *[33.20mAOD Poolbeg]*
    - Lough Derg bottom of NOB = 30.40mAOD *[33.10mAOD Poolbeg].*

5. On Parteen Basin (Derg HMWB) ESB keep water levels within an upper and lower water level, for dam safety purposes. These water levels are as follows::
    - Parteen Basin upper water level = 30.86mAOD *[33.56mAOD Poolbeg]*
    - Parteen Basin lower water level = 30.00mAOD *[32.70mAOD Poolbeg]*.

6. Parteen Weir acts as the downstream control structure for water levels in the system. Water levels in Parteen Basin are maintained within the upper and lower levels at all times. During low flow conditions, the lower water level at Parteen Basin (30.0mAOD Malin), must be maintained for dam safety purposes and in doing this ESB ensures that water levels on Lough Derg are within the NOB as the waterbodies broadly operate as a combined system, in these conditions.

[37] This final version of the WSP hydrological model build has previously been referred to as the “Operational Principles Model” to differentiate it to the initial “Historical Model” build.

[38] To convert levels recorded to the Malin Head datum to the Poolbeg datum (in the vicinity of Lough Derg and Parteen Basin) a value of 2.7m needs to be added to the Malin Head level.

Note upon Lough Derg levels:

The Lough Derg levels referred to above are with respect to the levels as recorded at Killaloe (Pier Head). Reported water level on Lough Derg has been calculated in the modelling work as the mean of levels recorded at Portumna and at Pier Head, Killaloe. The Portumna and Killaloe levels can differ due to wind and flow effects through the lake, and the range of difference is about 0 to 0.4 m. These differences are a function of flow magnitude and wind direction and speed. When Ardnacrusha is operating at near full capacity there is on average about a 0.2m difference in the levels (meaning that there is approximately a 0.1m difference between the Killaloe level and the average lake level). During the summer period (when inflows are low) the recorded Killaloe level equates well to the average lake level.

7. The Parteen Basin lower water level was established for reasons of embankment structural safety.

8. Killaloe water levels will go above the top of Lough Derg NOB level during flood events. When this occurs then the flood needs to be safely passed through the system. This is done via opening gates on Parteen Weir to allow the water down the ORS. Once the level returns to the top of Lough Derg NOB level (and inflows reduces to the point that the Lough Derg NOB is not going to be exceeded again when all gates are closed at Parteen Weir) then the use of the Ardnacrusha abstraction (coupled with the compensation flow) is used to maintain the level within the Lough Derg NOB. During flood events water can also pass through Ardnacrusha to generate electricity up to its maximum rate[39].

9. The received ESB key principles/rules governing the level management of Lough Derg and Parteen Basin are provided in Table C.1.

Table C.1: Key ESB Principles and Rules Governing the Management of the Levels in the Lough Derg and Parteen Basin system

General Principle or Rule	Description	Comment
Water level to be kept within the Lough Derg Normal Operating Band (NOB)	The ESB manage the water levels (as monitored at Killaloe) to be within the Lough Derg Normal Operating Band (NOB) between 30.40mAOD and 30.86mAO. During sufficiently big floods the level of Lough Derg cannot be prevented from exceeding the top of the NOB and the Flood Rule comes into effect.	The Lough Derg NOB is further refined by the presence of the 30.50mAOD 'Black Start' reserve level for water that is reserved by ESB in case of a supply emergency upon the electricity network necessitating power to be supplied by Ardnacrusha. Whilst it is acknowledged that ESB may manage lake water levels not to encroach upon the Black Start reserve, the WSP hydrological models do not use the Black Start as a minimum threshold level, and are only concerned with simulated levels being maintained within the NOB.
Early summer Lough Derg level	ESB seek to have Lough Derg water levels towards the upper end of the NOB in late spring/ early summer.	A guide rather than a strict rule. The ESB do not aim to be at 30.86mAOD at Pier Head however tend to the upper end around 30.80mOD average Lough Derg level, subject to operational requirements which can, when there is sufficient water available, mean that they utilise the full operating band.
Autumn and winter Lough Derg level	ESB seek to have Lough Derg water levels towards the lower end of the band in autumn and winter.	A guide rather than a strict rule. The ESB do not aim to be at the black start level (30.50mOD at Pier Head, Killaloe), however tend to the lower end of the Lough Derg NOB around 30.60mOD Pier Head, Killaloe (equivalent to approximately 30.70mOD on the average lake level scale).
Low flow regime	Lough Derg inflow of 100m^3/s on a falling hydrograph is a trigger to commence retaining water towards the upper end of the band.	A guide rather than a strict rule. From the records it is evident that variation in the amounts of water going to Ardnacrusha during these times have resulted in fluctuations to the Lough Derg water level that take the level away from the upper end. Though it should be noted that the sensitivity of the level to the water balance of the system is such that these fluctuations can generally be addressed by subsequent changes to the amount going to Ardnacrusha. Set rules describing by how much the ESB curtail their abstraction during these periods are not given, though during the lowest inflow periods the ESB stop generating altogether.

[39] In a flood event the maximum amount of water possible, cognizant of Dam Safety and Operational Constraints, is discharged through Ardnacrusha Station regardless of commercial implications.

General Principle or Rule	Description	Comment
Compensation flow	Statutory compensation flow of 10m^3/s is released to the Old River Shannon (ORS), and 0.5m^3/s is also released at the Ardnacrusha fish pass.	The compensation flow of 10m^3/s at Parteen Weir is formed of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates.
Flood rule	When Lough Derg levels are greater than the top of NOB (30.86mOD) and inflow is greater than the maximum capacity of Ardnacrusha then excess is released down the ORS in such a way that the Parteen Basin level does not go below 30.00mOD or exceed 30.86mOD.	This is done until such time that (Pier Head) Killaloe level and inflows into Lough Derg are reduced to the extent that the top of the NOB (30.86mOD) will no longer be exceeded when all gates are closed at Parteen Weir When the gates at Parteen Weir are opened the level of Parteen Basin lowers and the turbine output at Ardnacrusha is reduced due to the lower head.

C.3 Codification of the Operational Rules

10. Based on the above information and interpretation of the level and flow time series (supplied by the ESB for Lough Derg and Parteen Basin), a means of simulating the likely day-by-day flow to Ardnacrusha was codified. The Ardnacrusha flows simulated by the WSP hydrological model perform well when compared to the ESB recorded (observed) flows to Ardnacrusha power station – see Image C.1. A 3-day running mean has been used for both lake levels and flows to slightly smooth the data as it removes the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends.

11. Good agreement is visually evident, the general rising and falling trends are well represented. The low abstraction rates during the summer and early autumn are well simulated and those during the drought of 2018 are also well simulated. During the flood periods (Ardnacrusha flow reaching a maximum of approximately 400m^3/s, and evident in the Lough Derg level trace), there is reasonable agreement during the smaller floods, but less good agreement during the biggest floods during which the Ardnacrusha flows are slightly lower than the simulated capacity of the turbines. The reason for this is understood to be related to the reduced head of water along the Ardnacrusha headrace due to the opening of the gates at Parteen Weir to release flood water down the ORS.

12. An exact match is not expected to be possible because the volume of water passed through the generators is in part dictated by income optimisation subject to staying within the normal operating range (i.e. commercial factors also have a bearing on the day-to-day abstraction). The provided description of the level management does not explicitly describe the rules governing this aspect. However, the resource (outside of flood periods) is finite and abstractions on one day (or several consecutive days) will need to be balanced out within subsequent abstractions to stay within the normal operating range.

13. The level of the Lough Derg and Parteen Basin system is quite sensitive to the amount of water flowing to Ardnacrusha. For example: with an average daily inflow of 100m^3/s and allowing for 10.5m^3/s compensation discharge[40], the lake level will rise 6.5cm with no generation in a 24-hour period. This means that the ESB have a reasonable degree of control on lough levels outside of flood and drought periods. This gives the ESB some freedom to vary their abstraction rates (outside of drought periods) to meet their short-term income optimisation requirements safe in the knowledge that there is sufficient near-term future inflow such that the lough level can be restored relatively easily.

14. The retrospective simulation of the Ardnacrusha flows using the algorithm developed is based upon: i) the net inflow from the previous day to Lough Derg and Parteen Basin, ii) the size of the compensation flow, iii) and a 20m^3/s inflow threshold below which the Ardnacrusha flow is switched to zero. Further refinement is not considered readily possible to account for income optimisation factors.

[40] Formed of 0.7m^3/s for the Parteen Weir fish pass and a release of 9.3m^3/s at one of the Parteen Weir gates, plus 0.5m^3/s for the Ardnacrusha fish pass

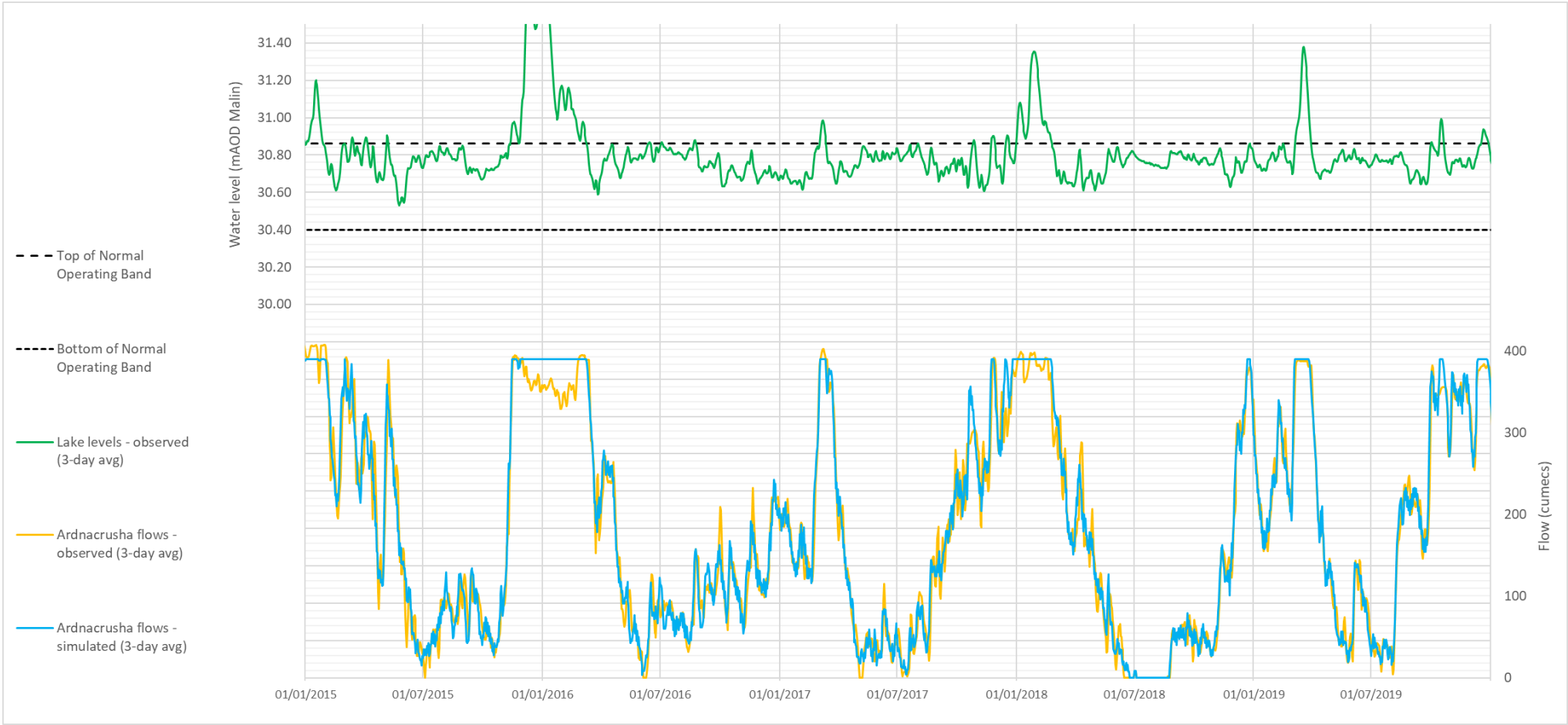


Image C.1: Comparison Between the Simulated and the Recorded Ardnacrusha Flows (2015-2019)

15. The Lough Derg and Parteen Basin system levels are sensitive to the Ardnacrusha abstraction. For example: minor differences in abstraction and/or compensation flow over a period of time will result in an additive displacement of the lake level. These adjustments can make the water balance modelling difficult as they result in inappropriate starting levels being simulated at the onset of a drought. If the simulated starting level were inappropriately too low, then it is more likely that the simulated drought level will drop towards the bottom of the Lough Derg NOB. To counter this, within the model a simple routine has been added that "hunts" to set the lough level either towards the upper end of the Lough Derg NOB during low inflow periods or towards the lower end of the band outside of the low inflow periods.

16. The hunting routine takes the Ardnacrusha simulated flow (as described above) and adds a small additional amount on if the lake level is above the targeted level. Conversely a small amount is subtracted from the Ardnacrusha simulated flow if the lake level is below the targeted level. This is continually applied on subsequent time steps and the simulated level will tend towards the target level. However, in flood periods the hunting routine is swamped, and the level will move above the targeted level. During drought periods (net inflows <20m^3/s) when the Ardnacrusha flow is switched off, the hunting routine is also switched off and the level will (if the outflow is greater than the net inflow) drawdown away from the targeted level.

17. The average lake level target levels used in the modelling are as follows. The upper target level is taken to be 30.80mOD *[33.50mOD Poolbeg]*. The lower target level is taken to be 30.70mOD *[33.40mOD Poolbeg]* (which is approximately equivalent to 30.60mOD *[33.30mOD Poolbeg]* when viewed from the perspective of the Pier Head gauge at Killaloe once the gradient of the lake's surface is allowed for during high flow periods). The selection of which target level to target is based upon the size of the simulated inflow. The threshold is set at 100m^3/s: with the higher target level chosen when the inflow is below 100m^3/s, and the lower target level chosen when the inflow is greater than 100m^3/s.

18. Image C.2 compares the simulated average water levels and Ardnacrusha flows of the WSP hydrological model (with this hunting routine included) to the recorded (observed) values. The model assumes a maximum Ardnacrusha generation capacity of 390m^3/s; and a compensation flow of 10m^3/s at Parteen Weir. The simulated Ardnacrusha flows still closely represent the actual recorded Ardnacrusha flows, and the targeted levels are evident within the simulation. Importantly the 2018 drought starts at an appropriate level in line with the ESB's guiding principles and the drawdown is simulated before recovering. Similar behaviour is simulated for the 1995 drought event (not shown). In the image it is seen that the recorded levels agreed reasonably well with the sought for levels from 2015 onwards, even though this period includes the notable 2018 drought.

19. Image C.3 shows the cumulative simulated flows using the model hunting routine compare well to those recorded (observed) over the 52-year period 1972 to 2023. The simulated total is about 1% greater than that recorded, and the overestimation seems to have occurred during the last couple of decades. The last couple of decades have experienced particularly large floods (2006/7, 2009, 2015/16, and 2020) and during these there is a slight reduction in the water going through the turbines due to the reduced head of water along the Ardnacrusha headrace due to the opening of the gates at Parteen Weir to release flood water down the ORS. This behaviour has not been included in the WSP hydrological model simulated Ardnacrusha flows and will account for some of the slight overestimation. However, its absence will have no effect upon the key low flow periods that are critical to the WSP environmental impact assessment. It is also noted that during the 1994/1995 winter the peak flow passing through the generators was constrained to about 300m^3/s which is understood to have been due to a turbine being out of action – this too will in part explain the overestimation evident in Image C.3.

20. The day-to-day income optimisation drivers for future scenarios (where the inflows will differ due to climate change) are not easily predictable, and the associated day-to-day variability in the levels (as evident in Image C.3) cannot therefore be simulated. But the appropriate positioning of the level in the run up to an impending drought will always be achieved.

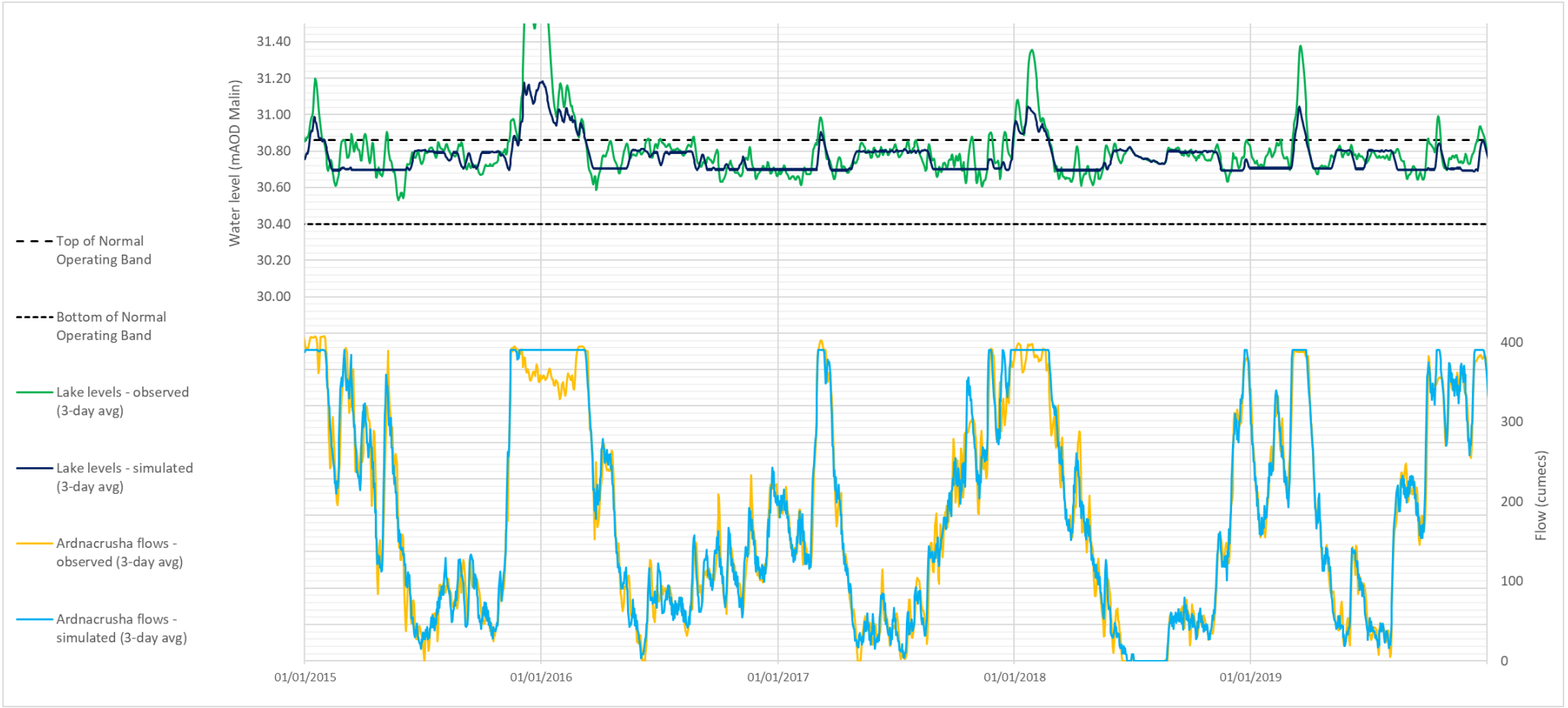


Image C.2: Comparison Between the Simulated and the Recorded Ardnacrusha Flows and Lake Levels Using the Model Hunting Routine (2015-2019)

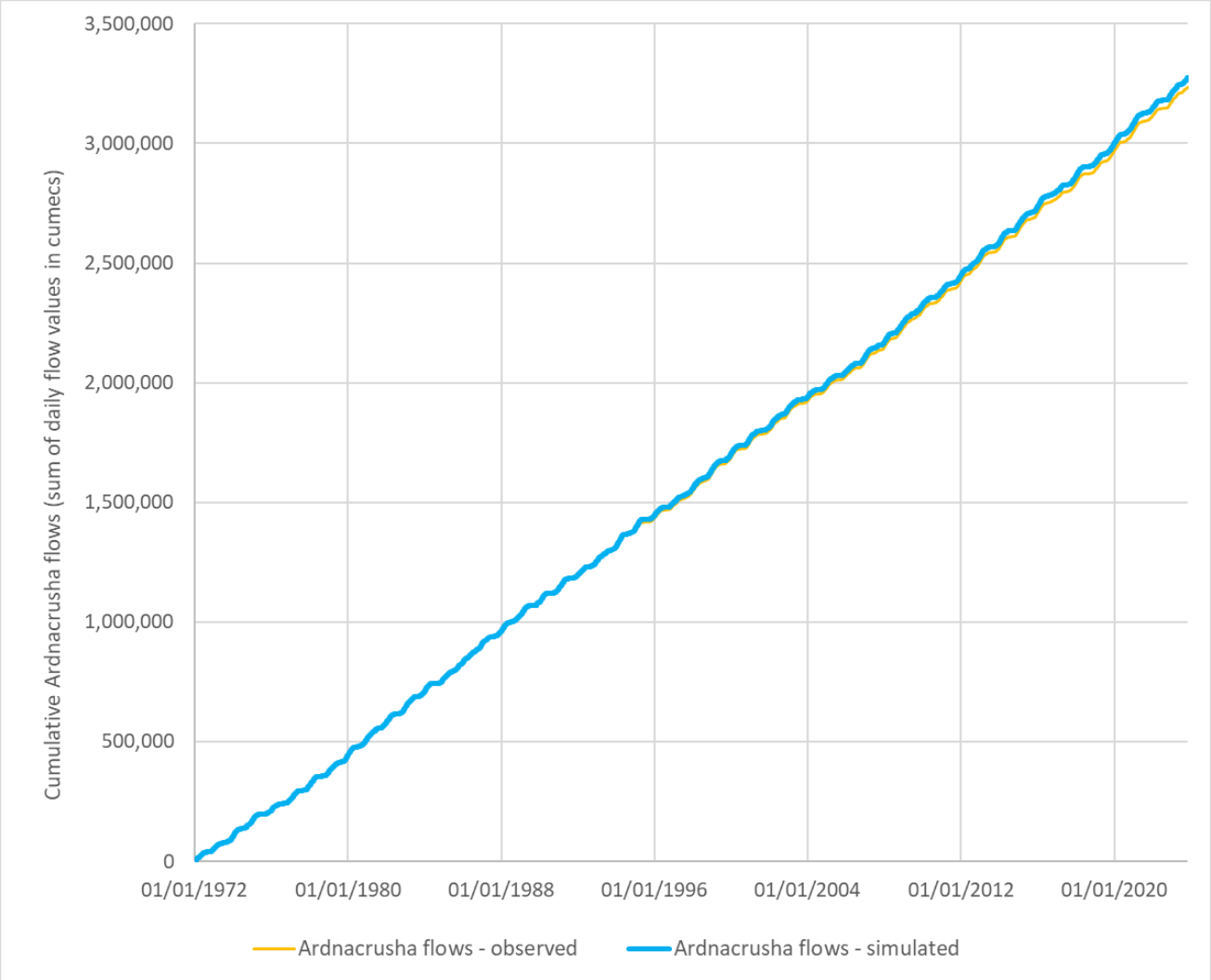


Image C.3: Comparison of the Cumulative Recorded and Simulated Ardnacrusha Flows Over the 52-year Period (1972-2023)

Attachment D. Hydrological Model Long-term Simulation Time Series

1. Images D.1 – D.13 show a series of graphs providing the WSP hydrological model[41] simulated Lough Derg and Parteen Basin system average levels and pass forward flows to the Old River Shannon (ORS) for the 52-year simulation period for 3 scenarios:

   Baseline – simulation of the level without WSP abstraction

   WSP 154 – the same as the Baseline but with a WSP constant abstraction of 154Mld (1.78m^3/s) included.

   WSP 300 – the same as the Baseline but with a WSP constant abstraction of 300Mld (3.47m^3/s) included.

2. A 2-day running mean is applied to the simulated lake water levels to remove the 'noise' of instantaneous daily peaks/ troughs to provide a better indication of the trends in levels. The graphs are split between level information on the 1st Y-axis and flow information on the 2nd Y-axis. To note the overlapping of the lines can cause the individual colours to be difficult to distinguish. To help see where significant level differences occur use the drought indicator[42] at the top of the graph as a guide – for example go to 1995 and 2018 during which the two most significant droughts to the system occurred.

3. The graphs show steady minor differences between the baseline and with WSP scenarios in the higher simulated lake levels during model flood conditions. This is because during flood conditions the Ardnacrusha flow is set to its maximum capacity (390m^3/s), the model hunting routine (which adjusts the Ardnacrusha flow to manage lake levels to a Lough Derg Normal Operating Band (NOB) target level) is switched off, the flood release/spill flows to the ORS are maintained as they would normally without the WSP abstraction in place, and the WSP abstraction flow must be provided from a minor depletion in the simulated lake storage (as described in Section 2.2.4) of the main report.

[41] The final version of the WSP hydrological model build has previously been referred to as the "Operational Principles Model" to differentiate it to the initial "Historical Model" build.

[42] the drought indicator is specific for the sensitivity of this system and is based upon flagging the occurrence of five consecutive days when the net inflow is less than 20m^3/s

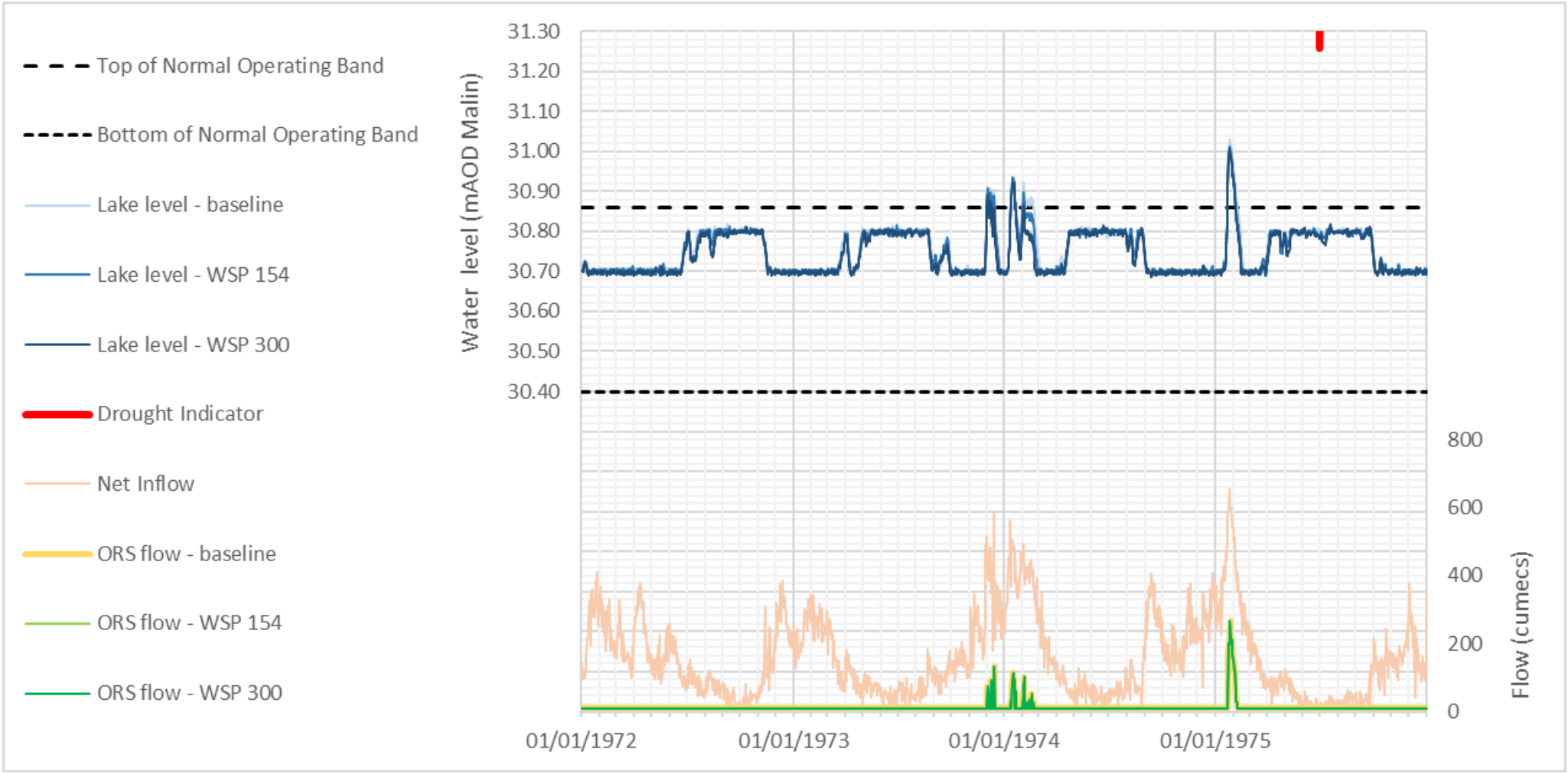


Image D.1: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (1972-1975)

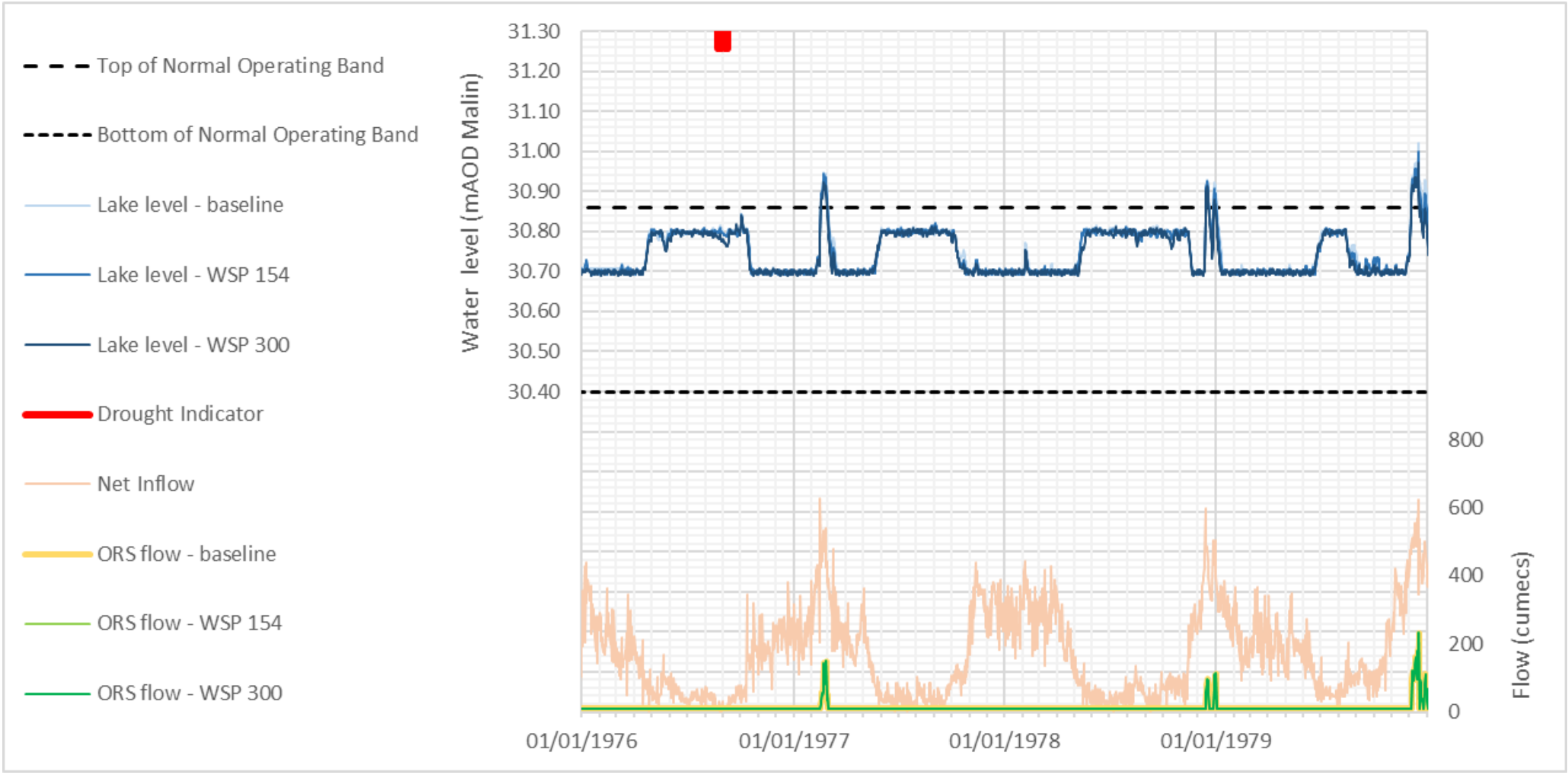


Image D.2 WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (1976-1979)

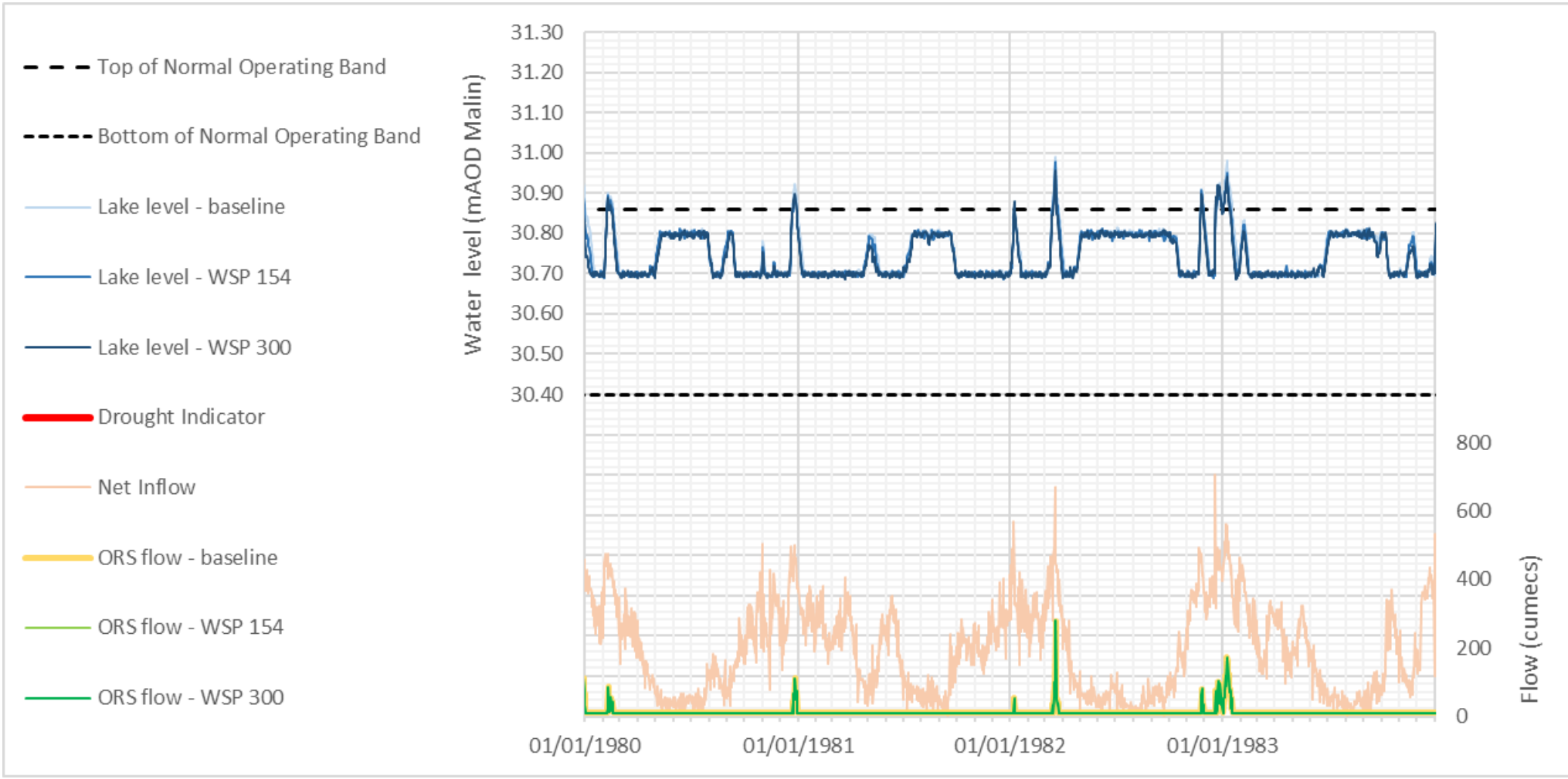


Image D.3: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (1980 - 1983)

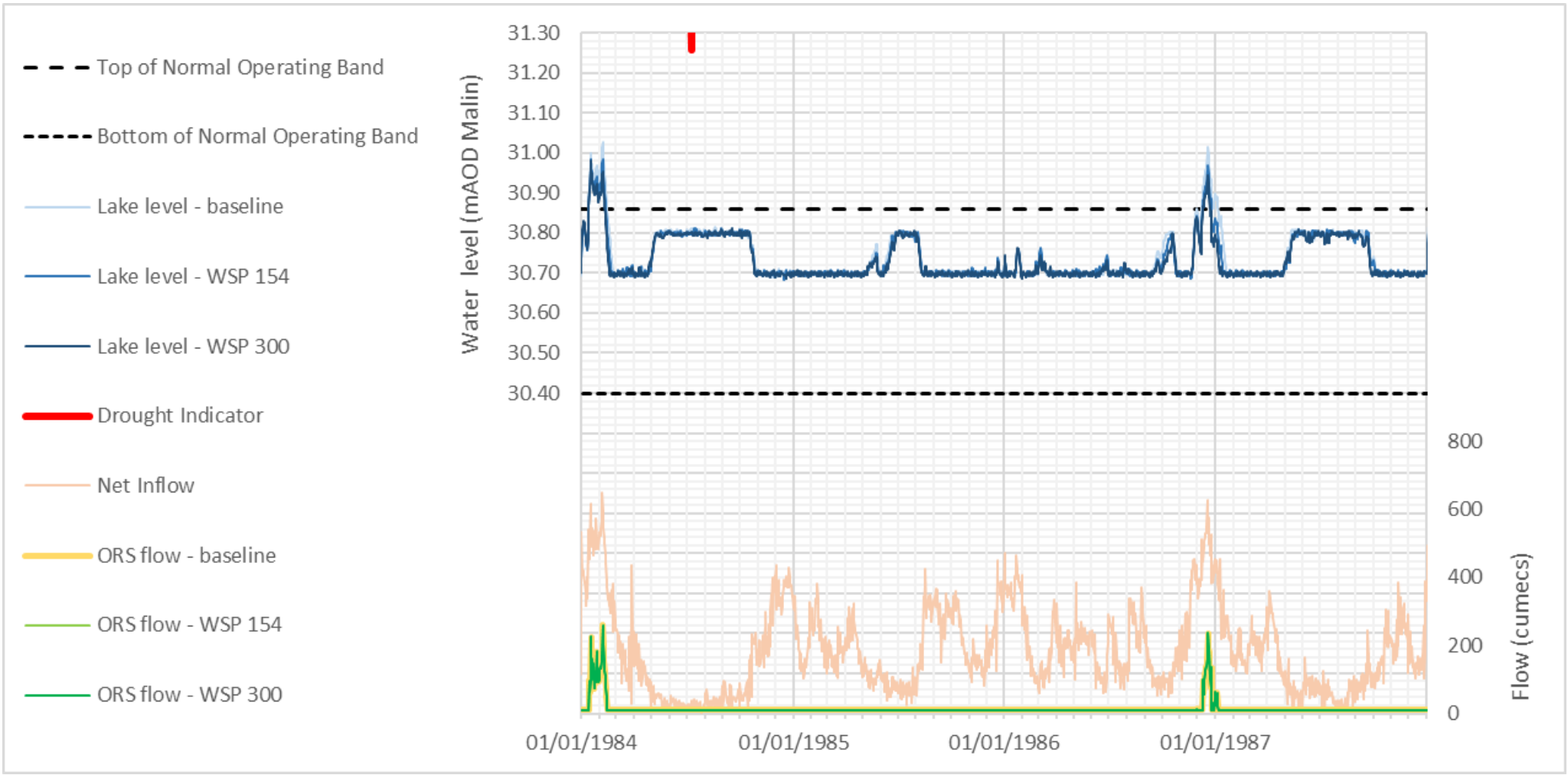


Image D.4 WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (1984-1987)

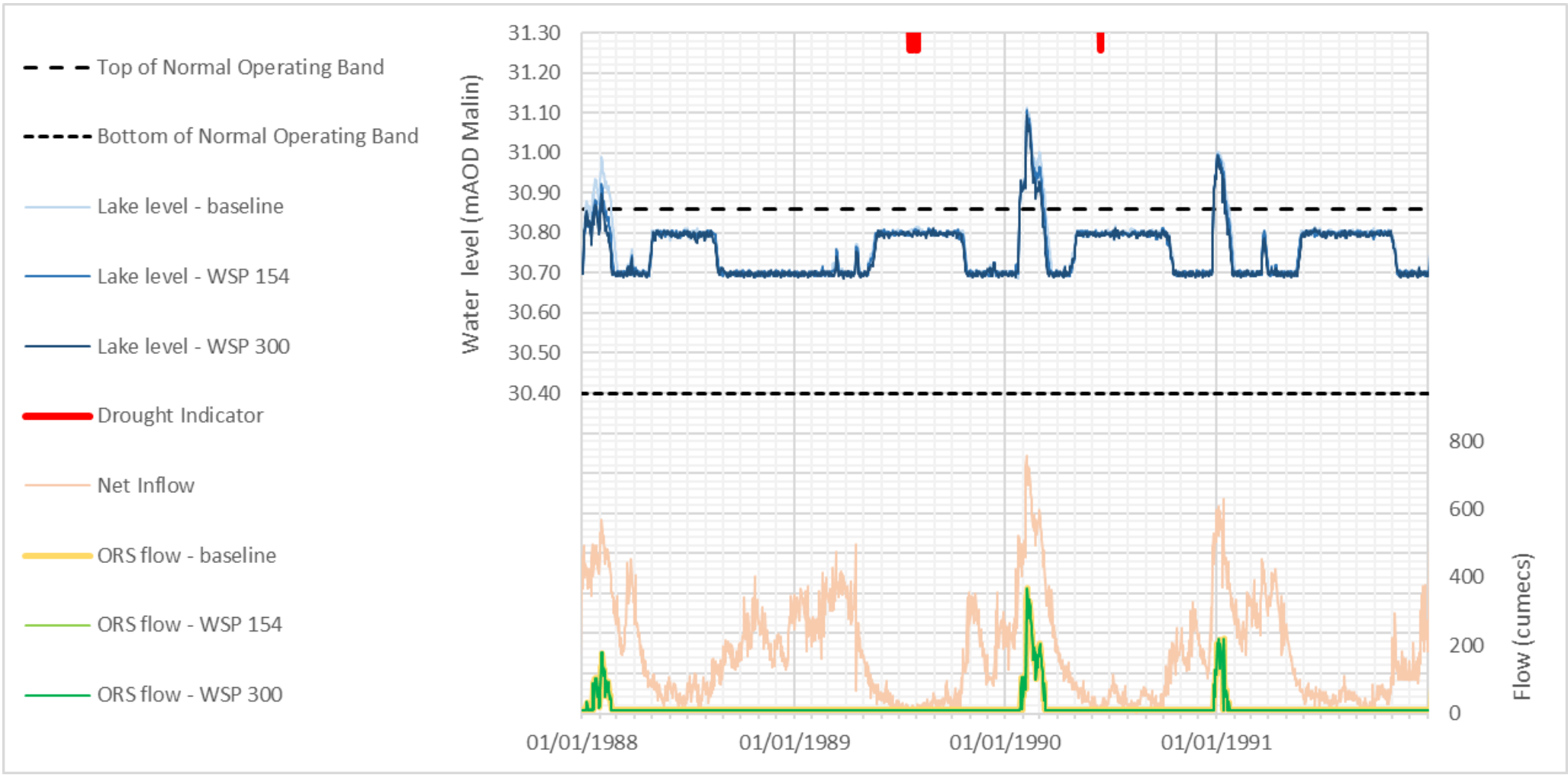


Image D.5: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (1988-1991)

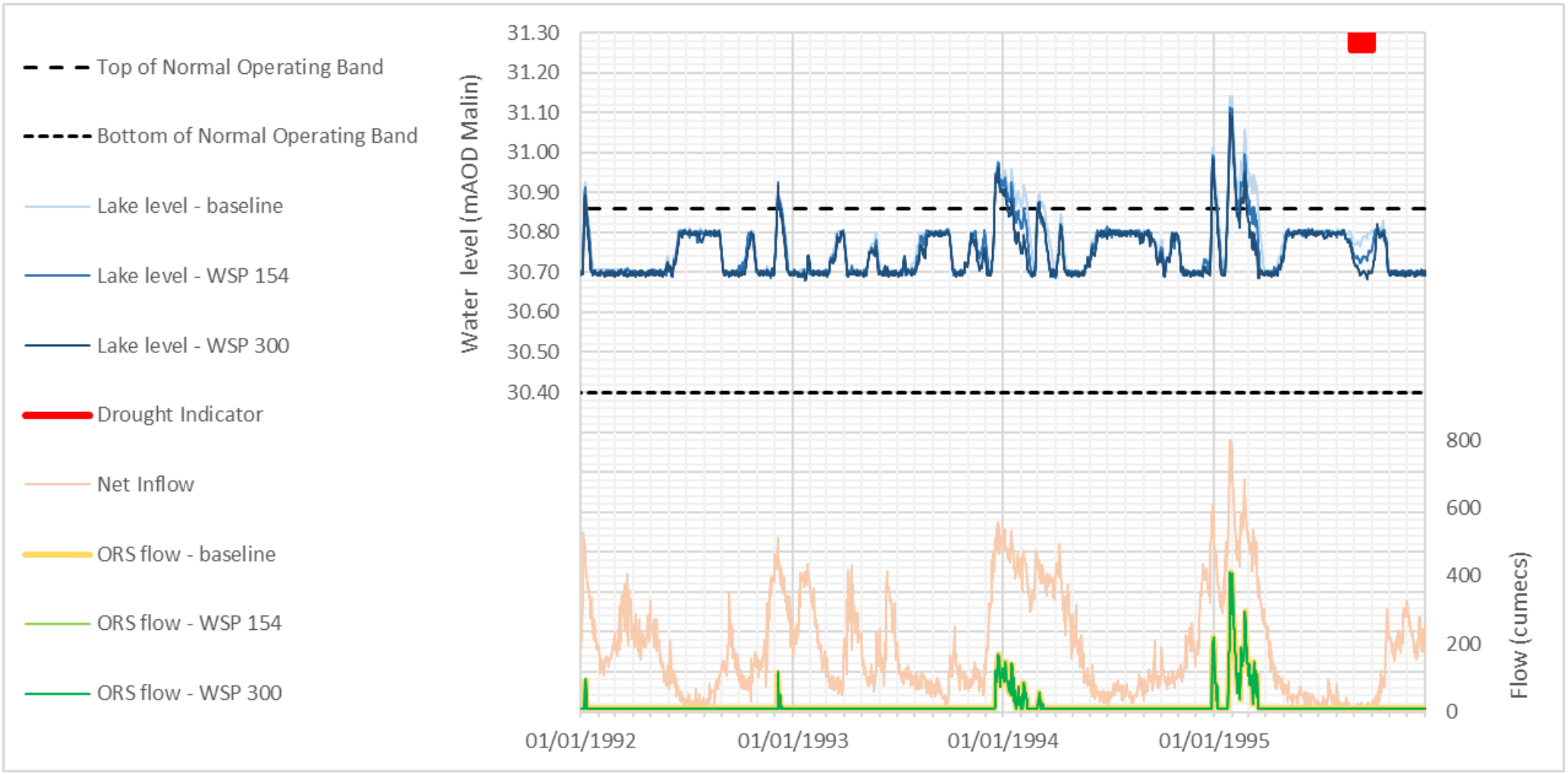


Image D.6: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (1992-1995)

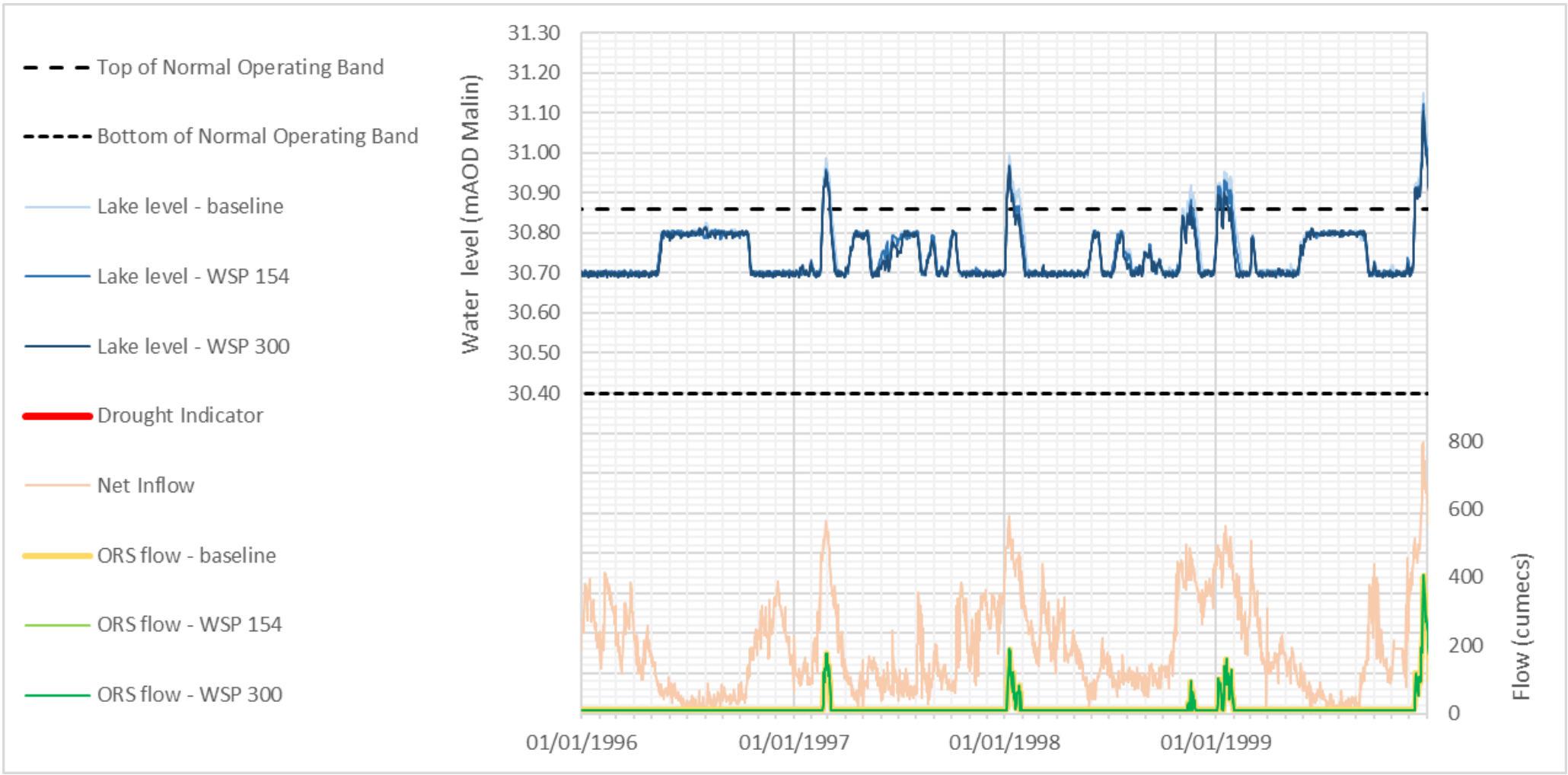


Image D.7: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (1996-1999)

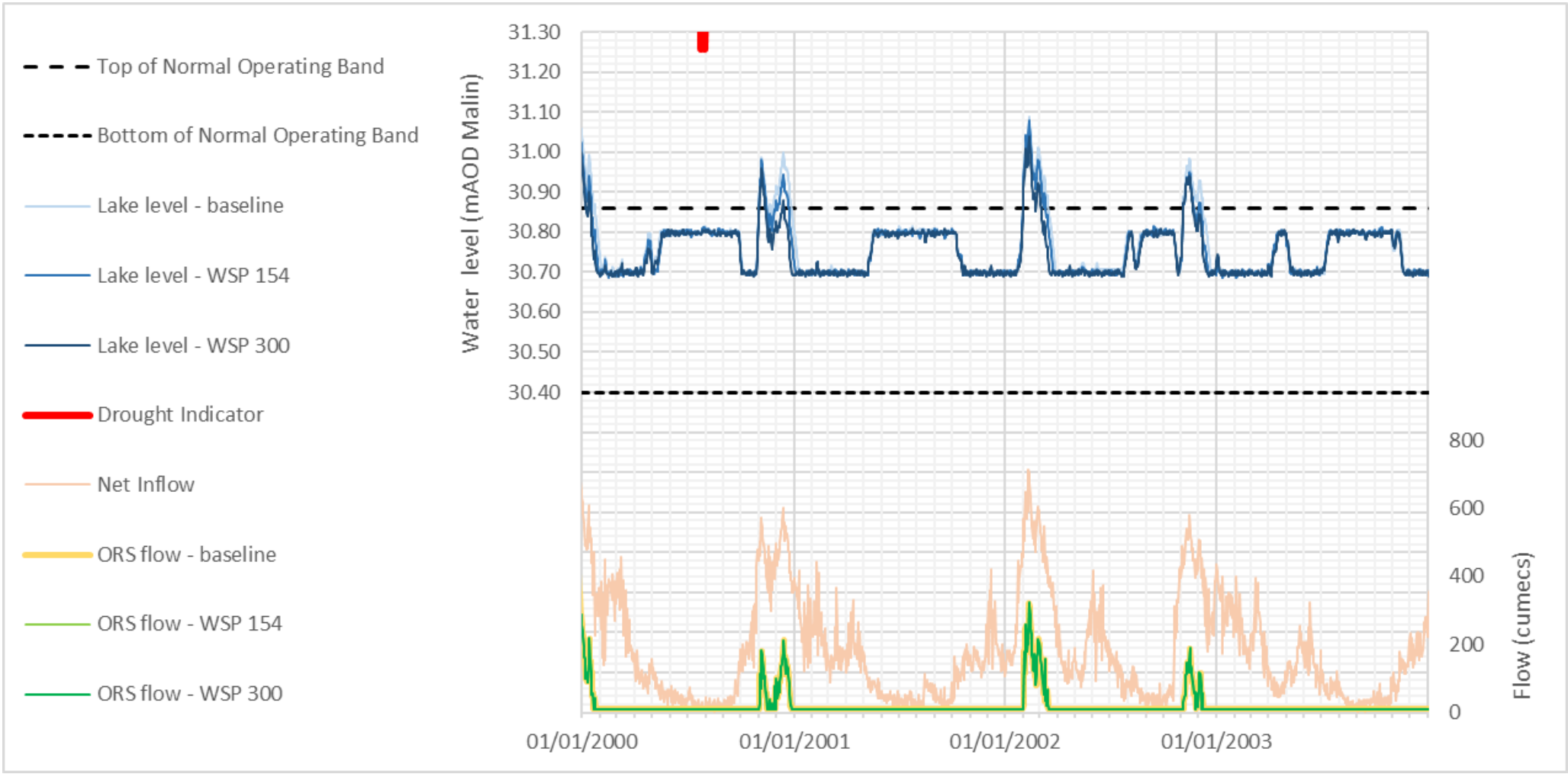


Image D.8: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (2000 - 2003)

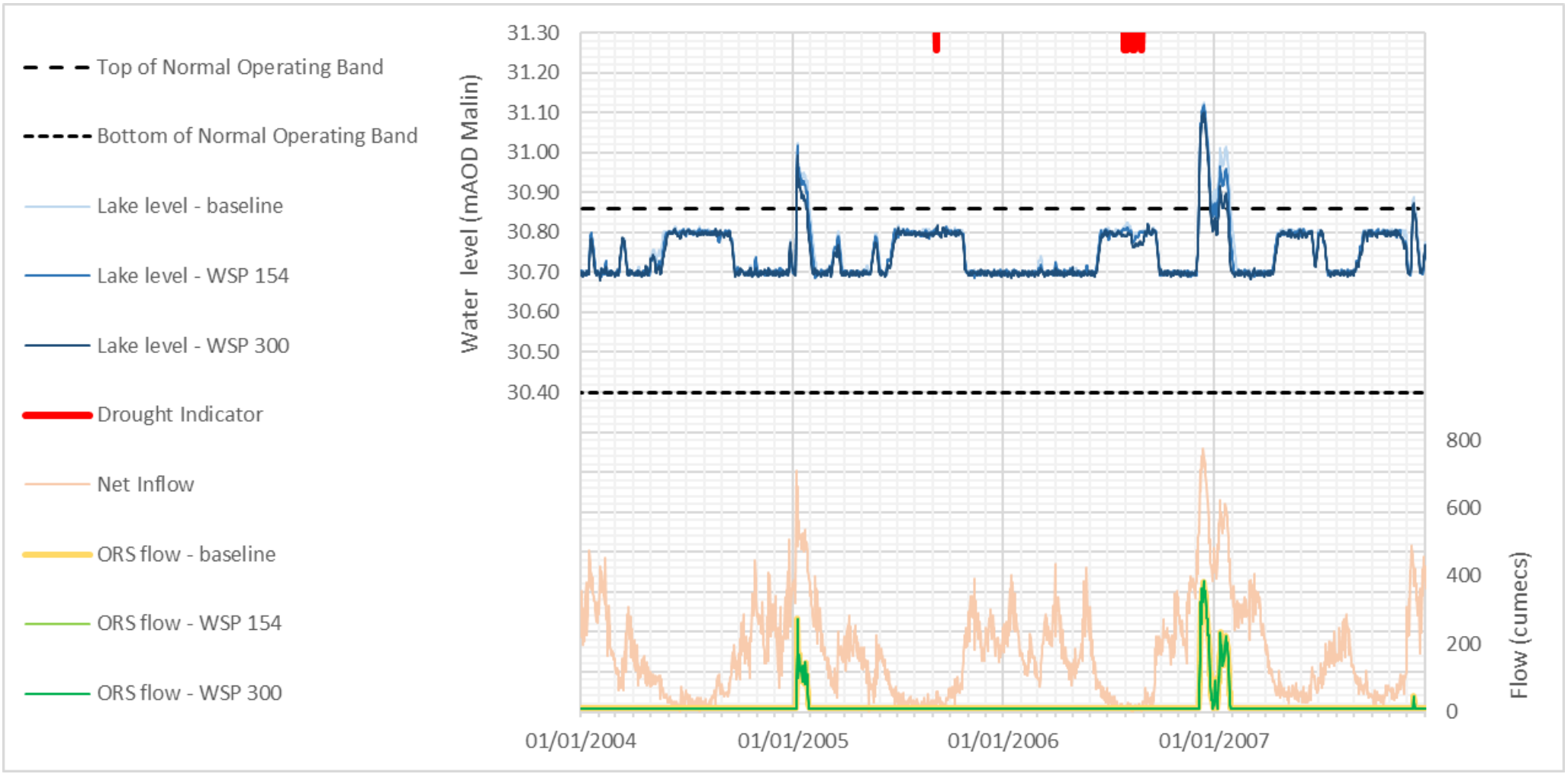


Image D.9: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (2004 -2007)

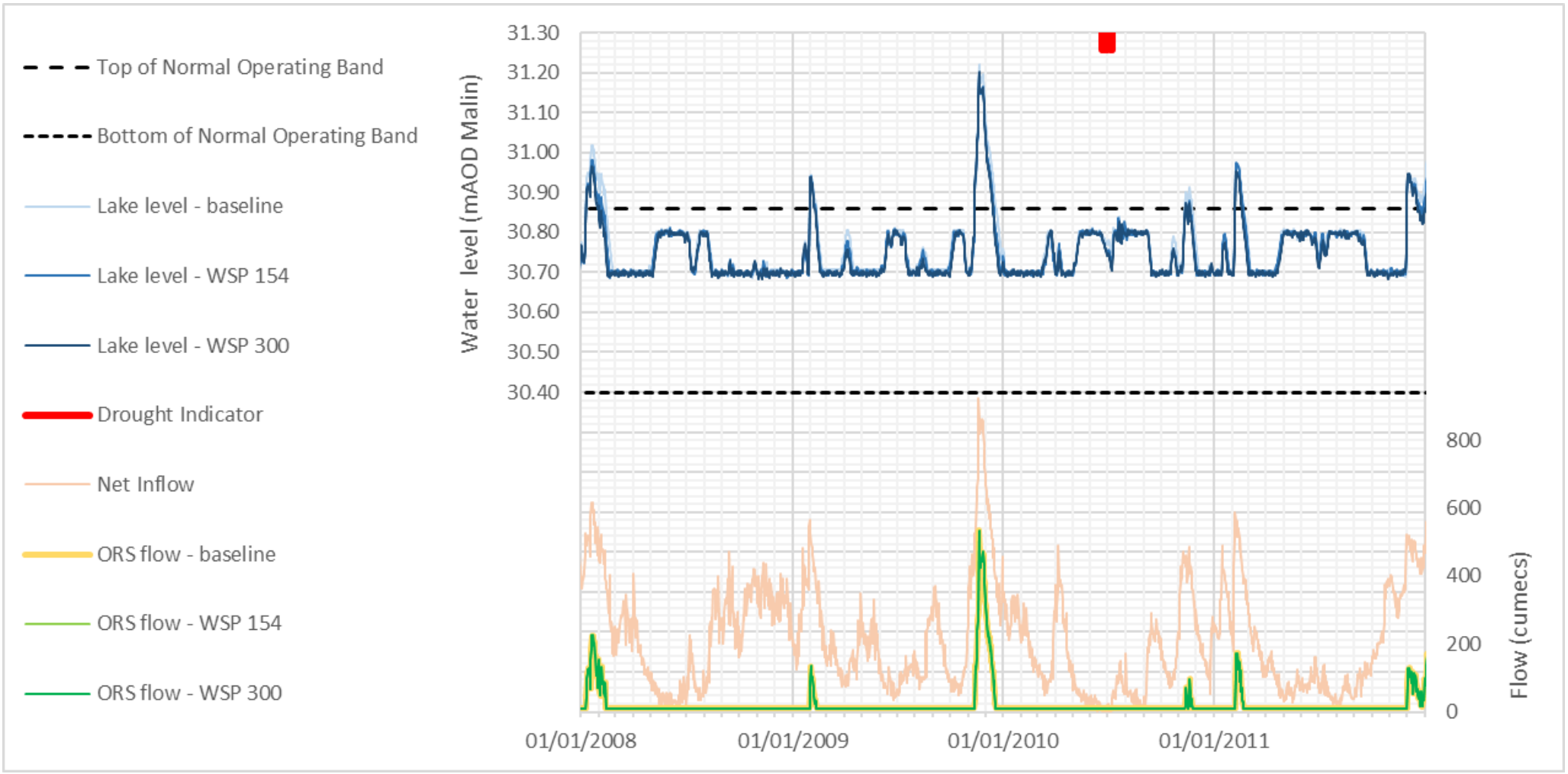


Image D.10: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (2008 - 2011)

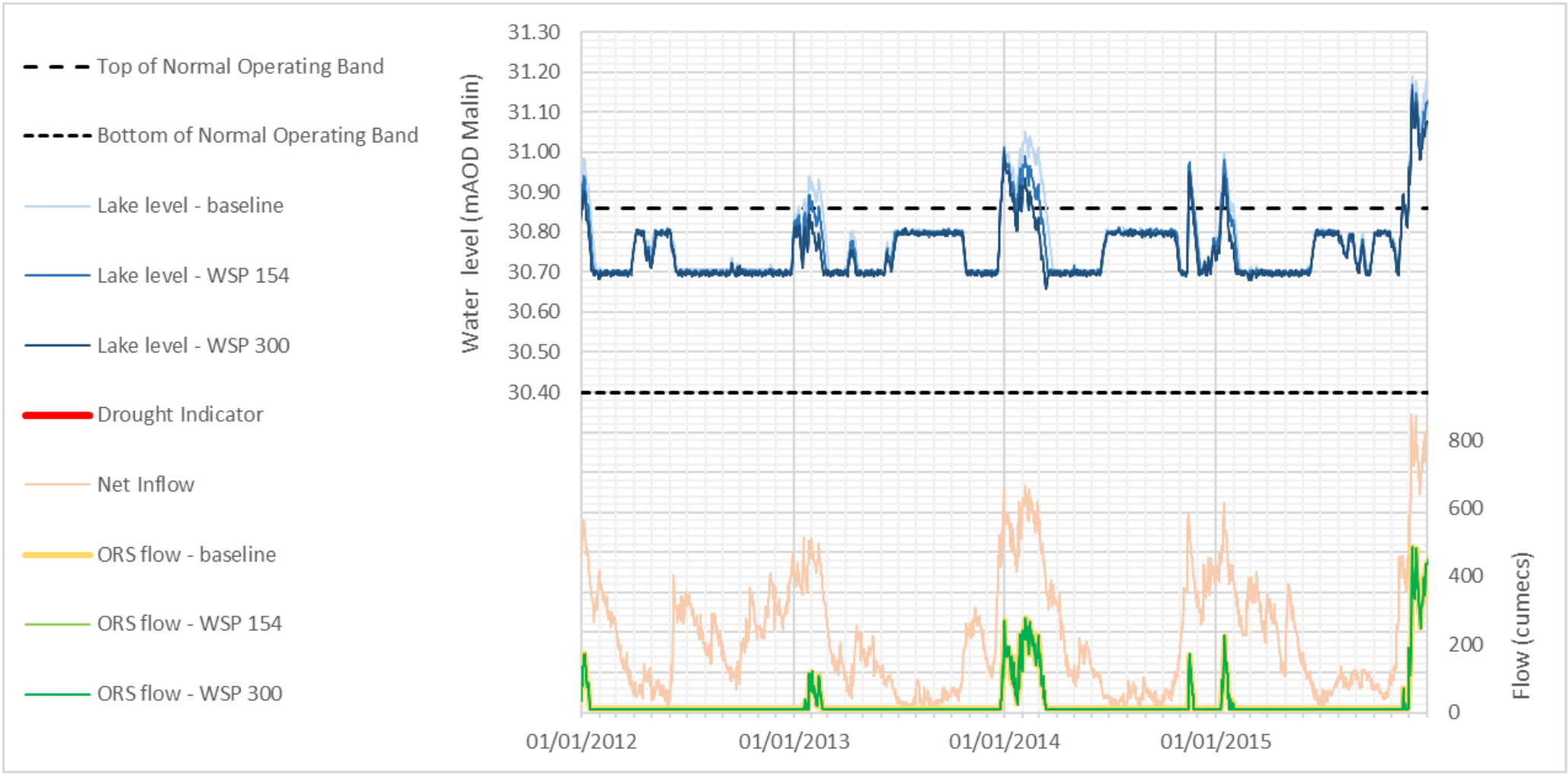


Image D.11: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (2012 - 2015)

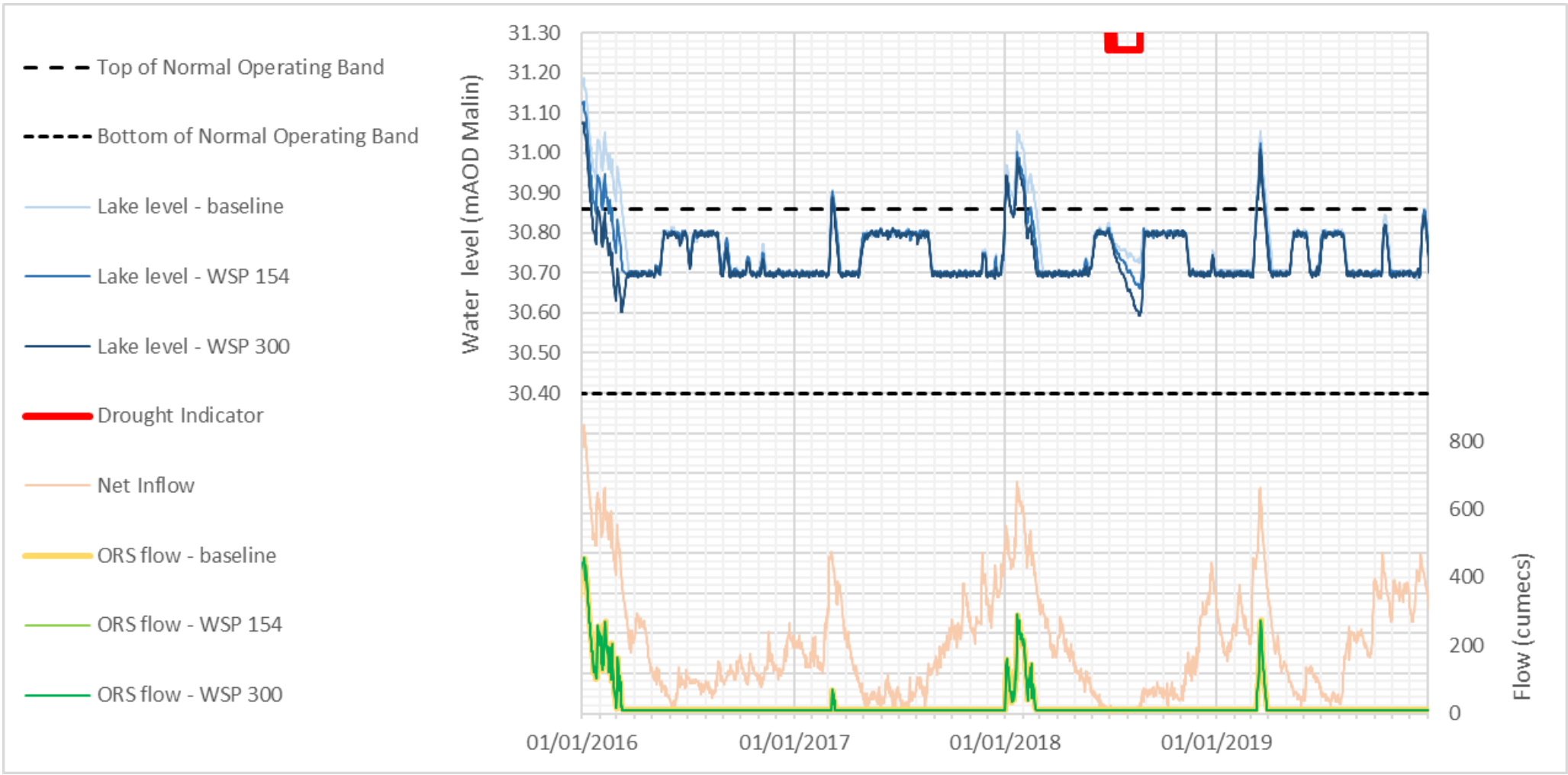


Image D.12: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (2016 - 2019)

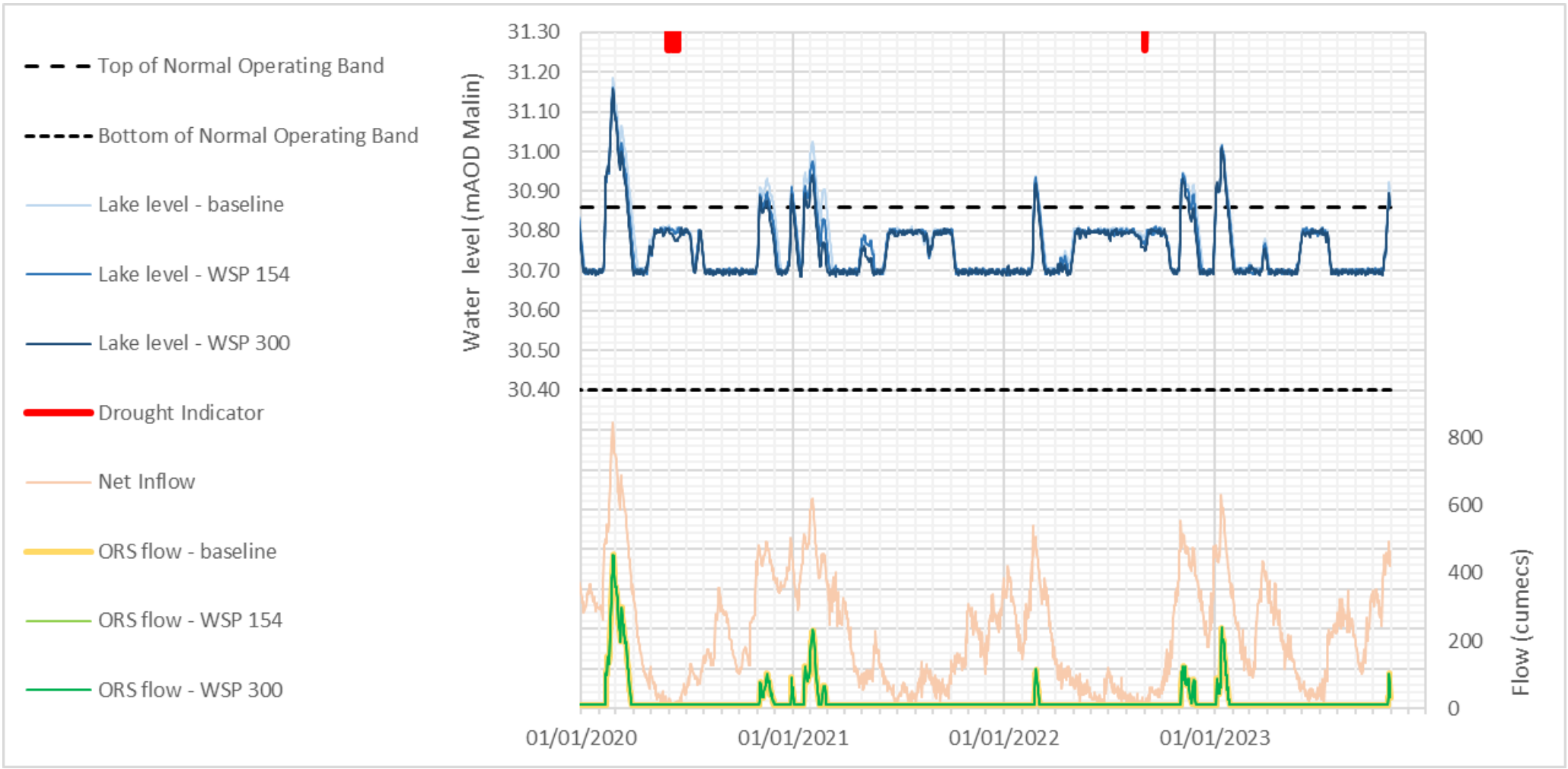


Image D.13: WSP Hydrological Model: Simulated Lough Derg and Parteen Basin System Lake Levels and Old River Shannon Flows Long-term Time Series (2020 - 2023)

Attachment E. Climate Change Allowances

1. This Attachment identifies the source material for the climate change allowances that have been applied.

E.1 Precipitation

2. The following publications were consulted:

- **Maynooth, 2008. Climate change – Refining the impacts for Ireland, Report for the EPA STRIVE Programme 2007 – 2013.**

  Provides outline precipitation projections in the form of spatially and seasonally distributed percentage changes from the 1961-1990 baseline period. Projections are based on the A2 and B2 emissions scenarios which represented medium-low and medium-high global surface warming scenarios.

- **Nolan P. O'Sullivan J, McGrath R, 2017. Impacts of climate change on mid-twenty-first-century rainfall in Ireland: high resolution regional climate model ensemble approach. International Journal of Climatology, 4347 – 4363.**

  The impacts of climate change on precipitation over Ireland are assessed for the mid-century period 2041-2060 using an ensemble of downscaled climate simulations. Based on medium-to-low and high emission scenarios. Results show significant projected decreases in mean annual, spring and summer precipitation amounts by mid-century. The projected decreases are largest for summer, with reductions ranging from 0 to 13% and from 3 to 20% for the medium-to-low and high emission scenarios, respectively.

- **Maynooth, 2018. Regional Climate Model Simulations for Ireland for the 21st Century (2011-CCRP-MS-2.2) EPA Research Report (EPA Research Programme 2014-2020).**

  Provides projected changes to precipitation based on the output from Regional Climate Models from the European component of the Coordinated Regional Downscaling Experiment (EURO-CORDEX). Multi-model ensemble values together with minimum and maximum ranges derived from the available EURO-CORDEX models for the land area of Ireland are provided. For RCP2.6 and RCP4.5 scenarios for the 2021-2050 and 2071-2100 the values are derived from 5 models and for the RCP8.5 scenario from 6 models. The authors identified that caution needs to be exercised with regards to interpreting the simulated changes in precipitation, particularly at a regional scale, as significant uncertainties exist at this scale.

- **Nolan P & Flanagan J, 2020. High-resolution Climate Projections for Ireland – A Multi-model Ensemble Approach, EPA Research Report, (2014-CCRP-MS.23).**

  Provides projections from regional climate models run at a spatial resolution of 3.8 and 4km, allowing a better evaluation of local effects of climate change. Climate was simulated for both the RCP4.5 and RCP8.5 scenarios for the 1981-2000 reference period and the 2041-2060 future period based upon downscaled CMIP05 GCM datasets (from a selection of GCM models). Substantial decreases in precipitation in the summer months are projected, with smaller changes in other seasons.

3. From a synthesis of the information provided the following seasonal allowances for precipitation were taken forward into the climate change modelling within this report (Table E.1 & Table E.2). Within the sources there is emphasis that there is reduced confidence in the projected changes compared to those for temperature. Based on the range in the numerical values provided an additive uncertainty of +/-5 has been applied to the 2050s central values to provide lower and upper estimates. For the 2080s projections an additive uncertainty of +/-7 is applied to the central values.

Table E.1: Precipitation Allowances for the 2050s

Season	Percentage Change (from 1961 – 1990 Baseline)		
	Central Estimate	Lower Estimate	Upper Estimate
December – February	+12	+7	+17
March – May	-7	-12	-2
June – August	-12	-17	-7
September - November	-3	-8	2

Table E.2: Precipitation Allowances for the 2080s

Season	Percentage change (from 1961 – 1990 baseline)		
	Central Estimate	Lower Estimate	Upper Estimate
December – February	+16	+9	+23
March – May	-8	-15	-1
June – August	-21	-28	-14
September - November	-8	-15	-1

E.2 Evaporation

4. The long-term evaporation series for the lake surface was derived by scaling a long-term estimated potential evaporation (PE) series (obtained from the ICARUS 2020[43] study from gridded daily temperature using the Oudin formula[44] for the Brosna catchment [Stn. No. 25006]) to that of the recorded PE record (2008 - 2023) at the Met Eireann Gurteen weather station (located between Borrisokane and Birr). This weather station is the closest Met Eireann station to Lough Derg to have a reasonably long time series of daily estimates of PE. The resulting PE series 1972 - 2023 was then converted to an open water estimate using the Finch formula following guidance given in Environment Agency (2001)[45]

5. As in the ICARUS study, the Oudin formula was used to convert the baseline PE to a +2°C warmer scenario (judged appropriate for the latter half of the 21st century in the ICARUS study) from which monthly evaporation scaling factors were derived. The daily estimates of open water evaporation were then adjusted according to these monthly factors. Application of the factors to the derived long-term open water evaporation series resulted in a 13% increase in the average annual open water evaporation (1972 - 2023 average annual open water evaporation was estimated to be 619mm; equivalent in a +2°C warmer scenario was estimated to be 700mm). In a similar manner, factors were also estimated for a +1.4°C and a +2.5°C warming scenario (Table E.3).

Table E.3: Open Water Evaporation Allowances

Month	Percentage Change in Open Water Evaporation (%)		
	+1.4°C Scenario	+2.0°C Scenario	+2.5°C Scenario
January	+14.8	+21.2	+26.5
February	+14.6	+20.8	+26.0
March	+12.6	+18.1	+22.6
April	+10.9	+15.5	+19.4
May	+9.1	+13.0	+16.2
June	+7.8	+11.1	+13.9

[43] ICARUS, 2020. Identification of climate sensitive catchments: Water Resources and Climate Change Adaptation. CRU Report.

[44] Oudin *et al.*, 2005. Which potential evapotranspiration input for a lumped rainfall-runoff model? Part 2 - Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling. Journal of Hydrology. 303(1-4). 290-306.

[45] Environment Agency, 2001. Estimation of Open Water Evaporation – A review of methods, R&D Technical Report W6-043/TR.

Month	Percentage Change in Open Water Evaporation (%)		
	+1.4°C Scenario	+2.0°C Scenario	+2.5°C Scenario
July	+7.1	+10.1	+12.6
August	+7.2	+10.3	+12.8
September	+8.0	+11.4	+14.3
October	+9.5	+13.6	+17.0
November	+12.1	+17.3	+21.6
December	+14.1	+20.1	+25.1

Note on the choice of the +1.4°C, +2°C, and 2.5°C temperature scenarios.

6. The following publications were consulted:
    - Maynooth, 2008. Climate change – Refining the impacts for Ireland, Report for the EPA STRIVE Programme 2007 – 2013
    - Maynooth, 2018. Regional Climate Model Simulations for Ireland for the 21st Century (2011-CCRP-MS-2.2) EPA Research Report (EPA Research Programme 2014-2020)
    - O'Sullivan J, Sweeney C, Nolan J and Gleeson E, 2016. A high-resolution, multi-model analysis of Irish temperatures for the mid-21st century. International Journal of Climatology, 36: 1256 – 1267
    - Nolan P & Flanagan J, 2020. High-resolution Climate Projections for Ireland – A Multi-model Ensemble Approach, EPA Research Report, (2014-CCRP-MS.23)
    - ICARUS, 2020. Identification of climate sensitive catchments: Water Resources and Climate Change Adaptation. CRU Report.

7. The above sources provide projections that are relatively consistent, though the interpretation of them is made more complicated as: different future epochs and baseline periods may be referred to, differing sampling of uncertainty, and some offer national values whilst other provide regional values. Based upon a synthesis of the information available an increase of +2°C by the 2080s was judged to be a central estimate coupled with an indicative uncertainty of approximately +/-0.5°C, whilst an increase of +1.4°C by the 2050s was taken to be the central estimate by the 2050s.

E.3 Fluvial Flows

8. Fewer sources are available offering projections into how Irish fluvial (river) flows are likely to change in the future. The following two publications were consulted:

    - **Maynooth, 2008. Climate change – Refining the impacts for Ireland, Report for the EPA STRIVE Programme 2007 – 2013.**

      Provides analysis upon the potential effect of climate change on nine catchments across Ireland for the 2020s, 2050s and 2080s relative to a baseline period of 1961 – 1990. Projections are based upon the A2 and B2 emissions scenarios which represented medium-low and medium-high global surface warming scenarios. Ensembles derived from each GCM run using both emissions scenarios are used to drive rainfall-runoff models and provide ensembles of future flow simulations such that future changes can be assessed. Monthly flow factors for each of the nine catchments, for each future time periods together with a measure of uncertainty are presented.

- **ICARUS, 2020. Identification of climate sensitive catchments: Water Resources and Climate Change Adaptation. CRU Report.**

  Supplies allowances (percentage changes) for Q95 low flows in Irish catchments assuming a 2°C rise in annual mean temperature. The allowances are supplied not only for a central estimate but also across a range that samples the probabilistic nature of the plausible outcomes. In this way more risk adverse assessments can sample less likely (yet still plausible) outcomes in an objective way. Projections are supplied for both the representative concentration pathways RCP4.5 and RCP8.5 for the 2080s time horizon. A means of applying the allowances to any river as a function of catchment type is provided. The underlying climate change projections of monthly rain are sourced from the CMIP5 dataset of climate change projections and as such involve ensembles of model outputs that range from approximately 70 to 110 in number. For a fuller description see Section F.2 of this report.

9. In studies that model the long-term performance of a fluvial system with storages involved (i.e. reservoirs, raised lakes, lakes) it is usually necessary to add the influence of climate change to the full flow regime. The ICARUS 2020 study however only supplies guidance on how the Q95 may change making its application to the full flow series problematic. Another aspect is how appropriate these allowances will be for rarer drought flows (and this is the subject of an investigation reported in 0).

10. To incorporate the information from the above two sources the following two approaches were taken.

E.4 National Water Resources Plan Approach

11. From the Maynooth 2008 study the monthly flow factors were combined into sub-groups (Central and Western catchments, Eastern catchments, Groundwater catchments) and the average factors calculated for the 2050s and 2080s separately. The average factors for the Central and Western catchments closely aligned to the average National factors (i.e. an average of all nine catchments) and were judged to be most appropriate for the Shannon basin. Obtaining a measure of uncertainty is constrained by the small sample size. To provide an indicative measure of uncertainty the standard deviation of monthly factors from all the catchments was used to represent an upper and a lower estimate (Image E.1, Table E.4, Table E.5). Cross reference to UK work suggested the general size of this uncertainty band was not dissimilar to that that is evident in UK water resource studies. This was the provisional approach used in the Uisce Éireann National Water Resources Project (NWRP)[46].

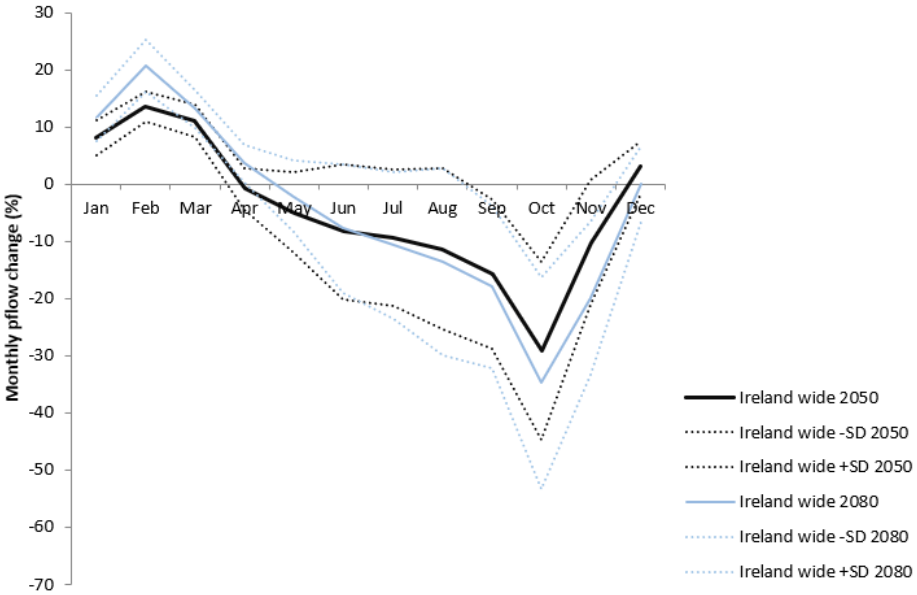


Image E.1: Fluvial Flow Factors Derived from the Output from the Maynooth 2008 Study

[46] Uisce Éireann, 2021. National Water Resources Plan – Appendix F

Table E.4: Fluvial Flow Allowances for the 2050s

Month	Percentage change (%)		
	Central Estimate	Lower Estimate	Upper Estimate
January	+8.1	+5.0	+11.2
February	+13.5	+10.8	+16.2
March	+11.0	+8.2	+13.8
April	-0.9	-4.5	+2.8
May	-5.0	-12.0	+2.0
June	-8.3	-20.2	+3.5
July	-9.4	-21.4	+2.6
August	-11.4	-25.4	+2.7
September	-15.7	-28.9	-2.6
October	-29.1	-44.6	-13.5
November	-10.2	-21.1	+0.7
December	+3.0	-1.5	+7.5

Table E.5: Fluvial Flow Allowances for the 2080s

Month	Percentage change (%)		
	Central Estimate	Lower Estimate	Upper Estimate
January	+11.5	+7.5	+15.6
February	+20.7	+16.1	+25.3
March	+13.2	+9.9	+16.5
April	+3.6	+0.3	+6.9
May	-2.1	-8.3	+4.1
June	-7.7	-18.9	+3.5
July	-10.7	-23.5	+2.1
August	-13.5	-29.9	+2.8
September	-18.0	-32.2	-3.8
October	-34.8	-53.3	-16.3
November	-20.1	-33.5	-6.7
December	0.0	-6.7	+6.7

E.5 National Water Resources Plan with ICARUS 2020 Variant Approach

12. The investigation into the applicability of the ICARUS 2020 climate change allowances for Q95 to rarer low flows provides supporting evidence for the Q95 allowances to be applied during droughts. In this variant approach the ICARUS 2020 allowances have been inserted into the NWRP approach at times of drought. To apply this requires the ICARUS 2020 catchment Type for the catchment to be established using the provided decision tree. The key catchment parameters for the combined Lough Derg and Parteen Basin are: SAAR = 1025mm, SAAPE = 485mm, ALLUV = 0.035 - giving the catchment a Type E classification.

13. The corresponding ICARUS mean allowances for the Type E catchments are given in Table E.6. The RCP 4.5, 6.0 and 8.5 (2040-2099) are taken forward to represent the ICARUS allowances in the current report.

Table E.6: ICARUS 2020 Climate Change Allowances for Q95 Flows in Type E Catchments

Risk level	Type E: Q95 Allowance (Percent Change) Assuming a 2°C Rise in Annual Mean Temperature		
	RCP8.5 (2080s)	RCP4.5 (2080s)	RCP4.5, 6.0, 8.5 (2040 – 2099)
Upper +	-45	-43	-43
Upper	-40	-38	-38
Upper 75th	-28	-20	**-27**
Central 50th	-17	-13	**-15**
Lower 25th	-7	-4	**-7**

14. The Central 50th risk level is considered to be equivalent to the Central estimate given in Table E.5. The risk levels Upper 75th and Lower 25th are interpreted as being approximately equivalent to the concept of the Lower and Upper estimates, respectively. These are the values that are used to replace the monthly flow factors for droughts in the ICARUS Variant approach.

Attachment F. ICARUS 2019 Climate Change Allowances

F.1 An Investigation into the Applicability of the ICARUS 2019 Climate Change Allowances for Q95 to Rarer Low Flows

F.1.1 Introduction

1. The WSP requires climate change to be incorporated into the hydrological understanding to enable both assessment of future environmental impacts and the implications to water source yields to be assessed. This requires an understanding of how catchment flows are likely to change in the future through to the end of the 21st century. To this end the following study, in particular, was referred to:

2. Identification of climate sensitive catchments: Water Resources and Climate Change Adaptation by Dr Ciaran Broderick and Dr Conor Murphy (2019). [Report prepared by Irish Climate Analysis and Research Units (ICARUS), Department of Geography, Maynooth University].

3. The findings of this study (commissioned by the Uisce Éireann CRU Water services Innovation Fund) were published in 2019 and the study is referred to in this technical note as ICARUS (2019). At the time of writing this technical note the ICARUS 2019 study was judged as providing the most detailed study available on the issue of how Irish river low flows are likely to be impacted by climate change (Jacobs, 2020). An overview of the ICARUS 2019 approach is provided in this technical note; though for a more detailed understanding of the complex approach it is recommended that the ICARUS (2019) report should be referred to.

4. ICARUS 2019 focuses solely on the likely change to the low flow measure Q95. This is the flow that on average is equalled or exceeded for 95% of the time. Whilst it is a low flow measure it is not a particularly rare one with on average 5% of the year (18 days each year) having lower flows. The ICARUS study did not provide guidance on any other flows, be they higher or lower. It is therefore unclear whether the projected changes to Q95 can be justified for use on rarer low flow events that are more often than not the focus of reliable yield studies (i.e. the focus is normally on drought flows). It is the purpose of this technical note to investigate whether there are grounds for accepting the ICARUS Q95 factors for application to rarer low flows events with some degree of confidence or not.

F.1.2 Objective

5. Using the ICARUS 2019 approach as a guide, use a sample of ICARUS calibrated rainfall-runoff models to investigate the relative sensitivity of a range of low flow indices to incremental changes in the climatic inputs, and draw conclusions as to whether the ICARUS Q95 allowances (provided as percent change) are appropriate or not for use on lower (drought) flow indices.

F.1.3 Technical Outline

6. To provide an insight into how low flows rarer than Q95 may respond to climate change a simplified approach based on that used in ICARUS 2019 was used which compares the relative change of the rarer low flows to that of the change in Q95. The following steps describe the outline of the approach followed.

    - Step 1: Example catchment selection
        - From the pool of 35 catchments that the ICARUS team investigated in detail[47], select a catchment to represent each of the five typical Catchment Types identified by ICARUS. Over and above this include any ICARUS catchments from within the Lough Derg/Parteen Weir basin.

[47] The authors of the ICARUS report made the datasets and their rainfall-runoff calibration details available to this study.

- Step 2: Run the rainfall-runoff model on the baseline
  - Using rainfall-runoff calibrations supplied by ICARUS, simulate the daily flows for the 57-yr period (1961–2017) based on available historic data. Produce flow duration curves and undertake extreme value analysis on the annual minimum flow values to provide estimates of low flows down to the 1 in 25-year drought flow.
- Step 3: Develop a matrix of possible rainfall futures and future evaporation
  - Using the harmonic formula developed by CEH Wallingford (2010) (and used by ICARUS (2019)) produce a matrix of plausible perturbed observed rainfall series with the extent of perturbation guided by ICARUS 2019. Also perturb the observed daily evaporation series in line with a +2^{o}C rise in mean temperature (this is the same temperature rise as focused upon in ICARUS 2019).
- Step 4: Run the rainfall-runoff model for each perturbed rainfall series in the rainfall matrix in the +2^{o}C future
  - Keeping the same calibration in the rainfall-runoff model, run each perturbed climate sequence through to derive a matrix of plausible daily flow series. For each derive a flow duration curve and undertake extreme value analysis on the series annual minimum flows to estimate T-year low flows.
- Step 5: Compare the sensitivity of Q95 changes to those of rarer low flows
  - For each catchment work out the change in Q95 from baseline to each future Q95 based on the matrix of plausible future climate series. This gives a change in Q95 sensitivity surface (the x and y axes of which are the percentage change of the two rainfall parameters used in the harmonic equation to describe the seasonal rainfall depth characteristics). Do likewise for other low flow indices (e.g. Q99, 5-year low flow, 10-year low flow etc). Compare the Q95 change surface to that of the other low flow indices.
- Step 6: Set within the context of the CMIP5 climate change model[48] plotting positions on the sensitivity surface
  - The extent of the sensitivity surface is initially determined by the size of the matrix used of incremental changes to the two rainfall parameters. Each CMIP5 climate change model provides a baseline and a future projection of monthly seasonal rainfall for each location. This enables a plotting position within the two-parameter space to be assigned to each CMIP5 model for any geographic location. When all CMIP5 data points have been plotted the resulting cluster of plotting positions defines where on the sensitivity surface to concentrate Step 5 on. At any location the cluster is invariant regardless of the flow indices being investigated. If within this region of focus the percentage change surfaces for the various low flow indices are similar to that for Q95 then this would suggest that the ICARUS Q95 allowance factors can be applied to the other rarer low flow events with some confidence. If markedly different change surfaces result: then this would shed doubt upon the suitability of the Q95 allowance factors being applied to these lower flows.

7. The above approach represents a simplified version of the full ICARUS 2019 approach which, for example, used a weather generator to extend the period of record tested and investigated the response surfaces using three different rainfall-runoff models. In this study only the best performing[49] rainfall-runoff model [GR4J: Perrin et al (2003)] was selected to provide an indication of how similar the changes to flows lower than Q95 are compared to those for Q95 on a catchment-by-catchment basis. The objective here is not to provide an absolute value of change but rather to see how similar the relative changes across a range of low flows compare to that for Q95 for each catchment separately.

[48] CMIP5 stands for Coupled Model Intercomparison Project Phase 5. It is an international project that serves to refine and improve climate models and international assessments of climate change. Phase 5 is the most recent completed phase and has provided output from numerous climate change models that in total supply projections of between 40 to 110 model ensembles for Ireland depending on the representative concentrate pathway (RCP) used. These are available and were use in the ICARUS 2019 study to define the relative likelihood of different outcomes on the sensitivity surface. This was achieved by plotting the position of each ensemble projection on the 2-parameter sensitivity surface and analysing what proportion of ensemble plotting points lay above or below the numerical value selected on the sensitivity surface.

[49] Based on statistical performance scores provided in ICARUS 2019

F.1.4 Methodology

F.1.4.1 The Example Catchments

8. The approach was applied to the seven gauged catchments identified in Table F.1, the locations of which are shown in Image F.1. These are selected from the 35 catchments that were investigated in detail in ICARUS 2019. The Brosna and Inny are the only ICARUS 2019 catchments that lie within the Shannon catchment.

Table F.1: Example Catchments

River	Gauge	Area (km^2)	SAAR [1] (mm)	ALLUV[2]	SAAPE[3] (mm)	TYPE[4]
Barrow	14019	1697	862	0.053	510	A
Bandon	20002	424	1669	0.045	518	B
Feale	23002	647	1345	0.038	514	C
Nore	15003	299	934	0.030	508	D
Boyne	7009	1658	869	0.037	507	E
Brosna	25006	1163	932	0.060	495	A
Inny	26021	1099	945	0.022	486	E

[1] Standard average annual rainfall
[2] FSU measure of the proportion of the catchment area that is covered by alluvial deposits
[3] Standard average annual potential evaporation
[4] Type refers to the ICARUS category that identifies likely similar climate change response

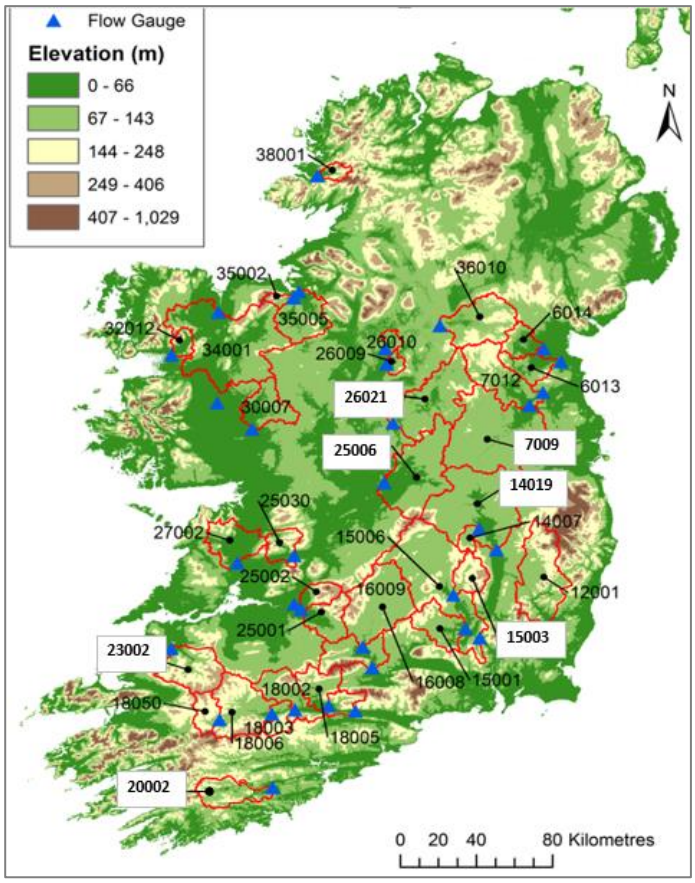


Image F.1: Location of Example Catchments [Source: background image from ICARUS 2019]

F.1.4.2 Selection of Rainfall-Runoff Model

9. The GR4J rainfall-runoff model was selected from the three used in the ICARUS 2019 study, based on it having the best performance statistics as provided in ICARUS 2019. The individual catchment calibration parameters were supplied by ICARUS, as were daily catchment rainfall and potential evaporation for the period 1961 – 2017, as well as the daily observed flow sequencies that had been used to calibrate the models.

F.1.4.3 Perturbation of Climatic Data

Rainfall

10. The same rainfall perturbation technique was used as in the ICARUS study. This perturbs both the mean annual amount of rainfall and the seasonality of the rainfall. For this the intercept and amplitude of a single-phase harmonic function are fitted to monthly mean values to represent the baseline annual precipitation cycle. The function used is defined as:

$$X_t = X_0 + A\cos\left(\frac{2\pi}{12}(t - \Phi)\right) \qquad (1)$$

11. X_t is the fitted value for each calendar month, A and Φ represent the amplitude and phase respectively, and X_0 is arithmetic mean of the annual rainfall. Following the approach taken by ICARUS 2019 the phase, denoting the month with the greatest mean precipitation, is considered to be a non-variable parameter and is fixed to December $(\Phi = 12)$. This corresponds with the median month for which the annual precipitation cycle peaks across the catchments sampled. To traverse the domain, the amplitude and intercept parameters are incrementally adjusted relative to the reference period (1976-2005) in 10% steps. Changes in mean annual rainfall are reflected in alterations to the intercept, while changes to the amplitude, represent changes in seasonality with positive percentage increases resulting in an intensification of the winter to summer rainfall ratio.

12. Although the ICARUS work sampled the change in mean rainfall across the range -40% and +60%, and changes in the amplitude across 0% to 120%, the climate change CMIP5 projections for Ireland by the end of the century suggest that a rainfall mean range of -10% to +10% and an amplitude range of 0% to 30% capture the clear majority of the climate change model projections for rainfall. For this reason, the following incremental changes were used to generate the matrix of rainfall series for exploring the relative change surfaces: Δmean -10%, 0%, +10%; Δamplitude 0%, +10%, +20%, and +30%.

13. Image F.2 shows an example of the fitted harmonic curves used to represent the perturbed Brosna average monthly rainfall pattern in the future. From these the baseline daily time series rainfall for the Brosna (25006) catchment was perturbed ready for use in the rainfall-runoff modelling.

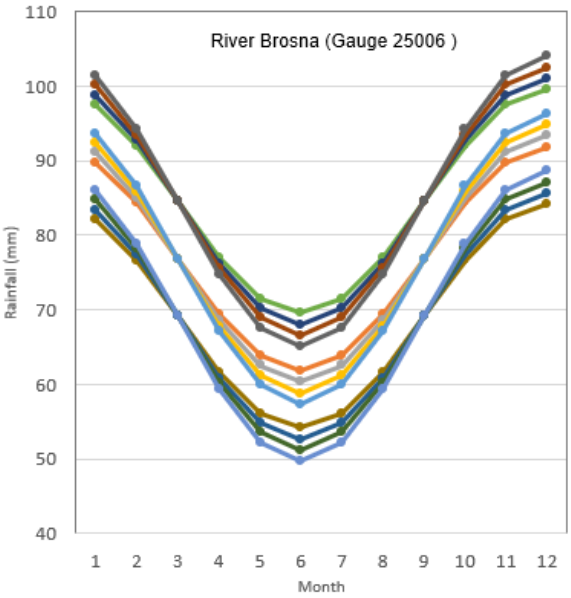


Image F.2: The Harmonic Curves used to Perturb the Brosna (25006) Rainfall Series

Evaporation

14. In its final output the ICARUS 2019 study only provided allowance factors for a warming scenario for Ireland of +2°C (relative to a 1976-2005 baseline). This is relatively consistent with other recent climate change model projections of temperature. This study has followed suit and used the same +2°C scenario to represent the likely average temperature change in the latter half of the 21st century.

15. As in the ICARUS study, the Oudin *et al* (2005) potential evapotranspiration (PET) equation was used to convert the baseline PET to a +2°C warmer scenario.

F.1.5 Analysis

16. For each catchment the rainfall-runoff model was run on the observed data (1961 – 2017). This was then repeated for each of the 12 perturbed rainfall scenarios defining the sensitivity surface for the +2°C future climate. Flow duration curves were derived for each run, and T-year low flow estimates were obtained from extreme value analysis of the annual minimum flows using the EV1 statistical distribution. The rarer T-year estimates however need to be treated with some caution as the calibration of the rainfall-runoff models targeted low flows close to Q95. As rarity increases the calibration may not be quite so strong. Also, confidence in extreme value analysis is dependent on the number of data points within the sample. As a rule-of-thumb the return period estimates based on annual min or max data are often considered reasonably robust only up to 0.5N, where N is the number of years of data points. In the 57-year simulated series this suggests that reasonably robust low flows up to a 25-year events may be attainable [though recognition of the calibration issue should also be borne in mind).

17. The sensitivity surfaces of the various measures of low flow are then compared and the degree of consistency between them assessed. If the percentage changes are similar to those for the change in Q95 then there would be grounds for applying the ICARUS allowance factors to these other low flow indices.

F.1.6 Results

18. An example of the estimated T-year low flow change factors for each combination of ∆mean and ∆amplitude in the +2°C world is given in Image F.3. These cover the region of ∆mean and ∆amplitude space that the great majority of the CMIP5 model projections sit. The full results for each of the catchments are given in this technical note.

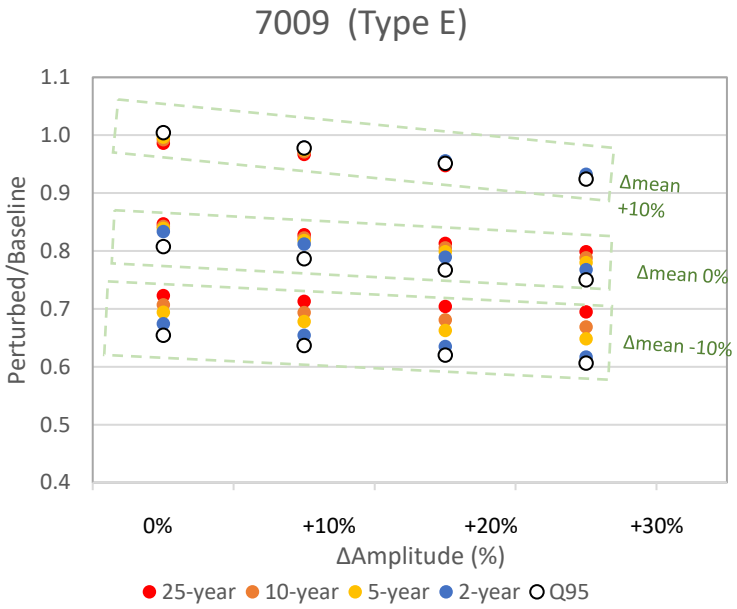


Image F.3: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 for the River Boyne (Stn. no. 7009) - Across a Range of Δmean and Δamplitude Rainfall Perturbation Scenarios where the Mean Temperature has Risen by +2oC

Image notes: The estimates associated with the same change in mean rainfall are denoted by the sub-group contained within the faint dashed green boxes. The change in the intensification of rainfall seasonality (winter to summer) is represented by the Δamplitude value plotted on the x-axis. The ranges used: Δmean (-10% to +10%) and Δamplitude (0% to 30%) cover the region in Δmean and Δamplitude space in which the great majority of CMIP5 rainfall projections sit. The y-axis provides the proportional change in the low flow measure (perturbed flow/ baseline flow).

19. If the T-year points were to have plotted directly on top of the Q95 values (depicted by the white circles) then the ICARUS allowances (in percent change) would have been directly transferrable to the T-year flows. This is because the plotting positions of the CMIP5 models in Δmean and Δamplitude space are fixed, and the surface representing the sensitivity of the T-year event in this space has also not changed (by virtue of the T-year points plotting directly on top of the Q95 values). Therefore, the probabilistic analysis of the likelihood of a certain sized percentage change would provide exactly the same outcome in terms of climate change allowances.

20. In the above River Boyne example, the T-year points for a Δmean of +10% almost exactly match the Q95 points, but as the sensitivity surface is traversed to a Δmean of -10% the T-year plotting positions are seen to give progressively slightly smaller percentage changes than those for Q95. In this particular example this will result in slightly smaller percentage changes in the upper estimates of change for the T-year events compared to those for Q95. For example, the image suggests that for the upper allowances, values of up to -35% to -40% would apply for Q95 whilst slightly lower values of -30 to -35 are suggested for the rarer T-year events. Whereas for lower allowances the values for both Q95 and T-year flows are predicted to be similar at a little less than 5%.

21. The analysis suggests that so long as the T-year plotting positions are fairly close to the Q95 plotting positions then the ICARUS allowances will offer helpful indicative T-year estimates. The further away the T-year plotting positions stray from those for the Q95 flows, the poorer the case for directly using the ICARUS allowances.

22. Several of the catchments do show a close match in plotting positions across the full range of Δmean (-10% to +10%) and Δamplitude (0% to 30%). For example: catchments 14019 and 18003 (Image F.4) are good examples of this - suggesting that for these catchments the ICARUS Q95 allowances are suitable for the T-year events. The two catchments from within the Shannon catchment (25006 & 26021) show similar characteristics to those shown in Image F.3 for the River Boyne. The interpretation for these three catchments is that ICARUS Q95 allowances may be slightly high for the rarer T-year upper allowances but similar at the lower allowances. In all the example catchments the results suggest that the Q95 upper allowances are unlikely to underestimate the allowances for the T-year flows.

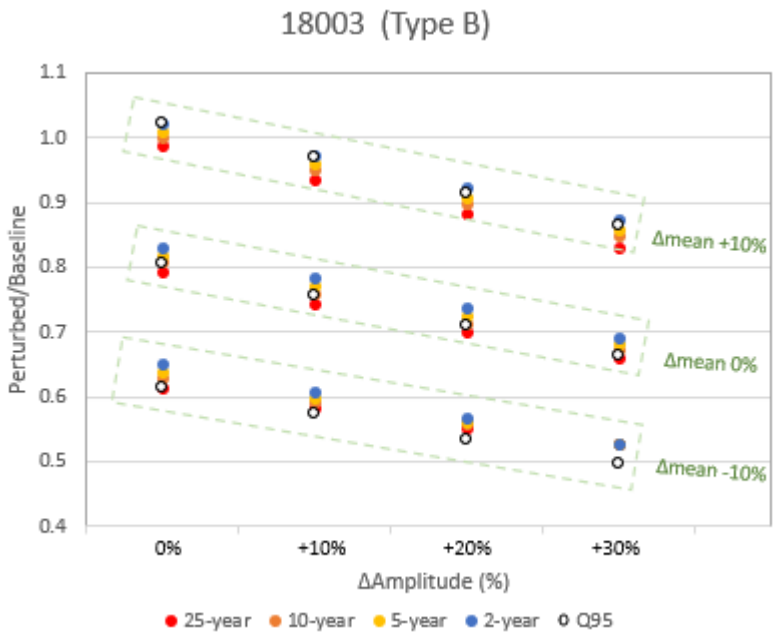


Image F.4: Catchment 18003 Showing Good Agreement Between the Q95 and the T-year Plotting Positions

23. As indicated, uncertainties do exist, particularly in the underlying extreme value analysis of the rarer T-year flows. Consequently, the above discussion runs the risk of over interpretation when other issues are potentially at play. To help try and offset this an average response derived from all seven catchments is shown in Image F.5; and offers an indicative general comparison. Similar features are present as seen in the River Boyne example, and similar interpretations result with the most extreme allowances (the upper end allowances) suggested to be slightly less than those provided for the change in Q95, though the lower end and central allowances are suggested to be similar.

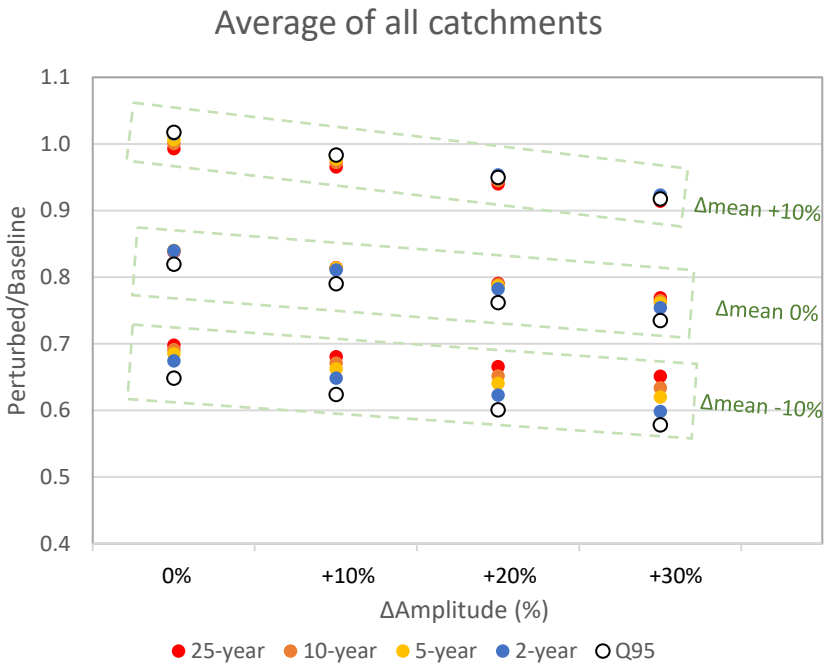


Image F.5: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 Based on an Average of all Seven Catchments - Across a Range of Δmean and Δamplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2°C

F.1.6.1 Implications for Lough Derg Inflows

24. The ICARUS 2019 catchment sensitivity Type for the combined Lough Derg and Parteen Basin is given as Type E following the ICARUS 2019 decision tree (catchment parameters SAAR = 1025mm, SAAPE = 485mm, ALLUV = 0.035). The corresponding ICARUS 2019 allowance factors for Type E are given in Table F.2.

Table F.2: ICARUS Allowances (% change) for Q95 Low Flows in Irish Type E Catchments Assuming a 2°C Rise in Mean Temperature

	2080's 2°C RCP8.5			
Catchment Type E	GR4J	HBV	NAM	Mean
upper +	-43	-55	-38	-45
upper	-38	-50	-33	-40
upper 75th	-27	-33	-23	-28
central 50th	-18	-20	-13	-17
lower 25th	-8	-8	-5	-7

	2080's 2°C RCP4.5			
Catchment Type E	GR4J	HBV	NAM	Mean
upper +	-43	-48	-38	-43
upper	-38	-43	-33	-38
upper 75th	-19	-23	-18	-20
central 50th	-13	-14	-12	-13
lower 25th	-5	-3	-3	-4

	2040-2099 2°C RCP 4.5, 6.0, 8.5			
Catchment Type E	GR4J	HBV	NAM	Mean
upper +	-43	-48	-38	-43
upper	-38	-43	-33	-38
upper 75th	-23	-38	-20	-27
central 50th	-15	-18	-13	-15
lower 25th	-8	-8	-5	-7

Table notes:

The ICARUS allowances supply values associated with each of the three rainfall-runoff models used in their research (viz GR4J, HBV, NAM) together with a mean value. The mean value (which is very similar to the GR4J value) is the value that is likely to be used in practical studies.

The allowances are supplied for different RCPs and over more than one future time horizon.

25. For the 2080s (based on RCP8.5 and relative to a baseline period of 1976 – 2005) the Central 50th estimate of change in Q95 is -17%. This is to say that it is equally likely that the value will be bigger or smaller than -17%. The Upper 75th percentile has a value of -28% meaning that 75% of the range of possible estimates of change are below this value and only 25% of the values fall above this value. The Upper estimate (-40%) relates to the highest estimate of change from all the possibilities investigated. The Upper + allowance (-45%) allows a further 5% change to account for the sample of ICARUS possibilities not sampling all possibilities. These 2080s allowances are graphically portrayed in Image F.6.

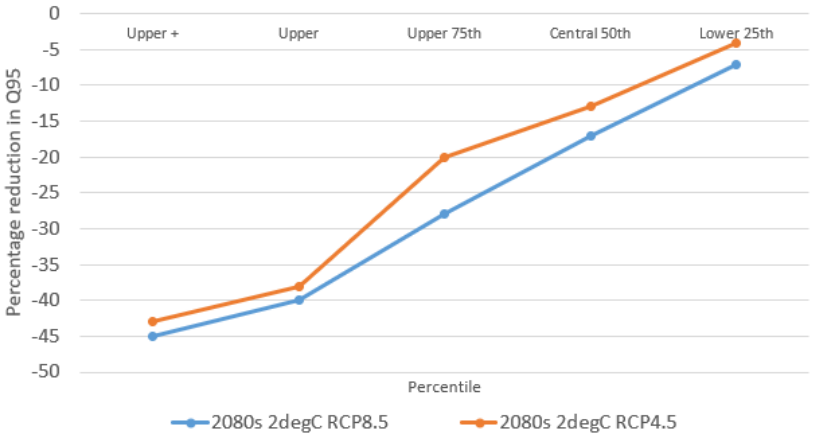


Image F.6: ICARUS Change in Q95 Allowances for the Lough Derg Catchment

26. The interpretation of the current exploratory study into rarer low flows gives broad grounds to support the use of the ICARUS ΔQ95 allowances for rarer low flows. The current study suggests that the more risk adverse projections (i.e. Upper and Upper+) may be slightly less than those portrayed in Image F.6 for the rarer low flow events, but that the central and lower end projections are likely to be similar.

F.1.7 Conclusions

27. The analysis has investigated whether it is justifiable to provisionally apply the ICARUS 2019 climate change Q95 allowances to rarer low flows.

28. Based on the rainfall-runoff modelling described it is found that the allowances are likely to provide a reasonable first-order estimate of allowances for low flows as rare as the 1 in 25-year low flow. Though it is caveated that greater uncertainties, and hence lower confidence, apply to those flows at the rarer end of the scale.

29. Based on the rainfall-runoff modelling it was predicted that the upper end ICARUS Q95 allowances tend to either slightly overestimate or be similar to the reductions predicted for the rarer low flows. The ICARUS lower end allowances for Q95 tend to be similar to those suggested for the rarer low flows.

30. There was no compelling evidence to suggest that the allowances for rarer low flows should greatly differ to those provided by ICARUS 2019 for Q95.

31. The findings however should be viewed as providing a line of evidence that the ICARUS Q95 allowances are likely to broadly hold for flows less than Q95. All climate change projections should be considered as only indicative and this is particularly true when considering extreme events, as is the case here. There is therefore greater uncertainty attached to the results for the rarer low flows investigated in this study.

F.2 Summary of the Main Features of the ICARUS 2019 Approach

32. The approach used is to first (and without recourse to climate change projections) undertake a sensitivity analysis of rainfall-runoff simulations to systematic perturbations of the daily rainfall and evaporation data used within the model. In this exercise the rainfall is incrementally changed in two ways:

    i) By scaling the entire series in 5% steps across the range -40% to +60% (this effectively decreases and increases the average annual rainfall, whilst keeping the timing and relative sizes of the daily rainfall the same as in the parent dataset).

    ii) By systematically intensifying the relative difference between the winter and summer rainfall (i.e. winters become relatively wetter and summers become relatively drier).

33. The perturbations to the parent daily rainfall series are achieved via the application of a scaling function based upon a sinusoidal (harmonic) function representing the changes to be applied on a monthly basis across the year. This scaling function can be uniformly moved up or down (to cover the incremental changes in average rainfall), and have its amplitude incrementally increased to intensify the relative difference between the winter and summer rainfall (which by itself has no impact upon the mean rainfall). The position of the sinusoidal wave across the calendar year is fixed such the biggest seasonal increase always occurs in December and the biggest relative decrease always occurs in June. This function has two degrees of freedom and allows the sensitivity of the output of the rainfall-runoff simulations to Δmean and Δamplitude to be plotted on an X-Y graph.

34. The sensitivity of the rainfall-runoff simulations to a change in potential evaporation (also a climate variable within the rainfall-runoff models) for incremental increases in mean annual temperature were also explored by running the assessment separately for three uniformly applied changes in average temperature of 0°C, +2°C and +4°C scenarios, with the +2°C scenario favoured for representing the latter half of the 21st century for Ireland.

35. The resulting "response surfaces" to these perturbations described how the output of the rainfall-runoff model responds to any combination of these perturbations. Therefore, if the likely future change of the mean annual rainfall, winter-summer relative rainfall intensification, and mean annual temperature is known then its position on the response surface can be identified and linked to a change in the hydrological response. The hydrological response that is the principal focus of the ICARUS work is the change in Q95[50]. Climate change projections are subject to significant uncertainty and this uncertainty has been included in the assessment by plotting the position of all the CMIP5[51] climate change model projections (circa 70 – 110 depending on scenario) on the response surfaces. This provides a scatter of what are taken to be equally plausible climate change plotting positions across the response surface; and allows a probabilistic assessment of the likelihood that a certain threshold change in Q95 will occur in the future. This adds the risk-based aspect associated with how the projections are presented in terms of percentiles.

36. Cluster analysis was used to assess if distinct sub-groups of catchment sensitivity existed within the sample of catchments investigated. This led to five different catchment sensitivity types being identified having broadly similar characteristics. This enabled the authors to provide a method for allocating a Type classification to any catchment in Ireland according to their climatological and physical attributes. From this typical (average) response surfaces for each of the five catchment sensitivity types were derived and the percentage of CMIP5 climate change projections (plotted on the response surface) that exceed incremental threshold values of change in Q95 could be derived. This in turns allows a risk-based presentation of the changes in Q95 for each of the 5 catchment Types – based upon the percentage of climate change models that exceed the estimated change threshold.

37. The actual process followed is more detailed than the above overview alludes to. Reference to the ICARUS report is recommended for more detail, though Table F.3 identifies some of the specification and detail of the component parts used within the study

Table F.3: Additional Details Describing the ICARUS Approach

Aspect of the Approach	Comment
Number of gauged catchments analysed in detail = 35.	Selected to cover a reasonable range of hydro-climatic conditions across Ireland.
Number of different rainfall-runoff models calibrated and used on each of the analysed catchments = 3.	Each rainfall-runoff model was given equal weight within the analysis. Different models represent the flow processes in different manners and hence give different numerical answers. Using multiple models allows the uncertainty in this aspect to be sampled.

[50] Q95 is a low flow statistic. It is the daily flow that is equalled or exceeded for 95% of the time in the record.

[51] CMIP5 stands for Coupled Model Intercomparison Project Phase 5. It is an international project that serves to refine and improve climate models and international assessments of climate change. Phase 5 is the most recent completed phase.

Aspect of the Approach	Comment
Calibration of each rainfall-runoff model followed the GLUE method.	This recognises uncertainty in the individual model parameter values. Offers a detailed and sophisticated approach to calibration and validation that takes into account the uncertainty to optimise the models.
A weather generator was used to stochastically synthesise a 400-year daily input data series for each catchment for input into the rainfall-runoff models. The 400-year series formed the length of data used in the analysis.	This potentially covers a fuller range of plausible baseline climatic conditions from which to derive the runoff response.
Number of individual rainfall-runoff model runs undertaken to derive the catchment specific response surface for one temperature scenario = 525	This is repeated for each of the three different temperature scenarios: +0°C, +2°C, +4°C,
Baseline period (1976 – 2005)	This is the period that the current response of the catchments is describing (being the period of data that the stochastic weather generator was trained on).
Number of CMIP5 ensemble members RCP 4.5 = 111 RCP 6.0 = 43 RCP 8.5 = 71	The number of available climate change model outputs is dependent on the RCP scenario. Each given equal weight in the analysis. This is understood to represent all CMIP5 models that are available.
Climate change scenarios which are reported in the "key findings" section: 2080s, RCP 8.5 rainfall, +2°C 2080s, RCP 4.5 rainfall, +2°C 2040-2099, combined RCP4.5, 6.0 & 8.5, +2°C All provide derived allowances [percentage change] for Q95 that are risk based relative to the full CMIP5 ensemble.	Within the Attachment similar information in graphical form is available for the +0°C scenario and for the +4°C scenario.

38. Image F.6 shows an example of a ΔQ95 response surface to incremental changes in the two rainfall parameters Δmean and Δamplitude (as described above) in a climate where the average temperature has increased uniformly by +2°C. The background colours identify the value of the percentage change in Q95 associated with each rainfall perturbation. On top of this the CMIP5 climate change model ensemble plotting positions for that location have been plotted (the RCP coloured dots). These CMIP5 plotting positions were use in the ICARUS 2019 study to define the relative likelihood of different outcomes on the sensitivity surface. This was achieved by analysing what proportion of ensemble plotting points lay above or below the numerical value selected on the sensitivity surface.

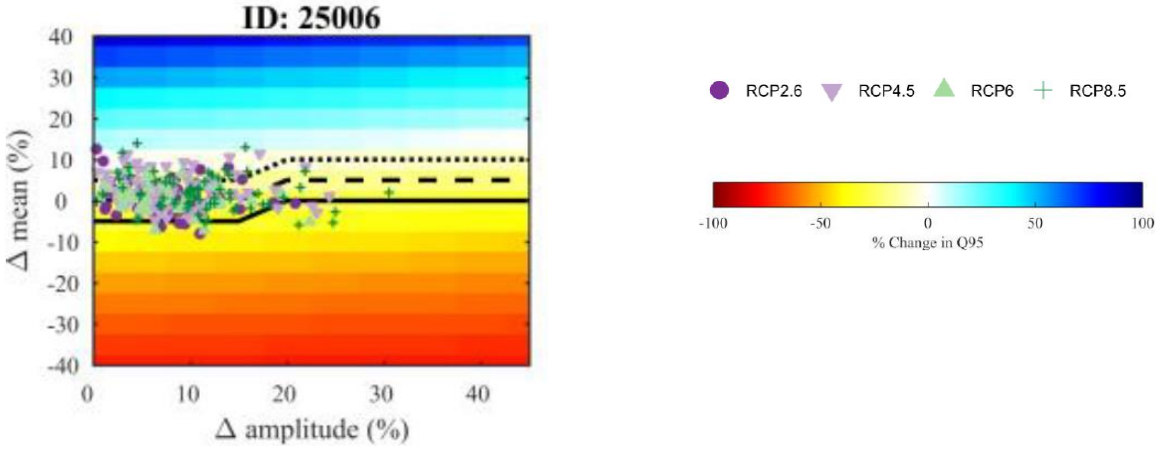


Image F.6: Example Change in Q95 Response Surface Together with the CMIP5 Plotting Positions for Different RCPs [Source: ICARUS 2019]

39. Table F.4 provides the final resulting allowances for changes to Q95 from the ICARUS study.

Table F.4: ICARUS 2019 Allowances (Percent Change) for Q95 Low Flows in Irish Catchments Assuming a 2-degree Celsius Rise in Annual Mean Temperature [Source: ICARUS 2019]

	2080's 2°C RCP8.5			
Catchment Type A	GR4J	HBV	NAM	Mean
Upper+	-40	-38	-38	-38
Upper	-35	-33	-33	-33
Upper 75th	-25	-23	-20	-23
Central 50th	-15	-13	-9	-12
Lower 25th	-5	-4	0	-3
Catchment Type B				
upper +	-70	-60	-48	-59
upper	-60	-50	-38	-49
upper 75th	-45	-38	-30	-38
central 50th	-33	-28	-20	-27
lower 25th	-23	-18	-13	-18
Catchment Type C				
upper +	-50	-50	-55	-52
upper	-45	-45	-50	-47
upper 75th	-35	-35	-41	-37
central 50th	-26	-25	-28	-26
lower 25th	-16	-14	-14	-15
Catchment Type D				
upper +	-40	-48	-43	-44
upper	-35	-43	-38	-39
upper 75th	-24	-32	-27	-28
central 50th	-18	-23	-18	-19
lower 25th	-7	-10	-3	-7
Catchment Type E				
upper +	-43	-55	-38	-45
upper	-38	-50	-33	-40
upper 75th	-27	-33	-23	-28
central 50th	-18	-20	-13	-17
lower 25th	-8	-8	-5	-7

	2080's 2°C RCP4.5			
Catchment Type A	GR4J	HBV	NAM	Mean
Upper+	-40	-40	-32	-37
Upper	-35	-35	-28	-33
Upper 75th	-18	-18	-15	-17
Central 50th	-13	-11	-8	-11
Lower 25th	-5	-4	-2	-4
Catchment Type B				
upper +	-55	-50	-45	-50
upper	-50	-45	-40	-45
upper 75th	-33	-28	-23	-28
central 50th	-25	-23	-18	-22
lower 25th	-18	-13	-10	-14
Catchment Type C				
upper +	-50	-50	-57	-52
upper	-45	-45	-52	-47
upper 75th	-27	-25	-31	-28
central 50th	-20	-17	-20	-19
lower 25th	-13	-10	-9	-11
Catchment Type D				
upper +	-40	-47	-45	-44
upper	-35	-42	-40	-39
upper 75th	-18	-25	-21	-21
central 50th	-13	-18	-12	-14
lower 25th	-5	-7	-3	-5
Catchment Type E				
upper +	-43	-48	-38	-43
upper	-38	-43	-33	-38
upper 75th	-19	-23	-18	-20
central 50th	-13	-14	-12	-13
lower 25th	-5	-3	-3	-4

	2040-2099 2°C RCP 4.5, 6.0, 8.5			
Catchment Type A	GR4J	HBV	NAM	Mean
Upper+	-40	-40	-38	-39
Upper	-35	-35	-33	-34
Upper 75th	-21	-18	-17	-19
Central 50th	-13	-12	-11	-12
Lower 25th	-5	-3	-3	-4
Catchment Type B				
upper +	-60	-55	-45	-53
upper	-55	-50	-40	-48
upper 75th	-36	-32	-26	-31
central 50th	-28	-24	-20	-24
lower 25th	-20	-15	-13	-16
Catchment Type C				
upper +	-50	-50	-60	-53
upper	-45	-45	-55	-48
upper 75th	-30	-29	-34	-31
central 50th	-22	-20	-23	-22
lower 25th	-15	-13	-12	-13
Catchment Type D				
upper +	-40	-50	-45	-45
upper	-35	-45	-40	-40
upper 75th	-22	-28	-23	-24
central 50th	-15	-20	-15	-17
lower 25th	-8	-12	-5	-8
Catchment Type E				
upper +	-43	-48	-38	-43
upper	-38	-43	-33	-38
upper 75th	-23	-38	-20	-27
central 50th	-15	-18	-13	-15
lower 25th	-8	-8	-5	-7

F.3 Full tabulated and graphical results

7009

Proportional change in measures of low flow
(Simulated flow from perturbed rainfall scenario in a +2degC world/ simulated baseline flow)

	Φ	12	12	12	12	12	12	12	12	12	12	12	12
Amplitude	A	0%	10%	20%	30%	0%	10%	20%	30%	0%	10%	20%	30%
Mean	Xo	0%	0%	0%	0%	10%	10%	10%	10%	-10%	-10%	-10%	-10%

Return period	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
2-year	1.00	0.83	0.81	0.79	0.77	1.00	0.98	0.96	0.93	0.67	0.65	0.64	0.62
5-year	1.00	0.84	0.82	0.80	0.78	1.00	0.97	0.95	0.93	0.69	0.68	0.66	0.65
10-year	1.00	0.84	0.82	0.81	0.79	0.99	0.97	0.95	0.93	0.71	0.69	0.68	0.67
25-year	1.00	0.85	0.83	0.81	0.80	0.99	0.97	0.95	0.93	0.72	0.71	0.70	0.70

Flow %-tile	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
Qmean	1.00	0.90	0.91	0.91	0.91	1.07	1.08	1.08	1.08	0.74	0.74	0.75	0.75
Q50	1.00	0.85	0.84	0.83	0.82	1.05	1.04	1.03	1.03	0.66	0.65	0.64	0.63
Q90	1.00	0.80	0.77	0.75	0.73	1.01	0.98	0.96	0.93	0.62	0.61	0.59	0.57
Q95	1.00	0.81	0.79	0.77	0.75	1.00	0.98	0.95	0.92	0.65	0.64	0.62	0.61
Q99	1.00	0.85	0.84	0.82	0.80	1.00	0.98	0.96	0.94	0.72	0.71	0.70	0.68

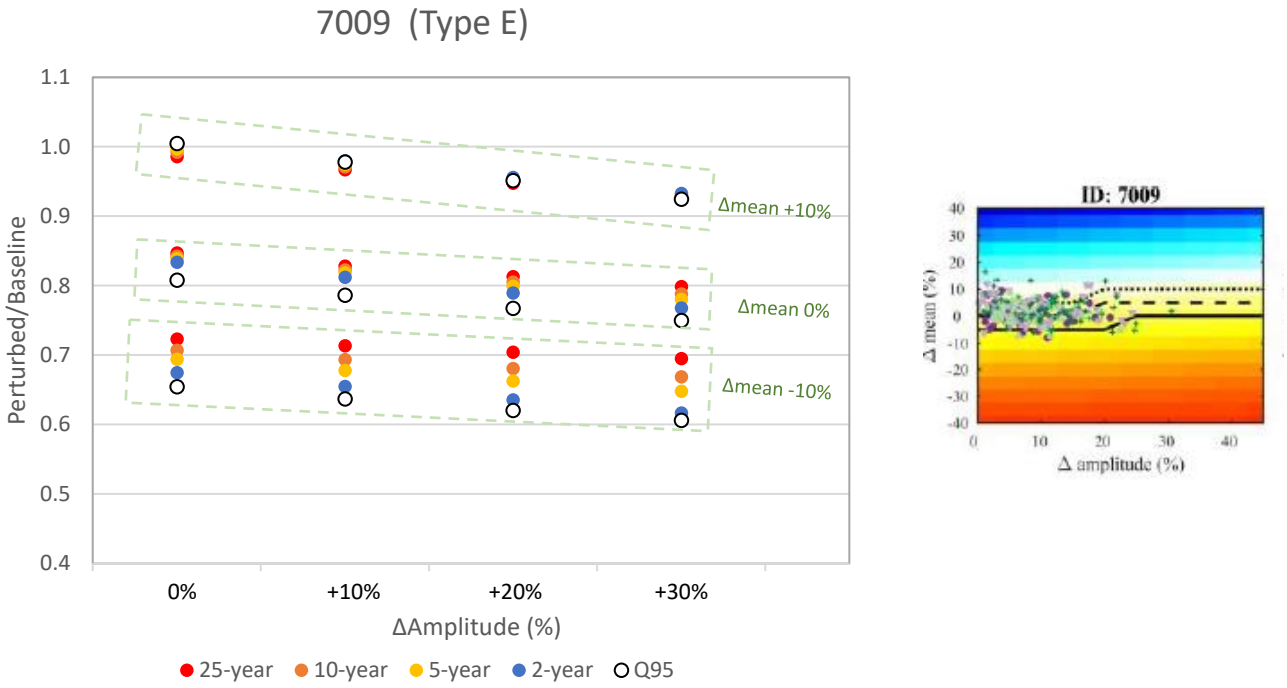


Image F.7: Comparison of the Predicted T-year Low Flow Change Factors to Those Predicted for Q95 for the River Boyne (Stn. no. 7009) - Across a Range of ∆mean and ∆amplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2oC. (Inserted to the side is the ICARUS 2019 sensitivity surface showing the general spread of the CMIP5 plotting positions for this catchment).

40. Interpretation guide: If the T-year points plot on top of the Q95 points it would suggest that the ICARUS Q95 allowance factors are directly transferrable to the rarer low flow events. The insert allows the extent of the CMIP5 plotting points to be taken into account when considering which of the data points in the main graph to focus upon.

14019
Proportional change in measures of low flow
(Simulated flow from perturbed rainfall scenario in a +2degC world/ simulated baseline flow)

	Φ	12	12	12	12	12	12	12	12	12	12	12	12
Amplitude	A	0%	10%	20%	30%	0%	10%	20%	30%	0%	10%	20%	30%
Mean	Xo	0%	0%	0%	0%	10%	10%	10%	10%	-10%	-10%	-10%	-10%

Return period	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
2-year	1.00	0.80	0.79	0.77	0.75	0.99	0.97	0.95	0.93	0.63	0.62	0.60	0.59
5-year	1.00	0.80	0.78	0.77	0.75	0.97	0.95	0.94	0.92	0.64	0.62	0.61	0.60
10-year	1.00	0.80	0.78	0.77	0.75	0.96	0.94	0.93	0.91	0.64	0.63	0.61	0.60
25-year	1.00	0.79	0.78	0.76	0.75	0.95	0.93	0.92	0.90	0.64	0.63	0.62	0.61

Flow %-tile	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
Qmean	1.00	0.87	0.87	0.87	0.87	1.07	1.07	1.07	1.07	0.68	0.68	0.68	0.69
Q50	1.00	0.85	0.84	0.84	0.84	1.05	1.04	1.04	1.03	0.65	0.65	0.65	0.64
Q90	1.00	0.79	0.77	0.75	0.73	1.00	0.98	0.96	0.94	0.60	0.58	0.57	0.55
Q95	1.00	0.79	0.77	0.75	0.74	0.99	0.97	0.95	0.93	0.61	0.59	0.58	0.56
Q99	1.00	0.79	0.78	0.76	0.75	0.97	0.95	0.93	0.91	0.63	0.62	0.60	0.59

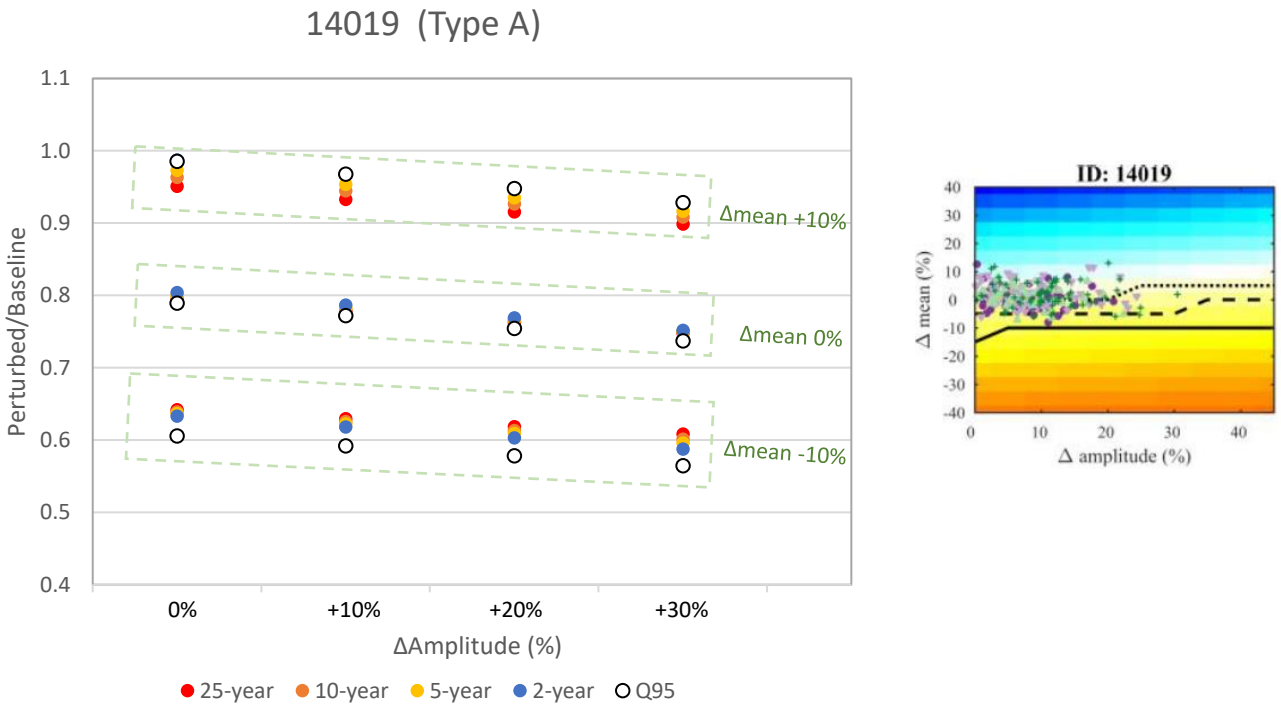


Image F.8: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 for the River Barrow (Stn. no. 14019) - Across a Range of ∆mean and ∆amplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2ºC. (Inserted to the side is the ICARUS 2019 sensitivity surface showing the general spread of the CMIP5 plotting positions for this catchment).

41. Interpretation guide: If the T-year points plot on top of the Q95 points it would suggest that the ICARUS Q95 allowance factors are directly transferrable to the rarer low flow events. The insert allows the extent of the CMIP5 plotting points to be taken into account when considering which of the data points in the main graph to focus upon.

15003

Proportional change in measures of low flow
(Simulated flow from perturbed rainfall scenario in a +2degC world/ simulated baseline flow)

	Φ	12	12	12	12	12	12	12	12	12	12	12	12
Amplitude	A	0%	10%	20%	30%	0%	10%	20%	30%	0%	10%	20%	30%
Mean	Xo	0%	0%	0%	0%	10%	10%	10%	10%	-10%	-10%	-10%	-10%

Return period	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
2-year	1.00	0.82	0.80	0.78	0.76	0.99	0.97	0.94	0.92	0.66	0.64	0.62	0.60
5-year	1.00	0.82	0.79	0.77	0.75	0.99	0.96	0.94	0.92	0.66	0.64	0.62	0.61
10-year	1.00	0.81	0.79	0.77	0.75	0.99	0.96	0.94	0.92	0.66	0.64	0.63	0.61
25-year	1.00	0.80	0.78	0.76	0.75	0.98	0.96	0.93	0.91	0.66	0.65	0.63	0.62

Flow %-tile	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
Qmean	1.00	0.92	0.92	0.92	0.92	1.08	1.08	1.08	1.08	0.76	0.76	0.77	0.77
Q50	1.00	0.88	0.87	0.87	0.86	1.05	1.04	1.03	1.02	0.71	0.71	0.70	0.69
Q90	1.00	0.77	0.75	0.73	0.70	1.00	0.97	0.94	0.91	0.59	0.56	0.54	0.52
Q95	1.00	0.78	0.76	0.74	0.71	0.99	0.96	0.93	0.91	0.61	0.59	0.57	0.55
Q99	1.00	0.82	0.81	0.79	0.77	0.98	0.96	0.95	0.92	0.69	0.67	0.65	0.64

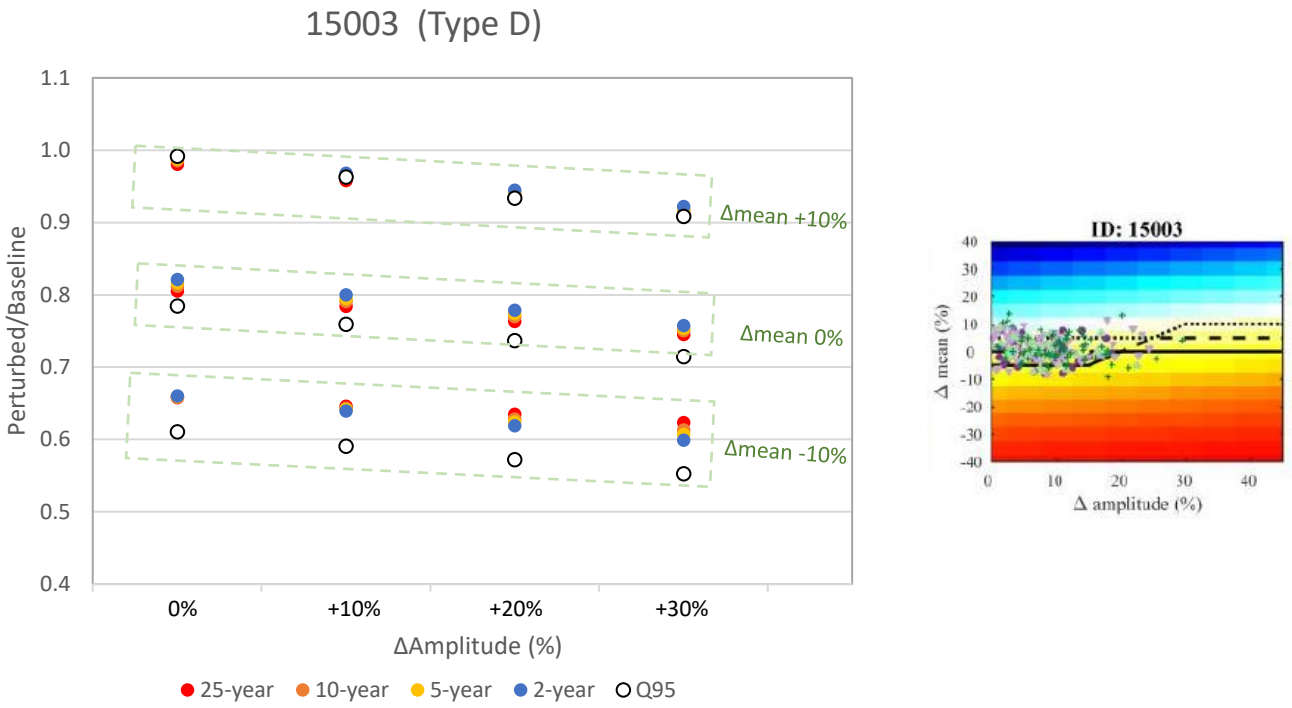


Image F.9: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 for the River Nore (Stn. no. 15003) - Across a Range of Δmean and Δamplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2°C. (Inserted to the side is the ICARUS 2019 sensitivity surface showing the general spread of the CMIP5 plotting positions for this catchment).

42. Interpretation guide: If the T-year points plot on top of the Q95 points it would suggest that the ICARUS Q95 allowance factors are directly transferrable to the rarer low flow events. The insert allows the extent of the CMIP5 plotting points to be taken into account when considering which of the data points in the main graph to focus upon.

18003

Proportional change in measures of low flow
(Simulated flow from perturbed rainfall scenario in a +2degC world/ simulated baseline flow)

	Φ	12	12	12	12	12	12	12	12	12	12	12	12
Amplitude	A	0%	10%	20%	30%	0%	10%	20%	30%	0%	10%	20%	30%
Mean	Xo	0%	0%	0%	0%	10%	10%	10%	10%	-10%	-10%	-10%	-10%

Return period	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
2-year	1.00	0.83	0.78	0.74	0.69	1.02	0.97	0.92	0.87	0.65	0.61	0.57	0.53
5-year	1.00	0.82	0.77	0.72	0.68	1.01	0.96	0.91	0.86	0.64	0.60	0.56	0.53
10-year	1.00	0.81	0.76	0.71	0.67	1.00	0.95	0.90	0.85	0.63	0.59	0.56	0.53
25-year	1.00	0.79	0.74	0.70	0.66	0.99	0.93	0.88	0.83	0.61	0.58	0.55	0.53

Flow %-tile	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
Qmean	1.00	0.93	0.94	0.94	0.94	1.08	1.08	1.09	1.09	0.79	0.79	0.79	0.80
Q50	1.00	0.91	0.89	0.88	0.86	1.06	1.05	1.03	1.02	0.75	0.74	0.72	0.71
Q90	1.00	0.81	0.76	0.71	0.66	1.04	0.98	0.92	0.87	0.61	0.56	0.52	0.47
Q95	1.00	0.81	0.76	0.71	0.66	1.02	0.97	0.92	0.87	0.61	0.57	0.53	0.50
Q99	1.00	0.81	0.77	0.73	0.69	1.00	0.95	0.91	0.86	0.64	0.61	0.57	0.54

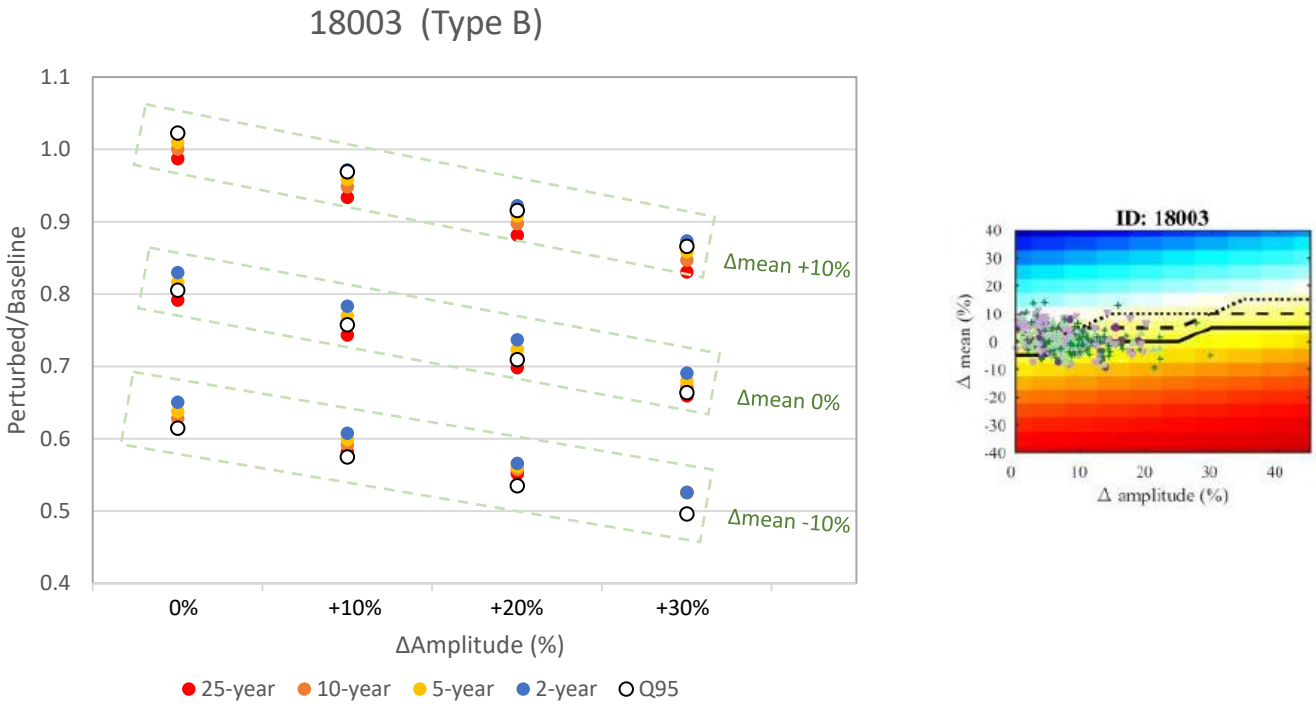


Image F.10: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 for the River Blackwater (Stn. no. 18003) - Across a Range of Δmean and Δamplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2ºC. (Side insert is the ICARUS 2019 sensitivity surface showing the general spread of the CMIP5 plotting positions for this catchment).

43. Interpretation guide: If the T-year points plot on top of the Q95 points it would suggest that the ICARUS Q95 allowance factors are directly transferrable to the rarer low flow events. The insert allows the extent of the CMIP5 plotting points to be taken into account when considering which of the data points in the main graph to focus upon.

23002

Proportional change in measures of low flow
(Simulated flow from perturbed rainfall scenario in a +2degC world/ simulated baseline flow)

	Φ	12	12	12	12	12	12	12	12	12	12	12	12
Amplitude	A	0%	10%	20%	30%	0%	10%	20%	30%	0%	10%	20%	30%
Mean	Xo	0%	0%	0%	0%	10%	10%	10%	10%	-10%	-10%	-10%	-10%

Return period	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
2-year	1.00	0.84	0.79	0.74	0.69	1.02	0.97	0.93	0.88	0.65	0.60	0.55	0.50
5-year	1.00	0.83	0.78	0.73	0.68	1.01	0.97	0.92	0.87	0.64	0.59	0.55	0.51
10-year	1.00	0.82	0.77	0.72	0.67	1.01	0.96	0.92	0.87	0.62	0.58	0.54	0.51
25-year	1.00	0.80	0.75	0.71	0.66	1.00	0.95	0.91	0.86	0.60	0.57	0.54	0.51

Flow %-tile	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
Qmean	1.00	0.94	0.94	0.95	0.95	1.08	1.08	1.08	1.09	0.81	0.81	0.81	0.82
Q50	1.00	0.91	0.88	0.87	0.85	1.06	1.04	1.02	1.00	0.75	0.73	0.71	0.70
Q90	1.00	0.79	0.73	0.67	0.61	1.05	0.98	0.92	0.85	0.56	0.51	0.47	0.42
Q95	1.00	0.80	0.74	0.68	0.63	1.04	0.98	0.92	0.85	0.58	0.52	0.48	0.43
Q99	1.00	0.80	0.76	0.71	0.67	1.02	0.96	0.91	0.86	0.63	0.59	0.55	0.51

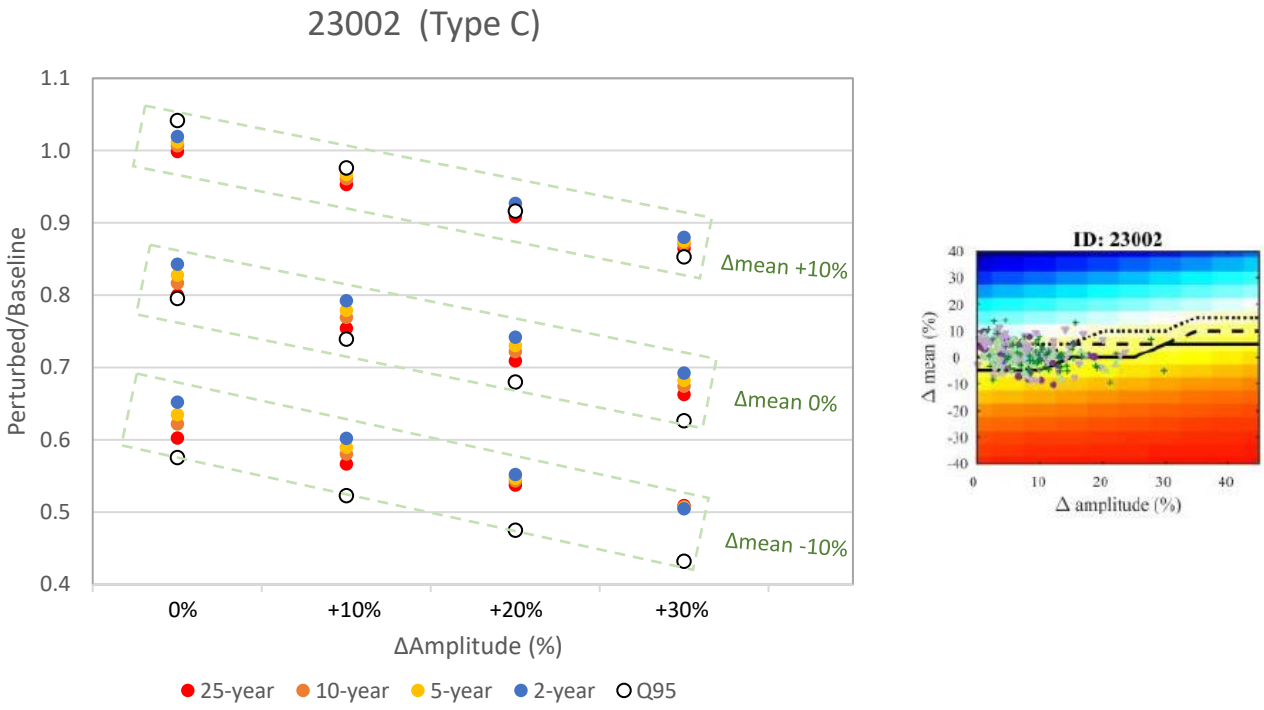


Image F.11: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 for the River Feale (Stn. no. 23002) - Across a Range of Δmean and Δamplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2°C. (Side insert is the ICARUS 2019 sensitivity surface showing the general spread of the CMIP5 plotting positions for this catchment).

44. Interpretation guide: If the T-year points plot on top of the Q95 points it would suggest that the ICARUS Q95 allowance factors are directly transferrable to the rarer low flow events. The insert allows the extent of the CMIP5 plotting points to be taken into account when considering which of the data points in the main graph to focus upon.

25006

Proportional change in measures of low flow
(Simulated flow from perturbed rainfall scenario in a +2degC world/ simulated baseline flow)

	Φ	12	12	12	12	12	12	12	12	12	12	12	12
Amplitude	A	0%	10%	20%	30%	0%	10%	20%	30%	0%	10%	20%	30%
Mean	Xo	0%	0%	0%	0%	10%	10%	10%	10%	-10%	-10%	-10%	-10%

Return period	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
2-year	1.00	0.88	0.86	0.84	0.83	1.04	1.02	1.00	0.97	0.74	0.73	0.71	0.70
5-year	1.00	0.90	0.88	0.87	0.85	1.04	1.02	1.00	0.98	0.78	0.76	0.75	0.74
10-year	1.00	0.91	0.90	0.88	0.87	1.04	1.02	1.00	0.99	0.80	0.79	0.78	0.77
25-year	1.00	0.92	0.91	0.90	0.89	1.03	1.02	1.00	0.99	0.82	0.82	0.81	0.80

Flow %-tile	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
Qmean	1.00	0.93	0.93	0.94	0.94	1.08	1.08	1.09	1.09	0.78	0.79	0.80	0.80
Q50	1.00	0.89	0.88	0.87	0.87	1.06	1.05	1.04	1.04	0.71	0.71	0.70	0.70
Q90	1.00	0.87	0.85	0.84	0.82	1.05	1.03	1.00	0.98	0.73	0.71	0.70	0.68
Q95	1.00	0.88	0.87	0.85	0.83	1.04	1.02	1.00	0.98	0.74	0.73	0.72	0.71
Q99	1.00	0.90	0.88	0.87	0.86	1.03	1.01	1.00	0.98	0.78	0.77	0.76	0.76

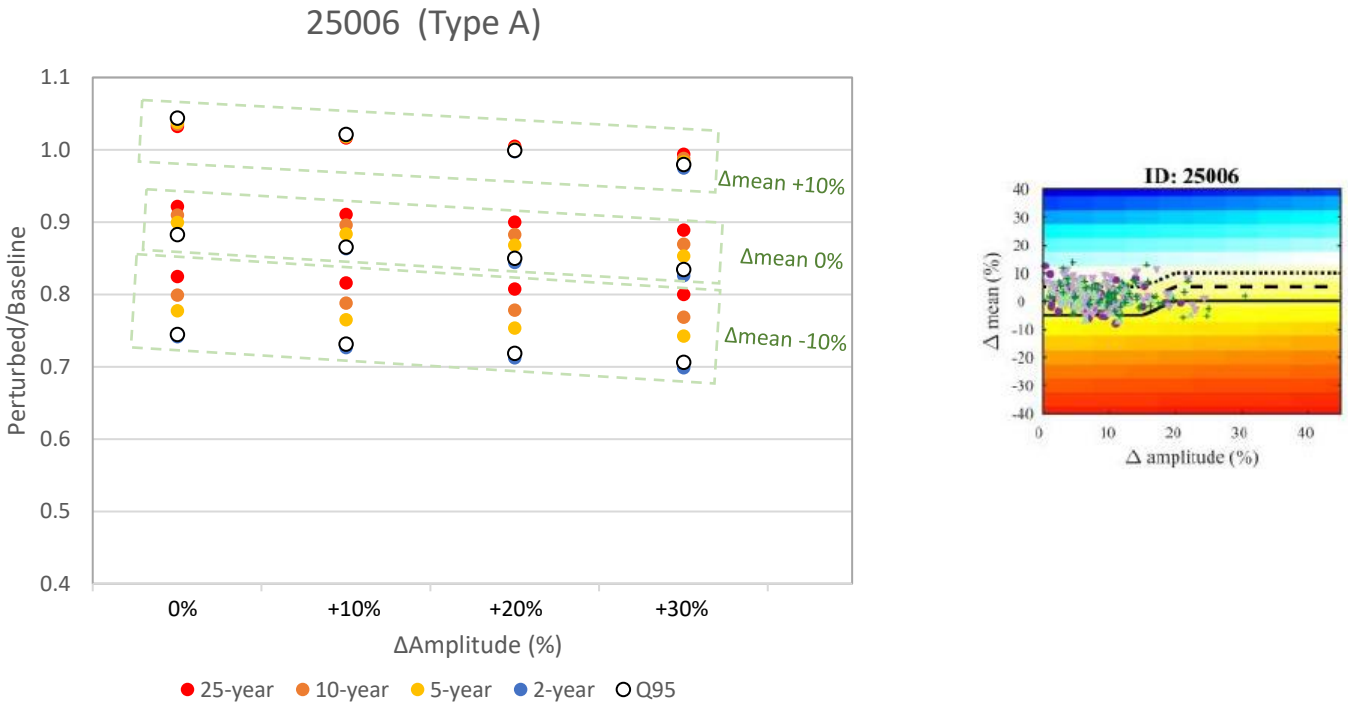


Image F.12: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 for the River Brosna (Stn. no. 25006) - Across a Range of Δmean and Δamplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2°C. (Side insert is the ICARUS 2019 sensitivity surface showing the general spread of the CMIP5 plotting positions for this catchment).

45. Interpretation guide: If the T-year points plot on top of the Q95 points it would suggest that the ICARUS Q95 allowance factors are directly transferrable to the rarer low flow events. The insert allows the extent of the CMIP5 plotting points to be taken into account when considering which of the data points in the main graph to focus upon.

26021

Proportional change in measures of low flow
(Simulated flow from perturbed rainfall scenario in a +2degC world/ simulated baseline flow)

	Φ	12	12	12	12	12	12	12	12	12	12	12	12
Amplitude	A	0%	10%	20%	30%	0%	10%	20%	30%	0%	10%	20%	30%
Mean	Xo	0%	0%	0%	0%	10%	10%	10%	10%	-10%	-10%	-10%	-10%

Return period	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
2-year	1.00	0.86	0.84	0.82	0.79	1.04	1.01	0.98	0.95	0.71	0.69	0.68	0.66
5-year	1.00	0.88	0.87	0.85	0.83	1.03	1.01	0.98	0.96	0.76	0.74	0.73	0.72
10-year	1.00	0.90	0.88	0.87	0.85	1.02	1.00	0.99	0.97	0.79	0.77	0.76	0.75
25-year	1.00	0.91	0.90	0.89	0.88	1.02	1.00	0.99	0.97	0.82	0.81	0.81	0.80

Flow %-tile	Qbaseline	Q0,0	Q10,0	Q20,0	Q30,0	Q0,10	Q10,10	Q20,10	Q30,10	Q0,-10	Q10,-10	Q20,-10	Q30,-10
Qmean	1.00	0.92	0.93	0.93	0.94	1.08	1.08	1.09	1.09	0.78	0.78	0.79	0.80
Q50	1.00	0.88	0.87	0.85	0.84	1.06	1.05	1.05	1.03	0.69	0.68	0.67	0.67
Q90	1.00	0.85	0.83	0.81	0.79	1.05	1.02	0.99	0.96	0.71	0.69	0.67	0.66
Q95	1.00	0.87	0.85	0.84	0.82	1.03	1.01	0.99	0.96	0.73	0.72	0.71	0.69
Q99	1.00	0.89	0.88	0.86	0.85	1.02	1.00	0.99	0.97	0.78	0.77	0.76	0.75

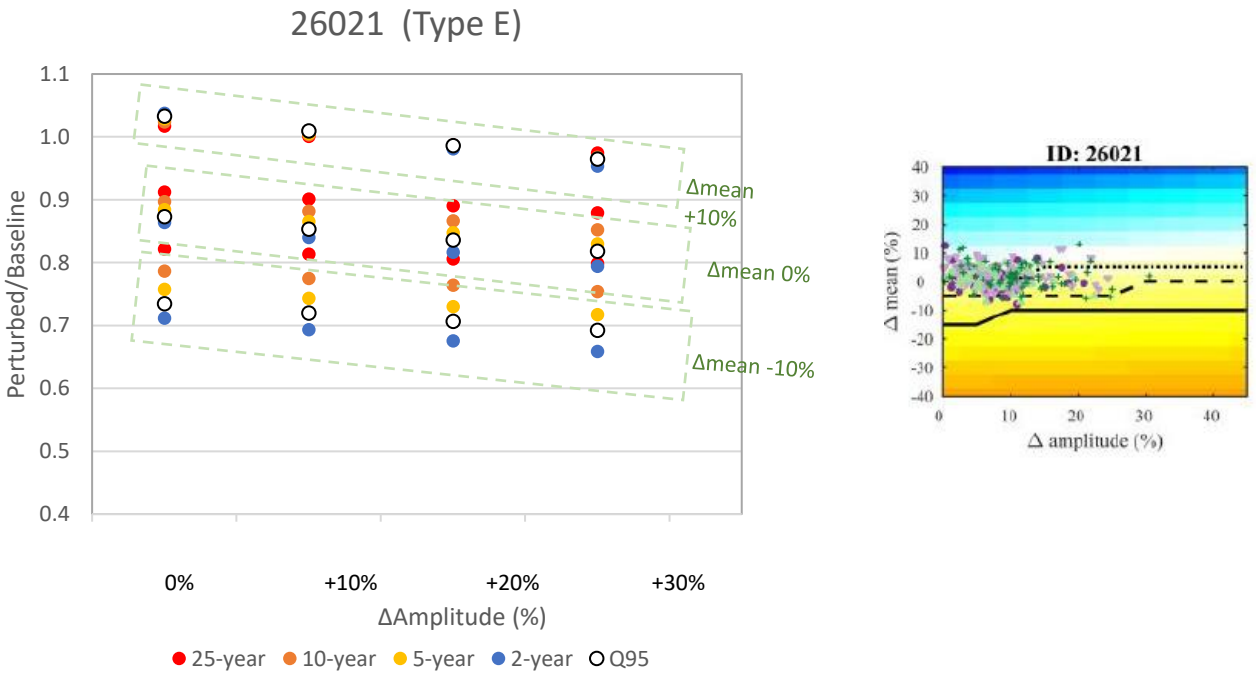


Image F.13: Comparison of the Predicted T-year Low Flow Change Factors to those Predicted for Q95 for the River Inny (Stn. no. 26021) - Across a Range of Δmean and Δamplitude Rainfall Perturbation Scenarios Where the Mean Temperature has Risen by +2°C. (Side insert is the ICARUS 2019 sensitivity surface showing the general spread of the CMIP5 plotting positions for this catchment).

46. Interpretation guide: If the T-year points plot on top of the Q95 points it would suggest that the ICARUS Q95 allowance factors are directly transferrable to the rarer low flow events. The insert allows the extent of the CMIP5 plotting points to be taken into account when considering which of the data points in the main graph to focus upon.

F.4 References

ICARUS, 2019. Identification of climate sensitive catchments: Water Resources and Climate Change Adaptation. Report for Uisce Éireann prepared by Irish Climate Analysis and Research Units (ICARUS), Department of Geography, Maynooth University.

Jacobs, 2020. ICARUS Climate Review -An investigation into the applicability of the ICARUS 2019 climate change allowances for Q95 to rarer low flows, Report for Uisce Éireann.

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Perrin et al., 2003. Improvement of a parsimonious model for streamflow simulation, Journal of Hydrology, 279(1-4), 275-289.

Prudomme, C., Wilby,R.L., Crooks, S., Kay, A. & Reynard, N.S., 2010. Scenario-neutral approach to climate change impact studies: Application to flood risk. Journal of Hydrology, Vol 390, Iss 3-4, p 198-209.

Attachment G. Additional Sensitivity Analyses

1. This Attachment presents the results of additional sensitivity analyses undertaken on the simulated impact of WSP abstractions on lake levels as simulated by the WSP hydrological model[52]. Three aspects are investigated:
    - Uncertainty in the lake level monitoring offsets
    - Uncertainty in the ESB provided flow data
    - Sensitivity to the target levels.

G.1 Sensitivity to lake level monitoring offsets

2. As discussed in Attachment A there is some uncertainty as to what the absolute levels at Portumna and Killaloe should be. There is confidence in the day-to-day changes in levels [as shown by the comparison to the Uisce Éireann continuous monitoring (Attachment A)]; but what appear to be systematic offsets are evident between the Uisce Éireann and the ESB recorded levels, and between different periods within the ESB record. This sensitivity analysis explores whether these offsets will have an effect upon the size of the simulated impacts of WSP on the water levels and the forward flows to the ORS at Parteen Weir.

3. To do this the ESB Portumna level was systematically decreased by 0.08m from the winter of 1983/84 and the net inflow to Lough Derg and Parteen Basin recalculated. Image G.1 shows the sensitivity of the model to this by plotting the inflows, simulated levels and forward flows down the ORS with and without the Portumna 0.08m offset included in the runs. The inclusion of the offset within the inflow data calculation makes no difference to the simulated impacts of the WSP abstraction. This is because the day-to-day change in the average level of the lake is the same with or without the systematic offset included.

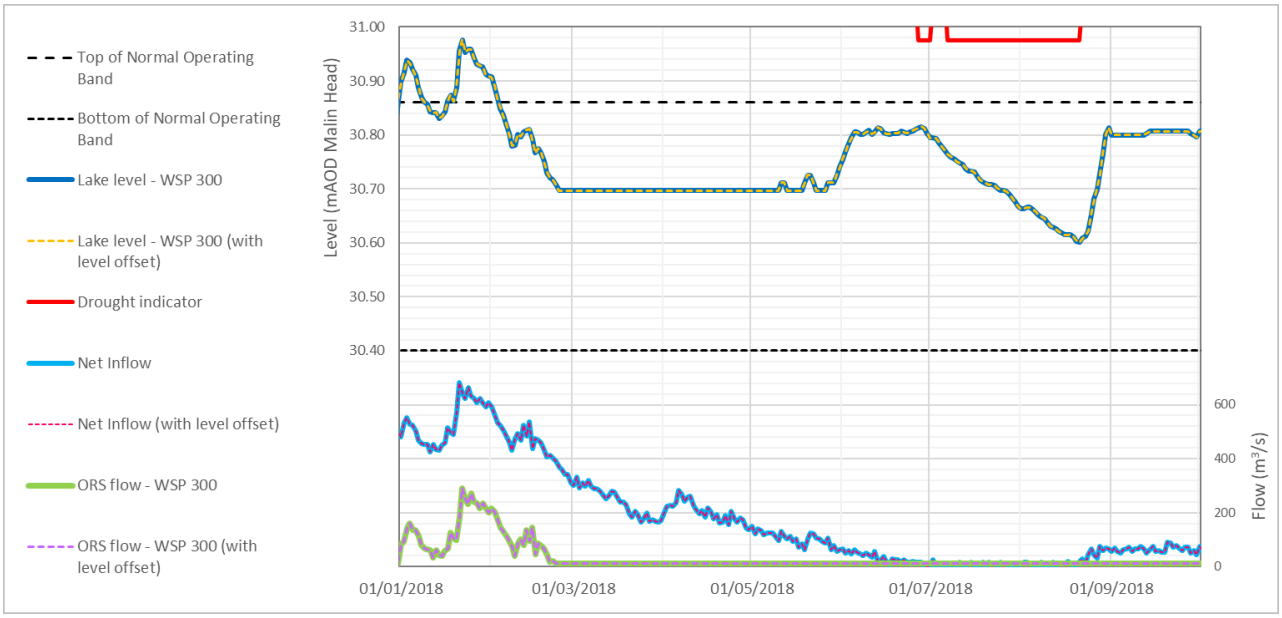

Image G.1: Sensitivity of the Simulated Impacts with and without the 0.08m Level Offset Applied to the Portumna Level Record

[52] The final version of the WSP hydrological model build has previously been referred to as the "Operational Principles Model" to differentiate it to the initial "Historical Model" build.

G.2 Sensitivity to Uncertainty in the ESB Supplied Flow Data

4. Flow data can be subject to error. Hydrometric errors up to +/- 10% are typical. To investigate the possible effect of this upon the modelled impacts of the WSP abstraction the following sensitivity analyses were run in which systematic reductions to the recorded Ardnacrusha flows and those recorded as flowing into the Old River Shannon (ORS) at Parteen Weir were introduced into the calculation of the Net Inflow.

5. The scenarios considered:

Table G.1: Scenarios Considered for the Sensitivity Analysis using Various Flow Reductions at Ardnacrusha

Scenario	Abbreviation
Ardnacrusha x 1.0 & ORS x 1.0	1A 1ORS
Ardnacrusha x 0.9 & ORS x 1.0	0.9A 1ORS
Ardnacrusha x 1.0 & ORS x 0.9	1A 0.9ORS
Ardnacrusha x 0.9 & ORS x 0.9	0.9A 0.9ORS

6. In the following there are three sets of graphs that provide the simulated sensitivity of the WSP impact (in terms of lake water level and forward flow to the ORS) to the systematic scaling of the recorded Ardnacrusha and ORS flows within the calculation of the Net Inflow. Each version of the net inflow is used within the Operational Principles Model, and the baseline (no WSP) and the WSP 300Mld runs are undertaken and compared. Within these simulations it is assumed that the modelled releases at Ardnacrusha and to the ORS will be correct (e.g. that in the simulation a $10m^3/s$ compensation flow will be accurately released even if the historical recorded data is subject to the imposed systematic error).

7. The three graphs provide sensitivity information for:
   i) Systematic error in recorded flows to the ORS
   ii) Systematic error in recorded flows through Ardnacrusha
   iii) The same systematic error in both the recorded ORS and Ardnacrusha flows.

8. Note: uncertainty in the hydrometric performance of a flow gauge is most usually given as a percentage uncertainty range over or below the value given (e.g. +/- 10%). In the sensitivity analysis provided here only the negative uncertainty is investigated since the system will be more impacted by reduced amounts of water. However, the sensitivity of the impacts to the positive uncertainty (i.e. when recorded flows are actually less than what really occurred) could equally occur and this should be recognised within the overall consideration.

9. Applying the uncertainty as a scaling factor in this way assumes the possible error to be both systematic and of equal relative size across the full range of the flows that were recorded.
   i) Systematic error in recorded flows to the ORS

10. Image G.2 shows the sensitivity of the WSP impacts to systematic error in the monitoring of the flows going into the ORS. If the monitored forward flows to the ORS were in fact lower than recorded by 10% (i.e. the monitoring had overestimated the flows) then the calculated net inflows during the drought period would have been too high. In the sensitivity analysis this is simulated to be the case and the net inflow series has been recalculated to amend for this. With this revised net inflow series used in the modelling of both the baseline case and the WSP 300Mld scenario the dotted traces in Image G.2 result.

11. For the levels outside of drought periods there is almost no change. During the drought period the lower simulated net inflow causes both the baseline (no WSP) and the WSP 300Mld scenario simulated levels to be lower.

12. Simulated ORS flows are not affected during non-flood periods, whilst during the flood periods the flows are slightly less than had the original net inflow series been used. However, there is no noticeable difference between the baseline (no WSP) and WSP 300Mld scenarios when the revised net inflow series is used (i.e. no significant impact to the ORS flows due to the inclusion of the WSP abstraction).

Image G.2: WSP Impact Sensitivity to Systematic Error in Recorded Forward Flows to the Old River Shannon Being Incorporated into the Net Inflow Sequence

ii) Systematic error in recorded flows through Ardnacrusha;

13. Image G.3 shows the sensitivity of the WSP impacts to systematic error in the monitoring of the Ardnacrusha flows. If the monitored Ardnacrusha flows were in fact lower than recorded by 10% (i.e. the monitoring had overestimated the flows) then the calculated net inflows during the periods when the generators were working would have been too high. In the sensitivity analysis this is simulated to be the case and the net inflow series has been recalculated to amend for this. With this revised net inflow series used in the modelling of both the baseline (no WSP) case and the WSP 300Mld scenario the dotted traces in Image G.3 result. For the levels during drought periods there is no change. This is because during the drought periods the Ardnacrusha generator are switched off, and therefore there is no sensitivity to any error in the associated flows. Outside of drought periods the revised net inflow series is lower than the original net inflow series. This results in a change in the timing of when the system targets the lower (wet period) and upper (dry period) target levels, and in a reduction of the flood flows entering into the ORS. However, there is no noticeable difference between the baseline and WSP 300Mld scenarios when the revised net inflow series is used (i.e. no significant WSP impact).

Image G.3: WSP Impact Sensitivity to Systematic Error in Recorded Ardnacrusha Flows Being Incorporated into the Net Inflow Sequence

iii) The same systematic error in both the recorded ORS and Ardnacrusha flows.

14. Image G.4 shows the sensitivity of the WSP impacts to equal error in the monitoring of both the Ardnacrusha flows and the flows entering the ORS at Parteen Weir.

Image G.4: WSP Impact Sensitivity to Equal Systematic Error in both the Ardnacrusha Flows and the Forward Flows to the Old River Shannon Being Incorporated into the Net Inflow Sequence

G.3 Sensitivity to Different Target Average Water Levels

15. In the model the upper target level (dry period) average lake water level is set at 30.80mAOD, and the lower target level (wet period) average lake water level at 30.70mAOD. In this sensitivity analysis two separate scenarios are investigated:

i) Sensitivity to raising the upper target level (dry period) – upper target level raised to 30.84mAOD, whilst keeping the lower target level (wet period) at 30.70mAOD

ii) Sensitivity to lowering the lower target level (wet period) - leaving the upper target level at 30.80mAOD and dropping the lower target level to 30.60mAOD.

16. Image G.5 and Image G.6 present the results.

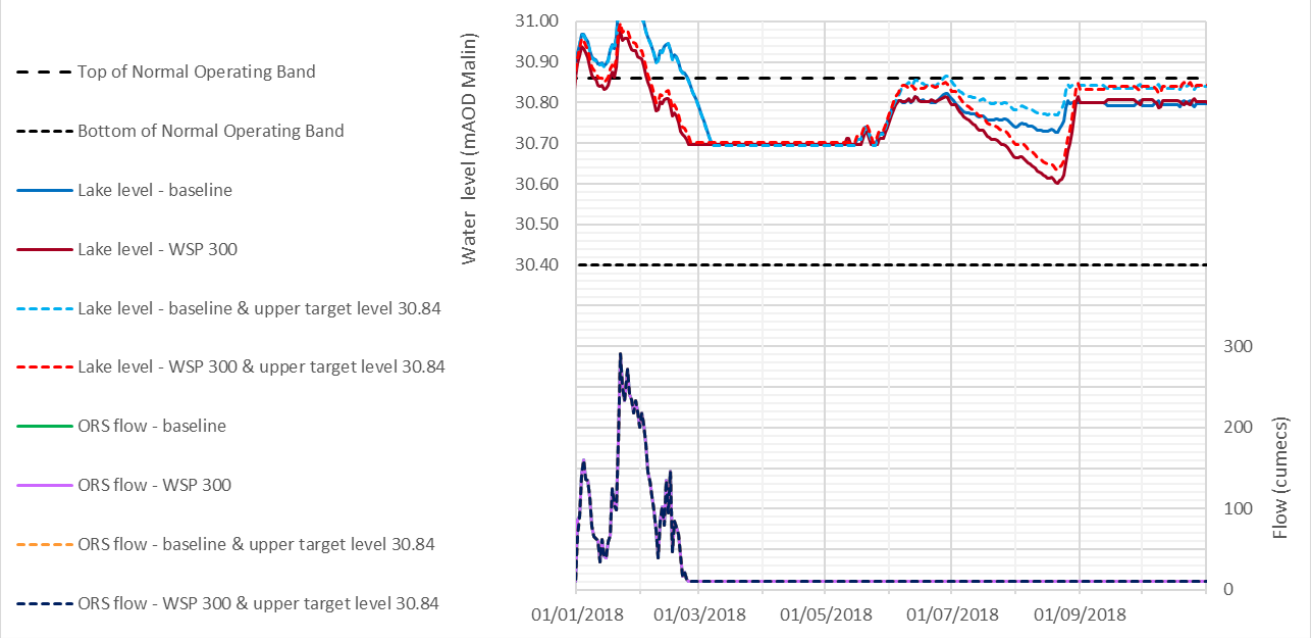

Image G.5: WSP Impact Sensitivity to Increasing the Upper Target Level from 30.80 to 30.84mAOD

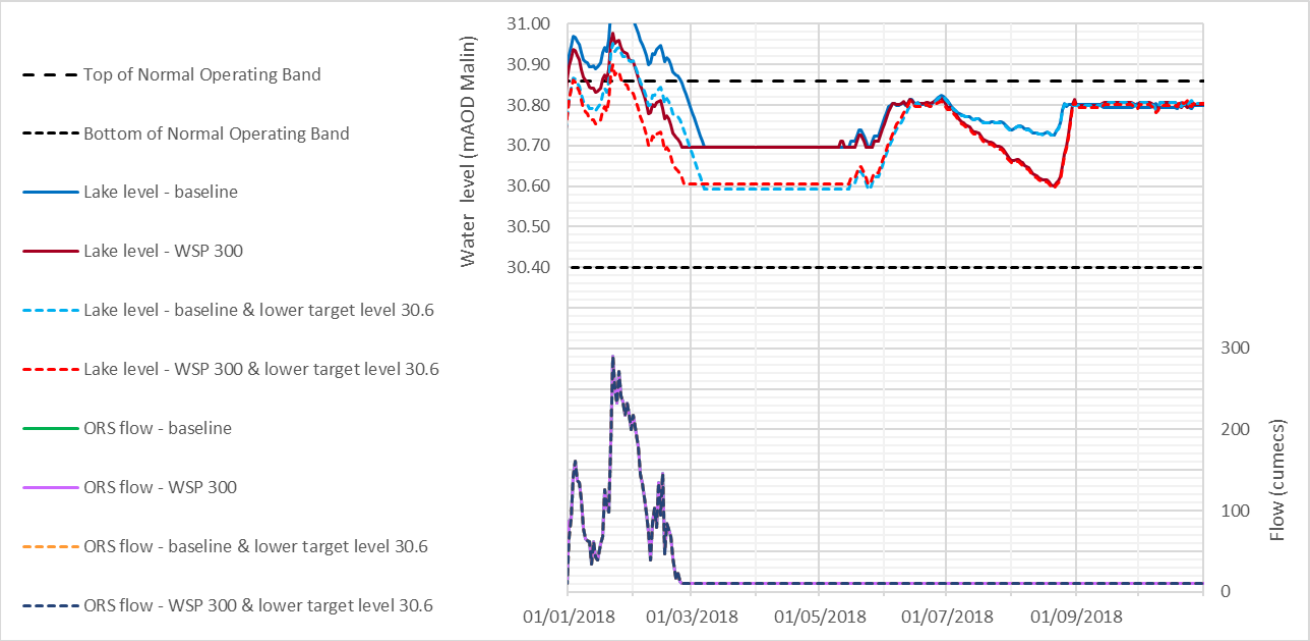

Image G. 6: WSP Impact Sensitivity to Lowering the Lower Target Level from 30.70 to 30.60mAOD

17. When the upper target level (dry period) is raised the WSP impact during the drought is simulated to be of the same size but to occur 0.04m above the levels of the case where the upper target level is 30.80mAOD.

18. Conversely when the lower target level (wet period) is lowered it has no effect upon the impact of the WSP abstraction during the drought period. Given that the WSP impacts are only simulated to occur during drought periods, this suggests that the precise level of the targeted wet period (upper level) average water level between 30.60 and 30.70mAOD does not have an effect upon the WSP impact.

Attachment H. Water Transparency in Lough Derg and Parteen Basin

1. (Reproduction of the report provided by D. Minchin of the Lough Derg Science Group)

Water transparency in Lough Derg and the Parteen Reservoir, Shannon River

Prepared for Dr David Price, Jacobs, 95 Bothwell St, Glasgow G27HX

by

Dan Minchin, *Lough Derg Science Group*, 3 Marina Village, Ballina, Killaloe, Co Clare, Ireland

Research vessel 'Trinity' heading to the Dromaan Deep station, summer 2016

Report: moi: 128/2021 **22 September 2021**

Minchin, D. (2021) Water transparency in Lough Derg and the Parteen Reservoir, Shannon River. *Lough Derg Science Group*, Unpublished Report, 10pp.

Water transparency in Lough Derg and the Parteen Reservoir, Shannon River

Introduction

The Shannon River has a catchment of 17% of the land area of Ireland. The lowest and largest Shannon lake, Lough Derg, is 118 km^2 with extensive shallows and depths measured to 37m, an average depth of 7.5m and a volume of 0.887 km^3 (**Fig. 1**). It has a strongly brown coloured water due to run-off from peatlands thereby reducing water clarity and the depth to which plants can exist. These humic acids are discharged to the oligotrophic Lough Allen, the most northern lake of the Shannon, and from the midland bogs on either side of most of the length of the Shannon. It is unclear whether the extensive period of midlands peat harvesting, used for power, will have influenced water transparency. Water entering the Shannon is buffered from Carboniferous limestone bedrock of varying age and alkaline soils to the east of the mid- to lower Shannon. Shales and sandstones also occur about Lough Derg. Lough Derg generally has a lower conductivity level in the rivers entering the western side of the lake and on the eastern side the rivers are clearer and more alkaline.

The normal range above Ordinance Datum for Lough Derg is 33.32m to 33.70m, a range of 38cm. The water levels in the Parteen Reservoir and Lough Derg are controlled by the regulatory amount of water required to pass over the Parteen Dam for the water flow of the Shannon River and the diversion of a headrace leading to the Ardnacrusha Hydroelectric Installation; and in accordance with the Electricity (Supply)(Amendment) (No. 2) Act, 1934 which is between 110 and 112 feet, a range of 61 cm. The different lake levels, before and after the development of the Ardnacrusha power station in 1929 was approximately three feet (90cm) the previous level for Lough Derg being controlled by the Killaloe weir erected in 1845. Before this date water levels in Lough Derg would have been even lower, with an annual range in 1836 of six foot eight inches (2.03m) (Shannon Commissioners, 1837). The water levels in the Parteen Reservoir and Lough Derg are controlled by the regulatory amount of water required to pass over the Parteen Dam for the water flow of the Shannon River at a minimum of $10m^3$/second with excesses being for the diversion of water *via* a headrace leading to the Ardnacrusha Hydroelectric Dam.

This study provides information on changes in water transparency and reports on the depths of aquatic flowering plants and charophyte and their estimated maximum depths of existence. The impact of the filter-feeding zebra mussel, *Dreissena polymorpha*, and its biomass and likely changes to water transparency are discussed. Possible further changes to water transparency may arise from the further expansion of the Asian clam, *Corbicula fluminea*, and the recently discovered quagga mussel, *Dreissena rostriformis bugensis*.

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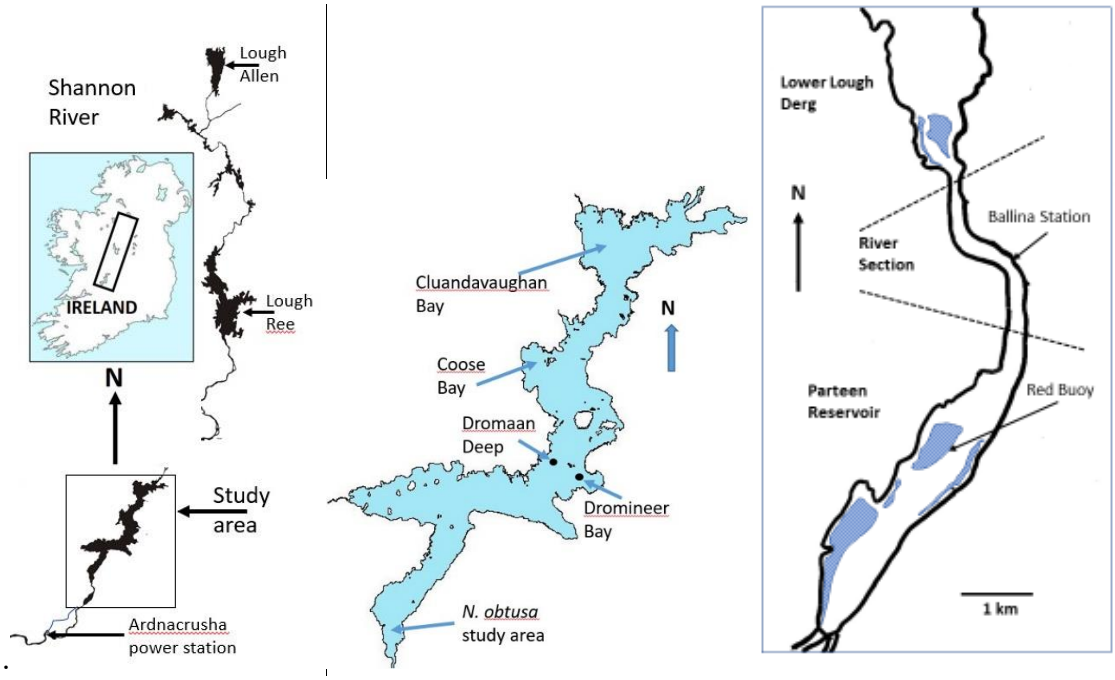

Fig. 1. Lough Derg and main Shannon lakes (left), Lough Derg and sites mention in text (middle), Lower Lough Derg and the Parteen Basin (right) showing meadows of *N. obtuse* (in blue)

Water transparency:

Two stations involved in hydrographic studies by the Lough Derg Science Group are situated in the central region of Lough Derg, in Dromineer Bay (5.5 m depth, 52° 56' 01" N; 08° 17' 39" W) and over the trench of the mid-lake at the Dromaan Deep (24 m depth, 52° 55' 54" N; 08° 19' 53" W) (**Fig 1**). Visual extinction of the Secchi disc were measured to the nearest 0.1m, using a weighted 30cm diameter disc and knotted line. These were taken throughout the year at infrequent intervals to include selected meteorological events. Measurements in winter of low transparency, due to siltation in the water, arises from increased river flow discharging sediments and lower light intensity at this time of year.

A 3 km river section exists between Lough Derg and the Parteen Reservoir (**Fig. 1**). This reservoir is 4.5 km in length and has replaced a shallow river following the building of the Ardnacrusha Dam, which is served by a 12 km long headrace.

Water transparency has varied in Lough Derg according to trophic status and the presence of filter feeding bivalves. Early levels in the 1970s indicate levels of 2 m + with a decline in the early 1990s, most probably as a result of eutrophication (**Table 1**). Subsequently, following the arrival of the zebra mussel the levels of water transparency increased as chlorophyll ɑ levels in summer declined. Summarised Secchi disc measurements taken at the two hydrographic stations provide a total range from 1.0 to 4.0 m with a mean value of 2.6m for years (2006-2016)(**Fig. 2**).

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Table 1. Classification of Lough Derg as being eutrophic based on these features (in: Bowman, 1998)

Year	Total P mg m^{-3} mean	Chlorophyll mg m^{-3} mean	Chlorophyll mg m^{-3} max	Transparency m mean	Transparency M min
1976	25	8.2	24	2.2	0.8
1977	18	6.6	21	2.3	1.5
1978	20	6.8	29	2.1	0.9
1991-2	43	17.0	72	1.7	0.9
1995-6			44		

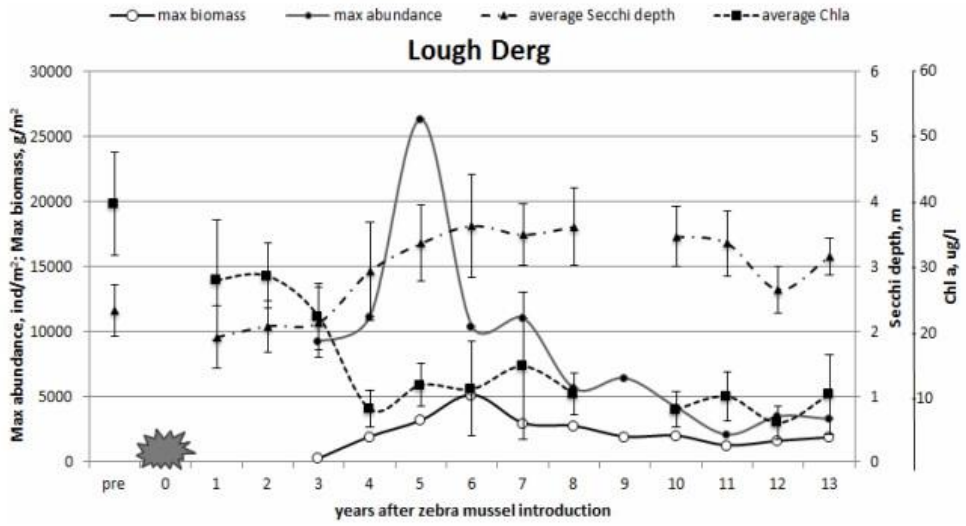

Fig. 2. General trends following the arrival of the zebra mussel (with start date 1994) of water transparency (dashes); Chlorophyll α (dotted); Numbers of mussels (line) and biomass (lower line). From Zaiko *et al.* 2014.

Maximum depths of aquatic flowering plants

Depths were calculated based on the soundings from a Navman 4500 sonar at 200 kHz. Flowering plants were visible down to a maximum depth of 3.2 m on the sounder. These included some with near surface leaves (*Potamogeton* spp.) which would be rooted in the sediment at this depth. Anecdotal, but notable during the late 1990s into the mid-2000s, was the increase in aquatic flowering plants in shallow bays, such as Dromineer Bay and Kilgarvan Harbour. This was consistent with the expansion of zebra mussel biomass.

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Depth distribution of charophytes

The distribution of *N. obtusa* was surveyed using a five-pronged grapnel (overall diameter of 25cm) with a ten-metre non-kink terylene throwing line with a hand loop. A van-Veen grab, 14 cm x 18 cm, was also used. Plants in lower Lough Derg were quantified according to three levels of abundance on retrieval: ***present***, where traces of plants, plant fragment(s); ***common***, entire trailing plants with bulbils; ***abundant***, extensive trailing plants covering all grapnel tines. Also examined was a '*meadow'*, where an extensive stand, in the Parteen Reservoir, was observed using an underwater viewer, only undertaken in shallows. Collections were made from July to December 2016, May and September 2017 and April to August 2018. Depths where samples were taken were determined to 10 cm intervals using a Navman© fish 4500 sonar at 200kHz.

The starry stonewort, a charophyte *Nitellopsis obtusa,* was abundant in the shallows of the southern section of Lough Derg and formed extensive '*meadows*' in the Parteen Reservoir (Minchin *et al.,* 2017) and in the Lower Shannon. Collections are of a perennial female clone. Plants occurred between depths of 1 m and 5 m and could co-occur with aquatic angiosperms in shallower water that include the yellow water lily *Nuphar lutea*, pondweeds *Potamogeton* spp and the non-native Nuttall's waterweed *Elodea nuttalli*. In sheltered shallows of the Parteen Reservoir *N. obtusa* formed extensive meadows in depths of 2.1 m to 4.7 m*.

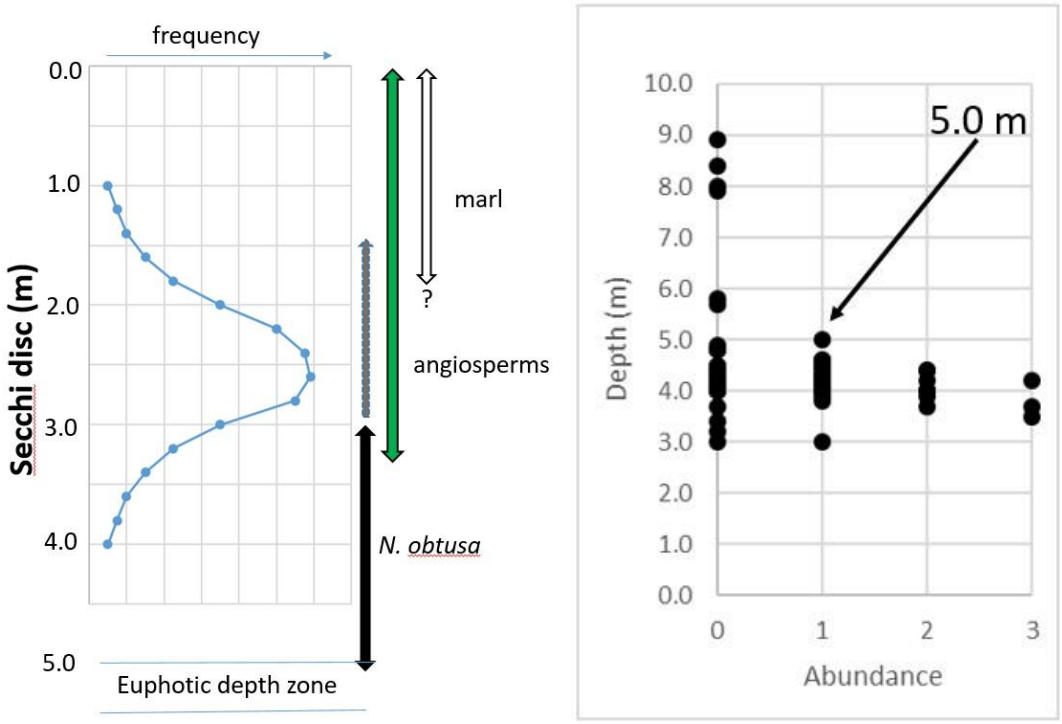

Fig. 3. Relationship of water transparency (smoothed) to plant depth distributions (left). Study of *N. obtusa* in southern Lough Derg, showing low abundance of *N. obtusa* at 5.0 m.

*Note: Until further information becomes available the status of N. obtusa should be classified as a cryptogen, being clearly neither native nor alien.

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Nitellopsis obtusa is extensively distributed within the southern region of Lough Derg and the Parteen Reservoir (**Fig. 2**). It formed meadows of some hectares in the shallows of the western, more sheltered, side of the reservoir at depths of 2.1 to 4.7m and was found in a narrow band along the eastern side at 3.5 to 4.3 m. It was common during April and abundant during August. In the southern region of Lough Derg plants were more scattered (**Fig 2**) and present at 3 to 5m with the greatest abundance between 3.4 and 4.3m (**Fig. 3**). Here thirty-three of the sixty stations had *N. obtusa* and were abundant at five stations and common at six stations.

The depths where charophytes exist will depend on the clarity of the water. Secchi disc measurements have varied during recent decades ranging from a means of 2.2m in 1976, declining to 1.7 m in the early 1990s (Bowman, 1998 – **Table 1**) and since 2010 mean levels

have been ~2.6 m (**Fig. 3**). The recent clearances being due to the filtration ability of zebra mussels (Zaiko *et al.,* 2014), having arrived in 1993/4 (Pollux *et al.,* 2003). Almost fifteen years later the arrival of a further suspension feeder the Asian clam, *Corbicula fluminea,* arrived (Minchin and Boelens, 2018). In the summer of 2018 the maximum Secchi disc measurement of 4.1m was obtained. The prolonged dry summer of 2018 could have reduced the release of discoloured water from bogs. This acid runoff becomes neutralised by limestone within the river and lake. It is interesting to note that charophyte stands have been associated with clearer water by promoting a sedimentation buffer (Blindow, 1992; Van den Berg *et al.,*1998).

Future scenarios

With many impacting biological invasions there are different stages of colonisation, an establishment is followed by expansion to reach a high biomass peak, an outbreak, then a subsequent decline. This has been the pattern of the zebra mussel in Lough Derg, studied over ten years. During the expansion and outbreak phase there was a corresponding increase in water transparency (**Fig. 2**). Based on the literature, and recent surveys, the Asian clam is expected to continue to expand its range and density in Lough Derg; The expansion of this clam is comparatively slow due to the lack of a pelagic larval phase. This is because young clams are brooded within adult gill pouches and released as miniature forms of the adults. These young clams do have the capability of spreading by producing a byssal thread which acts as a drag-line. The lake currents distribute these young clams principally along the main axis of the lake. It has not yet reached the Parteen Reservoir; but this is expected in time.

The third impacting species, the quagga mussel, has a pelagic larva, like the zebra mussel, and consequently can spread more rapidly (Strayer *et al.,* 2019). While presently occurring at low levels in Lough Derg its expansion in the next few years is of particular concern. Already this species has become locally abundant in the upstream lake of Lough Ree.

6

Minchin, D. (2021) Water transparency in Lough Derg and the Parteen Reservoir, Shannon River. *Lough Derg Science Group*, Unpublished Report, 10pp.

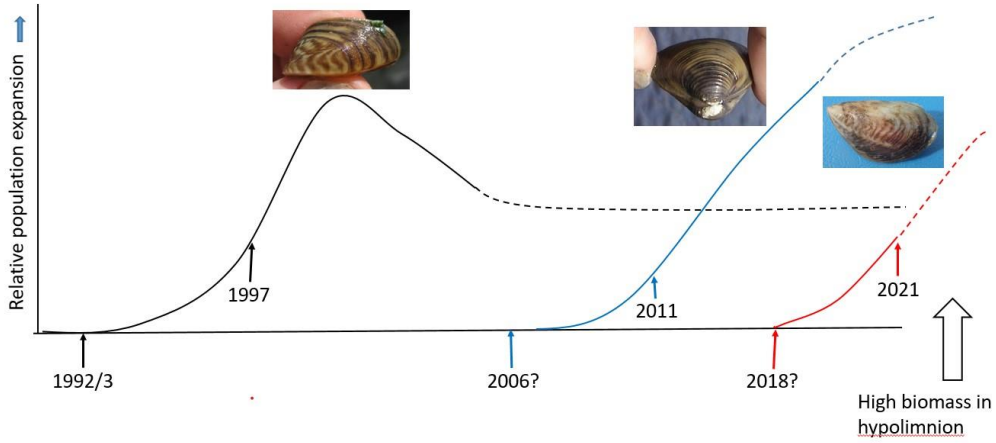

Fig. 4. Scheme of succession of invasive filter feeding bivalve biomass trends with dotted lines indicating future predictions for two species. Left to right the zebra mussel *D. polymorpha* (dotted line indicating general trend, when not fully surveyed); The Asian clam *C. fluminea* and the quagga mussel *D. rostriformis bugensis* (Baars *et al.,* 2021). Possible arrival dates and dates of first recognition indicated with arrows. Accumulation of biomass indicated.

Such predicted increases in range and density of these recent invaders are likely to take place to all depths within the lake, leading to a greater biomass within the hypolimnion (**Fig. 4**). While circulation within the lake is generally due to wind mixing, prolonged periods of calm weather with high solar insolation, as can occur during an anticyclone event leading to declines in oxygen within the hypolimnion. We have noted a separation of the water column during an anticyclone event in 2013 (**Fig. 5**). During anticyclone events we have noted progressive declines in oxygen. As these species are intolerant of extended low oxygen levels a de-oxygen event might take place during an extended anticyclone.

We can predict with some confidence that the combined biomass of the filter feeders is likely to lead to further increases in clarity. However, following the cessation of commercial peat harvesting for fuel the drainage from peatlands may result in additional spectrophotometric changes to water colour.

7

Minchin, D. (2021) Water transparency in Lough Derg and the Parteen Reservoir, Shannon River. *Lough Derg Science Group*, Unpublished Report, 10pp.

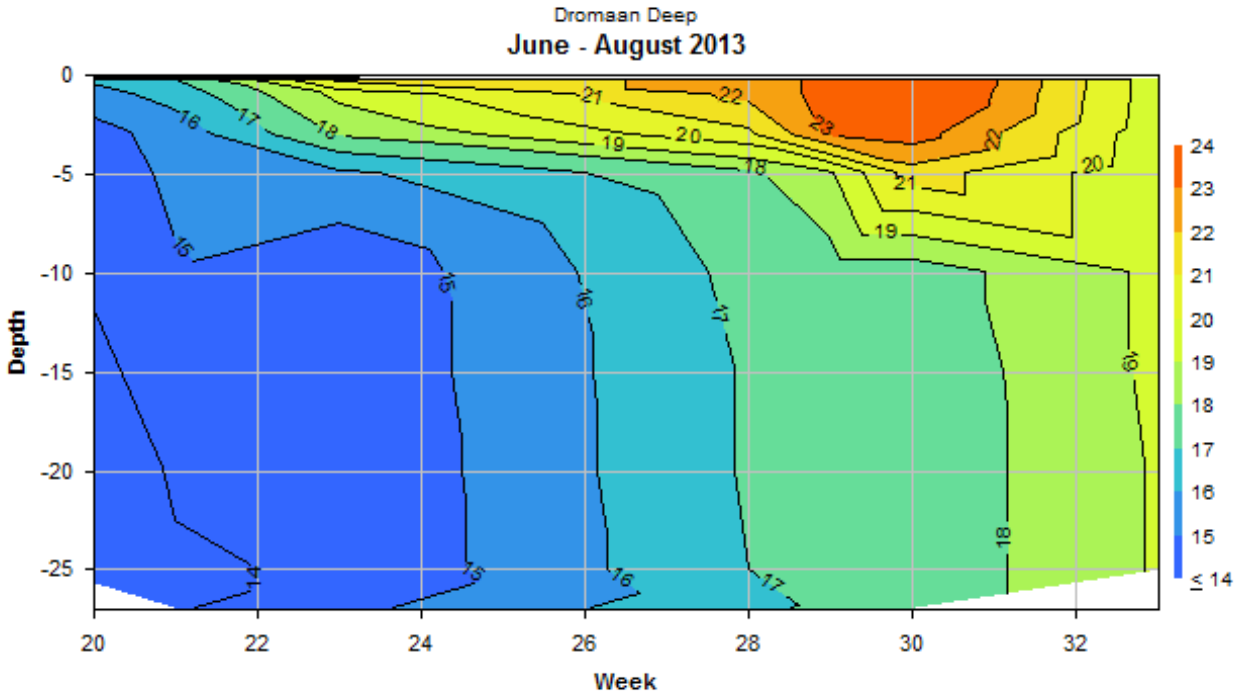

Fig. 5. Vertical temperature profile of temperature. Central region of Lough Derg during the summer of 2013 (from Minchin et al. 2016)

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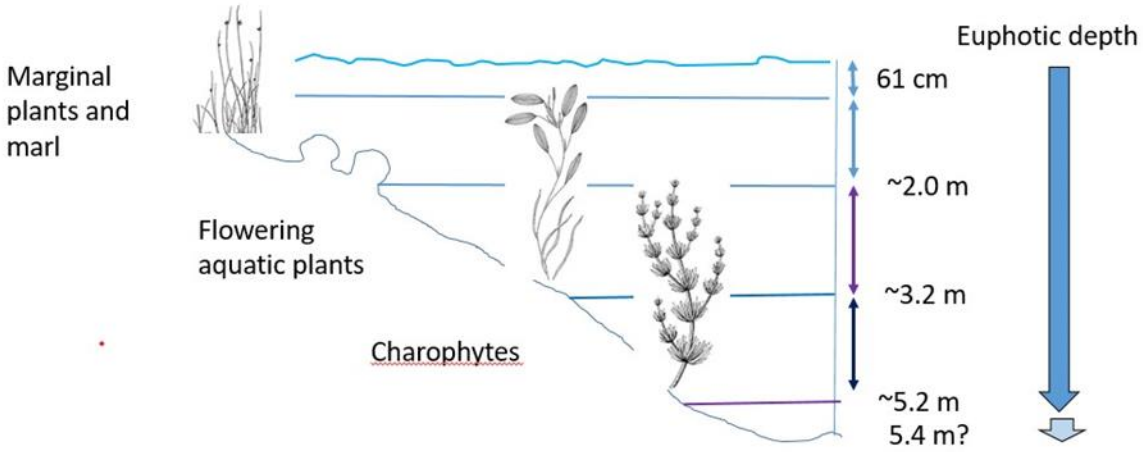
Minchin, D. (2021) Water transparency in Lough Derg and the Parteen Reservoir, Shannon River. *Lough Derg Science Group*, Unpublished Report, 10pp.

Conclusive remarks

The estimate of euphotic depth during the recent years 2016 to 2018 was based on grab and grapnel samples of charophytes taken at sites where sounder depth was recorded. The eutrophic depth measurement will depends upon the water level within the lake (and reservoir) at the time of the study. These levels are generally low during the summer and early autumn when these studies took place. The lowest depth level in the Parteen Reservoir for *N. obtusa* was 4.7 m; however, the maximum depth of this charophyte was not sought in the Parteen reservoir. In the lower part of Lough Derg *N. obtusa* was found to 5.0 m and this would approximate to a likely euphotic depth. This plant is perennial in Lough Derg and as a result this maximum recorded depth is likely to be representative for this species. As the passage of water from the lower region of Lough Derg to the Parteen Reservoir is about 3 km+, the water quality would not be expected to greatly change between these two sites. While it is not certain *N. obtusa* is fully representative for a charophyte for Lough Derg because there are depth preferences for different charophyte species. During 2021, the charophyte c.f. *Nitella flexilis* was present at 5.4 m in Coose Bay and in Cluandavaun Bay at 4.2 m. Future changes to euphotic depth may be influenced by the almost certain increase of non-native bivalves. There may be additional changes from a reduction of commercial peat harvesting thereby reducing the volume of humic acids entering the watercourse, and there is an uncertain effect of a de-oxygenation turn-over event, should this take place.



Summary of general vertical distributions of plants within Lough Derg.

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Minchin, D. (2021) Water transparency in Lough Derg and the Parteen Reservoir, Shannon River. *Lough Derg Science Group*, Unpublished Report, 10pp.

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Attachment I. Application of the UKTAG WFD Lake Level Test to Lough Derg and Parteen Basin

I.1 Water Framework Directive Lake Level Test

I.1.1 Introduction

1. This Attachment describes the application of the UK Water Framework Directive (WFD) lake level test to Lough Derg and to Parteen Basin. The UK test is used as there is not yet an Irish test for impacts of flow regime change of lake water bodies available. The project discussed this with the Environment Protection Agency (EPA), and it was agreed that there would be merit in applying the UK approach, as documented in the UK Technical Advisory Group (UKTAG) River Basin Management (2015 – 21) report[53], as a surrogate WFD means of assessing the environmental impact of level changes resulting from the proposed WSP abstraction.

2. The UKTAG report identifies:

    - The ecological quality of lakes can be significantly affected by changes to the quality and extent of shallow water through which sunlight can penetrate to the lakebed. This is because this habitat, known as the littoral zone, has a particularly productive ecology, supporting rooted plants and bottom-living algae. The depth to which light penetrates depends on the clarity of the water but generally falls into the range from 1 to 10 metres. The depth of light penetration in peaty lakes is typically much less than in clear water lakes

    - Lowering the water levels in lakes can change the area of the littoral zone and impact upon other lake habitats such as through the settling of resuspended sediment on aphotic habitats below the littoral zone. It can also change the quality of the habitat by increasing the extent of very shallow areas exposed to the erosive effects of wave action.

3. The current guidance from UKTAG stipulates that the standards for which lakes should be assessed under the WFD, should be specified directly in terms of any change in lake habitat area (the littoral zone).

I.1.2 Methodology

4. The UKTAG lake standards are presented in Table I.1.

Table I.1: Standards for the Effect of Water Level Changes on Lake Surface Area

Daily Maximum Percentage Reductions in Lake Surface Area in 99 Percent of Days in Any Year			
High	Good	Moderate	Poor
1	5	10	20
Lake surface area means, for any day, (a) the area under the reference conditions of the lake's surface that would overly water from the shore out to 5 metres deeper than the depth to which light penetration to the lake bed would be sufficient, under those conditions, to enable the growth of rooted plants or bottom-living algae; or (b), if the deepest part of the lake is shallower than this, the whole area of the lake's surface, under reference conditions. The lake habitat extends 5m below the zone of light penetration to account for impacts on the aphotic habitat. Reference conditions means the absence of any abstractions or discharges* that could affect the surface area of the lake. For the purposes of setting a maximum allowable abstraction, it is recommended that reference conditions should be representative of the current standard UK Meteorological Office climate reference period (currently 1981 to 2010). In terms of determining the depth of light penetration, reference conditions should be determined in habitats where water clarity is not affected by water quality impacts such as eutrophication. In the absence of field data to the contrary, the depth to which light penetration to the lakebed is sufficient to enable the growth of rooted plants or bottom-living algae may be taken to be 2 metres for lakes with the geological sub-type of "peat" and 7 metres for all other lake types. A lake is considered to have the sub-type of “peat” where (i) its mean water colour is more than 90 hazen units; or (ii), where information on colour is unavailable, more than 75 % of the soils of its catchment area are comprised of peat.			

[53] UKTAG (2013) Updated recommendations on Environmental Standards, River Basin Management (2015-21) [http://www.wfduk.org/sites/default/files/Media/Environmental%20standards/UKTAG%20Environmental%20Standards%20Phase%203%20Final%20Report%2004112013.pdf]

*For lakes designated as heavily modified for water storage, “reference conditions” may be taken to mean the regime as (a) altered by the use for which the lake has been designated; and (b) with all mitigation measures that can be put in place without a significant adverse impact on the use or the wider environment.

5. Image I.1 (reproduced from the UKTAG guidance) schematically represents a lake where its water level has been lowered for a particular day (d). For each day a percentage reduction in lake surface area is calculated.

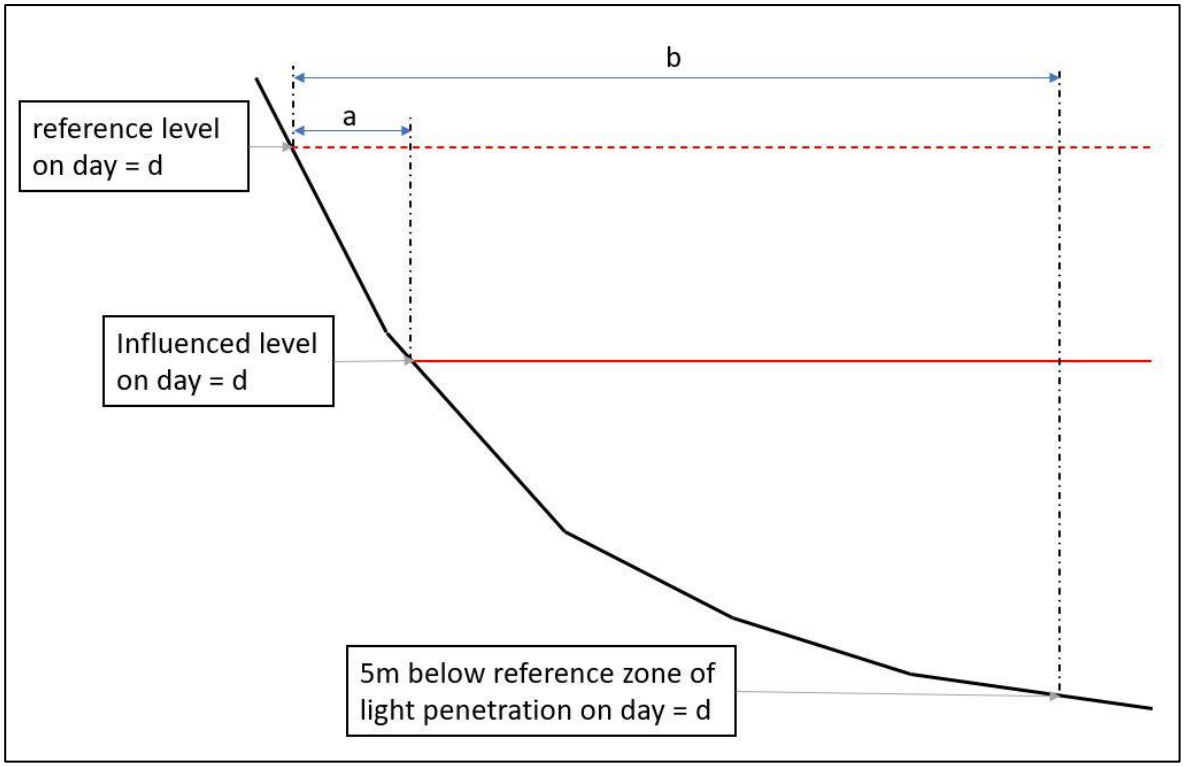

Image I.1: Schematic Representation of a Lake Where Level has been Lowered on Day = d

6. The percentage reduction in lake surface area on day d is given by the equation:

$$100 \times \frac{a}{b}$$

7. Where:
   - “a” is the difference between “b” and the area of the lake on day “d” as affected by abstraction pressures
   - “b” is the lake surface area that the lake would have on day “d” under reference conditions
   - “Lake surface area” means the area of the lake water surface beneath which the depth of water is no more than 5 metres deeper than the maximum depth to which light would penetrate under reference conditions.

8. The recommended standards stipulate the percentage reduction in area that may not be exceeded for more than 1% of days in any one year.

9. To undertake the assessment the following input data are required:
   1) Daily lake water levels for period (1972-2023 for this analysis) under reference conditions
   2) Daily lake water levels for period (1972-2023 for this analysis) under abstraction pressures
   3) Bathymetric survey data for both Lough Derg and for Parteen Basin

4) The euphotic depth for both water bodies (euphotic depth = depth to where sufficient light penetrates to enable photosynthesis).

I.1.3 Application of Method

10. Bathymetric survey data for both Parteen Basin[54] and Lough Derg[55] was provided during the initial phase of the Proposed Project. The bathymetric data was used to derive a level-area relationship at 1m intervals between levels of 9mAOD [Malin} to 30.86mAOD [Malin] as illustrated in Image I.2 and Image I.3 with the level-area relationships shown in Table I.2 and Table I.3.

Table I.2: Parteen Basin Level-Area Relationship

Level (mAOD [Malin])	Area (m^2)
30.86	3,616,243
28.00	2,681,232
27.00	2,354,138
26.00	1,770,318
25.00	950,046
24.00	637,645
23.00	486,088
22.00	395,034
21.00	280,090
20.00	233,264
19.00	185,515
17.00	78,320
15.00	15,522
13.00	6,248
11.00	1,797
9.00	329

[54] ParteenMesh.jpg, received from MarCon Computations International (March 2021)

[55] Geomara (2015) Report of Survey, Lough Derg Hydrographic Survey, Ireland

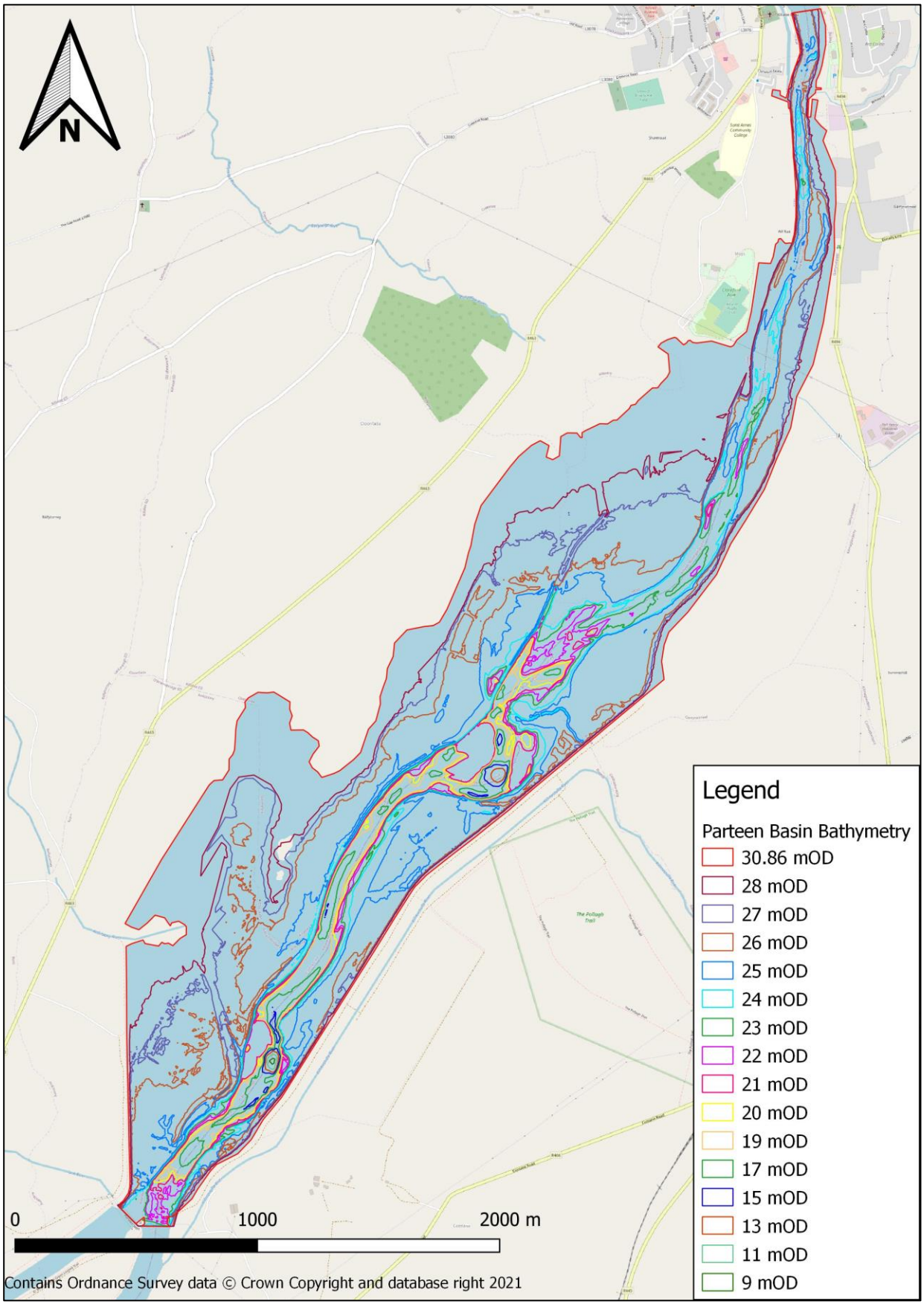

Image I.2: Parteen Basin Bathymetry

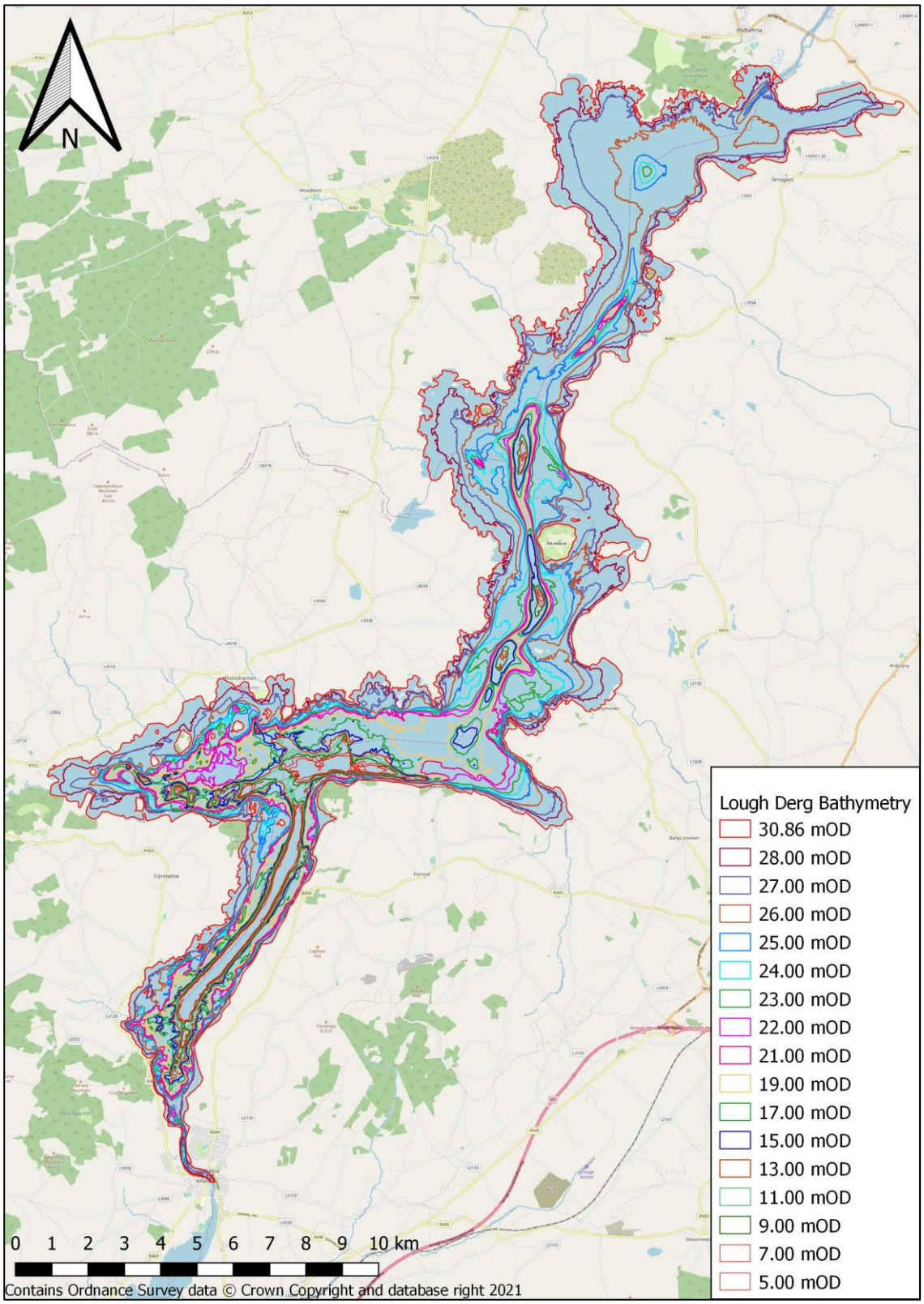

Image I.3: Lough Derg Bathymetry

Table I.3: Lough Derg Level-Area Relationship

Level (mOD)	Area (m^2)
30.86	116,440,162
28.00	95,568,853
27.00	80,776,040
26.00	63,473,907
25.00	49,153,528
24.00	41,855,435
23.00	35,592,444
22.00	31,367,811
21.00	28,292,184
19.00	20,708,549
17.00	14,705,313
15.00	10,838,010
13.00	7,218,409
11.00	5,727,281
9.00	4,915,151
7.00	3,585,577
5.00	2,596,691

11. The long-term daily levels (1972-2023) used in the UKTAG WFD lake level test are those that are obtained from the hydrological modelling for the baseline case (without WSP abstraction) and for the case with WSP abstraction. Two constant WSP abstraction scenarios were investigated:

    1) 154Mld
    2) 300Mld.

12. The euphotic depths for Lough Derg and Parteen Basin are required to determine the depth at which light is able to penetrate through water to the lakebed. Based upon monitoring data the Lough Derg and Parteen Basin euphotic depths are both estimated[56] to be 5m (Attachment H).

13. A spreadsheet model was developed to calculate the percentage reduction of the lake surface area, in which full lake areas are interpolated from the level-area relationships given in Table I.2 and Table I.3.

Results

14. Results of the WFD lake tests undertaken using the output from the WSP hydrological model[57] are presented in Table I.4, Table I.5 and Table I.6. Only those values that exceed the thresholds given in Table I.1 are given, values that are less than 1% change are simply indicated as being <1.

[56] Minchin, D (2021) Water transparency in Lough Derg and Parteen Reservoir, Shannon River. Lough Derg Science Group, Unpublished Report.

[57] The final version of the WSP hydrological model build has previously been referred to as the “Operational Principles Model” to differentiate it to the initial “Historical Model” build.

Table I.4: UKTAG WFD Lake Test Results for Both Lough Derg and Parteen Basin – Based on Simulated Levels from the WSP Hydrological Model

Year	Days/year	Percentage Reduction in Lake Surface Area* Equalled or Exceeded for 1% of the Days in the Year			
		WSP 154Mld		WSP 300Mld	
		Lough Derg	Parteen Basin	Lough Derg	Parteen Basin
1972	366	<1	<1	<1	<1
1973	365	<1	<1	<1	<1
1974	365	<1	<1	<1	<1
1975	365	<1	<1	<1	<1
1976	366	<1	<1	<1	<1
1977	365	<1	<1	<1	<1
1978	365	<1	<1	<1	<1
1979	365	<1	<1	<1	<1
1980	366	<1	<1	<1	<1
1981	365	<1	<1	<1	<1
1982	365	<1	<1	<1	<1
1983	365	<1	<1	<1	<1
1984	366	<1	<1	<1	<1
1985	365	<1	<1	<1	<1
1986	365	<1	<1	<1	<1
1987	365	<1	<1	<1	1.17
1988	366	<1	<1	<1	1.14
1989	365	<1	<1	<1	<1
1990	365	<1	<1	<1	<1
1991	365	<1	<1	<1	<1
1992	366	<1	<1	<1	<1
1993	365	<1	<1	<1	<1
1994	365	<1	<1	<1	1.17
1995	365	<1	<1	1.06	1.26
1996	366	<1	<1	<1	<1
1997	365	<1	<1	<1	<1
1998	365	<1	<1	<1	<1
1999	365	<1	<1	<1	<1
2000	366	<1	<1	1.13	1.34
2001	365	<1	<1	<1	<1
2002	365	<1	<1	<1	1.19
2003	365	<1	<1	<1	<1
2004	366	<1	<1	<1	<1
2005	365	<1	<1	<1	<1
2006	365	<1	<1	<1	<1
2007	365	<1	<1	<1	1.16
2008	366	<1	<1	<1	1.09
2009	365	<1	<1	<1	<1
2010	365	<1	<1	<1	<1

Year	Days/year	Percentage Reduction in Lake Surface Area* Equalled or Exceeded for 1% of the Days in the Year			
		WSP 154Mld		WSP 300Mld	
		Lough Derg	Parteen Basin	Lough Derg	Parteen Basin
2011	365	<1	<1	<1	<1
2012	366	<1	<1	<1	<1
2013	365	<1	<1	1.07	1.28
2014	365	<1	1.07	1.44	1.71
2015	365	<1	<1	<1	<1
2016	366	<1	1.19	2.00	2.37
2017	365	<1	<1	<1	<1
2018	365	<1	<1	1.18	1.40
2019	365	<1	<1	<1	<1
2020	366	<1	<1	<1	1.06
2021	365	<1	<1	1.01	1.21
2022	365	<1	<1	<1	<1
2023	304	<1	<1	<1	<1

* The percentage reduction of the area of the lake water surface beneath which the depth of water is no more than 5 metres deeper than the maximum depth to which light would penetrate under reference conditions.

15. Lough Derg (Derg TN) has Moderate WFD status and Parteen Basin (Derg HMWB) has Good WFD status (2016-2021). As Parteen Basin is classified as a heavily modified water body (HMWB), the water body has an objective to achieve Good Ecological Potential (GEP) rather than Good Ecological Status (GES). However, for the purpose of presenting the application of the UKTAG test on the two water bodies, the results focus on achieving the WFD Good status lake standard. See Appendix A9.1 (Abstraction Assessment) for more details on the ongoing HMWB designation process in Ireland and GEP requirements.

16. The recommended standards (Table I.1) stipulate the percentage reduction in area that may not be exceeded for more than 1% of days in any one year. The 5% change in lake surface area threshold for WFD Good status standards is not exceeded in any scenario across the 52-year simulation period.

17. Based on the UKTAG WFD criteria (Table I.1) the following standards are met for the two WSP abstraction rates:

    - A constant WSP abstraction of 154Mld results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
    - A constant WSP abstraction of 300Mld results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard.

18. It is noted that the amount by which the 300Mld abstraction breaks the 1% change in lake surface area threshold is simulated to be small, i.e. the Good status range is from 1% to 5% reduction in lake surface area and the values for the one year where the threshold is broken only reach up to a reduction of 2.37%.

19. The UK guidance recommends that the reference conditions should be representative of the current standard UK Meteorological Office climate reference period (which at the time of writing the guidance was the 30-year period 1981-2010). Rather than fixing the above assessment to a fixed period the approach has been to consider its application on all years of available data (52 years). The choice of a 30-year period[58] fixed to the UK standard periods seems somewhat arbitrary and the results have therefore not been presented based upon that exact 30-year period. It could be argued that the analysis should be

[58] Climatologists traditionally use a 30-year period of data to characterise a climate as it is considered sufficiently long to capture the natural variability of the climate at the time.

undertaken on the last 30-year period (1994-2023) to be most representative of the current conditions rather than the 52-year period of data available. If this were done it would still result in the same WFD standard outcomes.

20. The results of the UKTAG WFD lake level test including simulated lake levels from the WSP hydrological model with the 2080s climate change impacts scenario are given in Table I.5. Similar standards are met for the two WSP abstraction rates, viz:

    - A constant WSP abstraction of 154Mld with projected "reasonable worst case" climate change allowances (2080s Lower scenario) results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
    - A constant WSP abstraction of 300Mld with projected "reasonable worst case" climate change allowances (2080s Lower scenario) results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard.

Table I.5: UKTAG WFD Lake Test Results for Both Lough Derg and Parteen Basin – Based on Simulated Levels from the WSP Hydrological Model Including Climate Change Impacts

Year	Days/year	Percentage Reduction in Lake Surface Area* Equalled or Exceeded for 1% of the Days in the Year			
		WSP 154Mld & CC 2080s Lower		WSP 300Mld & CC 2080s Lower	
		Lough Derg	Parteen Basin	Lough Derg	Parteen Basin
1972	366	<1	<1	<1	<1
1973	365	<1	<1	<1	<1
1974	365	<1	<1	1.03	1.22
1975	365	<1	<1	<1	<1
1976	366	<1	<1	<1	<1
1977	365	<1	<1	<1	<1
1978	365	<1	<1	<1	<1
1979	365	<1	<1	<1	<1
1980	366	<1	<1	<1	1.06
1981	365	<1	<1	<1	<1
1982	365	<1	<1	<1	<1
1983	365	<1	<1	<1	<1
1984	366	<1	<1	1.13	1.34
1985	365	<1	<1	<1	<1
1986	365	<1	<1	<1	<1
1987	365	<1	<1	<1	<1
1988	366	<1	<1	1.13	1.35
1989	365	<1	<1	<1	1.11
1990	365	<1	<1	<1	1.13
1991	365	<1	<1	<1	<1
1992	366	<1	<1	<1	<1
1993	365	<1	<1	<1	<1
1994	365	1.11	1.32	1.37	1.63
1995	365	<1	<1	1.41	1.68
1996	366	<1	<1	<1	<1
1997	365	<1	<1	<1	<1
1998	365	<1	<1	<1	<1

Year	Days/year	Percentage Reduction in Lake Surface Area* Equalled or Exceeded for 1% of the Days in the Year			
		WSP 154Mld & CC 2080s Lower		WSP 300Mld & CC 2080s Lower	
		Lough Derg	Parteen Basin	Lough Derg	Parteen Basin
1999	365	<1	<1	1.02	1.21
2000	366	<1	<1	<1	<1
2001	365	<1	<1	<1	<1
2002	365	<1	<1	1.10	1.31
2003	365	<1	<1	<1	<1
2004	366	<1	<1	<1	<1
2005	365	<1	<1	<1	<1
2006	365	<1	<1	1.06	1.27
2007	365	<1	<1	1.13	1.34
2008	366	<1	<1	1.01	1.21
2009	365	<1	<1	<1	<1
2010	365	<1	<1	<1	<1
2011	365	<1	<1	<1	<1
2012	366	<1	<1	<1	1.04
2013	365	<1	<1	<1	1.19
2014	365	<1	1.05	1.47	1.75
2015	365	<1	<1	<1	1.03
2016	366	<1	1.17	1.82	2.17
2017	365	<1	<1	<1	<1
2018	365	<1	<1	1.56	1.86
2019	365	<1	<1	<1	<1
2020	366	<1	<1	1.03	1.22
2021	365	<1	<1	1.22	1.45
2022	365	<1	<1	<1	<1
2023	304	<1	<1	<1	<1

* The percentage reduction of the area of the lake water surface beneath which the depth of water is no more than 5 metres deeper than the maximum depth to which light would penetrate under reference conditions.

21. The results of the UKTAG WFD lake level test including simulated lake levels from the WSP hydrological model with the proposed Old River Shannon (ORS) Eflows release regime sensitivity (and including climate change) are given in Table I.6. Similar standards are met for the two WSP abstraction rates, viz:

    - A constant WSP abstraction of 300Mld with a proposed ORS Eflows release regime sensitivity results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard
    - A constant WSP abstraction of 300Mld with a proposed ORS Eflows release regime sensitivity and including projected “reasonable worst case” climate change allowances (2080s Lower scenario) results in both the water bodies meeting the lake level requirements for the WFD Good status (Potential) standard.

Table I.6: UKTAG WFD Lake Test Results for Both Lough Derg and Parteen Basin – Based on Simulated Levels from the WSP Hydrological Model Including the ORS Proposed Eflows Regime and Climate Change Impacts

Year	Days/year	Percentage Reduction in Lake Surface Area* Equalled or Exceeded for 1% of the Days in the Year			
		WSP 300Mld & Eflows		WSP 300Mld & Eflows & CC 2080s Lower	
		Lough Derg	Parteen Basin	Lough Derg	Parteen Basin
1972	366	<1	<1	<1	<1
1973	365	<1	<1	<1	<1
1974	365	<1	1.10	<1	<1
1975	365	<1	<1	<1	<1
1976	366	<1	<1	<1	<1
1977	365	<1	<1	<1	<1
1978	365	<1	<1	<1	<1
1979	365	<1	<1	<1	<1
1980	366	<1	<1	<1	<1
1981	365	<1	<1	<1	<1
1982	365	<1	<1	<1	<1
1983	365	<1	<1	<1	<1
1984	366	<1	<1	<1	<1
1985	365	<1	<1	<1	<1
1986	365	<1	<1	<1	<1
1987	365	<1	<1	<1	<1
1988	366	<1	1.18	1.19	1.41
1989	365	<1	<1	<1	1.14
1990	365	<1	1.12	<1	1.17
1991	365	<1	<1	<1	<1
1992	366	<1	<1	<1	<1
1993	365	<1	<1	<1	<1
1994	365	1.12	1.33	1.13	1.34
1995	365	1.17	1.39	1.30	1.55
1996	366	<1	<1	<1	<1
1997	365	<1	<1	<1	<1
1998	365	<1	<1	<1	<1
1999	365	<1	<1	<1	<1
2000	366	1.22	1.45	<1	1.02
2001	365	<1	<1	<1	<1
2002	365	1.12	1.34	1.11	1.32
2003	365	<1	<1	<1	<1
2004	366	<1	<1	<1	<1
2005	365	<1	<1	<1	<1
2006	365	<1	<1	1.10	1.31
2007	365	1.03	1.23	1.13	1.34
2008	366	<1	<1	<1	1.06
2009	365	<1	<1	<1	<1
2010	365	<1	<1	<1	<1

Year	Days/year	Percentage Reduction in Lake Surface Area* Equalled or Exceeded for 1% of the Days in the Year			
		WSP 300Mld & Eflows		WSP 300Mld & Eflows & CC 2080s Lower	
		Lough Derg	Parteen Basin	Lough Derg	Parteen Basin
2011	365	<1	<1	<1	<1
2012	366	<1	1.04	<1	1.10
2013	365	<1	<1	1.13	1.34
2014	365	1.78	2.11	1.50	1.79
2015	365	<1	<1	<1	<1
2016	366	2.28	2.72	1.91	2.27
2017	365	<1	<1	<1	<1
2018	365	1.15	1.37	1.60	1.92
2019	365	<1	<1	<1	<1
2020	366	<1	1.12	<1	1.14
2021	365	<1	<1	1.05	1.25
2022	365	<1	<1	<1	<1
2023	304	<1	<1	<1	<1

* The percentage reduction of the area of the lake water surface beneath which the depth of water is no more than 5 metres deeper than the maximum depth to which light would penetrate under reference conditions.

Conclusion

22. Application of the UKTAG WFD lake level standard test gives the following outcome:

    - A constant WSP abstraction of 154Mld results in both the water bodies (Lough Derg and Parteen Basin) meeting the lake level requirements for the WFD Good status (Potential) standard
    - A constant WSP abstraction of 300Mld results in both the water bodies (Lough Derg and Parteen Basin) meeting the lake level requirements for the WFD Good status (Potential) standard.

23. Inclusion of the future “reasonable worst case” climate change impacts and/or proposed ORS Eflows regime sensitivity analyses results in both the water bodies still meeting the lake level requirements for the WFD Good status (Potential) standard for a constant WSP abstraction of 154Mld or 300Mld.

Tionscadal Soláthair Uisce
Water Supply Project

Environmental Impact Assessment Report (EIAR)

Volume 6 of 6: Appendices

(Appendix A9.1 Annex B) Water Quality Modelling Report

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Water Supply Project – East & Midlands Region

DA2: Hydrodynamic and Water Quality Modelling

EIAR Scenario Modelling

Final Report

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1. Introduction

As part of the Water Supply Project – East and Midlands Region (WSP) project, MarCon Computations International were tasked with the Stage Deliverables Abstraction (DA) work package DA2: Hydrodynamic and Water Quality Model of Lough Derg.

This report details the scenarios modelled for the purposes of reporting on the predicted environmental impacts on the water quality of Lough Derg and Parteen Basin because of the proposed abstraction in Parteen Basin.

2. Model Development

This section provides an overview of the development of the three dimensional hydrodynamic and water quality model of Lough Derg and Parteen Basin study area. For full details please refer to the previous Model Calibration Report[1], and Model Recalibration Report in Appendix I.

2.1. Bathymetry

The modelled study area extends from Portumna Bridge at the north of Lough Derg to Parteen Weir / Ardnacrusha Headrace in the south. The bathymetry of the study area was provided by Geomara who completed the bathymetric survey of Lough Derg and Parteen Basin in August 2015. The bathymetric dataset was loaded into the MIKE3 Flexible Mesh Generator along with the EPA's Water Framework Directive GIS shapefiles of Lough Derg and Parteen Basin. The computational grid mesh was then generated by the MIKE3 software, as presented in Figure 1.

2.2. Boundary Locations

The main in-flowing boundary specified to the model was the River Shannon, entering the study area in the north through Portumna Bridge. One out-flowing boundary was specified in Parteen Basin representing the combined outflow through Parteen Weir and down the Ardnacrusha Headrace in the south of the study area. Water level boundary conditions were also specified at both Portumna Bridge and Parteen Weir/Ardnacrusha Headrace.

Twenty-one additional inflowing boundaries were specified, representing the rivers and streams draining the catchments surrounding Lough Derg and Parteen Basin. The locations of the twenty-one river catchments are shown in Figure 2.

Recorded meteorological boundary conditions were specified to the model. The model accounts for wind induced circulation patterns due to variations in wind speed and direction, effects of evaporation and precipitation, and thermal stratification due to solar radiation effects.

Recorded water quality concentrations for the twenty-one in-flowing rivers and streams draining the catchments surrounding Lough Derg and Parteen Basin were specified to the model. Where recorded data was not available for some of the smaller rivers, constant ambient concentrations were specified.

[1] MarCon Computations International, 2017. Water Supply Project – East & Midlands Region DA2: Hydrodynamic and Water Quality Modelling DA2.2: Model Calibration Report. Document Reference: G201301_doc005_04

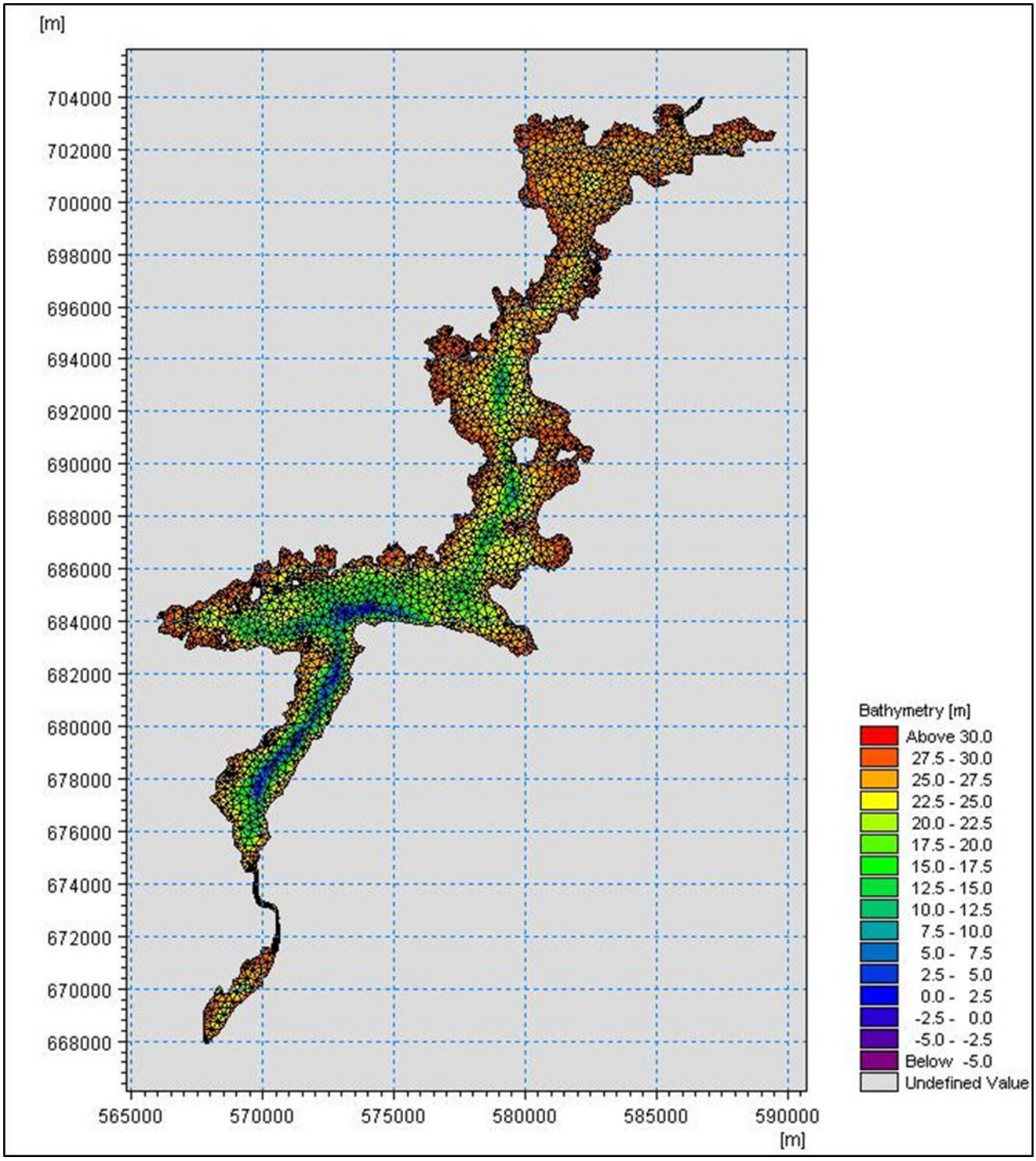


Figure 1: Computational model mesh superimposed on bathymetry (above Ordnance Datum Malin Head)

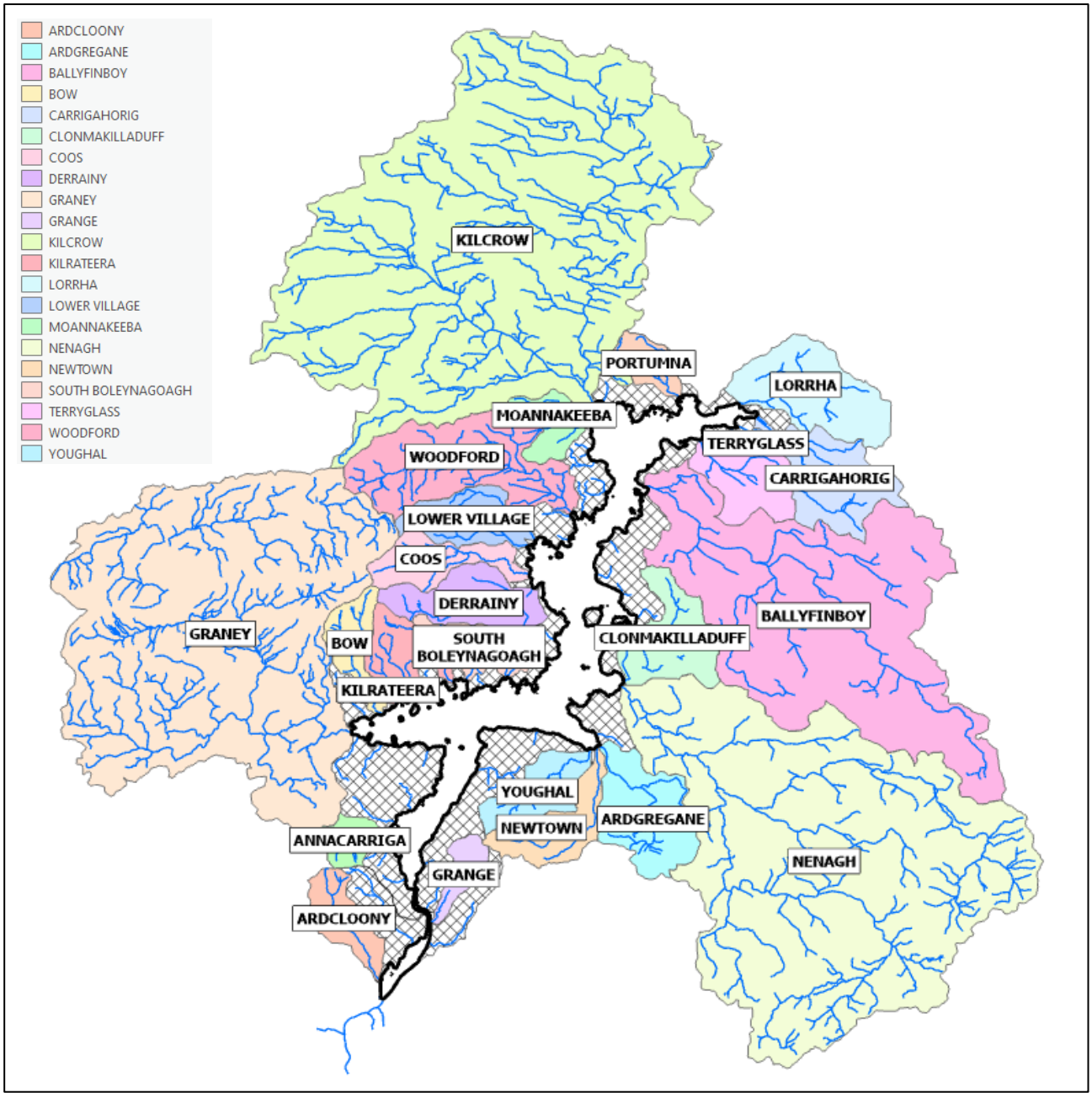


Figure 2: Locations of twenty-one in-flowing river catchment boundaries.

3. Model Calibration

This section provides an overview of the original calibration of the hydrodynamic and water quality components of the three-dimensional model of Lough Derg and Parteen Basin. For full details please refer to the Model Calibration Report [2].

3.1. Hydrodynamics

The hydrodynamic model calibration was undertaken over the period 01/03/2016 to 31/12/2016 as this period contained coincident recorded datasets for all model boundary forcing conditions. The model predictions were compared against recorded datasets from instruments deployed within Lough Derg as part of the hydrographic survey campaign.

3.1.1. Water Surface Levels

The water surface levels predicted by the model were compared against three water level recorders located at Coolbawn Marina towards the north of the lough, Garrykennedy Marina in the centre of the lough, and Kincora Marina towards the south of the lough.

Over the course of the model calibration period, the model simulated the recorded water levels at Coolbawn Marina to within ±0.05 m for 90% of the time, at Garrykennedy Marina to within ±0.05 m for 93% of the time, and at Kincora Marina to within ±0.05 m for 86% of the time.

3.1.2. Water Currents

The water current speeds and velocity vectors (east-west component and north-south component) predicted by the model were compared against two of the three vertical Acoustic Doppler Current Profiler (ADCP) recorders in Lough Derg.

At both the OL02 and OL09 ADCP locations the modelled current vectors show very good agreement with the recorded current vectors, with changes in the direction and magnitude of the flow occurring at the same times. Calibration of modelled currents against the OL15 ADCP was not undertaken as the data quality was compromised due to excessive suspended sediments and fouling of the instrument.

3.1.3. Water Temperature

The water temperatures predicted by the model were compared against six of the nineteen thermistor temperature recorders deployed within Lough Derg as part of the hydrographic survey campaign.

The modelled water temperature generally showed good agreement against the recorded water temperature. Although the agreement was best at the northern end of Lough Derg, owing to the influence of the River Shannon, at all stations down through the system the model simulated the dominant heating and cooling events at the correct times.

[2] ibid.

3.2. Water Quality

The water quality model calibration was undertaken over the period 01/03/2016 to 31/12/2016 as this period contained coincident recorded datasets for all model boundary forcing conditions. The model was calibrated against the following parameters: biochemical oxygen demand (BOD), dissolved oxygen (DO), chlorophyll-a (CHL), nitrite (NO2-N), ammonia (NH3-N), nitrate (NO3-N), and ortho-phosphate (PO4-P). The model predictions were compared against samples recorded every eight hours by four automatic nutrient analysers deployed throughout Lough Derg and against manual samples collected on average every fortnight at seven locations throughout Lough Derg.

3.2.1. Biochemical Oxygen Demand (BOD)

Towards the north of Lough Derg, the modelled BOD values were slightly over estimated when compared with the sampled values. Towards the middle and southern sections of Lough Derg the modelled BOD values were slightly underestimated when compared with the sampled values. The modelled BOD showed a decrease from initial values in March, to lower values in mid-summer and increased again in the winter months, which agreed with the annual trend in the sampled data.

3.2.2. Dissolved Oxygen (DO)

In the north, middle and southern sections of Lough Derg the modelled DO values showed agreement against the sampled values with modelled values lying within the range of sampled data and following the trend in annual variation. The modelled DO showed a decrease from initial values in March to lower values in mid-summer and increased again in the winter months, which agreed with the annual trend in the sampled data.

3.2.3. Nitrite (NO2-N)

The majority of the NO2-N manual samples were reported as below the limit of detection by the accredited laboratory but were included for comparison purposes. Most of the NO2-N values recorded by the automatic nutrient analysers were below the calibrated limit of detection of the instrument but were included for comparison purposes. The water quality model predicted very low NO2-N concentrations throughout Lough Derg over the period of model calibration, lower than the manual sampling's limit of detection. To this extent the model showed agreement with sampled data.

3.2.4. Ammonia (NH3-N)

The majority of the NH3-N manual samples were reported below the limit of detection by the accredited laboratory. Most of the NH3-N values recorded by the automatic nutrient analysers were below the calibrated limit of detection of the instrument but were included for comparison purposes. The water quality model predicted very low NH3-N concentrations throughout Lough Derg over the period of calibration, lower than the manual sampling's limit of detection. To this extent the model showed agreement with sampled data

3.2.5. Nitrate (NO3-N)

At all locations, except in the north of the lough, the modelled NO3-N concentrations showed good agreement with the sampled data. Modelled NO3-N concentrations were under-estimated in the

northern section of Lough Derg over the April to June period but showed agreement with the general annual trend in the sampled data.

3.2.6. Chlorophyll-a (CHL)

The modelled CHL values were over-estimated when compared with the sampled CHL values throughout Lough Derg. In general, modelled values were approximately 4µg/l greater than the sampled CHL concentrations. Sampled CHL values were very low throughout the year when compared with the long-term record.

3.2.7. Phosphate Phosphorus (PO4-P)

Most PO4-P values recorded by the automatic nutrient analysers were below the limit of detection of the calibrated instrument but were included for comparison purposes. The modelled PO4-P concentrations lay within the uncalibrated range of the automatic nutrient analysers' PO4-P readings the year. To this extent the model showed good agreement with sampled data.

At the manual sampling locations towards the north of Lough Derg the modelled PO4-P values showed good agreement with sampled data. At the manual sampling locations towards the middle and southern sections of Lough Derg the manual samples were reported below the limit of detection by the accredited laboratory and the modelled PO4-P values were also all below the manual sampling limit of detection. To that extent the model showed good agreement with sampled data.

3.3. Calibration Statement

In general, the comparison of the modelled and measured datasets, both statistically and visually, would suggest a robust calibration agreement. The summary of calibration results presented above show that the numerical model has been successfully calibrated against field measurements to provide a sufficiently accurate representation of the hydrodynamic and water quality components within the study region.

4. Model Re-calibration

This section provides an overview of the re-calibration of the hydrodynamic and water quality components of the three-dimensional model of Lough Derg and Parteen Basin. For full details please refer to the Model Re-calibration Report in Appendix I.

4.1. Hydrodynamics

The hydrodynamic model re-calibration was undertaken over the period 01/10/2017 to 31/12/2018 as this period was identified as one of the most extreme drought periods experienced in Lough Derg across historical records. The model predictions were compared quantitatively against recorded datasets from instruments and samples collected within Lough Derg as part of the hydrographic survey campaign.

4.1.1. Water Surface Levels

The water surface levels predicted by the model were compared against one water level recorder located at Ballyvalley towards the south of the lough. Over the course of the model verification period, the model simulated the recorded water levels at Ballyvalley to within ±0.05m for 90% of the time

4.2. Water Quality

The water quality model re-calibration was undertaken over the period 01/10/2018 to 31/12/2018 as this period was identified as one of the most extreme drought periods experienced in Lough Derg across historical records and contained sufficient coincident recorded datasets for model re-calibration. The model was re-calibrated against the following parameters: biochemical oxygen demand (BOD), dissolved oxygen (DO), chlorophyll-a (CHL), nitrite (NO2-N), ammonia (NH3-N), nitrate (NO3-N), and ortho-phosphate (PO4-P). The model predictions were compared against manual samples collected on average every fortnight at seven locations throughout Lough Derg.

4.2.1. Biochemical Oxygen Demand (BOD)

At location WQMS-1 the modelled values showed very good agreement when compared with the sampled values. At location WQMS-5 the modelled values were slightly under predicted when compared with the sampled values at the final quarter of 2018. At location WQMS-8 the modelled values were under predicted when compared with the sampled values at the latter half of 2018. In general, the modelled BOD concentrations reproduced the increasing concentrations in Spring, falling to lower values in mid-Summer and increased again in the Winter, thus the modelled BOD concentrations showed agreement with the general annual trend in the sampled data.

4.2.2. Dissolved Oxygen (DO)

At location WQMS-1 the modelled values showed a slight under prediction of DO concentrations but closely followed the annual trend when compared with the sampled values. At location WQMS-5 again the modelled values showed a slight under prediction of DO concentrations but closely followed the annual trend when compared with the sampled values. At location WQMS-8 although the model recreated the rise and fall of DO concentrations throughout the course of the year, it did not predict the magnitude of the peak or trough in sampled DO concentrations. The modelled DO concentrations

reproduced the increasing concentrations in Spring, falling to lower values in mid-Summer and increased again in the Winter. This agreed with the annual trend in the sampled data.

4.2.3. Nitrite (NO2-N)

Almost all the NO2-N manual samples analysed were below the limit of detection by the accredited laboratory. At all locations the modelled values were all predicted to be below the analytical limit of detection for the manual samples. To that extent, the model showed agreement with sampled data and to the same level of accuracy.

4.2.4. Ammonia (NH3-N)

At location WQMS-1 the modelled values showed agreement when compared with the sampled values. At location WQMS-5 the modelled values showed good agreement when compared with the sampled values. At location WQMS-8 the modelled values again showed a level of agreement with the sampled values. As a result of the re-calibration exercise, the predicted NH3-N concentrations showed much better agreement with the sampled data than presented previously in the water quality model verification exercise.

4.2.5. Nitrate (NO3-N)

At location WQMS-1 the modelled values showed very good agreement when compared with the sampled values. At location WQMS-5 the modelled values were under predicted when compared with the sampled values at the latter half of 2018. At location WQMS-8 the modelled values were generally under predicted when compared with the sampled values. The modelled NO3-N concentrations reproduced the peak concentrations in February then continuously reducing throughout the year to lower values in late Autumn and increased again in the Winter. The modelled NO3-N concentrations showed agreement with the general annual trend in the sampled data.

4.2.6. Chlorophyll-a (CHL)

At location WQMS-1 the model slightly over predicted values compared with the sampled values during the first half of the year, but with both modelled and sampled values at very low levels with both at very low (1 - 2 ug/l). At location WQMS-5 the modelled values showed good agreement when compared with the sampled values with both modelled and sampled values at very low levels (1 - 2 ug/l). At location WQMS-8 the modelled values did not accurately predict the magnitude of the autumnal bloom.

4.2.7. Phosphate Phosphorus (PO4-P)

At location WQMS-1 the modelled values showed very good agreement when compared with the sampled values. At location WQMS-5 the modelled values showed good agreement when compared with the sampled values. At location WQMS-8 the model tended to slightly overpredict concentrations when compared with the sampled values.

4.3. Re-calibration Statement

In general, the comparison of the modelled and measured datasets, both statistically and visually, shows a good agreement, and in the case of the water quality components a more accurate

representation of the system than achieved in the original model calibration exercise, and a much better representation of ammonia when compared against the previous model verification exercise. The re-calibration results presented above show that the numerical model has been successfully re-calibrated against field measurements to provide an accurate representation of the hydrodynamic and water quality components within the study region.

5. Hydrological Model OPM

A hydrological model was developed to assess the impact of the proposed abstraction on the water levels of Lough Derg and Parteen Basin and the pass forward flows released to the Old River Shannon.

Two constant rates of proposed abstraction have been investigated in the hydrological model: i) 154 Ml/d – taken to be representative of normal operation demand by the year 2050, and ii) 300 Ml/d – projected peak demand at year 2050. Constant abstraction rates have been used since future transfer rates on a day-by-day basis are not known. Applying an abstraction rate of 154 Ml/d across the entire period of simulation allows the impact of that typical abstraction to be assessed every day. The projected peak of 300Ml/d is only envisaged to be approached at times of major drought in the east which may or may not coincide with major drought in the Shannon basin. To apply this peak abstraction rate across all days in the simulation is very much a precautionary assessment of the impact that the abstraction could have.

The hydrological model was run using data from the period 1 January 1972 to 31 October 2023, allowing the simulation of daily levels and daily flows across this 52-year period with and without the proposed WSP abstraction in place. Runs of the model on earlier periods have not been undertaken as the water resources management practices differed to those of today: precluding the derivation of representative hydrological inflows.

The calibrated hydrodynamic and water quality model of Lough Derg and Parteen Basin relies on the recorded flows entering the system through the River Shannon at Portumna Bridge, minor rivers, and the recorded outflows through Ardnacrusha Headrace Canal and Parteen Weir. This will not be the case in future scenarios when climate change will alter the inflow regime.

Investigating the likely future WSP impacts needs an approach in which the Ardnacrusha flows can be estimated since the inflows into the system are projected to change; with winters likely to become wetter and summers drier. Use of the historical Ardnacrusha flows in such a future will not be appropriate since in future wetter periods Ardnacrusha is likely to use more water and in drier periods the flows will need to be reduced. There is therefore a need for a rules-based approach for predicting the Ardnacrusha flows and the management of the system

To model the future impact of WSP abstractions therefore requires the inclusion of operational rules that determine how much water will flow to Ardnacrusha based upon the changed inflow hydrology whilst still meeting the required compensation and fish pass flows and keeping the lake levels within the normal operating levels. This model is referred to as the WSP hydrological model's "Operational Principles Model (OPM)".

The description of the OPM, the codification of the operating principles, and the hydrological simulations incorporating climate change effects are detailed in Section 2 of the Hydrological Modelling Report (2025)[3].

This section details the application of the OPM to the hydrodynamic and water quality model and an assessment of the sensitivity of the water quality model's predictions to the application of the OPM.

[3] Uisce Éireann, 2025. Water Supply Project: Eastern and Midlands Region. Environmental Impact Assessment Report Appendix 9.1, Annex A, Hydrological Modelling Report.

5.1. Implementation

The OPM was set up as a standard water balance model run on a daily time-step codifying the ESB management regime with reference to water levels at the Pier Head Killaloe station with full details included in the Hydrological Modelling Report[4].

The hydrodynamic and water quality model has a timestep of the order of seconds and is forced at the boundaries with reference to water levels and flows at Portumna Bridge and Ardnacrusha Headrace/Parteen Weir.

To implement the OPM for climate change modelling within the hydrodynamic and water quality model it was necessary to determine a relationship to transpose the water levels at Pier Head Killaloe (the basis of the OPM) to both Portumna and Parteen Weir (the basis of the hydrodynamic and water quality model)

This was undertaken by first determining the relationship between the historic recorded water levels at Pier Head Killaloe and historic recorded water levels at Portumna over the period 01/10/2017 – 31/12/2018.

The relationship between both sets of recorded water levels was found to conform well to the linear relationship: $WL_{Portumna} = 1.2466 * WL_{Killaloe} - 7.5258$ as presented below in Figure 3.

Regarding lake water level datum, the ESB work to the Poolbeg datum, however the WSP models have been set up to work to the Malin Head datum. Therefore, all water level graphs in this report are given as metres Above Ordnance Datum (mAOD) with respect to Malin Head. To convert levels recorded to the Malin Head datum to the Poolbeg datum (in the vicinity of Lough Derg and Parteen Basin) a value of 2.7m needs to be added to the Malin Head level.

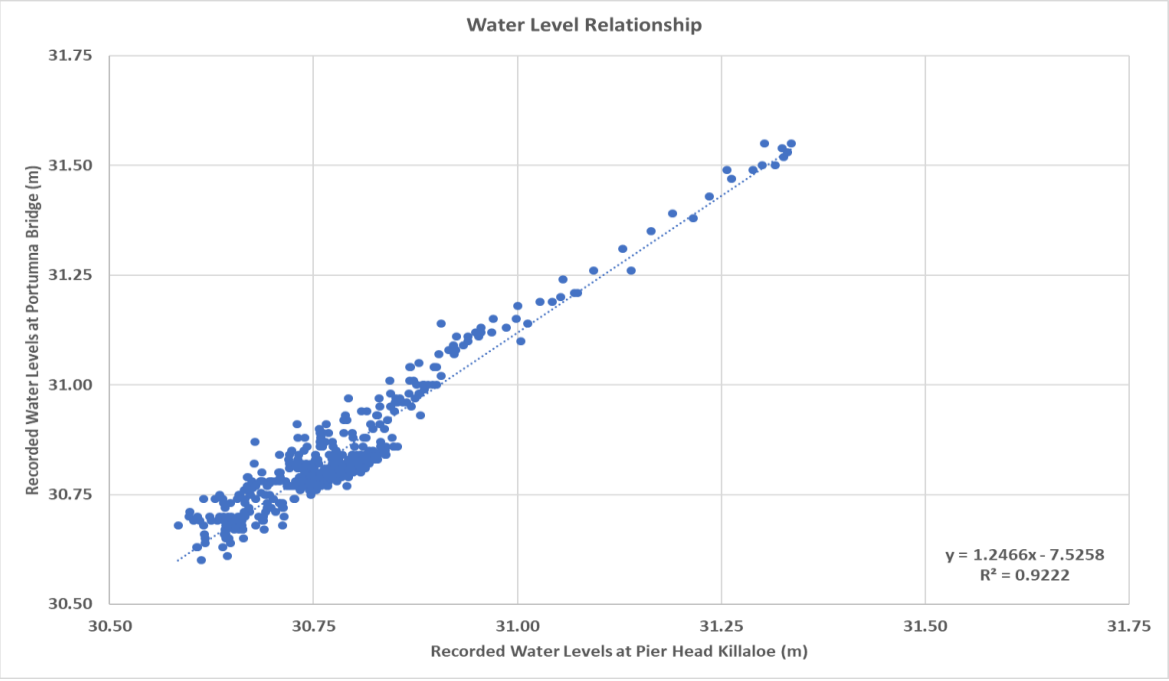


Figure 3: Recorded water level relationship between Pier Head Killaloe and Portumna.

[4] ibid

The comparison of the historic recorded water levels at Portumna against water levels at Portumna calculated from the above relationship over the same period is presented in Figure 4.

The relationship between the historic recorded water levels at Pier Head Killaloe and historic recorded water levels at Parteen Weir was more complex and was dependant on the total outflow (OF) through Ardnacrusha Headrace Canal and Parteen Weir rather than just Pier Head Killaloe water levels alone, according to the following relationship:

$WL_{Parteen} = WL_{Killaloe} - 0.1m$ (OF < 200 m^3/s)
$WL_{Parteen} = WL_{Killaloe} - [0.1m + (OF-200) / 450]$ (OF > 200 m^3/s)

The comparison of the historic recorded water levels at Parteen Weir against water levels at Parteen Weir calculated from the above relationship is presented in Figure 5.

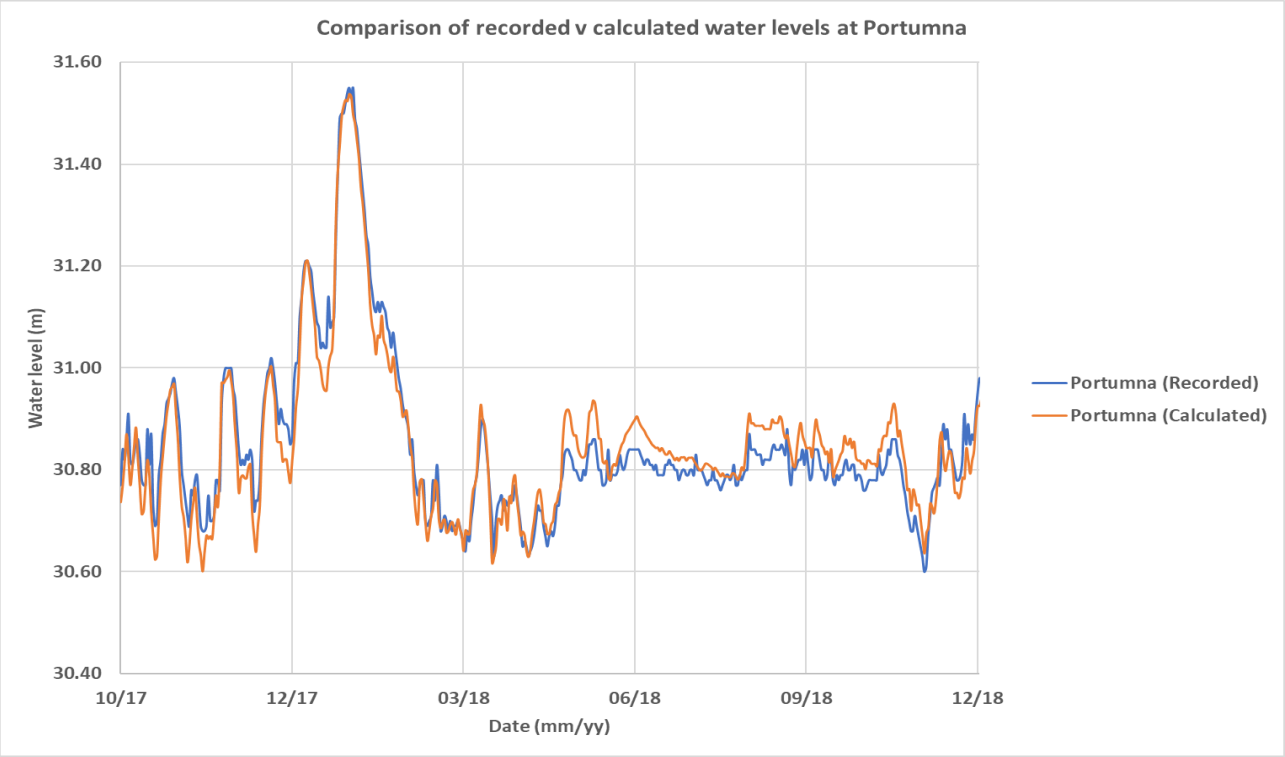


Figure 4: Comparison of recorded v calculated water levels at Portumna

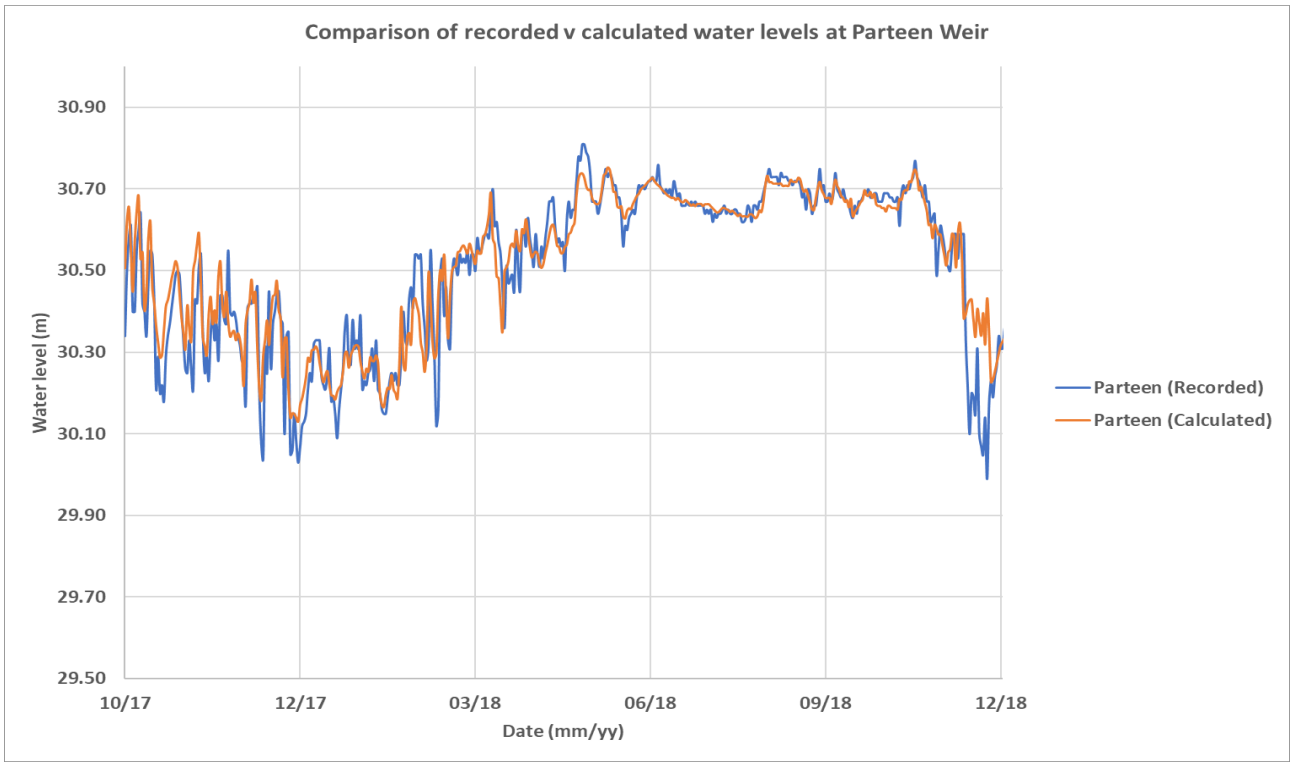


Figure 5: Comparison of recorded v calculated water levels at Parteen Weir

Having established the above relationships between recorded water levels at Pier Head Killaloe (upon which the OPM is based) and recorded water levels at Portumna and Parteen Weir (upon which the hydrodynamic and water quality model is based), synthesised water surface levels at both Portumna and Parteen Weir were then generated to incorporate the OPM into the hydrodynamic and water quality model.

5.2. Assessment of Effects

To determine the impacts of incorporating the OPM into the calibrated and verified hydrodynamic and water quality model, model predictions were compared against those of the verified hydrodynamic and water quality model presented previously.

5.2.1. Boundary Conditions

Figure 6 presents the water levels calculated at Pier Head Killaloe from the OPM against the historic water levels recorded at Pier Head Killaloe for the period 01/10/2017 – 31/12/2018.

The corresponding OPM water levels derived at both the Portumna and Parteen Weir model boundaries using the relationships developed previously are plotted against the recorded water levels at Portumna and Parteen Weir used in the verified hydrodynamic and water quality model and are presented in Figure 7 and Figure 8 respectively.

As discussed, for the purposes of the hydrodynamic and water quality modelling, the hydrological model OPM simulated lake water levels have been converted to provide synthesised levels for Parteen Weir using a derived Killaloe/Parteen Weir level relationship. The Parteen Weir water level graphs within this report may show OPM calculated levels below the 30.00mAOD Malin lower operating level that ESB applies to Parteen Basin during the 2017/18 winter flood period. There is a limitation

of the conversion due to the complexity of the Killaloe/Parteen Weir level relationship during flood periods as the levels are highly sensitive to the outflows through Ardnacrusha Headrace Canal and Parteen Weir. In reality, during flood periods ESB would manage the outflows to ensure that the Parteen Basin water level would not go below 30.00mAOD.

All other inputs to the calibrated and verified hydrodynamic and water quality model remained unchanged.

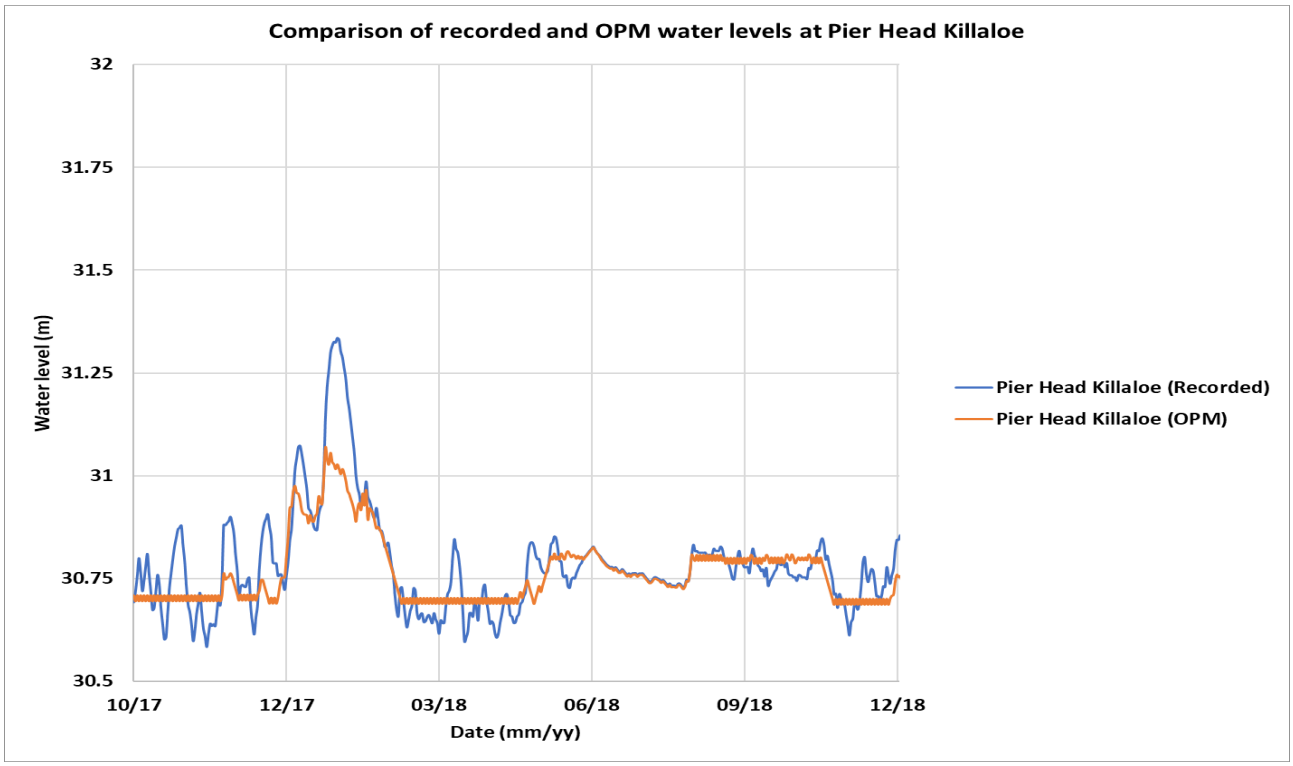


Figure 6: Comparison of recorded water levels v OPM water levels at Pier Head Killaloe

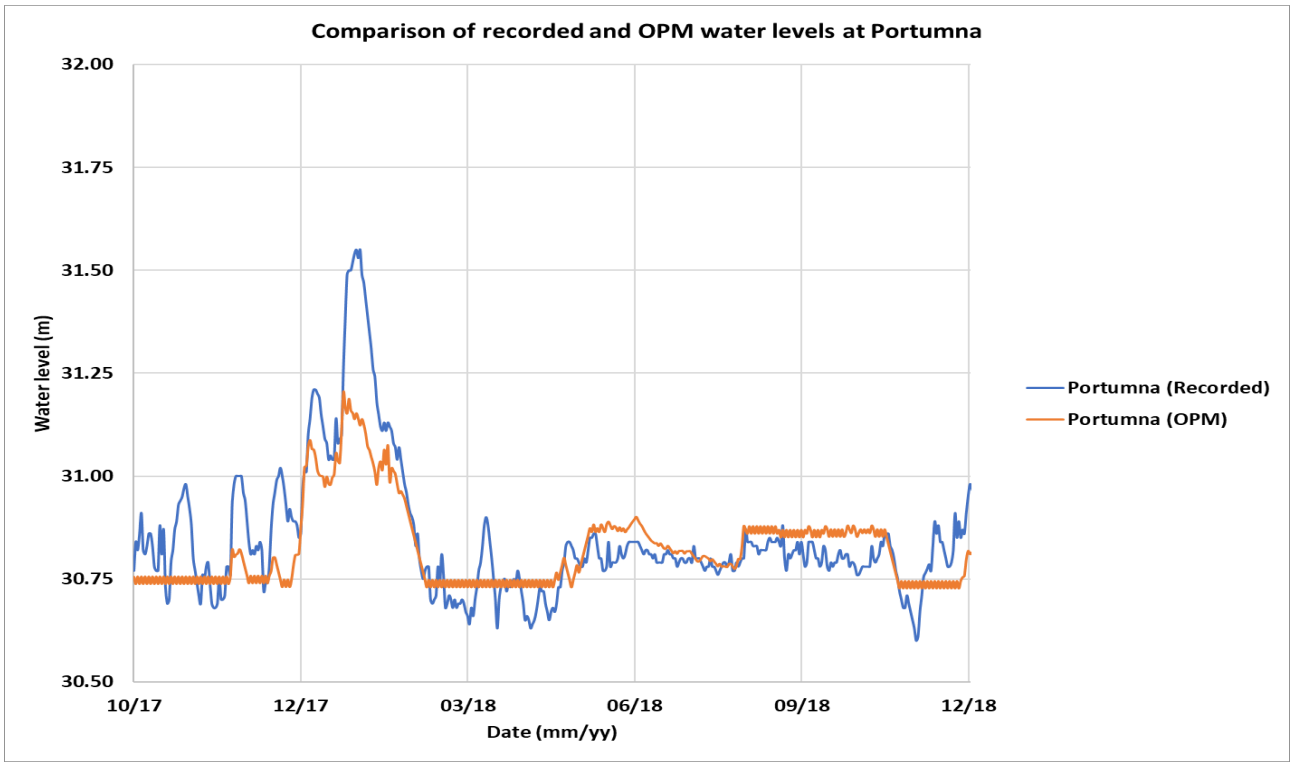


Figure 7: Comparison of recorded water levels v calculated OPM water levels at Portumna

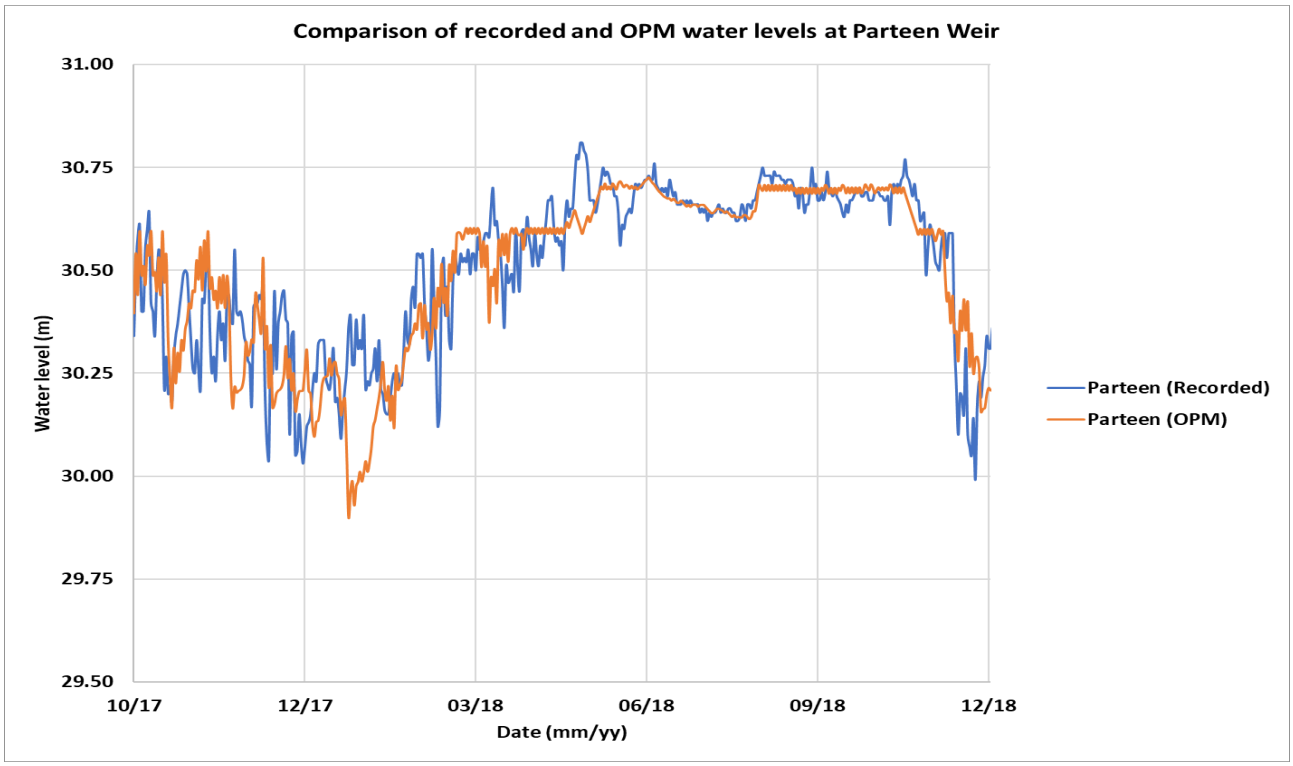


Figure 8: Comparison of recorded water levels v calculated OPM water levels at Parteen Weir

5.2.2. Current Speeds

Modelled current speeds from the verified hydrodynamic model were compared against the current speeds predicted by the model using the OPM water level boundary conditions at Portumna and Parteen Basin.

The locations at which the comparisons were undertaken corresponded to locations OL02 and OL09 used in both the hydrodynamic model calibration and verification exercises are presented in Figure 9.

The comparison of the verified hydrodynamic model's predicted current speeds against the current speeds predicted by the model using the OPM boundary conditions at location OL02 are presented in Figure 10.

The differences in predicted current speeds from both models are almost indistinguishable and are less than ±0.002 m/s (2 mm/s) more than 95% of the time. The plot of the differences in current speeds between both models is presented in Figure 11.

The comparison of predicted current speeds at location OL09 are presented in Figure 12. The differences in predicted current speeds from both models are almost indistinguishable and are less than ±0.002 m/s (2 mm/s) more than 83% of the time. The plot of the differences in current speeds between both models is presented in Figure 13.

The difference in predicted current speeds was at its most pronounced during periods when the OPM water levels at both Portumna and Parteen remained unchanged over the same periods (periods

between Mar – Jun 2018 and Aug – Nov 2018) when compared to the rate of change of water levels in the recorded data.

Differences of the order of less than ±0.002 m/s (2 mm/s) in predicted current speeds between both models were not considered to be significant.

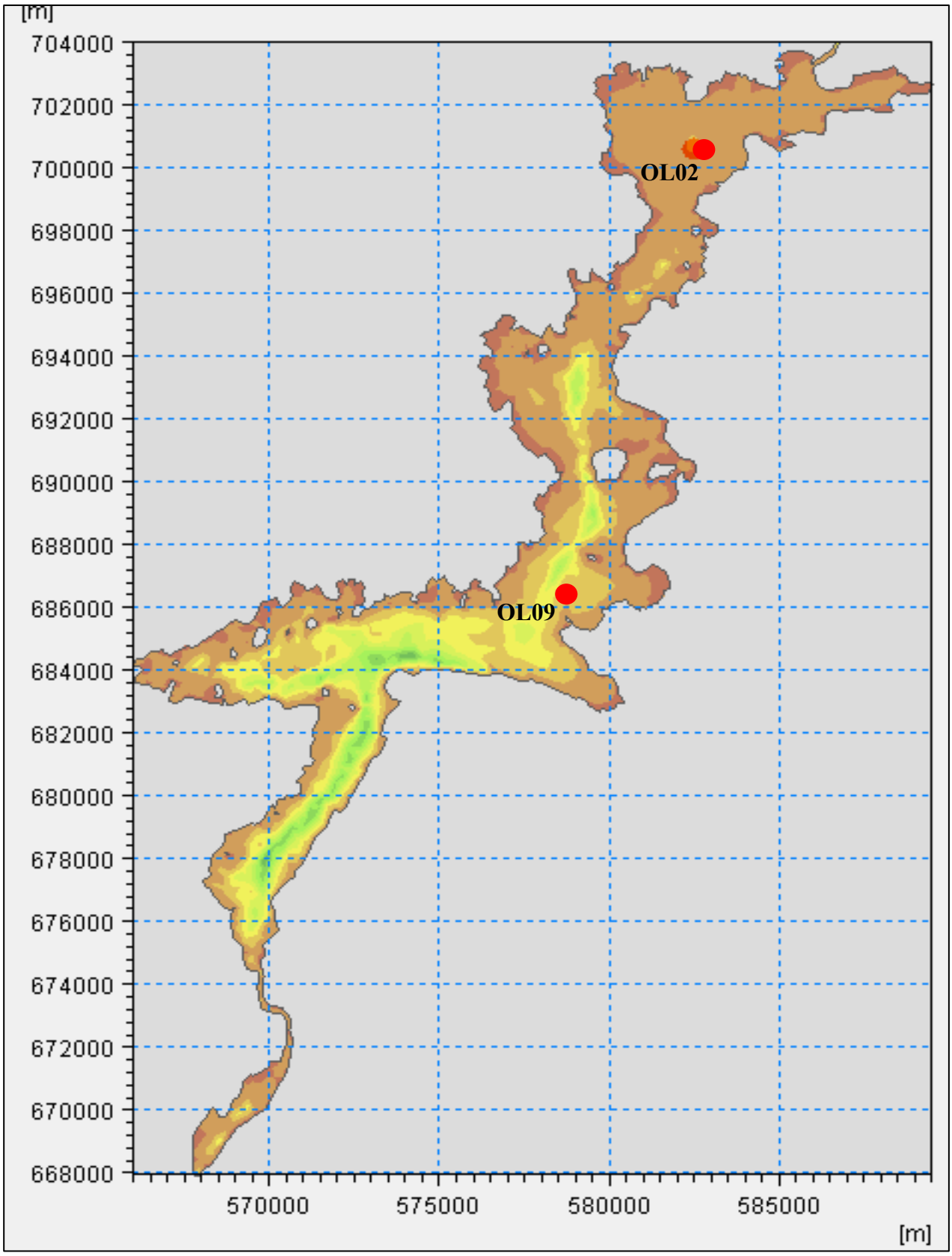


Figure 9: Location of model calibration stations OL02 and OL09

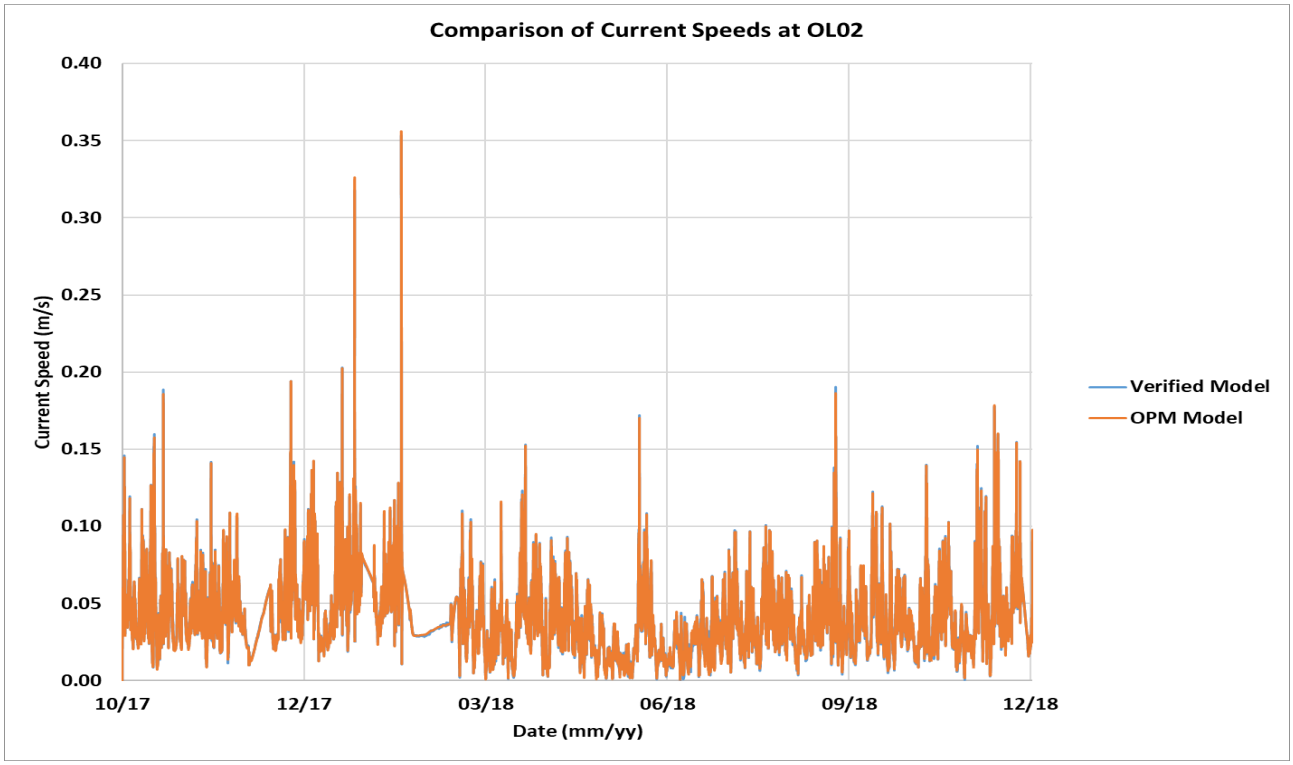


Figure 10: Comparison of modelled current speeds at OL02 from verified model and OPM.

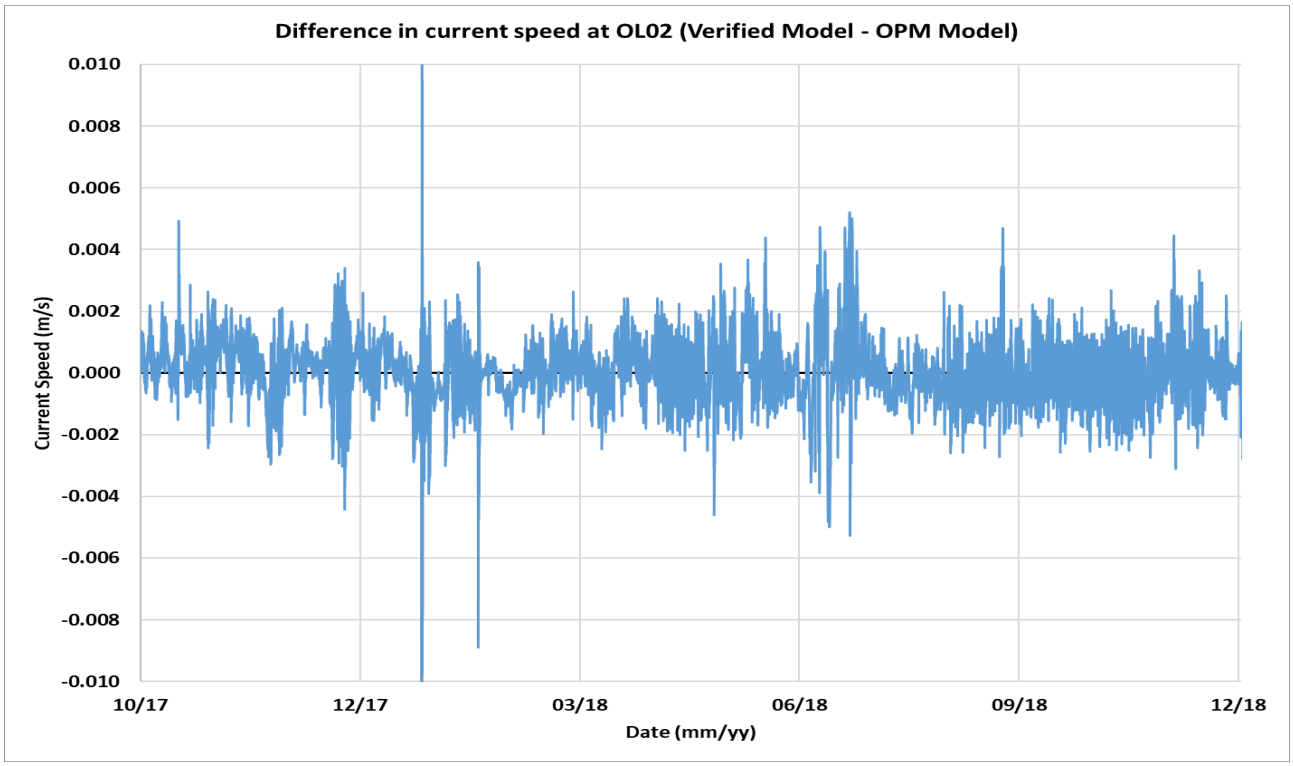


Figure 11: Difference in modelled current speeds at OL02 location (Verified - OPM)

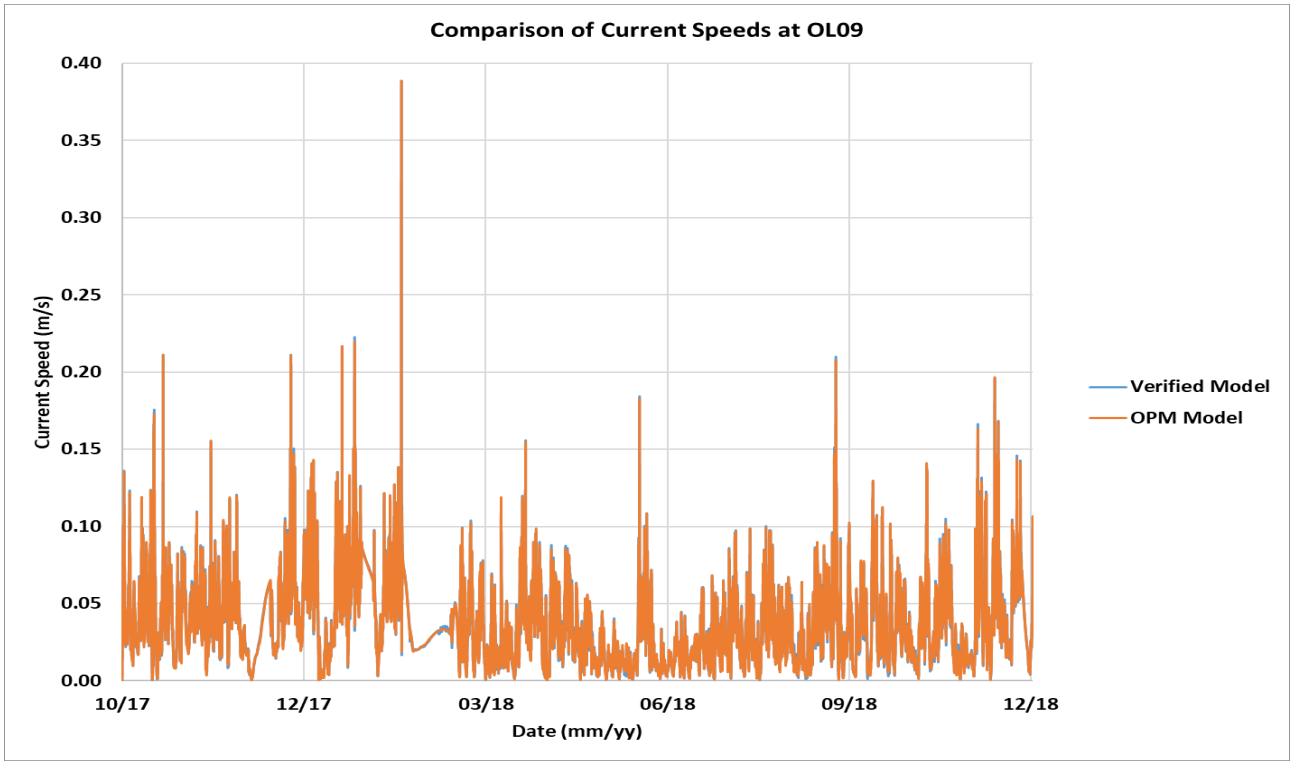


Figure 12: Comparison of modelled current speeds at OL09 from verified model and OPM.

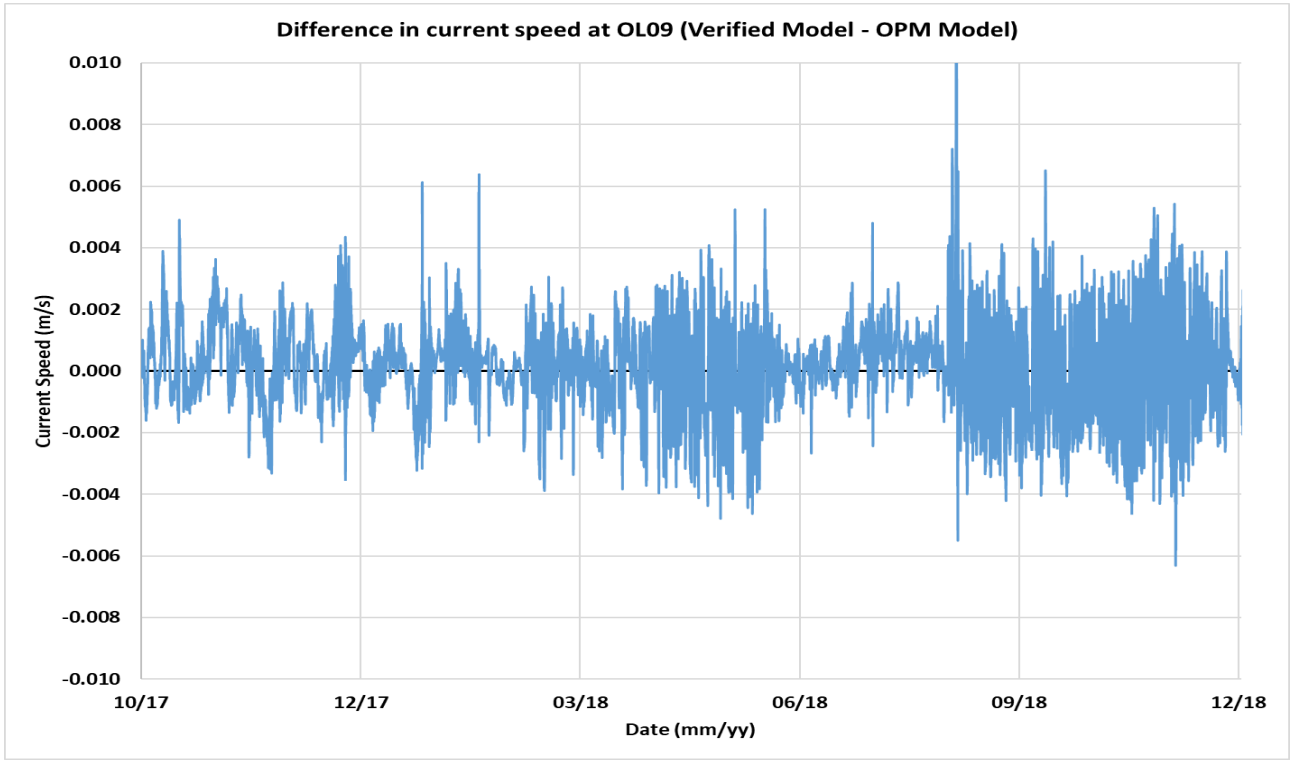


Figure 13: Difference in modelled current speeds at OL09 location (Verified - OPM)

5.2.3. Water quality

Modelled water quality parameters of biochemical oxygen demand (BOD) and nitrate nitrogen (NO3-N) from the re-calibrated water quality model were compared against those predicted by the model using the OPM water level boundary conditions at Portumna and Parteen Basin.

The locations at which the comparisons were undertaken are presented in Figure 14 and corresponded to WQMS1 in the north of the lake, WQMS5 in the centre of the lake, and WQMS8 in the south of the lake as used in both the model calibration and model re-calibration exercises

The comparison of the re-calibrated water quality model's predicted BOD concentrations against those predicted by the model using the OPM boundary conditions at location WQMS1, WQMS5 and WQMS8 are presented in Figure 15, Figure 16 and Figure 17 respectively.

The comparison of the re-calibrated water quality model's predicted DO concentrations against those predicted by the model using the derived OPM boundary conditions at location WQMS1, WQMS5 and WQMS8 are presented in Figure 18, Figure 19 and Figure 20 respectively.

The comparison of the re-calibrated water quality model's predicted CHL concentrations against those predicted by the model using the derived OPM boundary conditions at location WQMS1, WQMS5 and WQMS8 are presented in Figure 21, Figure 22 and Figure 23 respectively.

The comparison of the re-calibrated water quality model's predicted NO3-N concentrations against those predicted by the model using the derived OPM boundary conditions at location WQMS1, WQMS5 and WQMS8 are presented in Figure 24, Figure 25 and Figure 26 respectively.

The comparison of the re-calibrated water quality model's predicted PO4-P concentrations against those predicted by the model using the derived OPM boundary conditions at location WQMS1, WQMS5 and WQMS8 are presented in Figure 27, Figure 28 and Figure 29 respectively.

The differences in model predictions across most parameters are only slightly distinguishable between the re-calibrated water quality model and the water quality model forced with the OPM boundary conditions at each of the sampling locations assessed.

These slightly distinguishable differences between both models were not considered significant when adopting OPM water level boundary conditions for the re-calibrated water quality model as they do not impact the accuracy of the model predictions when compared against the sampled data against which the re-calibration of the water quality model was based.

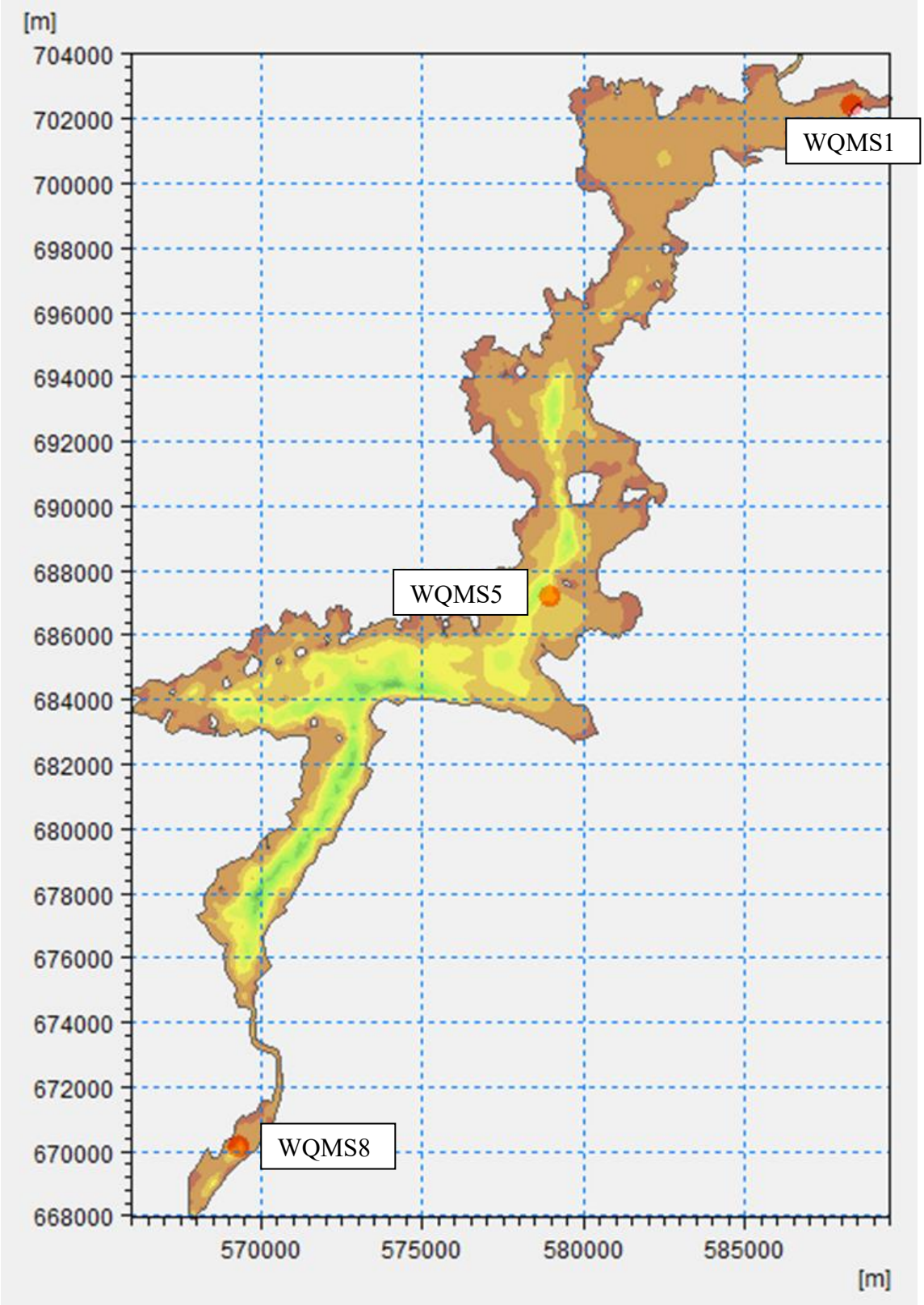


Figure 14: Water quality manual sampling (WQMS) locations for model verification

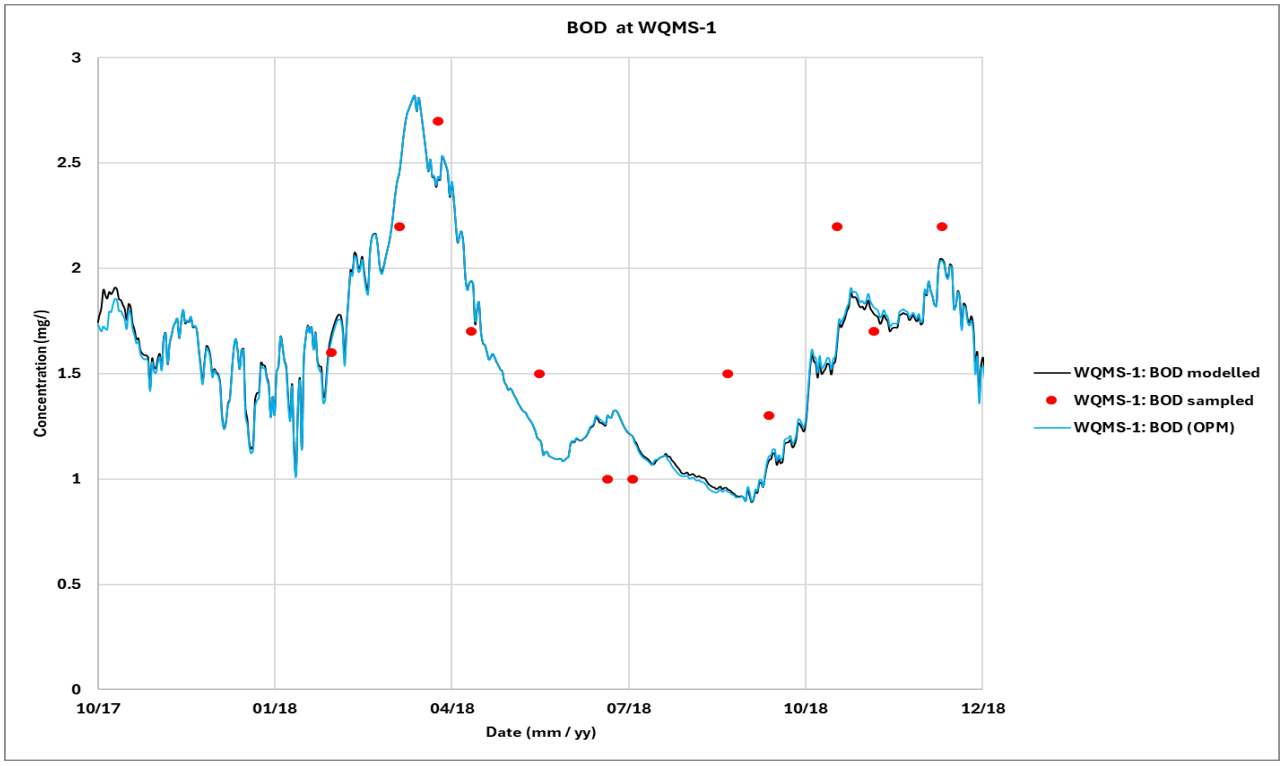


Figure 15: Comparison of BOD at WQMS-1 from re-calibrated model and OPM model.

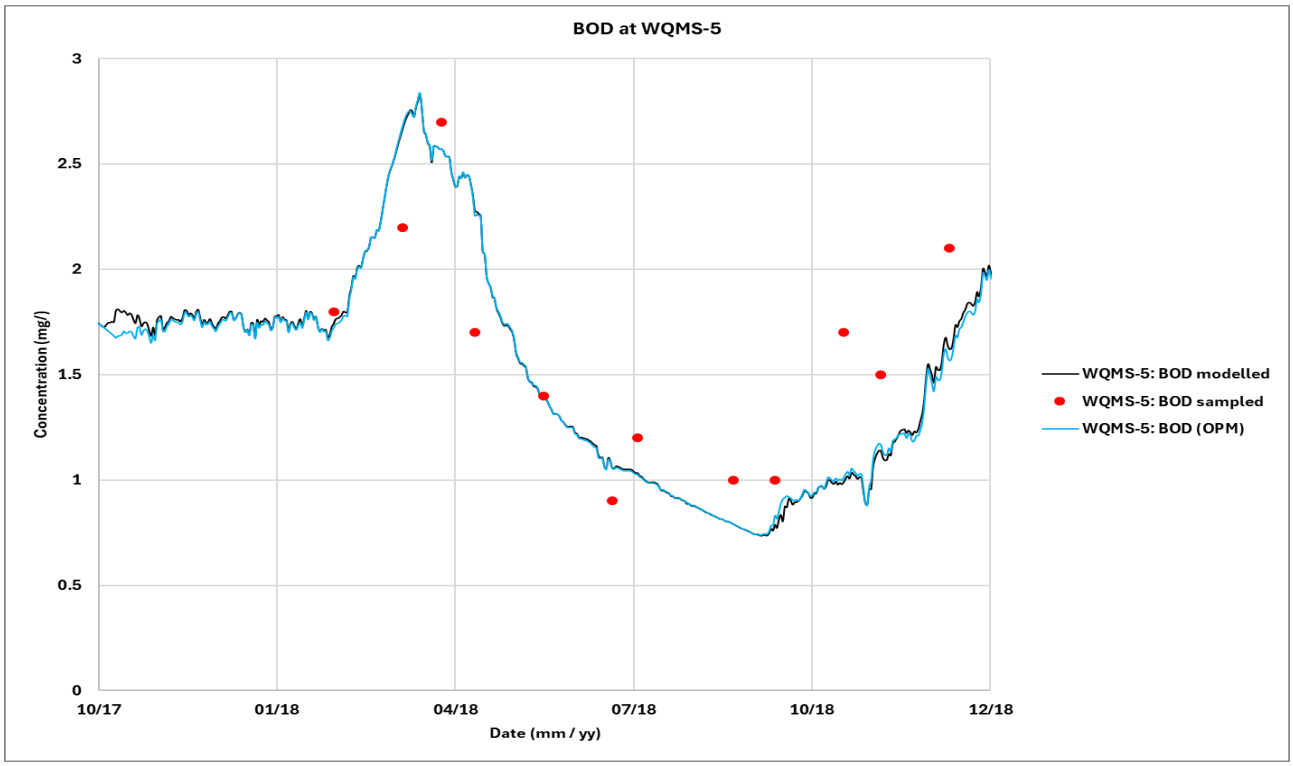


Figure 16: Comparison of BOD at WQMS-5 from re-calibrated model and OPM model.

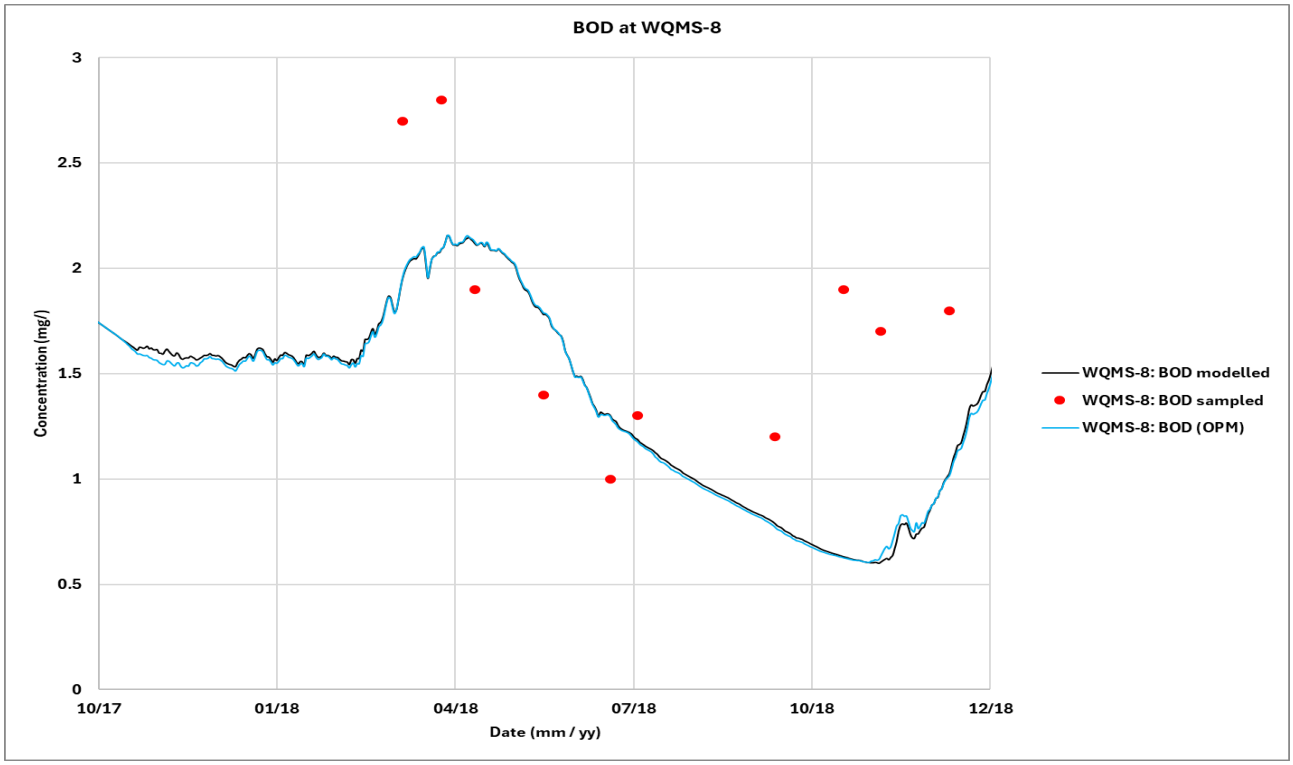


Figure 17: Comparison of BOD at WQMS-8 from re-calibrated model and OPM model.

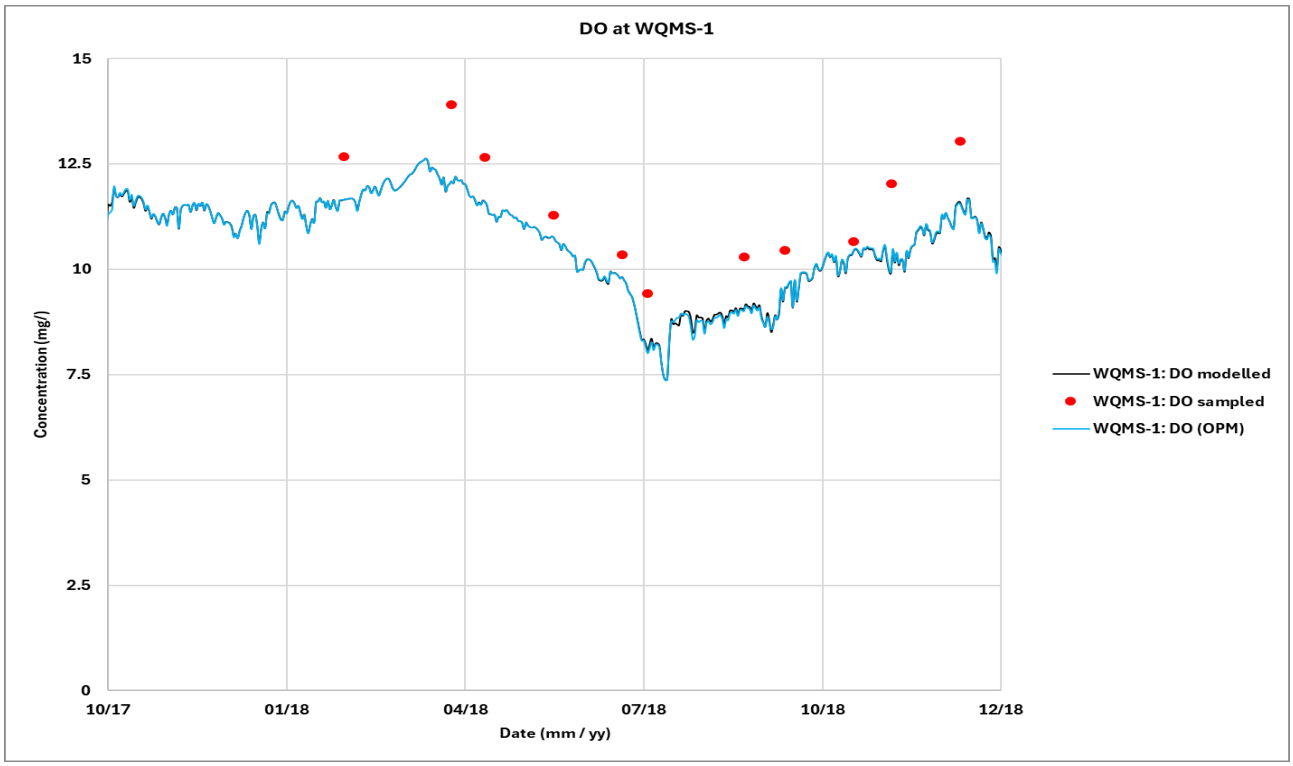


Figure 18: Comparison of DO at WQMS-1 from re-calibrated model and OPM model.

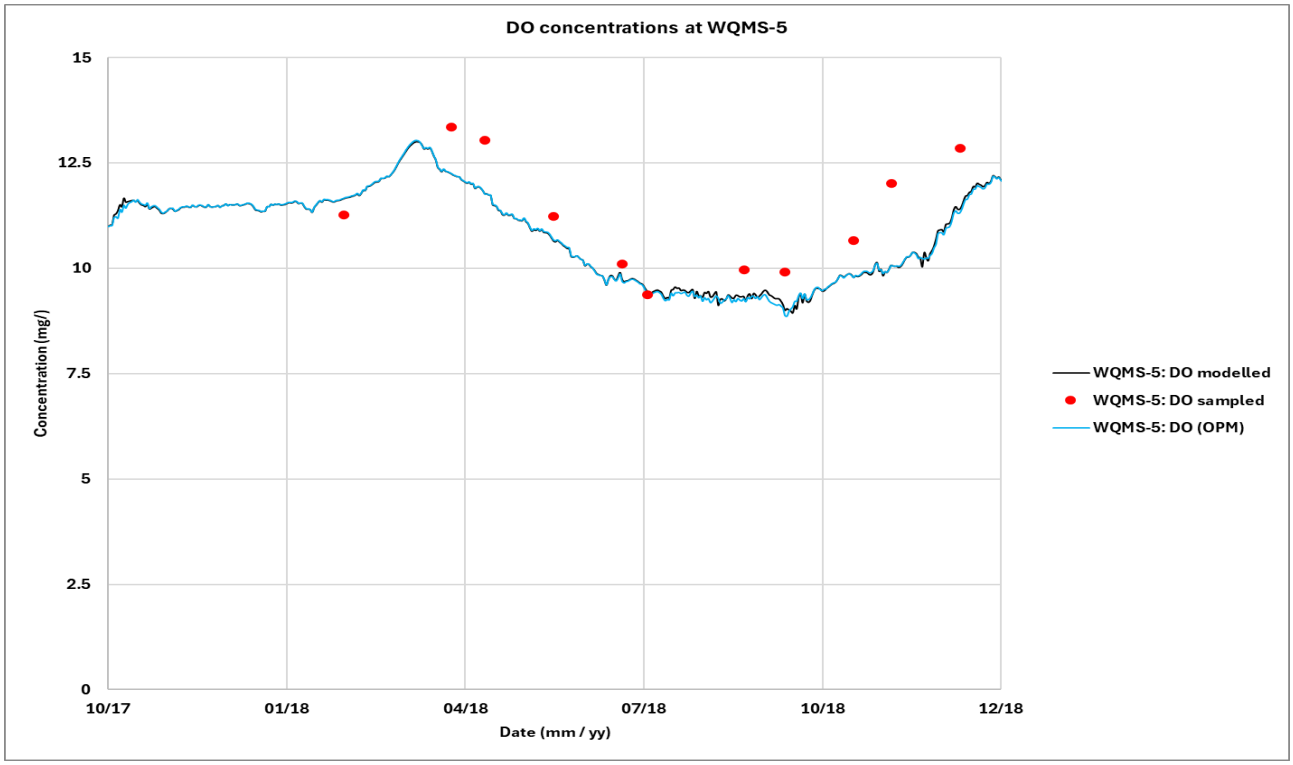


Figure 19: Comparison of DO at WQMS-5 from re-calibrated model and OPM model.

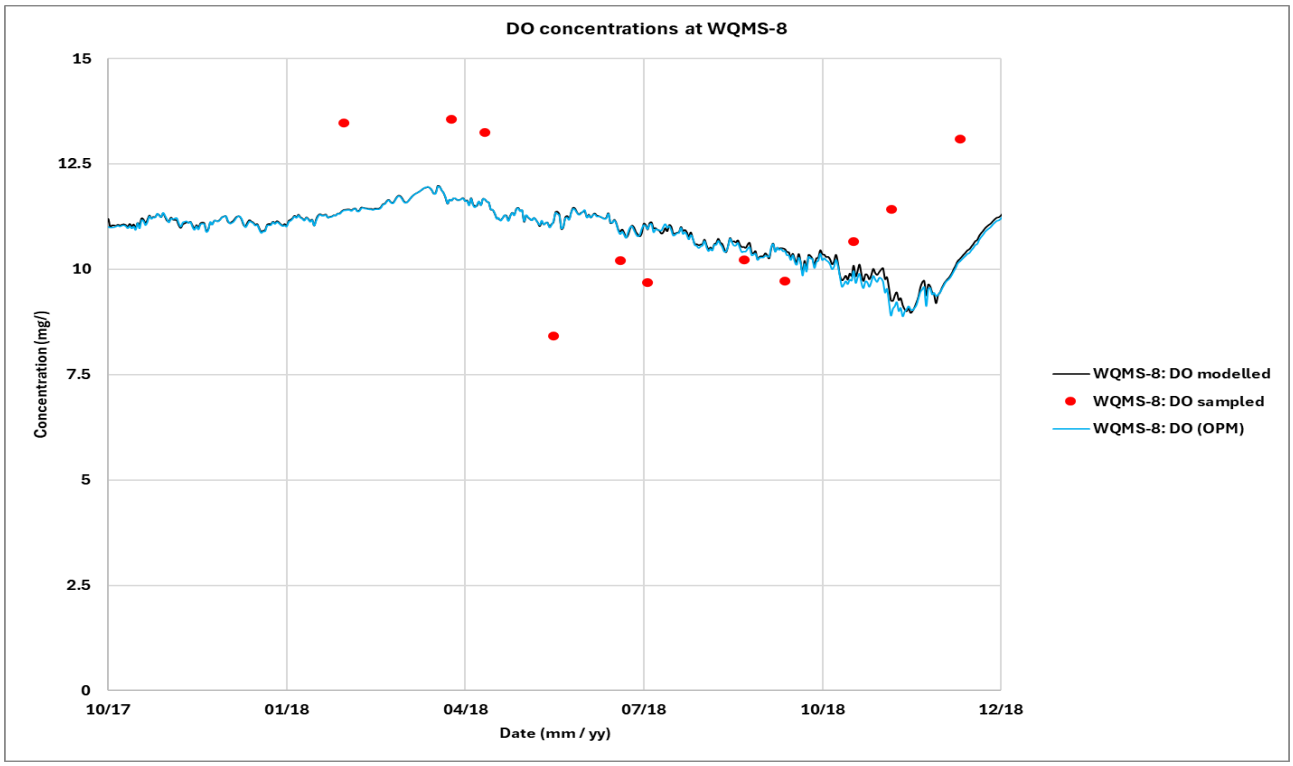


Figure 20: Comparison of DO at WQMS-8 from re-calibrated model and OPM model.

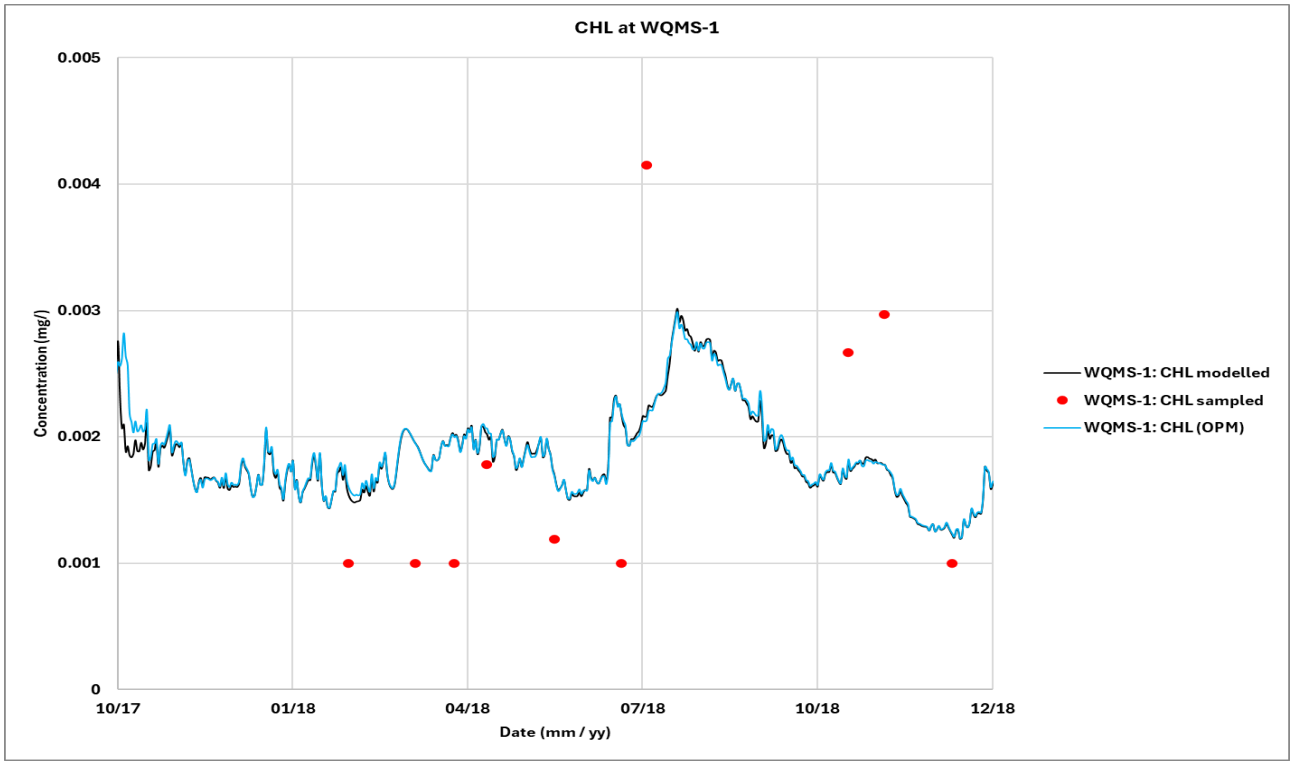


Figure 21: Comparison of CHL at WQMS-1 from re-calibrated model and OPM model.

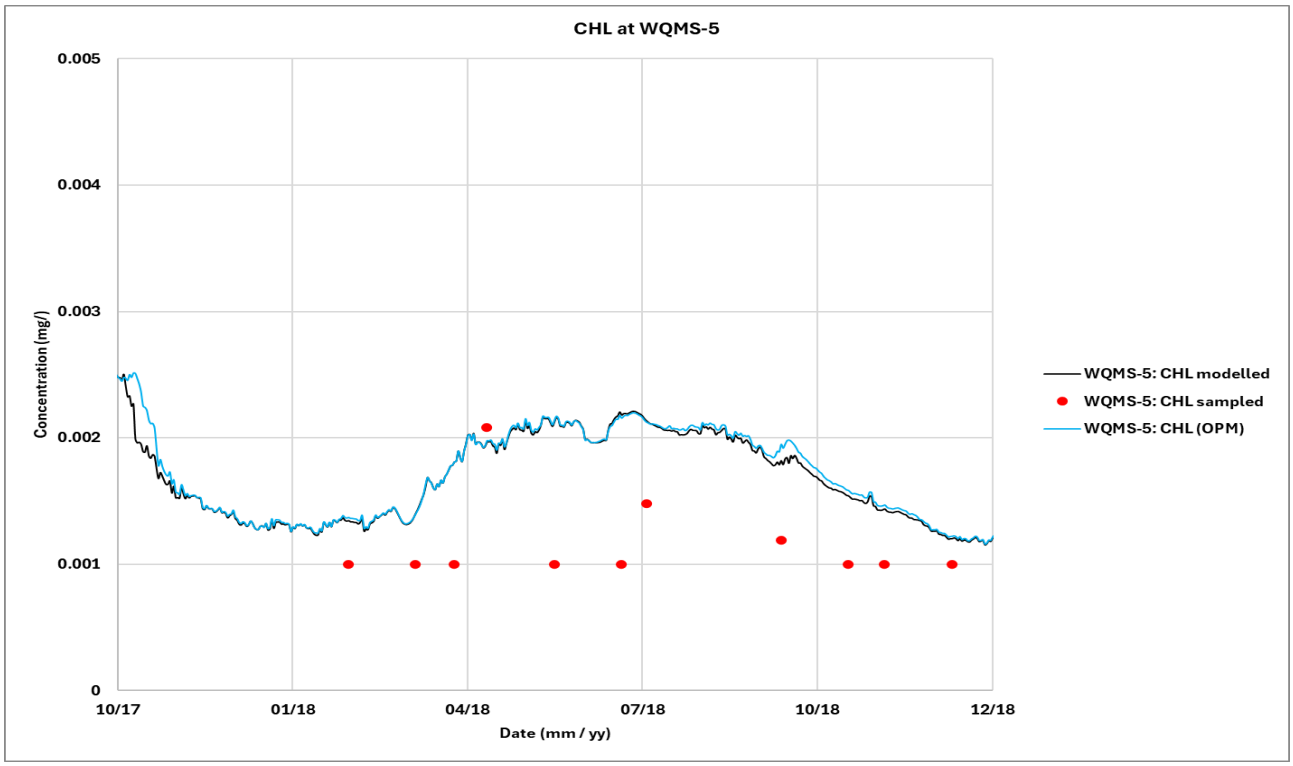


Figure 22: Comparison of CHL at WQMS-5 from re-calibrated model and OPM model.

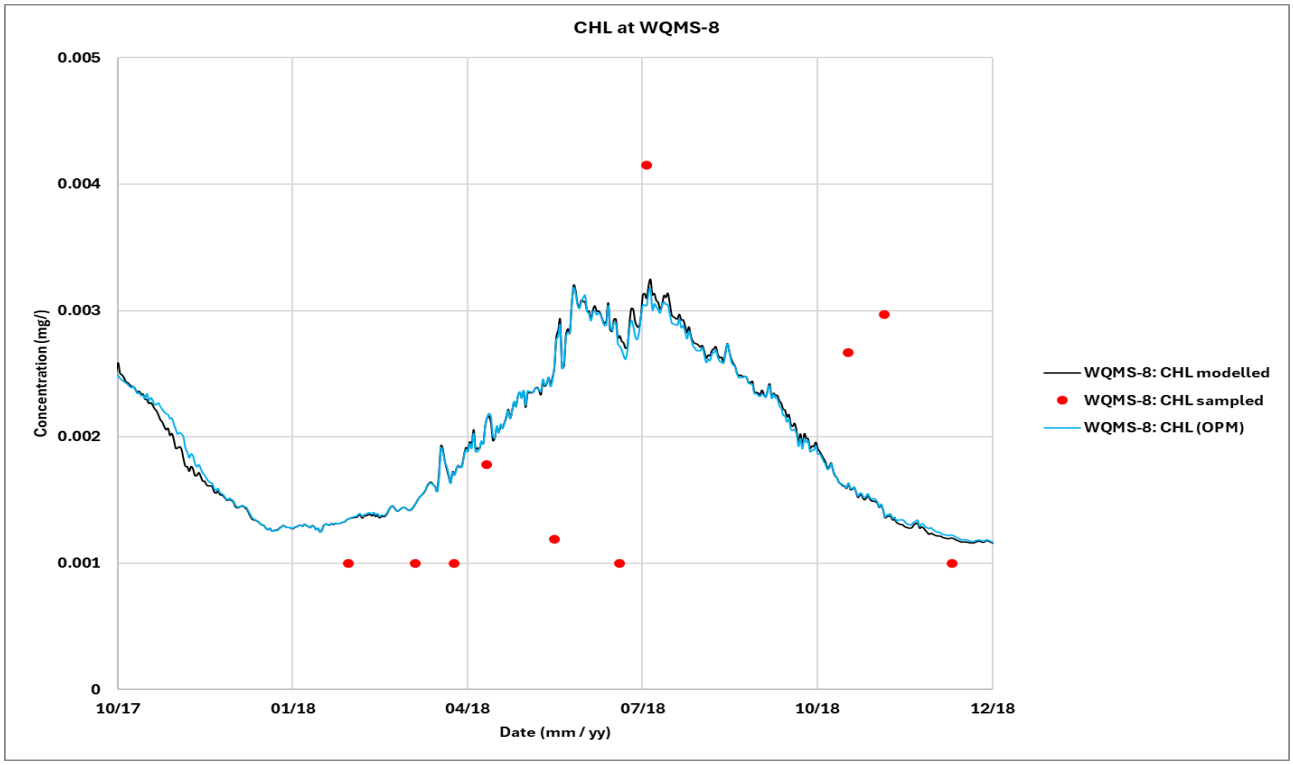


Figure 23: Comparison of CHL at WQMS-8 from re-calibrated model and OPM model.

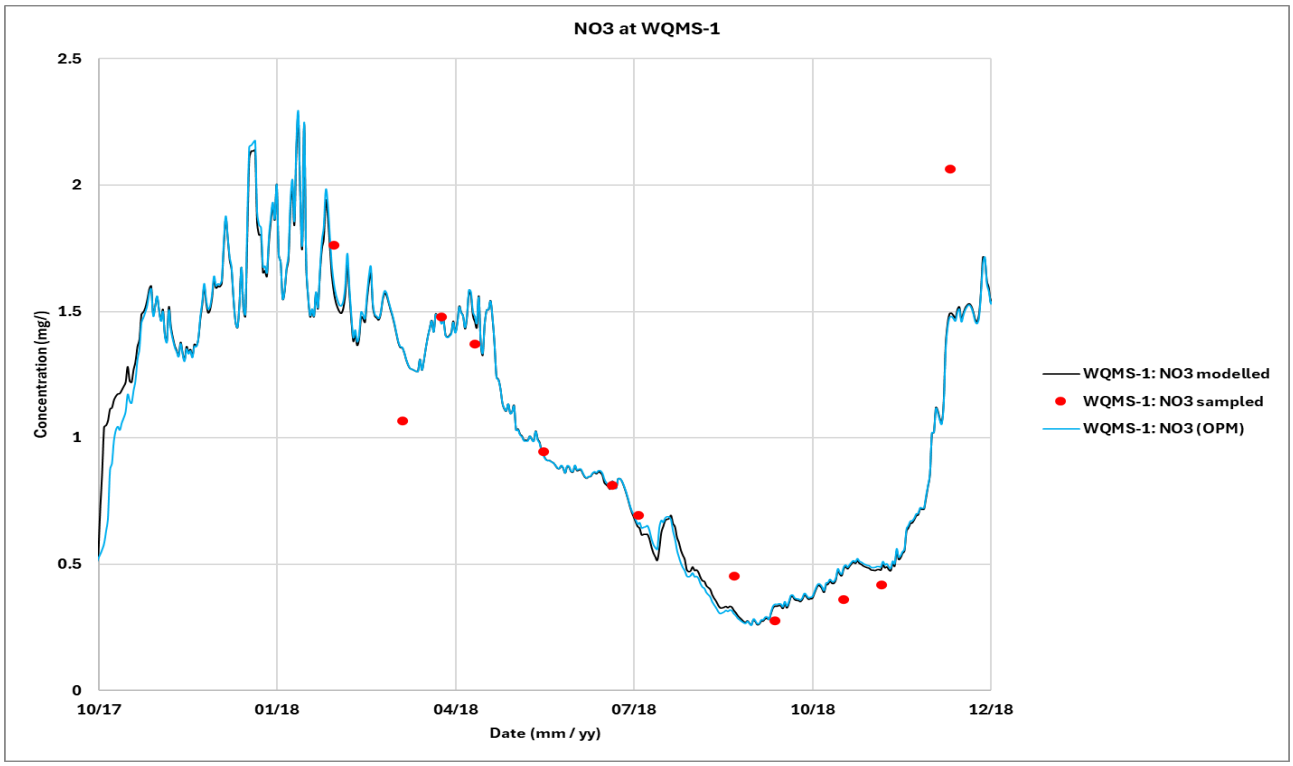


Figure 24: Comparison of NO3-N at WQMS-1 from re-calibrated model and OPM model.

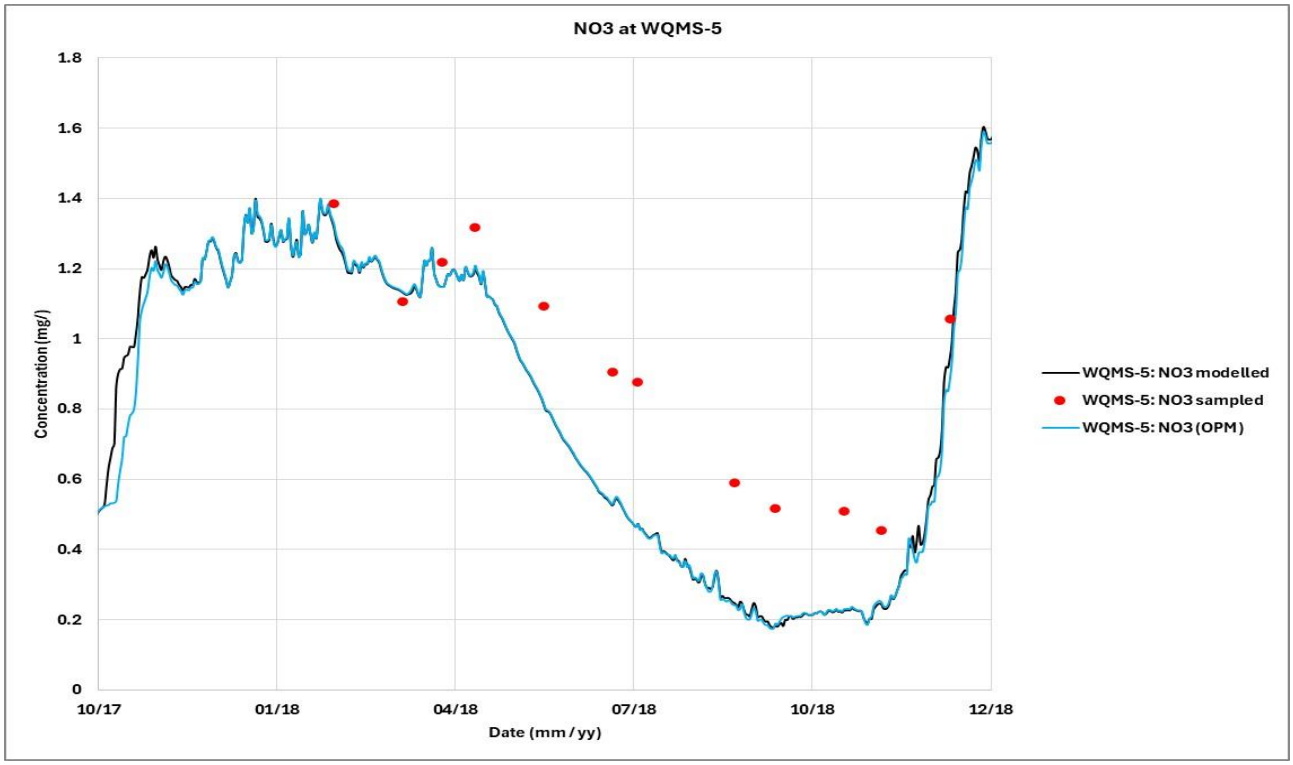


Figure 25: Comparison of NO3-N at WQMS-5 from re-calibrated model and OPM model.

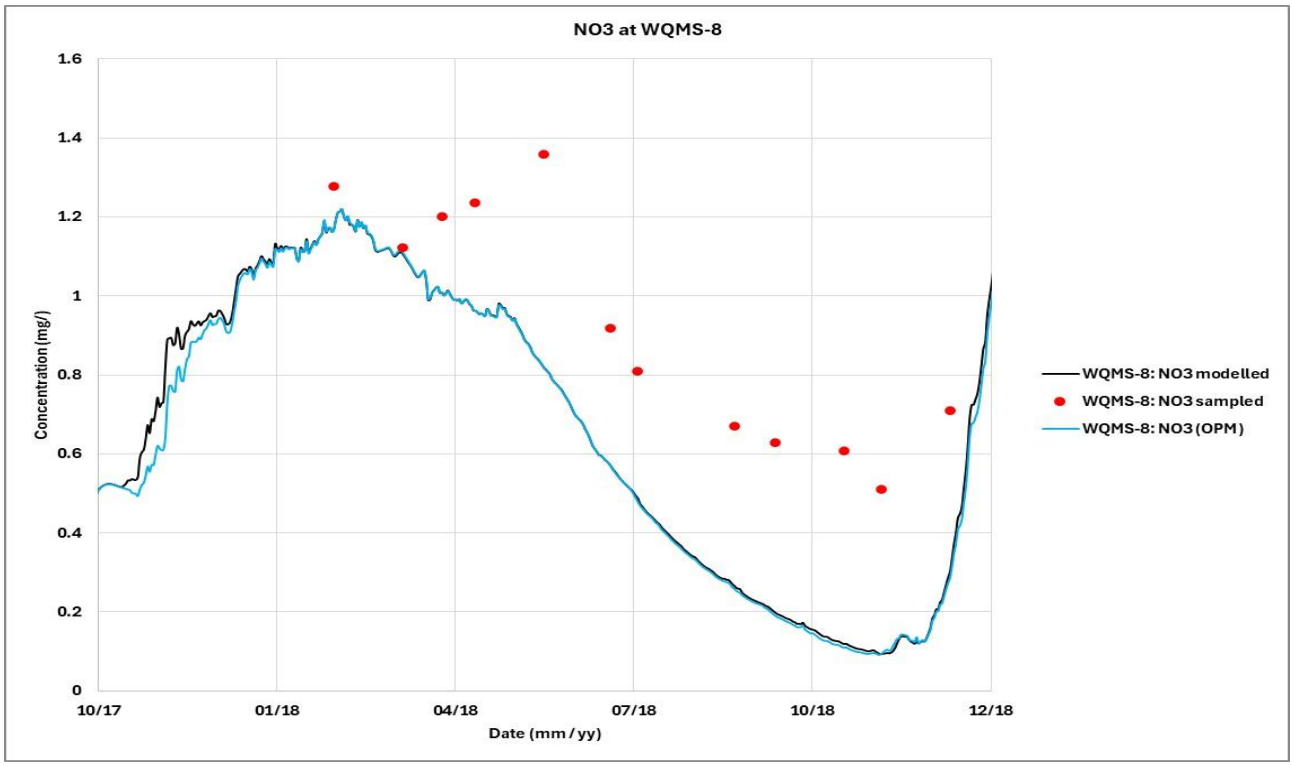


Figure 26: Comparison of NO3-N at WQMS-8 from re-calibrated model and OPM model.

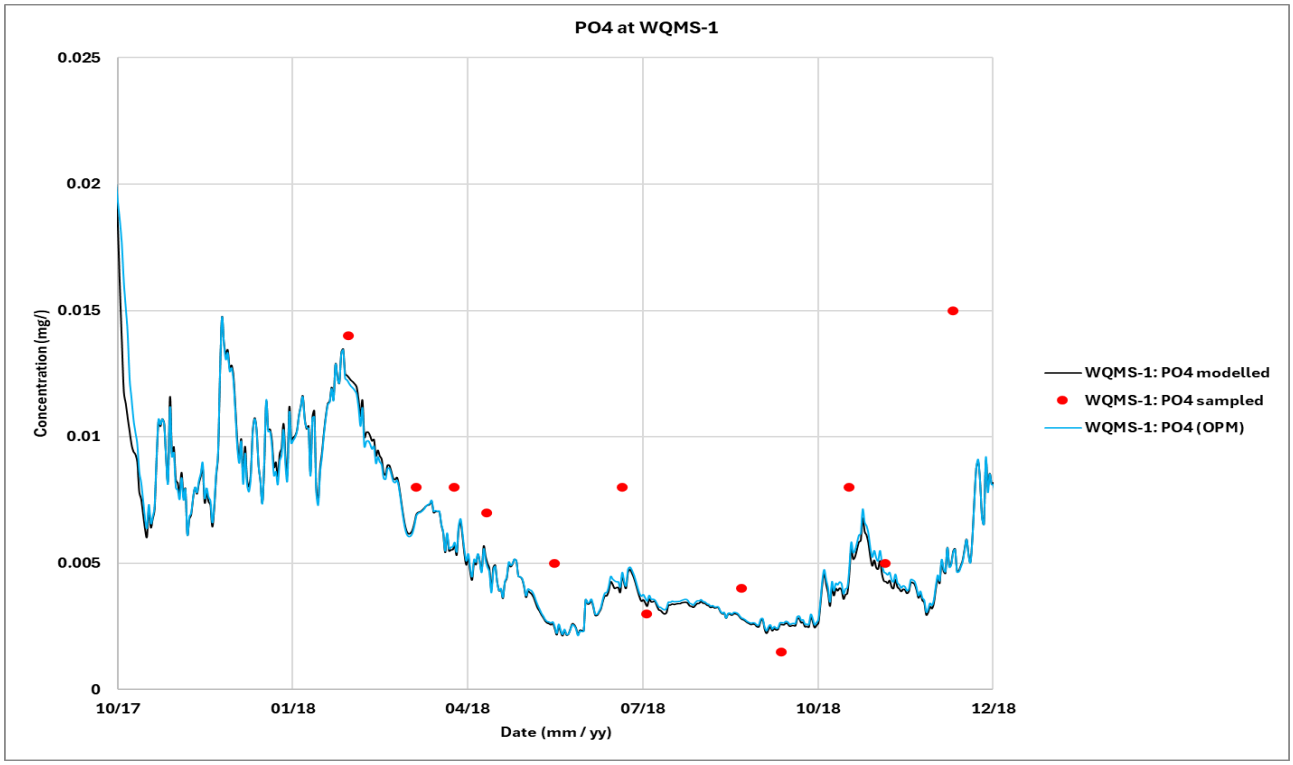


Figure 27: Comparison of PO4-P at WQMS-1 from re-calibrated model and OPM model.

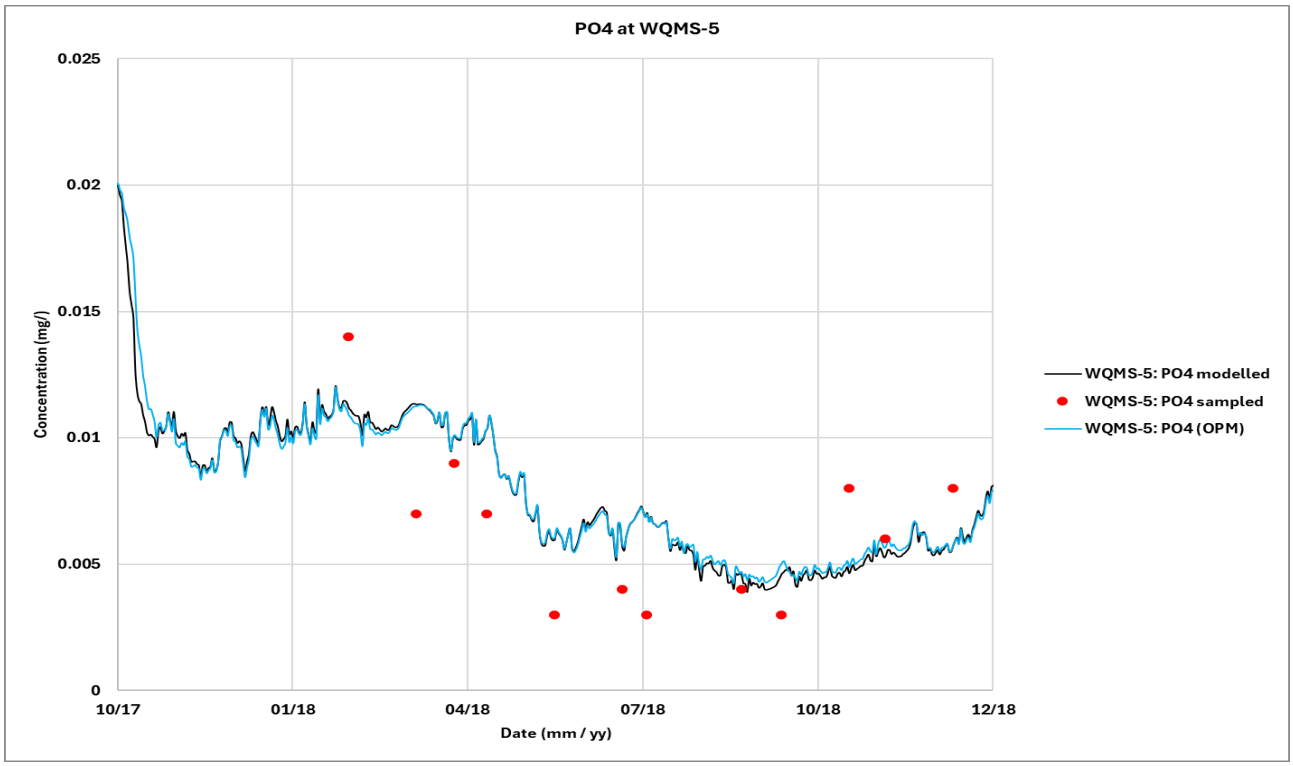


Figure 28: Comparison of PO4-P at WQMS-3 from re-calibrated model and OPM model.

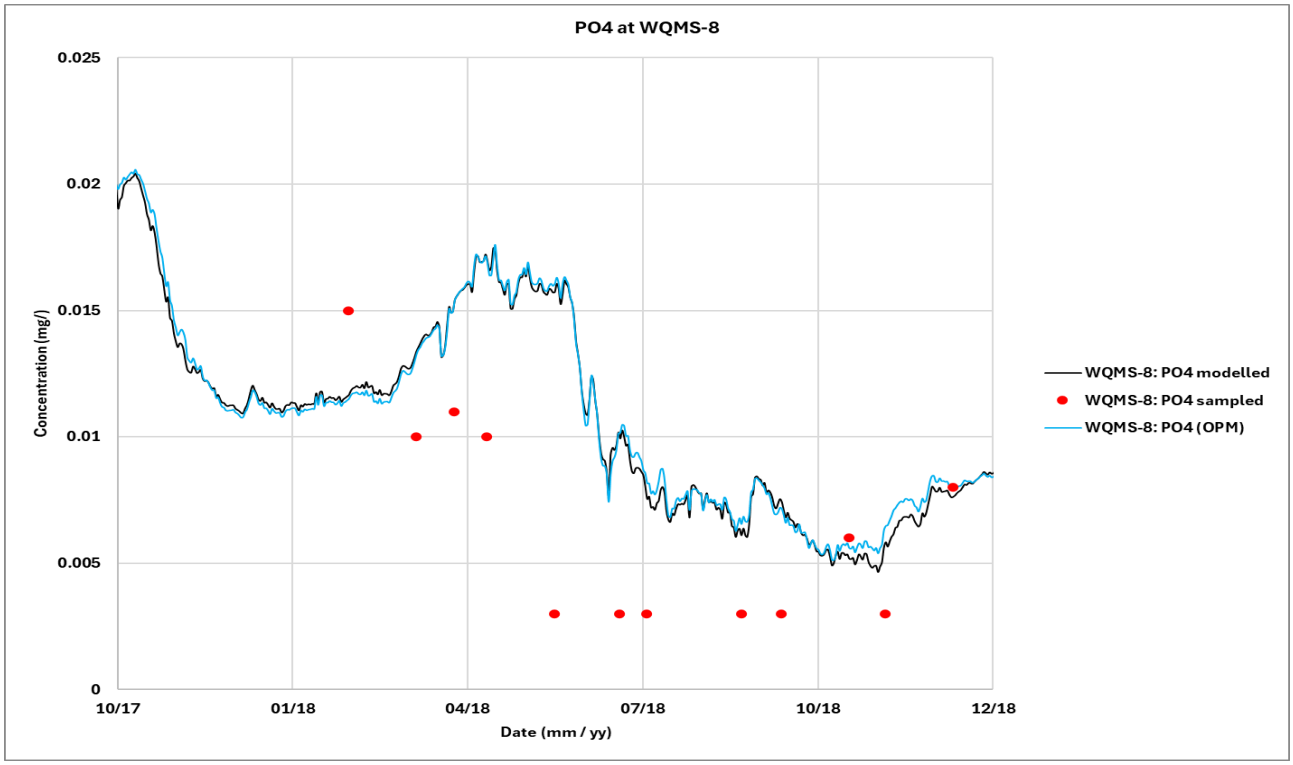


Figure 29: Comparison of PO4-P at WQMS-5 from re-calibrated model and OPM model.

5.3.Summary

To simulate climate change scenarios, the water level boundary conditions of the re-calibrated water quality model were altered to incorporate the water levels derived from the hydrology model's Operational Principles Model. The re-calibrated water quality model was re-run with the new water level boundary conditions and the results compared.

None of the (almost indistinguishable) differences between both model simulations were considered to impact on the accuracy of the water quality model, nor affect the model's ability to elucidate any predicted impacts of climate change above the given baseline and/or proposed abstraction scenarios.

6. Model Scenarios

The summer of 2018 has been identified as one of the most extreme drought periods experienced in Lough Derg across historical records and thus had the potential for impacts on water quality due to the very low flow rates through the system, the reduced water levels, and resultant reduced dilution capacity. The water quality model simulations undertaken to assess the potential impacts on the water quality of Lough Derg and Parteen Basin arising from the proposed abstraction regime from Parteen Basin are described in this section. The water quality model scenarios covered the period from 01/10/2017 to 31/12/2018.

The water quality model scenarios rely on the recorded Ardnacrusha flows being commensurate with the inflow that is entering the system. This is not the case when climate change scenarios alter the inflow regime. Modelling the climate change induced impact of the proposed abstraction required the inclusion of operational rules to determine how much water will flow to Ardnacrusha based upon the changed inflow hydrology whilst still meeting the required compensation flows and keeping the lake levels within the normal operating levels.

This model is referred to as the "Operational Principles Model" and is described in detail in the Hydrological Modelling Report (2025)[5].

6.1. Scenario 1: Baseline

The baseline scenario of Lough Derg and Parteen Basin for the year of 2018 against which to evaluate potential impacts on water quality arising from the proposed abstraction regime.

The summer of 2018 has been identified as one of the most extreme drought periods experienced in Lough Derg across historical records and thus had the potential for impacts on water quality due to the very low flow rates through the system, the reduced water levels, and resultant reduced dilution capacity. The boundary conditions described below representing the recorded prevailing conditions over the period from 01/10/2017 to 31/12/2018 were defined to the model for the Baseline Scenario.

6.1.1. Flows

The River Shannon inflow at the Portumna Bridge upstream boundary of the model was defined to the water quality model from the Project's hydrological model, less the calculated inflows from the twenty-one minor rivers. The outflowing discharge at the Parteen Weir/Ardnacrusha Headrace downstream boundary of the model was defined to the model from data recorded by ESB and made available to the Project and presented in Figure 30.

Inflows from four of the twenty-one smaller rivers flowing into the modelled study area were defined to the water quality model from daily average flow records recorded by the OPW at hydrometric stations installed on each of the four rivers Ballyfinboy, Nenagh, Graney, and Kilcrow.

Inflows from the seventeen remaining smaller rivers flowing into to the modelled study area without hydrometric stations were calculated using gauged area transposition from the adjoining / adjacent

[5] Uisce Éireann, 2025. Water Supply Project: Eastern and Midlands Region. Environmental Impact Assessment Report Appendix 9.1, Annex A, Hydrological Modelling Report.

gauged catchments and defined to the water quality model. The hydrographs for all inflows are presented in Figure 31. The hydrographs for the twenty-one smaller rivers are presented separately in Figure 32 for clarity.

The River Shannon at Portumna accounted for 79.4% of the total inflow to the modelled study area during the Baseline Scenario period from 01/10/2017 to 31/12/2018. The four gauged rivers (Ballyfinboy, Nenagh, Graney, and Kilcrow) accounted for 14.7%. The other seventeen smaller rivers combined, for which inflows were calculated based on the gauged area transposition method, represented <6% of the total inflows to the modelled study area.

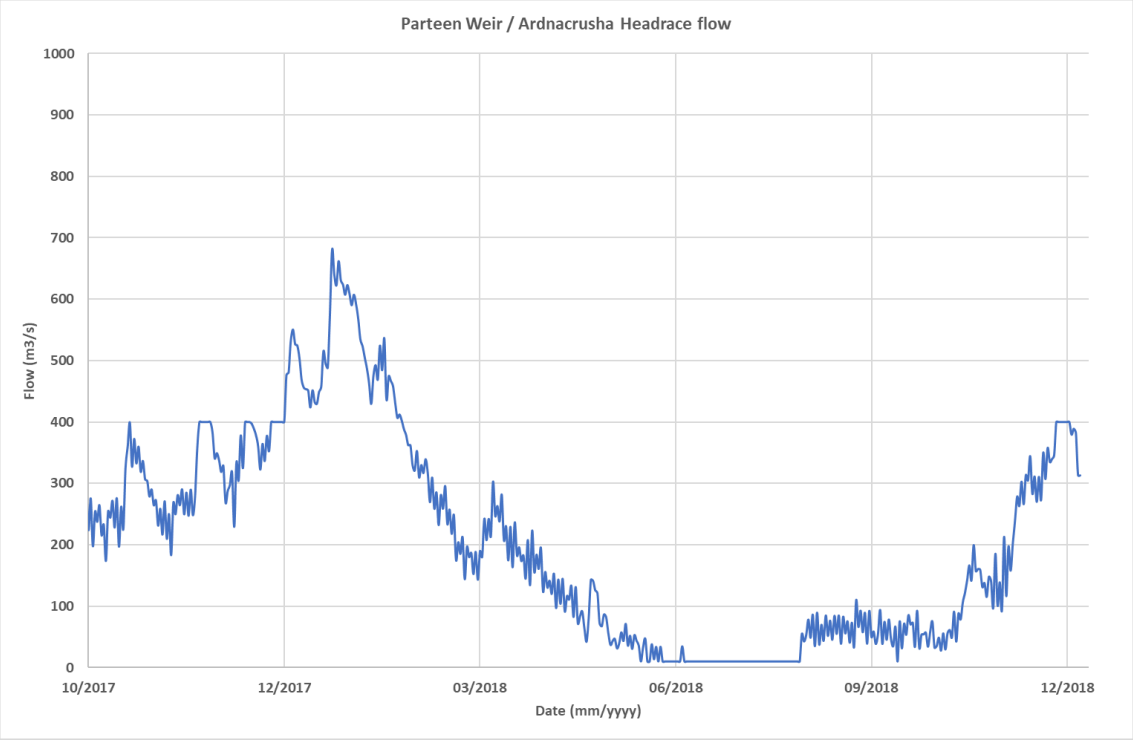


Figure 30: Recorded outflows at Parteen Weir / Ardnacrusha Headrace (01/10/2017 to 31/12/2018)

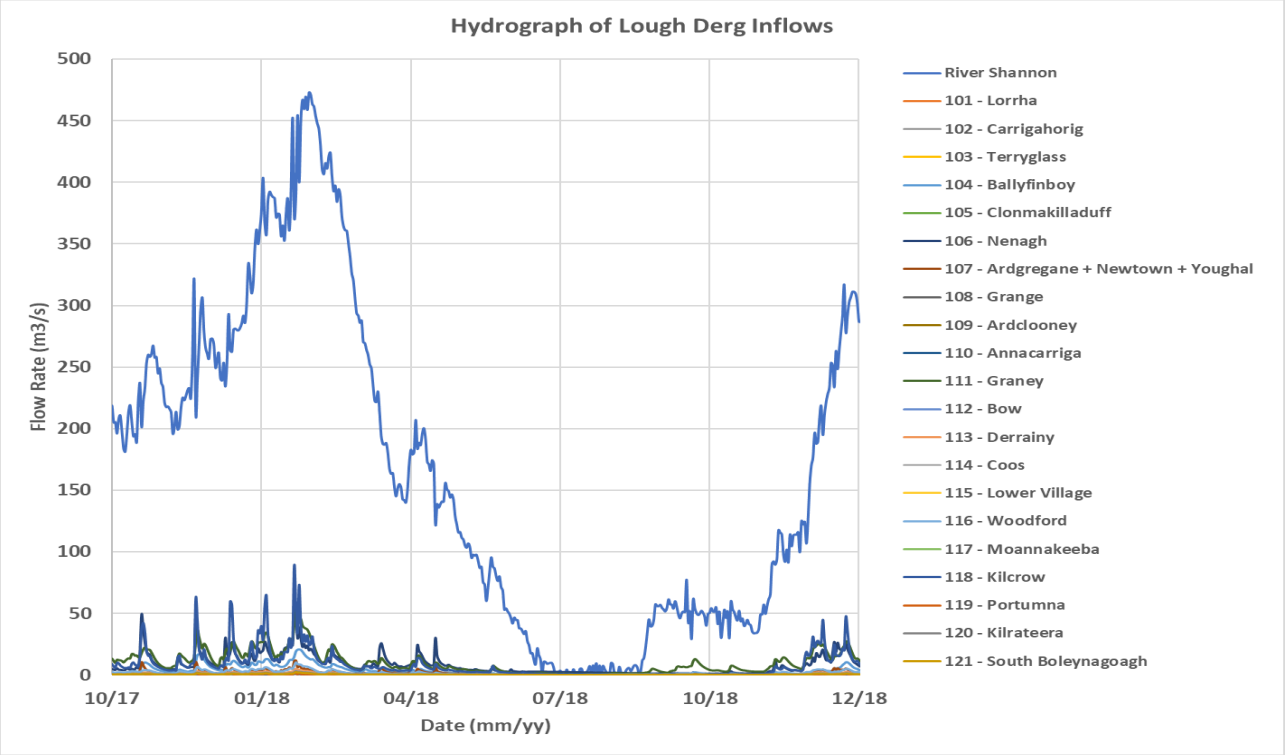


Figure 31: Hydrograph of all Lough Derg inflows (01/10/2017 to 31/12/2018)

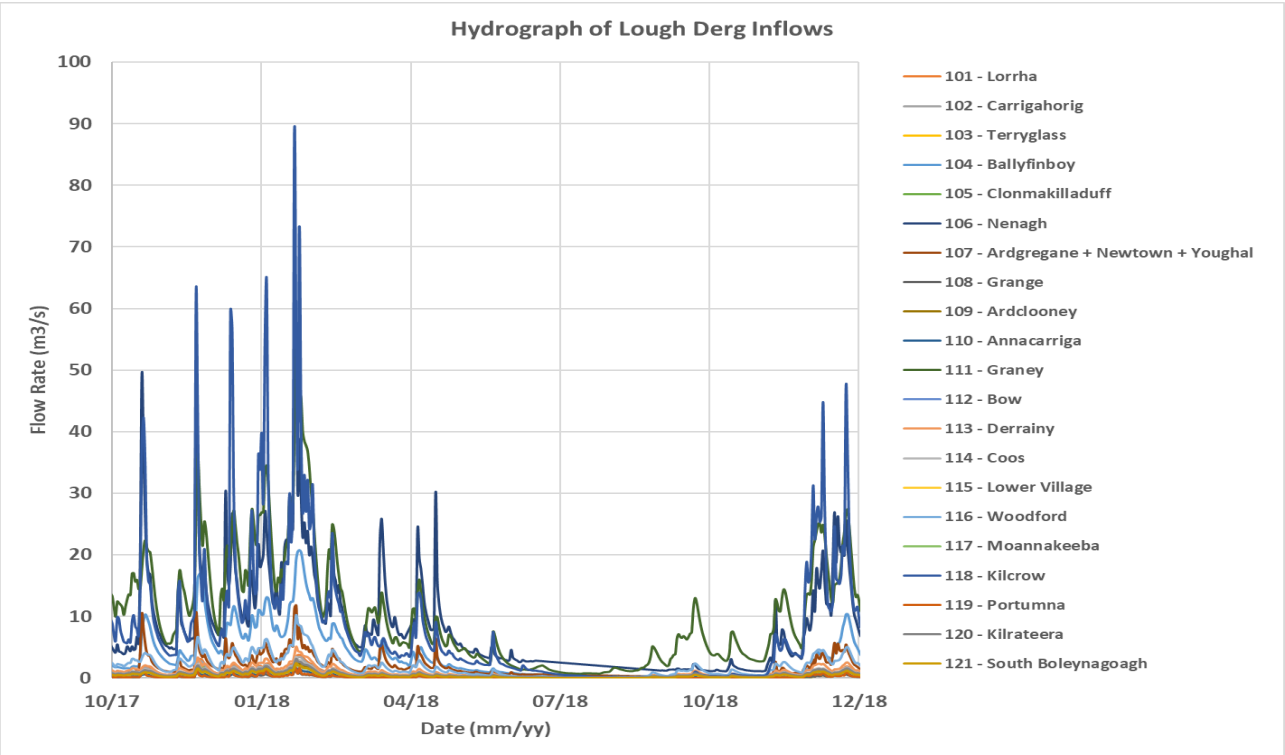


Figure 32: Hydrograph of Lough Derg inflows excluding River Shannon (01/10/2017 to 31/12/2018)

6.1.2. Water Levels

Water levels at both the Portumna Bridge upstream boundary of the model and the Parteen Weir/Ardnacrusha Headrace downstream boundary of the model were defined to the water quality model according to the Operational Principles Model (OPM) presented previously and are presented in Figure 33.

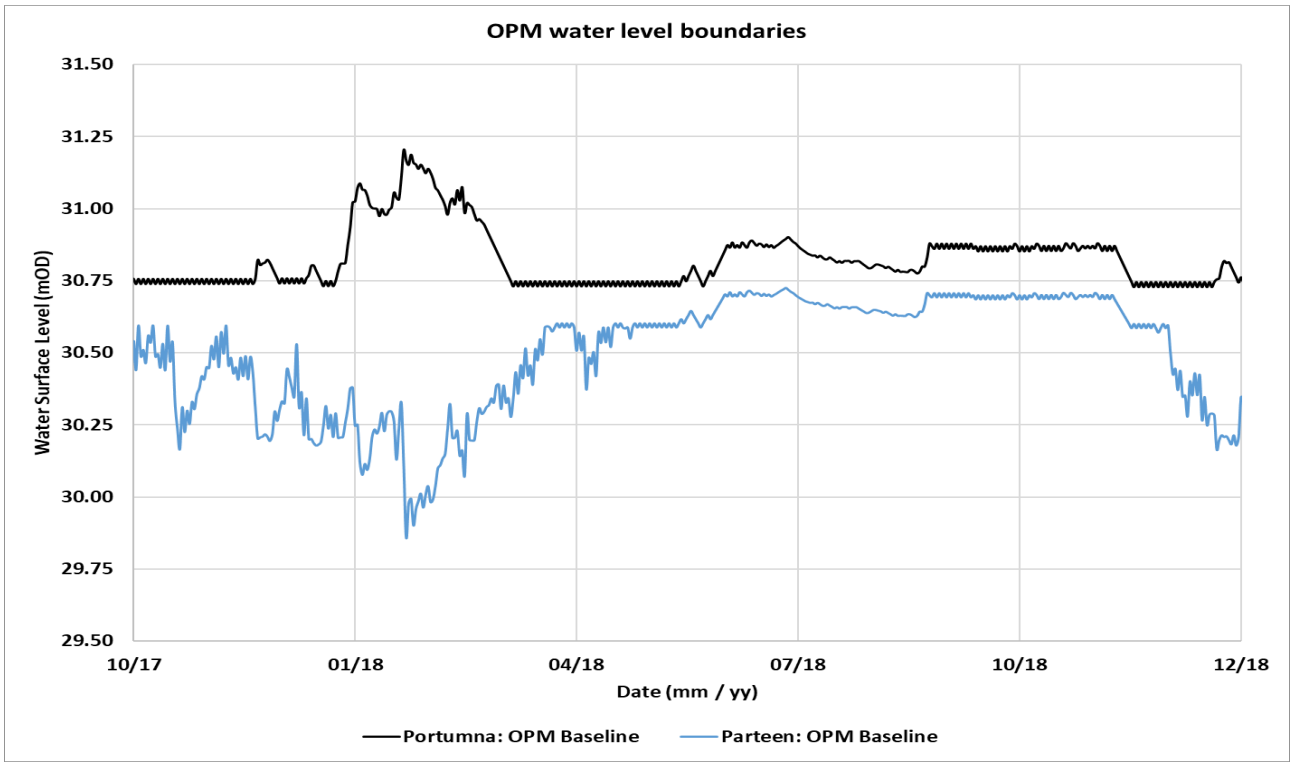


Figure 33: OPM water levels at Portumna Bridge and Parteen Weir (01/10/2017 to 31/12/2018)

6.1.3. Water Quality

The water quality parameters of interest were biochemical oxygen demand (BOD), dissolved oxygen (DO), chlorophyll-a (CHL), nitrite (NO2-N), ammonia (NH3-N), nitrate (NO3-N) and ortho-phosphate (PO4-P).

Concentrations of the above water quality parameters entering the study area from the various inflowing rivers were defined to the model. The water quality concentrations in the River Shannon were recorded at 8-hour intervals by automatic nutrient analyser SS01 located at Portumna Bridge.

Of the twenty-one smaller rivers flowing into the study area, eleven rivers were sampled for water quality parameters by the Project and the EPA's Water Framework Directive monitoring programme.

The remaining ten small rivers have historically not had a sampling programme and therefore constant ambient concentrations were specified for water quality parameters according to the method adopted in the water quality Model Re-calibration Report included as Appendix I to this document. The locations of the twenty-one smaller rivers draining to the modelled study area was presented in Figure 2.

The water quality concentrations defined in the River Shannon and the twenty-one rivers flowing into the modelled study area are detailed in Table 1. The Ardgregane, Newtown, and Youghal rivers all discharge in proximity to each other and have been defined to the model as a single point discharge. Graphs of the automatically recorded and manually sampled data for the respective parameters are presented in Figure 34 to Figure 39.

River / Parameter	BOD	DO	CHL	NO2-N	NH3-N	NO3-N	PO4-P
River Shannon	Sampled Data		0.003	Sampled Data			
101 - Lorrha	Sampled Data		0.003	Sampled Data			
102 - Carrigahorig	Sampled Data		0.003	Sampled Data			
103 - Terryglass	1.5	10.0	0.003	0.01	0.05	3.00	0.02
104 - Ballyfinboy	Sampled Data		0.003	Sampled Data			
105 - Clonmakilladuff	1.5	10.0	0.003	0.01	0.05	3.00	0.02
106 - Nenagh	Sampled Data		0.003	Sampled Data			
107 - Ardgregane + Newtown + Youghal	Sampled Data		0.003	Sampled Data			
108 - Grange	1.5	10.0	0.003	0.01	0.05	3.00	0.02
109 - Ardclooney	1.5	10.0	0.003	0.01	0.05	3.00	0.02
110 - Annacarriga	1.5	10.0	0.003	0.01	0.05	3.00	0.02
111 - Graney	Sampled Data		0.003	Sampled Data			
112 - Bow	Sampled Data		0.003	Sampled Data			
113 - Derrainy	1.5	10.0	0.003	0.01	0.05	3.00	0.02
114 - Coos	Sampled Data		0.003	Sampled Data			
115 - Lower Village	Sampled Data		0.003	Sampled Data			
116 - Woodford	Sampled Data		0.003	Sampled Data			
117 - Moannakeeba	1.5	10.0	0.003	0.01	0.05	3.00	0.02
118 - Kilcrow	Sampled Data		0.003	Sampled Data			
119 - Portumna	1.5	10.0	0.003	0.01	0.05	3.00	0.02
120 - Kilrateera	1.5	10.0	0.003	0.01	0.05	3.00	0.02
121 - South Boleynagoagh	1.5	10.0	0.003	0.01	0.05	3.00	0.02

Table 1: Water quality concentrations for each river boundary in the model domain.

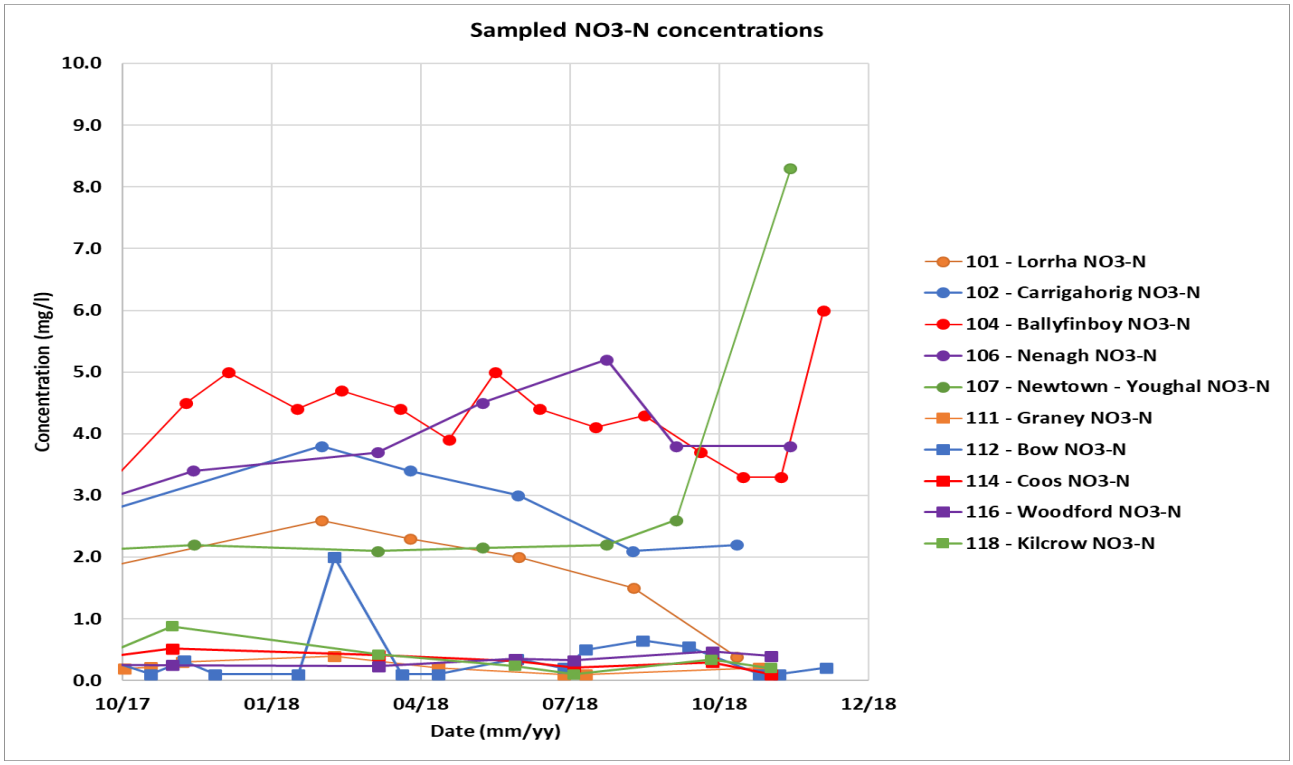


Figure 34: Sampled NO3-N concentrations (01/10/2017 to 31/12/2018)

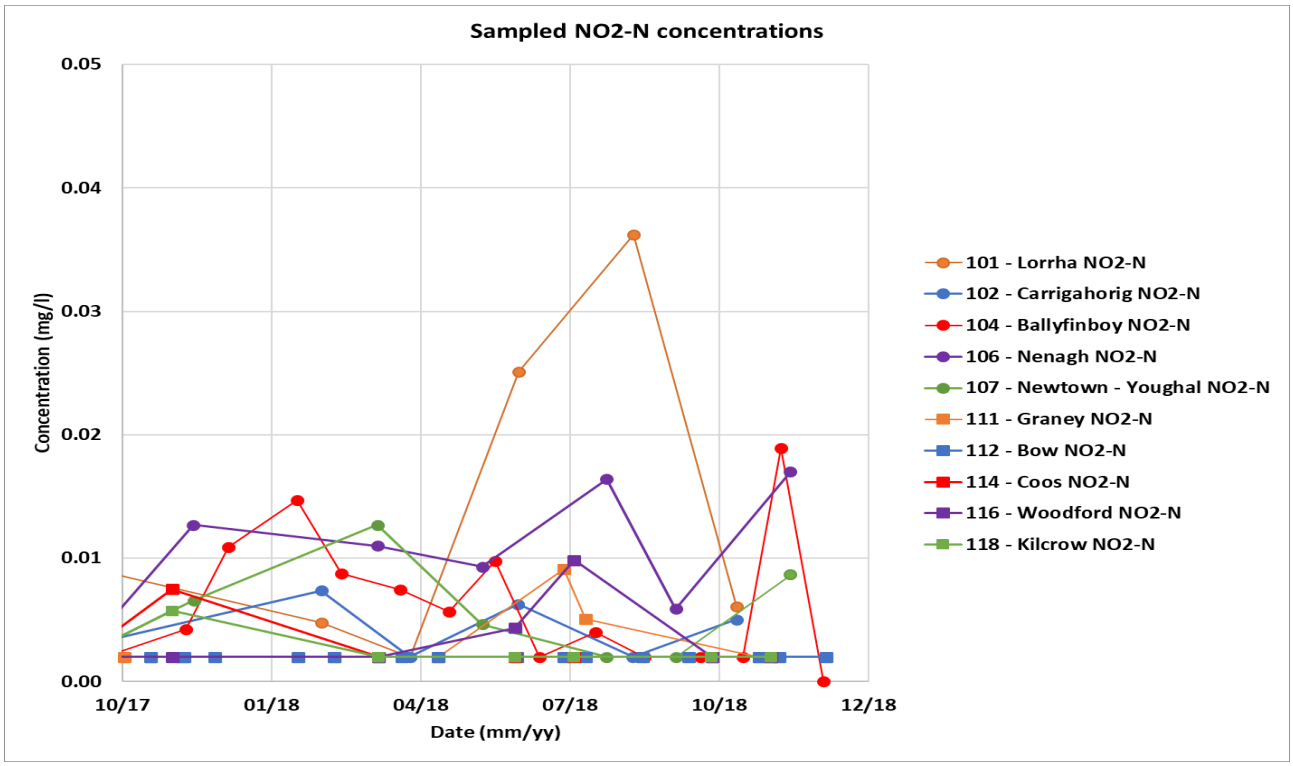


Figure 35: Sampled NO2-N concentrations (01/10/2017 to 31/12/2018)

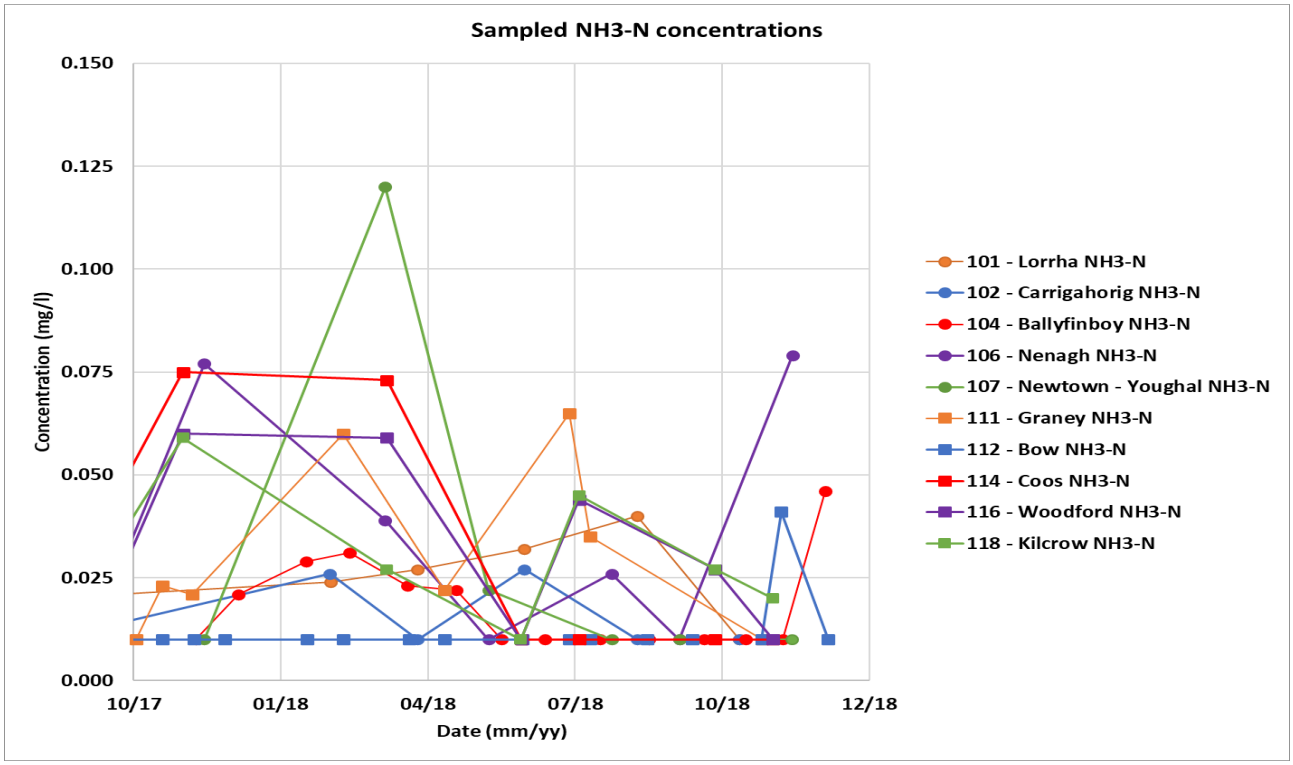


Figure 36: Sampled NH3-N concentrations (01/10/2017 to 31/12/2018)

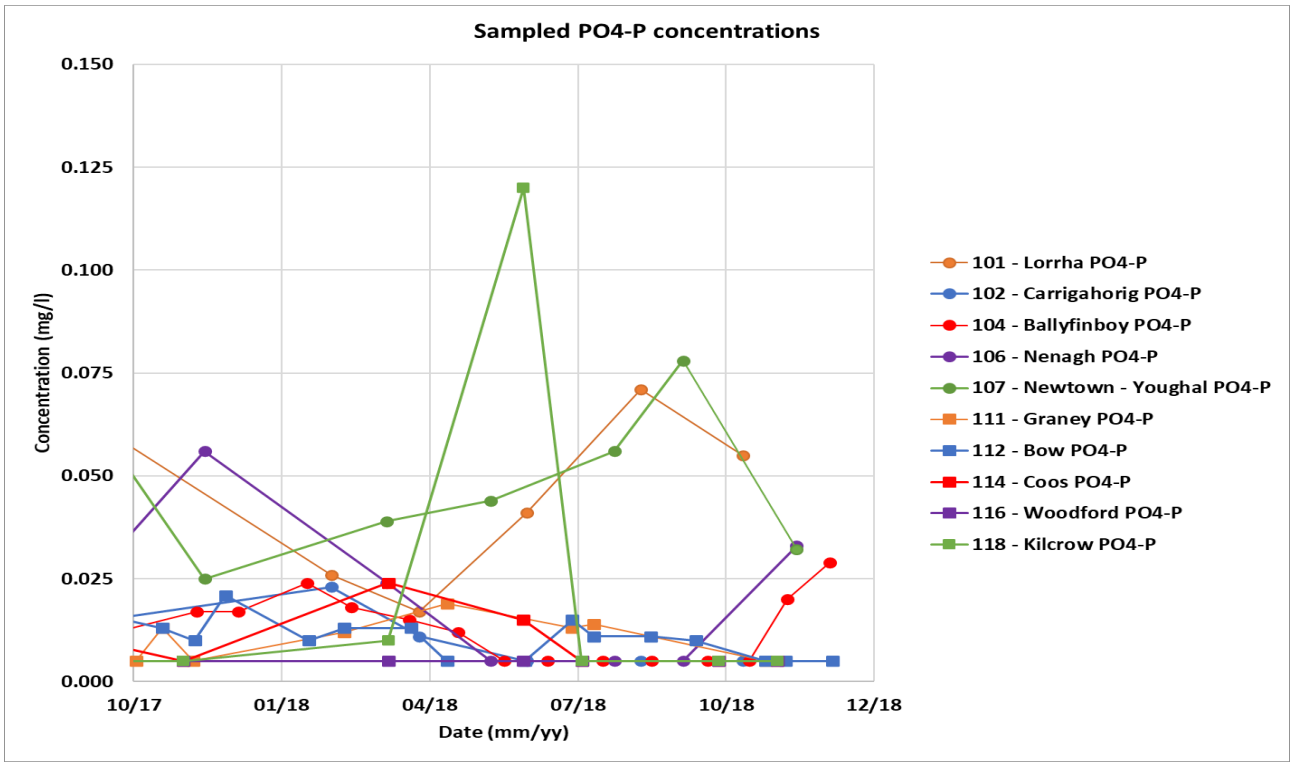


Figure 37: Sampled PO4-P concentrations (01/10/2017 to 31/12/2018)

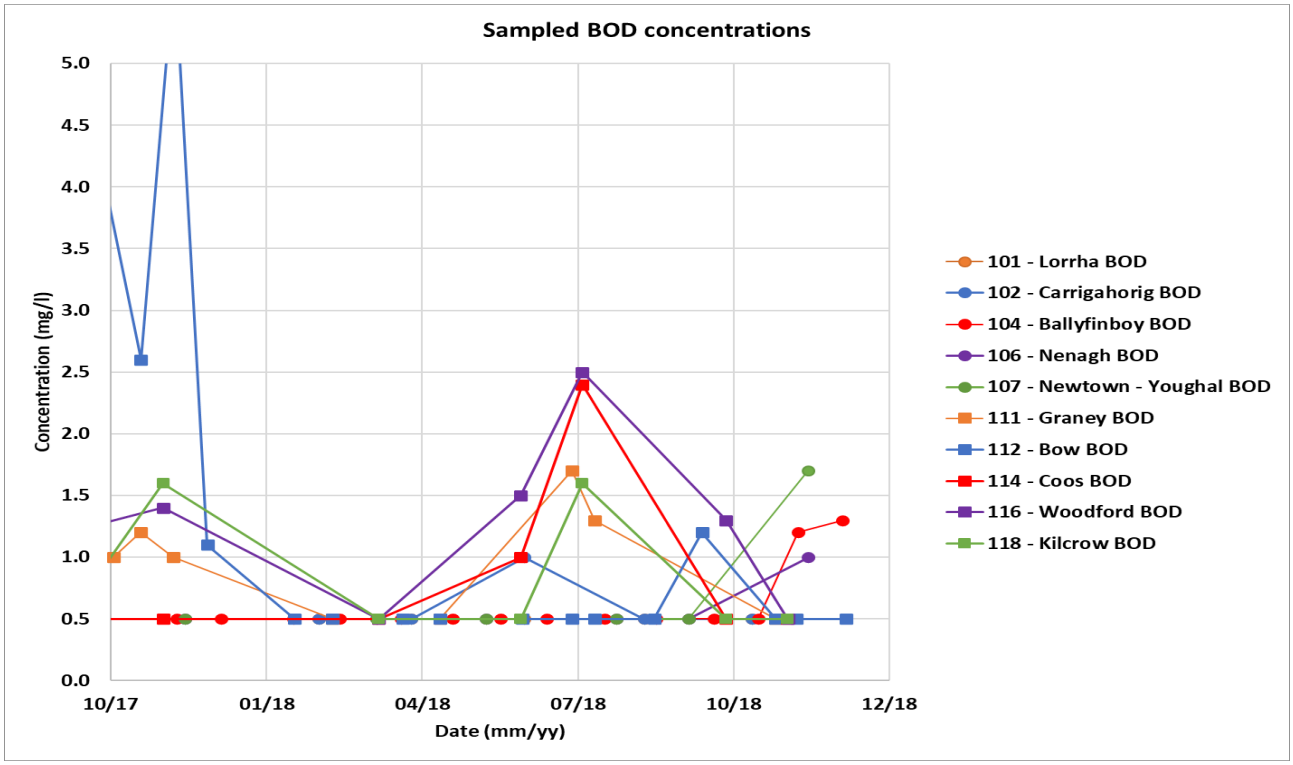


Figure 38: Sampled BOD concentrations (01/10/2017 to 31/12/2018)

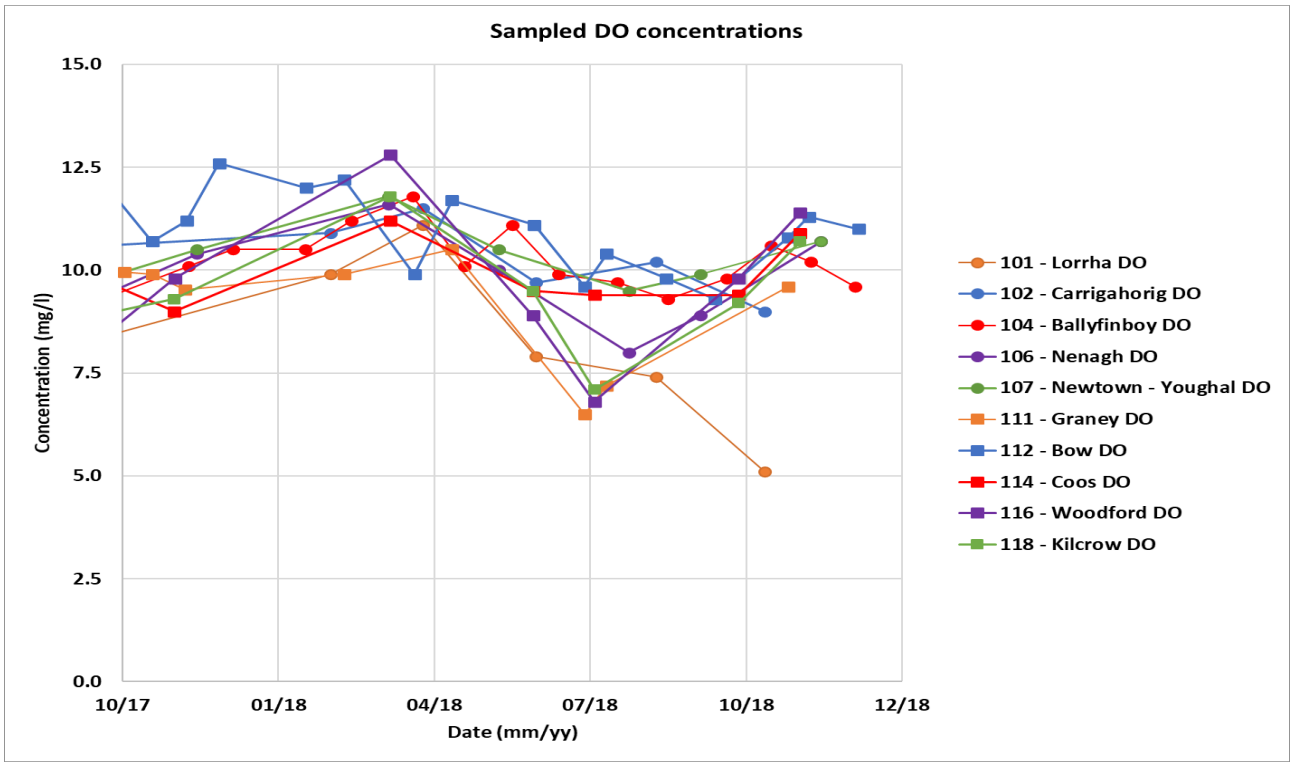


Figure 39: Sampled DO concentrations (01/10/2017 to 31/12/2018)

6.2. Scenario 2: Proposed Abstraction at constant 154 Ml/day

This scenario evaluated the potential impacts on water quality during one of the most extreme drought periods experienced in Lough Derg across historical records in summer 2018 if the proposed abstraction had been operating at a constant 154 Ml/day over the period 01/10/2017 to 31/12/2018.

This scenario consisted of re-running the Scenario 1: Baseline simulation incorporating the operation of the proposed 154 Ml/day abstraction regime in Parteen Basin. The boundary conditions described below were defined to the model over the period from 01/10/2017 to 31/12/2018

6.2.1. Flows

The River Shannon inflow at the Portumna Bridge upstream boundary of the model was unchanged from the Scenario 1: Baseline simulation previously detailed. Inflows for the twenty-one smaller rivers were unchanged from the Scenario 1: Baseline simulation previously detailed. The proposed abstraction in Parteen Basin was defined at a constant rate of 154 Ml/day.

The outflowing discharge at the Parteen Weir/Ardnacrusha headrace canal downstream boundary of the model was reduced to compensate for the proposed constant 154 Ml/day abstraction regime whilst maintaining the statutory flow of 10 m^3/s to the natural course of the River Shannon through Parteen Weir and 0.5 m^3/s through the Ardnacrusha fish pass.

The changes to outflowing discharge at the Parteen Weir/Ardnacrusha headrace canal downstream boundary of the model due to the proposed constant 154 Ml/day abstraction regime is presented in Figure 40.

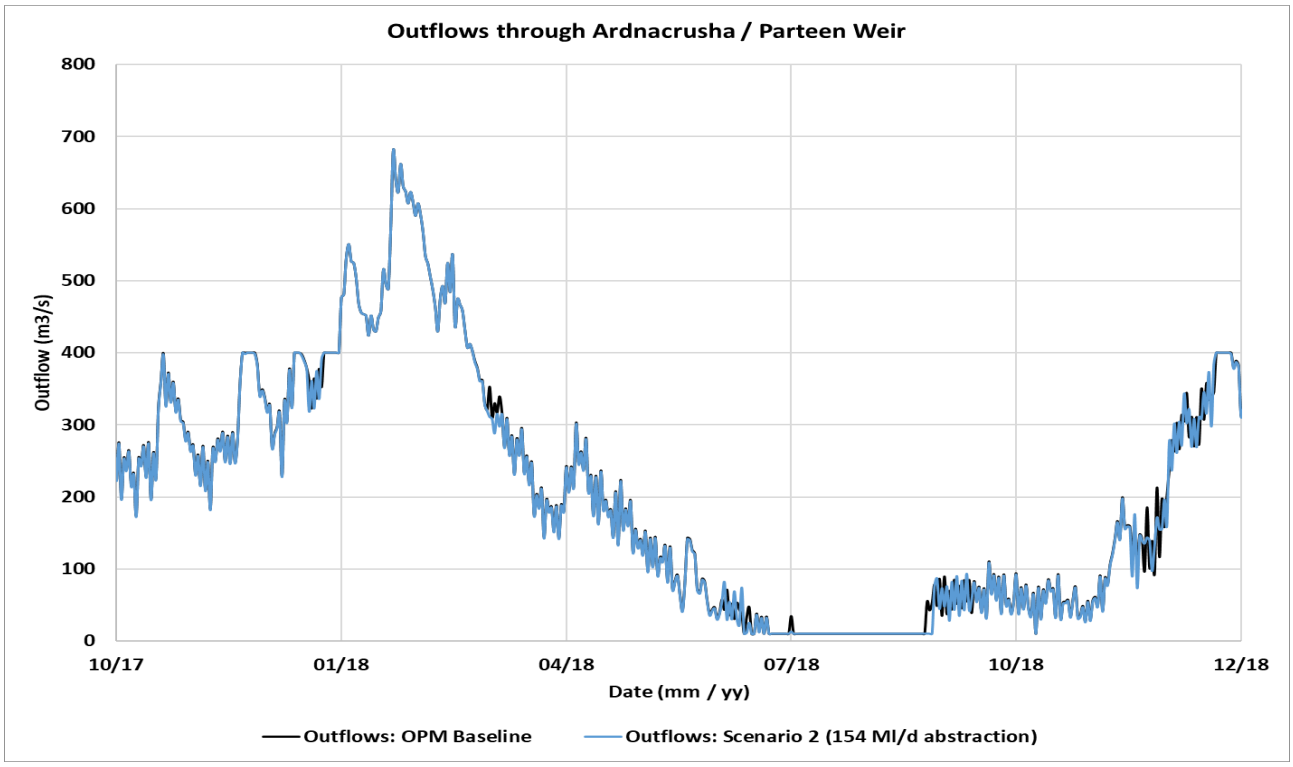


Figure 40: Baseline v Scenario 2 outflows through Ardnacrusha / Parteen Weir due to proposed 154Ml/d abstraction (01/10/2017 to 31/12/2018)

6.2.2. Water Levels

The volume of water required to meet the proposed abstraction (as well as the required statutory flow of 10 m^3/s to the natural course of the River Shannon and 0.5 m^3/s through the Ardnacrusha fish pass) is met through a combination of the low drought inflows and, when necessary, a depletion of the lake storage. Depletion of the lake storage results in a drop in water level which was modelled as being evenly distributed across the surface area of Lough Derg and Parteen Basin.

The changes to water levels at the Portumna Bridge upstream boundary of the model and the Parteen Weir/Ardnacrusha Headrace downstream boundary of the model due to the proposed constant 154 Ml/day abstraction regime are presented in Figure 41 and Figure 42 respectively.

6.2.3. Water Quality

Water quality data for the River Shannon and the twenty-one inflowing rivers was unchanged from the Scenario 1: Baseline simulation previously detailed.

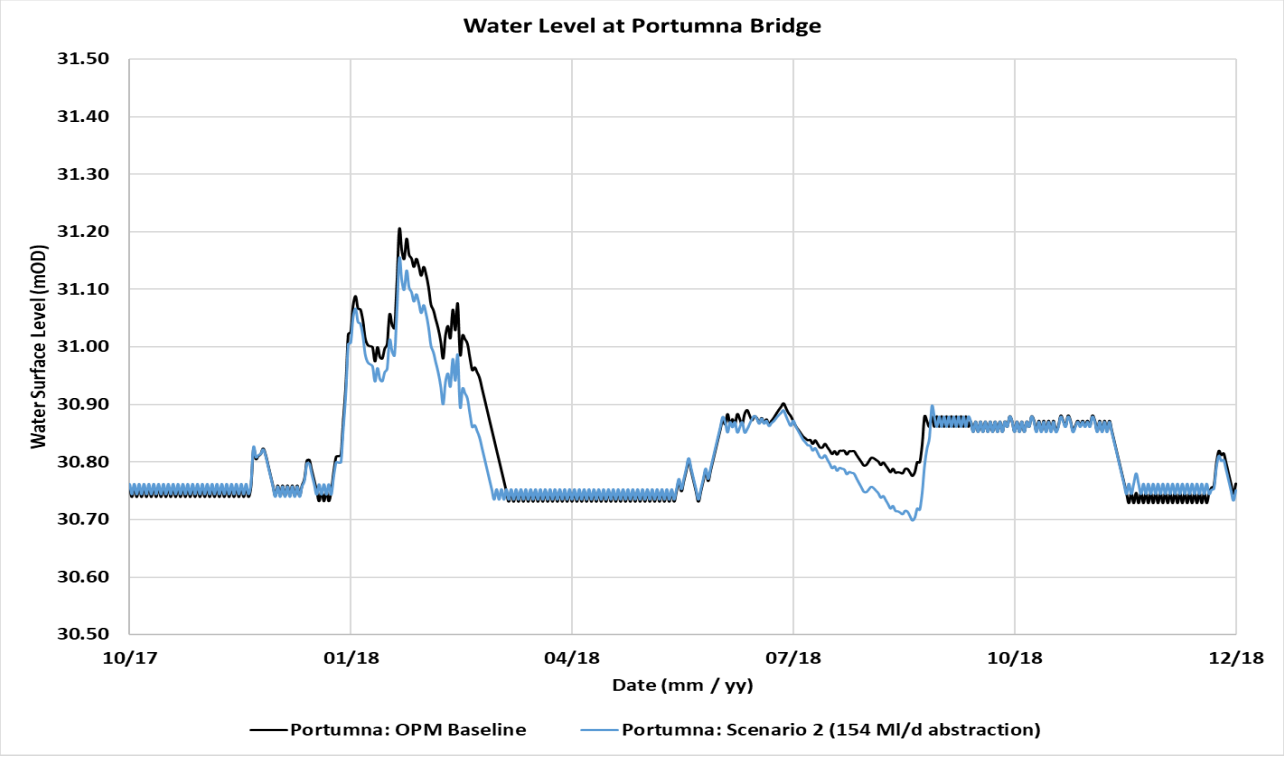


Figure 41: Baseline v Scenario 2 water levels at Portumna Bridge due to proposed 154 Ml/d abstraction (01/10/2017 to 31/12/2018)

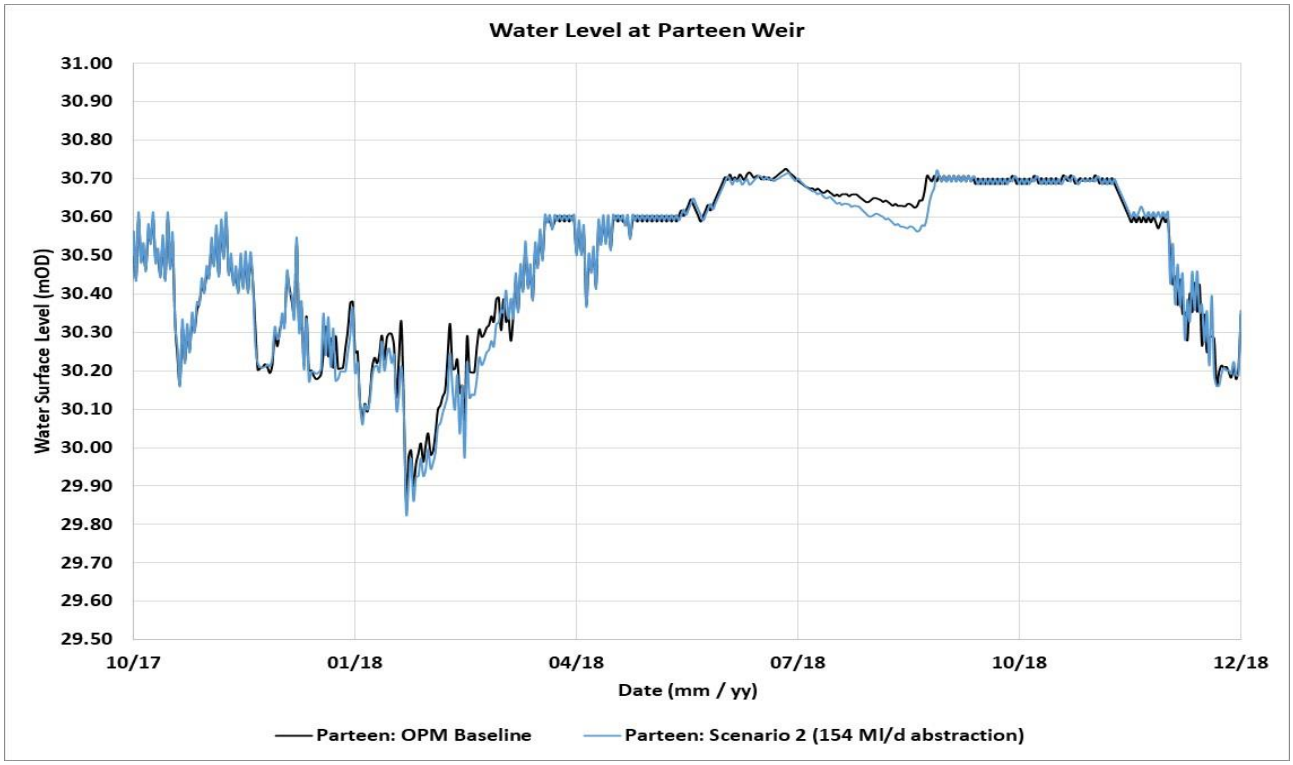


Figure 42: Baseline v Scenario 2 water levels at Parteen Weir due to proposed 154Ml/d abstraction (01/10/2017 to 31/12/2018)

6.3. Scenario 3: Proposed Abstraction at constant 300 Ml/day

This scenario evaluated the potential impacts on water quality during one of the most extreme drought periods experienced in Lough Derg across historical records in summer 2018 if the proposed abstraction had been operating at a constant 300 Ml/day over the period 01/10/2017 to 31/12/2018. This scenario consisted of re-running the Scenario 1: Baseline simulation incorporating the operation of the proposed 300 Ml/day abstraction regime in Parteen Basin.

6.3.1. Flows

The River Shannon inflow at the Portumna Bridge upstream boundary of the model was unchanged from the Scenario 1: Baseline simulation previously detailed. Inflows for the twenty-one smaller rivers were unchanged from the Scenario 1: Baseline simulation previously detailed. The proposed abstraction in Parteen Basin was defined at a constant rate of 300 Ml/day.

The outflowing discharge at the Parteen Weir/Ardnacrusha headrace canal downstream boundary of the model was reduced to compensate for the proposed abstraction rate whilst maintaining the statutory flow of 10 m^3/s to the natural course of the River Shannon through Parteen Weir and 0.5 m^3/s through the Ardnacrusha fish pass.

The changes to outflowing discharge at the Parteen Weir/Ardnacrusha headrace canal downstream boundary of the model due to the proposed constant 300 Ml/day abstraction regime is presented in Figure 43.

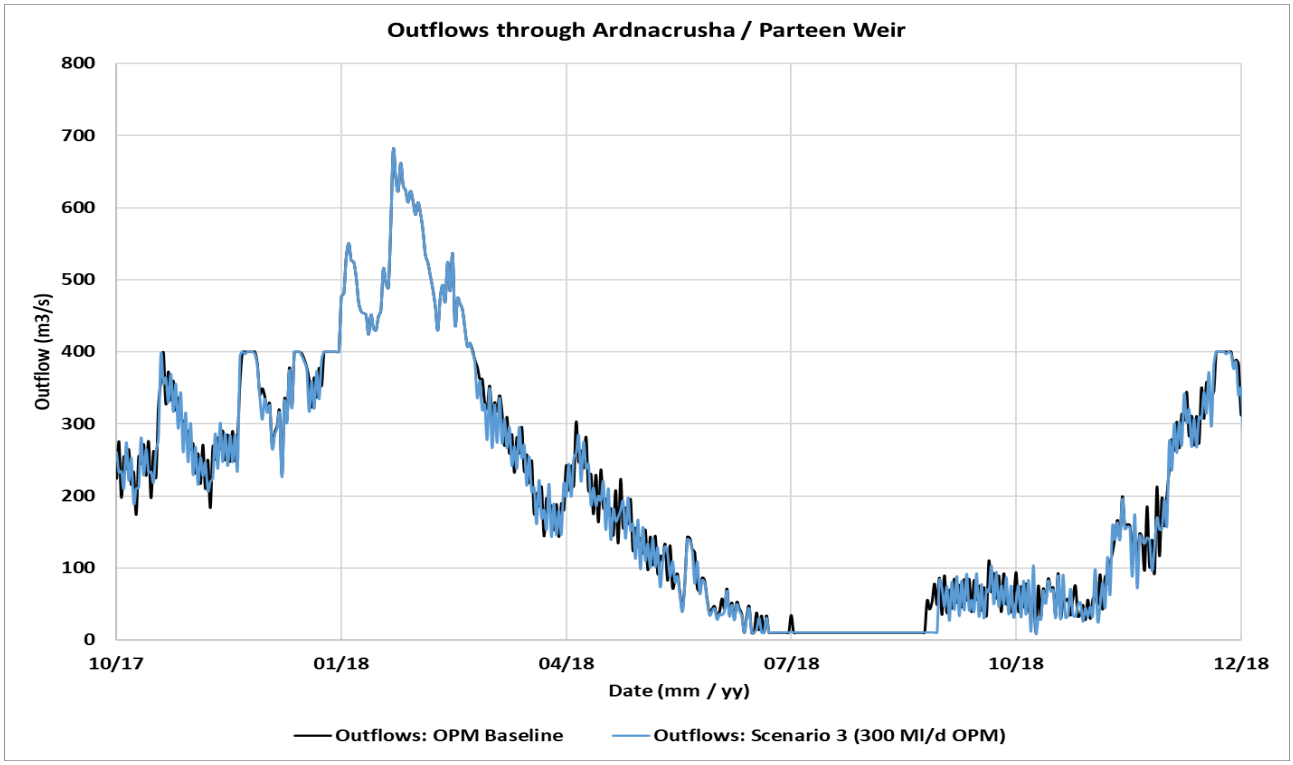


Figure 43: Baseline v Scenario 3 outflows through Ardnacrusha / Parteen Weir due to proposed 300 Ml/d abstraction (01/10/2017 to 31/12/2018)

6.3.2. Water Levels

The volume of water required to meet the proposed abstraction (as well as the required statutory flow of 10 m^3/s to the natural course of the River Shannon and 0.5 m^3/s through the Ardnacrusha fish pass) is met through a combination of the low drought inflows and, when necessary, a depletion of the lake storage. Depletion of the lake storage results in a drop in water level which was modelled as being evenly distributed across the surface area of Lough Derg and Parteen Basin.

The changes to water levels at the Portumna Bridge upstream boundary of the model and the Parteen Weir/Ardnacrusha headrace canal downstream boundary of the model due to the proposed constant 300 Ml/day abstraction regime are presented in Figure 44 and Figure 45 respectively.

6.3.3. Water Quality

Water quality data for the River Shannon and the twenty-one inflowing rivers were unchanged from the Scenario 1: Baseline simulation previously detailed.

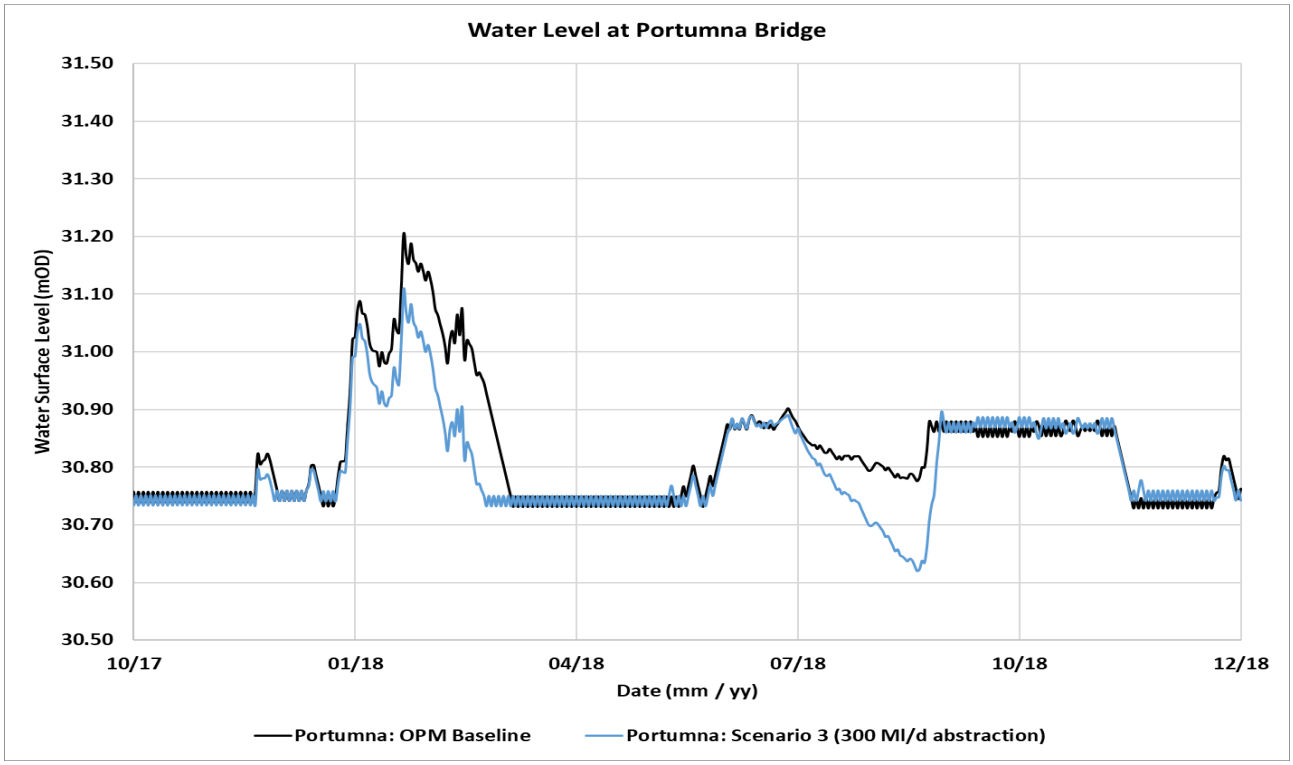


Figure 44: Baseline v Scenario 3 water levels at Portumna Bridge due to proposed 300Ml/d abstraction (01/10/2017 to 31/12/2018)

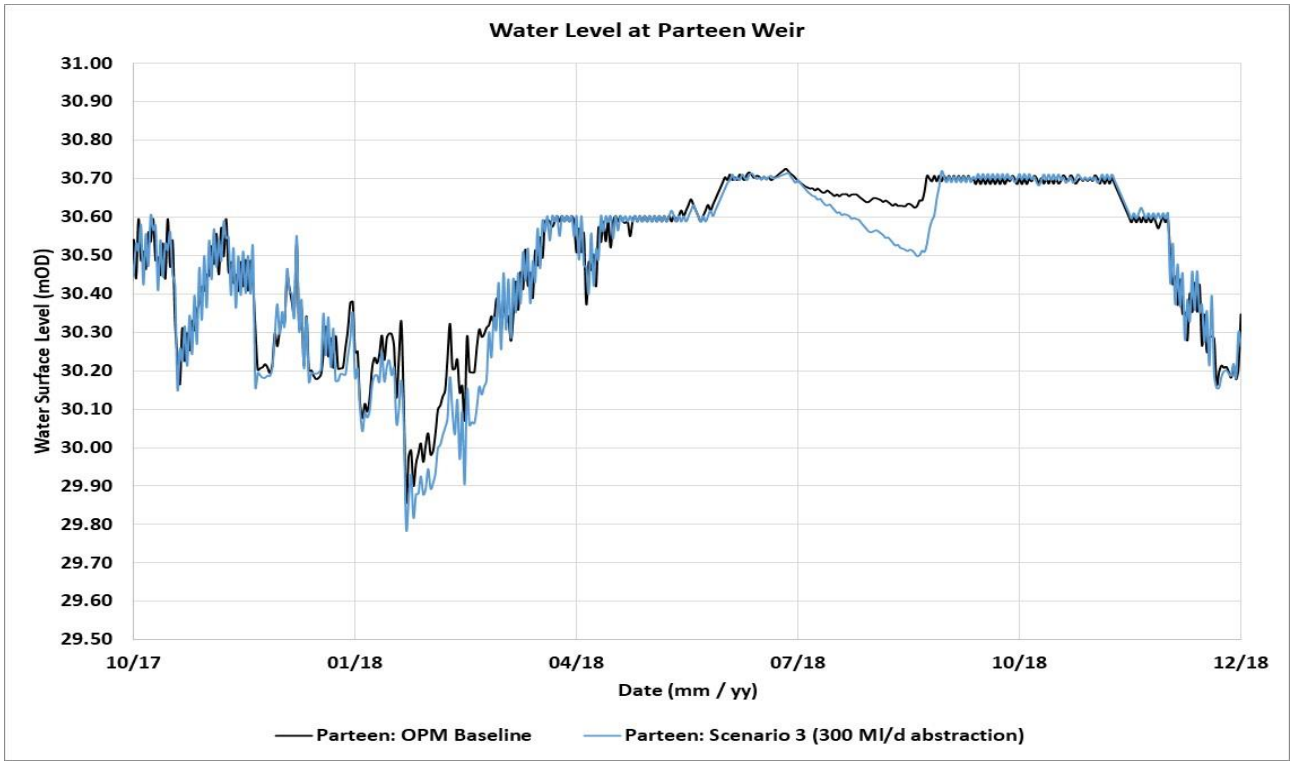


Figure 45: Baseline v Scenario 3 water levels at Parteen Weir due to proposed 300Ml/d abstraction (01/10/2017 to 31/12/2018)

6.4. Scenario 4: Proposed Abstraction at constant 154 Ml/day incorporating climate change effects

This scenario evaluated the potential impacts on water quality arising from the operation of the proposed abstraction at a constant rate of 154 Ml/day during a reasonable worst-case drought period incorporating climate change effects for the 2080 epoch into the 01/10/2017 to 31/12/2018 period.

The climate change effects for the 2080 epoch incorporated into the water quality modelling were developed in the hydrology modelling work programme. Full details of the methodology adopted are included in the Hydrology Modelling Report[6].

This scenario consisted of running Scenario 2: Proposed abstraction at constant 154 Ml/day and applying monthly change allowances in river flows for the 2080s from the National Water Resources Plan (NWRP)[7].

The 2080s Lower climate change allowances have been taken to represent the reasonable worst-case scenario as the values are lower in comparison to both the Central and Upper allowances thus resulting in a greater reduction of flow. For example, the Lower climate change allowance for the August percentage change in flow was -25.4%, whereas the Central and Upper allowances were -11.4% and +2.7% respectively.

6.4.1. Flows

The River Shannon inflow at the Portumna Bridge upstream boundary of the model and the twenty-one smaller rivers previously detailed in Scenario 1: Baseline were modified on a monthly basis by the Lower estimate climate change factors from the NWRP, detailed in Table 2.

The modified hydrograph for the River Shannon accounting for climate change effects is presented in Figure 46 alongside the corresponding hydrograph from the Baseline Scenario.

The proposed abstraction in Parteen Basin was defined at a constant rate of 154 Ml/day. The out-flow at the Parteen Weir/Ardnacrusha Headrace downstream boundary of the water quality model was generated by the Operational Principles Model accounting for climate change effects and presented in Figure 47 alongside the hydrograph from Scenario 2: Proposed abstraction at constant 154 Ml/day (without climate change effects).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Change in flow	+7.5	+16.1	+9.9	-0.3	-8.3	-18.9	-23.5	-29.9	-32.2	-53.3	-33.5	-6.7

Table 2: River flow climate change factors – lower estimate

[6] Irish Water, 2021. Water Supply Project: Eastern and Midlands Region. Hydrology Modelling Report
[7] Irish Water, 2021. National Water Resources Plan – Appendix F.

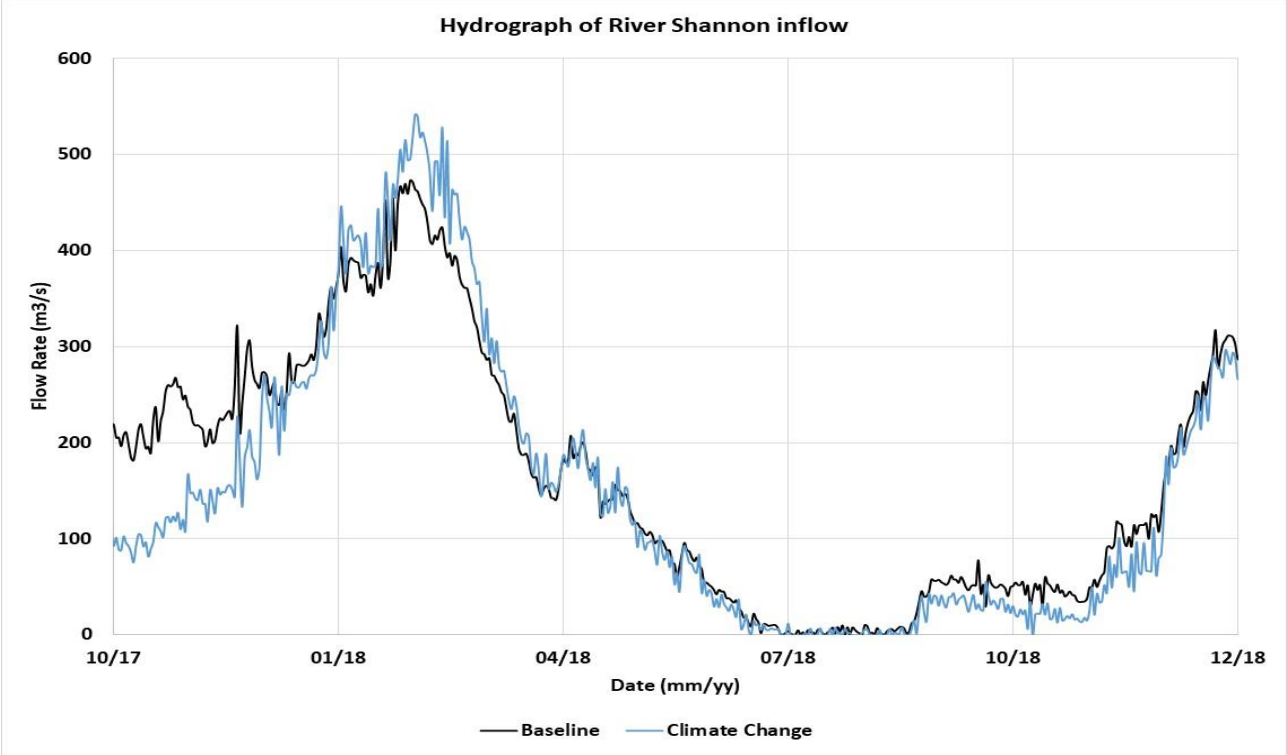


Figure 46: Hydrograph of River Shannon comparing Baseline to Climate Change affected inflow (01/10/2017 to 31/12/2108)

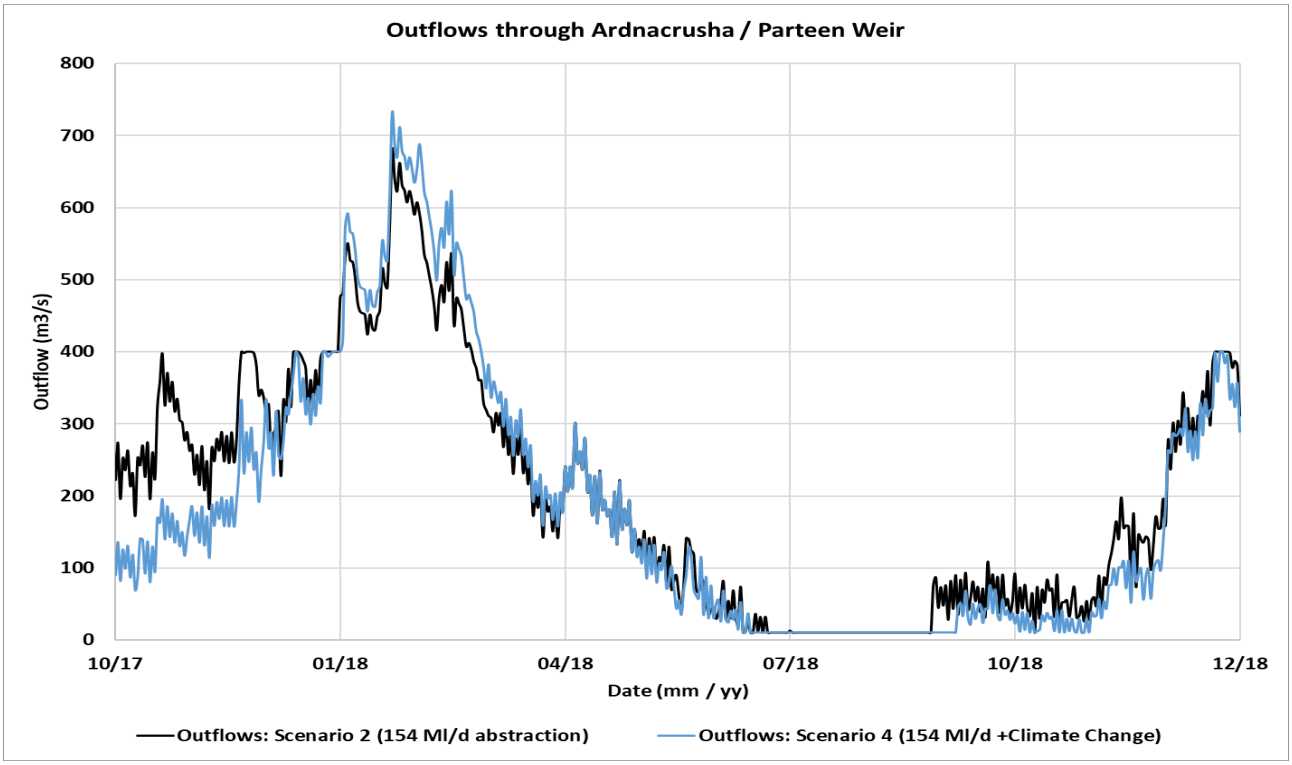


Figure 47: Scenario 2 v Scenario 4 outflows through Ardnacrusha / Parteen Weir due to proposed 154 Ml/d abstraction (01/10/2017 to 31/12/2018)

6.4.2. Water Levels

The volume of water required to meet the proposed abstraction (as well as the required statutory flow of 10 m^3/s to the natural course of the River Shannon and 0.5 m^3/s through the Ardnacrusha fish pass) is met through a combination of the low drought inflows and, when necessary, a depletion of the lake storage. Depletion of the lake storage results in a drop in water level which was modelled as being evenly distributed across the surface area of Lough Derg and Parteen Basin.

The changes to water levels at the Portumna Bridge upstream boundary of the model and the Parteen Weir/Ardnacrusha Headrace downstream boundary of the model due to the proposed constant 154 Ml/day abstraction regime incorporating climate change effects are presented in Figure 48 and Figure 49 respectively.

6.4.3. Water Quality

Water quality data for the River Shannon and the twenty-one inflowing rivers were unchanged from the Scenario 1: Baseline simulation previously detailed.

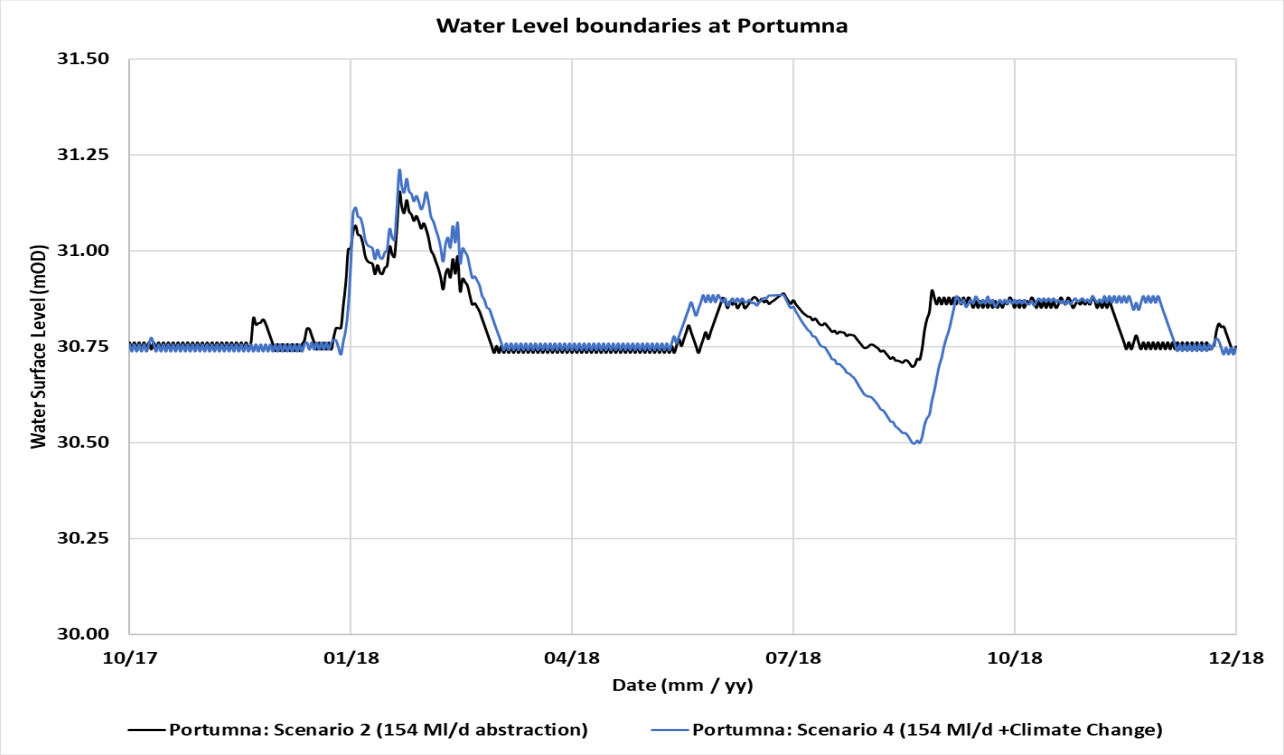


Figure 48: Scenario 2 v Scenario 4 water levels at Portumna due to proposed 154 Ml/d abstraction (01/10/2017 to 31/12/2018)

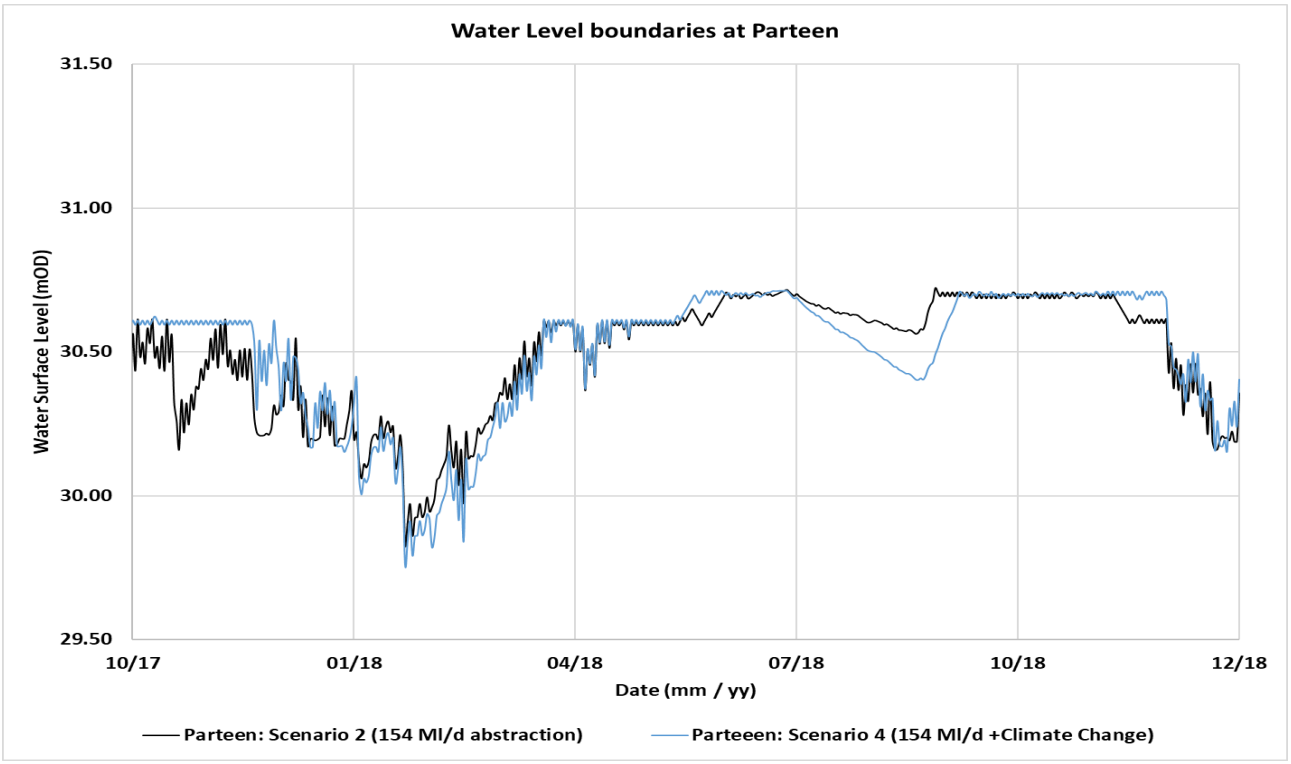


Figure 49: Scenario 2 v Scenario 4 water levels at Parteen Weir due to proposed 154 Ml/d abstraction (01/10/2017 to 31/12/2018)

6.5. Scenario 5: Proposed Abstraction at constant 300 Ml/day incorporating climate change effects

This scenario evaluated the potential impacts on water quality arising from the operation of the proposed abstraction at a constant rate of 300 Ml/day during a reasonable worst-case drought period incorporating climate change effects for the 2080 epoch into the 01/10/2017 to 31/12/2018 period.

The climate change effects for the 2080 epoch incorporated into the water quality modelling were developed in the hydrology modelling work programme. Full details of the methodology adopted are included in the Hydrology Modelling Report[8].

This scenario consisted of running Scenario 3: Proposed abstraction at constant 300 Ml/day applying monthly change allowances in river flows for the 2080s epoch from the National Water Resources Plan (NWRP)[9]. As for Scenario 4, the Lower climate change allowances are used to provide the reasonable worst-case scenario.

6.5.1. Flows

The River Shannon inflow at the Portumna Bridge upstream boundary of the model and the twenty-one smaller rivers previously detailed in Scenario 3: Proposed Abstraction at constant 300 Ml/day were unchanged.

[8] Irish Water, 2021. Water Supply Project: Eastern and Midlands Region. Hydrology Modelling Report
[9] ibid.

The proposed abstraction in Parteen Basin was defined at a constant rate of 300 Ml/day. The outflow at the Parteen Weir/Ardnacrusha Headrace downstream boundary of the water quality model was generated by the Operational Principles Model accounting for climate change effects and presented in Figure 50 alongside the hydrograph from Scenario 3: Proposed abstraction at constant 300Ml/day (without climate change effects).

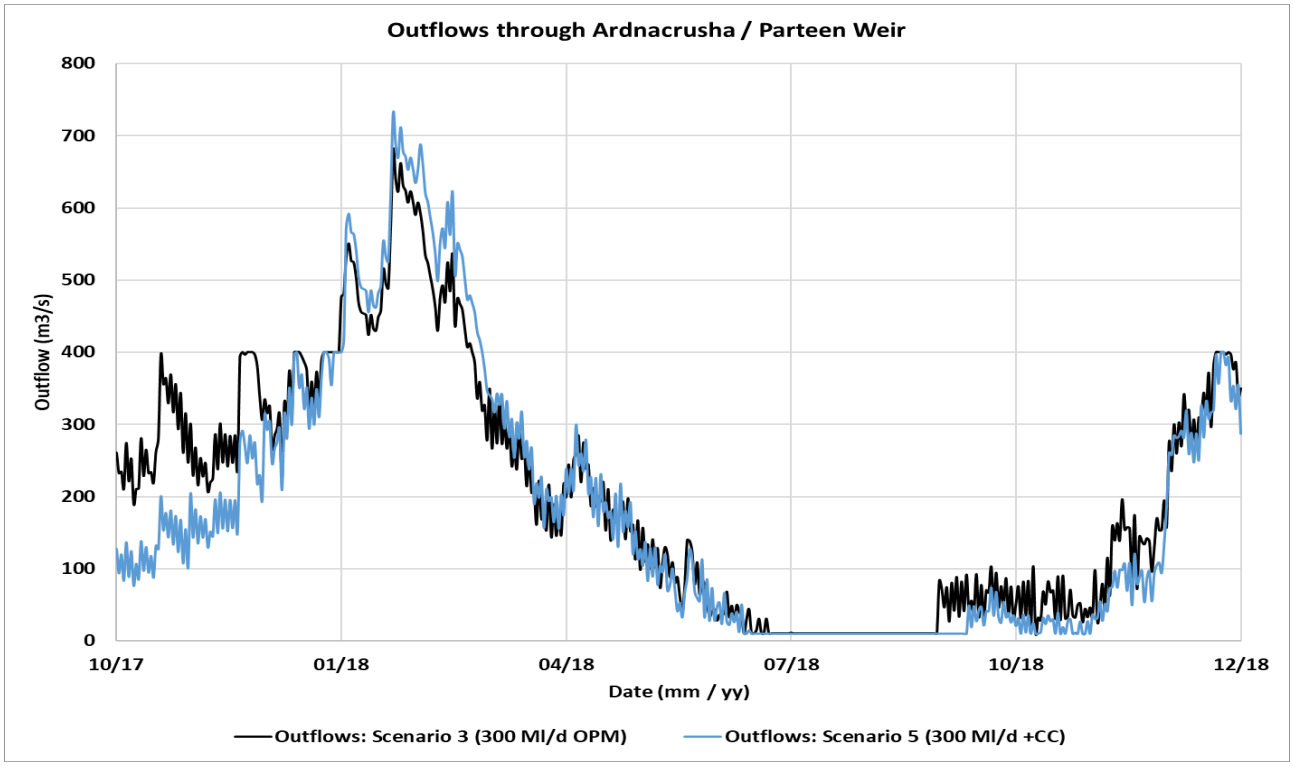


Figure 50: Scenario 3 v Scenario 5 outflows through Ardnacrusha / Parteen Weir due to proposed 300 Ml/d abstraction (01/10/2017 to 31/12/2018)

6.5.2. Water Levels

The volume of water required to meet the proposed abstraction (as well as the required statutory flow of 10 m^3/s to the natural course of the River Shannon and 0.5 m^3/s through the Ardnacrusha fish pass) is met through a combination of the low drought inflows and, when necessary, a depletion of the lake storage. Depletion of the lake storage results in a drop in water level which was modelled as being evenly distributed across the surface area of Lough Derg and Parteen Basin.

The changes to water levels at the Portumna Bridge upstream boundary of the model and the Parteen Weir/Ardnacrusha Headrace downstream boundary of the model due to the proposed constant 300 Ml/day abstraction regime under the effects of climate change are presented in Figure 51 and Figure 52 respectively.

6.5.3. Water Quality

Water quality data for the River Shannon and the twenty-one inflowing rivers were unchanged from the Scenario 1: Baseline simulation previously detailed.

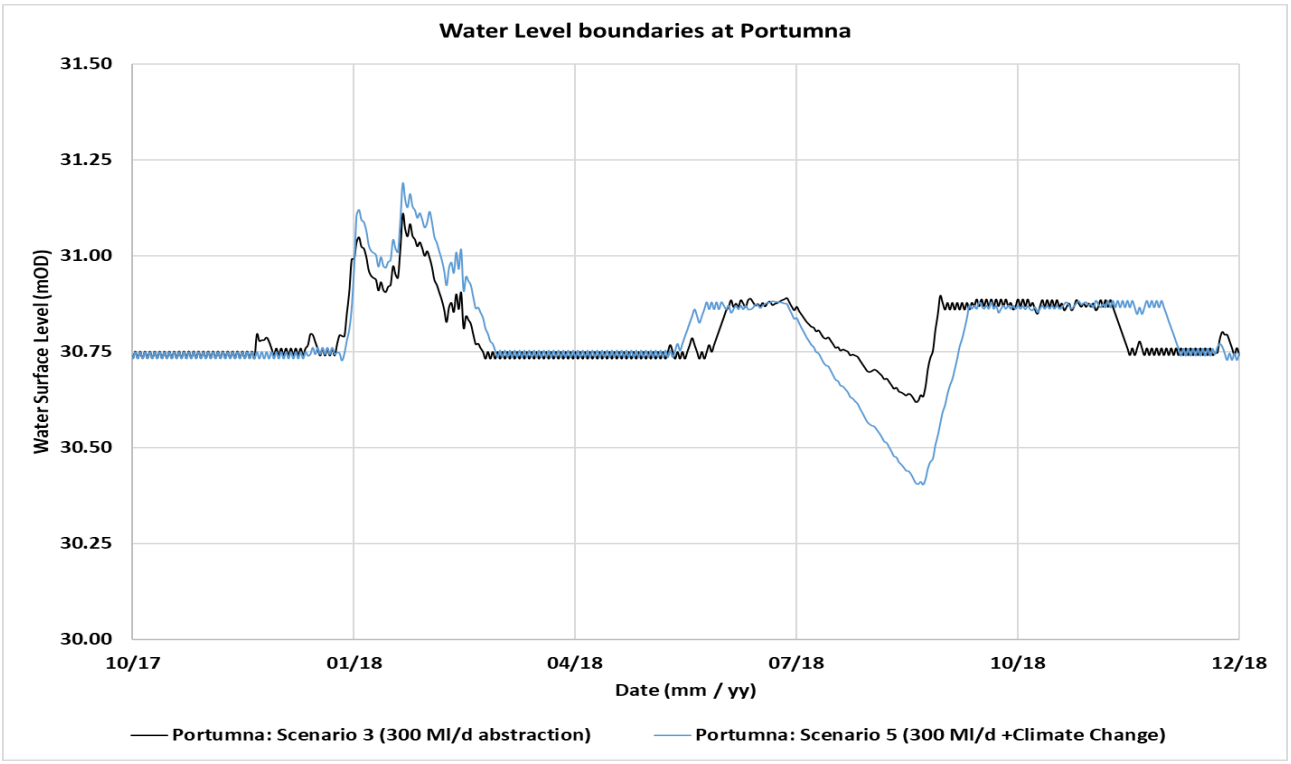


Figure 51: Scenario 3 v Scenario 5 water levels at Portumna due to proposed 300 Ml/d abstraction (01/10/2017 to 31/12/2018)

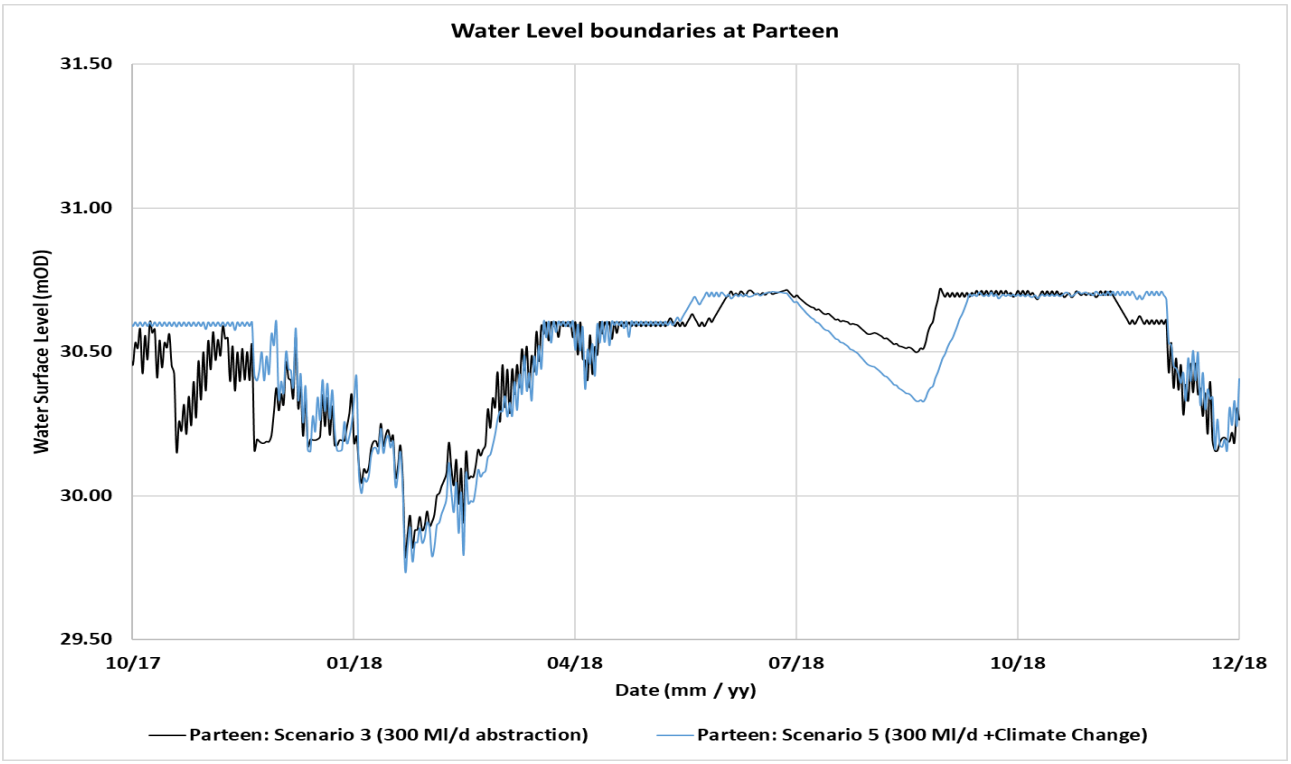


Figure 52: Scenario 3 v Scenario 5 water levels at Parteen Weir due to proposed 300 Ml/d abstraction (01/10/2017 to 31/12/2018)

7. Model Results

The results from the model scenarios are presented in this section. The results presented are the spatially varying concentration of each water quality parameter at the end of July, August and September 2018 as predicted by the model. The end of July, August and September are representative of the period in 2018 where the greatest variation in water surface levels between the different scenarios has been found, and thus the potential for greatest impact on water quality conditions in the modelled study area.

For the Baseline scenario, the predicted concentrations at the end of July, August and September for chlorophyll-a, nitrate, phosphate, dissolved oxygen and ammonia are presented in Figure 53 to Figure 57 respectively.

For Scenario 2: Proposed Abstraction at constant 154 Ml/day, the predicted concentrations at the end of July, August and September for chlorophyll-a, nitrate, phosphate, dissolved oxygen and ammonia are presented in Figure 58 to Figure 62 respectively.

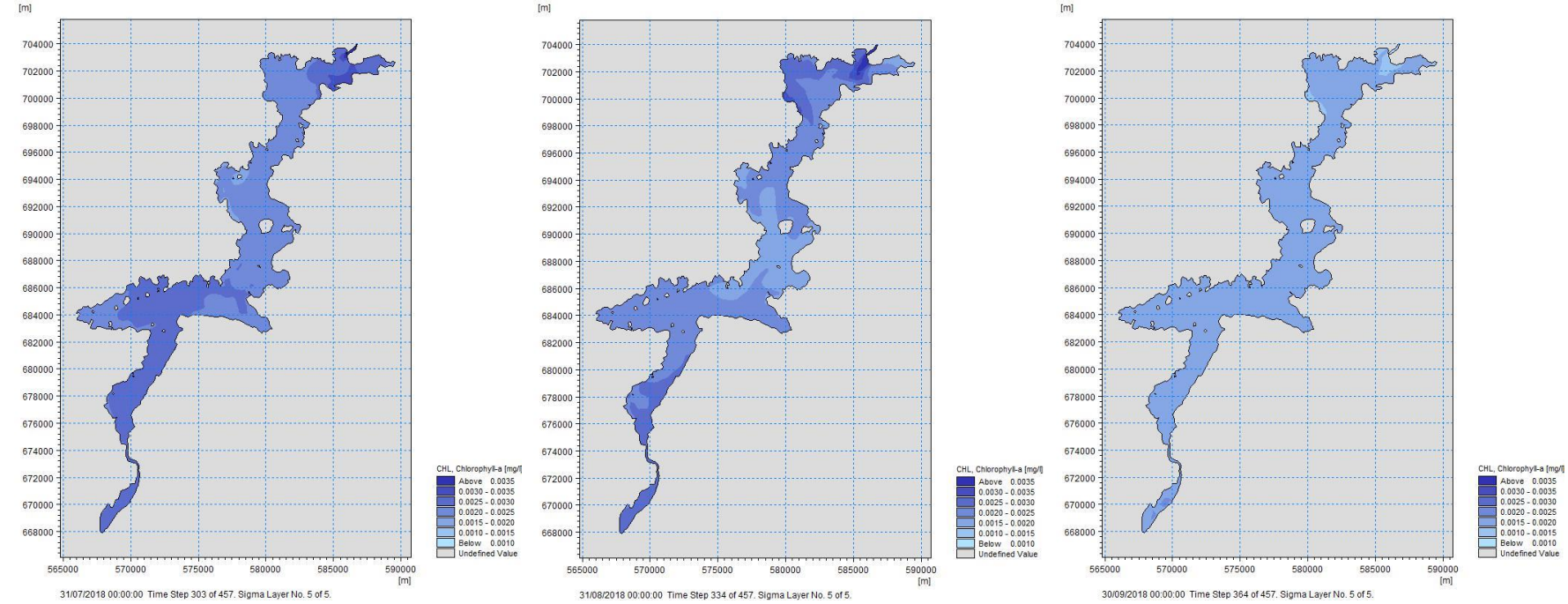
For Scenario 3: Proposed Abstraction at constant 300 Ml/day, the predicted concentrations at the end of July, August and September for chlorophyll-a, nitrate, phosphate, dissolved oxygen and ammonia are presented in Figure 63 to Figure 67 respectively.

For Scenario 4: Proposed Abstraction at constant 154 Ml/day incorporating climate change effects, the predicted concentrations at the end of July, August and September for chlorophyll-a, nitrate, phosphate, dissolved oxygen and ammonia are presented in Figure 68 to Figure 72 respectively.

For Scenario 5: Proposed Abstraction at constant 300 Ml/day incorporating climate change effects, the predicted concentrations at the end of July, August and September for chlorophyll-a, nitrate, phosphate, dissolved oxygen and ammonia are presented in Figure 73 to Figure 77 respectively.

7.1. Scenario 1: Baseline

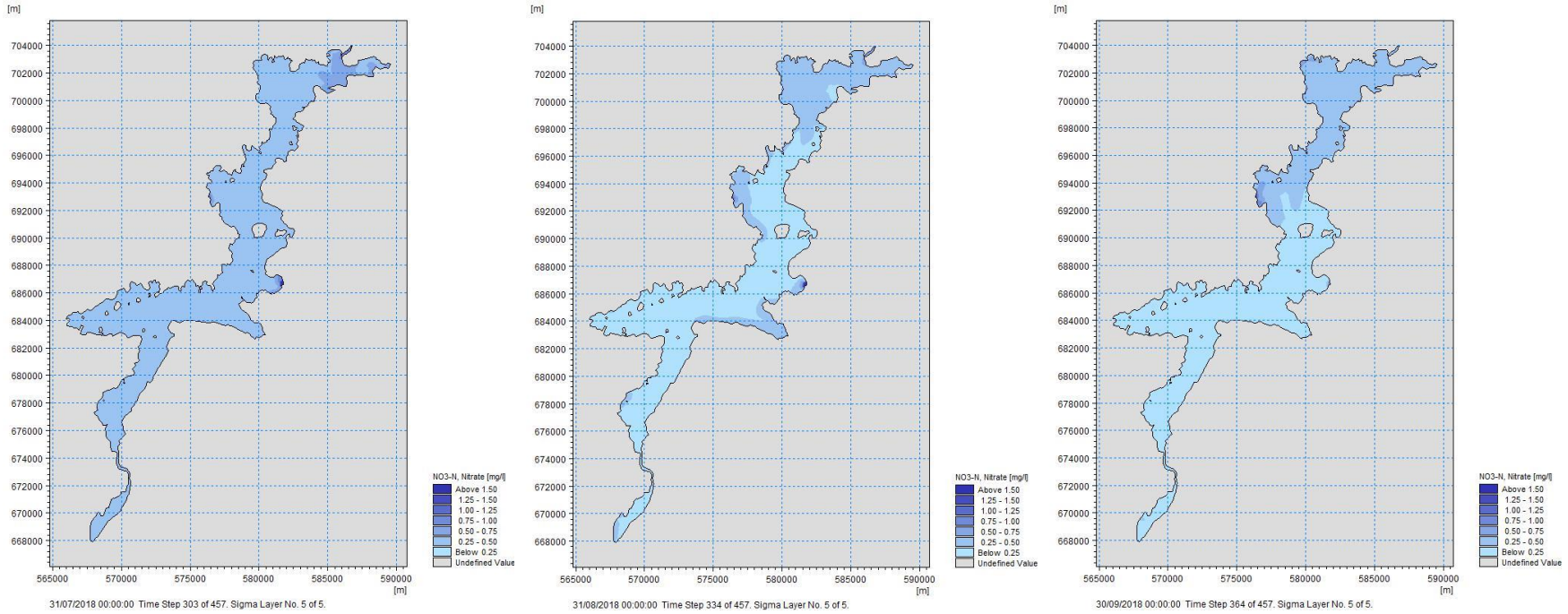
7.1.1. Chlorophyll-a (CHL)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 53: Scenario 1: Baseline CHL concentrations

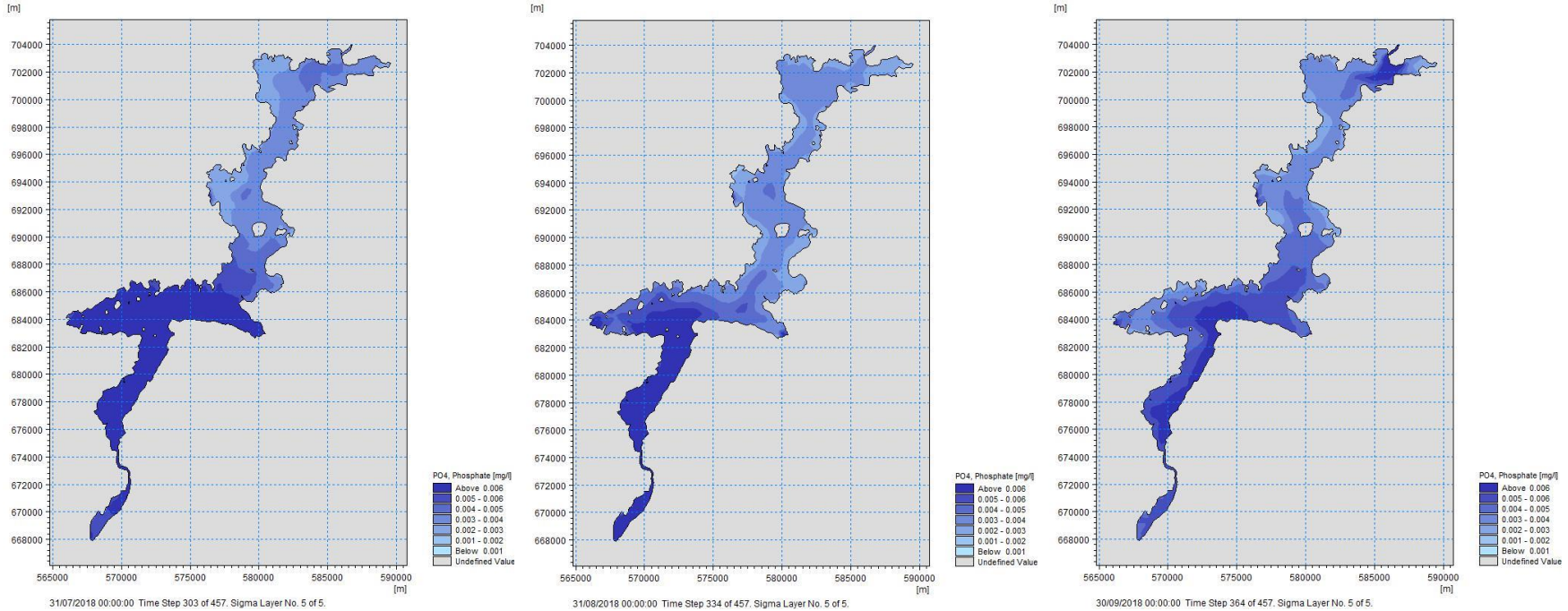
7.1.2. Nitrate (NO3-N)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 54: Scenario 1: Baseline NO3-N concentrations

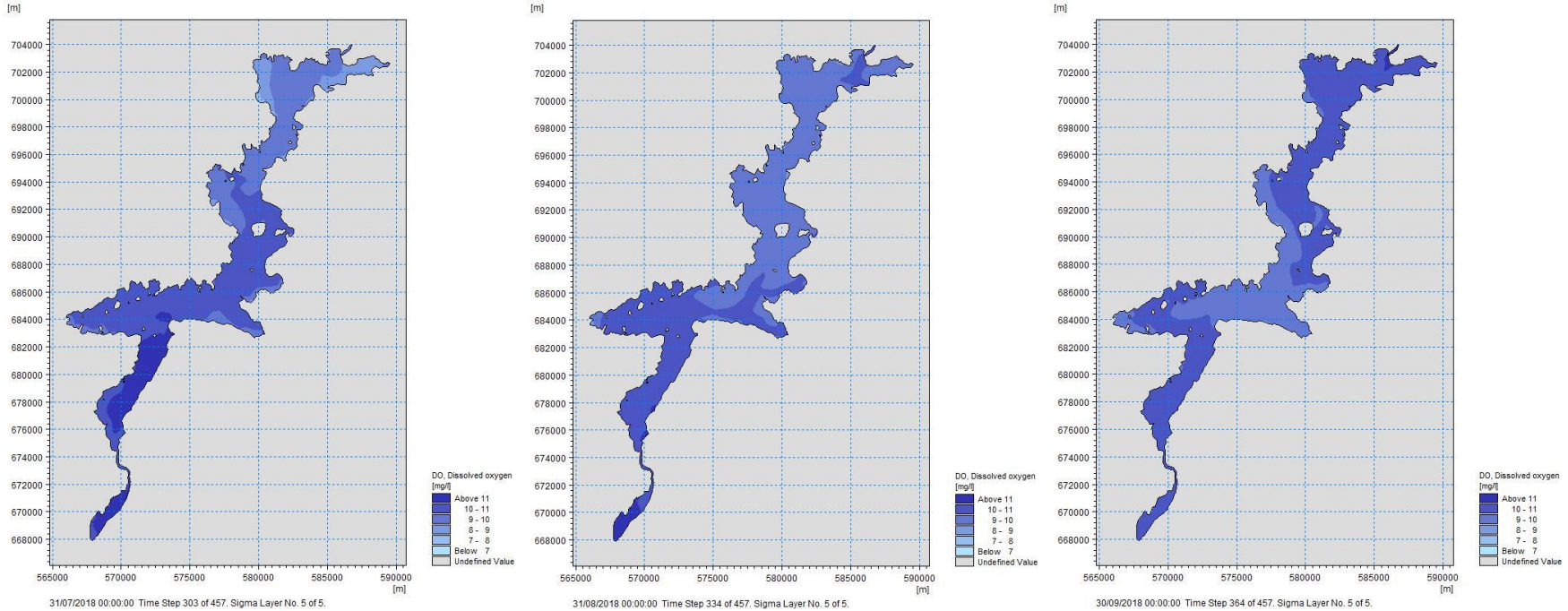
7.1.3. Orthophosphate (PO4-P)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 55: Scenario 1: Baseline PO4-P concentrations

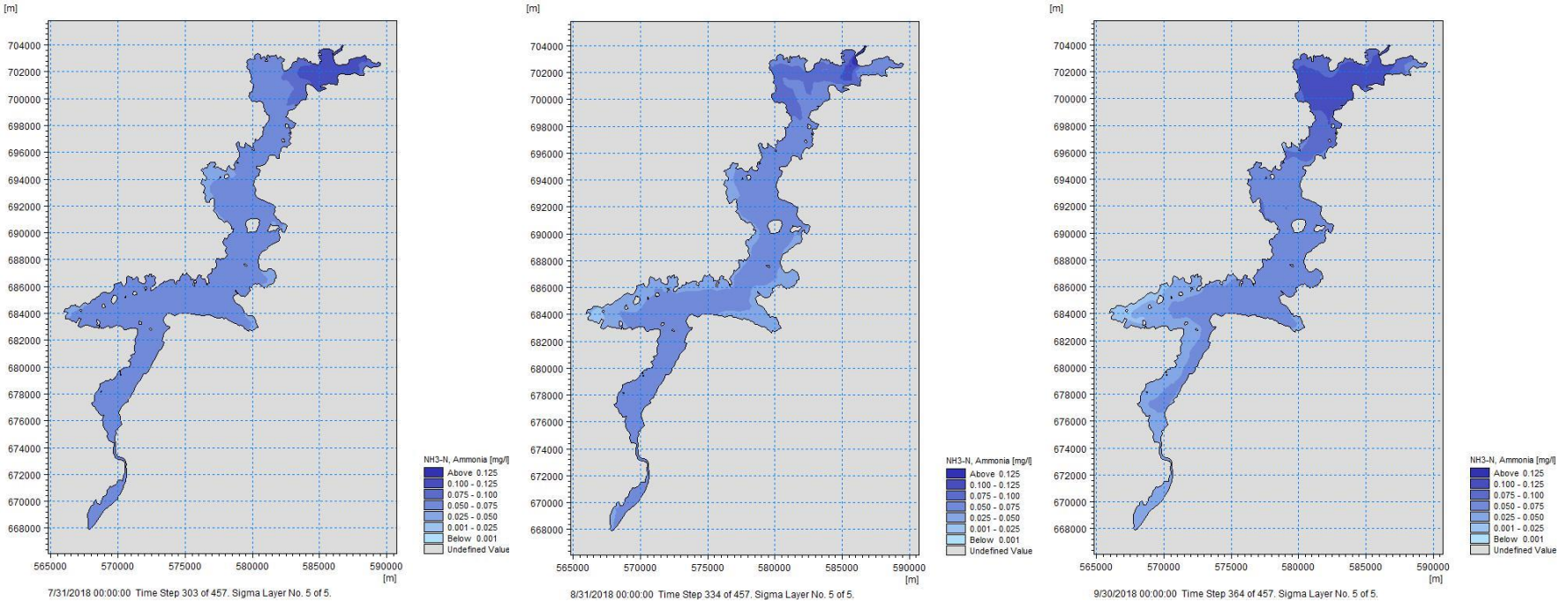
7.1.4. Dissolved Oxygen (DO)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 56: Scenario 1: Baseline DO concentrations

7.1.5. Ammonia (NH3-N)

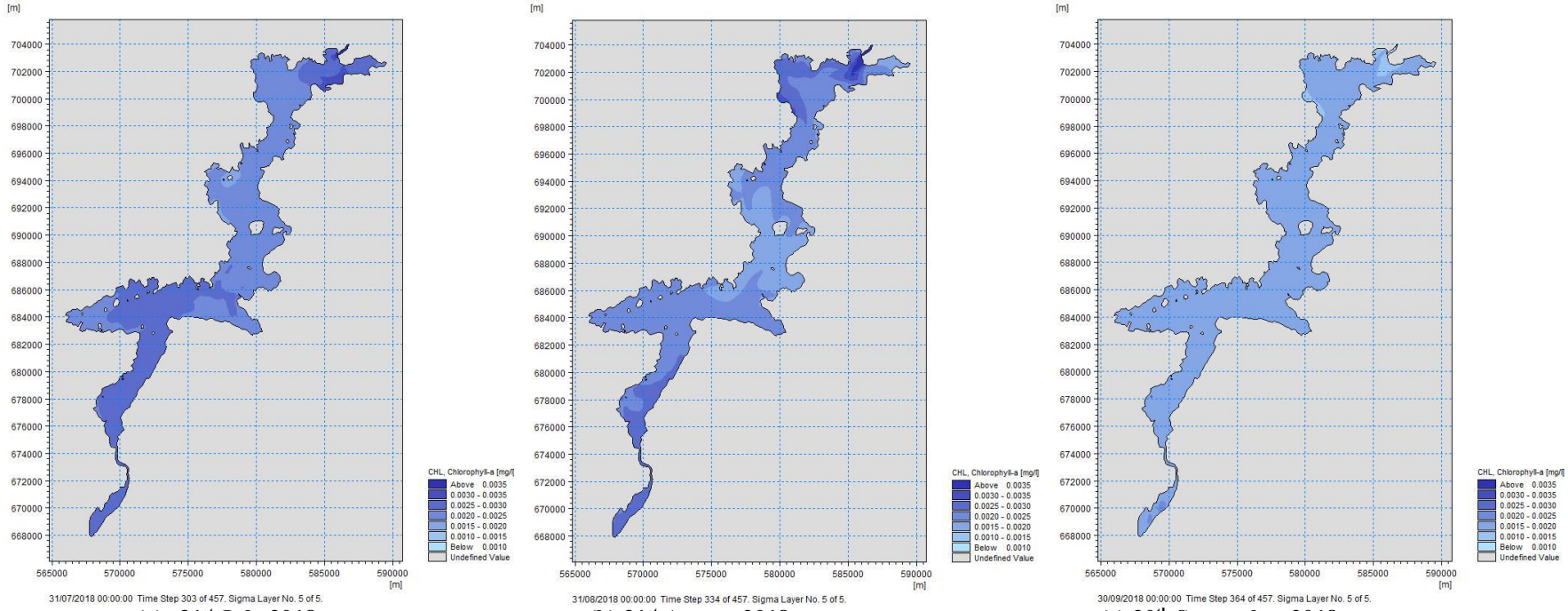


(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 57: Scenario 1: Baseline NH3-N concentrations

7.2. Scenario 2: Proposed Abstraction at constant 154 Ml/day

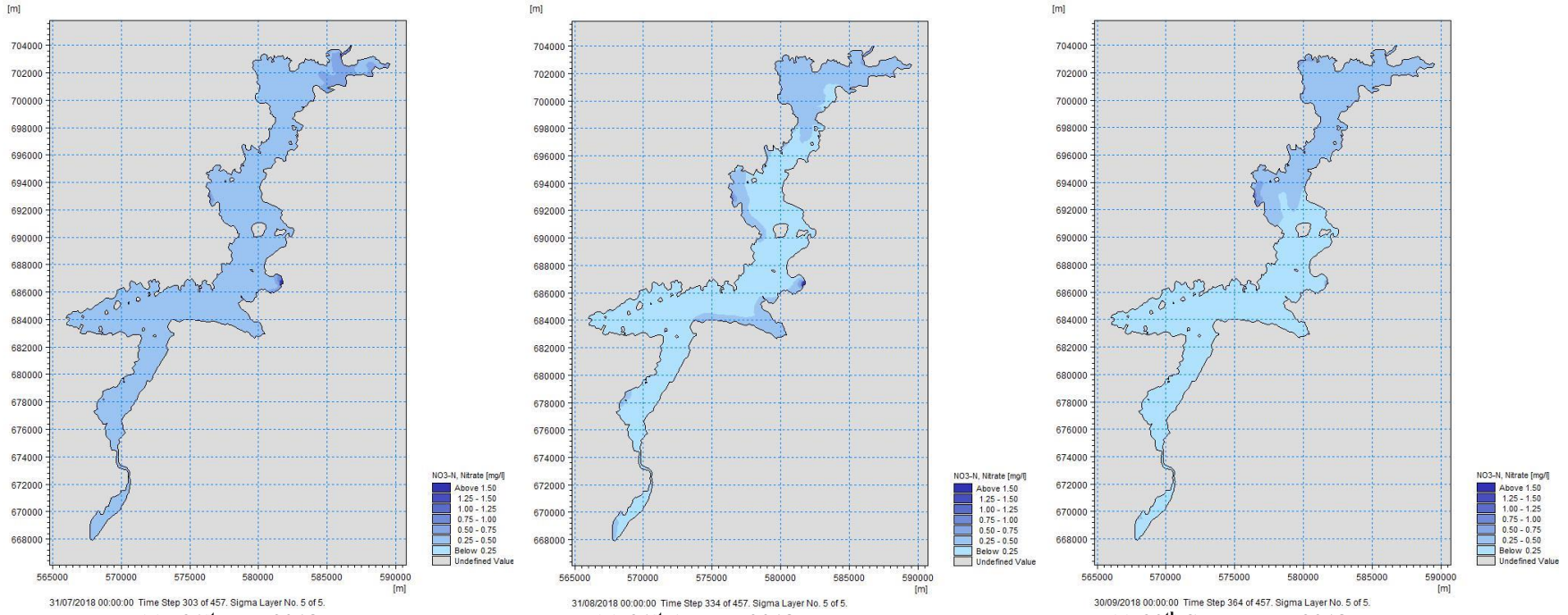
7.2.1. Chlorophyll-a (CHL)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 58: Scenario 2: 154 Ml/d Abstraction CHL concentrations

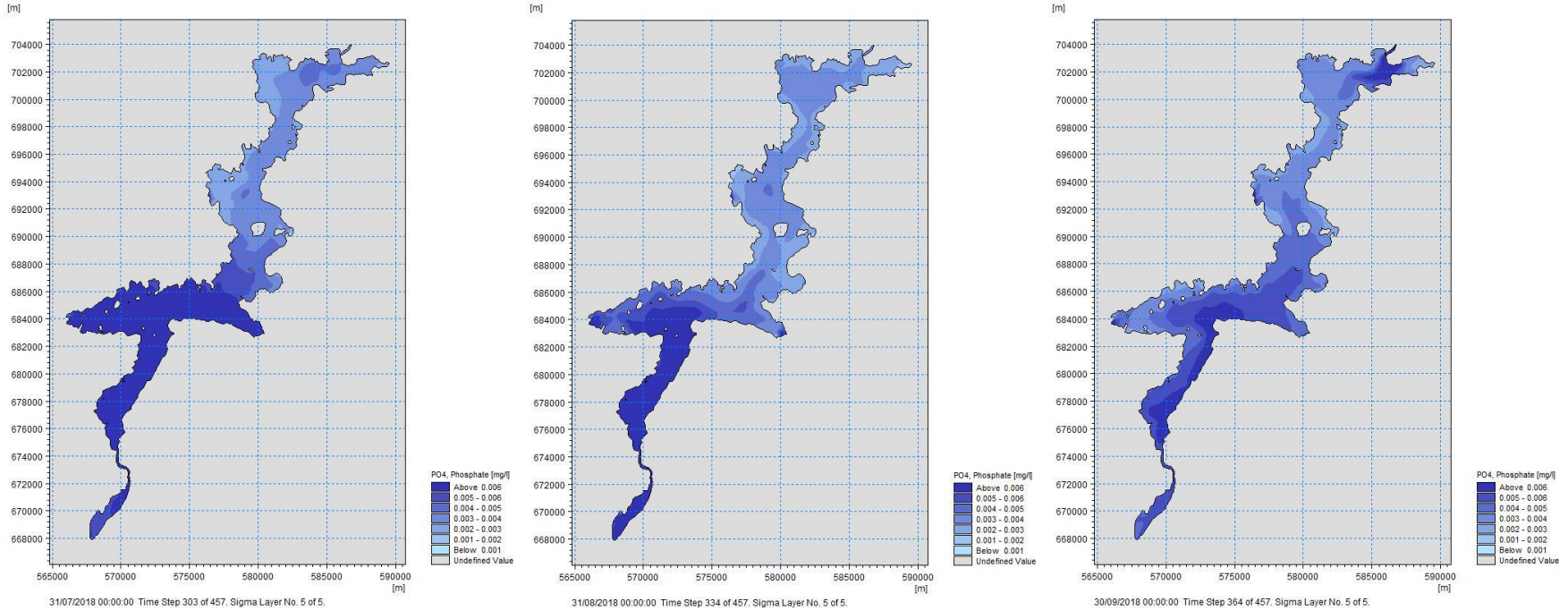
7.2.2. Nitrate (NO3-N)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 59: Scenario 2: 154 Ml/d Abstraction NO3-N concentrations

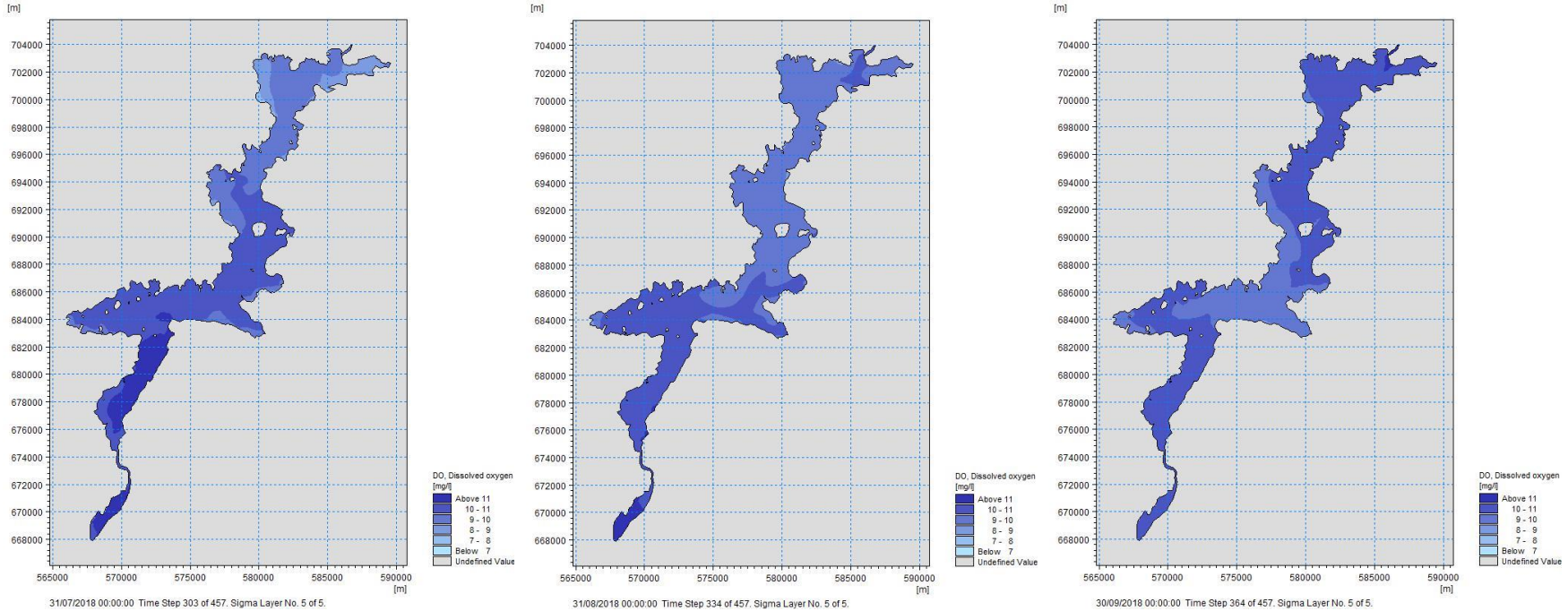
7.2.3. Orthophosphate (PO4-P)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 60: Scenario 2: 154 Ml/d Abstraction PO4-P concentrations

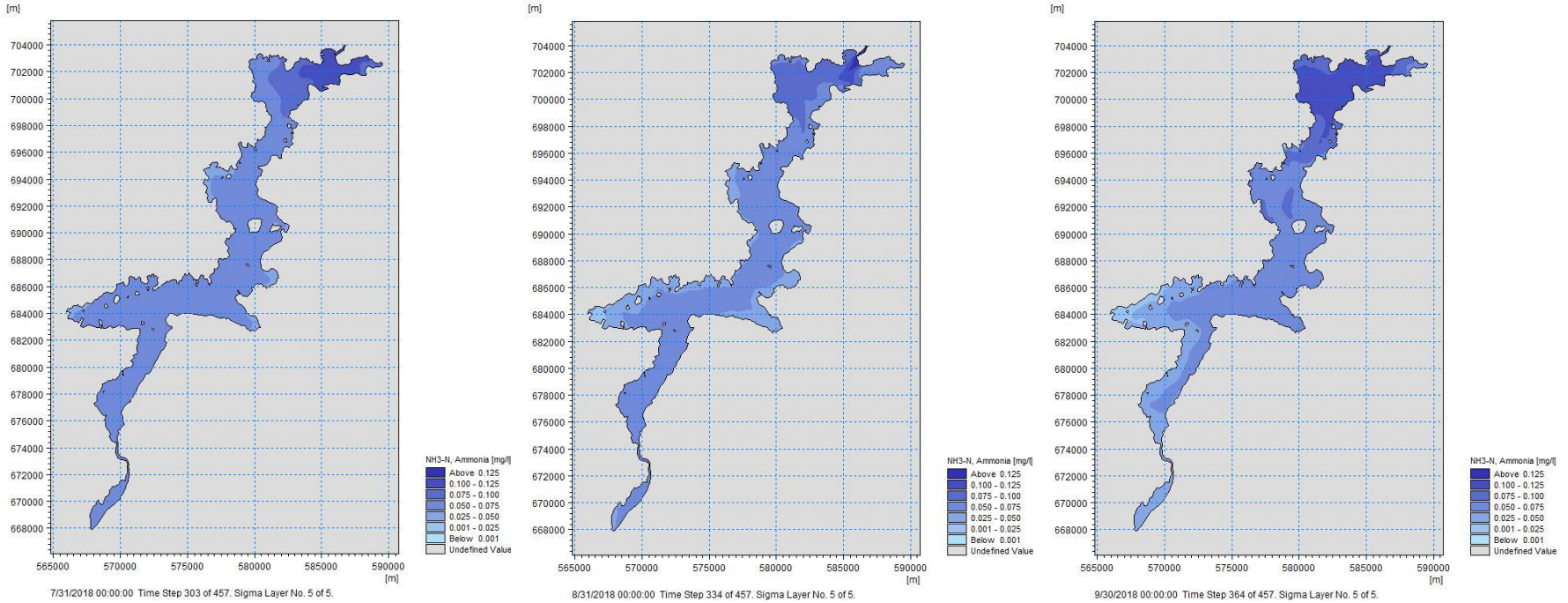
7.2.4. Dissolved Oxygen (DO)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 61: Scenario 2: 154 Ml/d Abstraction DO concentrations

7.2.5. Ammonia (NH3-N)

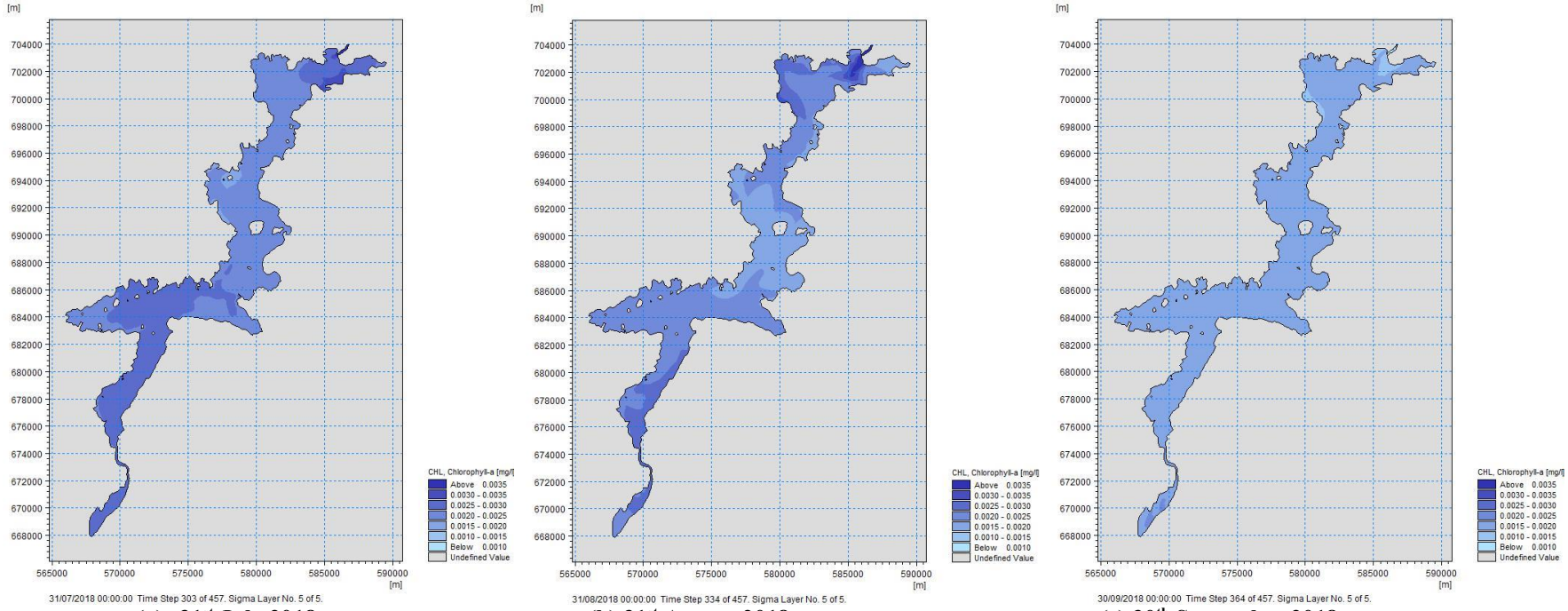


(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 62: Scenario 2: 154 Ml/d Abstraction NH3-N concentrations

7.3. Scenario 3: Proposed Abstraction at constant 300 Ml/day

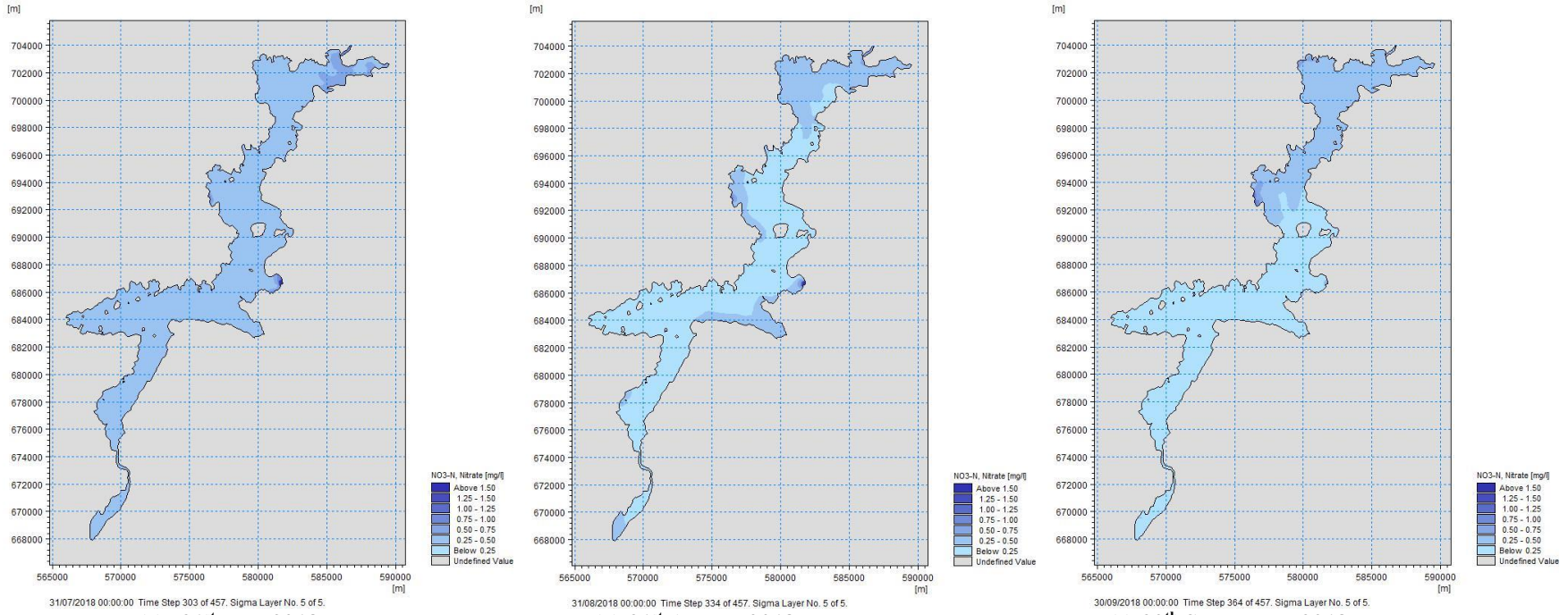
7.3.1. Chlorophyll-a (CHL)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 63: Scenario 3: 300 Ml/d Abstraction CHL concentrations

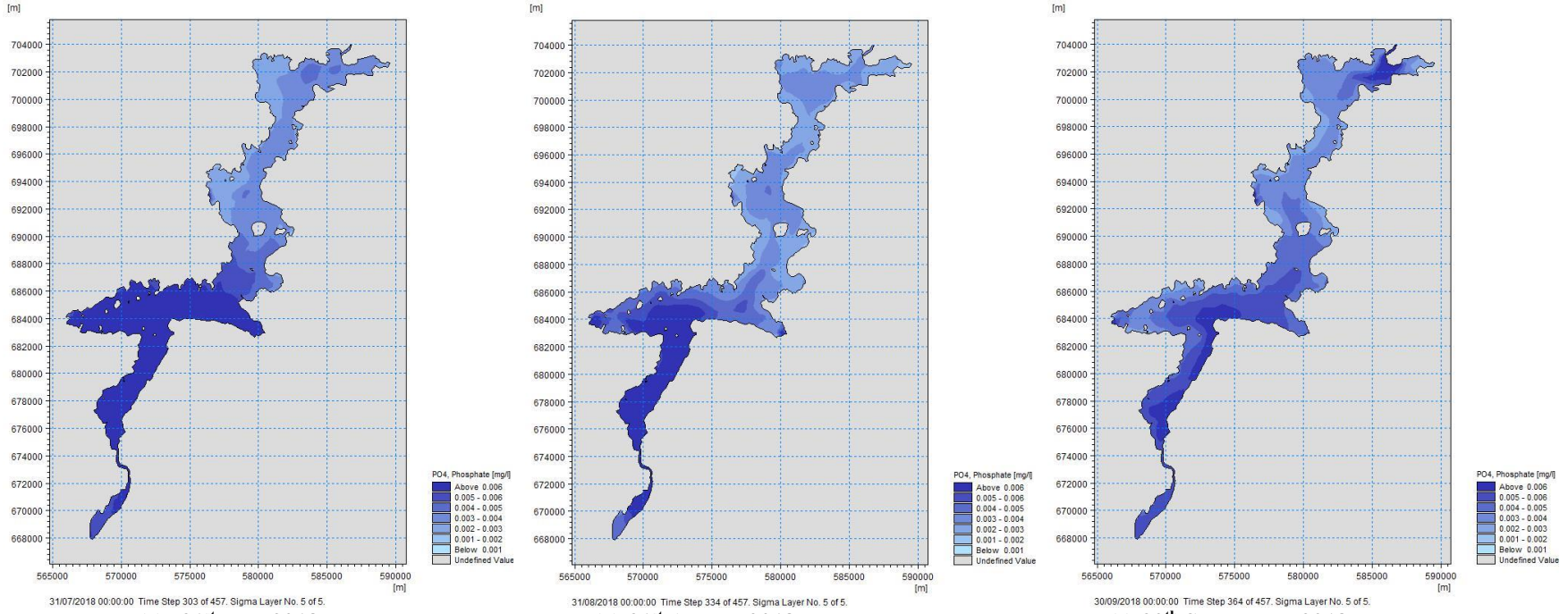
7.3.2. Nitrate (NO3-N)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 64: Scenario 3: 300 Ml/d Abstraction NO3-N concentrations

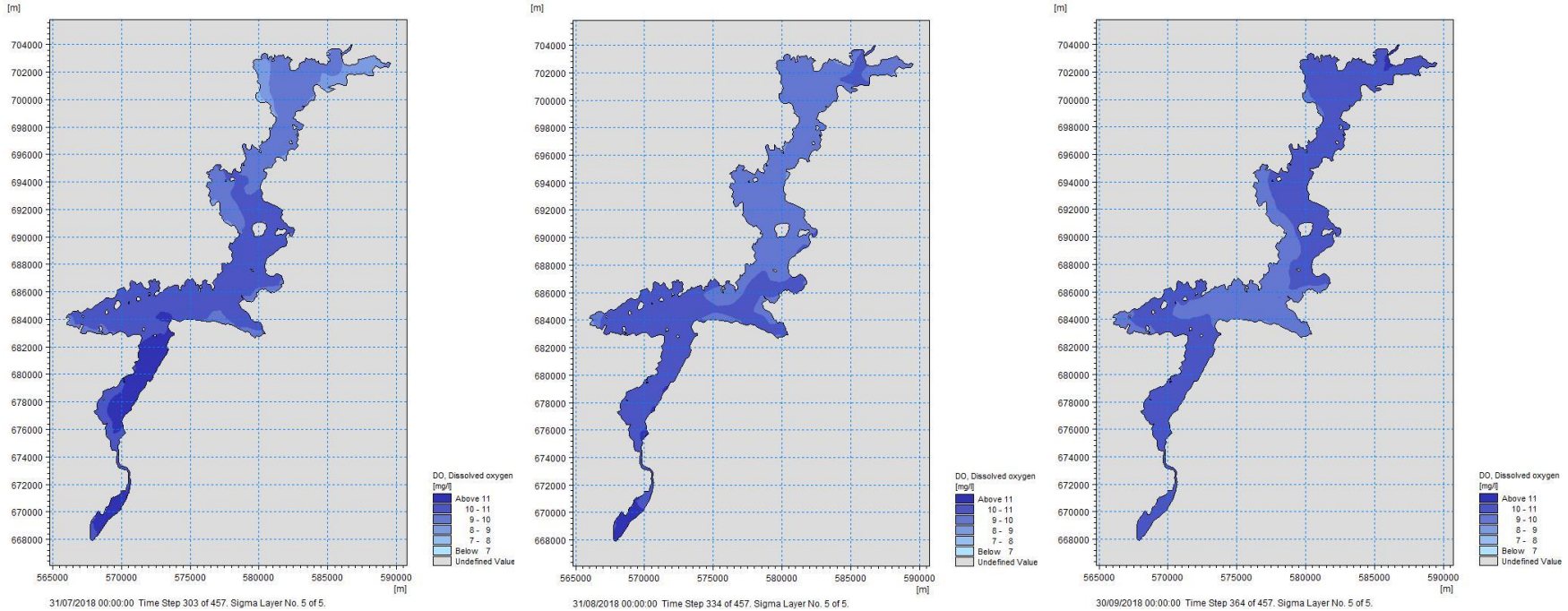
7.3.3. Orthophosphate (PO4-P)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 65: Scenario 3: 300 Ml/d Abstraction PO4-P concentrations

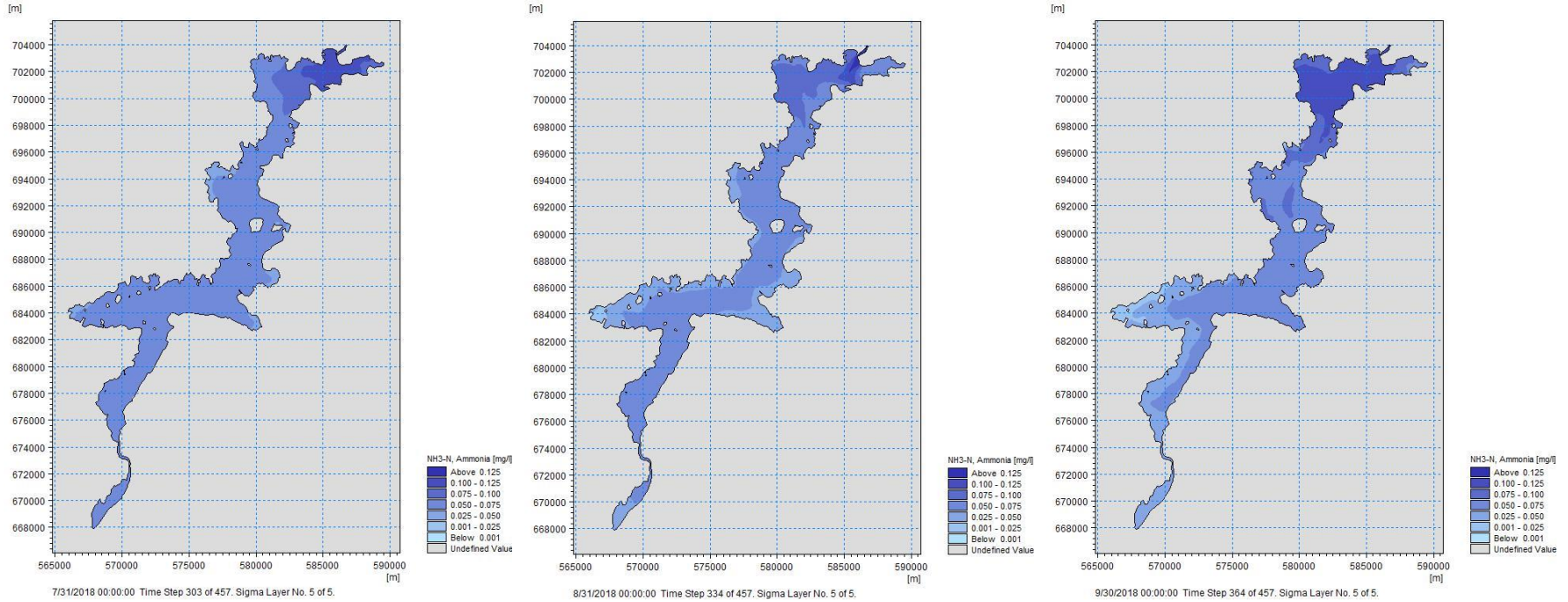
7.3.4. Dissolved Oxygen (DO)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 66: Scenario 3: 300 Ml/d Abstraction DO concentrations

7.3.5. Ammonia (NH3-N)

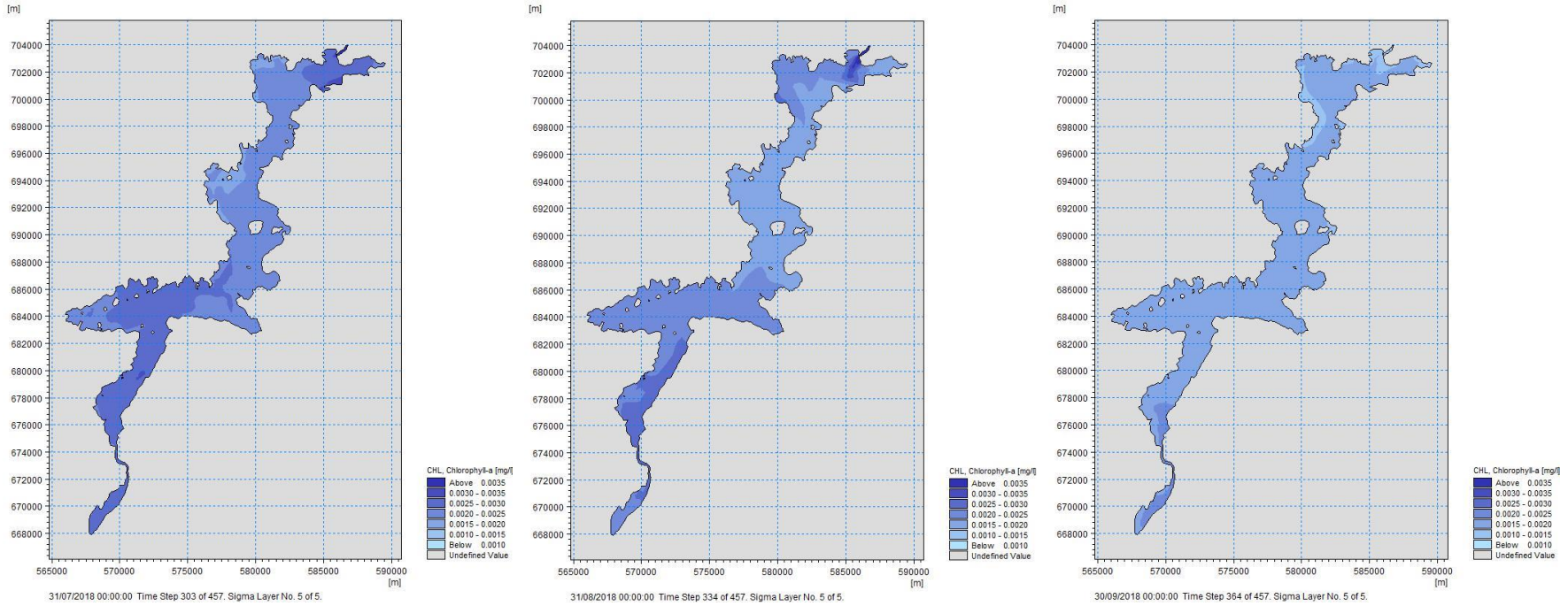


(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 67: Scenario 3: 300 Ml/d Abstraction NH3-N concentrations

7.4. Scenario 4: Proposed Abstraction at constant 154 Ml/day incorporating climate change effects

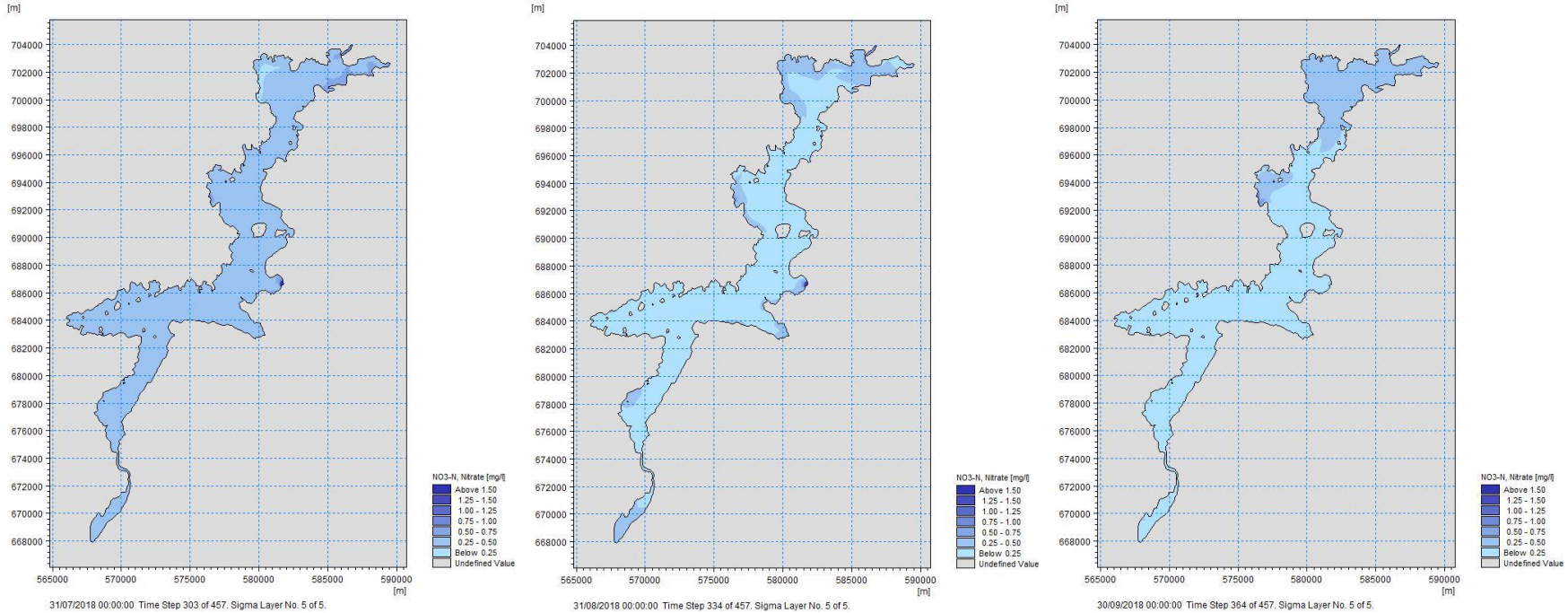
7.4.1. Chlorophyll-a (CHL)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 68: Scenario 4: 154 Ml/d Abstraction with climate change effects CHL concentrations

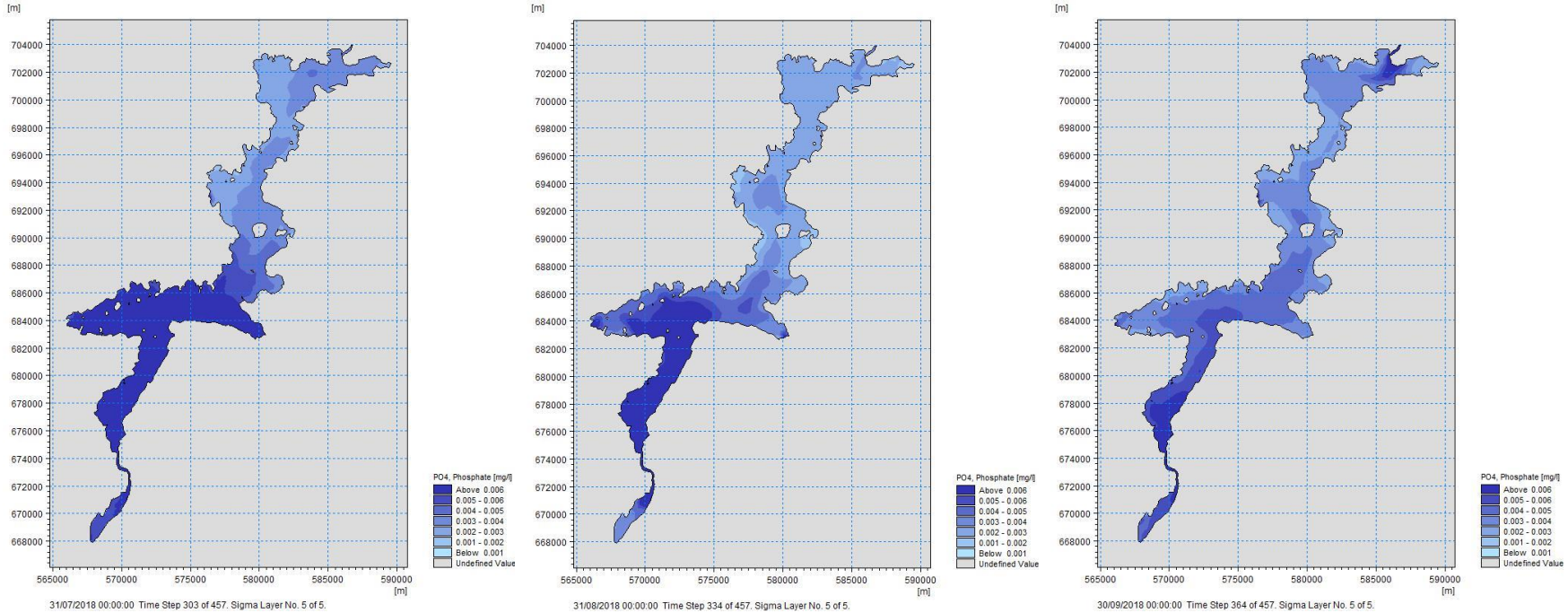
7.4.2. Nitrate (NO3-N)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 69: Scenario 4: 154 Ml/d Abstraction with climate change effects NO3-N concentrations

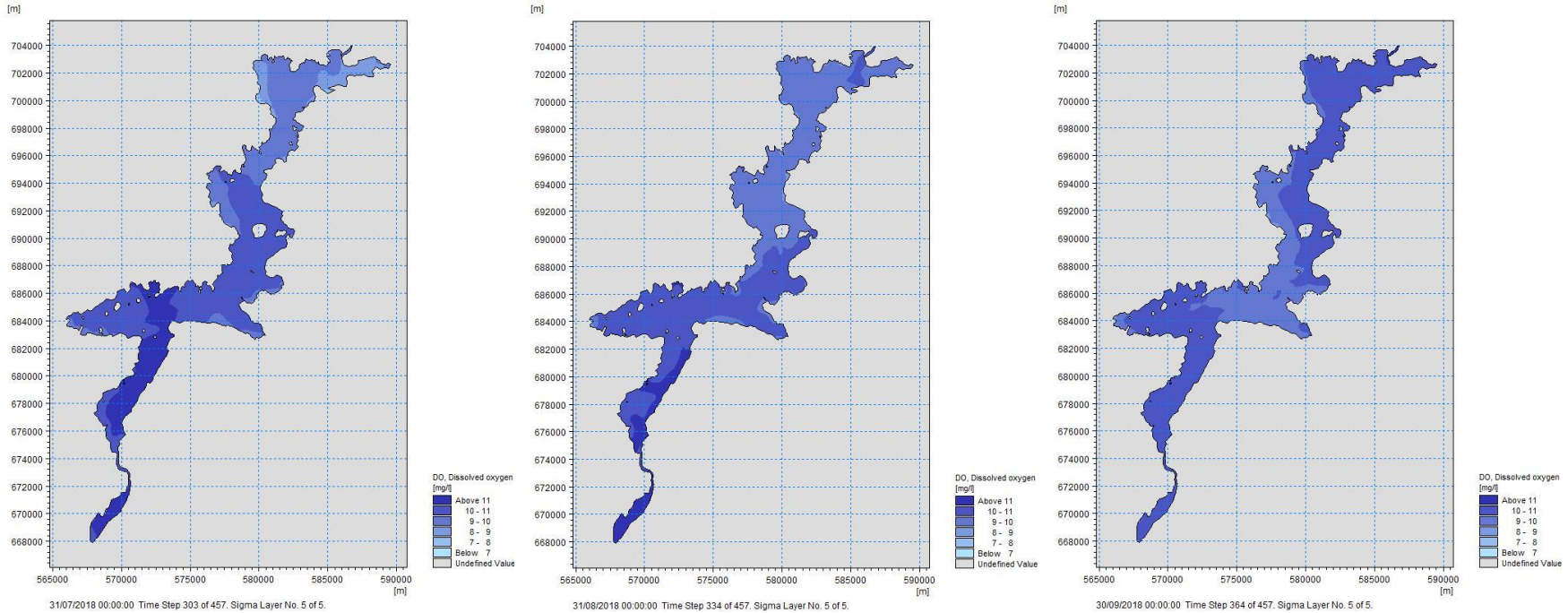
7.4.3. Orthophosphate (PO4-P)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 70: Scenario 4: 154 Ml/d Abstraction with climate change effects PO4-P concentrations

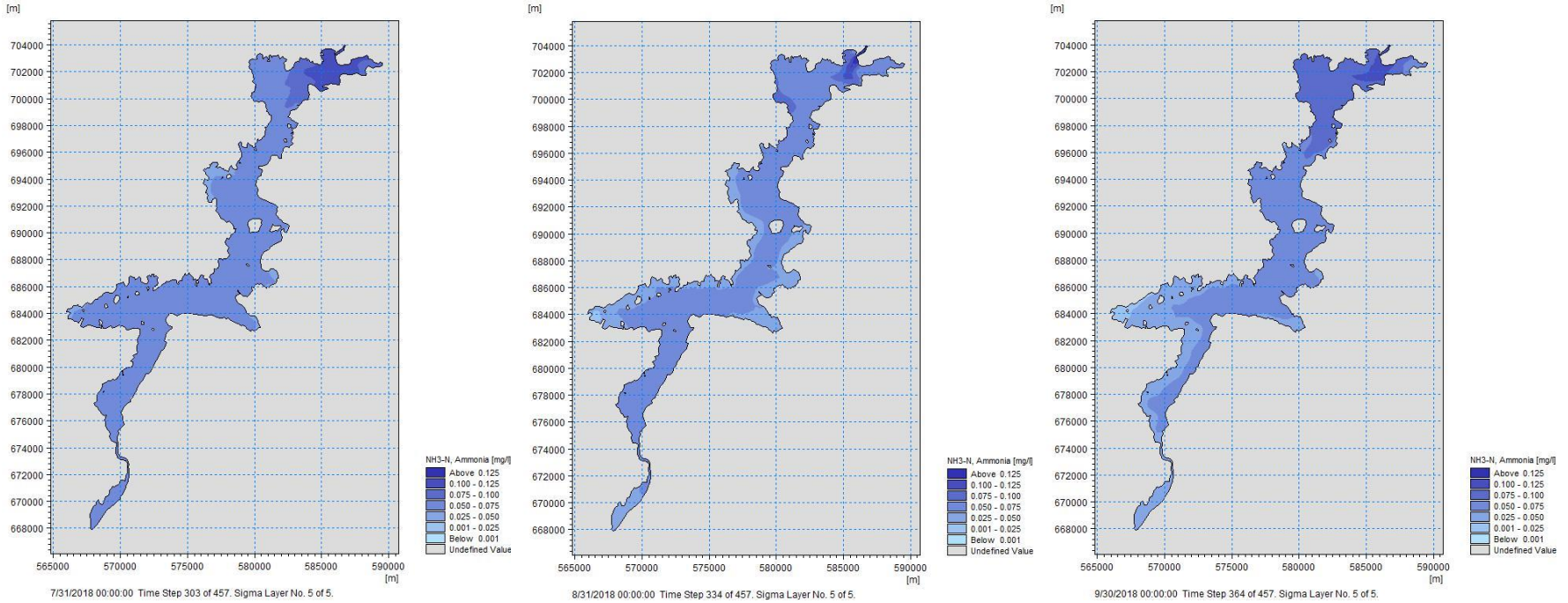
7.4.4. Dissolved Oxygen (DO)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 71: Scenario 4: 154 Ml/d Abstraction with climate change effects DO concentrations

7.4.5. Ammonia (NH3-N)

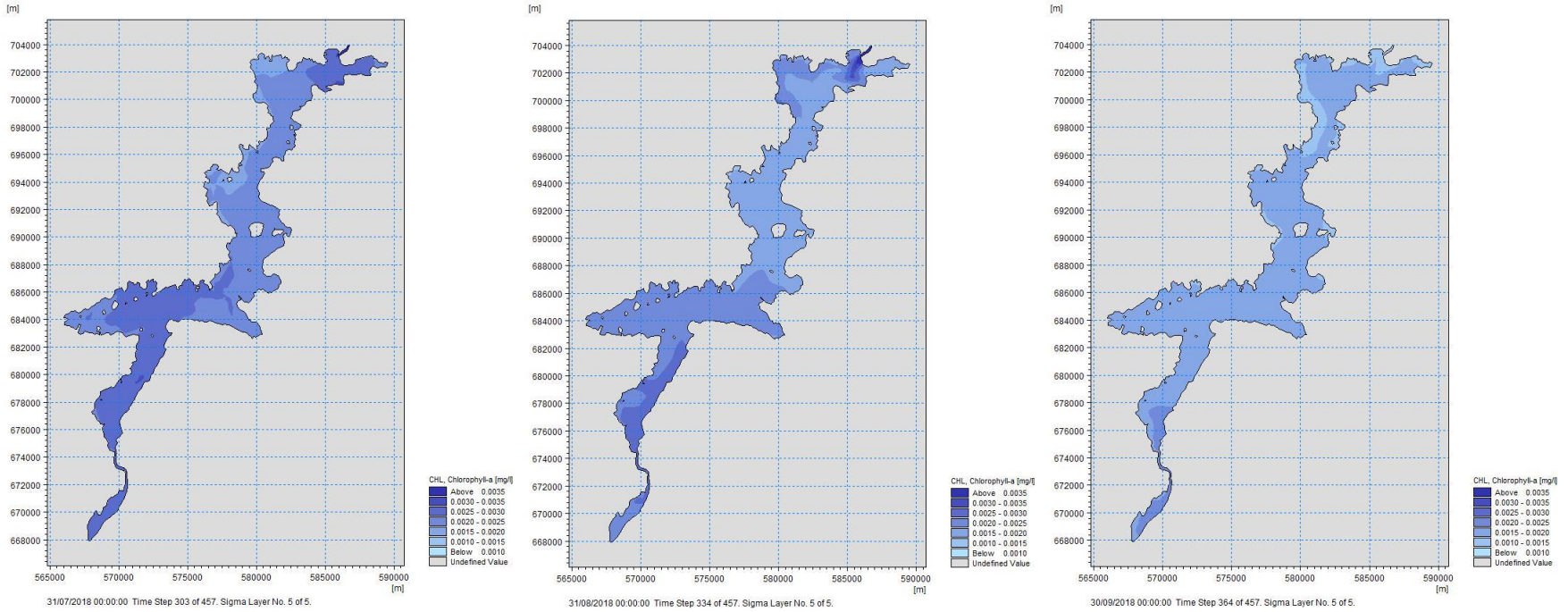


(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 72: Scenario 4: 154 Ml/d Abstraction with climate change effects NH3-N concentrations

7.5. Scenario 5: Proposed Abstraction at constant 300 Ml/day incorporating climate change effects

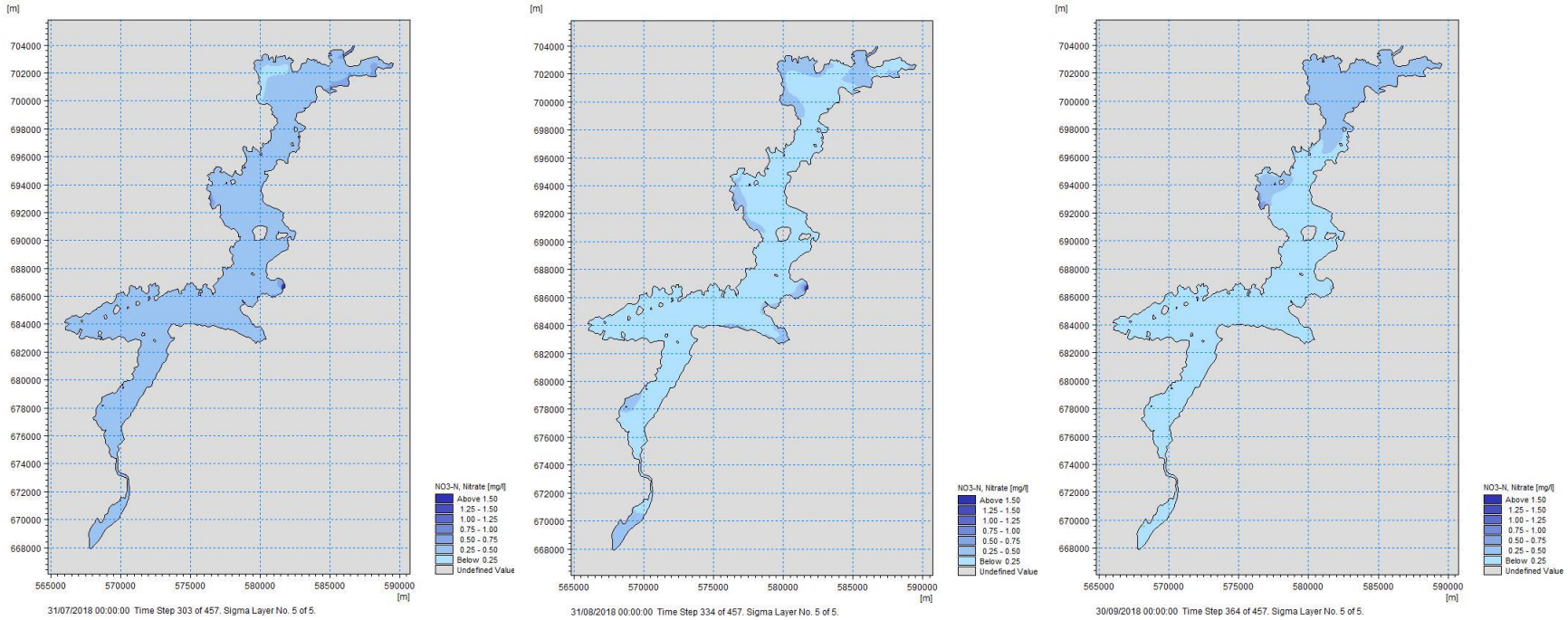
7.5.1. Chlorophyll-a (CHL)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 73: Scenario 5: 300 Ml/d Abstraction with climate change effects CHL concentrations

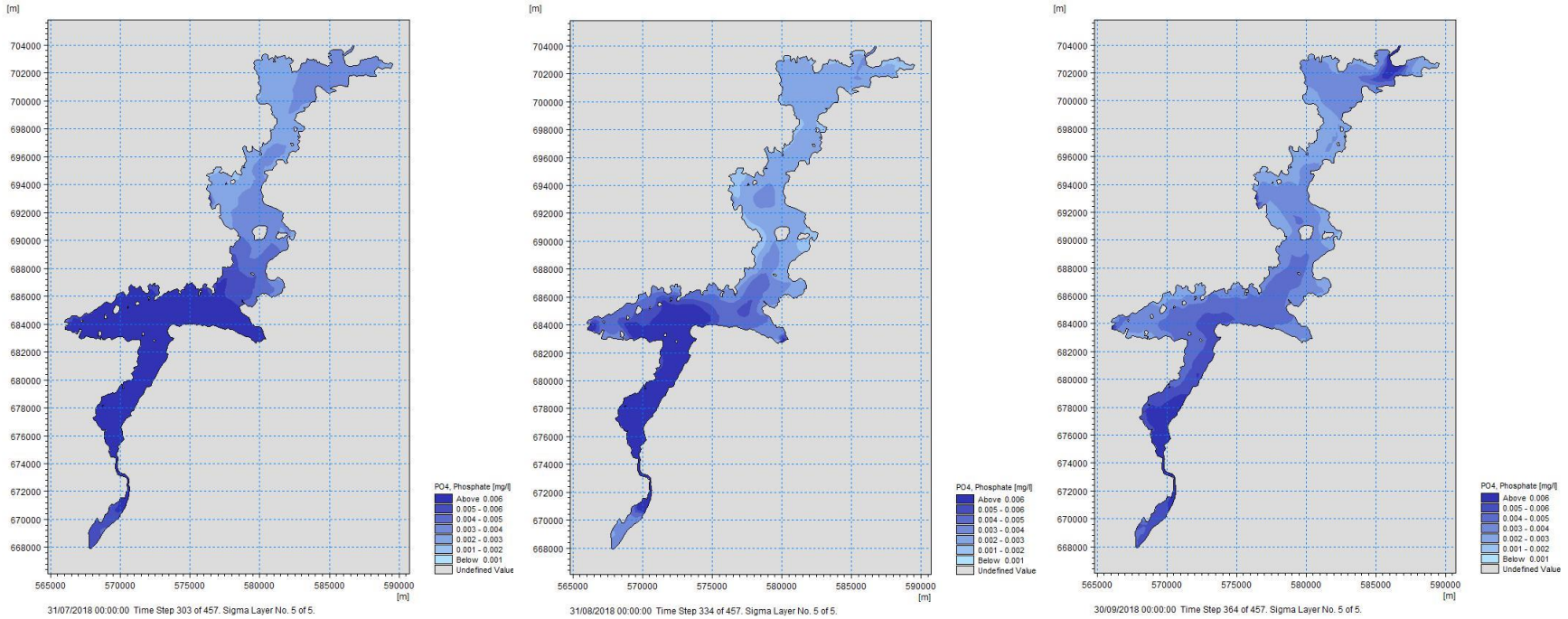
7.5.2. Nitrate (NO3-N)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 74: Scenario 5: 300 Ml/d Abstraction with climate change effects NO3-N concentrations

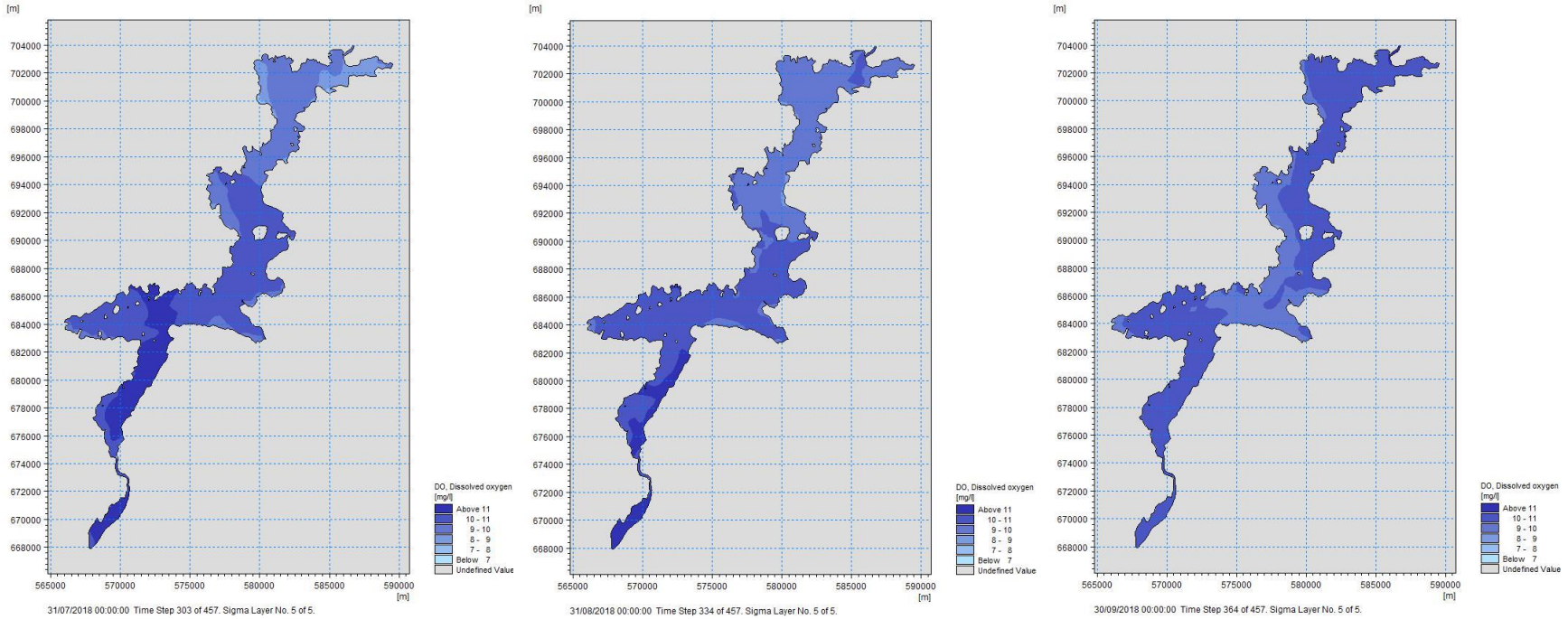
7.5.3. Orthophosphate (PO4-P)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 75: Scenario 5: 300 Ml/d Abstraction with climate change effects PO4-P concentrations

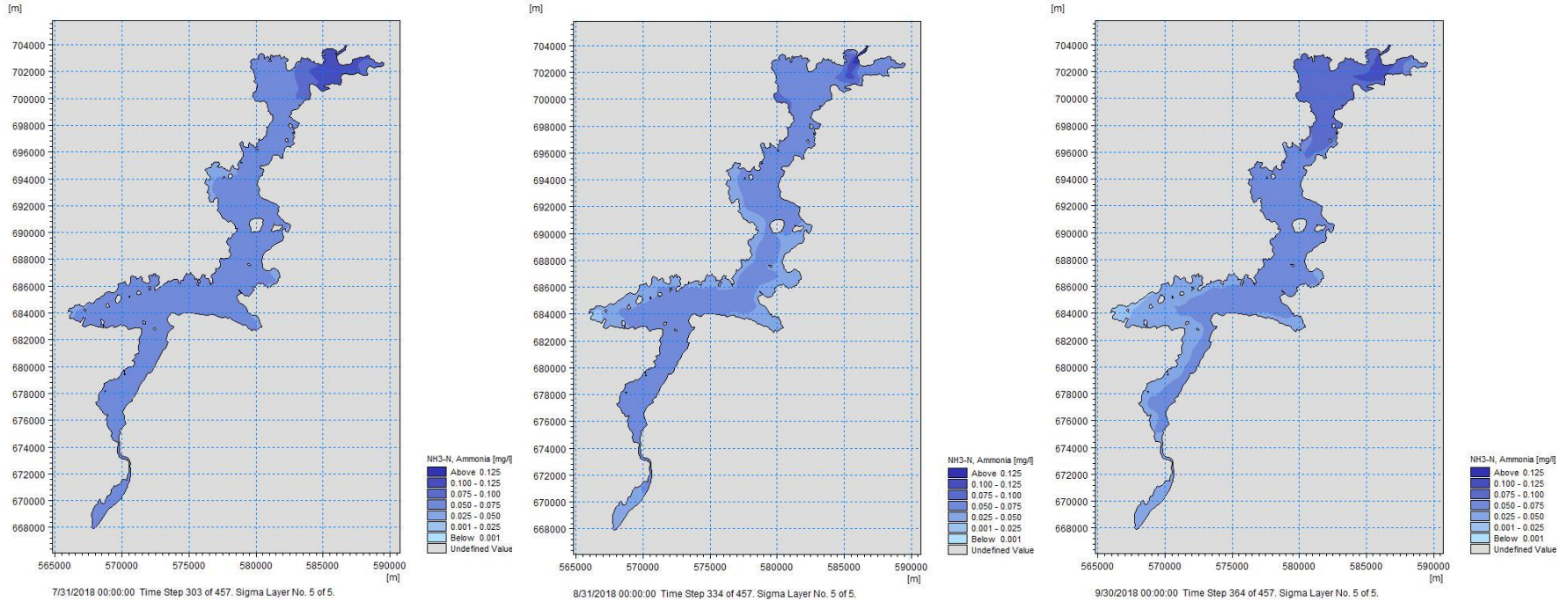
7.5.4. Dissolved Oxygen (DO)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 76: Scenario 5: 300 Ml/d Abstraction with climate change effects DO concentrations

7.5.5. Ammonia (NH3-N)



(a) 31st July 2018 **(b) 31st August 2018** **(c) 30th September 2018**

Figure 77: Scenario 5: 300 Ml/d Abstraction with climate change effects NH3-N concentrations

8. Spatial Analysis of Model Results

This section analyses the results from the model scenarios to determine the spatial variation of any effects throughout the lake at the end of the months of July, August and September arising from the operation of the proposed abstraction for both the 154 Ml/d abstraction and the 300 Ml/d abstraction, including climate change effects.

For each scenario, the predicted concentrations throughout the model study area were subtracted from the Baseline scenario's predicted concentrations at the end of July, August and September.

The end of July, August and September were representative of the period in 2018 where the greatest variation in water surface levels between the different scenarios had been found and thus the potential for greatest impact on water quality conditions in the study area.

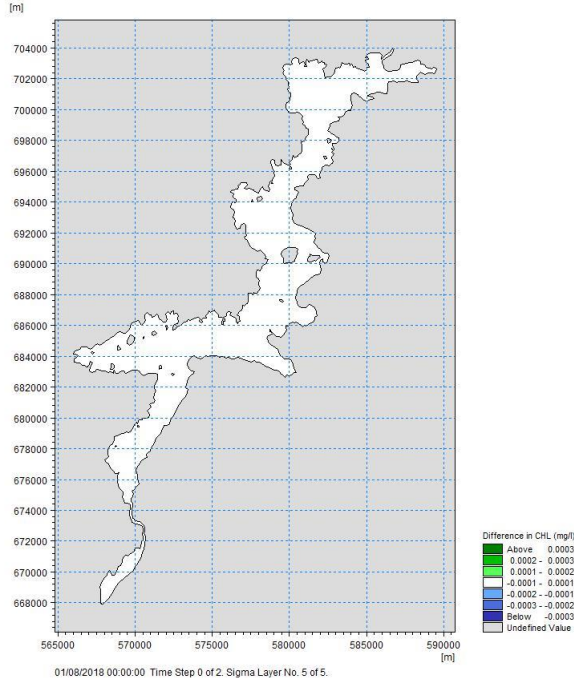
The resulting difference in concentrations for each water quality parameter was plotted spatially throughout the model study area.

A positive difference denotes a higher predicted concentration for the parameter in the Baseline scenario.

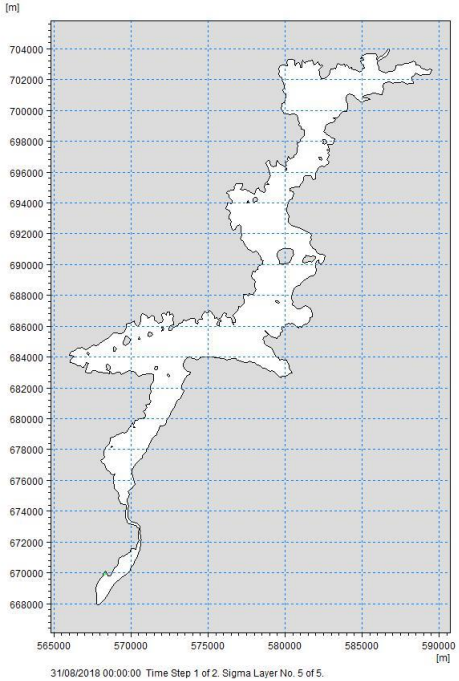
A negative difference denoted a lower predicted concentration for the parameter in the Baseline scenario.

8.1. Baseline v Proposed Abstraction at constant 154 Ml/day

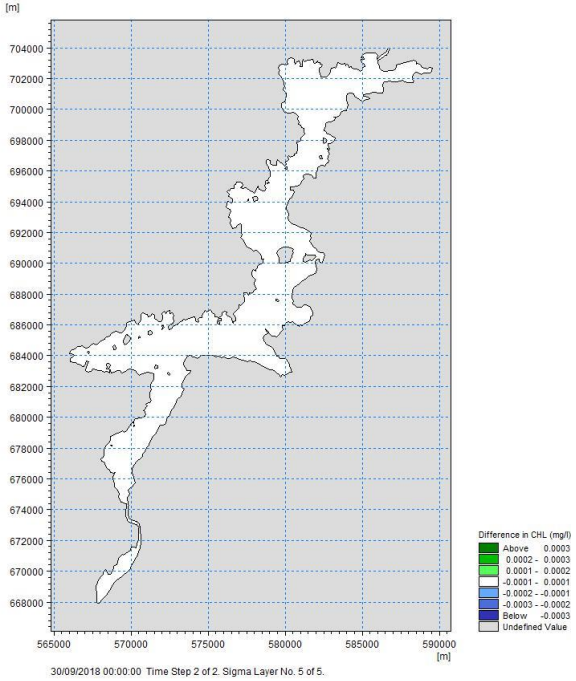
8.1.1. Chlorophyll-a (CHL)



(a) Baseline – 154 Ml/d (31st July 2018)



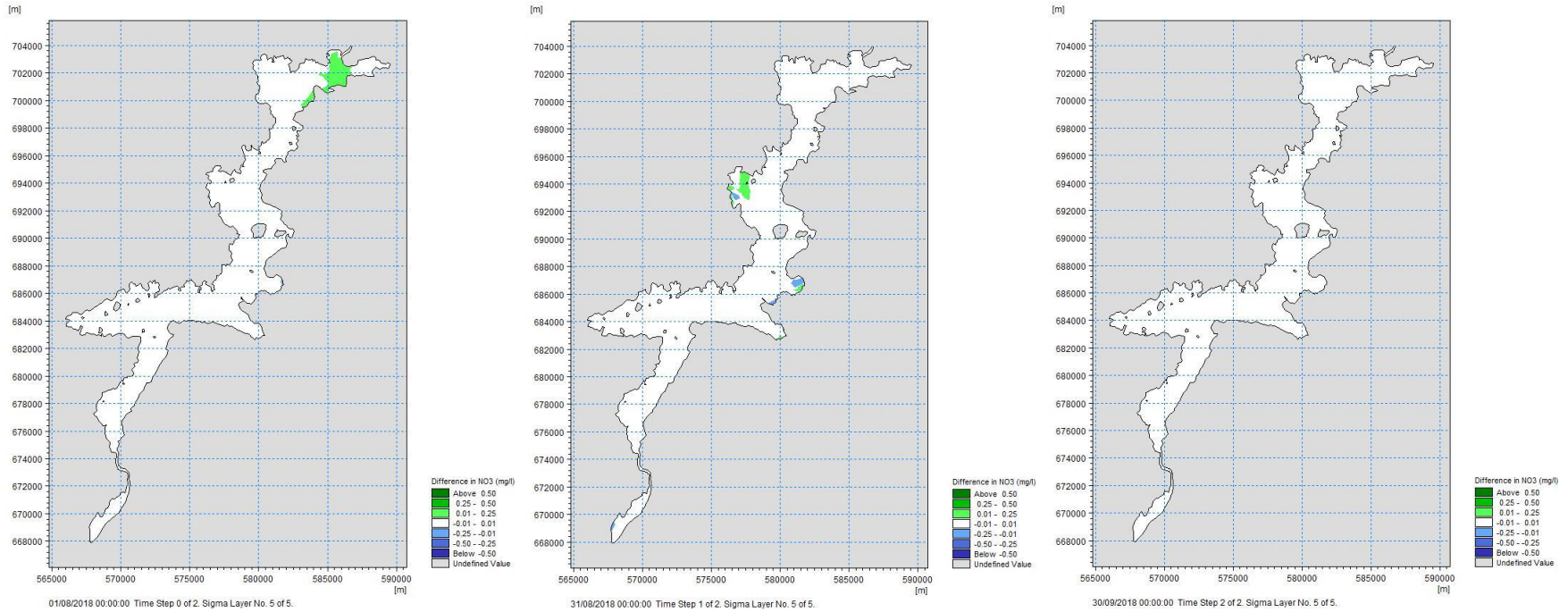
(b) Baseline – 154 Ml/d (30th August 2018)



(c) Baseline – 154 Ml/d (30th September 2018)

Predicted concentrations in CHL between the Baseline scenario and the 154 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed no differences outside the range of +/- 0.0001 mg/l (+/- 0.1 µg/l).

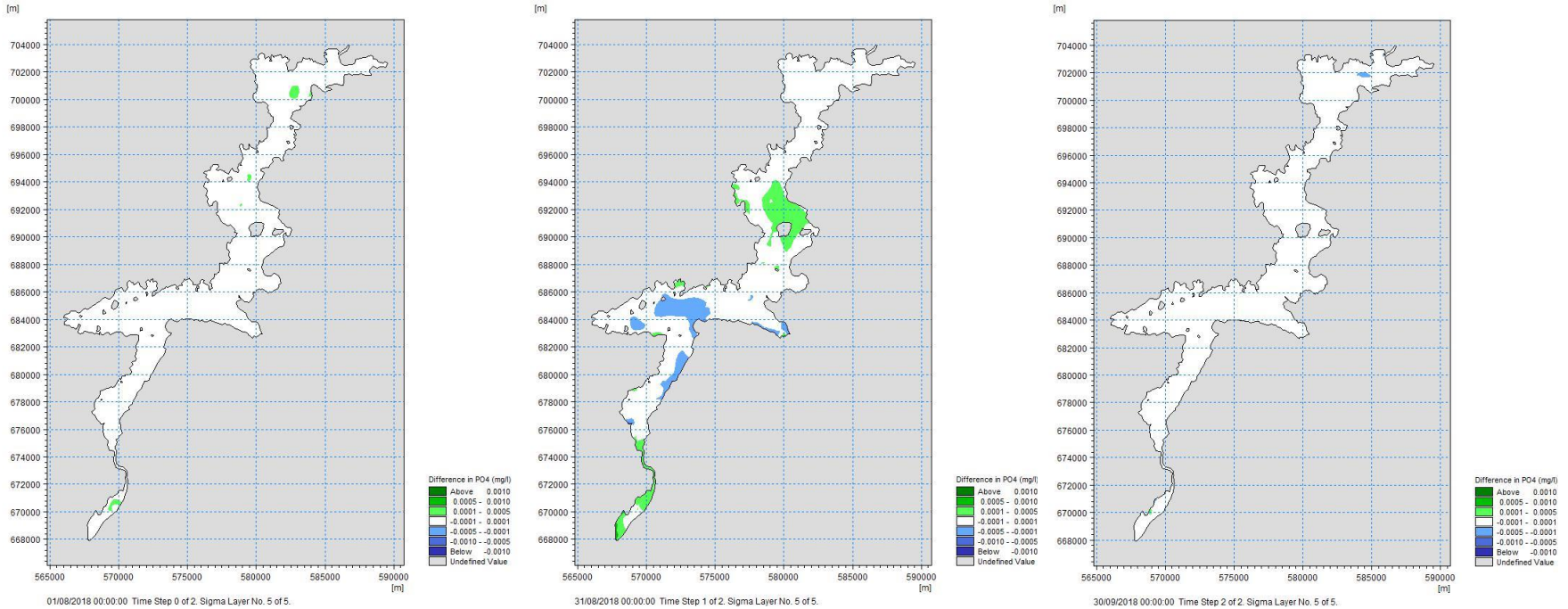
8.1.2. Nitrate (NO3-N)



(a) Baseline – 154 Ml/d (31st July 2018) **(b) Baseline – 154 Ml/d (30th August 2018)** **(c) Baseline – 154 Ml/d (30th September 2018)**

The difference in predicted concentrations in NO3-N between the Baseline scenario and the 154 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed some differences at specific locations only, within the range of +/- 0.25 mg/l. The majority of the lake showed no predicted differences outside the +/- 0.01 mg/l range

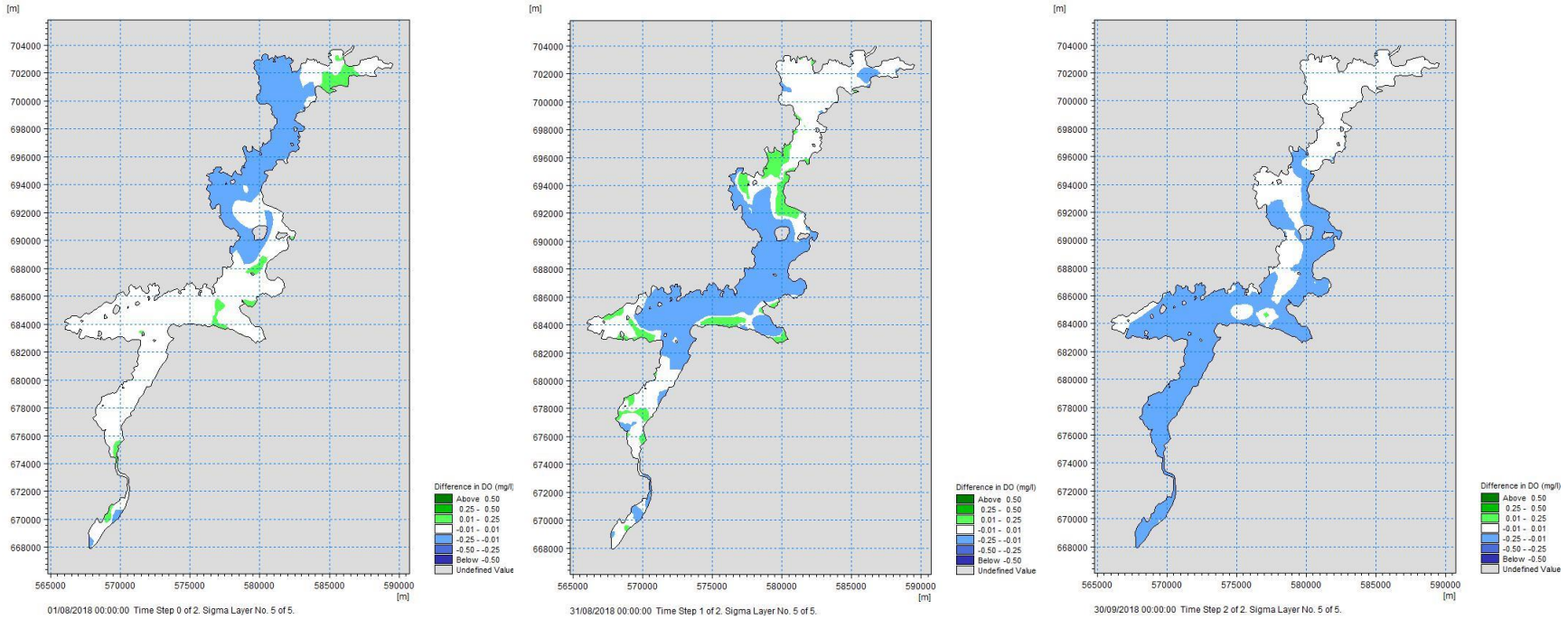
8.1.3. Orthophosphate (PO4-P)



(a) Baseline – 154 Ml/d (31st July 2018) **(b) Baseline – 154 Ml/d (30th August 2018)** **(c) Baseline – 154 Ml/d (30th September 2018)**

The difference in predicted concentrations in PO4-P between the Baseline scenario and the 154 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.0005 mg/l with the largest differences occurring in Late July in the central section of the lake.

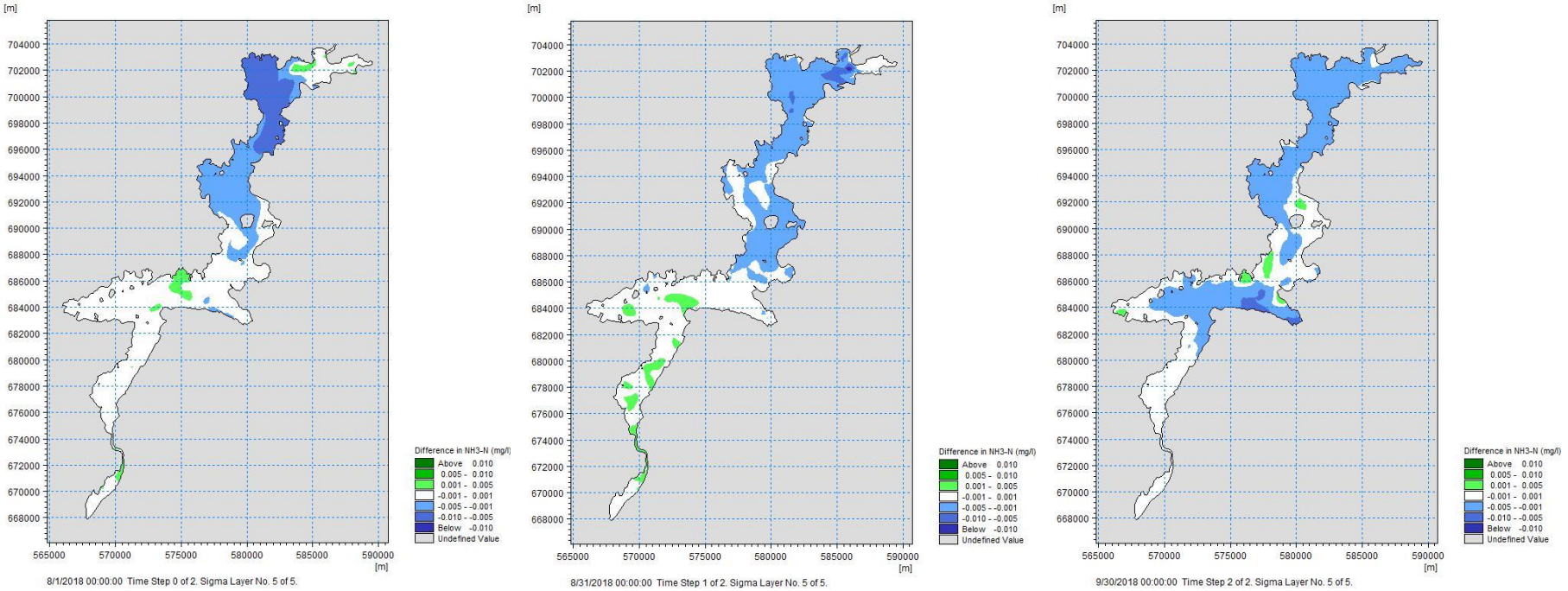
8.1.4. Dissolved Oxygen (DO)



(a) Baseline – 154 Ml/d (31st July 2018) **(b) Baseline – 154 Ml/d (30th August 2018)** **(c) Baseline – 154 Ml/d (30th September 2018)**

The difference in predicted concentrations in DO between the Baseline scenario and the 154 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences, in general, within the range of +/- 0.25 mg/l throughout the lake.

8.1.5. Ammonia (NH3-N)

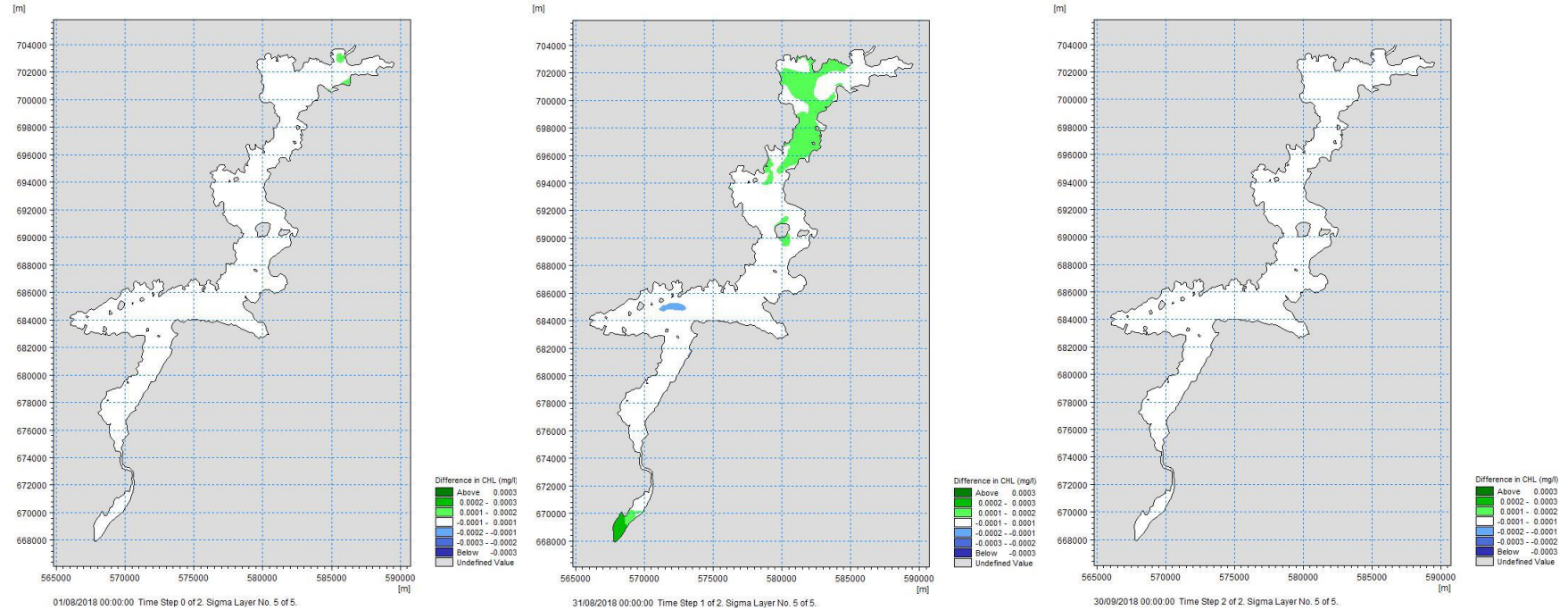


(a) Baseline – 154 Ml/d (31st July 2018) **(b) Baseline – 154 Ml/d (30th August 2018)** **(c) Baseline – 154 Ml/d (30th September 2018)**

The difference in predicted concentrations in NH3-N between the Baseline scenario and the 154 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences, in general, within the range of +/- 0.01 mg/l throughout the lake.

8.2. Baseline v Proposed Abstraction at constant 300 Ml/day

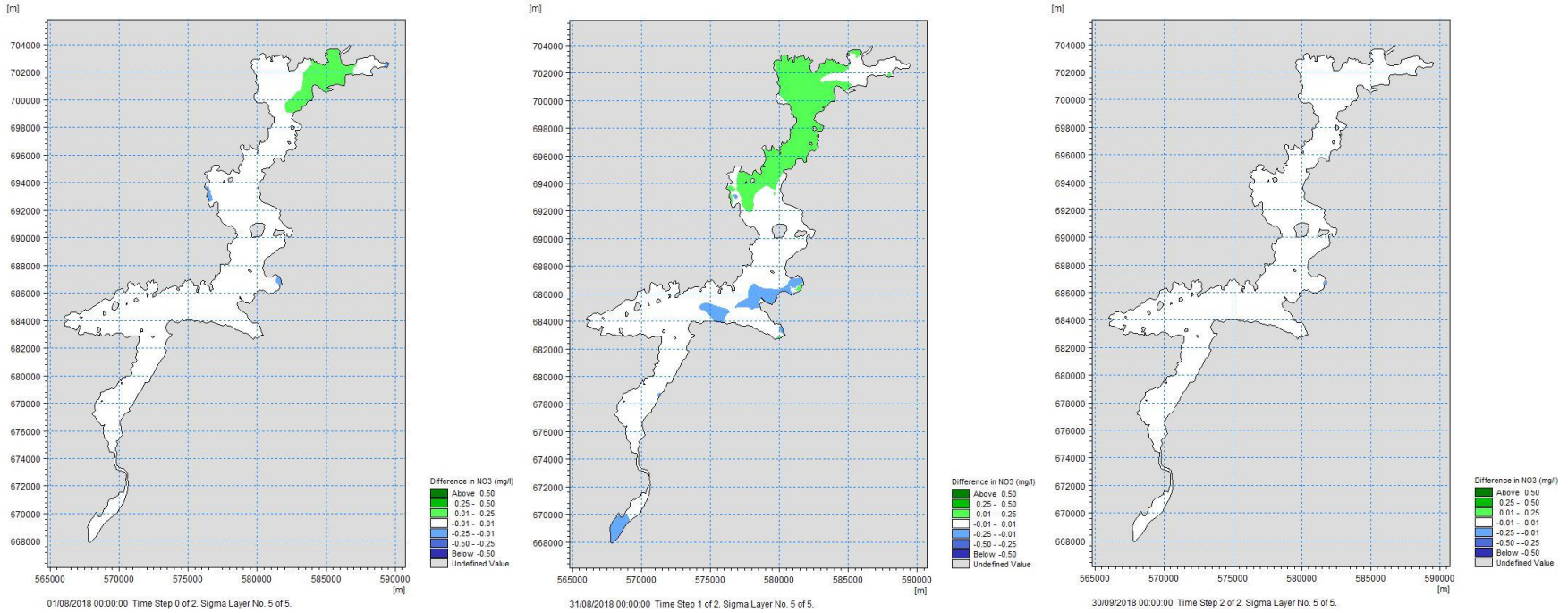
8.2.1. Chlorophyll-a (CHL)



(a) Baseline – 300 Ml/d (31st July 2018) **(b) Baseline – 300 Ml/d (30th August 2018)** **(c) Baseline – 300 Ml/d (30th September 2018)**

The difference in predicted concentrations in CHL between the Baseline scenario and the 300 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences in August only, generally within the range of +/- 0.0002 mg/l (+/- 0.2 µg/l) with the greatest difference occurring in the southern section of the lake in Parteen Basin.

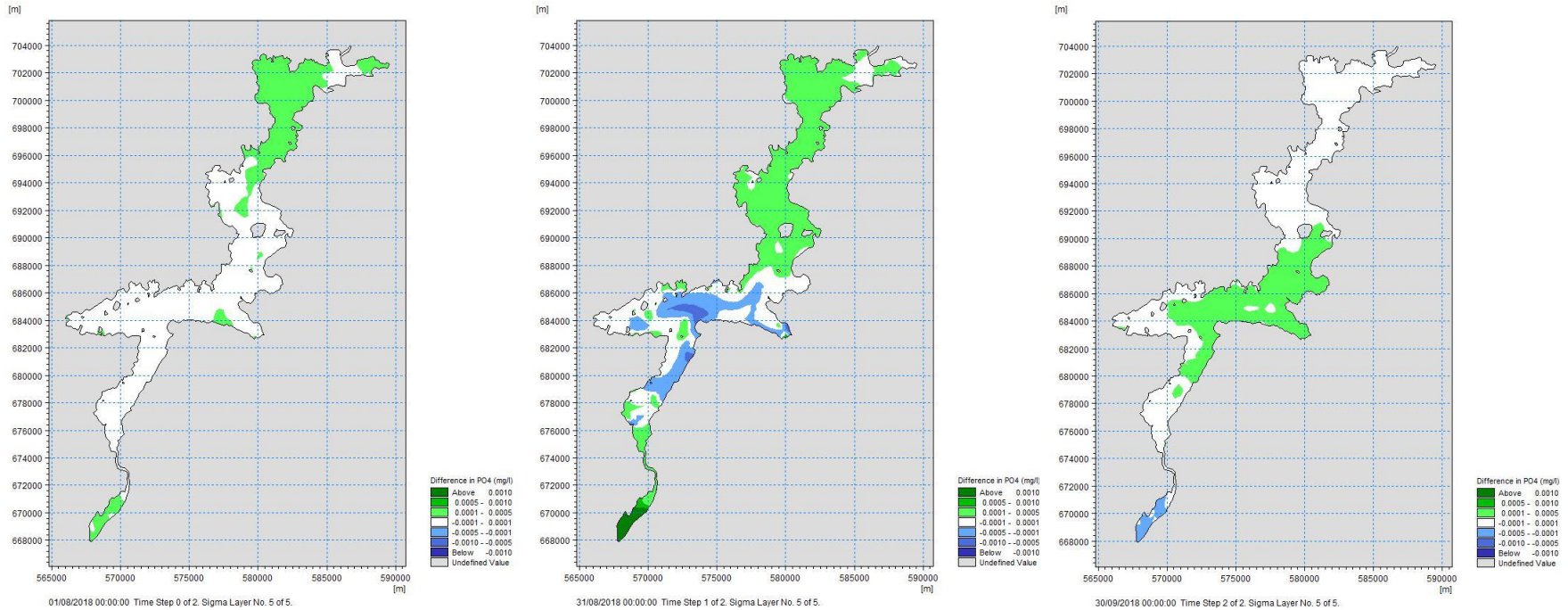
8.2.2. Nitrate (NO3-N)



(a) Baseline – 300 Ml/d (31st July 2018) **(b) Baseline – 300 Ml/d (30th August 2018)** **(c) Baseline – 300 Ml/d (30th September 2018)**

The difference in predicted concentrations in NO3-N between the Baseline scenario and the 300 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.25 mg/l with the greatest difference occurring in the northern section of the lake just downstream of Portumna in July and August.

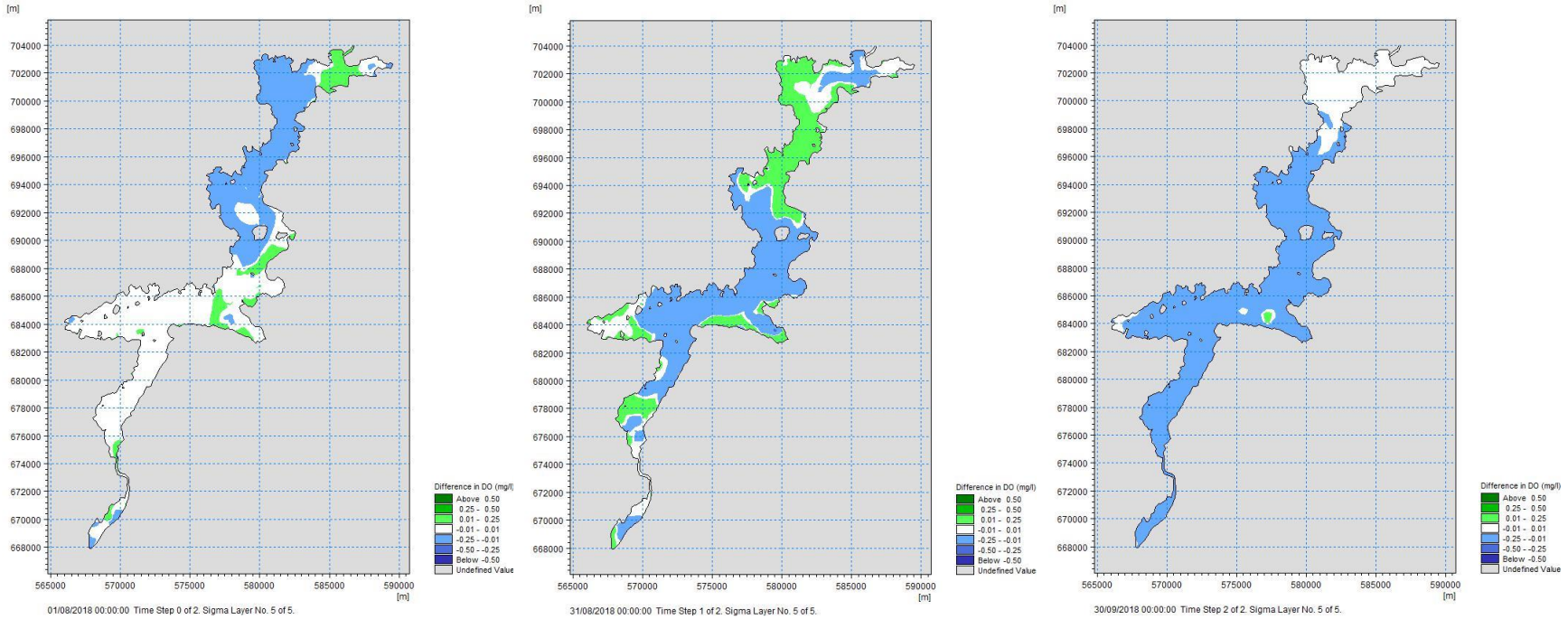
8.2.3. Orthophosphate (PO4-P)



(a) Baseline – 300 Ml/d (31st July 2018) **(b) Baseline – 300 Ml/d (30th August 2018)** **(c) Baseline – 300 Ml/d (30th September 2018)**

The difference in predicted concentrations in PO4-P between the Baseline scenario and the 300 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.005 mg/l throughout the lake. The greatest difference (>0.001 mg/l) occurring in the southern section of the lake in Parteen Basin during August.

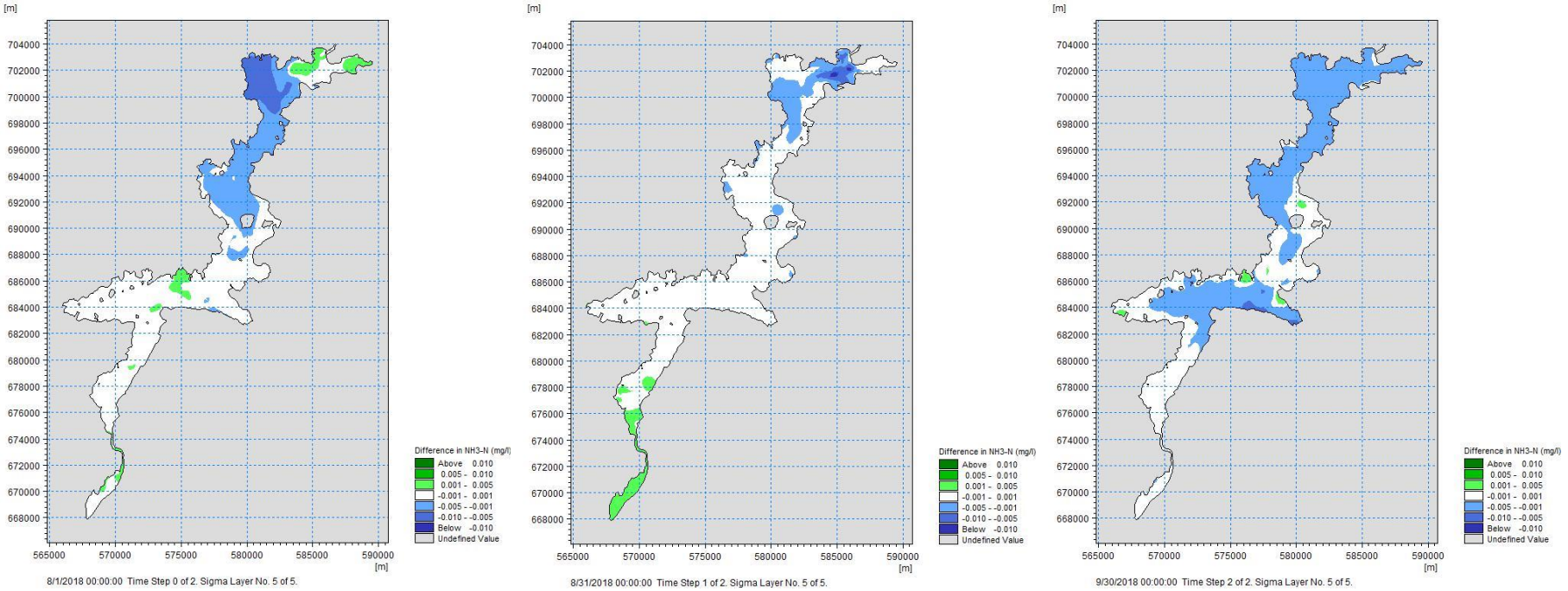
8.2.4. Dissolved Oxygen (DO)



(a) Baseline – 300 Ml/d (31st July 2018) **(b) Baseline – 300 Ml/d (30th August 2018)** **(c) Baseline – 300 Ml/d (30th September 2018)**

The difference in predicted concentrations in DO between the Baseline scenario and the 300 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.25 mg/l throughout the lake.

8.2.5. Ammonia (NH3-N)

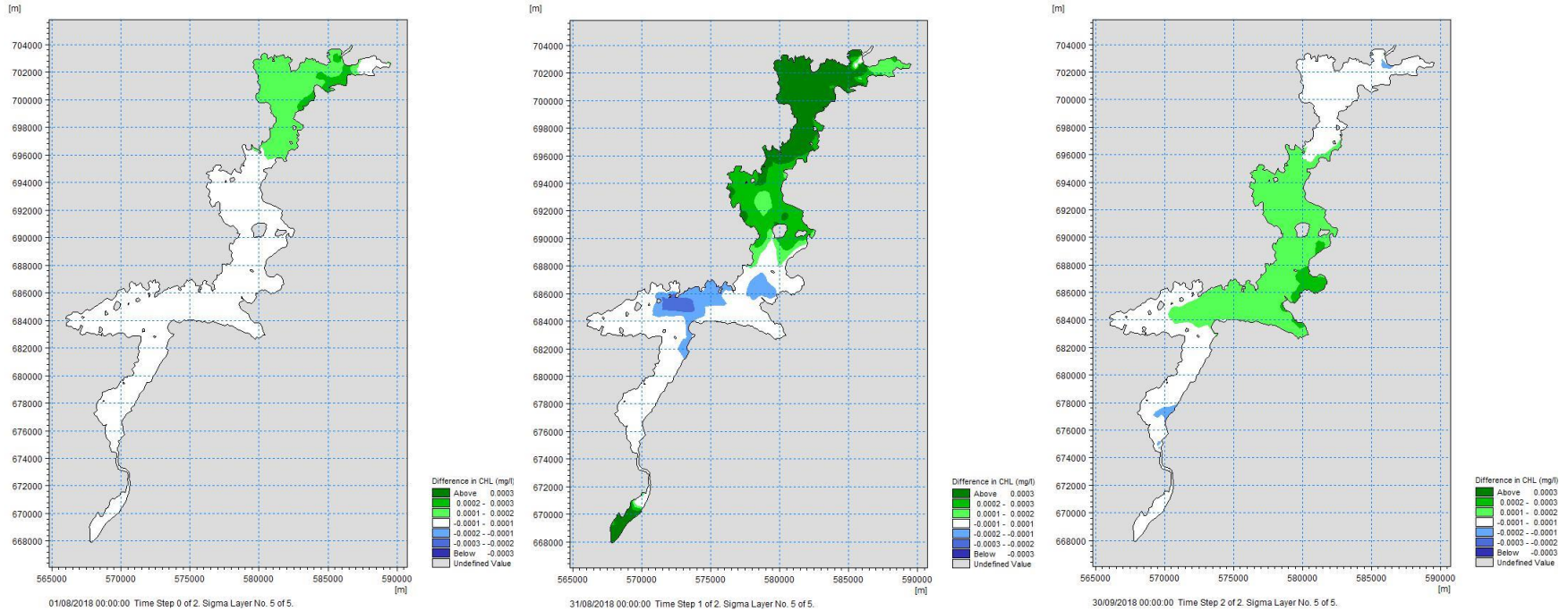


(a) Baseline – 300 Ml/d (31st July 2018) **(b) Baseline – 300 Ml/d (30th August 2018)** **(c) Baseline – 300 Ml/d (30th September 2018)**

The difference in predicted concentrations in NH3-N between the Baseline scenario and the 300 Ml/d abstraction scenario on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.01 mg/l throughout the lake.

8.3. Baseline v Proposed Abstraction at constant 154 Ml/day incorporating climate change effects

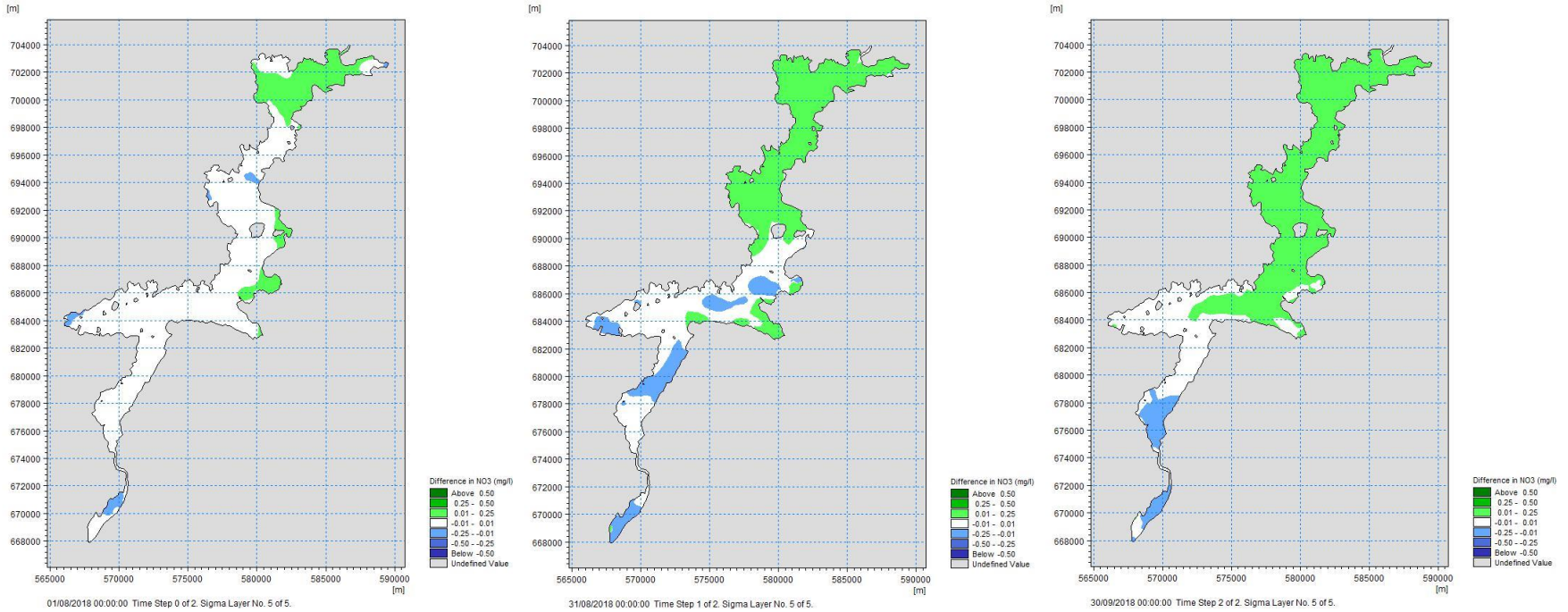
8.3.1. Chlorophyll-a (CHL)



(a) Baseline – 154 Ml/d CC (31st July 2018) **(b) Baseline – 154 Ml/d CC (30th August 2018)** **(c) Baseline – 154 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in CHL between the Baseline scenario and the 154 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences, in general, within the range of +/- 0.0003 mg/l (0.3 µg/l). Both the northern half of the lake and Parteen Basin displayed a reduction CHL concentrations of >0.3 µg/l throughout August.

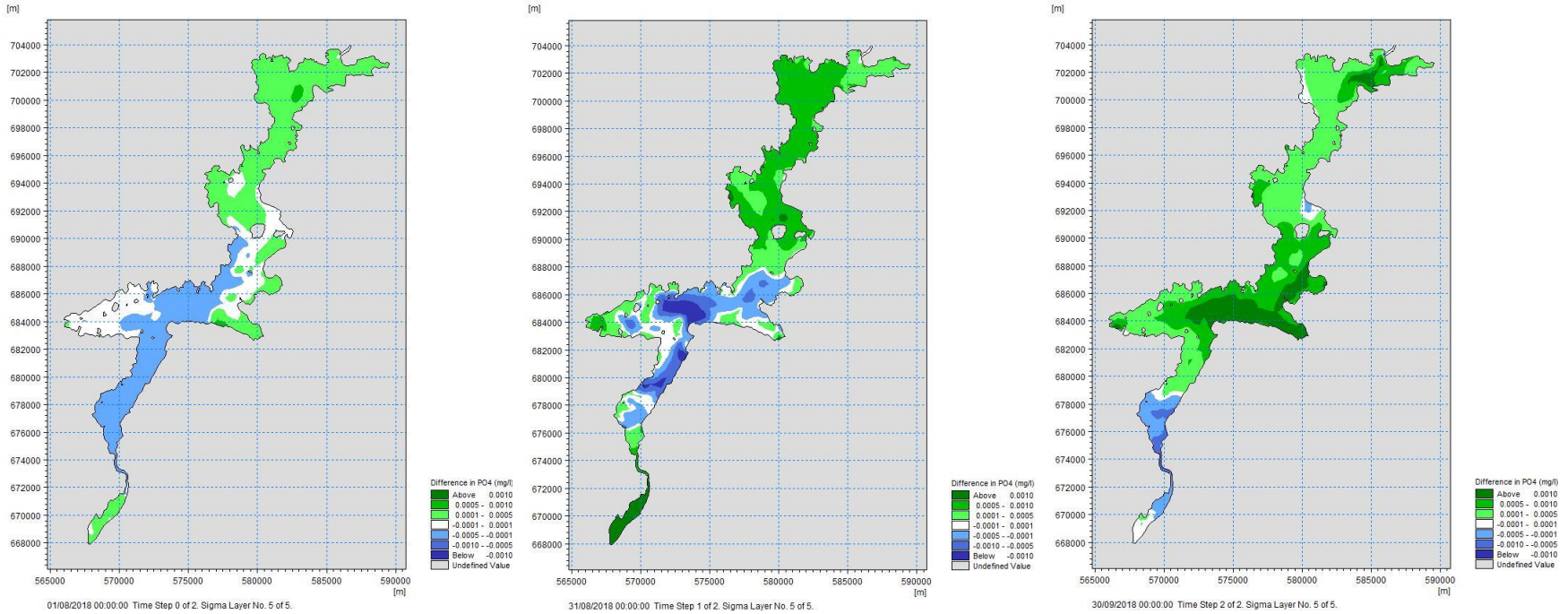
8.3.2. Nitrate (NO3-N)



(a) Baseline – 154 Ml/d CC (31st July 2018) **(b) Baseline – 154 Ml/d CC (30th August 2018)** **(c) Baseline – 154 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in NO3-N between the Baseline scenario and the 154 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.25 mg/l with the greatest variations occurring just downstream of Portumna.

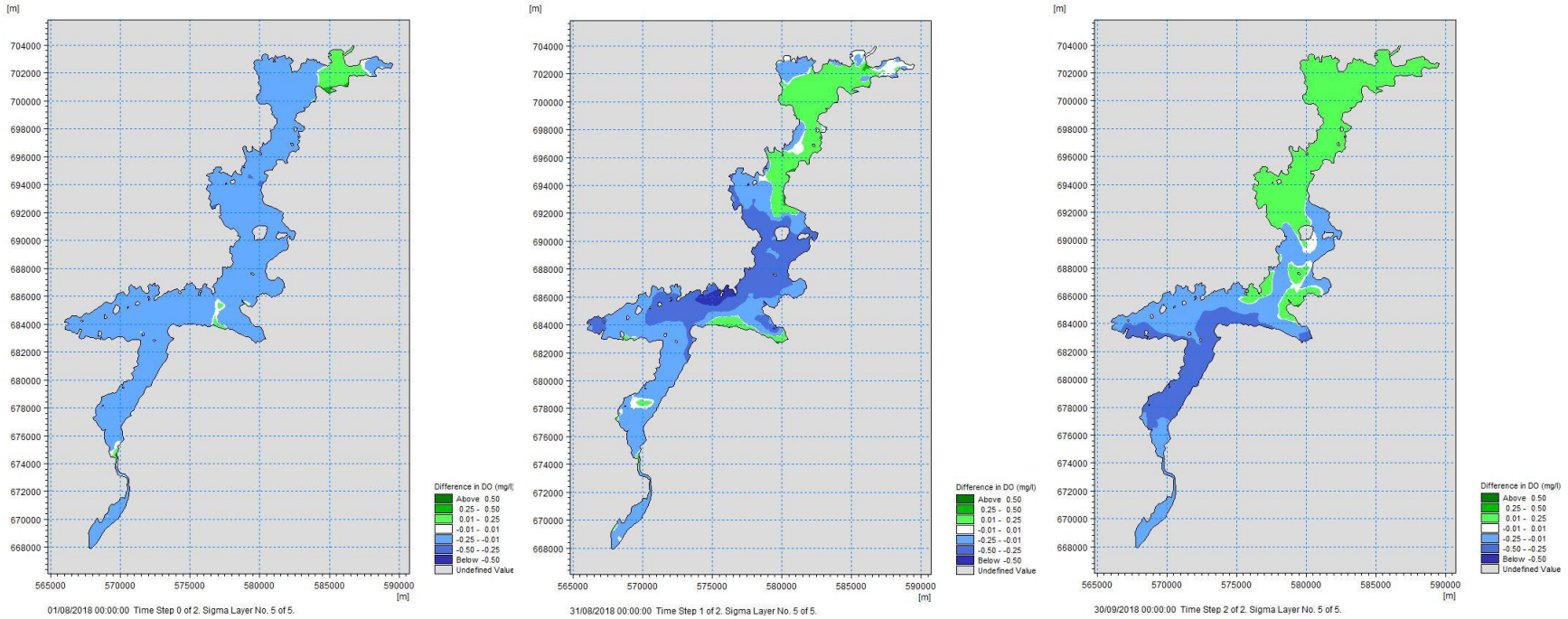
8.3.3. Orthophosphate (PO4-P)



(a) Baseline – 154 Ml/d CC (31st July 2018) **(b) Baseline – 154 Ml/d CC (30th August 2018)** **(c) Baseline – 154 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in PO4-P between the Baseline scenario and the 154 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.001 mg/l with the greatest differences occurring just downstream of Portumna. Differences greater than +/- 0.001 mg/l were predicted in the central and southern sections of the lake in August and September

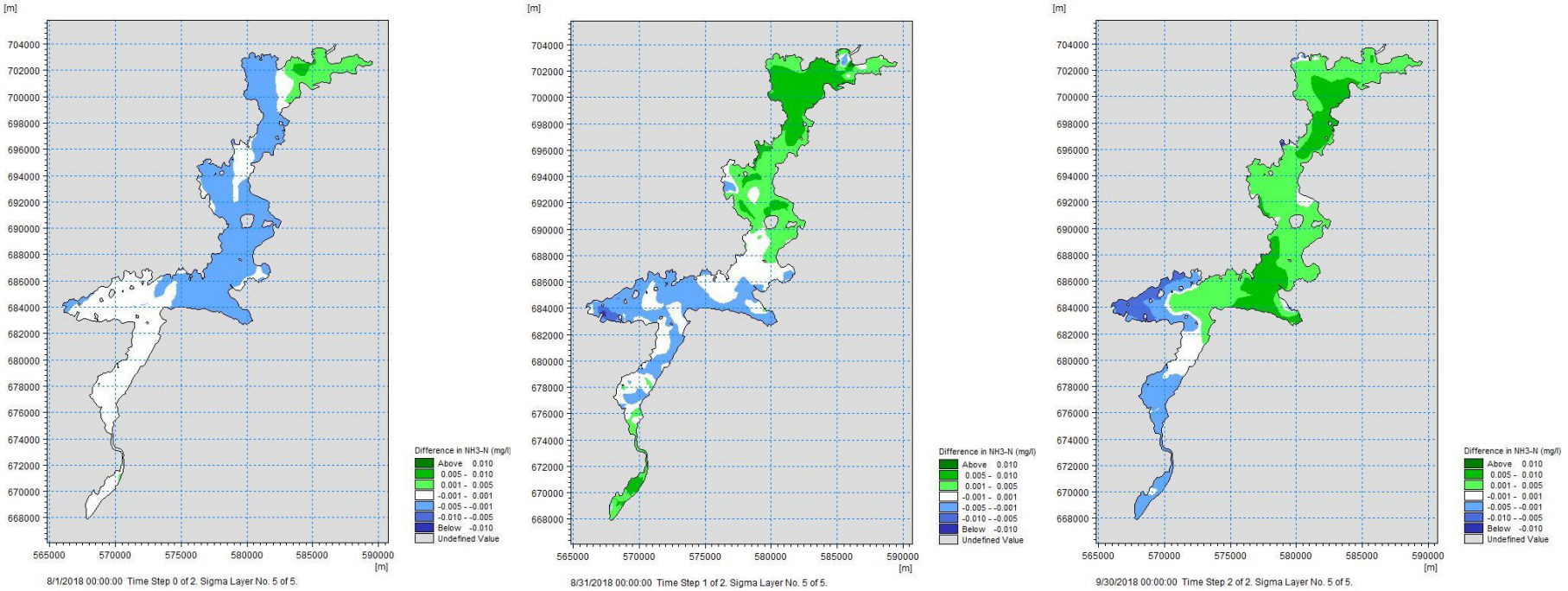
8.3.4. Dissolved Oxygen (DO)



(a) Baseline – 154 Ml/d (CC 31st July 2018) **(b) Baseline – 154 Ml/d CC (30th August 2018)** **(c) Baseline – 154 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in DO between the Baseline scenario and the 154 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.25 mg/l throughout the lake. The central section of the lake displayed an increase in DO concentrations of >0.50 mg/l in August.

8.3.5. Ammonia (NH3-N)

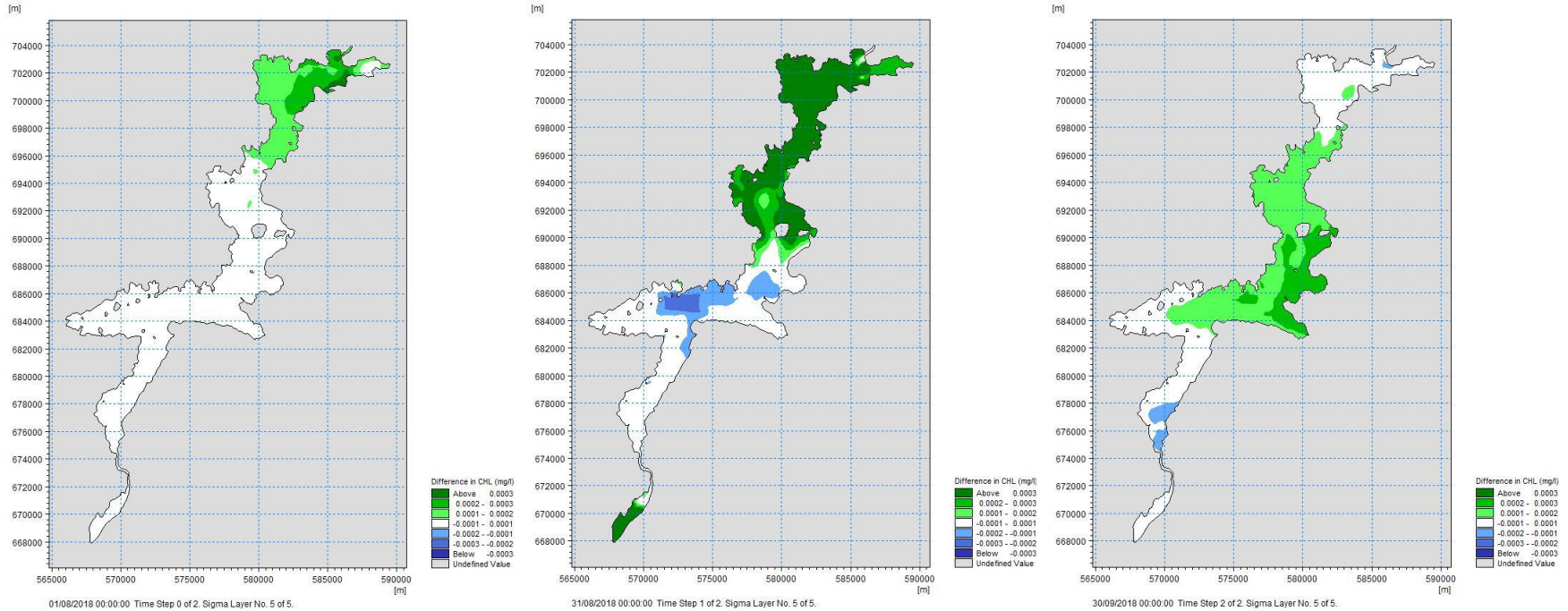


(a) Baseline – 154 Ml/d (CC 31st July 2018) **(b) Baseline – 154 Ml/d CC (30th August 2018)** **(c) Baseline – 154 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in NH3-N between the Baseline scenario and the 154 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences within the range of +/- 0.01 mg/l throughout the lake.

8.4. Baseline v Proposed Abstraction at constant 300 Ml/day incorporating climate change effects

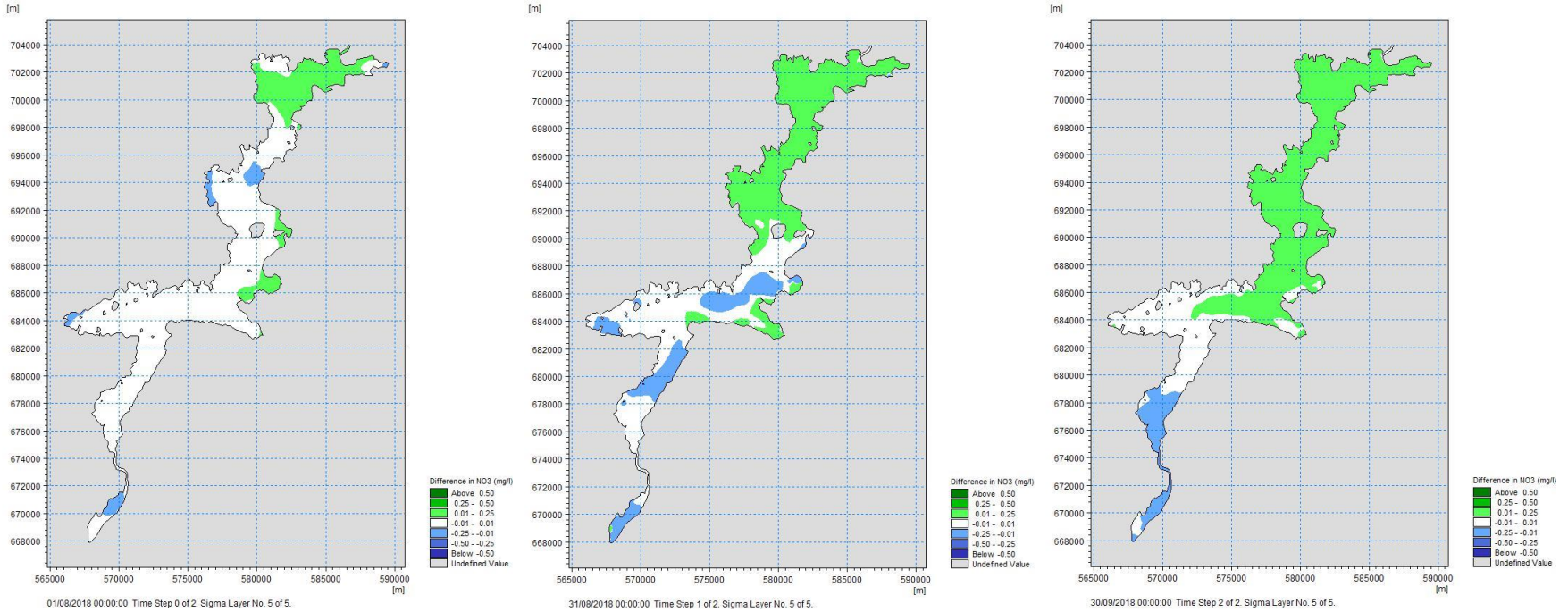
8.4.1. Chlorophyll-a (CHL)



(a) Baseline – 300 Ml/d CC (31st July 2018) **(b) Baseline – 300 Ml/d CC (30th August 2018)** **(c) Baseline – 300 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in CHL between the Baseline scenario and the 300 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences, in general, within the range of +/- 0.0003 mg/l (0.3 µg/l). The northern and central sections of the lake displayed a decrease in CHL concentrations of >0.3 µg/l in August.

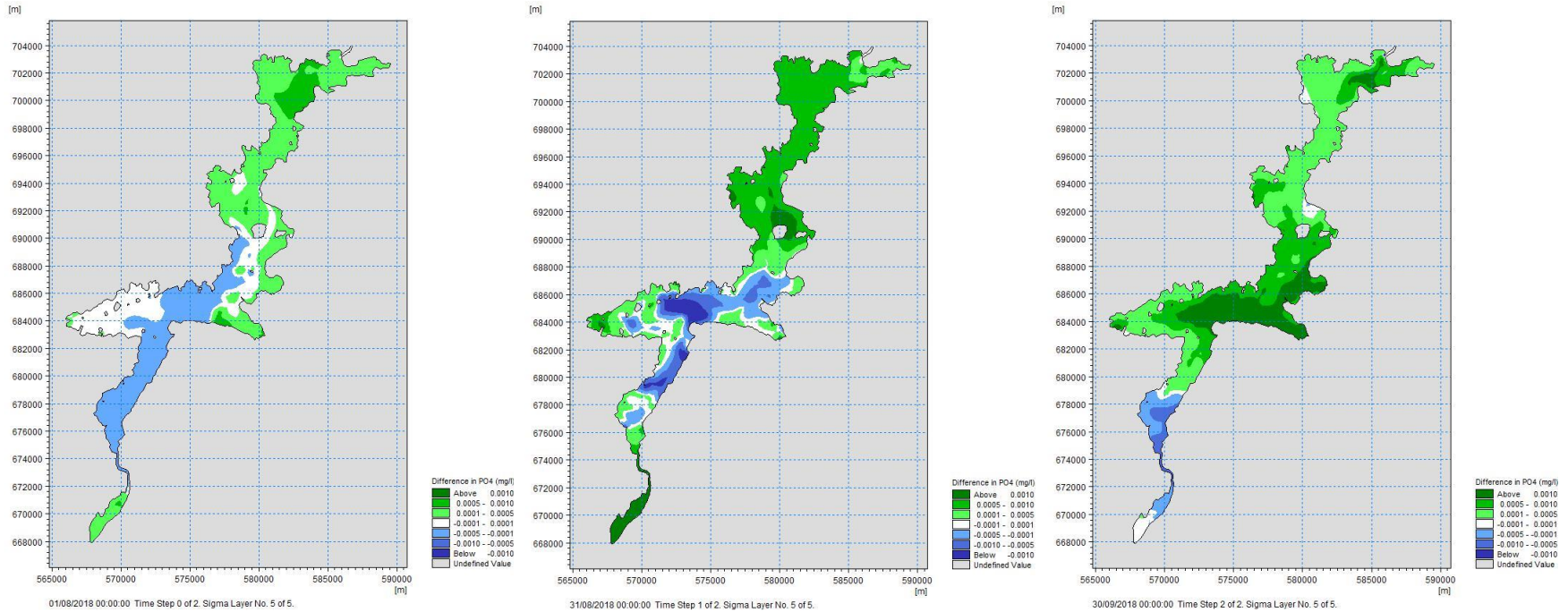
8.4.2. Nitrate (NO3-N)



(a) Baseline – 300 Ml/d CC (31st July 2018) **(b) Baseline – 300 Ml/d CC (30th August 2018)** **(c) Baseline – 300 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in NO3-N between the Baseline scenario and the 300 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences, in general, within the range of +/- 0.25 mg/l.

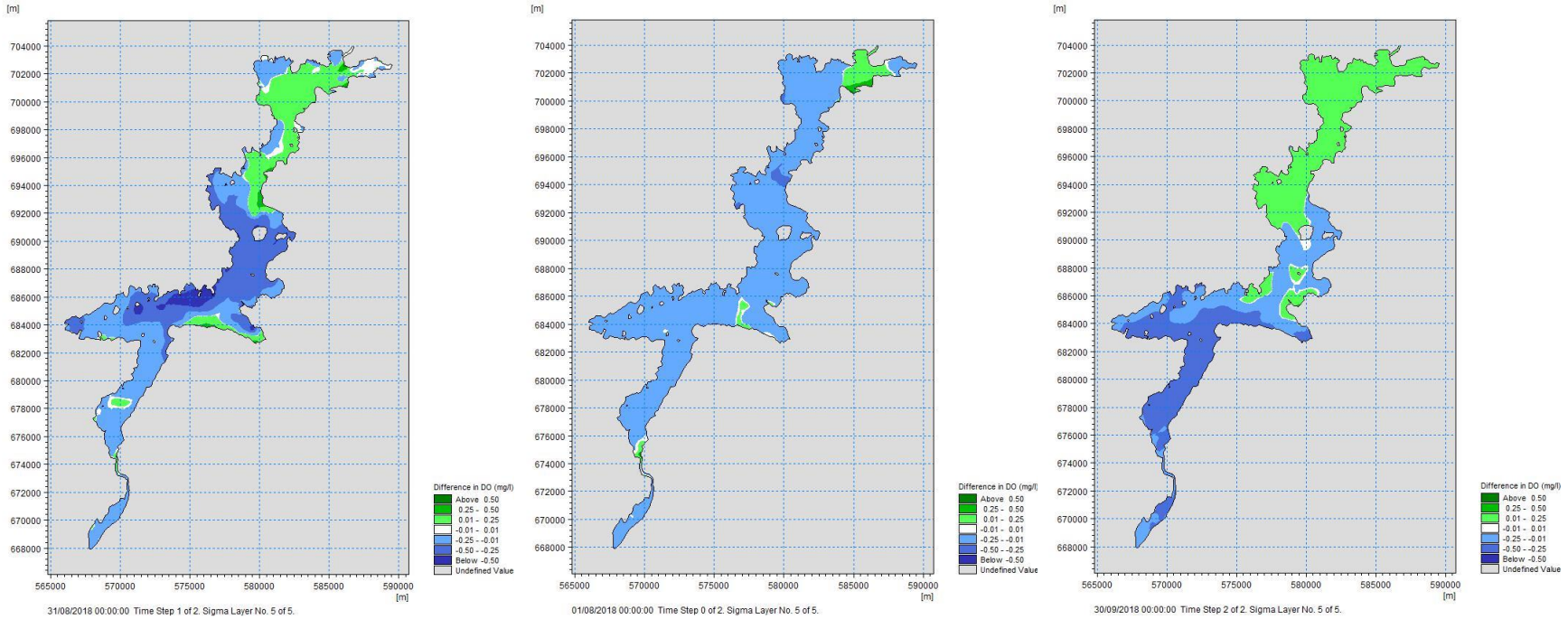
8.4.3. Orthophosphate (PO4-P)



(a) Baseline – 300 Ml/d CC (31st July 2018) **(b) Baseline – 300 Ml/d CC (30th August 2018)** **(c) Baseline – 300 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in PO4-P between the Baseline scenario and the 300 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences generally within the range of +/- 0.001 mg/l. The central section of the lake showed predicted increase in concentration > 0.001 mg/l during August and a predicted decrease in concentration >0.001 mg/l during September.

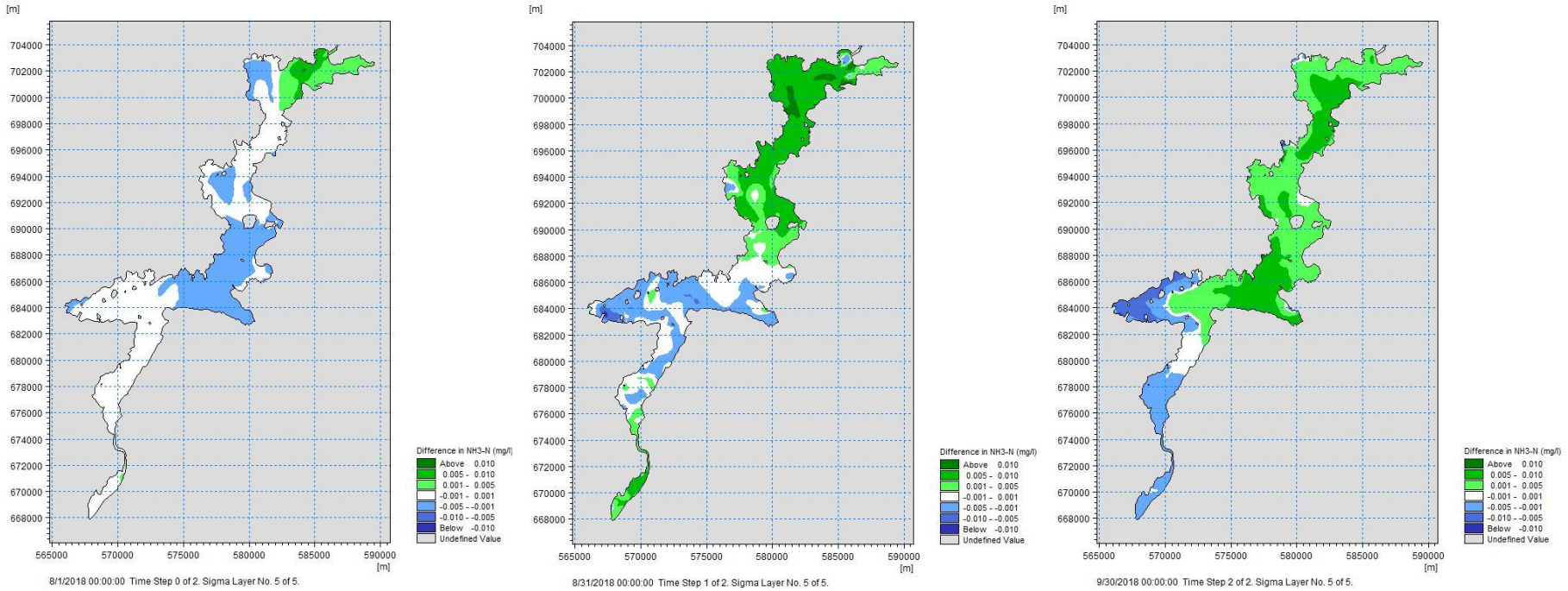
8.4.4. Dissolved Oxygen (DO)



(a) Baseline – 300 Ml/d (CC 31st July 2018) **(b) Baseline – 300 Ml/d CC (30th August 2018)** **(c) Baseline – 300 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in DO between the Baseline scenario and the 300 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences generally in the range of +/- 0.50 mg/l throughout the lake.

8.4.5. Ammonia (NH3-N)



(a) Baseline – 300 Ml/d (CC 31st July 2018) **(b) Baseline – 300 Ml/d CC (30th August 2018)** **(c) Baseline – 300 Ml/d CC (30th September 2018)**

The difference in predicted concentrations in NH3-N between the Baseline scenario and the 300 Ml/d abstraction scenario incorporating Climate Change effects on 31st July, 30th August, and 30th September 2018 showed differences generally in the range of +/- 0.01 mg/l throughout the lake.

9. Temporal Analysis of Model Results

The analyses of the predicted impacts on Lough Derg and Parteen Basin arising from the operation of both the proposed 154 Ml/d abstraction and the proposed 300 Ml/d abstraction, including the effects of climate change are presented in this section.

Analysis was undertaken by comparing the time series of model predictions for each of the water quality parameters in the i) Baseline, ii) 154 Ml/d Abstraction, iii) 300 Ml/d Abstraction, iv) 154 Ml/d Abstraction incorporating climate change effects, and v) 300 Ml/d Abstraction scenario incorporating climate change effects.

This analysis was undertaken at the manual sampling locations of WQMS-2, WQMS-5, and WQMS-8 in north, middle and south of the study area respectively. The locations are presented below in Figure 78.

The predicted concentrations of biochemical oxygen demand (BOD) at WQMS-2, WQMS-5, and WQMS-8 for each of the seven scenarios are presented in Figure 79 to Figure 81.

The predicted concentrations of dissolved oxygen (DO) at WQMS-2, WQMS-5, and WQMS-8 for each of the seven scenarios are presented in Figure 82 to Figure 84.

The predicted concentrations of chlorophyll-a (CHL) at WQMS-2, WQMS-5, and WQMS-8 for each of the seven scenarios are presented in Figure 85 to Figure 87.

The predicted concentrations of nitrate (NO3-N) at WQMS-2, WQMS-5, and WQMS-8 for each of the seven scenarios are presented in Figure 88 to Figure 90.

The predicted concentrations of orthophosphate (PO4-P) at WQMS-2, WQMS-5, and WQMS-8 for each of the seven scenarios are presented in Figure 91 to Figure 93.

The predicted concentrations of ammonia (NH3-N) at WQMS-2, WQMS-5, and WQMS-8 for each of the seven scenarios are presented in Figure 94 to Figure 96.

The tables below each set of figures details the maximum, minimum and average difference between the predicted Baseline concentrations and the respective abstraction scenarios at each location WQMS-2, WQMS-5 and WQMS-8 for the respective water quality parameter. The average difference is calculated over the final twelve-month period of the simulations from 01/01/2018 to 31/12/2018.

As with the spatial analysis, a positive difference denoted a higher predicted concentration in the Baseline scenario. A negative difference denoted a lower predicted concentration in the Baseline scenario.

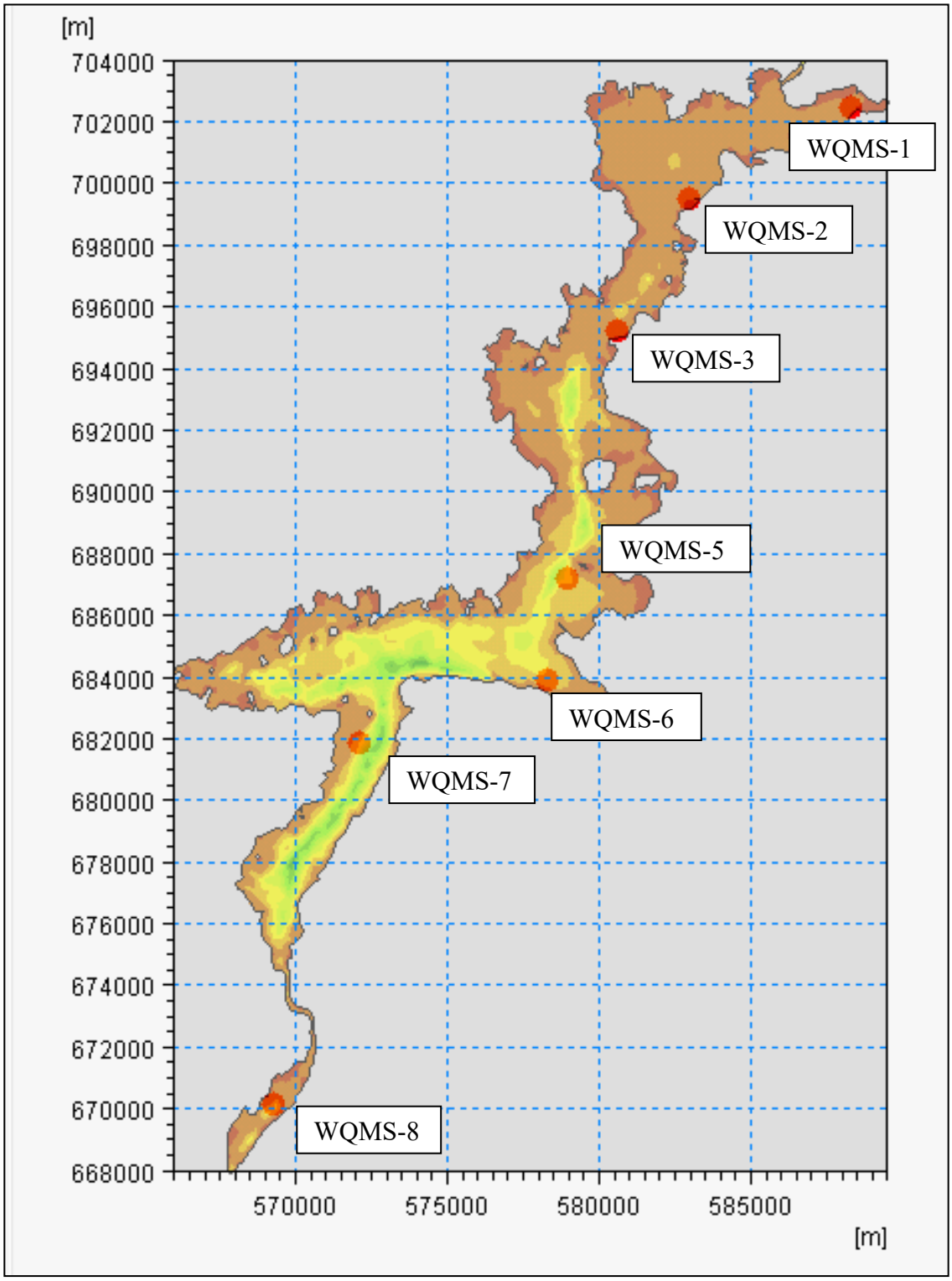


Figure 78: Water quality manual sampling (WQMS) locations

9.1. Biochemical Oxygen Demand (BOD)

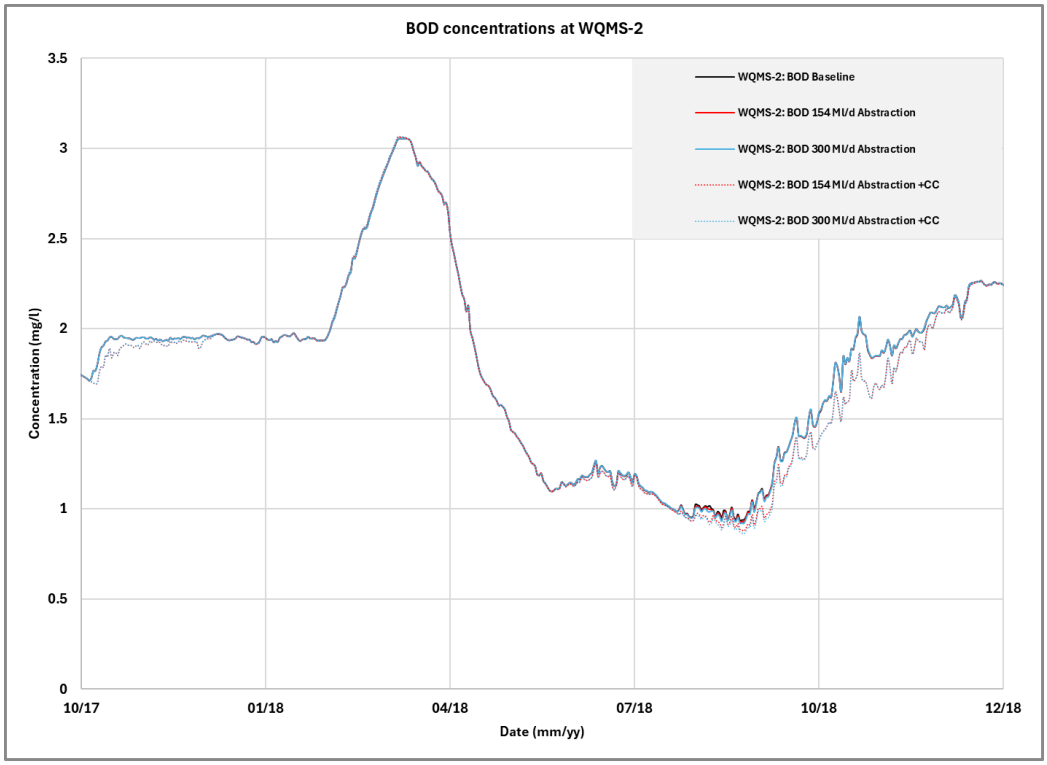


Figure 79: Predicted BOD concentrations at location WQMS-2

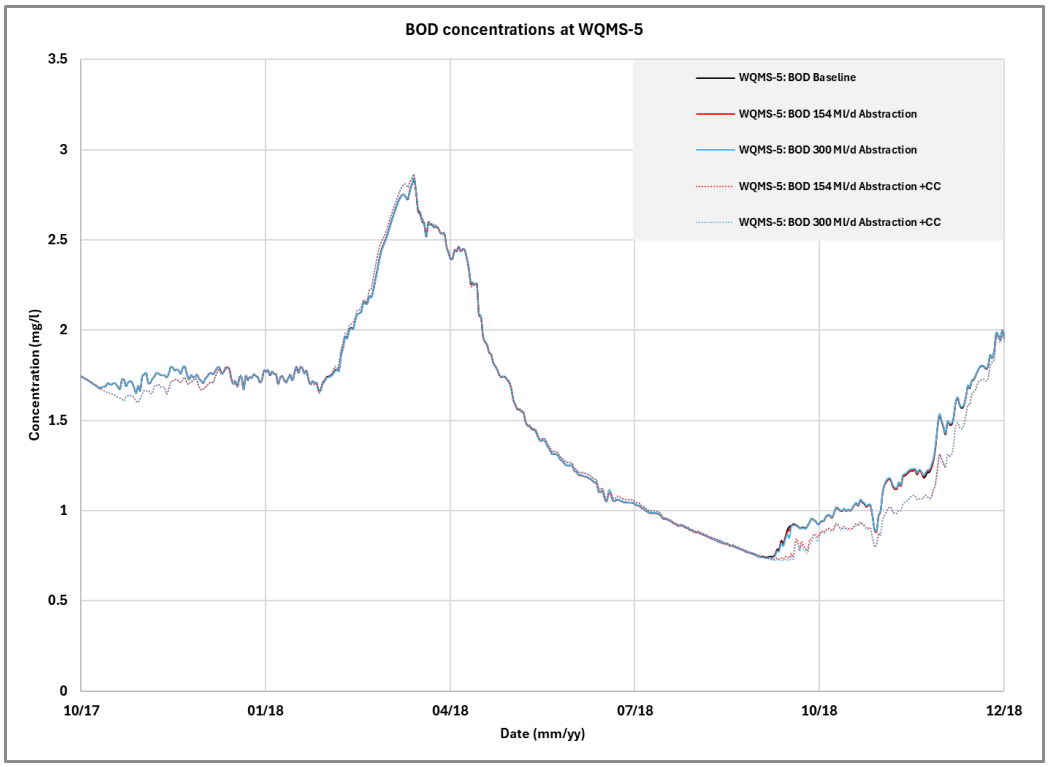


Figure 80: Predicted BOD concentrations at location WQMS-5

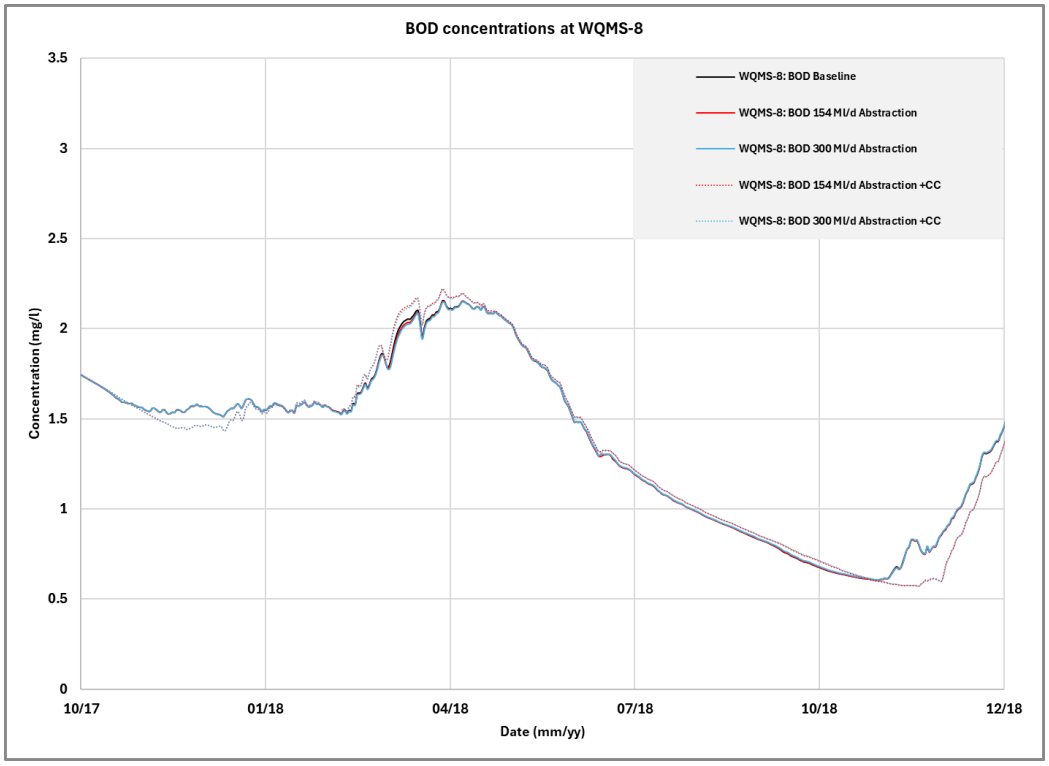


Figure 81: Predicted BOD concentrations at location WQMS-8

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
BOD (mg/)	Average	**WQMS-2**	**1.780 mg/l**	1.779 mg/l	1.779 mg/l	1.744 mg/l	1.742 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*-0.001 mg/l*	*-0.036 mg/l*	*-0.038 mg/l*
		% Difference from Baseline		*0.0%*	*-0.1%*	*-2.0%*	*-2.1%*
		WQMS-5	**1.521 mg/l**	1.521 mg/l	1.521 mg/l	1.492 mg/l	1.491 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*-0.029 mg/l*	*-0.029 mg/l*
		% Difference from Baseline		*0.0%*	*0.0%*	*-1.9%*	*-1.9%*
		WQMS-8	**1.368 mg/l**	1.366 mg/l	1.366 mg/l	1.356 mg/l	1.355 mg/l
		Difference from Baseline (mg/l)		*-0.001 mg/l*	*-0.002 mg/l*	*-0.012 mg/l*	*-0.012 mg/l*
		% Difference from Baseline		*-0.1%*	*-0.1%*	*-0.9%*	*-0.9%*

Table 3: Predicted differences in average BOD concentration per location per scenario.

The model predicted ***miniscule decreases*** (second decimal place) of between -0.1% to -2.1% with respect to Baseline in the average BOD concentrations over the course of the simulation period at all locations WQMS-2, WQMS-5 and WQMS-8 for all abstraction scenarios.

9.2.Dissolved Oxygen (DO)

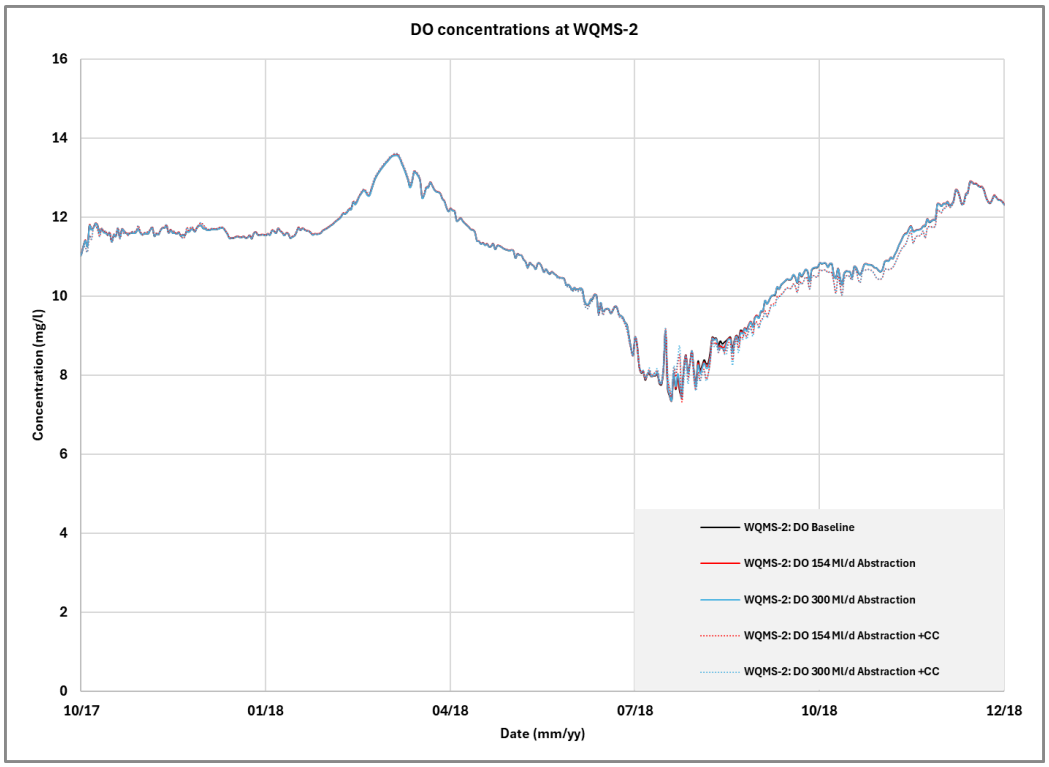


Figure 82: Predicted DO concentrations at location WQMS-2

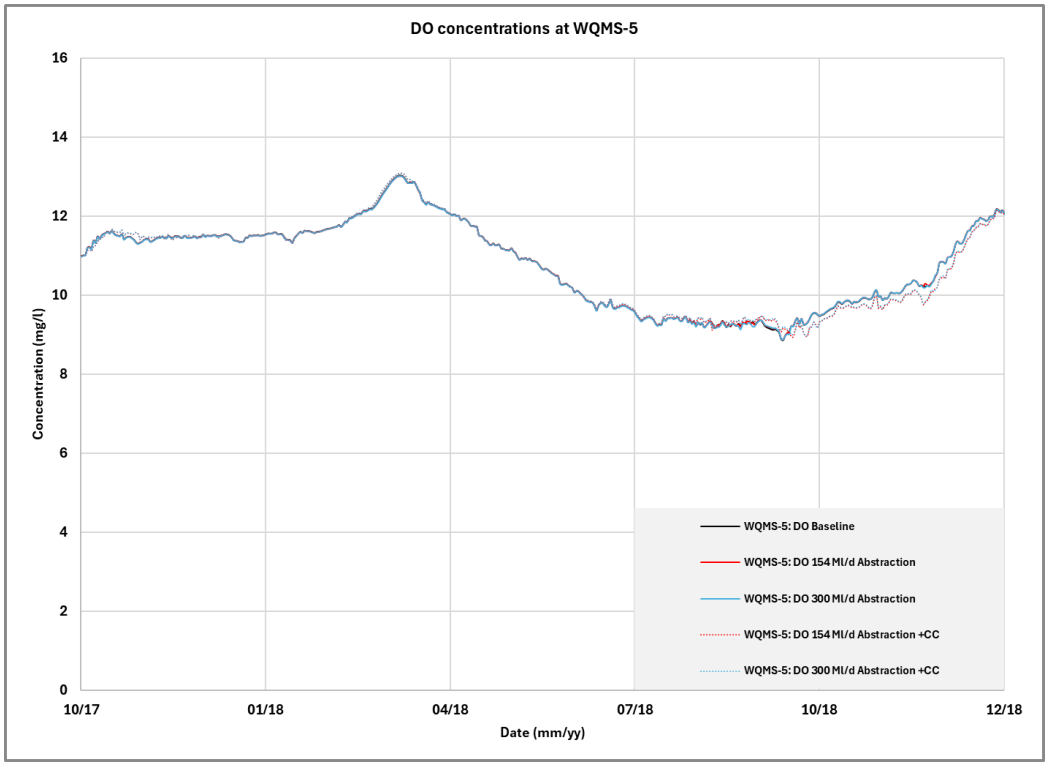


Figure 83: Predicted DO concentrations at location WQMS-5

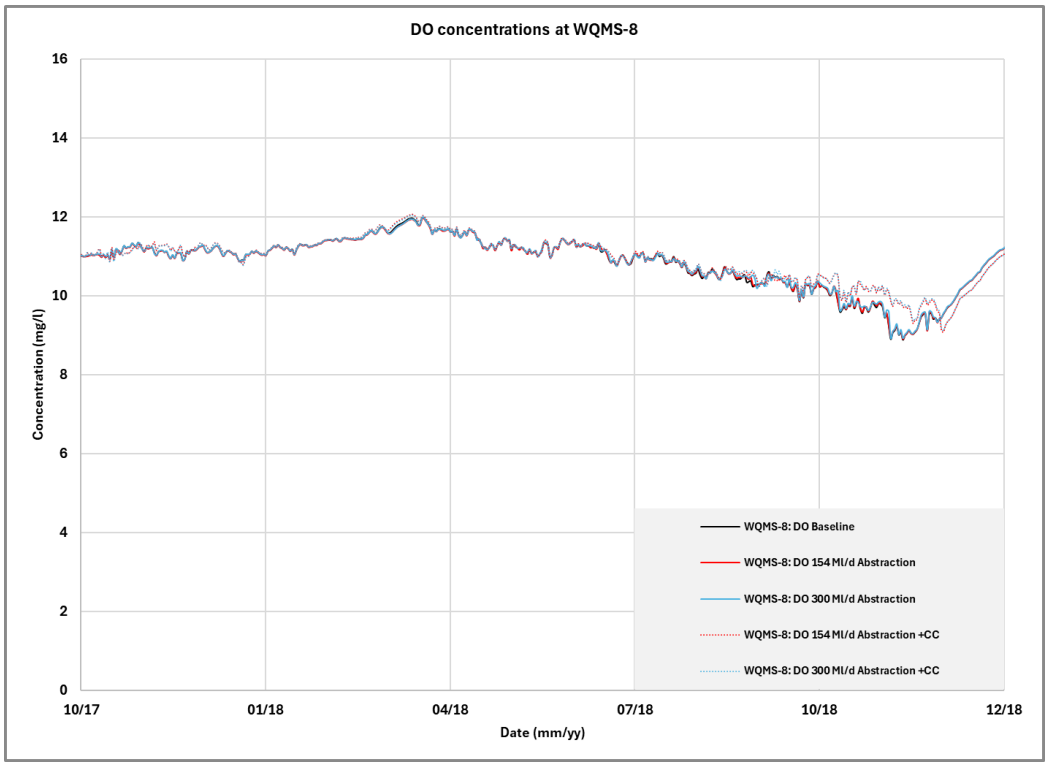


Figure 84: Predicted DO concentrations at location WQMS-8

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
DO (mg/)	Average	**WQMS-2**	**11.052 mg/l**	11.051 mg/l	11.049 mg/l	11.003 mg/l	11.001 mg/l
		Difference from Baseline (mg/l)		*-0.002 mg/l*	*-0.003 mg/l*	*-0.050 mg/l*	*-0.051 mg/l*
		% Difference from Baseline		*0.0%*	*0.0%*	*-0.5%*	*-0.5%*
		WQMS-5	**10.812 mg/l**	10.813 mg/l	10.814 mg/l	10.798 mg/l	10.801 mg/l
		Difference from Baseline (mg/l)		*0.002 mg/l*	*0.003 mg/l*	*-0.014 mg/l*	*-0.011 mg/l*
		% Difference from Baseline		*0.0%*	*0.0%*	*-0.1%*	*-0.1%*
		WQMS-8	**10.854 mg/l**	10.859 mg/l	10.863 mg/l	10.930 mg/l	10.937 mg/l
		Difference from Baseline (mg/l)		*0.005 mg/l*	*0.009 mg/l*	*0.076 mg/l*	*0.083 mg/l*
		% Difference from Baseline		*0.0%*	*0.1%*	*0.7%*	*0.8%*

Table 4: Predicted differences in average DO concentration per location per scenario.

The model predicted ***miniscule variations*** (second decimal place) of less than ±1% with respect to Baseline in the average DO concentrations over the course of the simulation period at all locations WQMS-2, WQMS-5 and WQMS-8 for all abstraction scenarios.

9.3.Chlorophyll-a (CHL)

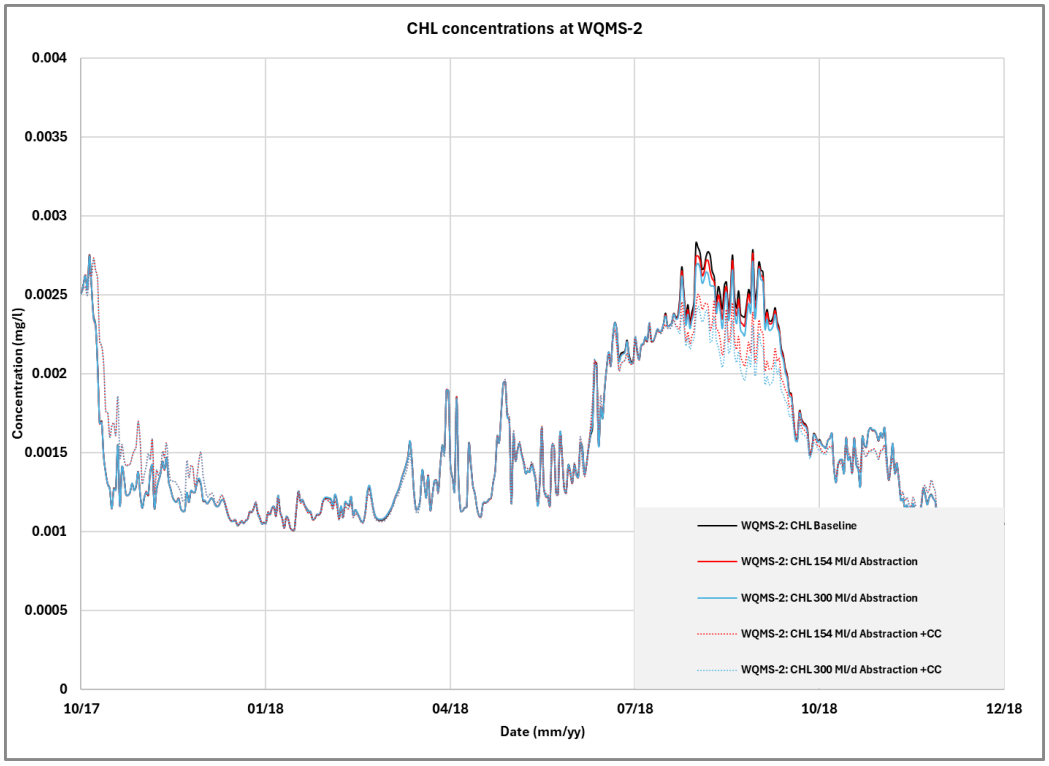


Figure 85: Predicted CHL concentrations at location WQMS-2

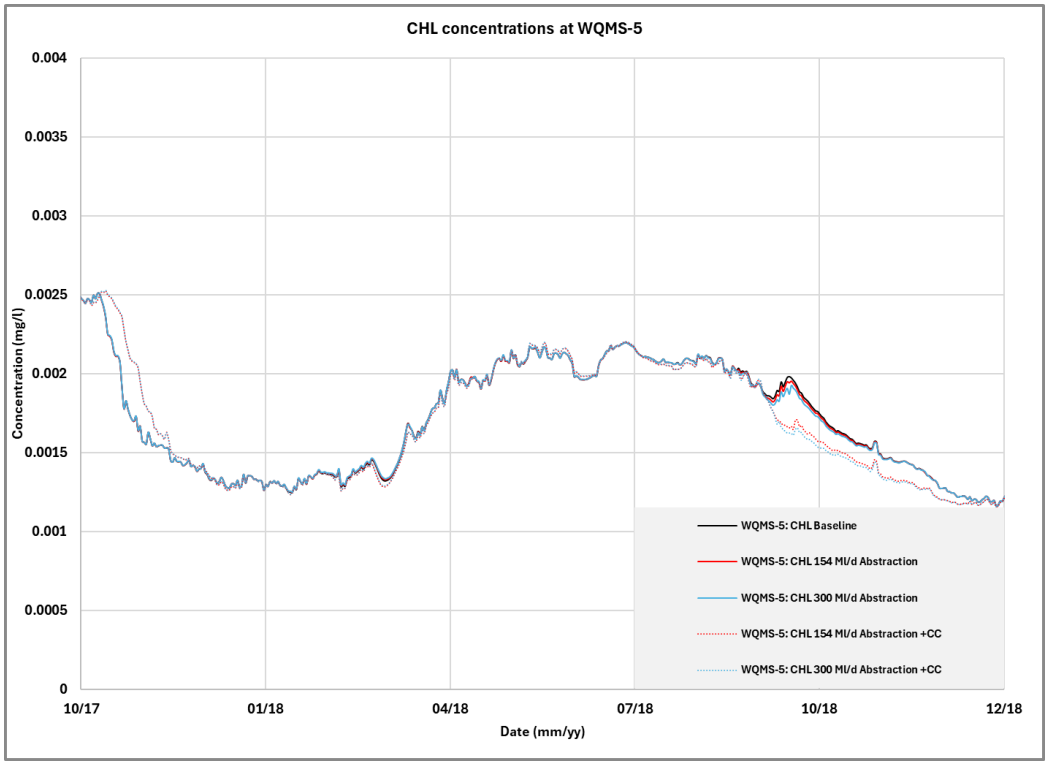


Figure 86: Predicted CHL concentrations at location WQMS-5

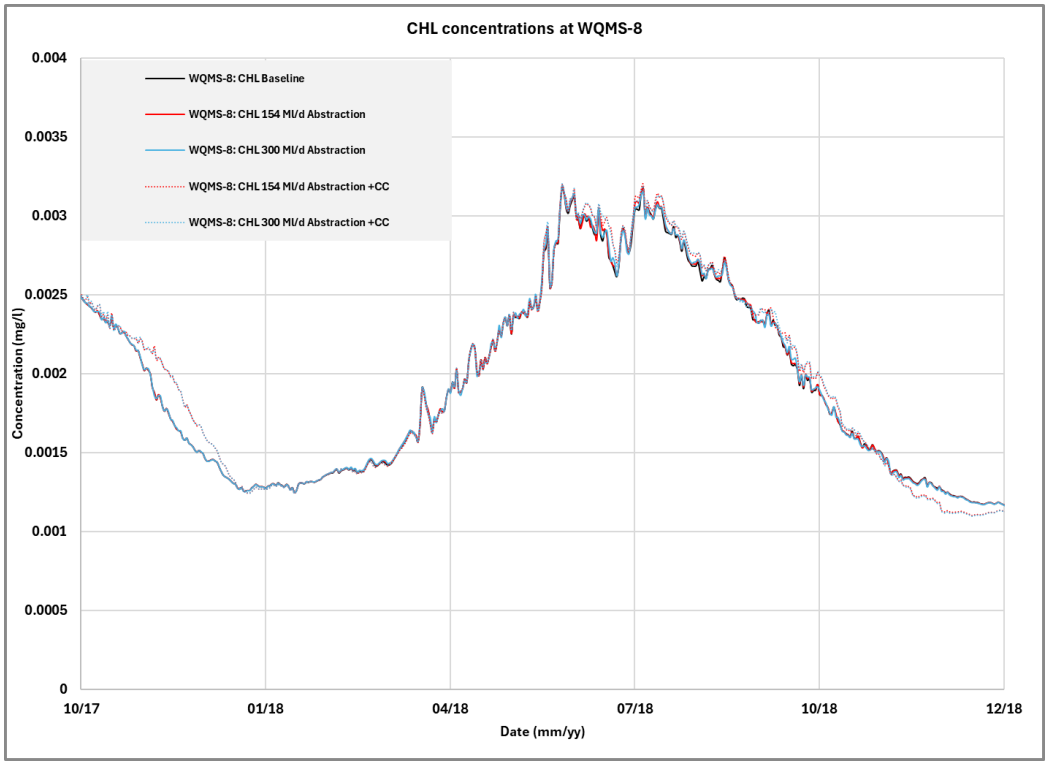


Figure 87: Predicted CHL concentrations at location WQMS-8

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
CHL (ug/)	Average	**WQMS-2**	**1.535 ug/l**	1.531 ug/l	1.526 ug/l	1.522 ug/l	1.512 ug/l
		Difference from Baseline (mg/l)		*-0.004 ug/l*	*-0.009 ug/l*	*-0.014 ug/l*	*-0.024 ug/l*
		% Difference from Baseline		*0%*	*-1%*	*-1%*	*-2%*
		WQMS-5	**1.714 ug/l**	1.712 ug/l	1.711 ug/l	1.698 ug/l	1.694 ug/l
		Difference from Baseline (mg/l)		*-0.002 ug/l*	*-0.003 ug/l*	*-0.016 ug/l*	*-0.020 ug/l*
		% Difference from Baseline		*0%*	*0%*	*-1%*	*-1%*
		WQMS-8	**1.943 ug/l**	1.946 ug/l	1.947 ug/l	1.969 ug/l	1.969 ug/l
		Difference from Baseline (mg/l)		*0.003 ug/l*	*0.004 ug/l*	*0.026 ug/l*	*0.026 ug/l*
		% Difference from Baseline		*0%*	*0%*	*1%*	*1%*

Table 5: Predicted differences in average CHL concentration per location per scenario.

The model predicted ***miniscule variations*** (second decimal place) of between -2% to +1% with respect to Baseline in the average CHL concentrations over the course of the simulation period at all locations WQMS-2, WQMS-5 and WQMS-8 for all abstraction scenarios.

9.4.Nitrate (NO3-N)

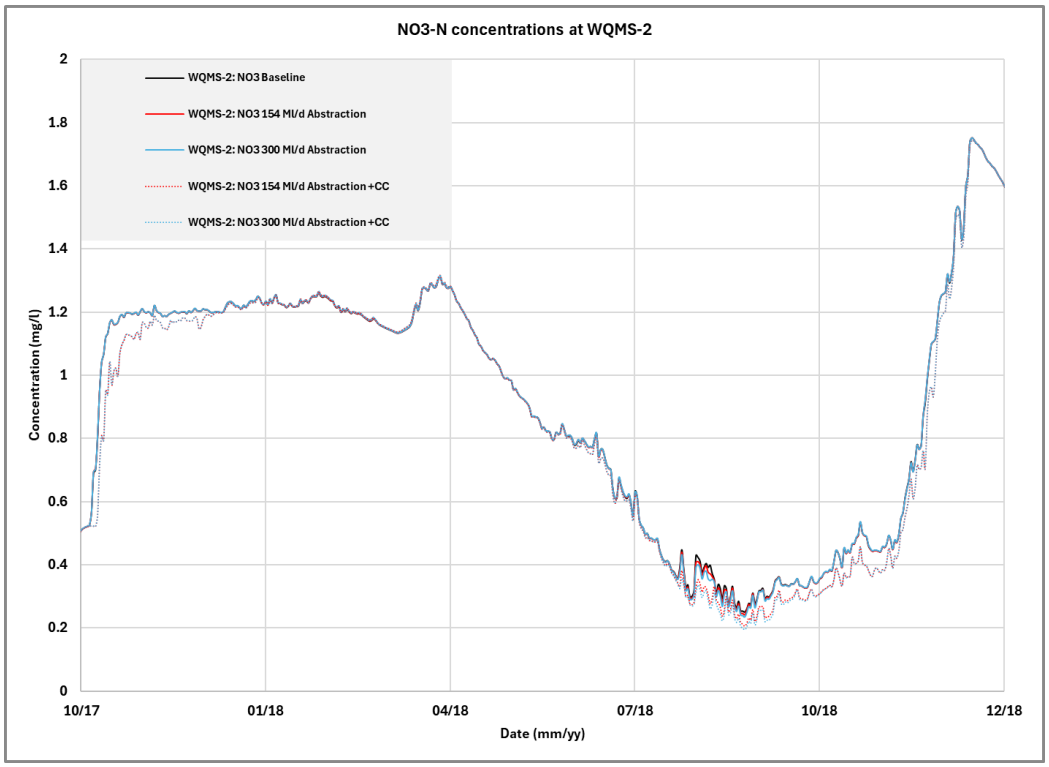


Figure 88: Predicted NO3-N concentrations at location WQMS-2

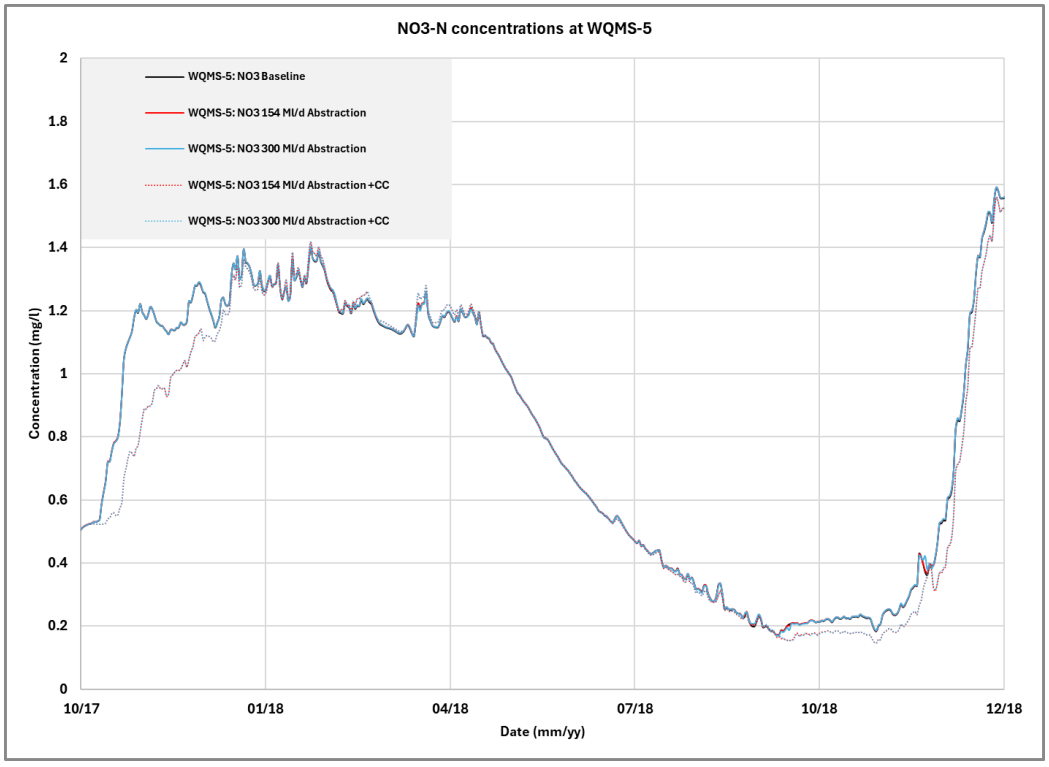


Figure 89: Predicted NO3-N concentrations at location WQMS-5

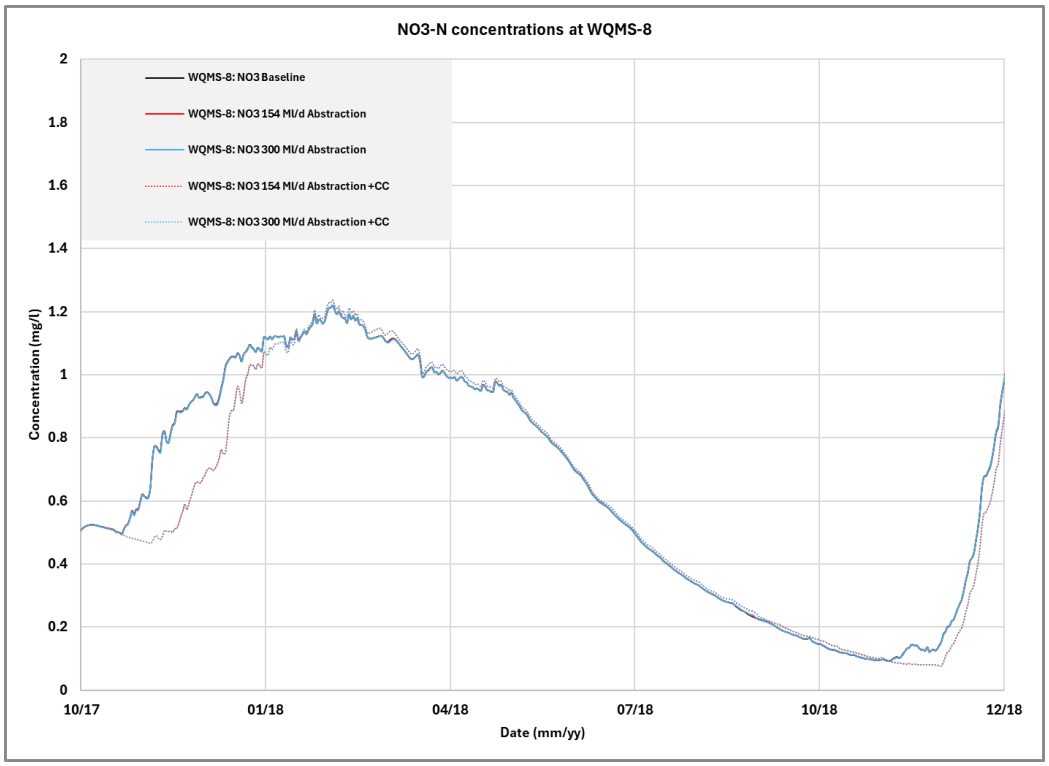


Figure 90: Predicted DO concentrations at location WQMS-8

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
NO3-N (mg/)	Average	**WQMS-2**	**0.908 mg/l**	0.907 mg/l	0.906 mg/l	0.879 mg/l	0.877 mg/l
		Difference from Baseline (mg/l)		*-0.001 mg/l*	*-0.001 mg/l*	*-0.029 mg/l*	*-0.031 mg/l*
		% Difference from Baseline		*-0.1%*	*-0.2%*	*-3.2%*	*-3.4%*
		WQMS-5	**0.804 mg/l**	0.804 mg/l	0.805 mg/l	0.760 mg/l	0.761 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.001 mg/l*	*-0.043 mg/l*	*-0.043 mg/l*
		% Difference from Baseline		*0.1%*	*0.1%*	*-5.4%*	*-5.3%*
		WQMS-8	**0.646 mg/l**	0.647 mg/l	0.647 mg/l	0.613 mg/l	0.613 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*-0.033 mg/l*	*-0.033 mg/l*
		% Difference from Baseline		*0.0%*	*0.1%*	*-5.1%*	*-5.1%*

Table 6: Predicted differences in NO3-N concentration per location per scenario.

The model predicted ***small decreases*** (second decimal place) of upto -5.4% with respect to Baseline in the average NO3-N concentrations over the course of the simulation period at all locations WQMS-2, WQMS-5 and WQMS-8 for most abstraction scenarios.

9.5. Orthophosphate (PO4-P)

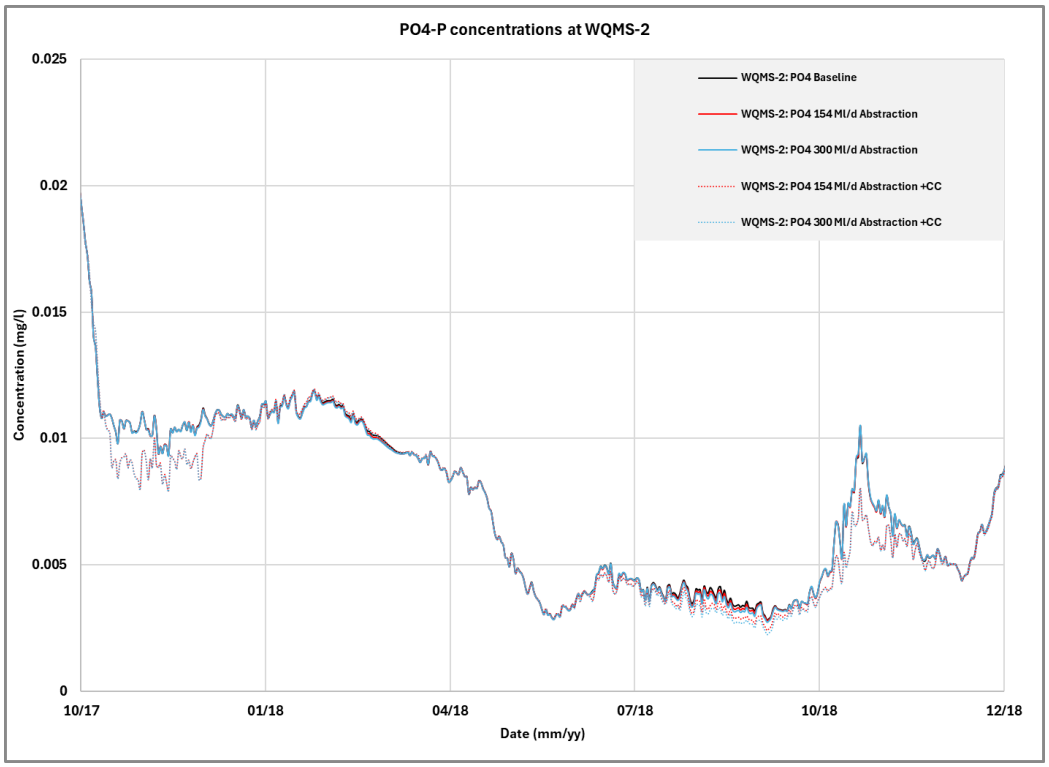


Figure 91: Predicted PO4-P concentrations at location WQMS-2

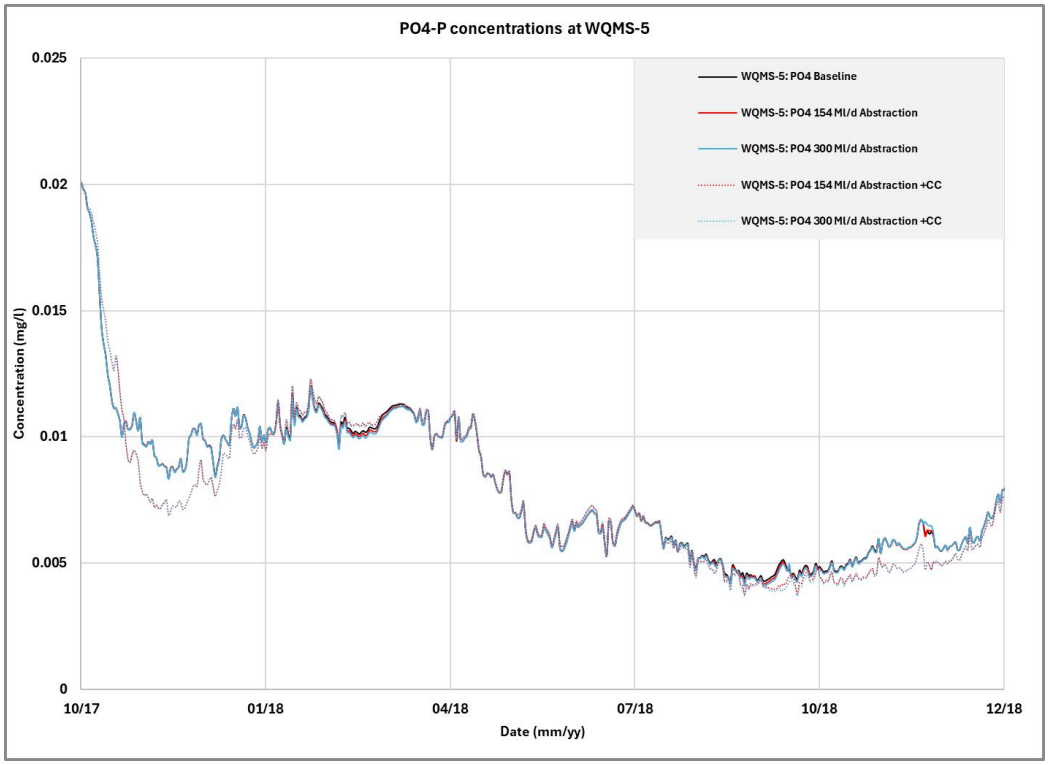


Figure 92: Predicted PO4-P concentrations at location WQMS-5

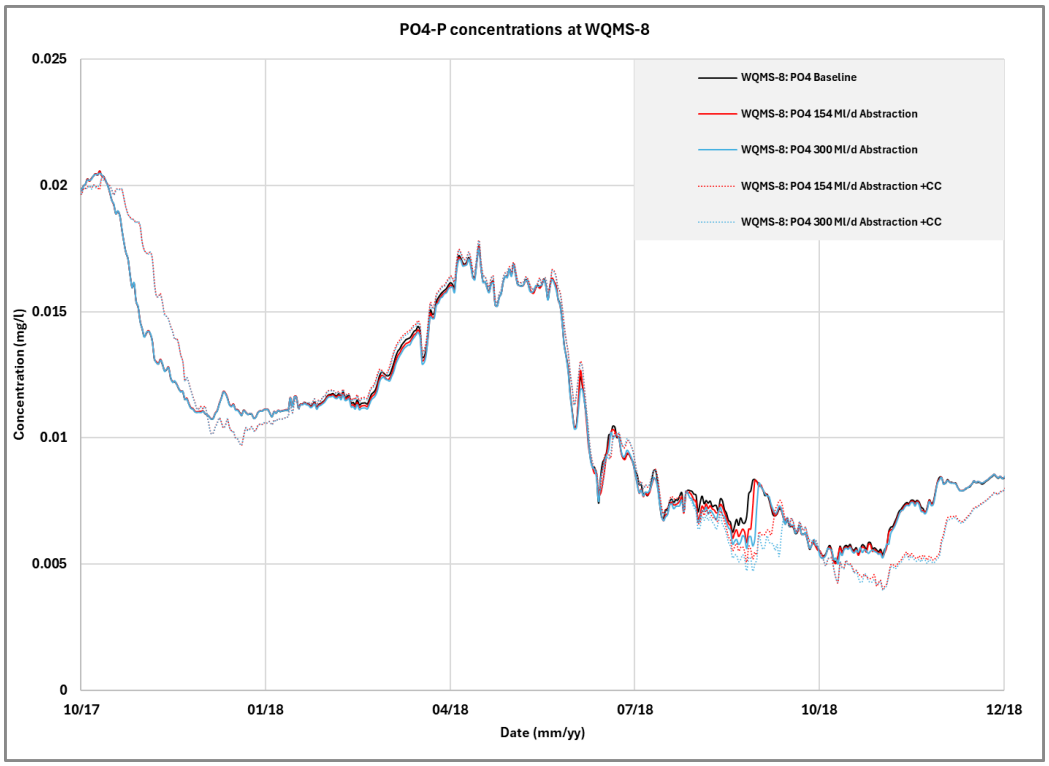


Figure 93: Predicted PO4-P concentrations at location WQMS-8

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
PO4-P (mg/)	Average	**WQMS-2**	**0.007 mg/l**	0.007 mg/l	0.007 mg/l	0.007 mg/l	0.007 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*
		% Difference from Baseline		*-0.2%*	*-0.4%*	*-4.9%*	*-5.2%*
		WQMS-5	**0.008 mg/l**	0.008 mg/l	0.008 mg/l	0.008 mg/l	0.008 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*
		% Difference from Baseline		*-0.2%*	*-0.4%*	*-3.4%*	*-3.8%*
		WQMS-8	**0.011 mg/l**	0.011 mg/l	0.011 mg/l	0.011 mg/l	0.011 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*	*0.000 mg/l*
		% Difference from Baseline		*-0.6%*	*-1.1%*	*-1.3%*	*-2.1%*

Table 7: Predicted differences in average PO4-P concentration per location per scenario.

The model predicted ***small decreases*** (second decimal place) of between -5.2% to -0.2% with respect to Baseline in the average PO4-P concentrations over the course of the simulation period at all locations WQMS-2, WQMS-5 and WQMS-8 for all abstraction scenarios.

9.6.Ammonia (NH3-N)

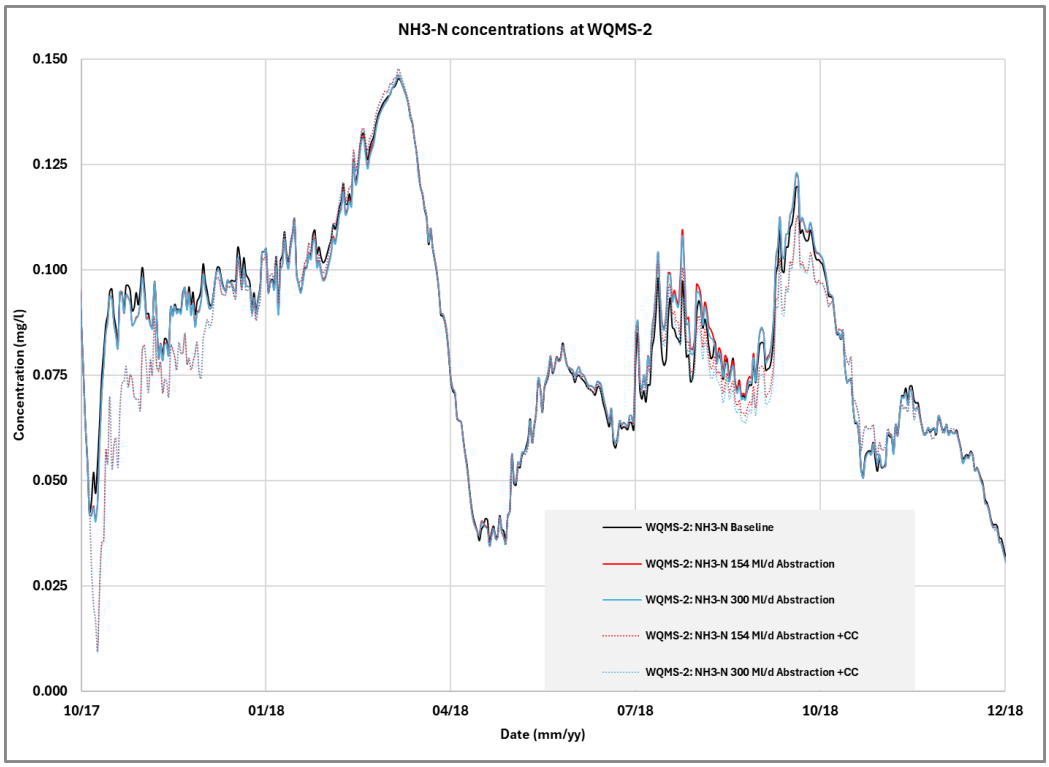


Figure 94: Predicted NH3-N concentrations at location WQMS-2

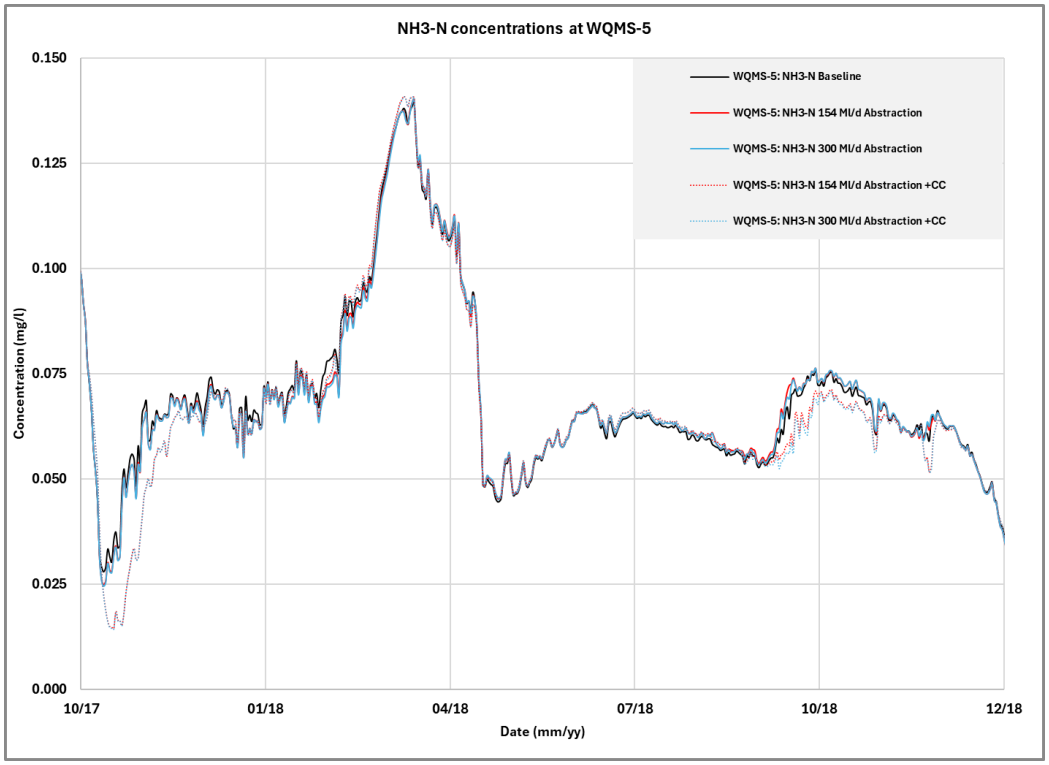


Figure 95: Predicted NH3-N concentrations at location WQMS-5

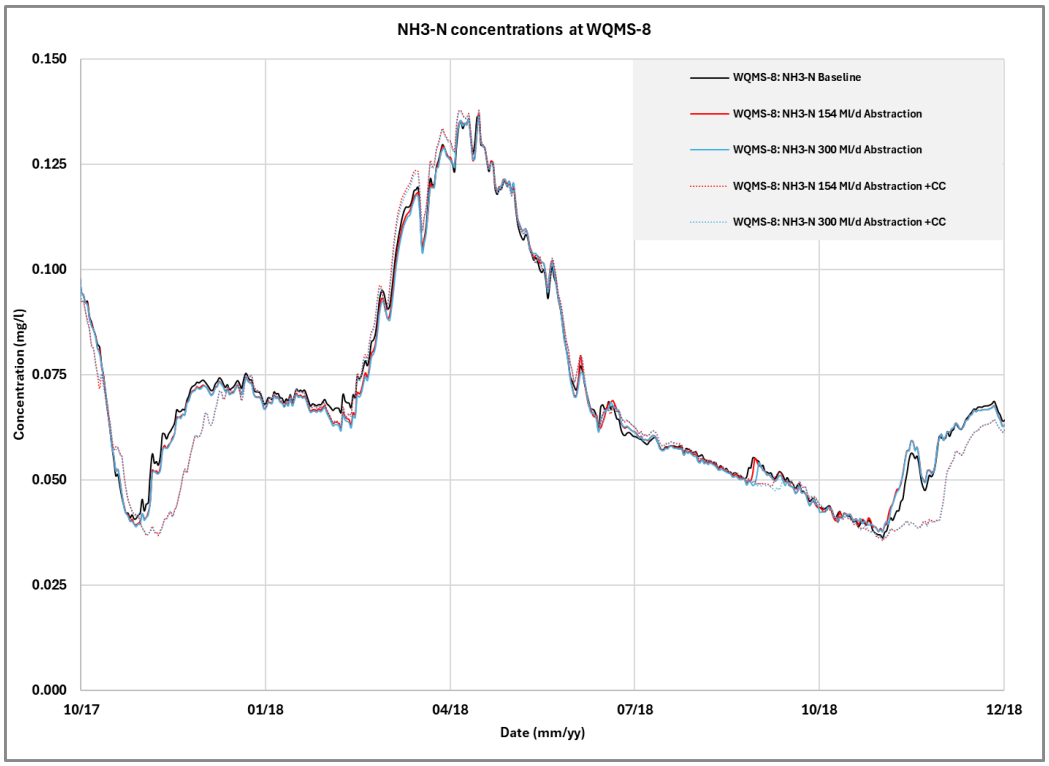


Figure 96: Predicted NH3-N concentrations at location WQMS-8

Parameter	Concentration	Location	Baseline	Scenario 154 Ml/d	300 Ml/d	154 Ml/d +CC	300 Ml/d +CC
NH3-N (mg/)	Average	**WQMS-2**	**0.083 mg/l**	0.083 mg/l	0.083 mg/l	0.080 mg/l	0.080 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*0.000 mg/l*	*-0.003 mg/l*	*-0.003 mg/l*
		% Difference from Baseline		*0.3%*	*0.0%*	*-3.6%*	*-4.0%*
		WQMS-5	**0.069 mg/l**	0.069 mg/l	0.069 mg/l	0.067 mg/l	0.067 mg/l
		Difference from Baseline (mg/l)		*0.000 mg/l*	*-0.001 mg/l*	*-0.002 mg/l*	*-0.002 mg/l*
		% Difference from Baseline		*-0.6%*	*-0.7%*	*-2.8%*	*-3.1%*
		WQMS-8	**0.071 mg/l**	0.071 mg/l	0.070 mg/l	0.069 mg/l	0.069 mg/l
		Difference from Baseline (mg/l)		*-0.001 mg/l*	*-0.001 mg/l*	*-0.002 mg/l*	*-0.002 mg/l*
		% Difference from Baseline		*-0.9%*	*-1.1%*	*-2.8%*	*-3.1%*

Table 8: Predicted differences in average NH3-N concentration per location per scenario.

The model predicted miniscule variations (third decimal place) of between -4% to +0.3% with respect to Baseline in the average NH3-N concentrations over the course of the simulation period at all locations WQMS-2, WQMS-5 and WQMS-8 for all abstraction scenarios.

10. Summary

A water quality modelling exercise was undertaken to examine the potential for impacts on the receiving water quality of Lough Derg and Parteen Basin arising from the operation of a constant 154 Ml/d proposed abstraction or a constant 300 Ml/d proposed abstraction from Parteen Basin during one of the most extreme drought periods experienced in Lough Derg across historical records. The potential for impacts were also assessed for a reasonable worst-case drought period incorporating climate change effects for the 2080 epoch.

11. Conclusion

Based on the predictions from the calibrated and verified water quality model it has been shown both spatially and temporally that there will be a neutral effect on the water quality of Lough Derg.

The impact has been classed as neutral as the computational modelling exercise predicted imperceptible positive and negative differences in water quality concentrations between different scenarios. The predicted differences between scenarios have been shown to be less than the natural variability of the system. The magnitude of the differences between scenarios at the locations assessed would be within the normal bounds of variation of laboratory results from coincident physical samples.

Tionscadal Soláthair Uisce
Water Supply Project

Environmental Impact Assessment Report (EIAR)

Volume 6 of 6: Appendices

(Appendix A9.1 Annex C) Water Quality Modelling Calibration Report

Document no: 32105801/EIARA9.1
Version: Final

December 2025

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Irish Water

Jacobs

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Water Supply Project – East & Midlands Region

DA2: Hydrodynamic and Water Quality Modelling

EIAR Scenario Modelling

Appendix I: Model Re-calibration Report

Document No: G201301_doc010_02_AppendixI.pdf

Status: Final

Date: 13 – 08 - 2025

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1. Introduction

As part of the Water Supply Project – Eastern and Midlands Region (WSP) project, MarCon Computations International were tasked with the Stage Deliverables Abstraction (DA) work package DA2: Hydrodynamic and Water Quality Model of Lough Derg and Parteen Basin.

This appendix details the work undertaken in re-calibrating the hydrodynamic and water quality model for Lough Derg.

2. Model Development

This section provides an overview of the development of the three dimensional hydrodynamic and water quality model of Lough Derg and Parteen Basin. For full details please refer to the original Model Calibration Report[1].

2.1. Bathymetry

The modelled study area extends from Portumna Bridge at the north of Lough Derg to Parteen Weir / Ardnacrusha Headrace in the south. The bathymetry of the study area was provided by Geomara who completed the bathymetric survey of Lough Derg and Parteen Basin in August 2015. The bathymetric dataset was loaded into the MIKE3 Flexible Mesh Generator along with the EPA's Water Framework Directive GIS shapefiles of Lough Derg and Parteen Basin. The computational grid mesh was then generated by the MIKE3 software, as presented in Figure 1.

2.2. Boundary Locations

The main in-flowing boundary specified to the model was the River Shannon, entering the study area in the north through Portumna Bridge. One out-flowing boundary was specified in Parteen Basin representing the combined outflow through Parteen Weir and down the Ardnacrusha Headrace in the south of the study area. Water level boundary conditions were also specified at both Portumna Bridge and Parteen Weir/Ardnacrusha Headrace.

[1] MarCon Computations International, 2017. Water Supply Project – East & Midlands Region DA2: Hydrodynamic and Water Quality Modelling DA2.2: Model Calibration Report. Document Reference: G201301_doc005_04

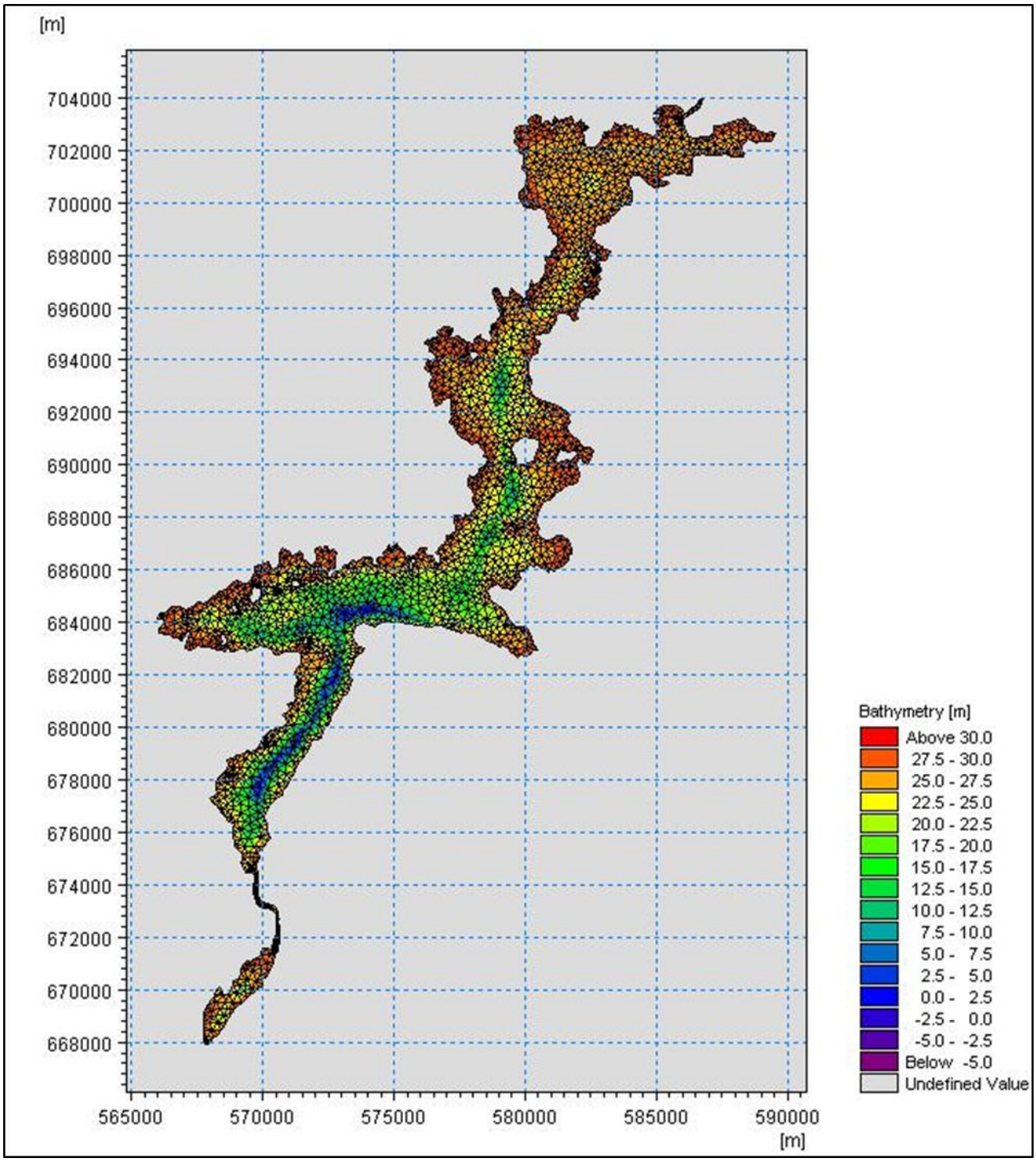

Figure 1: Computational model mesh superimposed on bathymetry (above Ordnance Datum Malin Head)

Twenty-one additional inflowing boundaries were specified, representing the rivers and streams draining the catchments surrounding Lough Derg and Parteen Basin. The locations of the twenty-one river catchments are shown in Figure 2.

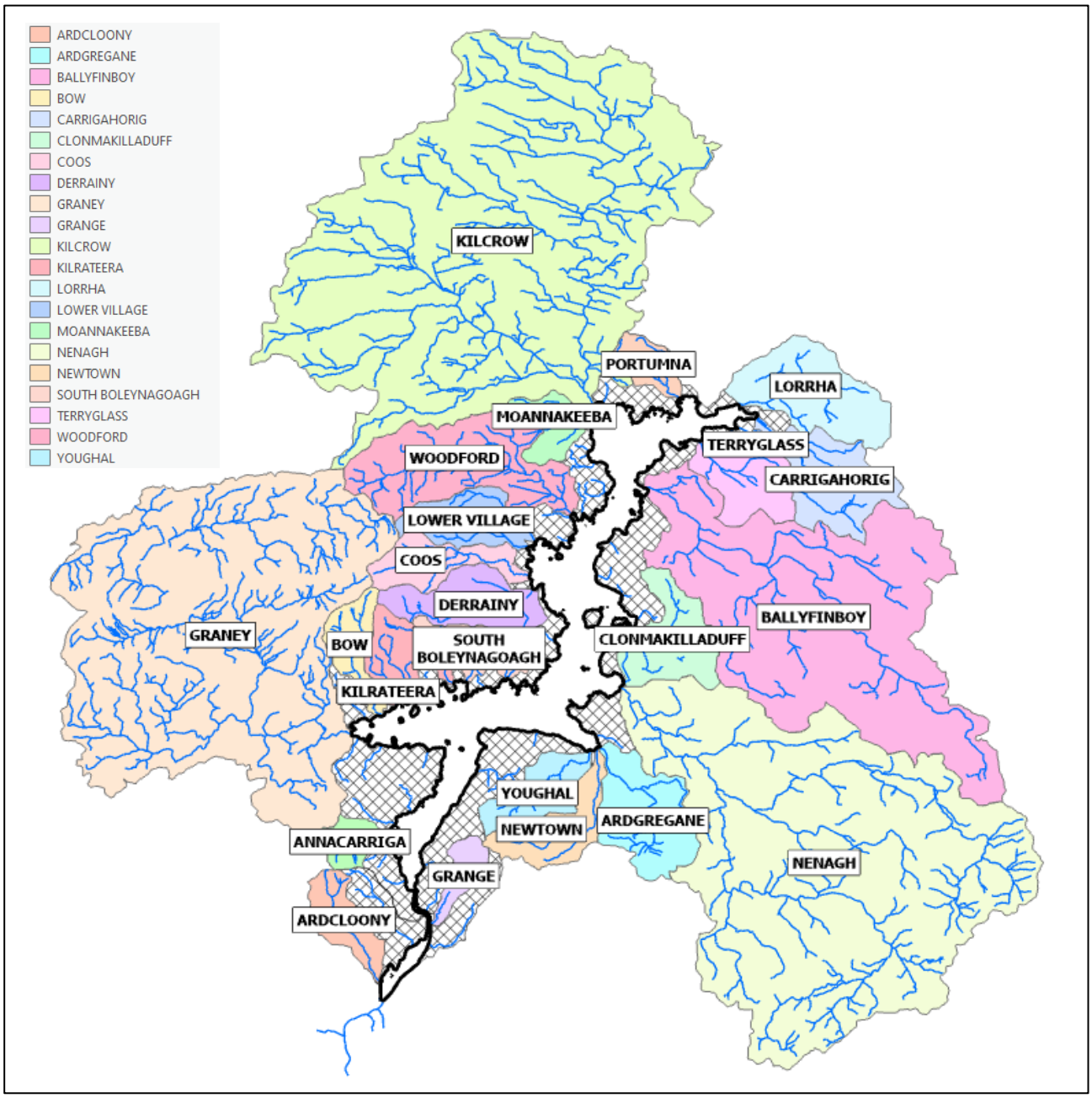

Figure 2: Locations of twenty-one in-flowing river catchment boundaries.

Recorded meteorological boundary conditions were specified to the model. The model accounts for wind induced circulation patterns due to variations in wind speed and direction, effects of evaporation and precipitation, and thermal stratification due to solar radiation effects.

Recorded water quality concentrations for the twenty-one in-flowing rivers and streams draining the catchments surrounding Lough Derg and Parteen Basin were specified to the model. Where recorded data was not available for some of the smaller rivers, constant ambient concentrations were specified.

3. Model Calibration

This section provides an overview of the original calibration of the hydrodynamic and water quality components of the three-dimensional model of Lough Derg and Parteen Basin. For full details please refer to the Model Calibration Report [2].

3.1. Hydrodynamics

The hydrodynamic model calibration was undertaken over the period 01/03/2016 to 31/12/2016 as this time period contained coincident recorded datasets for all model boundary forcing conditions. The model predictions were compared against recorded datasets from instruments deployed within Lough Derg as part of the hydrographic survey campaign.

3.1.1. Water Surface Levels

The water surface levels predicted by the model were compared against three water level recorders located at Coolbawn Marina towards the north of the lough, Garrykennedy Marina in the centre of the lough, and Kincora Marina towards the south of the lough.

Over the course of the model calibration period, the model simulated the recorded water levels at Coolbawn Marina to within ±0.05 m for 90% of the time, at Garrykennedy Marina to within ±0.05 m for 93% of the time, and at Kincora Marina to within ±0.05 m for 86% of the time.

3.1.2. Water Currents

The water current speeds and velocity vectors (east-west component and north-south component) predicted by the model were compared against two of the three vertical Acoustic Doppler Current Profiler (ADCP) recorders in Lough Derg.

At both the OL02 and OL09 ADCP locations the modelled current vectors show very good agreement with the recorded current vectors, with changes in the direction and magnitude of the flow occurring at the same times. Calibration of modelled currents against the OL15 ADCP was not undertaken as

[2] ibid.

the data quality was compromised due to excessive suspended sediments and fouling of the instrument.

3.1.3. Water Temperature

The water temperatures predicted by the model were compared against six of the nineteen thermistor temperature recorders deployed within Lough Derg as part of the hydrographic survey campaign.

The modelled water temperature generally showed good agreement against the recorded water temperature. Although the agreement was best at the northern end of Lough Derg, owing to the influence of the River Shannon, at all stations down through the system the model simulated the dominant heating and cooling events at the correct times.

3.2. Water Quality

The water quality model calibration was undertaken over the period 01/03/2016 to 31/12/2016 as this time period contained coincident recorded datasets for all model boundary forcing conditions. The model was calibrated against the following parameters; biochemical oxygen demand (BOD), dissolved oxygen (DO), chlorophyll-a (CHL), nitrite (NO2-N), ammonia (NH3-N), nitrate (NO3-N), and ortho-phosphate (PO4-P). The model predictions were compared against samples recorded every eight hours by four automatic nutrient analysers deployed throughout Lough Derg and against manual samples collected on average every fortnight at seven locations throughout Lough Derg.

3.2.1. Biochemical Oxygen Demand (BOD)

Towards the north of Lough Derg, the modelled BOD values were slightly over estimated when compared with the sampled values. Towards the middle and southern sections of Lough Derg the modelled BOD values were slightly underestimated when compared with the sampled values. The modelled BOD showed a decrease from initial values in March, to lower values in mid-summer and increased again in the winter months, which agreed with the annual trend in the sampled data.

3.2.2. Dissolved Oxygen (DO)

In the north, middle and southern sections of Lough Derg the modelled DO values showed agreement against the sampled values with modelled values lying within the range of sampled data and following the trend in annual variation. The modelled DO showed a decrease from initial values in March to

lower values in mid-summer and increased again in the winter months, which agreed with the annual trend in the sampled data.

3.2.3. Nitrite (NO2-N)

The majority of the NO2-N manual samples were reported as below the limit of detection by the accredited laboratory but were included for comparison purposes. Most of the NO2-N values recorded by the automatic nutrient analysers were below the calibrated limit of detection of the instrument but were included for comparison purposes. The water quality model predicted very low NO2-N concentrations throughout Lough Derg over the period of model calibration, lower than the manual sampling's limit of detection. To this extent the model showed agreement with sampled data.

3.2.4. Ammonia (NH3-N)

The majority of the NH3-N manual samples were reported below the limit of detection by the accredited laboratory. Most of the NH3-N values recorded by the automatic nutrient analysers were below the calibrated limit of detection of the instrument but were included for comparison purposes. The water quality model predicted very low NH3-N concentrations throughout Lough Derg over the period of calibration, lower than the manual sampling's limit of detection. To this extent the model showed agreement with sampled data

3.2.5. Nitrate (NO3-N)

At all locations, except in the north of the lough, the modelled NO3-N concentrations showed good agreement with the sampled data. Modelled NO3-N concentrations were under-estimated in the northern section of Lough Derg over the April to June period but showed agreement with the general annual trend in the sampled data.

3.2.6. Chlorophyll-a (CHL)

The modelled CHL values were over-estimated when compared with the sampled CHL values throughout Lough Derg. In general, modelled values were approximately 4µg/l greater than the sampled CHL concentrations. Sampled CHL values were very low throughout the year when compared with the long-term record.

3.2.7. Phosphate Phosphorus (PO4-P)

Most PO4-P values recorded by the automatic nutrient analysers were below the limit of detection of the calibrated instrument but were included for comparison purposes. The modelled PO4-P concentrations lay within the uncalibrated range of the automatic nutrient analysers' PO4-P readings the year. To this extent the model showed good agreement with sampled data.

At the manual sampling locations towards the north of Lough Derg the modelled PO4-P values showed good agreement with sampled data. At the manual sampling locations towards the middle and southern sections of Lough Derg the manual samples were reported below the limit of detection by the accredited laboratory and the modelled PO4-P values were also all below the manual sampling limit of detection. To that extent the model showed good agreement with sampled data.

3.3. Calibration Statement

In general, the comparison of the modelled and measured datasets, both statistically and visually, would suggest a robust calibration agreement. The summary of calibration results presented above show that the numerical model has been successfully calibrated against field measurements to provide a sufficiently accurate representation of the hydrodynamic and water quality components within the study region.

4. Model Re-calibration

The water quality model re-calibration has been undertaken over the period 01/10/2017 to 31/12/2018. The model predictions have been compared against recorded datasets from instruments deployed within Lough Derg as part of the survey campaigns.

4.1. Hydrodynamic Boundary Definitions

4.1.1. Water Levels

Water levels at the upstream boundary of the study area at Portumna Bridge were provided by the ESB water level recording station at 15-minute intervals from 01/10/2017 to 31/12/2018. The recorded ESB water levels were transformed from Ordnance Datum Poolbeg datum to Ordnance Datum Malin Head datum. Water levels at the downstream boundary of the study area at Parteen Weir were provided by the ESB water level recording station at 15-minute intervals from 01/10/2017 to 31/12/2018. The recorded ESB water levels were transformed from Ordnance Datum Poolbeg datum to Ordnance Datum Malin Head datum. The recorded water levels are presented in Figure 3.

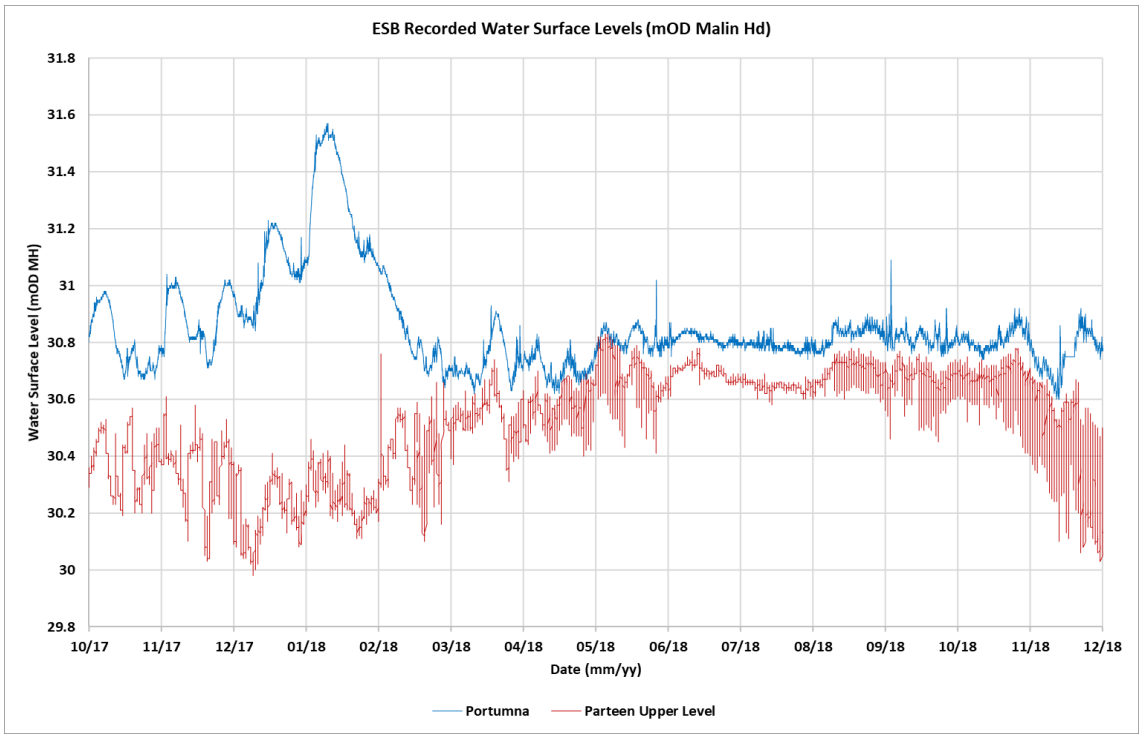

Figure 3: Recorded water levels at Portumna Bridge and Parteen Weir (01/10/2017 to 31/12/2018)

4.1.2. Flows

The River Shannon inflow at the Portumna Bridge upstream boundary of the model was defined to the water quality model from the Project's hydrological model, less the calculated inflows from the twenty-one minor rivers. The outflowing discharge at the Parteen Weir/Ardnacrusha Headrace downstream boundary of the model was defined to the model from data recorded by ESB and made available to the Project and presented in Figure 4.

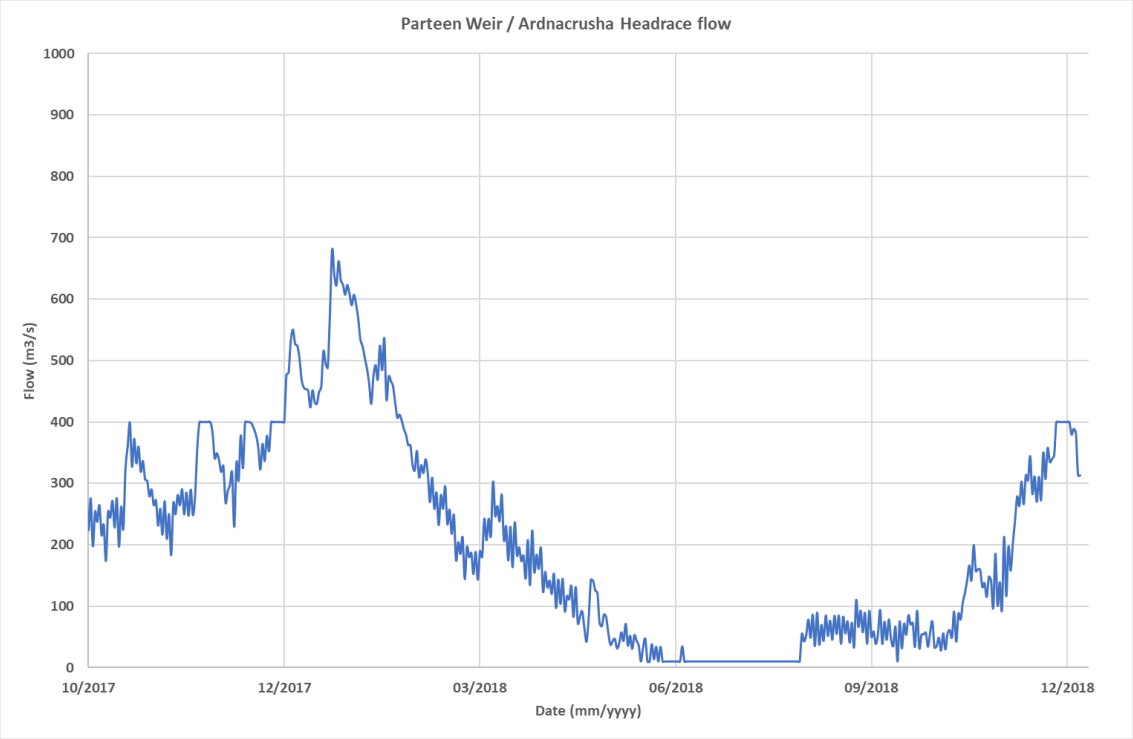

Figure 4: Recorded outflows at Parteen Weir / Ardnacrusha Headrace (01/10/2017 to 31/12/2018)

Inflows from four of the twenty-one smaller rivers flowing into the modelled study area were defined to the water quality model from daily average flow records recorded by the OPW at hydrometric stations installed on each of the four rivers Ballyfinboy, Nenagh, Graney, and Kilcrow.

Inflows from the seventeen remaining smaller rivers flowing into to the modelled study area without hydrometric stations were calculated using gauged area transposition from the adjoining / adjacent gauged catchments and defined to the water quality model. The hydrographs for all inflows are presented in Figure 5. The hydrographs for the twenty-one smaller rivers are presented separately in Figure 6 for clarity.

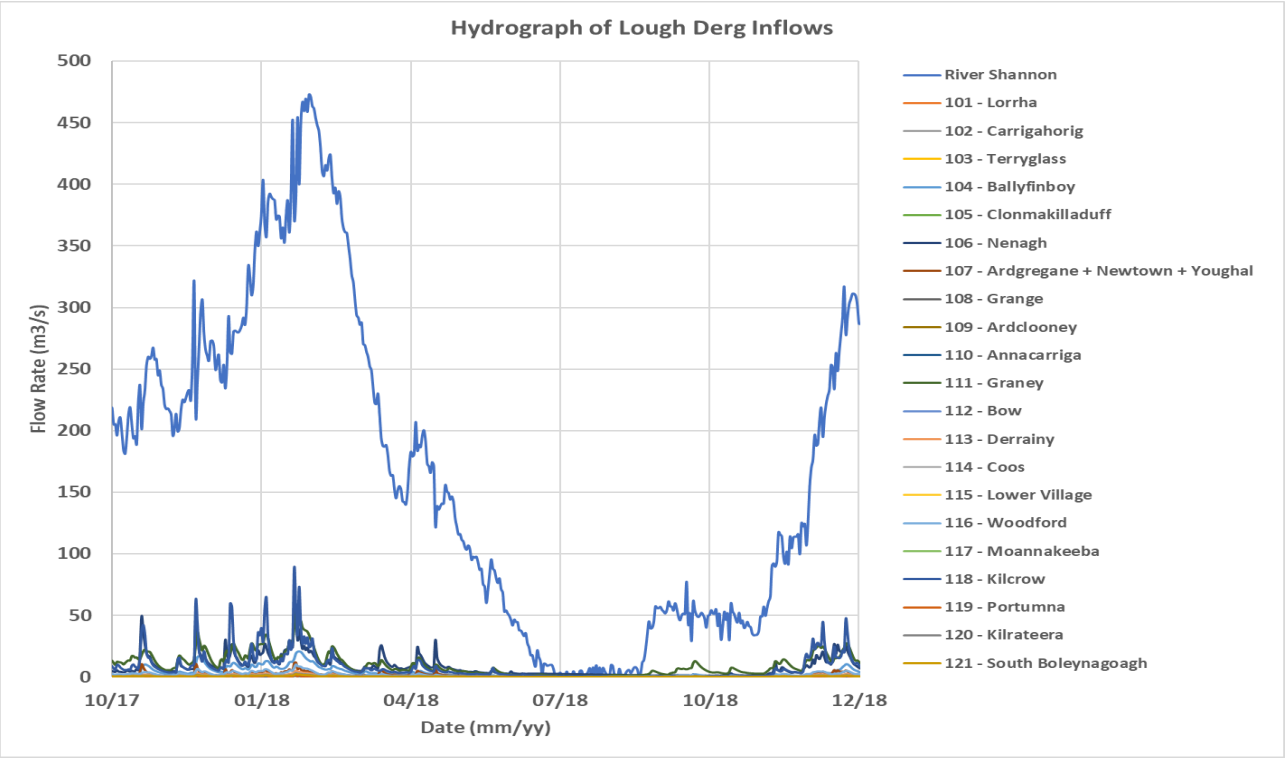

Figure 5: Hydrograph of all Lough Derg inflows (01/10/2017 to 31/12/2018)

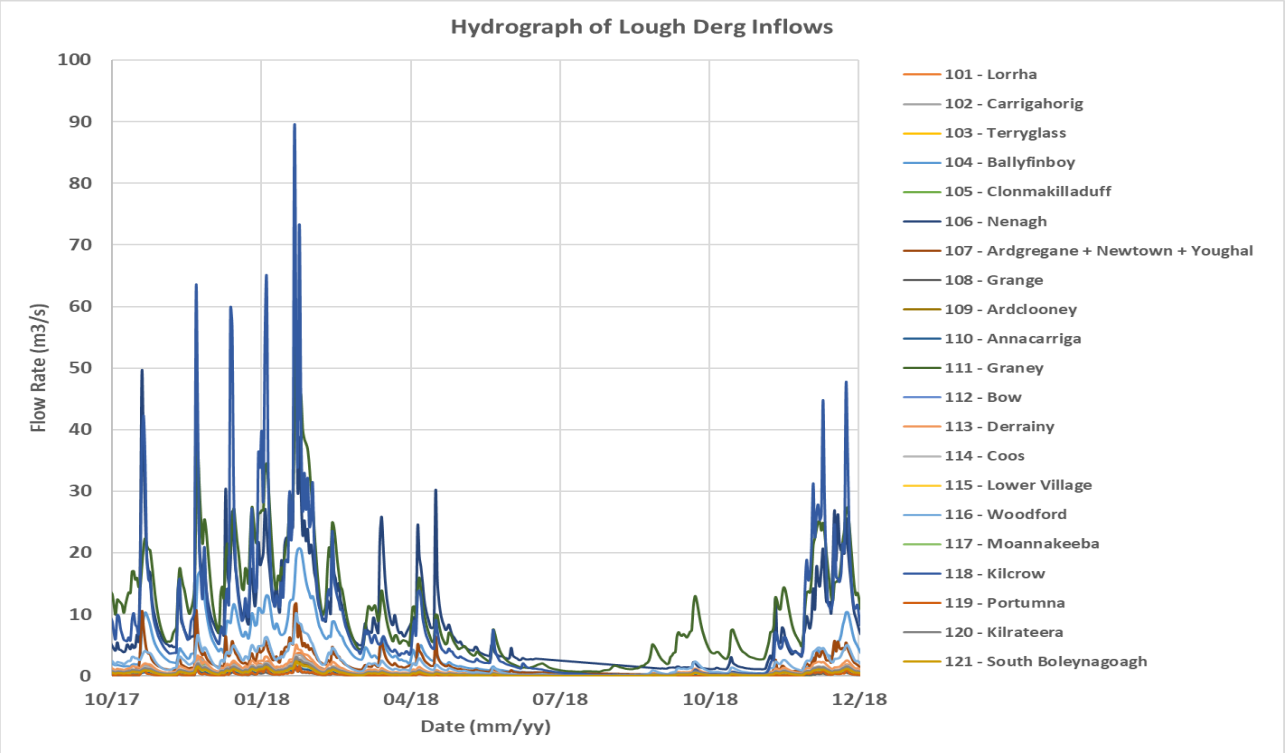

Figure 6: Hydrograph of Lough Derg inflows excluding River Shannon (01/10/2017 to 31/12/2018)

The River Shannon at Portumna accounted for 79.4% of the total inflow to the modelled study area during the Baseline Scenario period from 01/10/2017 to 31/12/2018. The four gauged inflowing rivers (Ballyfinboy, Nenagh, Graney, and Kilcrow) accounted for 14.7%. The other seventeen smaller rivers combined, for which inflows were calculated based on the gauged area transposition method, represented <6% of the total inflows to the modelled study area.

4.1.3. Meteorology

Wind speed and direction from station MS02 from 01/10/2017 to 31/12/2018 was used in the calibration of the hydrodynamic model of Lough Derg, and presented in Figure 7 and Figure 8 respectively. The effects of rainfall and evaporation on the water balance of the lough were captured in the hydrological model and were therefore not included here.

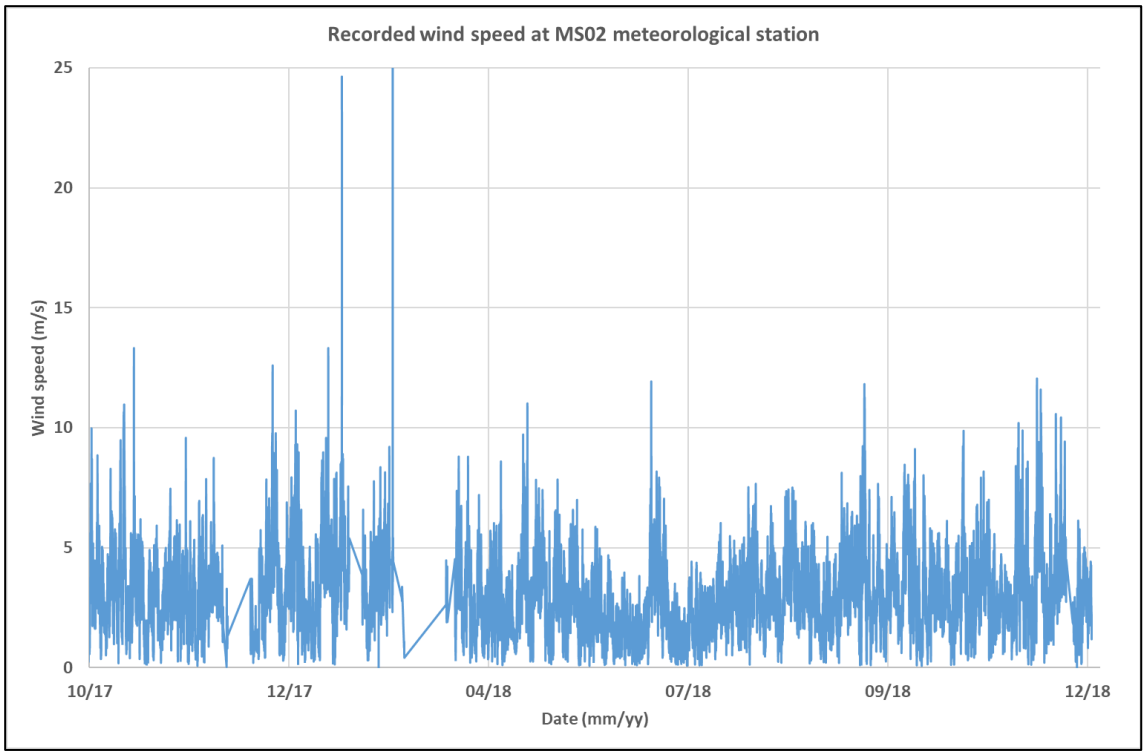

Figure 7: Recorded wind speeds at MS02 meteorological station

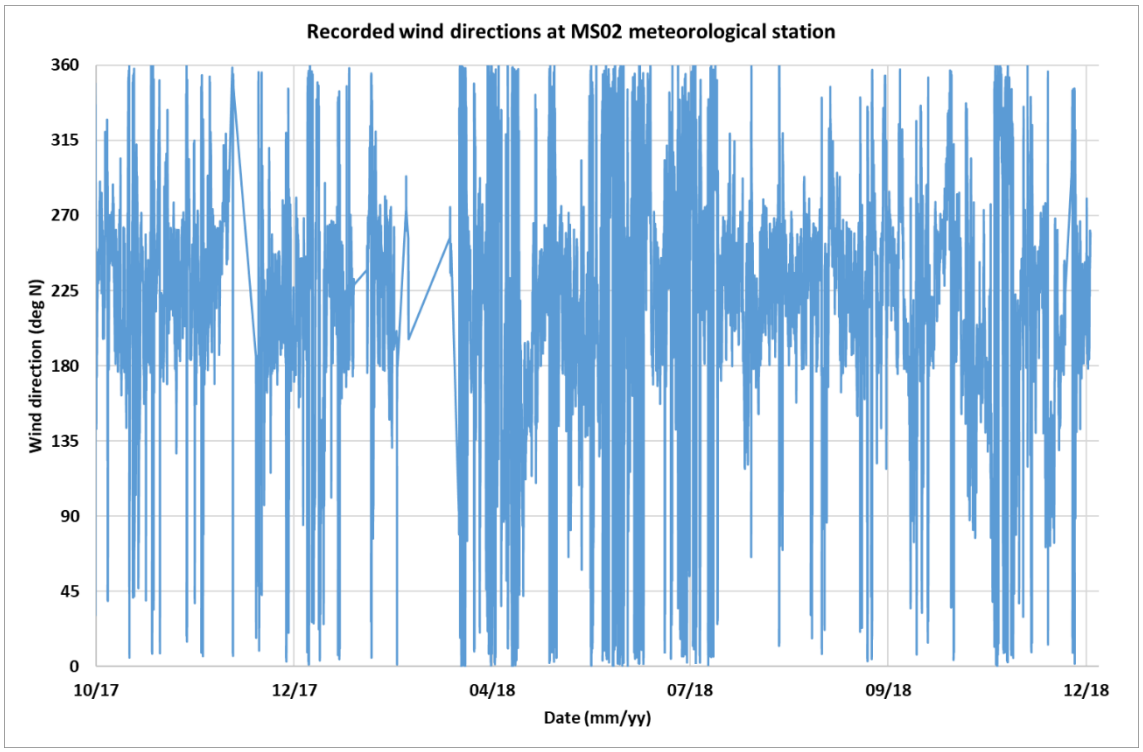

Figure 8: Recorded wind direction at MS02 meteorological station

4.2. Water Quality Boundary Definitions

The water quality parameters of interest in the study of Lough Derg were biological oxygen demand (BOD), dissolved oxygen (DO), chlorophyll-a (CHL), nitrite nitrogen (NO2-N), ammonia nitrogen (NH3-N), nitrate nitrogen (NO3-N) and phosphate phosphorus (PO4-P).

Concentrations of the above water quality parameters entering the Lough Derg system from the various inflowing rivers were defined to the model. The water quality concentrations in the River Shannon were defined to the model from results of the manually sampled data acquired from the ongoing water quality sampling programme at station WQMS-4 north of Portumna Bridge.

The water quality concentrations in the twenty-one smaller rivers flowing into Lough Derg were defined to the model from results of the manually sampled data acquired from the EPA's Water Framework Directive sampling programme where available.

Some of the smaller catchments have no WFD sampling programme and therefore constant background concentrations were specified for the water quality parameters in those cases. The locations of the rivers draining to Lough Derg was presented previously in Figure 2.

The water quality concentrations defined in the River Shannon and the twenty-one rivers flowing into Lough Derg is detailed in

River / Parameter	BOD	DO	CHL	NO2-N	NH3-N	NO3-N	PO4-P
River Shannon	Sampled Data		0.003	Sampled Data			
101 - Lorrha	Sampled Data		0.003	Sampled Data			
102 - Carrigahorig	Sampled Data		0.003	Sampled Data			
103 - Terryglass	1.5	10.0	0.003	0.01	0.05	3.00	0.02
104 - Ballyfinboy	Sampled Data		0.003	Sampled Data			
105 - Clonmakilladuff	1.5	10.0	0.003	0.01	0.05	3.00	0.02
106 - Nenagh	Sampled Data		0.003	Sampled Data			
107 - Ardgregane + Newtown + Youghal	Sampled Data		0.003	Sampled Data			
108 - Grange	1.5	10.0	0.003	0.01	0.05	3.00	0.02
109 - Ardclooney	1.5	10.0	0.003	0.01	0.05	3.00	0.02
110 - Annacarriga	1.5	10.0	0.003	0.01	0.05	3.00	0.02
111 - Graney	Sampled Data		0.003	Sampled Data			
112 - Bow	Sampled Data		0.003	Sampled Data			
113 - Derrainy	1.5	10.0	0.003	0.01	0.05	3.00	0.02
114 - Coos	Sampled Data		0.003	Sampled Data			
115 - Lower Village	Sampled Data		0.003	Sampled Data			
116 - Woodford	Sampled Data		0.003	Sampled Data			
117 - Moannakeeba	1.5	10.0	0.003	0.01	0.05	3.00	0.02
118 - Kilcrow	Sampled Data		0.003	Sampled Data			
119 - Portumna	1.5	10.0	0.003	0.01	0.05	3.00	0.02
120 - Kilrateera	1.5	10.0	0.003	0.01	0.05	3.00	0.02
121 - South Boleynagoagh	1.5	10.0	0.003	0.01	0.05	3.00	0.02

Table 1. The Ardgregane, Newtown and Youghal rivers all discharge near each other and have been defined to the modelling system as a single point discharge. Graphs of the automatically recorded

and manually sampled data for the respective parameters is presented in Figure 9 to Figure 14.

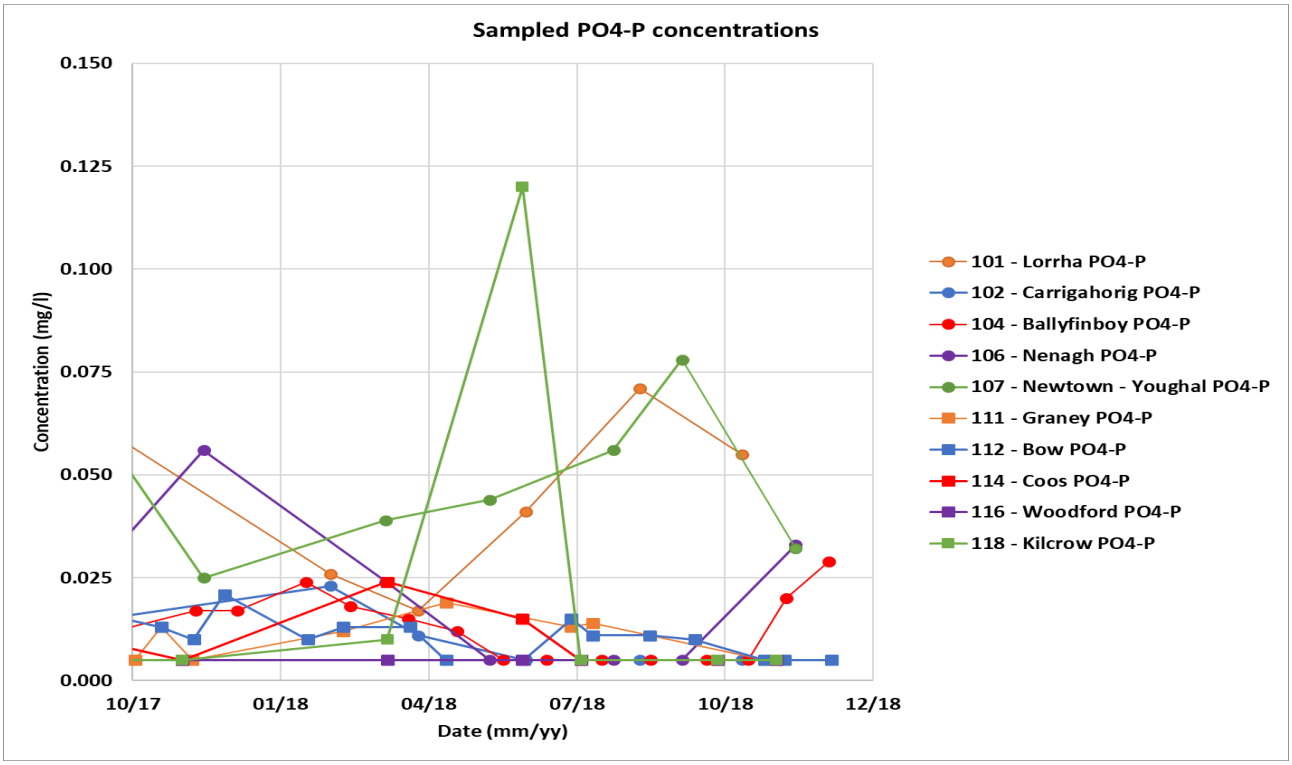

Figure 14

River / Parameter	BOD	DO	CHL	NO2-N	NH3-N	NO3-N	PO4-P
River Shannon	Sampled Data		0.003	Sampled Data			
101 - Lorrha	Sampled Data		0.003	Sampled Data			
102 - Carrigahorig	Sampled Data		0.003	Sampled Data			
103 - Terryglass	1.5	10.0	0.003	0.01	0.05	3.00	0.02
104 - Ballyfinboy	Sampled Data		0.003	Sampled Data			
105 - Clonmakilladuff	1.5	10.0	0.003	0.01	0.05	3.00	0.02
106 - Nenagh	Sampled Data		0.003	Sampled Data			
107 - Ardgregane + Newtown + Youghal	Sampled Data		0.003	Sampled Data			
108 - Grange	1.5	10.0	0.003	0.01	0.05	3.00	0.02
109 - Ardclooney	1.5	10.0	0.003	0.01	0.05	3.00	0.02
110 - Annacarriga	1.5	10.0	0.003	0.01	0.05	3.00	0.02
111 - Graney	Sampled Data		0.003	Sampled Data			
112 - Bow	Sampled Data		0.003	Sampled Data			
113 - Derrainy	1.5	10.0	0.003	0.01	0.05	3.00	0.02
114 - Coos	Sampled Data		0.003	Sampled Data			
115 - Lower Village	Sampled Data		0.003	Sampled Data			
116 - Woodford	Sampled Data		0.003	Sampled Data			
117 - Moannakeeba	1.5	10.0	0.003	0.01	0.05	3.00	0.02
118 - Kilcrow	Sampled Data		0.003	Sampled Data			
119 - Portumna	1.5	10.0	0.003	0.01	0.05	3.00	0.02
120 - Kilrateera	1.5	10.0	0.003	0.01	0.05	3.00	0.02
121 - South Boleynagoagh	1.5	10.0	0.003	0.01	0.05	3.00	0.02

Table 1: Water quality concentrations for each inflowing river

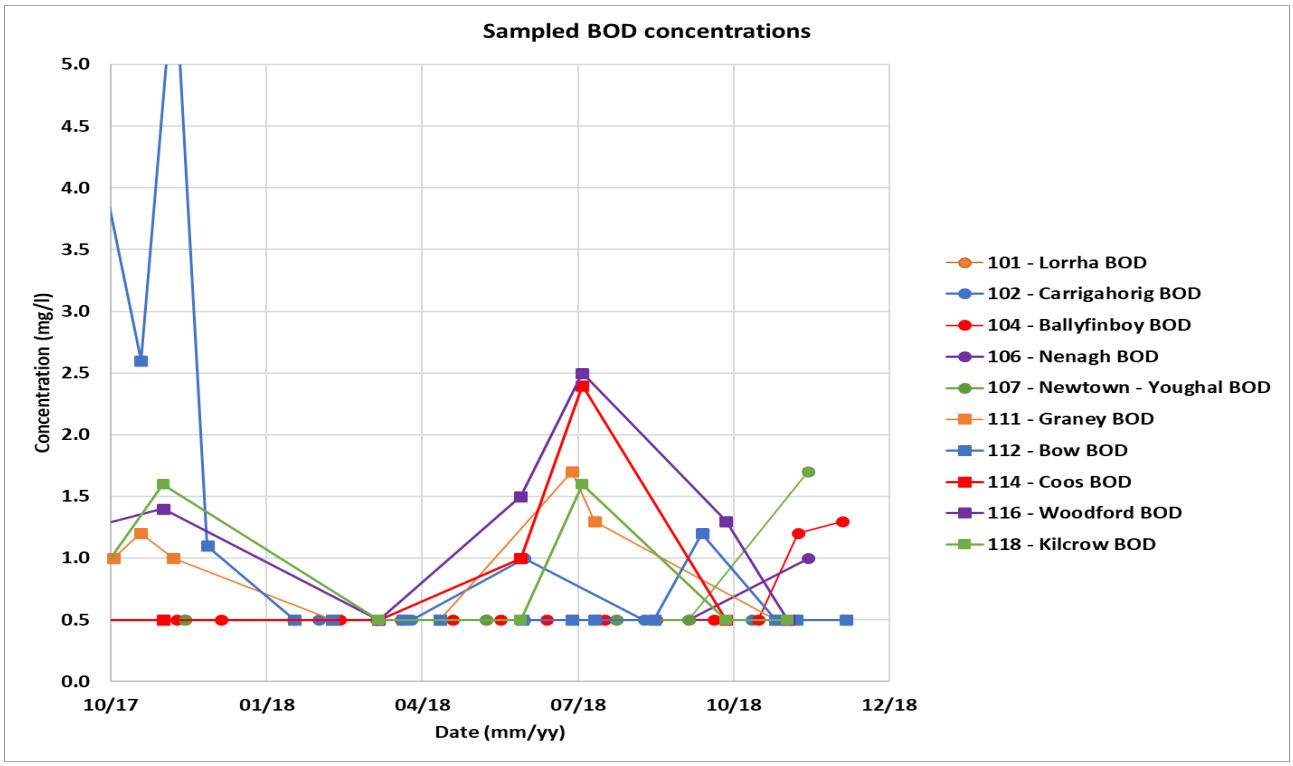

Figure 9: Sampled BOD concentrations

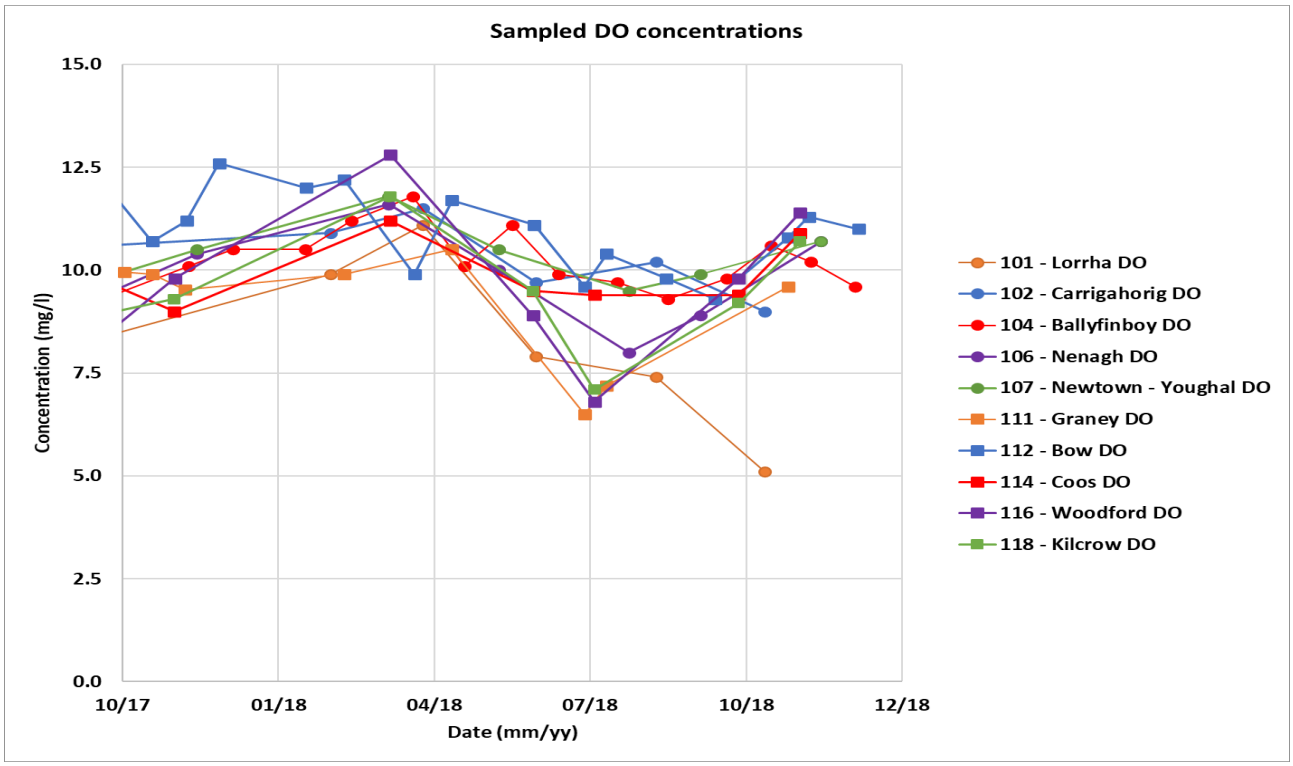

Figure 10: Sampled DO concentrations

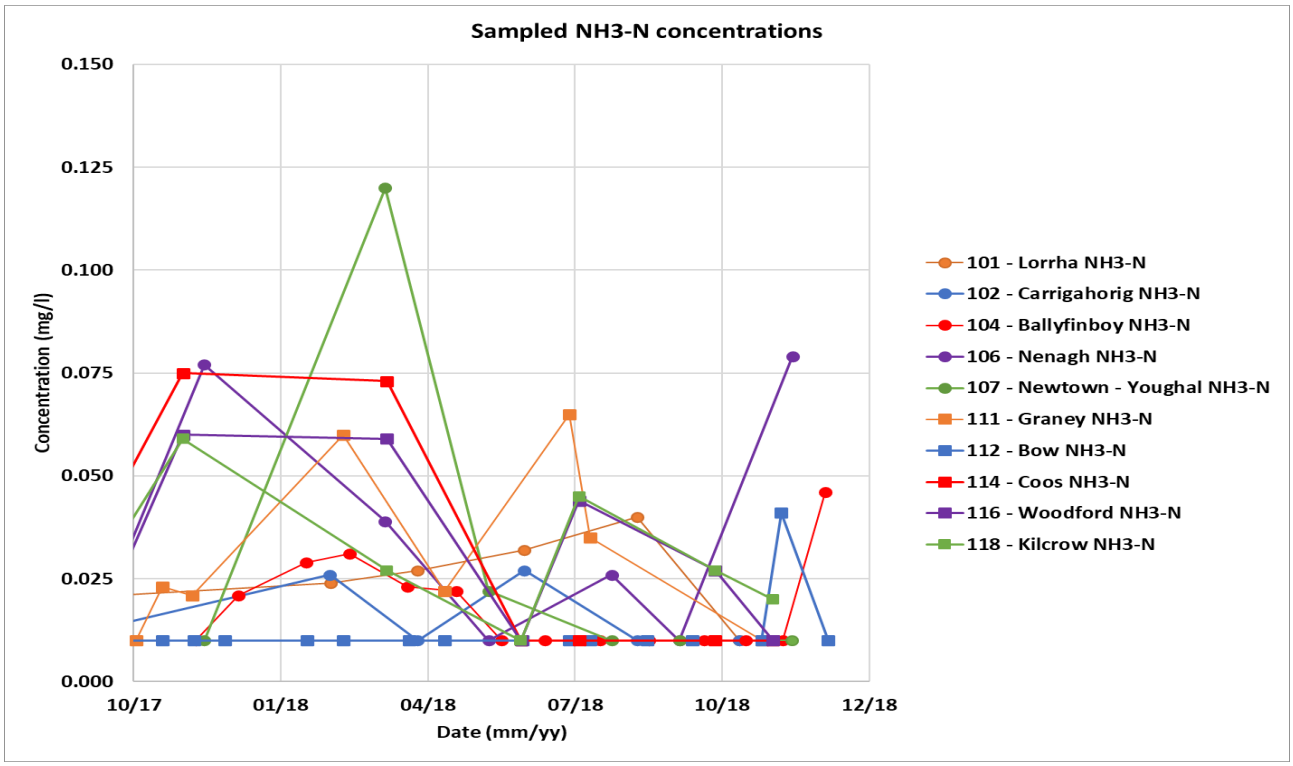

Figure 11 Sampled NH3-N concentrations

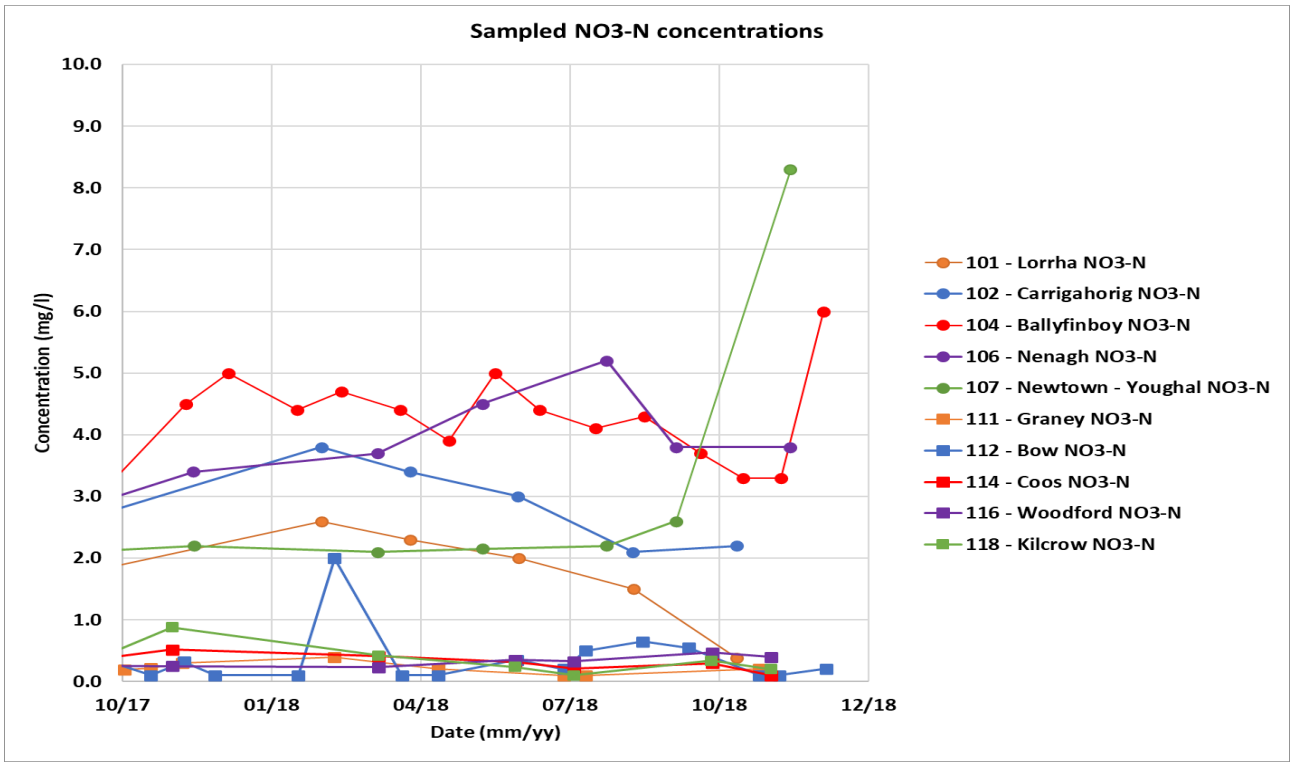

Figure 12: Sampled NO3-Nconcentrations

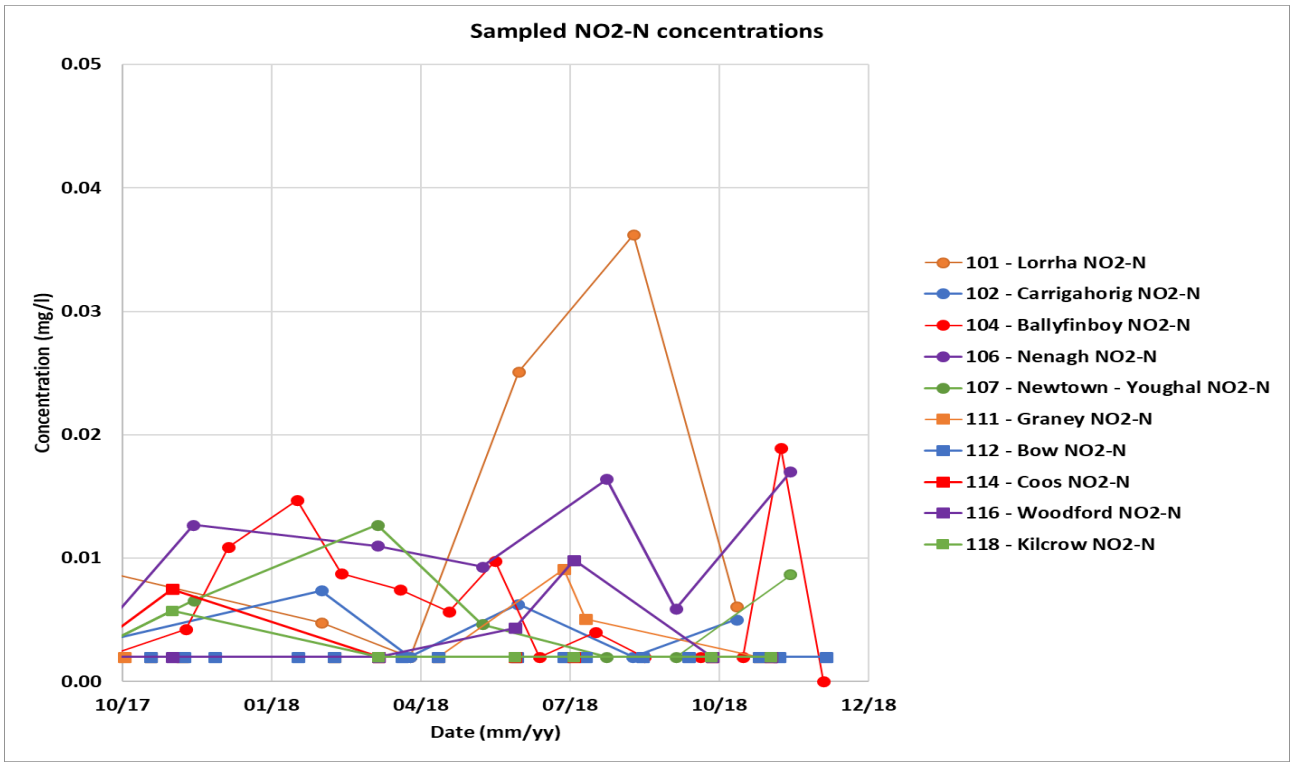

Figure 13: Sampled NO2-N concentrations

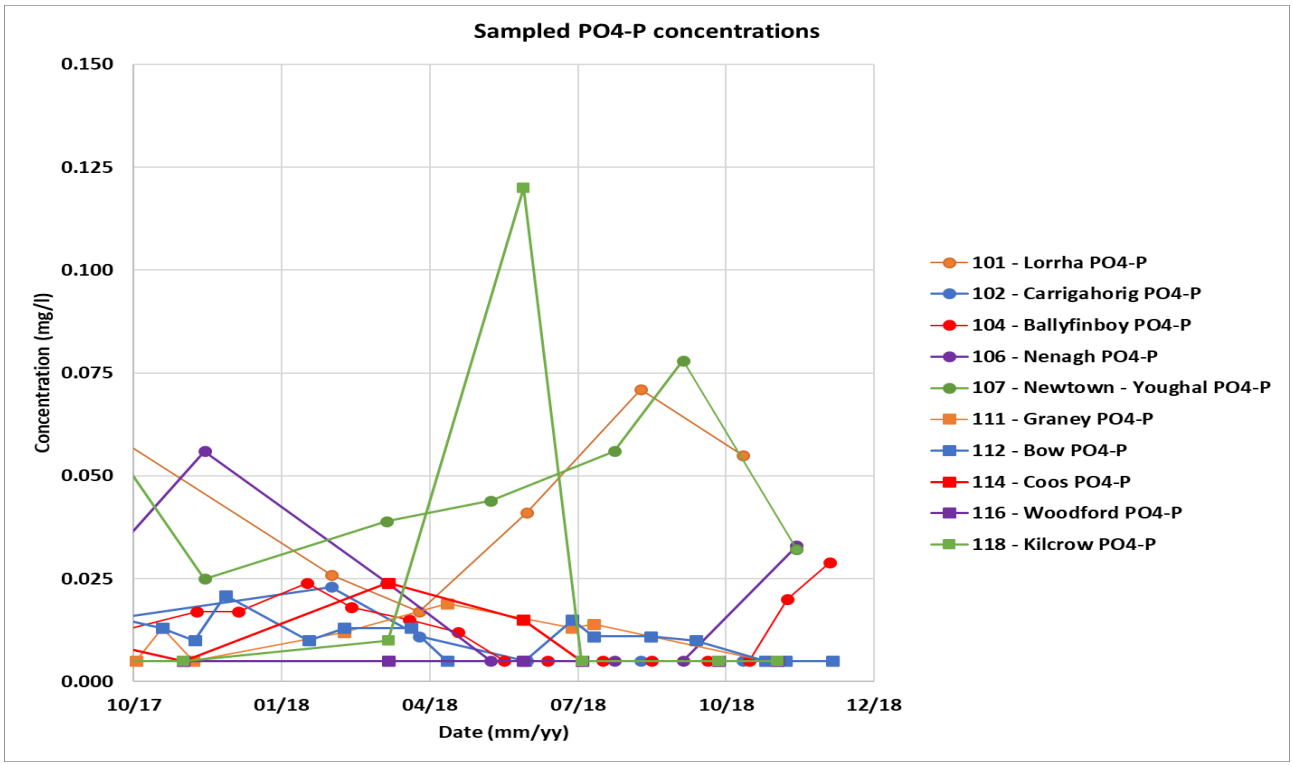

Figure 14: Sampled PO4-P concentrations

4.3. Hydrodynamic Verification

The hydrodynamic model was verified over the period 01/10/2017 to 31/12/2018. The model predictions were compared against recorded datasets from instruments deployed within Lough Derg where available.

4.3.1. Water Surface Levels

The water surface levels predicted by the model were compared against the ESB water level recorder located at Ballyvalley just north of Killaloe towards the south of the lough. The location of the ESB water level recorder at Ballyvalley is presented in Figure 15.

Figure 16 presents the water surface levels predicted by the model against the ESB water level recorder at Ballyvalley. The model was cold-started at an initial water surface level condition of 30.0mODM. Visually, the comparison between modelled and recorded water surface levels at Ballyvalley showed good agreement. Over the course of the model verification period, the model simulated the recorded water levels to within ± 0.05m for 82% of the time as shown in Figure 16.

This is comparable accuracy to that achieved in the model calibration exercise at Kincora marina (adjacent to Ballyvalley) where the model simulated the recorded water levels to within ± 0.05m for 86% of the time.

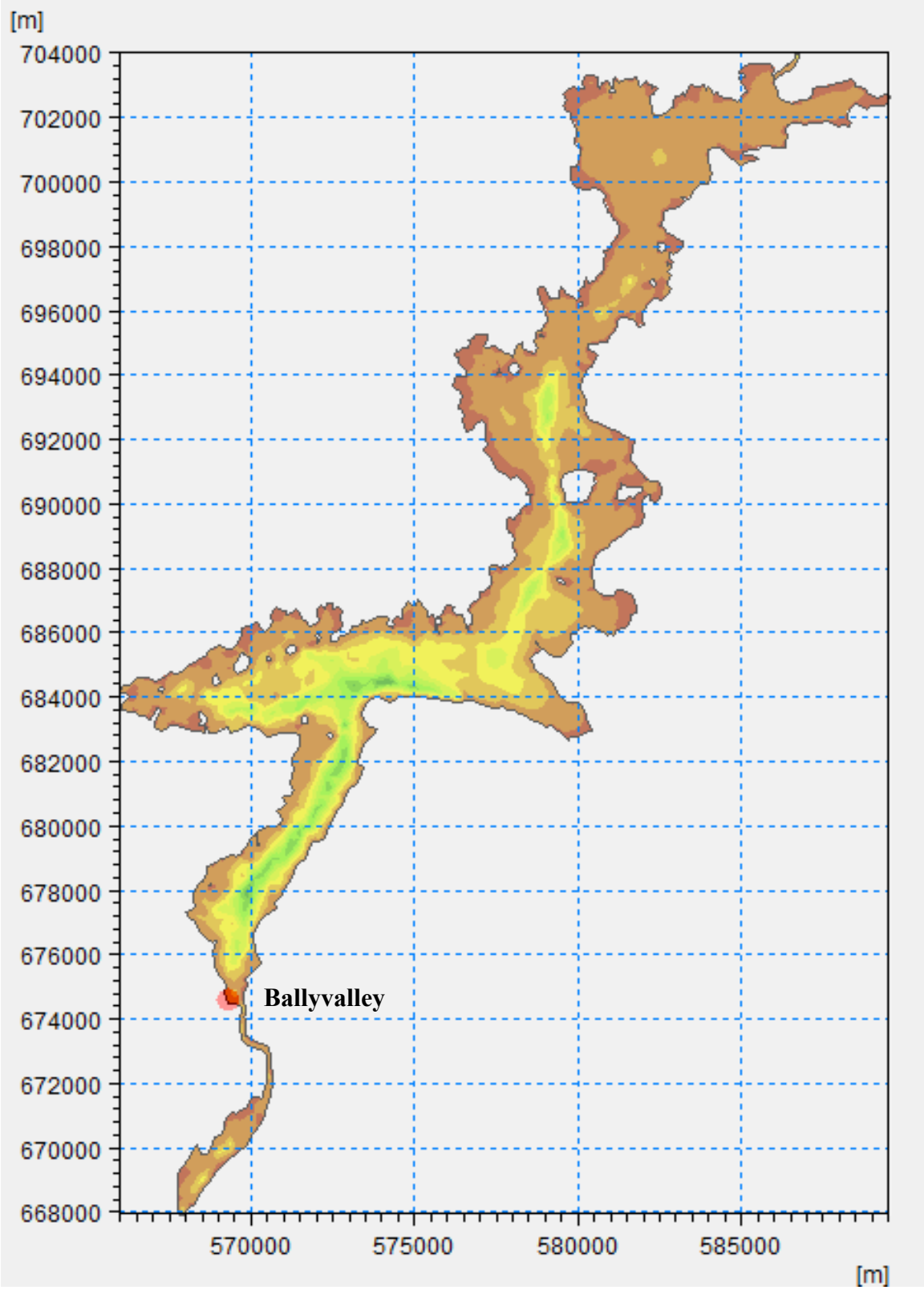

Figure 15: Location of Ballyvalley water level calibration station

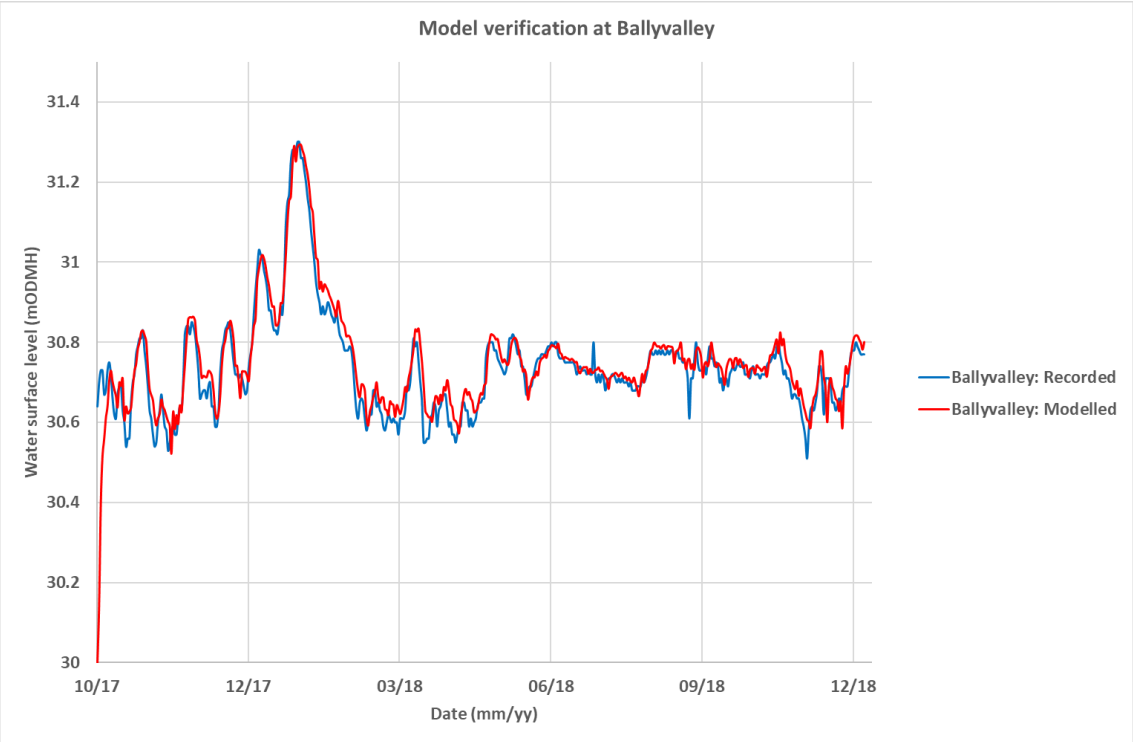

Figure 16: Water surface level calibration at Ballyvalley

4.3.2. Water Currents

No vertical Acoustic Doppler Current Profile (ADCP) recorders were deployed in Lough Derg during the period of the model verification therefore only qualitative verification of modelled current speeds and directions was undertaken. The locations at which the qualitative verification of the model was undertaken corresponded to locations OL02 and OL09 used in the original model calibration exercise and are presented in Figure 17.

The comparison of the original calibrated model's predicted current speeds from 2016 against the predicted current speeds for the 2018 period of verification at location OL02 are presented in Figure 18 on a calendar month basis. The comparison of the original calibrated model's predicted current speeds from 2016 against the predicted current speeds for the 2018 period of verification at location OL09 are presented in Figure 18 on a calendar month basis.

In both locations the current speeds predicted during the 2018 model verification period are of the same magnitude as those of the originally calibrated model.

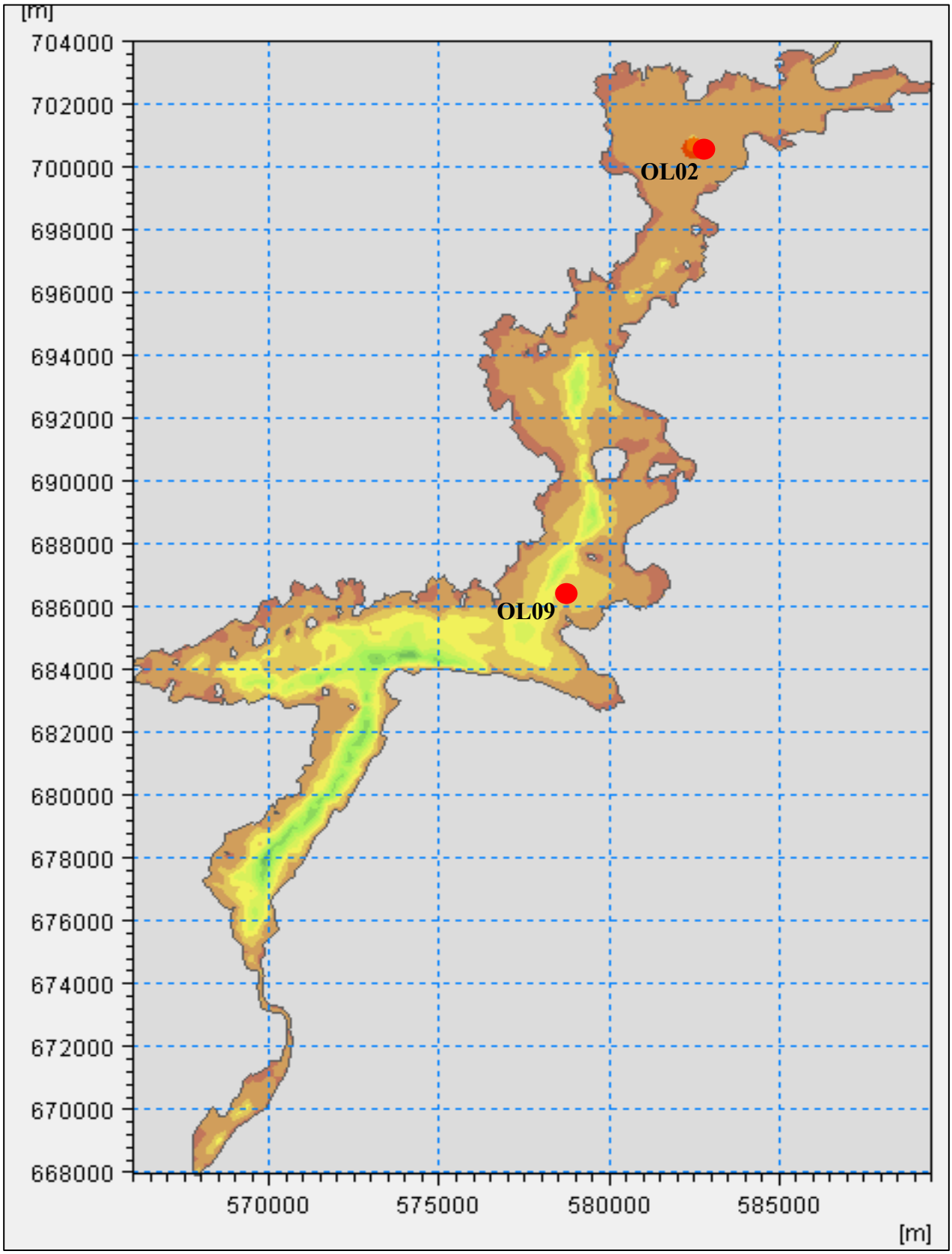

Figure 17: Location of model calibration stations OL02 and OL09

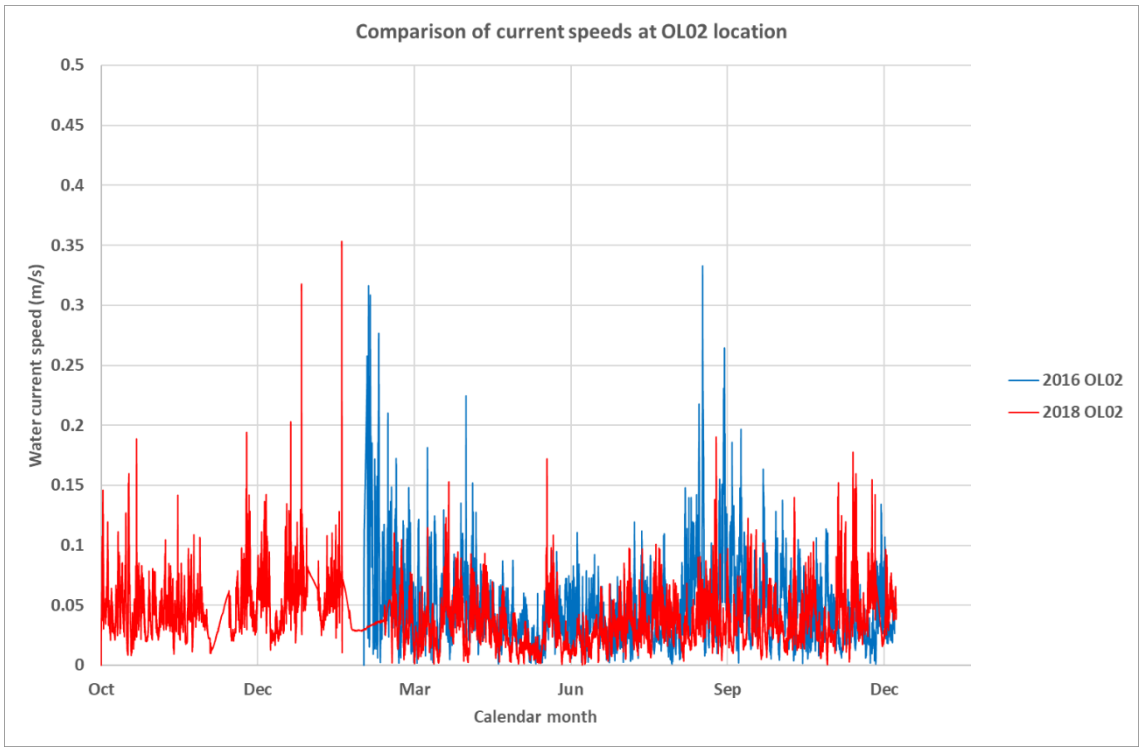

Figure 18: Comparison of modelled current speeds at OL02 location from calibrated (2016) model and verified (2018) model.

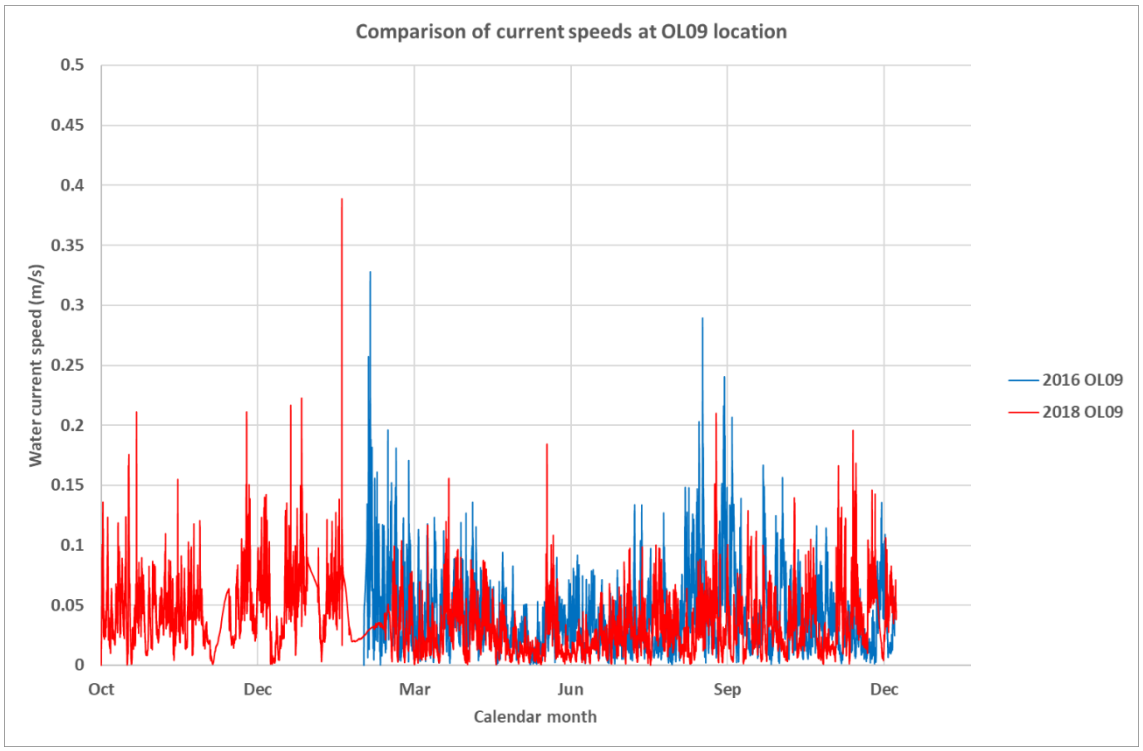

Figure 19: Comparison of modelled current speeds at OL02 location from calibrated (2016) model and verified (2018) model.

4.4. Water Quality Model Re-calibration

The water quality model re-calibration was undertaken over the period 01/10/2017 to 31/12/2018 to improve the representation of ammonia (NH3-N) in the model. The model was initialised with constant concentrations of BOD, DO, CHL, NO2-N, NH3-N, NO3-N and PO4-P in line with recorded values at the start of October 2017.

For model re-calibration purposes, the model predictions were compared against samples collected at three of the seven locations at which the water quality manual sampling (WQMS) survey of Lough Derg was undertaken. The three manual sampling locations chosen for model re-calibration purposes were WQMS-1 in the north of the lake, WQMS-5 in the centre of the lake, and WQMS-8 in the south of the lake, as presenting in Figure 20.

The manual samples were analysed for biochemical oxygen demand (BOD), dissolved oxygen (DO), chlorophyll-a (CHL), nitrite nitrogen (NO2-N), ammonia (NH3-N), nitrate nitrogen (NO3-N), and phosphate phosphorus (PO4-P). The manual samples were collected on average every fortnight.

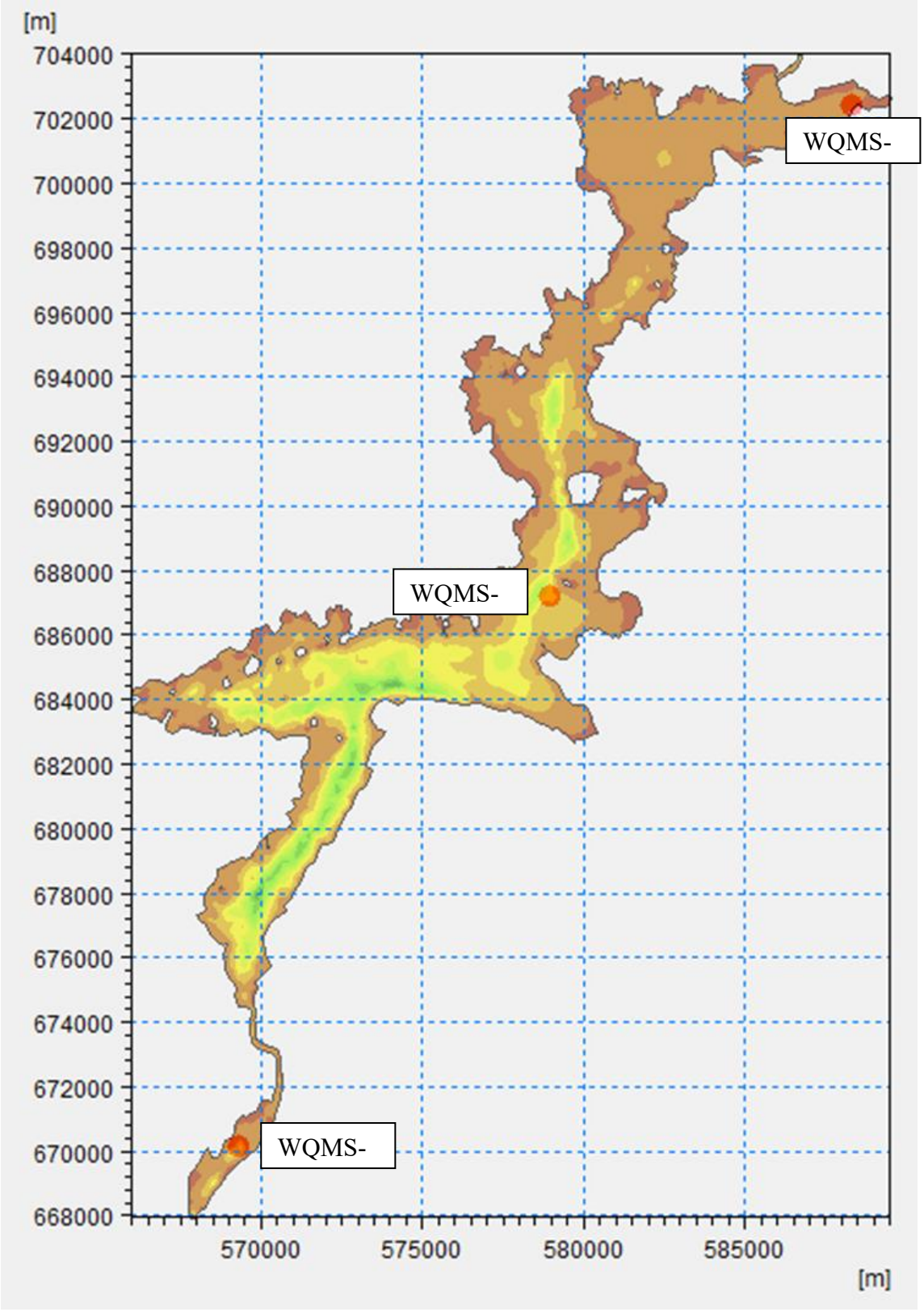

Figure 20: Water quality manual sampling (WQMS) locations for model re-calibration

4.4.1. Biological Oxygen Demand (BOD)

Comparison of modelled BOD against sampled BOD at locations WQMS-1, WQMS-5 and WQMS-8 are presented in Figure 21 to Figure 23.

At location WQMS-1 the modelled values showed very good agreement when compared with the sampled values. At location WQMS-5 the modelled values were slightly under predicted when compared with the sampled values at the final quarter of 2018. At location WQMS-8 the modelled values were under predicted when compared with the sampled values at the latter half of 2018.

In general, the modelled BOD concentrations reproduced the increasing concentrations in Spring, falling to lower values in mid-Summer and increased again in the Winter, thus the modelled BOD concentrations showed agreement with the general annual trend in the sampled data. The re-calibrated water quality model exhibits the same level of accuracy in predicting BOD concentrations throughout the study area as the previously verified water quality model.

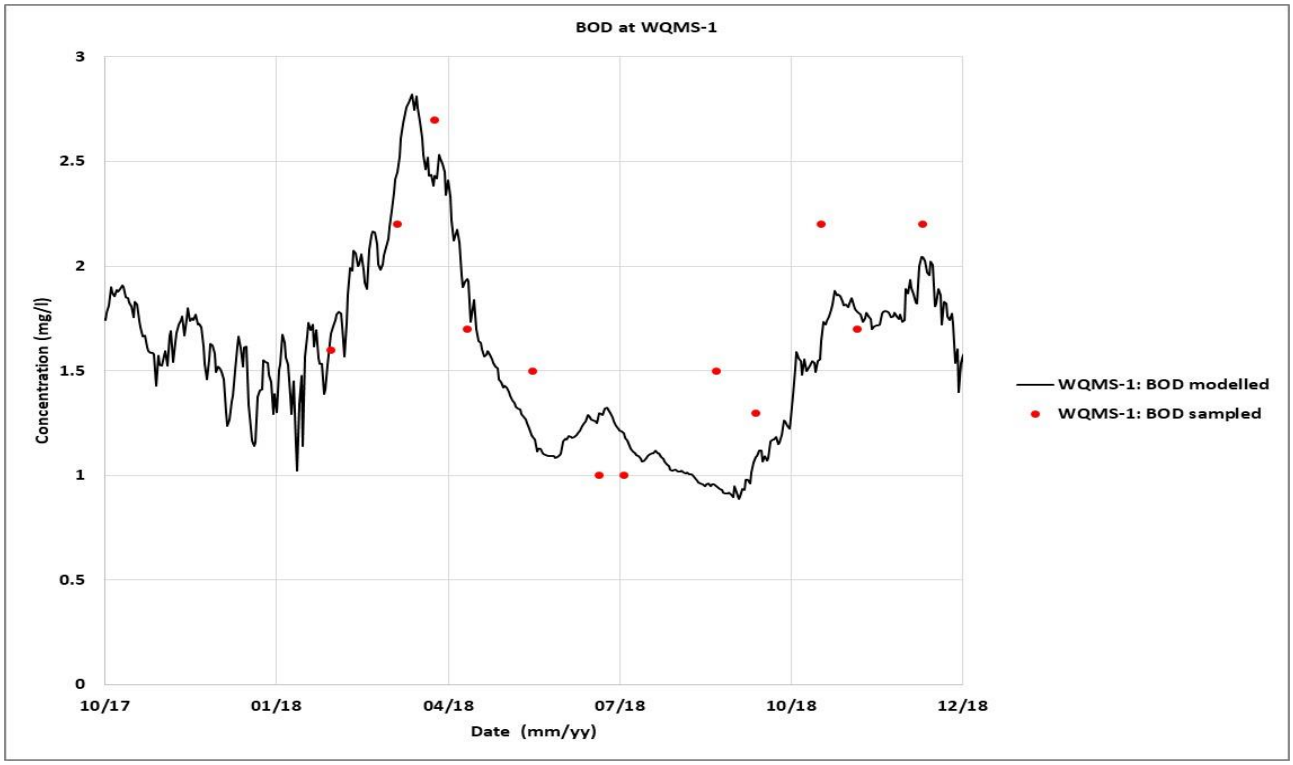

Figure 21: BOD re-calibration at WQMS-1

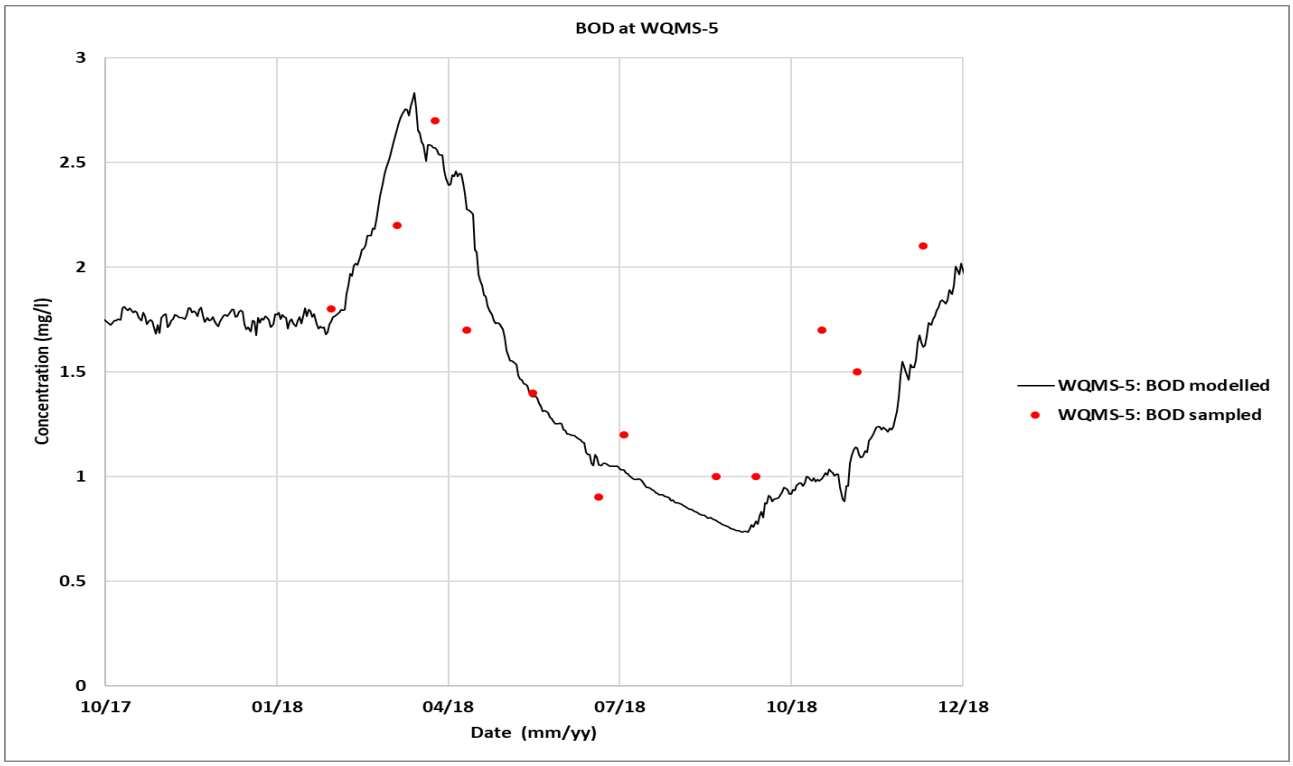

Figure 22: BOD re-calibration at WQMS-5

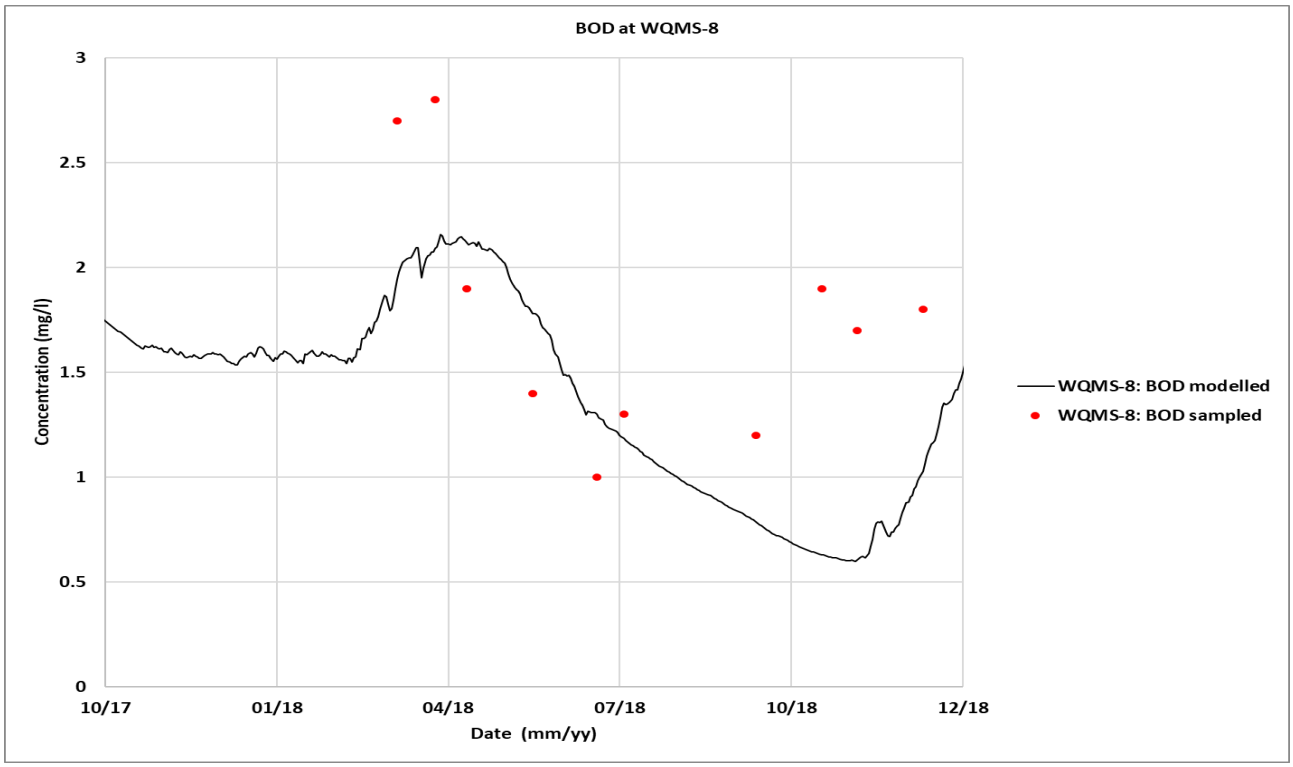

Figure 23: BOD re-calibration at WQMS-8

4.4.2. Dissolved Oxygen (DO)

Comparison of modelled DO against sampled DO at locations WQMS-1, WQMS-5 and WQMS-8 are presented in Figure 24 to Figure 26.

At location WQMS-1 the modelled values showed a slight under prediction of DO concentrations but closely followed the annual trend when compared with the sampled values. At location WQMS-5 again the modelled values showed a slight under prediction of DO concentrations but closely followed the annual trend when compared with the sampled values. At location WQMS-8 although the model recreated the rise and fall of DO concentrations throughout the course of the year, it did not predict the magnitude of the peak or trough in sampled DO concentrations.

The modelled DO concentrations reproduced the increasing concentrations in Spring, falling to lower values in mid-Summer and increased again in the Winter. This agreed with the annual trend in the sampled data. The re-calibrated water quality model exhibits the same level of accuracy in predicting DO concentrations throughout the study area as the previously verified water quality model.

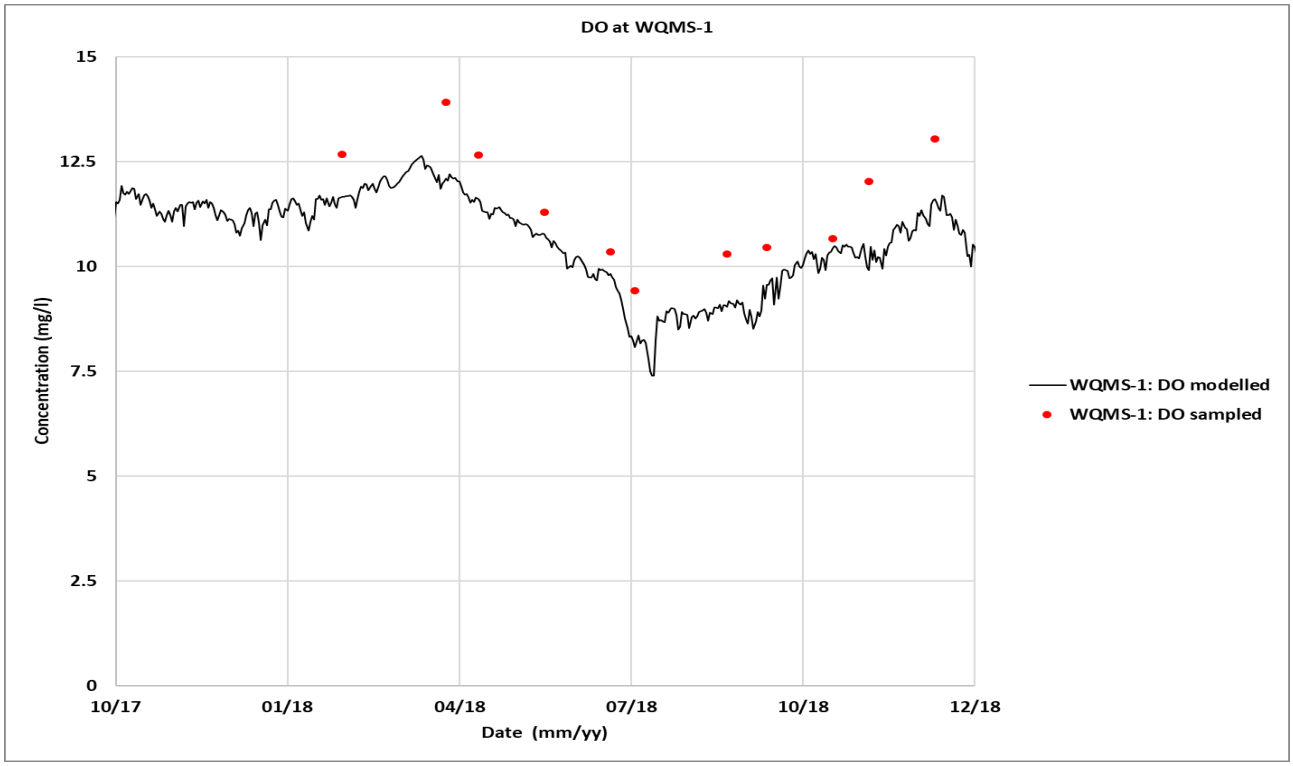

Figure 24: DO re-calibration at WQMS-1

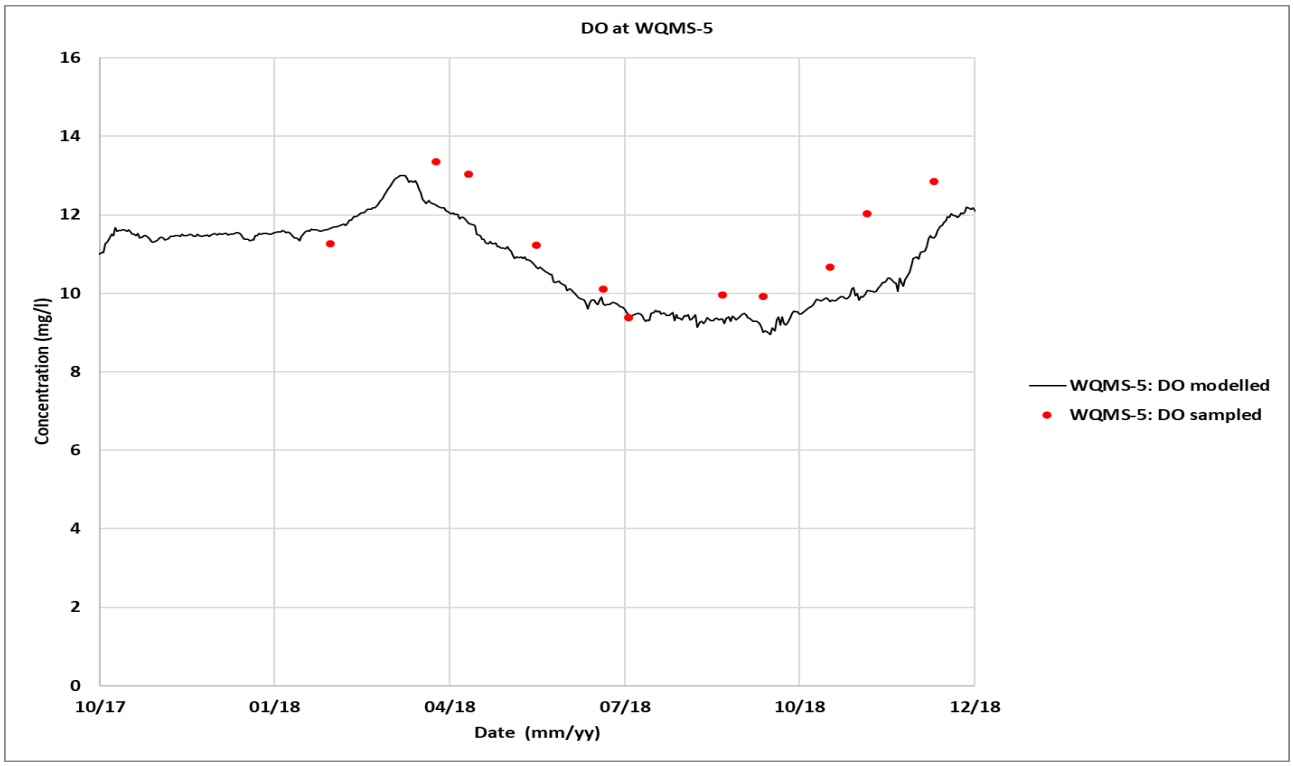

Figure 25: DO re-calibration at WQMS-5

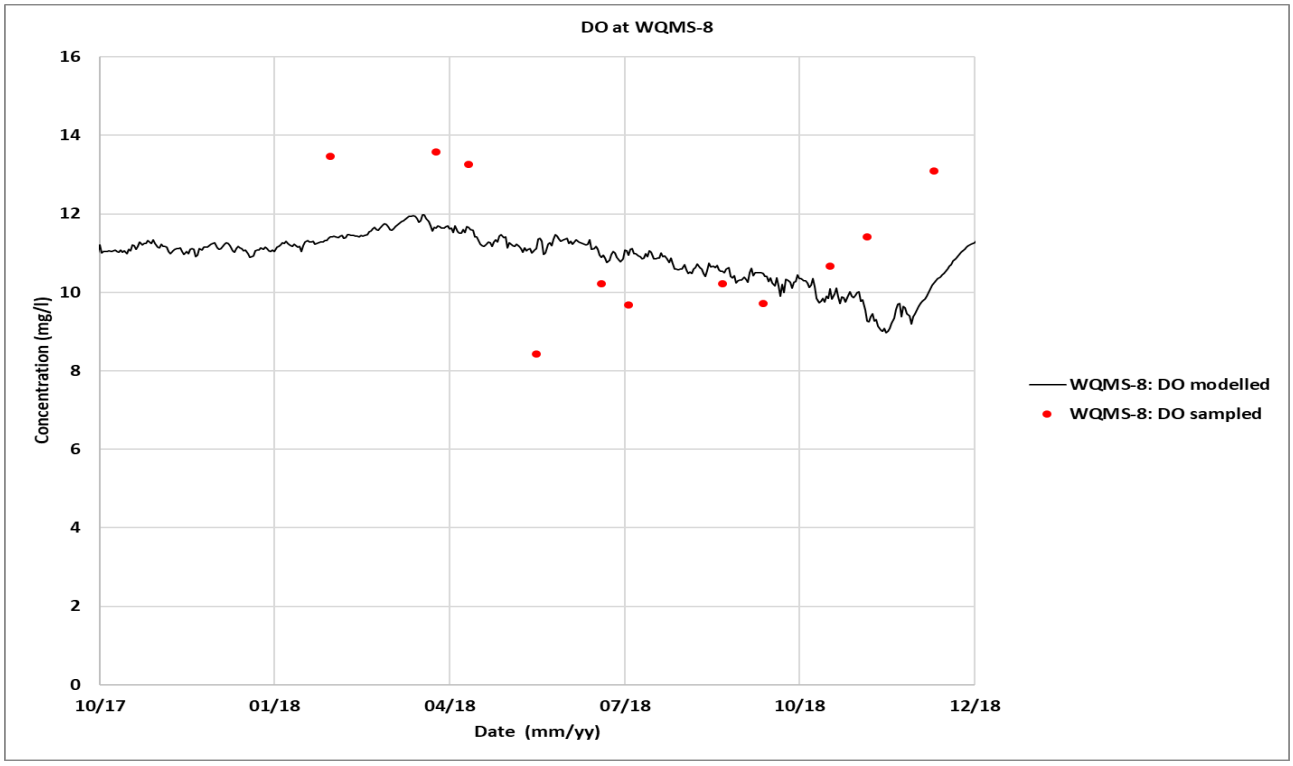

Figure 26: DO re-calibration at WQMS-8

4.4.3. Nitrate Nitrogen (NO3-N)

Comparison of modelled NO3-N against sampled NO3-N at locations WQMS-1, WQMS-5 and WQMS-8 are presented in Figure 27 to Figure 29**.**

At location WQMS-1 the modelled values showed very good agreement when compared with the sampled values. At location WQMS-5 the modelled values were under predicted when compared with the sampled values at the latter half of 2018. At location WQMS-8 the modelled values were generally under predicted when compared with the sampled values.

The modelled NO3-N concentrations reproduced the peak concentrations in February then continuously reducing throughout the year to lower values in late Autumn and increased again in the Winter. The modelled NO3-N concentrations showed agreement with the general annual trend in the sampled data. The re-calibrated water quality model exhibits the same level of accuracy in predicting NO3-N concentrations throughout the study area as the previously verified water quality model.

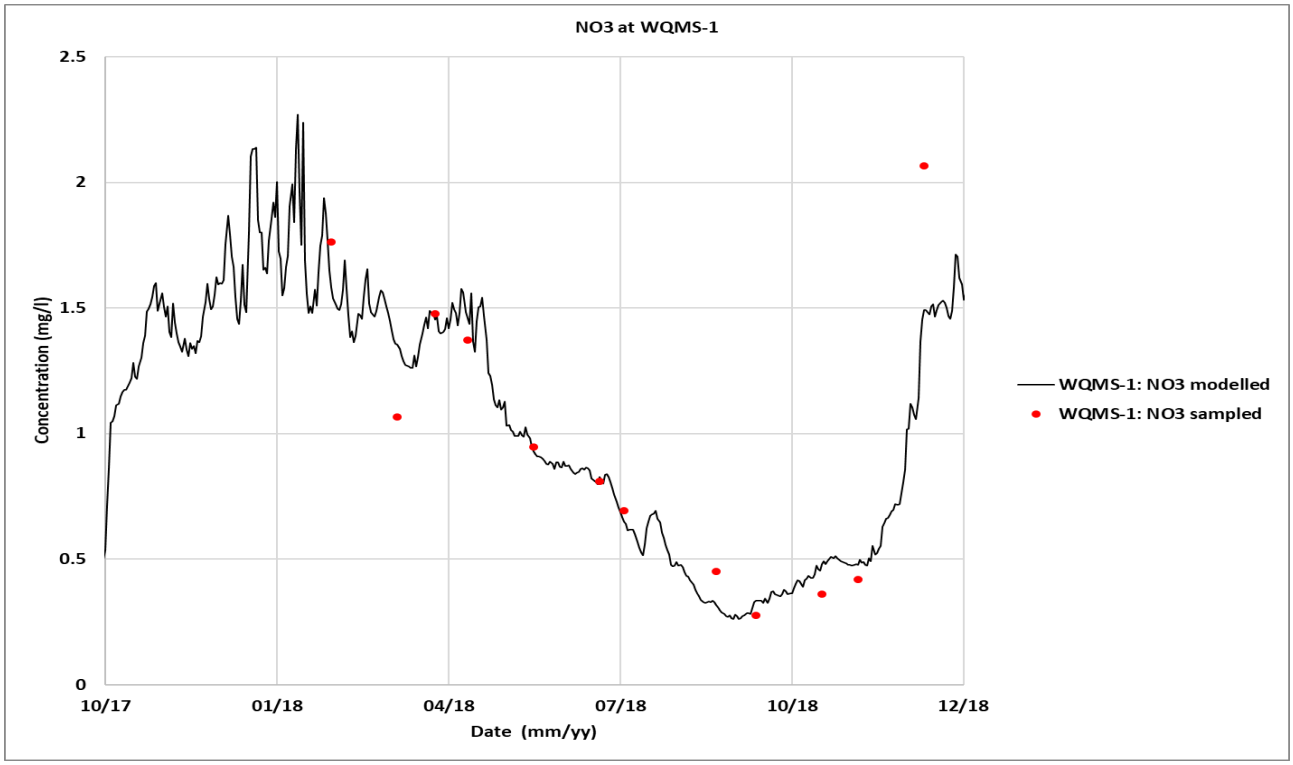

Figure 27: NO3-N re-calibration at WQMS-1

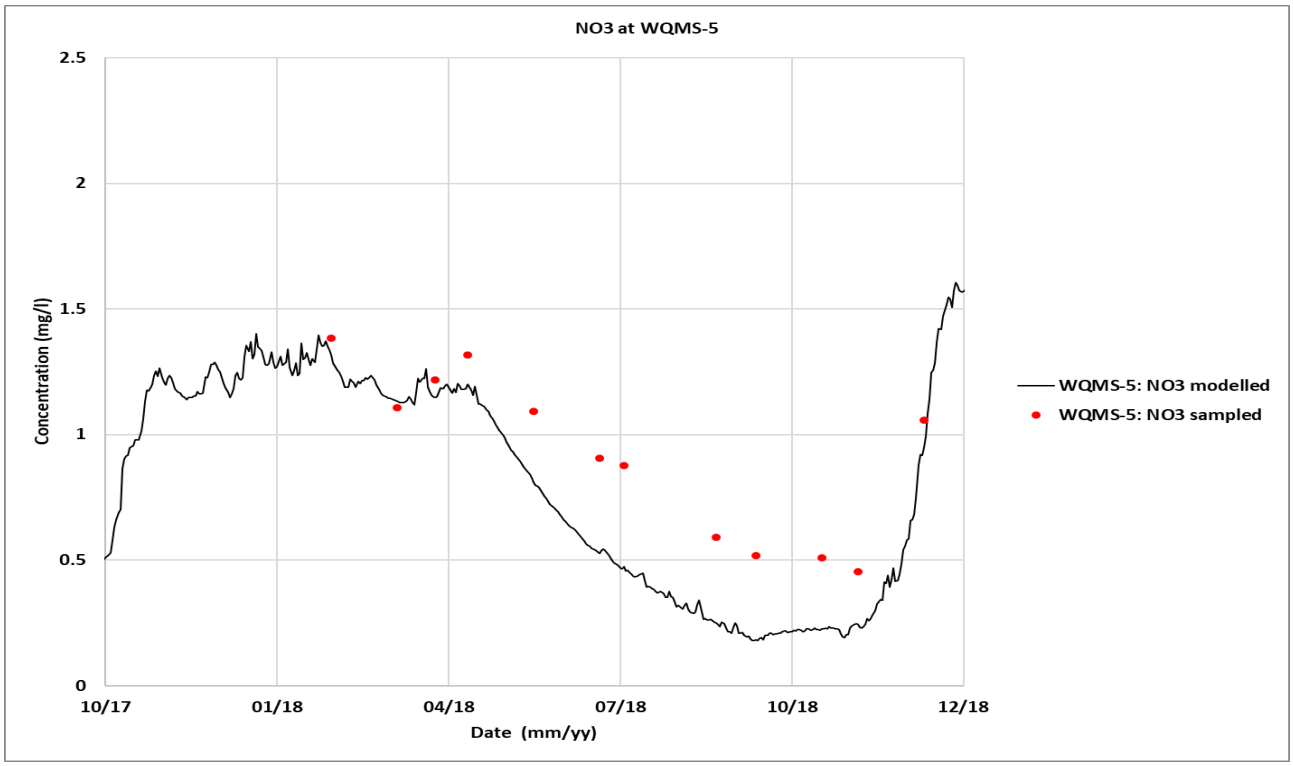

Figure 28: NO3-N re-calibration at WQMS-5

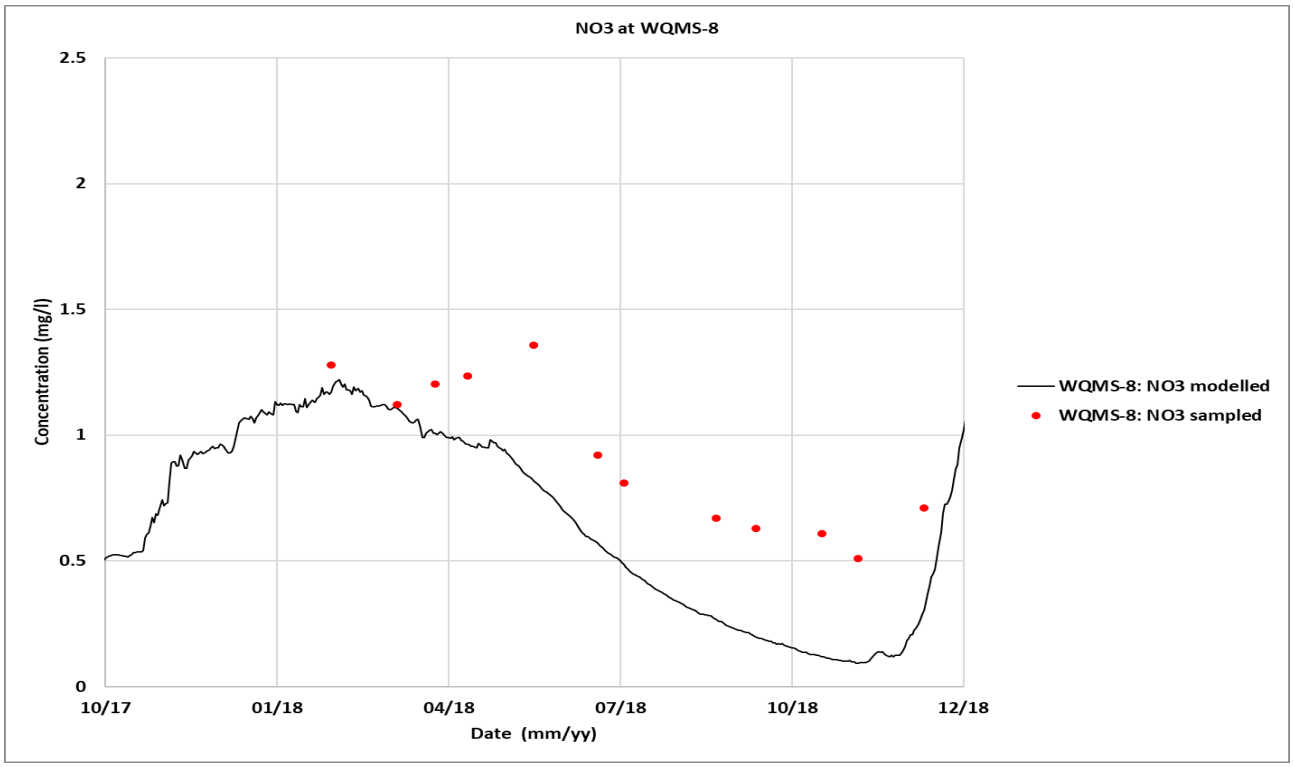

Figure 29: NO3-N re-calibration at WQMS-8

4.4.4. Ammonia Nitrogen (NH3-N)

Comparison of modelled NH3-N against sampled NH3-N at locations WQMS-1, WQMS-5 and WQMS-8 are presented in Figure 30 to Figure 32. Re-analysis of the manual NH3-N samples in the laboratory using a lower lower limit of detection than previously employed provided better representation of sampled NH3-N concentrations thus facilitating the re-calibration of the water quality numerical mode.

At location WQMS-1 the modelled values showed agreement when compared with the sampled values. At location WQMS-5 the modelled values showed good agreement when compared with the sampled values. At location WQMS-8 the modelled values again showed a level of agreement with the sampled values.

As a result of the re-calibration exercise, the predicted NH3-N concentrations showed much better agreement with the sampled data than presented previously in the water quality model verification exercise. The re-calibrated water quality model exhibits a much-improved level of accuracy in predicting NH3-N concentrations throughout the study area over the previously verified water quality model.

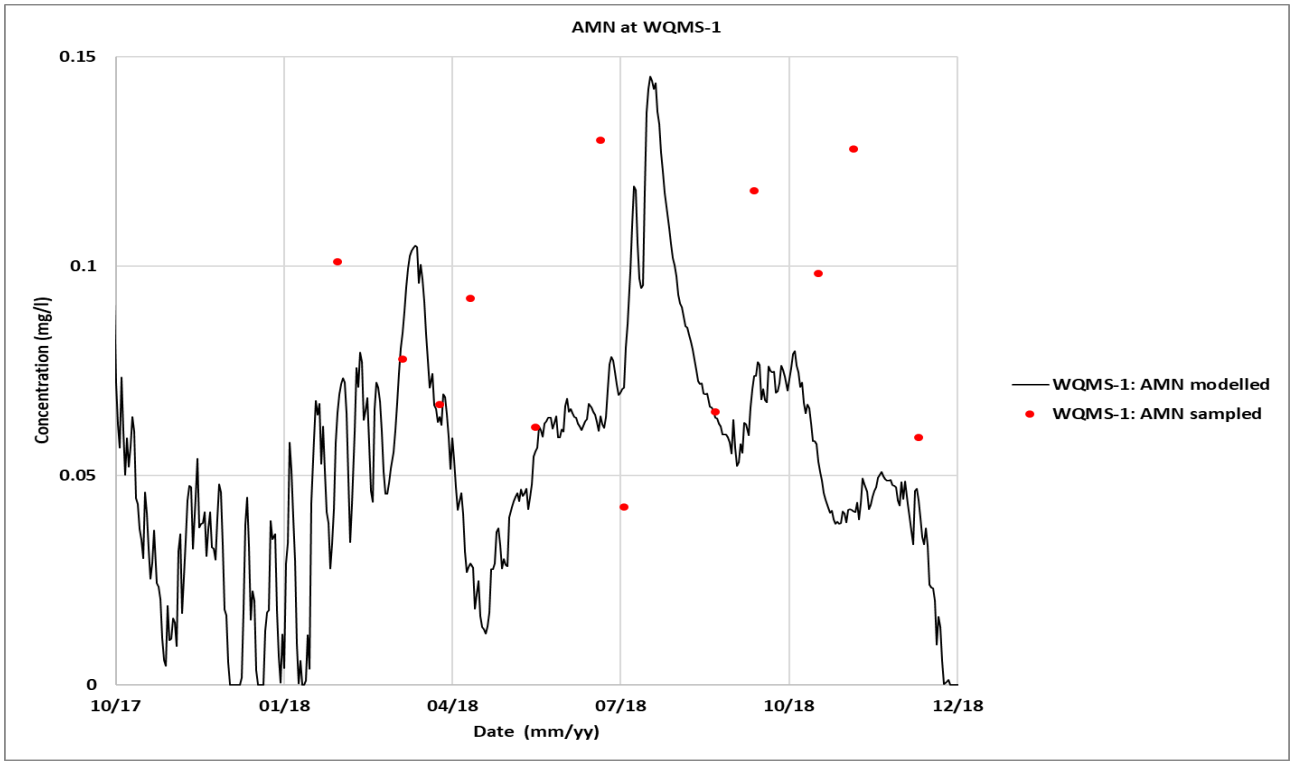

Figure 30: NH3-N re-calibration at WQMS-1

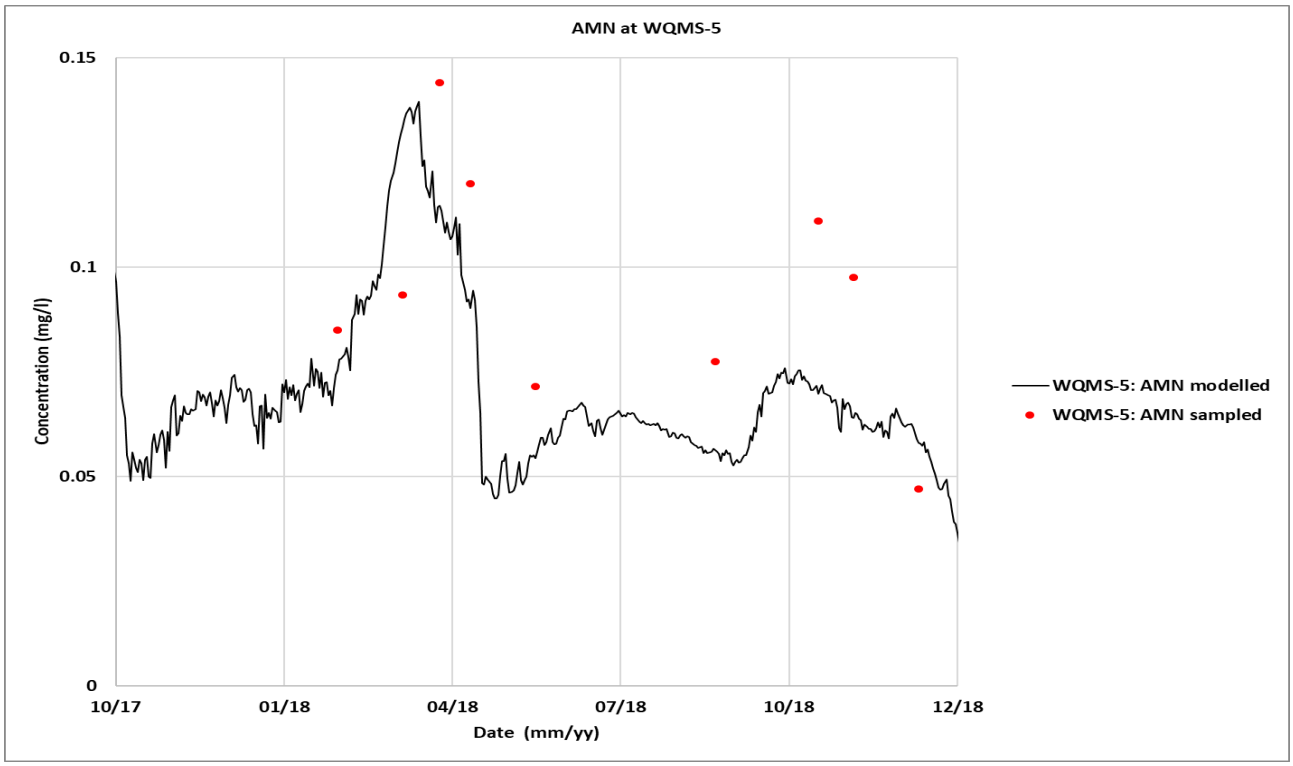

Figure 31: NH3-N re-calibration at WQMS-5

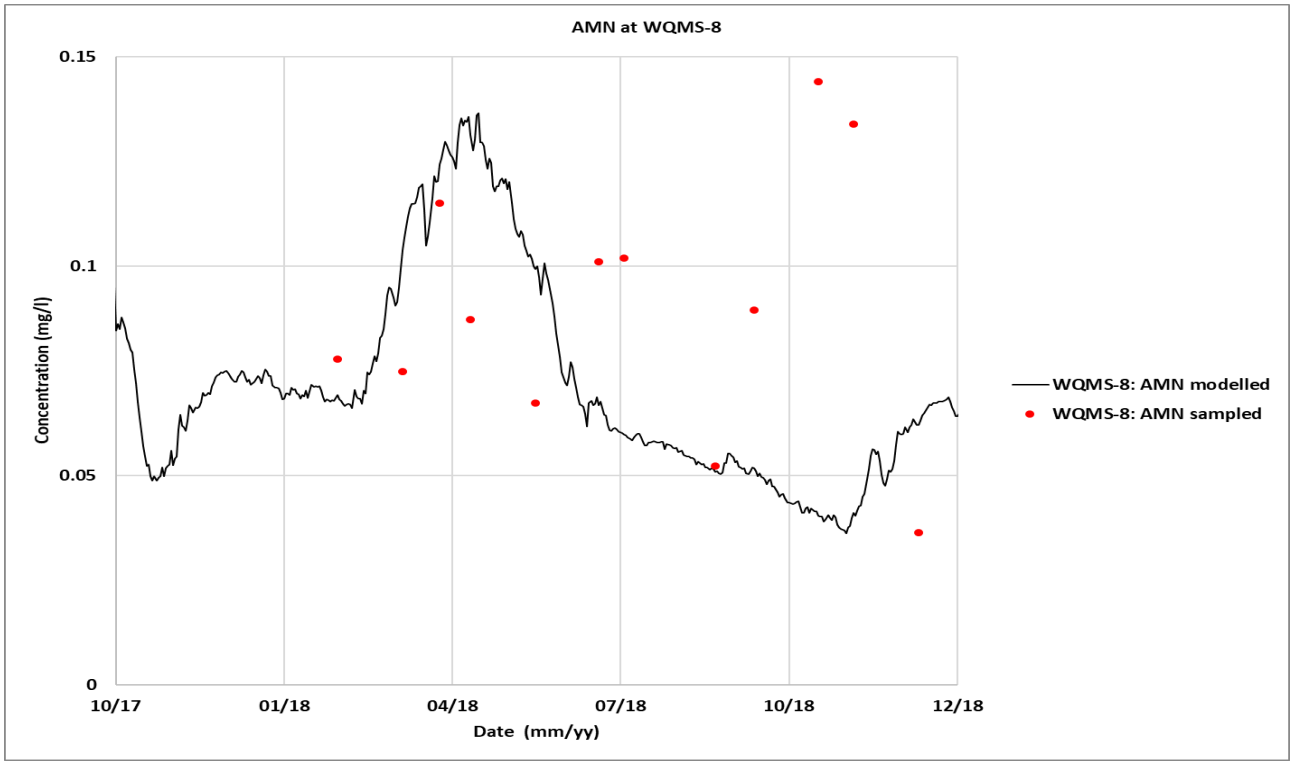

Figure 32: NH3-N re-calibration at WQMS-8

4.4.5. Nitrite Nitrogen (NO2-N)

Comparison of modelled NO2-N against sampled NO2-N at locations WQMS-1, WQMS-5 and WQMS-8 are presented in Figure 33 to Figure 35. Almost all the NO2-N manual samples analysed were below the limit of detection by the accredited laboratory.

At all locations the modelled values were all predicted to be below the analytical limit of detection for the manual samples. To that extent, the model showed agreement with sampled data and to the same level of accuracy.

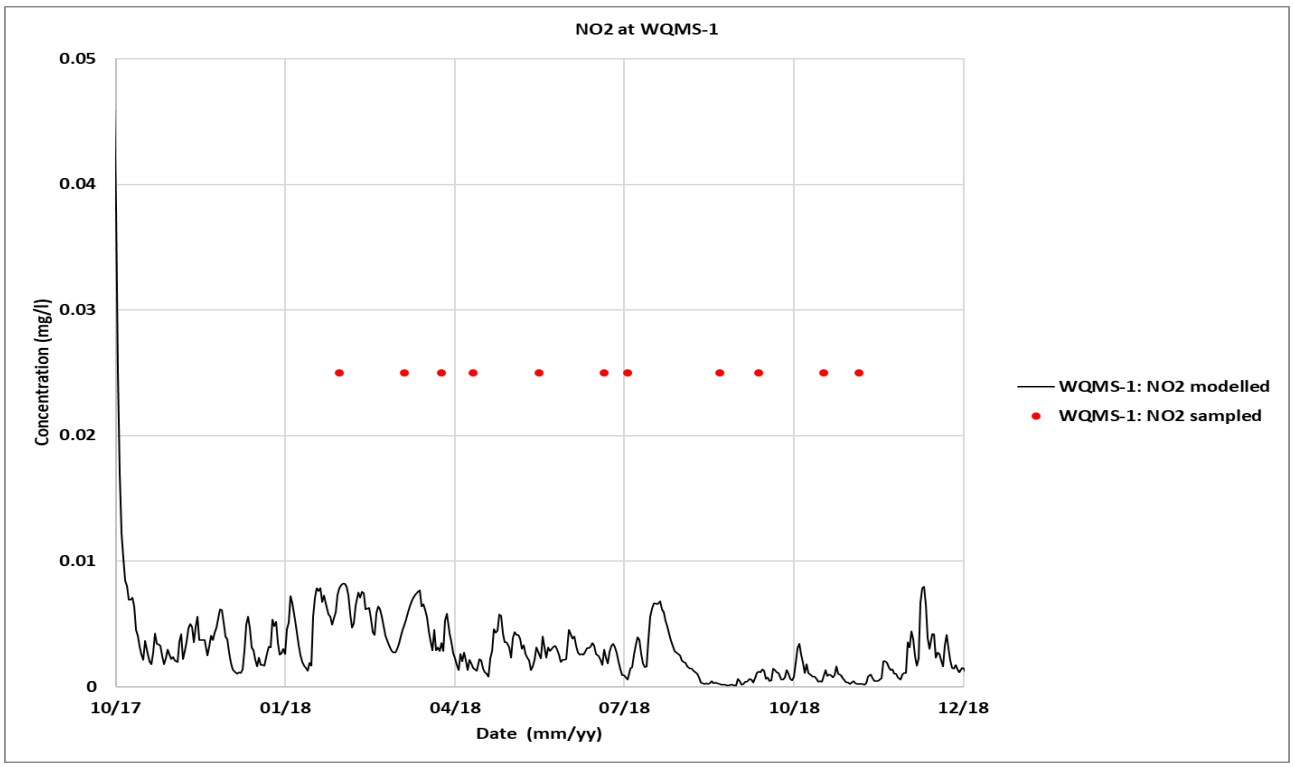

Figure 33: NO2-N re-calibration at WQMS-1

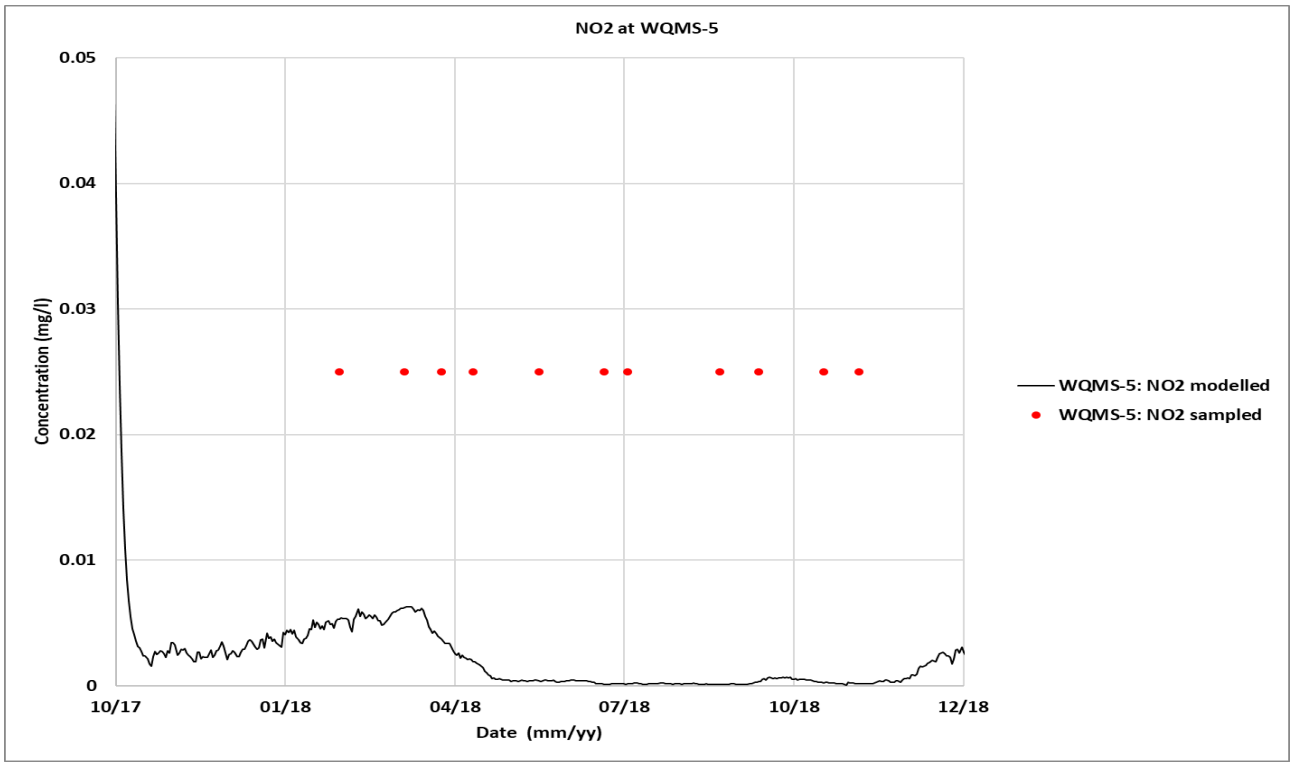

Figure 34: NO2-N re-calibration at WQMS-5

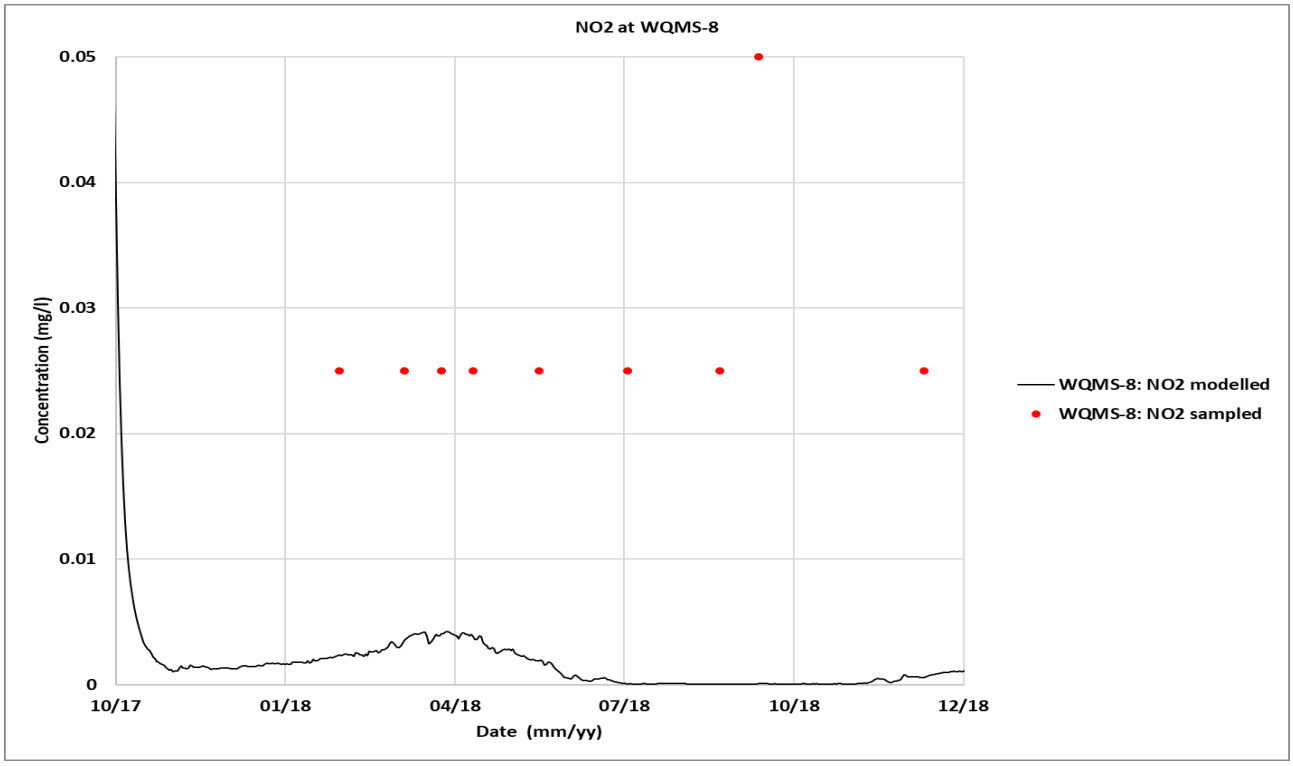

Figure 35: NO2-N re-calibration at WQMS-8

4.4.6. Chlorophyll-a (CHL)

Comparison of modelled CHL against sampled CHL at locations WQMS-1, WQMS-5 and WQMS-8 are presented in Figure 36 to Figure 38.

At location WQMS-1 the model slightly over predicted values compared with the sampled values during the first half of the year, but with both modelled and sampled values at very low levels with both at very low (1 - 2 ug/l). At location WQMS-5 the modelled values showed good agreement when compared with the sampled values with both modelled and sampled values at very low levels (1 - 2 ug/l). At location WQMS-8 the modelled values did not accurately predict the magnitude of the autumnal bloom.

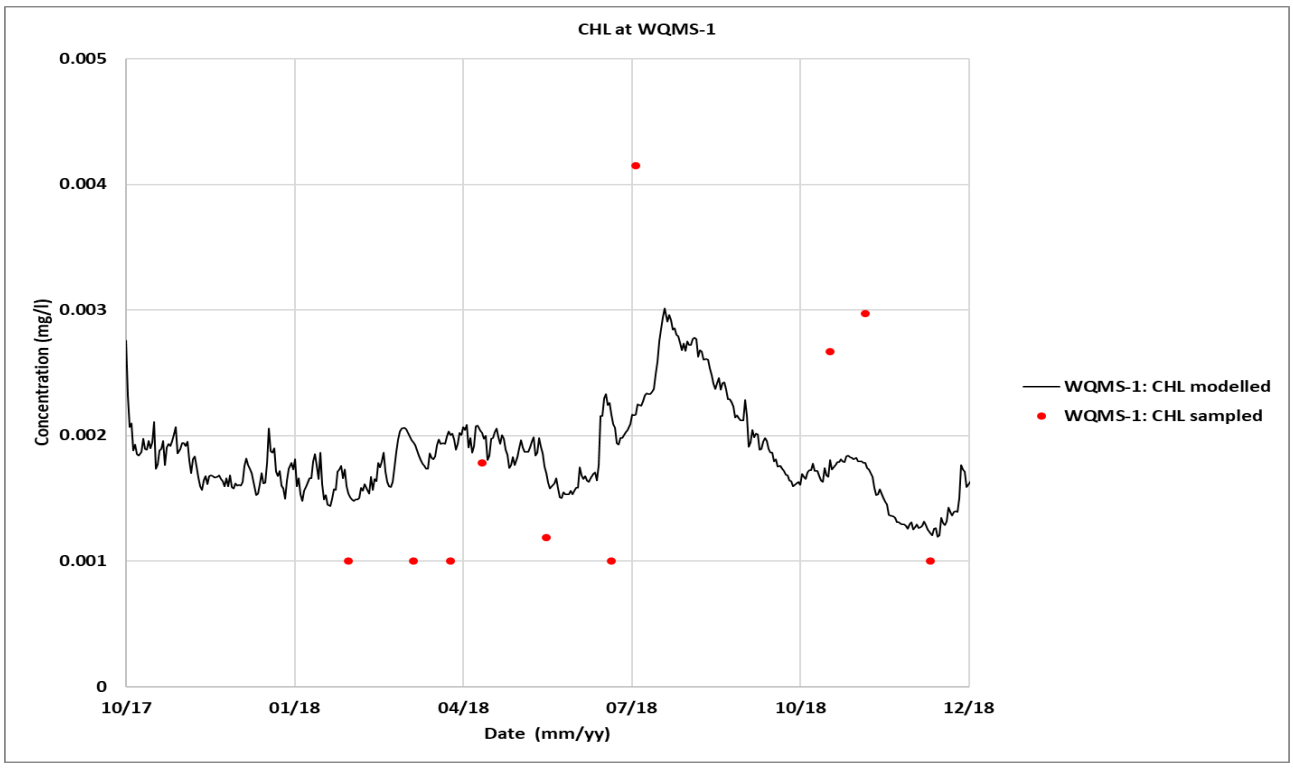

Figure 36: CHL-a re-calibration at WQMS-1

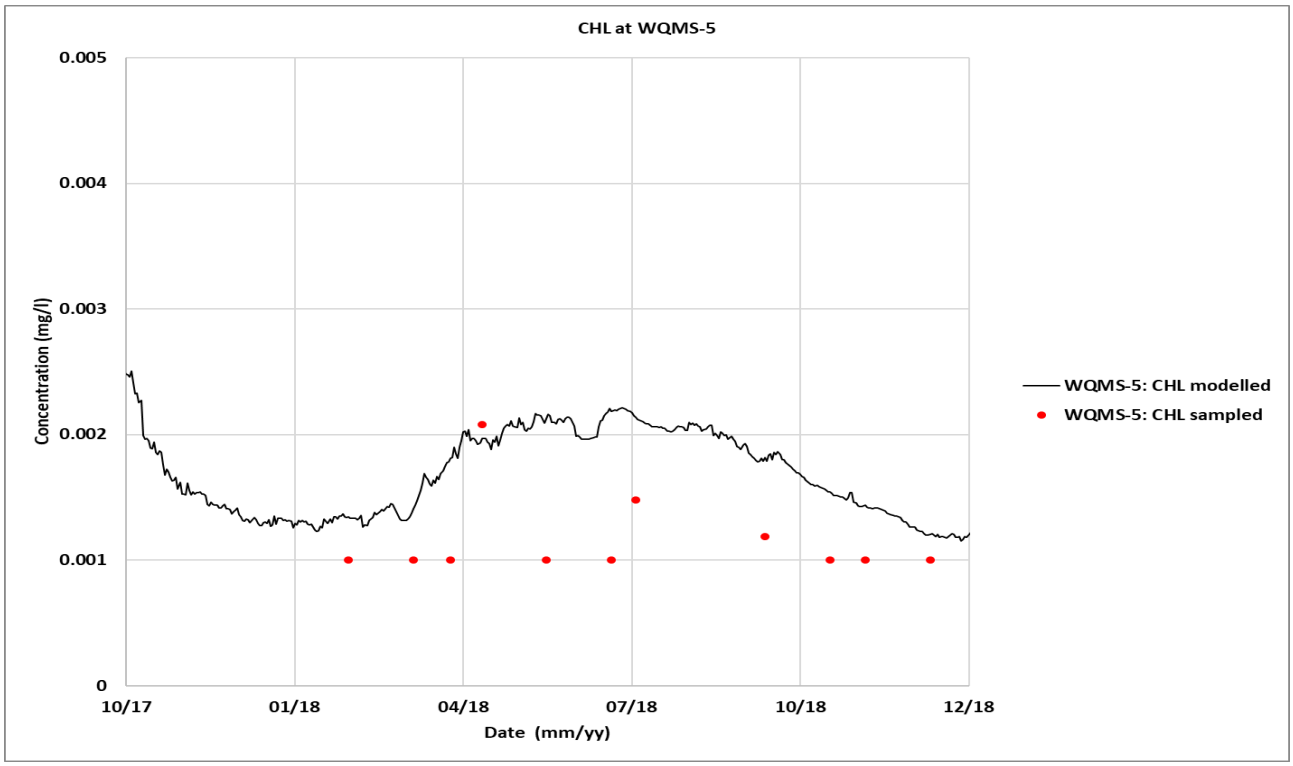

Figure 37: CHL-a re-calibration at WQMS-5

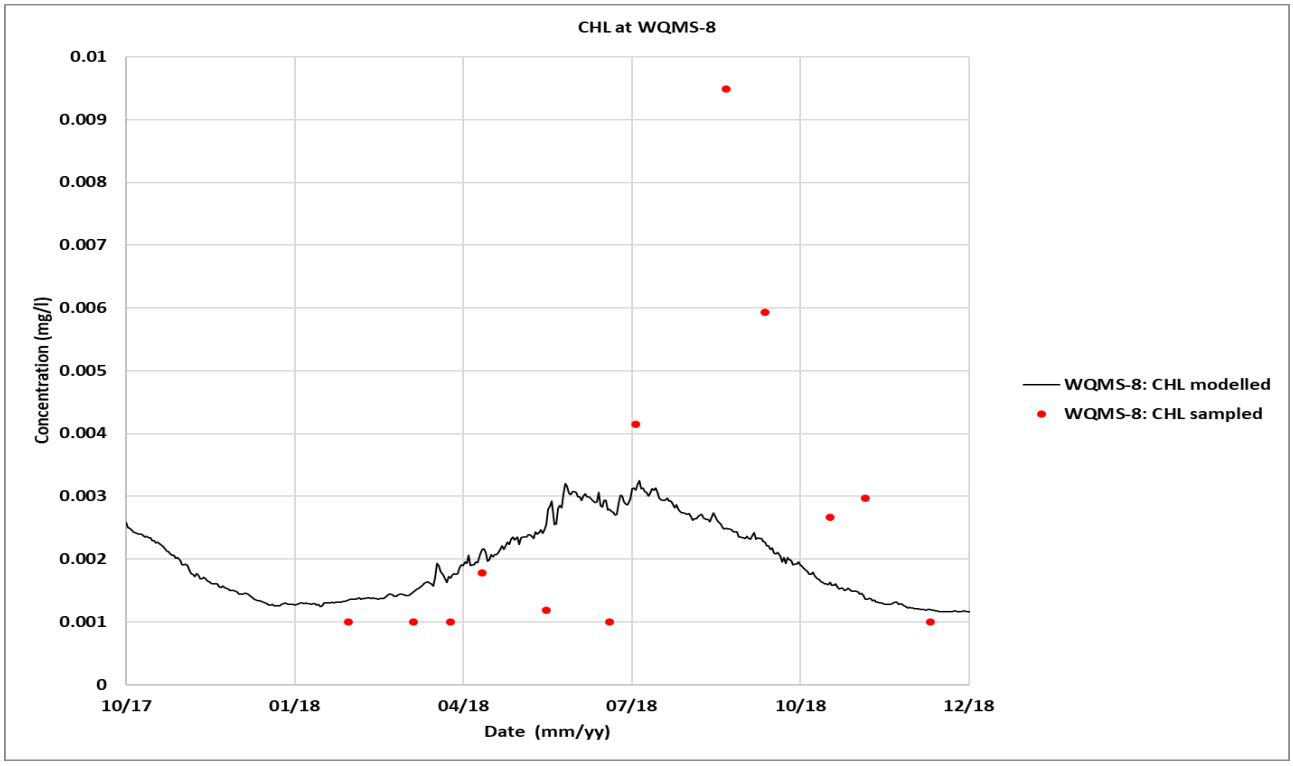

Figure 38: CHL-a re-calibration at WQMS-8

4.4.7. Orthophosphate (PO4-P)

Comparison of modelled PO4-P against sampled PO4-P at locations WQMS-1, WQMS-5 and WQMS-8 are presented in Figure 39 to Figure 41.

At location WQMS-1 the modelled values showed very good agreement when compared with the sampled values. At location WQMS-5 the modelled values showed good agreement when compared with the sampled values. At location WQMS-8 the model tended to slightly overpredict concentrations when compared with the sampled values.

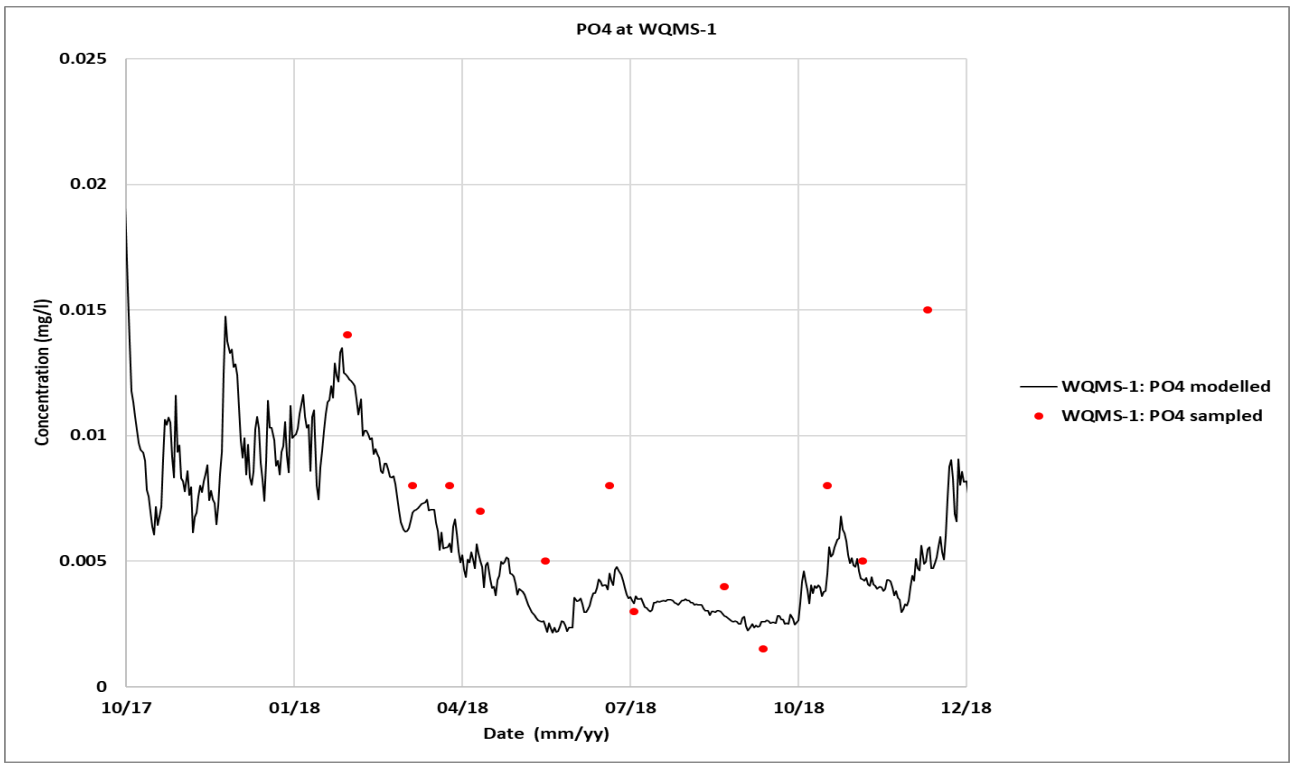

Figure 39: PO4-P re-calibration at WQMS-1

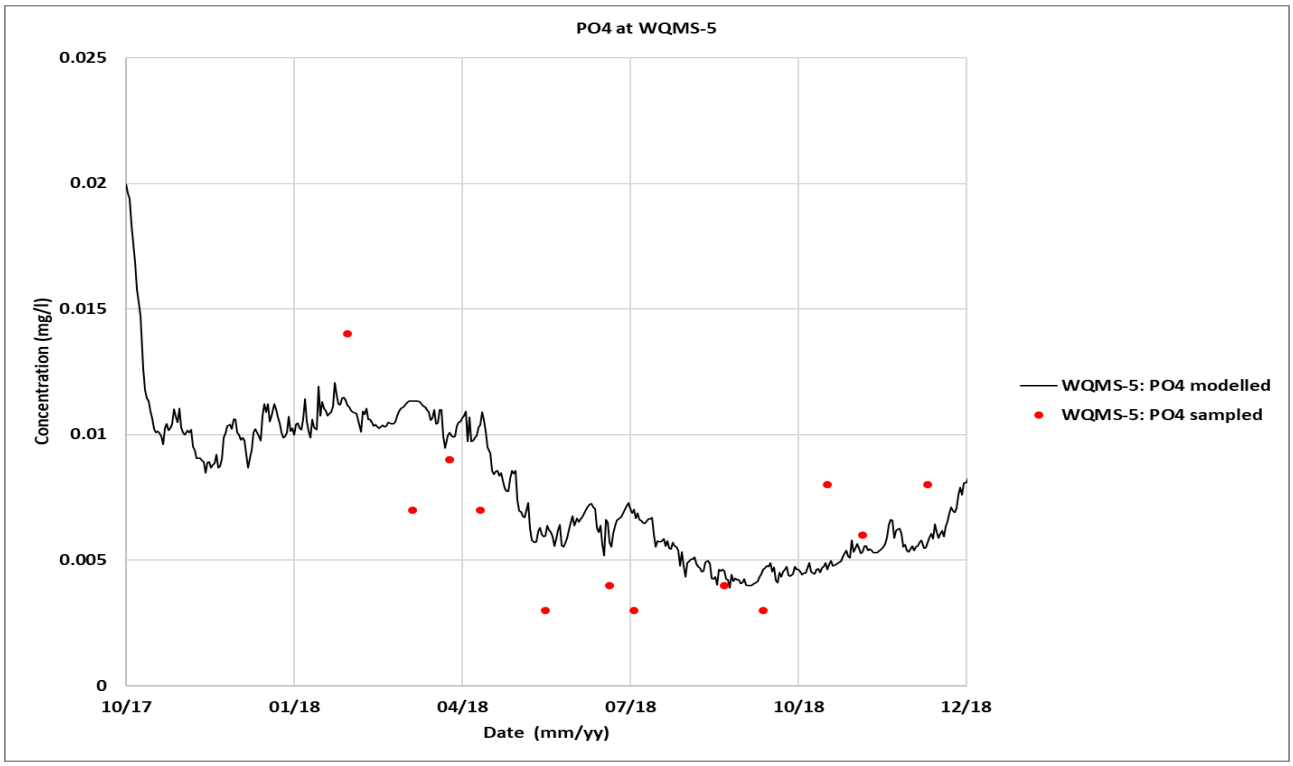

Figure 40: PO4-P re-calibration at WQMS-5

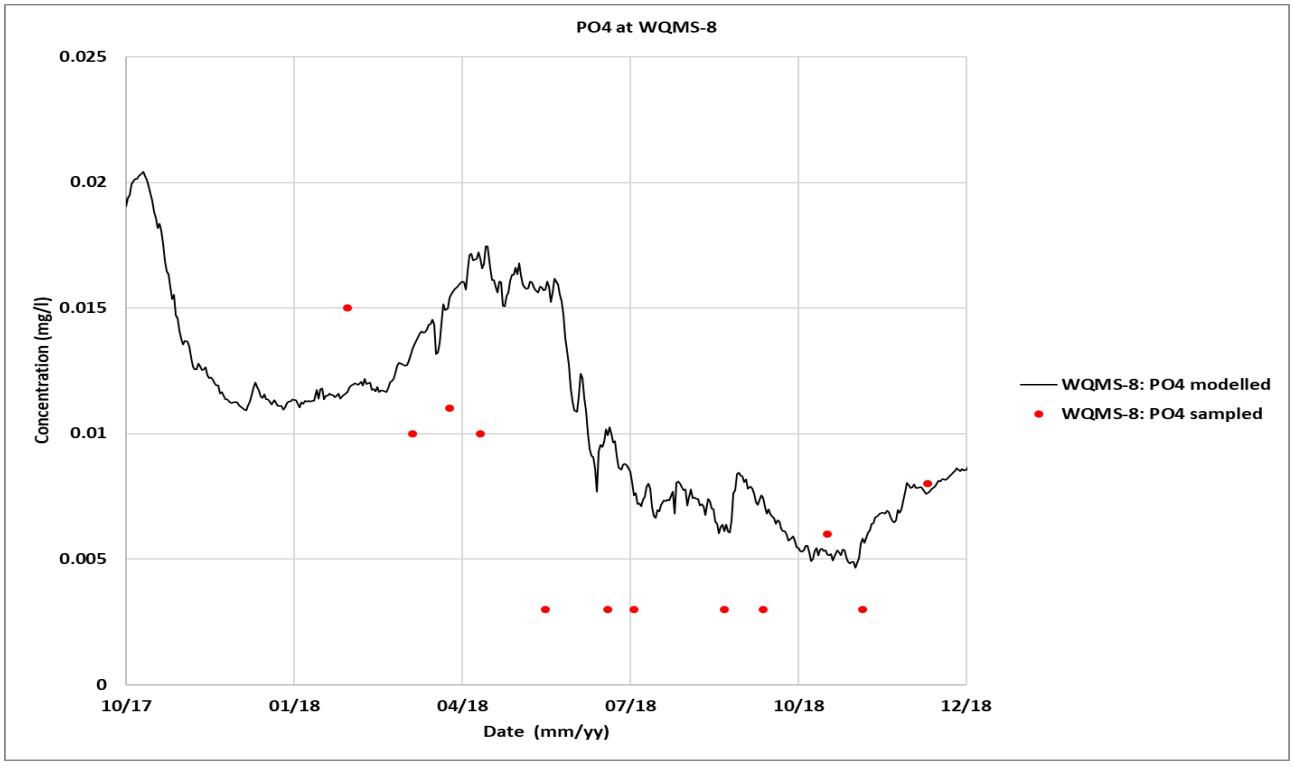

Figure 41: PO4-P re-calibration at WQMS-8

4.5.Re-calibration Statement

In general, the comparison of the modelled and measured datasets, both statistically and visually, shows a good agreement, and in the case of the water quality components a more accurate representation of the system than achieved in the original model calibration exercise, and a much better representation of ammonia when compared against the previous model verification exercise. The re-calibration results presented above show that the numerical model has been successfully re-calibrated against field measurements to provide an accurate representation of the hydrodynamic and water quality components within the study region.

5. Summary

Re-calibration of the three dimensional hydrodynamic and water quality model of Lough Derg and Parteen Basin was undertaken over the period 01/10/2017 to 31/12/2018. The model domain extended from Portumna Bridge in the north to Parteen Weir / Ardnacrusha Headrace in the south.

The main hydrodynamic boundary conditions specified to the model were the River Shannon, entering through Portumna Bridge and the combined outflow of Parteen Weir and Headrace Canal. Water level boundary conditions were also specified at both Portumna Bridge and Parteen Weir/Ardnacrusha Headrace. Twenty-one additional smaller inflowing boundaries were specified, representing the rivers and streams draining the catchments surrounding Lough Derg and Parteen Basin.

Recorded meteorological boundary conditions were specified to the model to account for wind induced circulation patterns due to variations in wind speed and direction. Recorded water quality concentrations for the twenty-one smaller streams draining the catchments surrounding Lough Derg and Parteen Basin were specified to the model.

Modelled water surface levels were compared against recorded water surface levels at one location in Lough Derg. The modelled values showed good agreement with the recorded values and exhibited the same level of accuracy as the originally calibrated model.

Modelled water current speeds were compared against the water current speeds from the calibrated model at two locations in Lough Derg. At both locations the modelled values of current speed during the re-calibration period were of the same magnitude as those during the original calibration period, providing a qualitatively that the re-calibrated model exhibited the same level of accuracy as the calibrated model.

Modelled concentrations of the water quality parameters BOD, DO, NO2-N, NH3-N, NO3-N, CHL and PO4-P in the lake were compared against manual water quality samples collected at three of seven locations throughout Lough Derg.

The modelled BOD concentrations showed general agreement with the sampled data, and with the annual trend in the sampled data sampled data exhibiting the same level of accuracy as the originally calibrated model. The modelled DO concentrations showed good agreement with the sampled data, exhibiting the same level of accuracy as the originally calibrated model. At all locations, the modelled NO2-N values were predicted to be below the analytical limit of detection for the manual samples. To that extent the model showed agreement with the sampled NO2-N data, the same as the originally calibrated model. The modelled NH3-N concentrations showed improved agreement with the sampled data especially in the central region of the study area. The modelled NO3-N concentrations showed good agreement with the sampled data, and to a similar level of accuracy as the originally calibrated model. The modelled CHL concentrations showed good agreement with the sampled data, and more accurate than the originally calibrated model results. The modelled PO4-P concentrations showed good agreement with the sampled data and to a higher level of accuracy than the originally calibrated model.

Tionscadal Soláthair Uisce
Water Supply Project

Environmental Impact Assessment Report (EIAR)

Volume 6 of 6: Appendices

(Appendix A9.1 Annex D) Summary Reports Of Lough Derg Water Quality Monitoring May 2015 to December 2023

Document no: 32105801/EIARA9.1
Version: Final

December 2025

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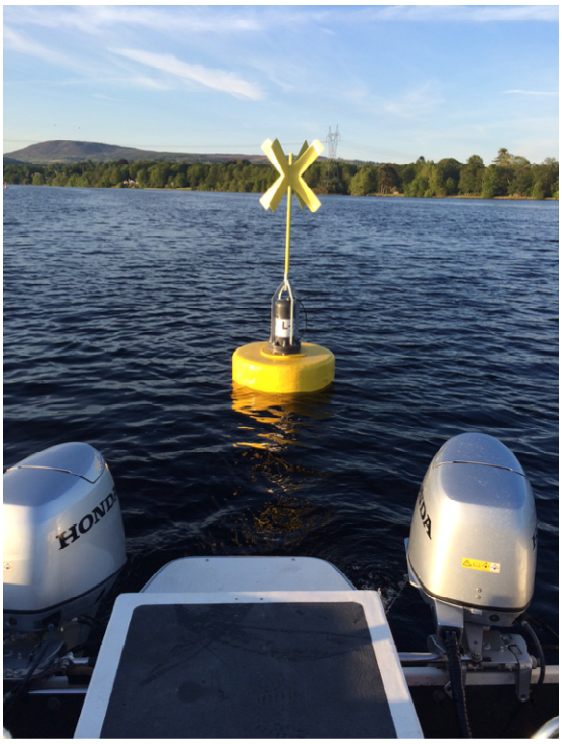
1. Introduction

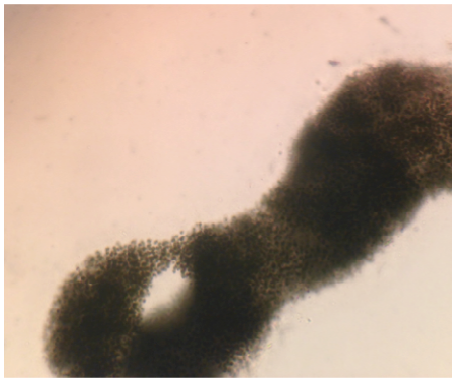
1. This annex provides a collation of the Annual Reports of the Lough Derg Monitoring Project undertaken by Water Technology Ltd, who were engaged by Jacobs-Tobins to undertake a limnological water quality data collection in Lough Derg. This annex presents the reporting of this multi-year data collection and reporting from May 2015 to December 2023. Reports from 2015 to 2017 are presented as quarterly and reports from 2018 to 2023 are presented annually.

1.1 Document Contains:

- Data report for Lough Derg Monitoring Project (May 2015-December 2015)
- Data report for Lough Derg Monitoring Project (December 2015-February 2016)
- Data report for Lough Derg Monitoring Project (March 2016-May 2016)
- Data report for Lough Derg Monitoring Project (June 2016-August 2016)
- Data report for Lough Derg Monitoring Project (September 2016-November 2016)
- Data report for Lough Derg Monitoring Project (December 2016-February 2017)
- Data report for Lough Derg Monitoring Project (March 2017-May 2017)
- Data report for Lough Derg Monitoring Project (Annual Report 2018)
- Data report for Lough Derg Monitoring Project (Annual Report 2019)
- Data report for Lough Derg Monitoring Project (Annual Report 2020)
- Data report for Lough Derg Monitoring Project (Annual Report 2021)
- Data report for Lough Derg Monitoring Project (Annual Report 2022)
- Data report for Lough Derg Monitoring Project (January 2023 - December 2023)

Water Quality Survey for the Water Supply Project – Dublin Region 13/013 (OJEU REF 2014/S 034-056342) – Lough Derg Monitoring Project (LDMP)





Client:	**Jacobs Consulting Engineers**
Project Title:	**Water Quality Survey for the Water Supply Project – Dublin Region**
Document Title:	**Data report for Lough Derg Monitoring Project (May 2015 - December 2015)**
Document Number:	**LDMP/R/004**
Text Pages:	**20**

1. Introduction

Water Technology Ltd, in conjunction with technical partners are engaged in a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers.

The project was awarded in December 2014 and work to procure and preparations for project implementation began immediately. Table 1 shows notable project dates.

Table 1: Notable Project Milestones

Project Milestones	**Date**
Project award	December 2014
Procurement commences	December 2014
Permissions (Land based)	March 2014
Land based installations	March – April 2015
Permissions (Lake based)	May 2015
Lake based installations.	May – July 2015
Instruction to commence sampling programme	May 2015
Sampling programme - first run	May 2015
Project equipment fully operational	August 2015
Request for Monthly reporting	August 2015
Submission of reports	September 2015 November 2015 December 2015

1.1. Sampling and Servicing Statistics

Sampling and servicing is ongoing, Table 2 shows a summary of tasks carried out to date.

Table 2: Summary of tasks completed by LDMP project to date

LDMP tasks	Number of cruises
Deployment	19
Serving/maintenance including battery replacement, replacement canisters, Systea and general maintenance	25
Lake Sampling	12
River Sampling	11
Additional tasks required due to power issues, changing of batteries/installation of wind turbines	10
Instrumentation specific	7

1. Results to Date

1.1. Data Management

The project is now producing large amounts of data which is being transmitted from the project locations directly to a server, and from which data is retrieved for reporting purposes. A web front end is used for data display purposes and data tables are checked on a daily basis. System generated graphs are also used for data checking and general project progress monitoring. Figures 2, 4 and 5 show screenshots from website of water level, temperature and ADCP data.

1.2. Water Level Survey

Level stations were installed at 6 locations (3 lake sites and 3 river sites) . Figure 2 shows an example of raw water level data incoming to the LDMP website from December 2015. An high increase of water level was noted in this month due to flooding after severe rainfalls. All water level data was converted to Malin OD. Figure 3 shows water level data converted to Malin OD from 5 water level station over the course of the project.

1.3. Temperature Survey

Temperature sensors have been installed at 19 lake station at varying depths. Figure 4 shows temperature data from all sites at 0.5m depth for the months of November and December.

1.4. ADCP

Figure 5 shows typical vertical ADCP detected in the lake at different sections of the water column.

Figure 2: Water level results from Kincora level station (December 2015). Note recent water level rises associated with December 2015 flooding.

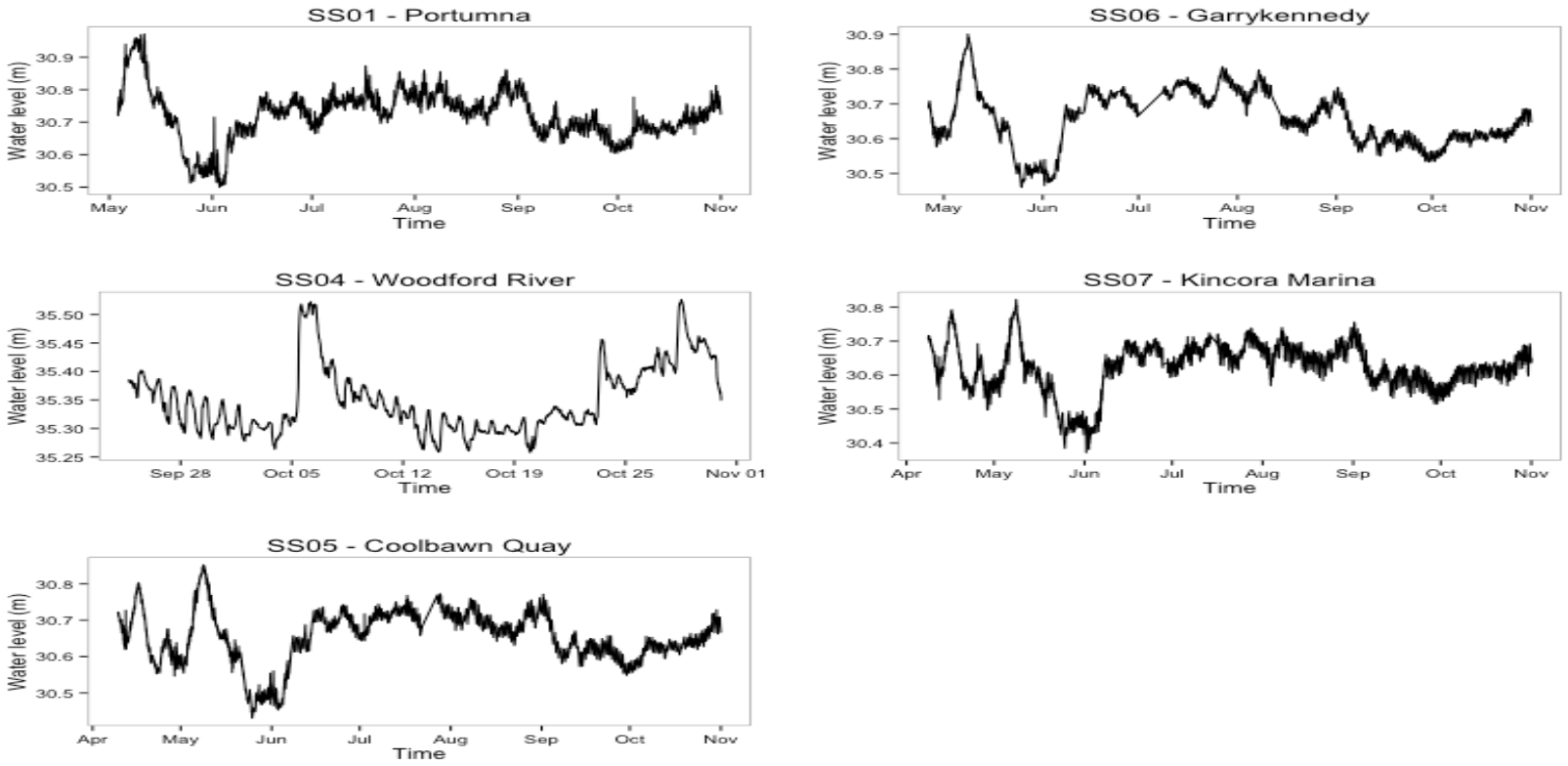


Figure 3: Water level data converted to Malin OD (m) from 5 stations over several months. X axes start dates vary with installation dates.

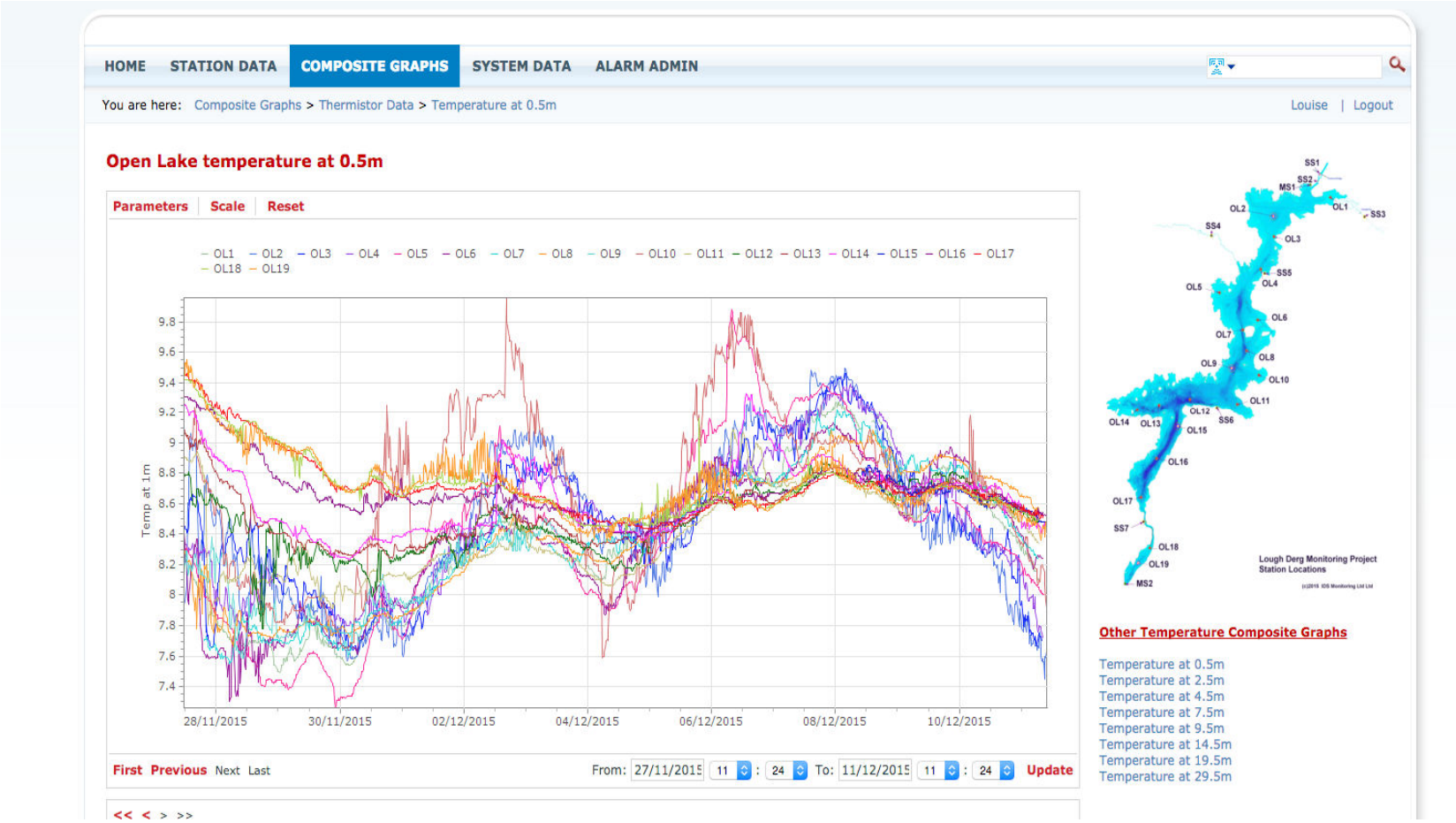


Figure 4: Mix of temperature data from depth 0.5m below surface from all installations.

Figure 5: ADCP data from OL09 showing North-South flows in cm s^{-1}

1.5. Water Quality Survey

Water quality surveying of lake and river sites has been ongoing since May 13th 2015. Table 2 summarises all sampling dates and analysis carried out.

Sample Date	WQMS-Fortnightly	WTMS – Fortnightly	WTMS - Quarterly	Ecological
13/05/15	X	X	X	
15/05/15				X
26/05/15	X	X		X
10/06/15	X	X		X
23/06/15	X	X		X
09/07/15	X	X		X
22/07/15	X	X		X
06/08/15	X	X	X	X
12/08/15 - 13/08/15			X	
18/08/15	X	X		X
02/09/15	X	X		X
15/09/15	X	X		X
30/09/15	X	X		X
14/09/15	X	X		X
03/11/15	X	X	X	

1.5.1. Chemistry

Figures 3 and 4 show the results of the main nutrients sampled from the water quality sites on Lough Derg at all depths. Figure 5 shows main nutrients from inflowing rivers into Lough Derg.

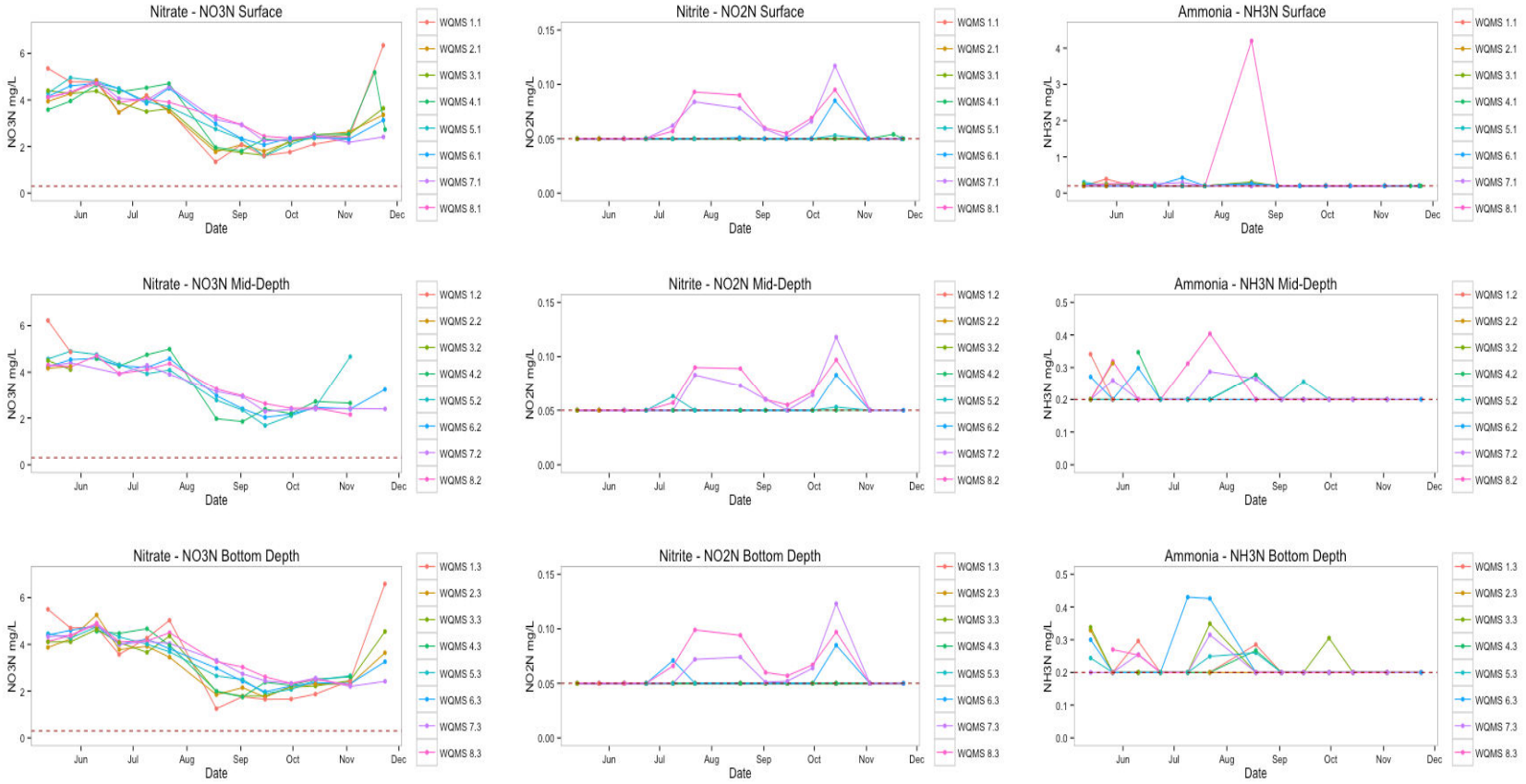


Figure 6: Survey results from all lake water quality sites of nitrate (NO3N), nitrite (NO2N), and ammonia (NH3N) (Please note red dashed line indicates limit of detection of analysis).

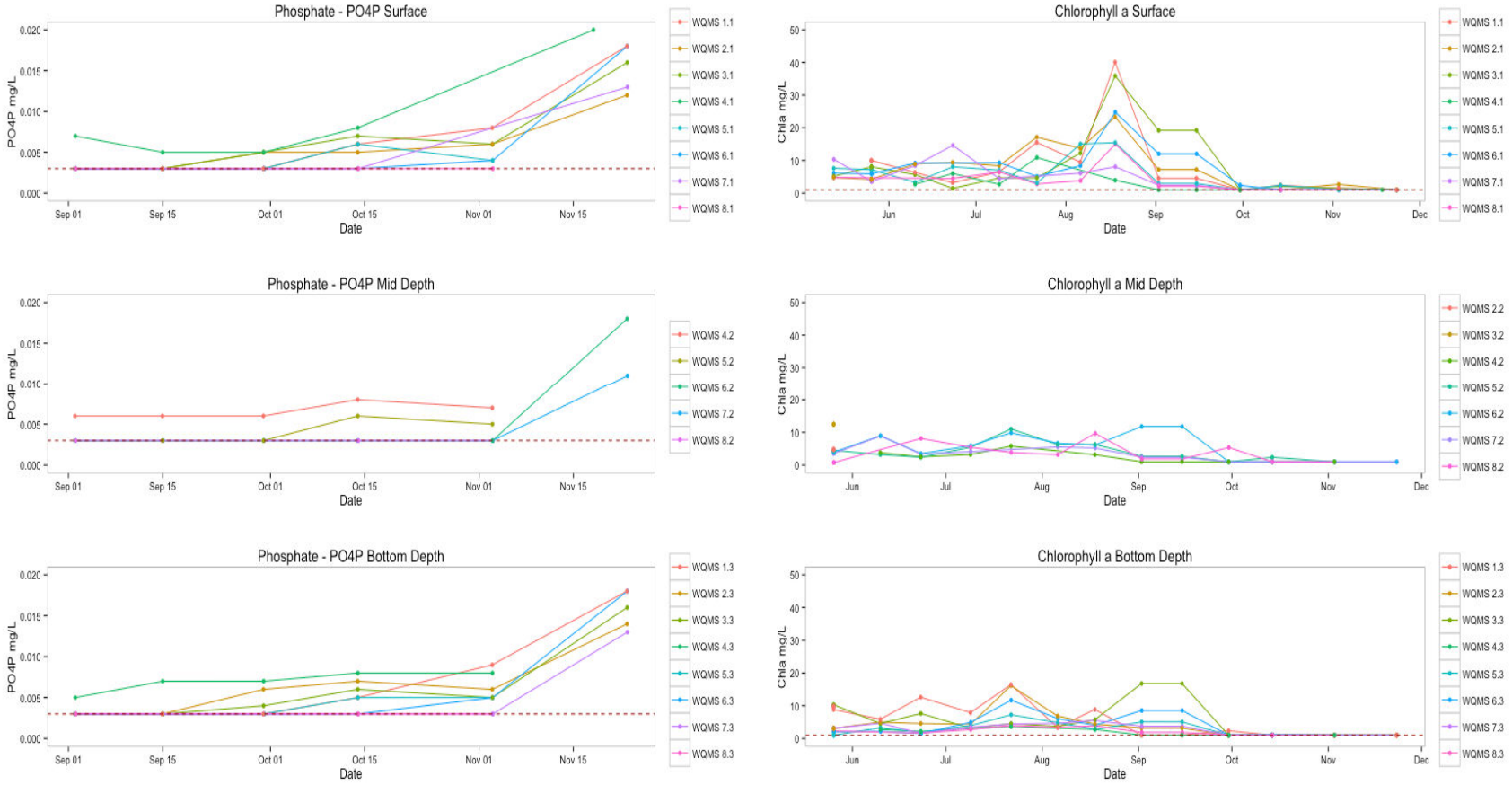


Figure 7: Survey results from all lake water quality sites of phosphate (PO4P) and chlorophyll *a* (Please note red dashed line indicates limit of detection of analysis).

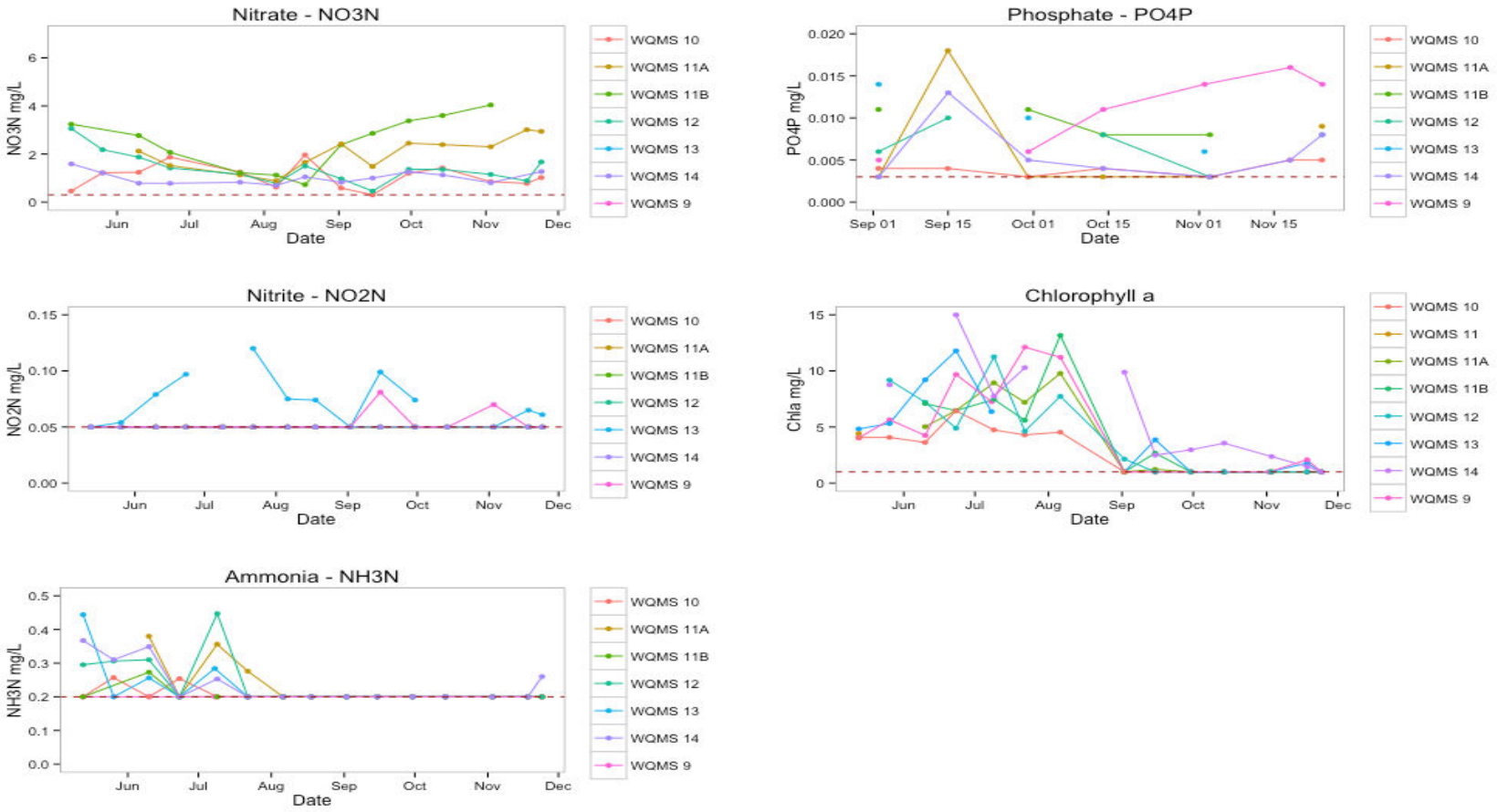


Figure 8: Survey results from all inflowing river water quality sites of nitrate (NO3N), nitrite (NO2N), and ammonia (NH3N) phosphate (PO4P) and Chlorophyll *a* (Please note red dashed line indicates limit of detection of analysis).

1.5.2. Ecology

If the surface water samples from WQMS5 & WQMS 7 (open water sites) and also WQMS6 and WQMS 1 (typical bay sites) are reviewed it is possible to see a spike in Chlorophyll *a* consistent with an algal bloom (Figure 9).

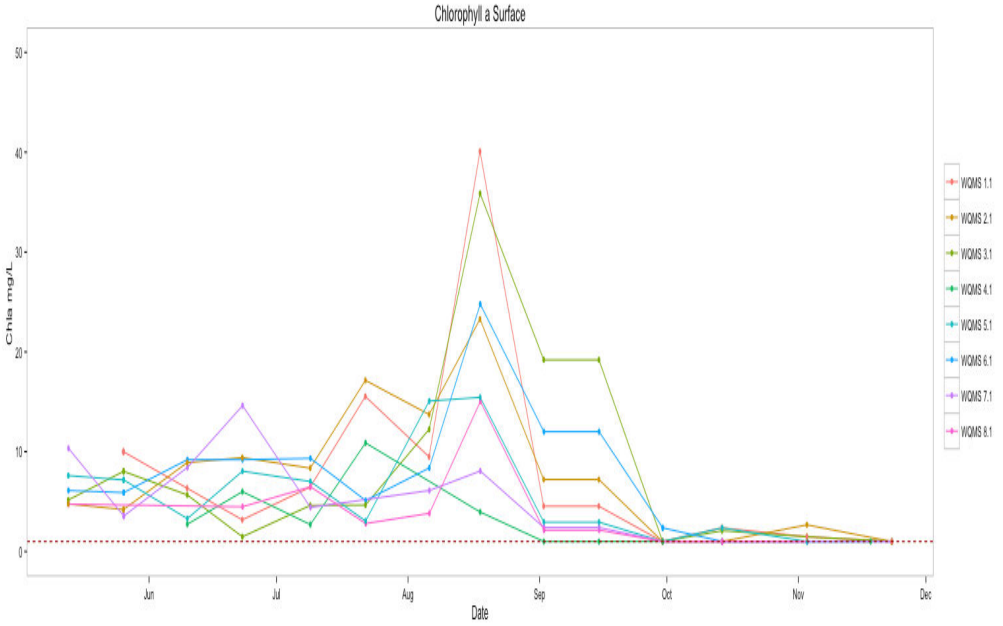


Figure 9: Chlorophyll *a* results from water quality survey surface sites.

Preliminary analysis of the associated plankton samples have indicated a high dominance of *Microcystis aeruginosa* (Figure 10) particularly during the summer months and into early September. *M. aeruginosa* is a common cyanobacterial bloom forming species in freshwaters producing harmful neurotoxins and peptide hepatotoxins, such as microcystin and cyanopeptolin. A dinoflagellate bloom of a species of *Peridinium* was noted near Kilgarvan quay in June lasting approximately 1 week. Counts and analysis of phytoplankton and zooplankton is ongoing.

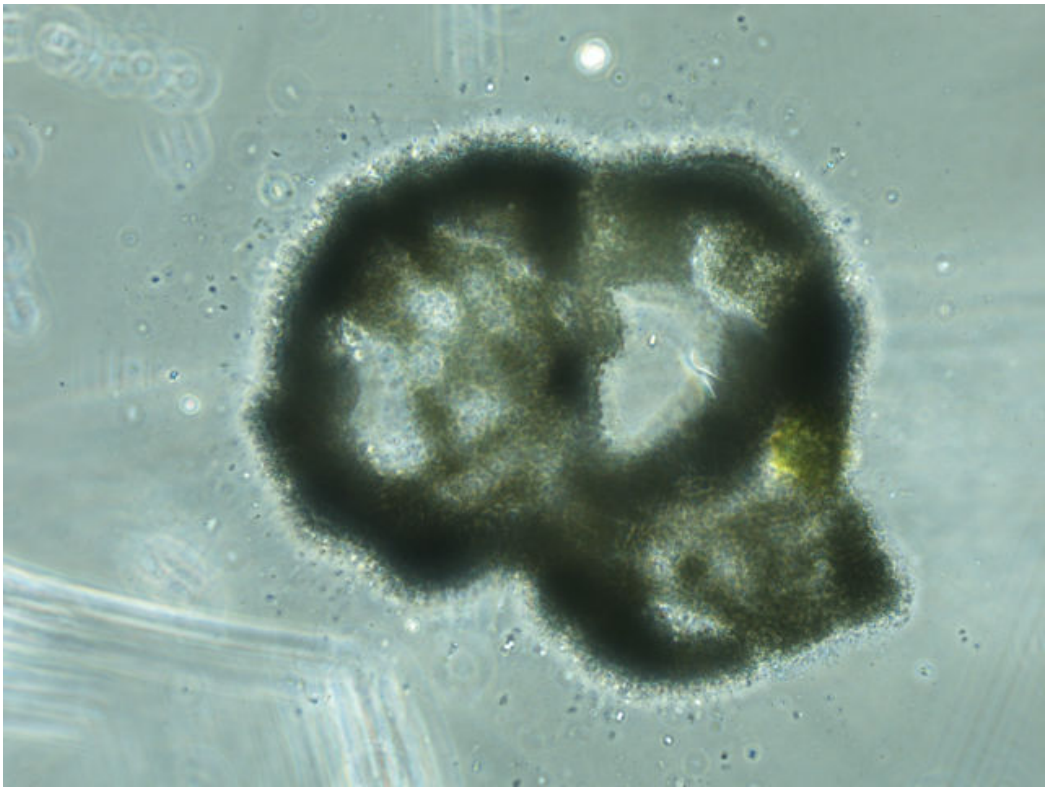


Figure 10: *Microcystis aeruginosa* from Lough Derg

Appendix 1: Summary of sensors deployed on Lough Derg and deployment status

Station Type	Station Code	Station ID	Data Logger	Sensor type	Fully Deployed	Status
Level Station	LDMP-SS-03	Carraigahorrig River	Yes	DP	Yes	Live
Level Station	LDMP-SS-04	Woodford River	Yes	US	Yes	Live
Level Station	LDMP-SS-05	Coolbaun Quay	Yes	DP	Yes	Live
Level Station	LDMP-SS-06	Garrykennedy	Yes	DP	Yes	Removed due to flooding on 14.12.15
Level Station	LDMP-SS-07	Kincora Marina	Yes	DP	Yes	Live
Level Station, Thermistor, ADCP, Water Quality	LDMP-SS-01	Portumna Bridge	Yes	DP	Yes	Live
Thermistor Buoy Unit	LDMP-OL-01	OL - 01 Carrigahorrig Bay	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-03	OL - 03 Near Drominagh Point	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-04	OL - 04 Off Brookfield Point	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m & 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-05	OL - 05 Edge of Coose Bay	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live

Station Type	Station Code	Station ID	Data Logger	Sensor type	Fully Deployed	Status
Thermistor Buoy Unit	LDMP-OL-06	OL - 06 NE of Illaunmore	Yes	2Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-07	OL - 07 NW tip of Illaunmore	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m & 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-08	OL- 08 North of Corrikeen Island	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m & 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-10	OL-10 Dromineer Bay	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-11	OL -11 Youghal Bay	Yes	4 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m & 7.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-12	OL -12 Deep NE of Packers PT	Yes	8 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m, 9.5m, 14.5m, 19.5m, 29.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-13	OL -13 SE of Middle round Rocks	Yes	4 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m & 7.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-14	OL-14 Near Cahir Island	Yes	4 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m & 7.5m	Yes	Live

Station Type	Station Code	Station ID	Data Logger	Sensor type	Fully Deployed	Status
Thermistor Buoy Unit	LDMP-OL-16	OL-16 West of Derry Point	Yes	7 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m, 9.5m & 14.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-17	OL-17 Near Ballyvalley	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m and 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-18	OL-18 Top of Parteen Basin	Yes	3 Nexsens T- Node. Attached at 0.5m, 2.5m, & 4.5m	Yes	Battery low, service scheduled 15.12.15
ADCP Unit / Systea unit / Probes /Thermistor	LDMP-OL-02	OL - 02 East of Cloondauvan	Yes	3 Nexsens T- Node 0.5m, 4m & 6m,6 * Poncel WQ Sensors, (2 * DO, PH & Conductivity) - Deployed at 1m, & 6m, 1 * Turner Cyclops Chl-a, 1*Turner Cyclops Turbidity - Deployed at 1M, 1*Vertical ADCP, 1*Systea nutrient analyser	Yes	Live
ADCP Unit / Systea unit / Probes /Thermistor	LDMP-OL-09	OL-09 South East of Dromaan	Yes	3 Nexsens T- Node deployed @ 0.5m, 4m, 7m, 9.5m, 14.5m & 19.5m, 9 * Poncel WQ Sensors, (3 * DO, PH & Conductivity) - Deployed at 1m, 10m & 19m, 1 * Turner Cyclops Chl-a, 1 * Turner Cyclops Turbidity - Deployed at 1M, 1*Vertical ADCP, 1*Systea nutrient analyser	Yes	Live
ADCP Unit / Systea unit / Probes /Thermistor	LDMP-OL-15	OL-15 NW of Castlelough Beach	Yes	3 Nexsens T- Node deployed @ 0.5m, 2.5m, 4.5m, 7.5m, 9.5m & 14.5m, 9 * Poncel WQ Sensors, (3 * DO, PH & Conductivity) - Deployed at 1m, 6m & 15m, 1 * Turner Cyclops Chl-a, 1 * Turner Cyclops Turbidity - Deployed at 1M, 1*Vertical ADCP, 1*Systea nutrient analyser	Yes	Live

Station Type	Station Code	Station ID	Data Logger	Sensor type	Fully Deployed	Status
ADCP Unit	LDMP-SS-2	SS- 02 Horizontal ADCP Portumna	Yes	1*Horizontal ADCP	Yes	Live
Systea unit / Probes / Thermistor	LDMP-OL-19	OL-19 Parteen Basin	Yes	3 Nexsens T- Node 0.5m, 2.5m & 4.5m, 6 * Poncel WQ Sensors, (2 * DO, PH & Conductivity) - Deployed at 0.5m & 6m, 1 * Turner Cyclops Chl-a, 1 X Turner Cyclops Turbidity - Deployed at 1M, 1*Systea nutrient analyser	Yes	Batteries depleted, unable to service due to high flood conditions on River Shannon, Service scheduled for 15.12.15
Met Station	MS- 01	To be confirmed by client		Met Station	No	Location to be confirmed by client
Met Station	MS-02	To be confirmed by client		Met Station	No	Location to be confirmed by client

Appendix 2: Summary of manual water quality survey sites and analysis

ID_No.	Site Type	ITM		Water Column Depth (m)	Water Quality	Samples taken				Frequency
		X	Y			Ecology	Surface	Mid	Lower	
WQMS_1	Lake	588305	702442	4	✓	✓	✓	×	✓	Fortnightly
WQMS_2	Lake	582953	699533	5.5	✓	✓	✓	×	✓	Fortnightly
WQMS_3	Lake	580603	695206	4	✓	✓	✓	×	✓	Fortnightly
WQMS_4	River	587304	705047	10	✓	✓	✓	✓	✓	Fortnightly
WQMS_5	Lake	578918	687204	15	✓	✓	✓	✓	✓	Fortnightly
WQMS_6	Lake	578291	683887	11	✓	✓	✓	✓	✓	Fortnightly
WQMS_7	Lake	572132	681861	11	✓	✓	✓	✓	✓	Fortnightly
WQMS_8	Lake	569300	670174	8	✓	✓	✓	✓	✓	Fortnightly
WQMS_9	River	591167	701448	N/A	✓	✓	✓	×	×	Fortnightly
WQMS_10	River	579772	703624	N/A	✓	✓	✓	×	×	Fortnightly
WQMS_11A	River	579775	705698	3	✓	✓	✓	×	×	Fortnightly
WQMS_11B	River	545697	588279	3	✓	✓	✓	×	×	Fortnightly
WQMS_12	River	575631	693131	N/A	✓	✓	✓	×	×	Fortnightly
WQMS_13	River	582249	685558	N/A	✓	✓	✓	×	×	Fortnightly
WQMS_14	River	565509	683841	N/A	✓	✓	✓	×	×	Fortnightly
ECO1	Lake	569801	677895	32	×	✓	✓	×	×	Fortnightly
ECO2	Lake	568623	684139	12	×	✓	✓	×	×	Fortnightly
ECO3	Lake	575270	684975	12	×	✓	✓	×	×	Fortnightly
ECO4	Lake	579965	691644	6	×	✓	✓	×	×	Fortnightly
WTMS_1	Lake	587198	702213	4	✓	×	✓	×	×	Fortnightly
WTMS_2	Lake	581152	689468	4	✓	×	✓	×	×	Fortnightly
WTMS_3	Lake	575401	684213	11	✓	×	✓	×	×	Fortnightly
WTMS_4	Lake	568801	669526	8	✓	×	✓	×	×	Fortnightly

*Manual Sampling carried out in accordance with:

ISO 5667

ISO 6107-2, Water quality

Alpha (2012) Standard Methods for the Examination of Water and Wastewater, 21st edition. - Plankton

CEN (2006) Water quality- Guidance standard on the enumeration of phytoplankton using inverted microscopy (Utermöhl technique) CEN 15204:2006

Water Quality Survey for the Water Supply Project – Dublin Region 13/013 (OJEU REF 2014/S 034-056342) – Lough Derg Monitoring Project (LDMP)

Client:	**Jacobs Consulting Engineers**
Project Title:	**Water Quality Survey for the Water Supply Project – Dublin Region**
Document Title:	**Data report for Lough Derg Monitoring Project (December 2015 – February 2016)**
Document Number:	**LDMP/R/006**
Text Pages:	**20**

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1. Introduction

The Lough Derg Monitoring Project technical partnership led by Water Technology Ltd. Are engaged in a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers.

2. Results to date

2.1. T300 Water Flow and Current Survey

2.1.1. ADCP Survey

Four Acoustic Doppler Current Profilers (ADCP's) have been installed in the study region (three vertical ADCP at open lake sites, one horizontal ADCP on the River Shannon near Portuma). The horizontal ADCP suffered flood damage on in December resulting in excessively noisy data in the December to February dataset.

The vertical ADCP have been subject to high levels of sedimentation during the reporting period resulting in errant data. Figure 1 shows North-South and East-West flows from station OL09 from December 2015 – February 2016.

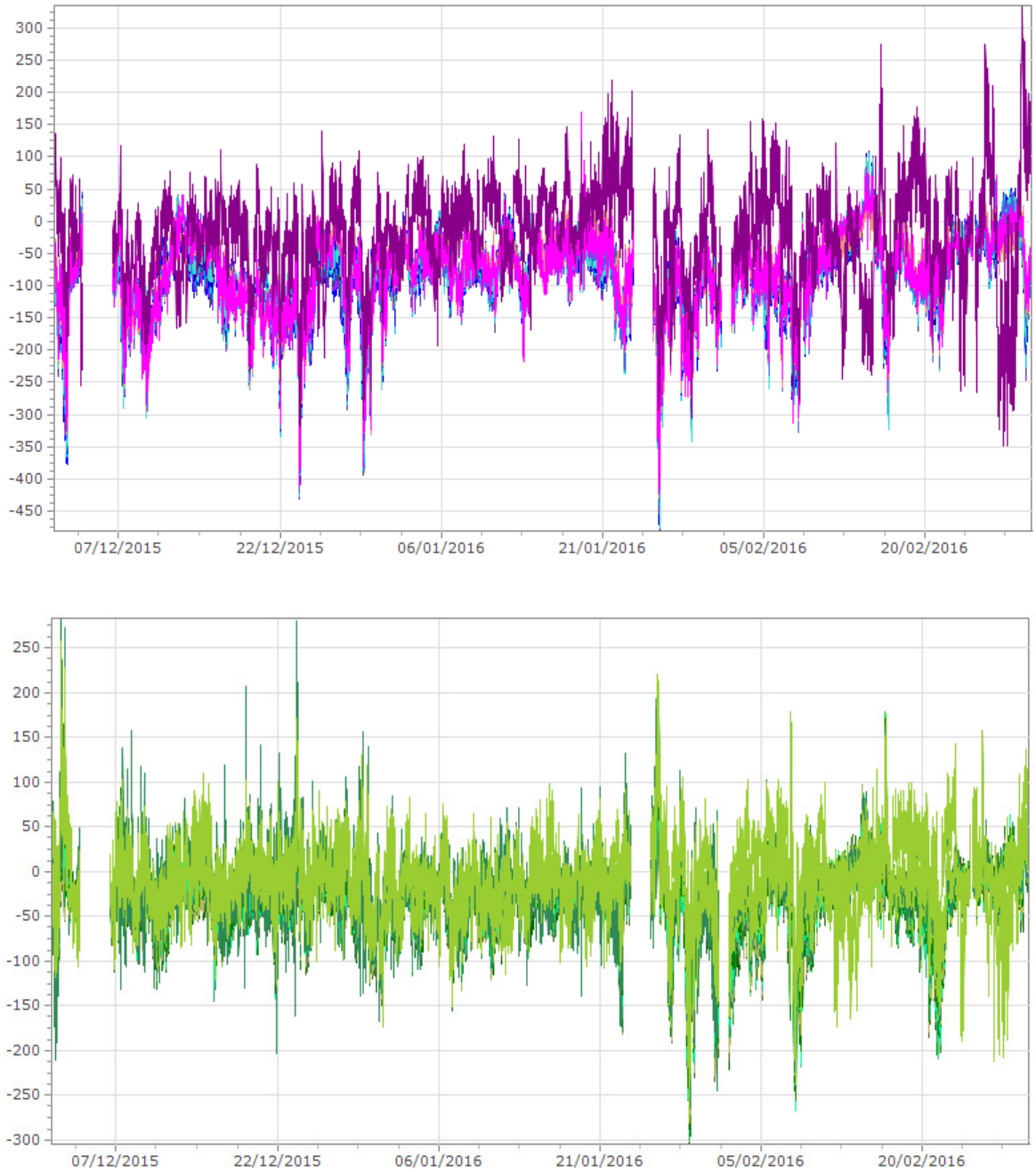

Figure 1: Flow data from OL09 cm/s (Top Panel- North South flows, Bottom Panel - East West flows) from December 2015 - February 2016).

2.2. T400 Water Level Survey

Level stations are installed at 6 locations (3 lake sites and 3 river sites). The winter of 2015/2016 experienced extremely high levels in Lough Derg and the surrounding catchments. Figure 2 shows water level data from all stations over the time period December 2015 – February 2016. A significant increase in water level was noted during December and January due to flooding after severe rainfalls. The level station at SS03 (Coolbaun) suffered flood damage in December and was removed for servicing. The station was reinstalled in January with the data logging equipment in a higher position with the permission of the landowner. The level station at Garrykennedy marina was removed by Waterways Ireland staff on 14/12/15 because it was interfering with the pontoon rising during high floods. Negotiations are ongoing with Waterways Ireland regarding the reinstallation of the level station at this site. Inflow and outflow level stations of the lake at Portumna and Kincora show similar patterns with respect to the onset of flood conditions.

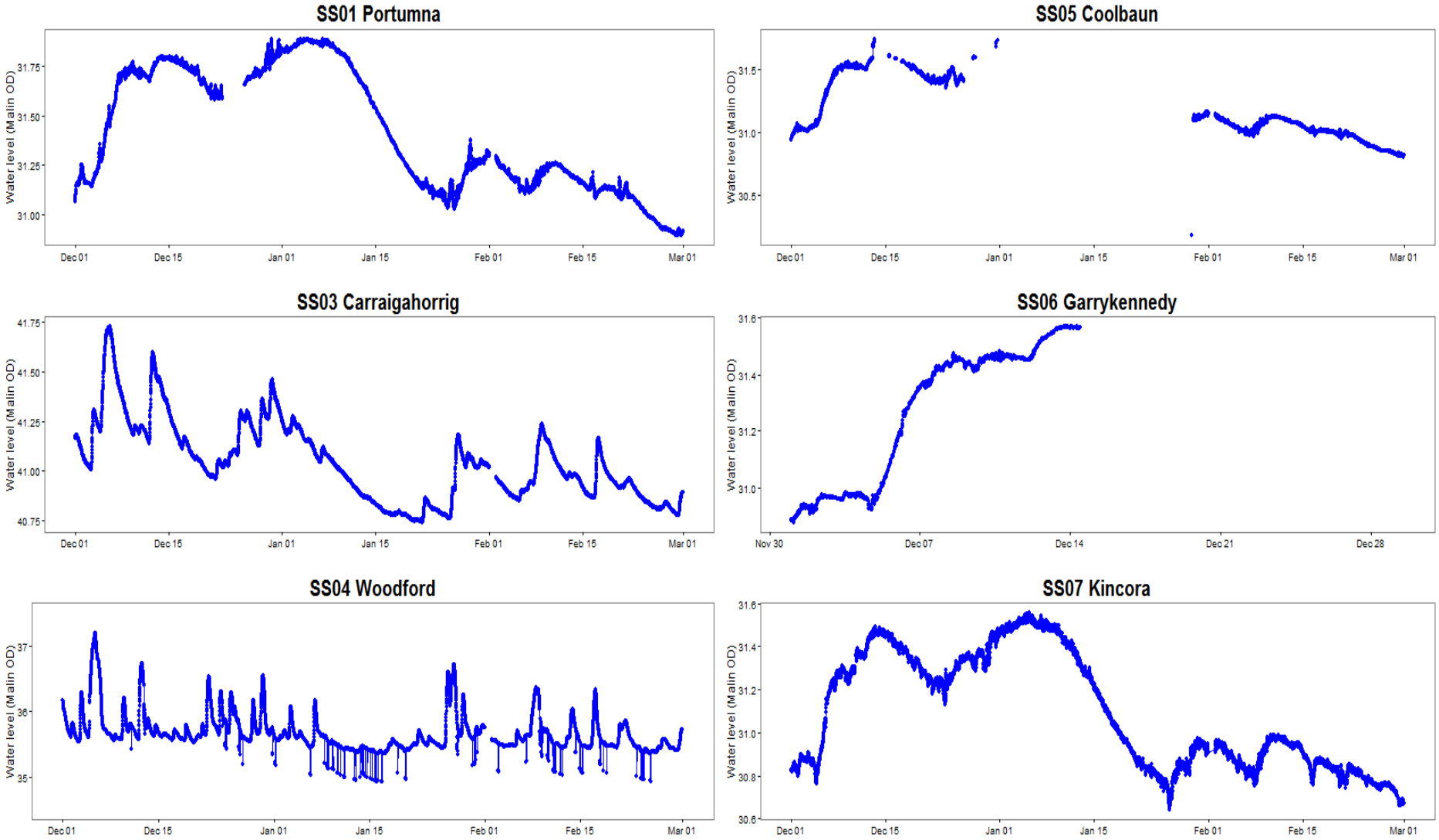

Figure 2: Water level data converted to Malin OD (m) from 6 stations from December 2015 - February 2016.

2.3. T500 Water Quality Survey

2.3.1. In-situ sampling

Nineteen monitoring stations are deployed on Lough Derg, fifteen thermistor stations and four water quality stations.

Five in-situ nutrient analysers are deployed, four at open lake sites and one on the inflowing River Shannon at Portumna Bridge. Systea Wiz probes allow, in the standard configuration, the detection at suitable levels of the main four nutrients compounds:

- ammonia (NH_3N)
- orthophosphate (PO_4P)
- nitrate + nitrite N-(NO_3+NO_2)
- nitrite (NO_2N)

Nitrate data was corrected for nitrite where the nitrite value was greater than 2.5% of the nitrate value as below this is statistically insignificant.

2.3.2. Spot sampling

Water quality surveying of lake and river sites has been ongoing since May 13th 2015. Figure 3 , Figure 4 and Figure 5 show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate and chlorophyll *a* from water quality sites on Lough Derg at all depths. Figure 6 shows the water quality data from all sites on the inflowing rivers into Lough Derg. A trend in nitrate can be seen across all sites and depths over the course of the study period with nitrate decreasing in autumn and starting to increase again over the winter months and into spring. It is difficult to see trends throughout the sample period in other nutrient parameters (nitrite, ammonia and phosphate) due to large numbers of data being below the limit of detection. Dissolved phosphate shows an increase in lake sites over the winter months and then begins to decrease in spring.

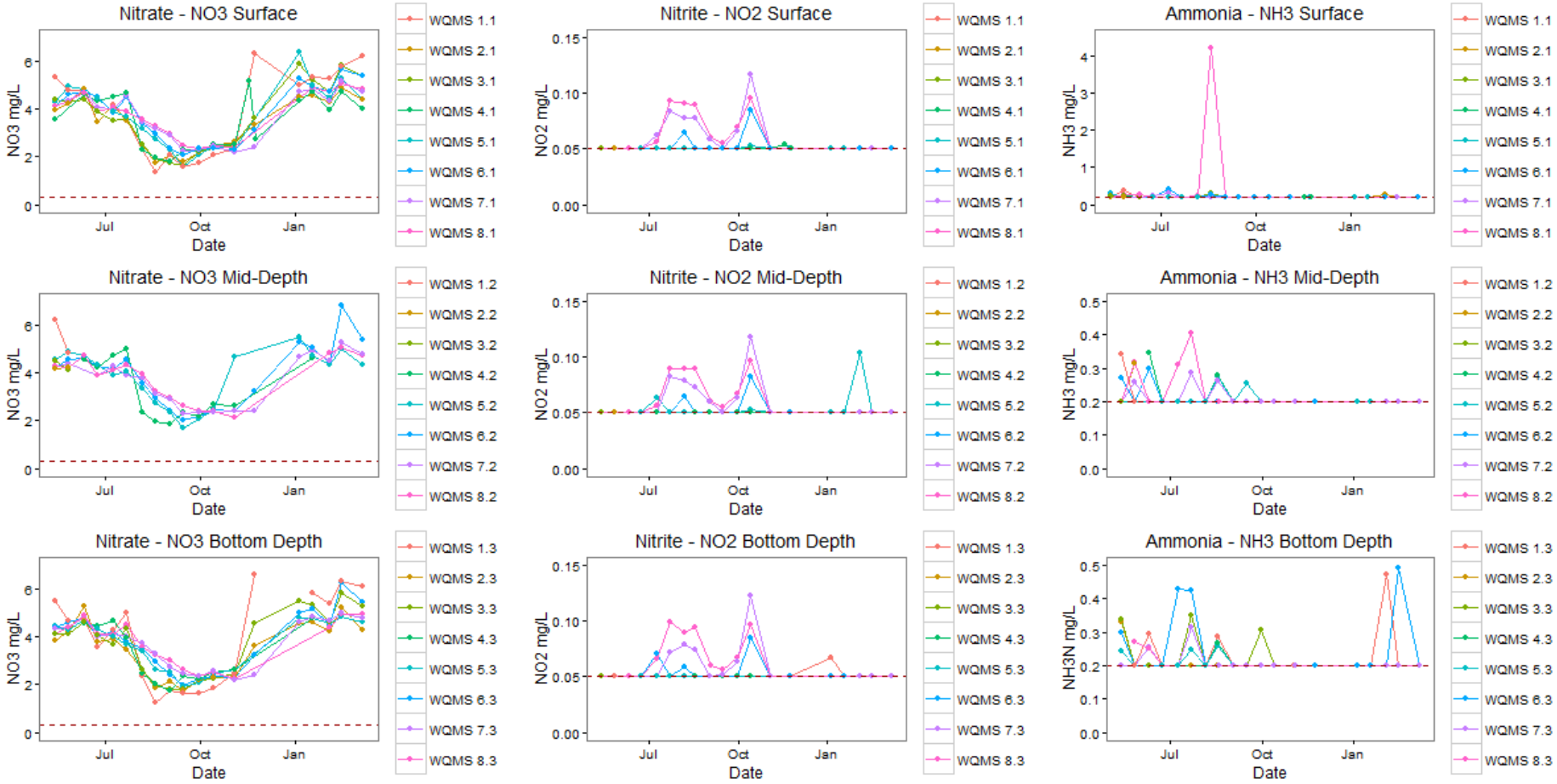

Figure 3: Survey results from all lake water quality sites of nitrate (NO3), nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicates limit of detection of analysis).

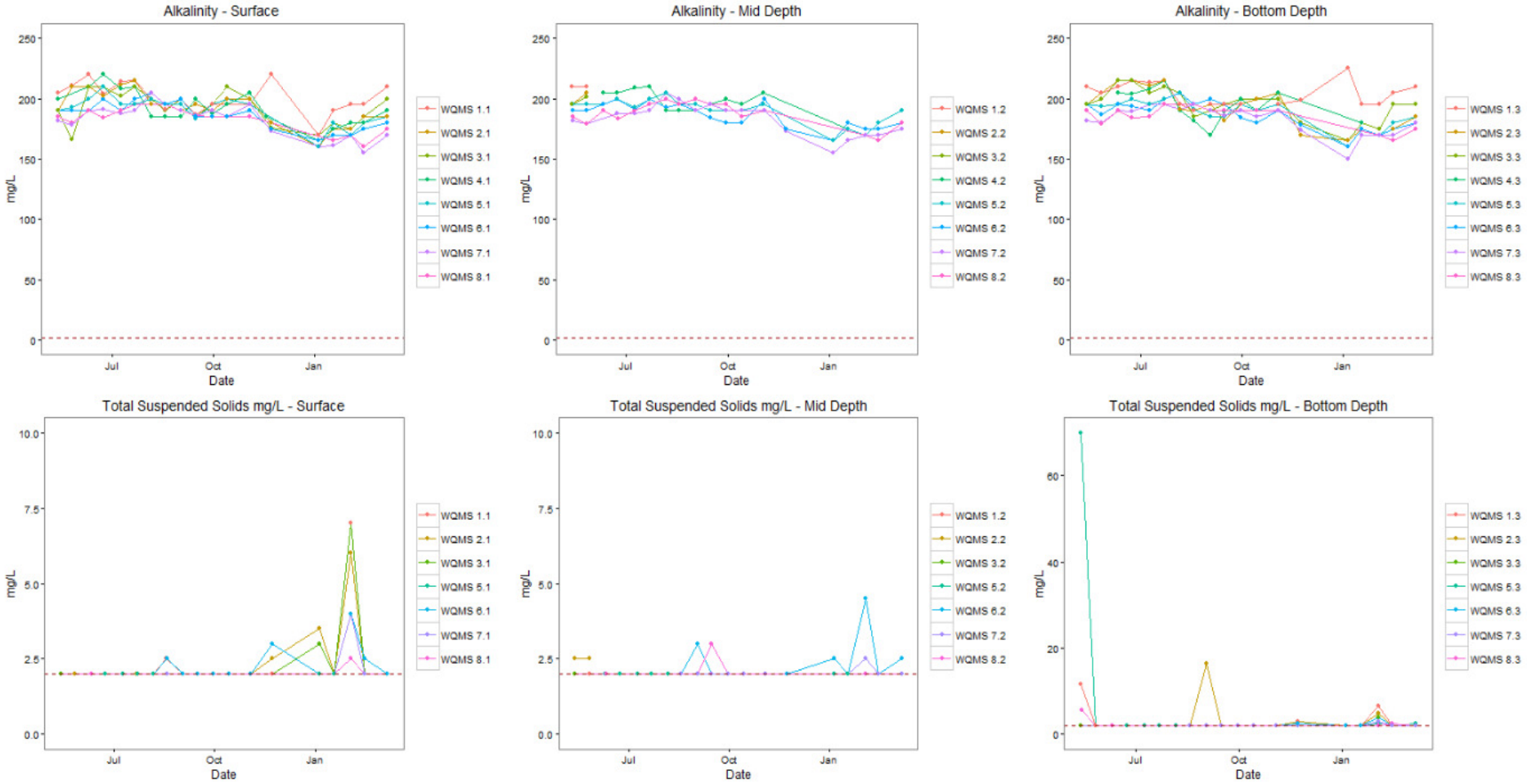

Figure 4: Survey results from all lake water quality sites of Alkalinity as CaCO3 and Total Suspended Solids (Please note red dashed lines indicates limit of detection of analysis).

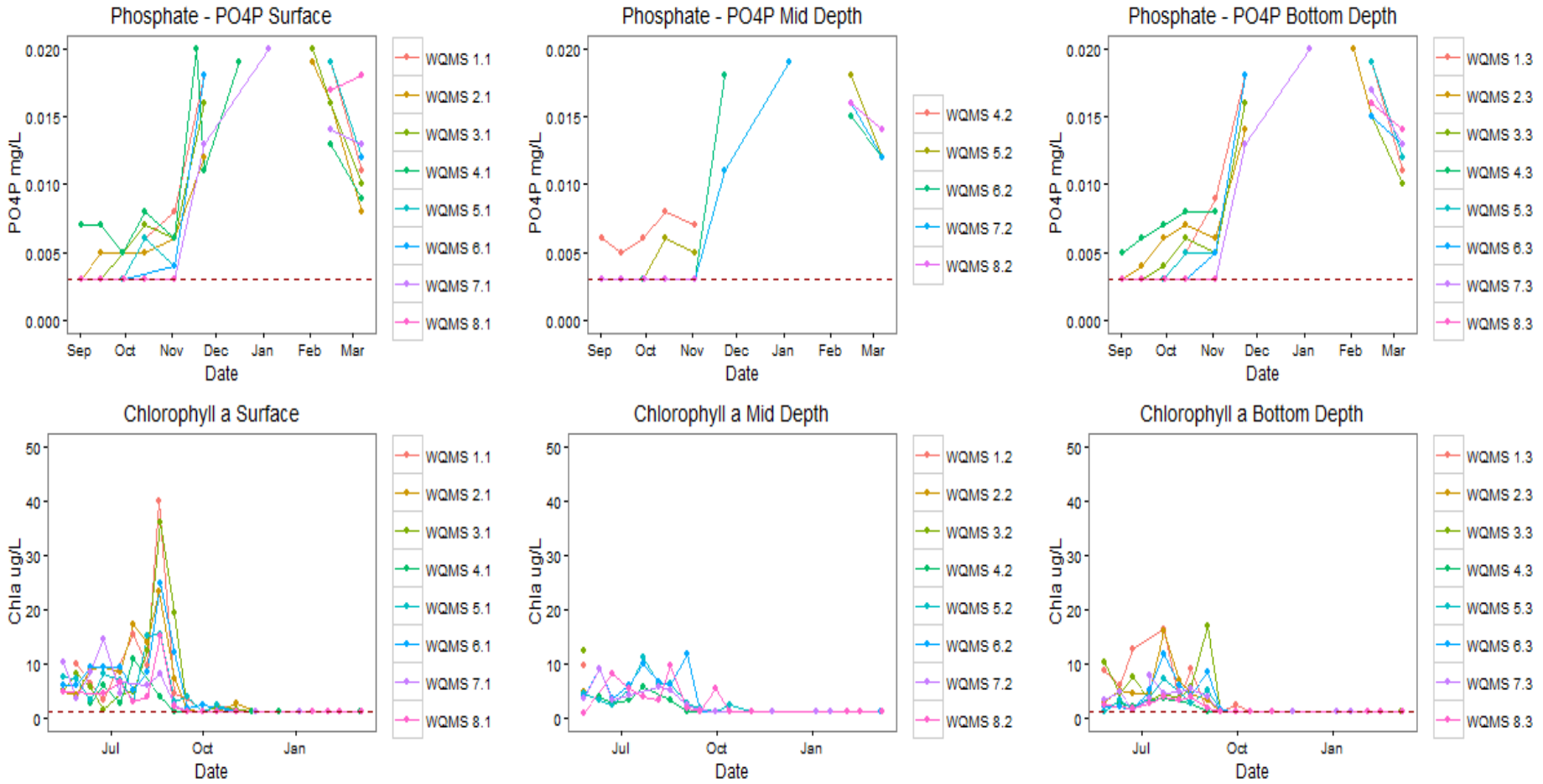

Figure 5: Survey results from all lake water quality sites of Phosphate as PO4P and Chlorophyll a (Please note red dashed lines indicates limit of detection of analysis).

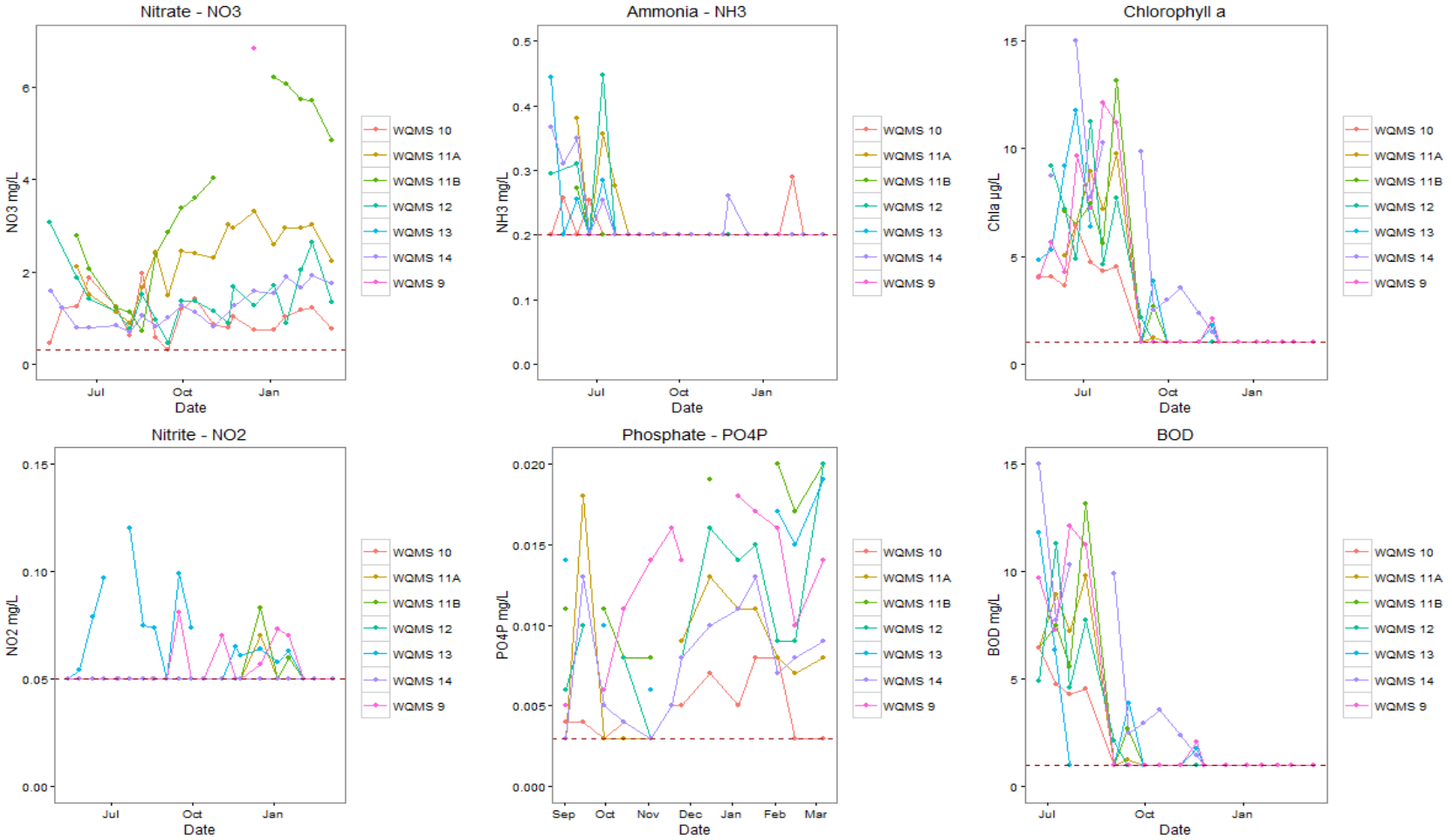

Figure 6: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll *a* and BOD (Please note red dashed lines indicates limit of detection of analysis.

2.4. T600 Water Treatability Survey

Water treatability surveying of lake sites has been ongoing since May 13th 2015. Fortnightly samples are taken from the surface at four sites on the lake and analysed for a suite of water treatability parameters. A further suite of parameters are analysed on a quarterly basis. To date four quarterly sample runs have been achieved. Appendix 1 summarises all sampling events including water treatability analysis.

2.5. T800 Meteorological Survey

Two meteorological stations were installed on the eastern and western shore of Lough Derg on the 17th/18th February 2016. Stations were deployed with sensors measuring wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity. Table 1 shows the instruments deployed and relative accuracies associated with each parameter. Each station has been measuring at 15 minute intervals since deployment. Figure 7 and Figure 8 show meteorological data from both stations at Ballinderry and Whitegate from installation the end of February.

Table 1: Deployed Meteorological Stations parameters with instrument type and accuracies.

Parameter	Instrument
Wind Speed	Airmar WX150
Wind Direction	Airmar WX150
Precipitation	RM Young Tipping gauge
Barometric Pressure	Airmar WX150
Air Temperature	Airmar WX150
Solar Radiance	Licor Irradiance Sensor
Relative Humidity	Airmar WX150
Compass	Airmar WX150

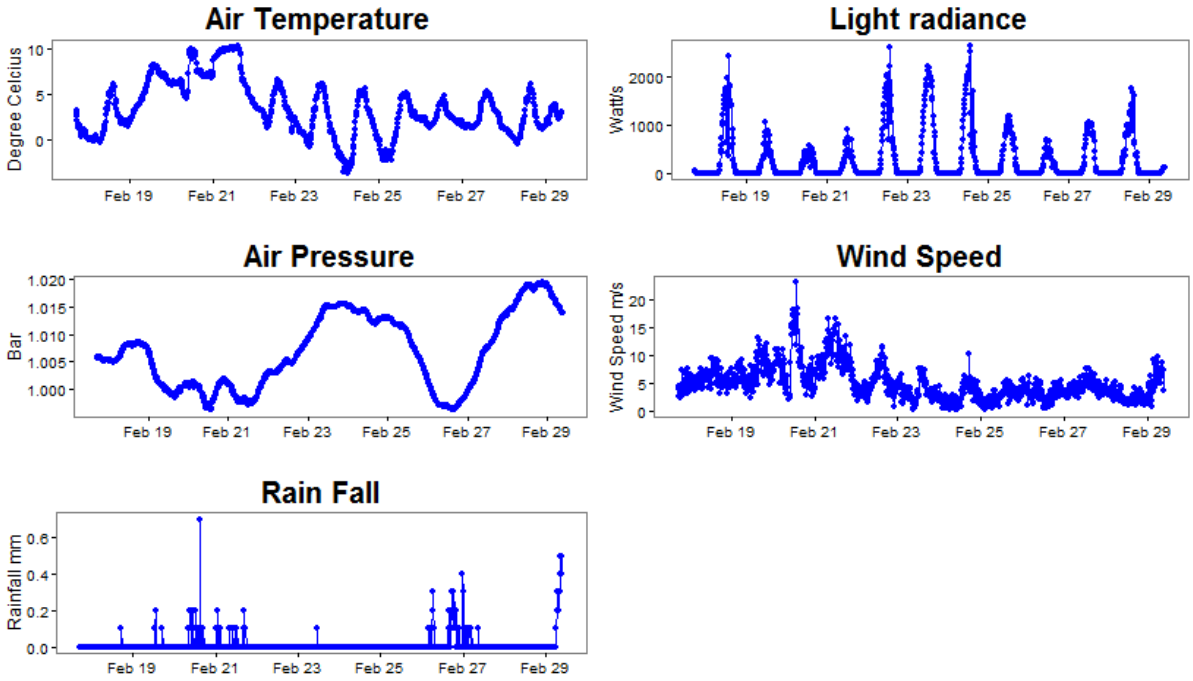

Figure 7: Data from MS01 (Ballinderry) from installation to end February 2016.

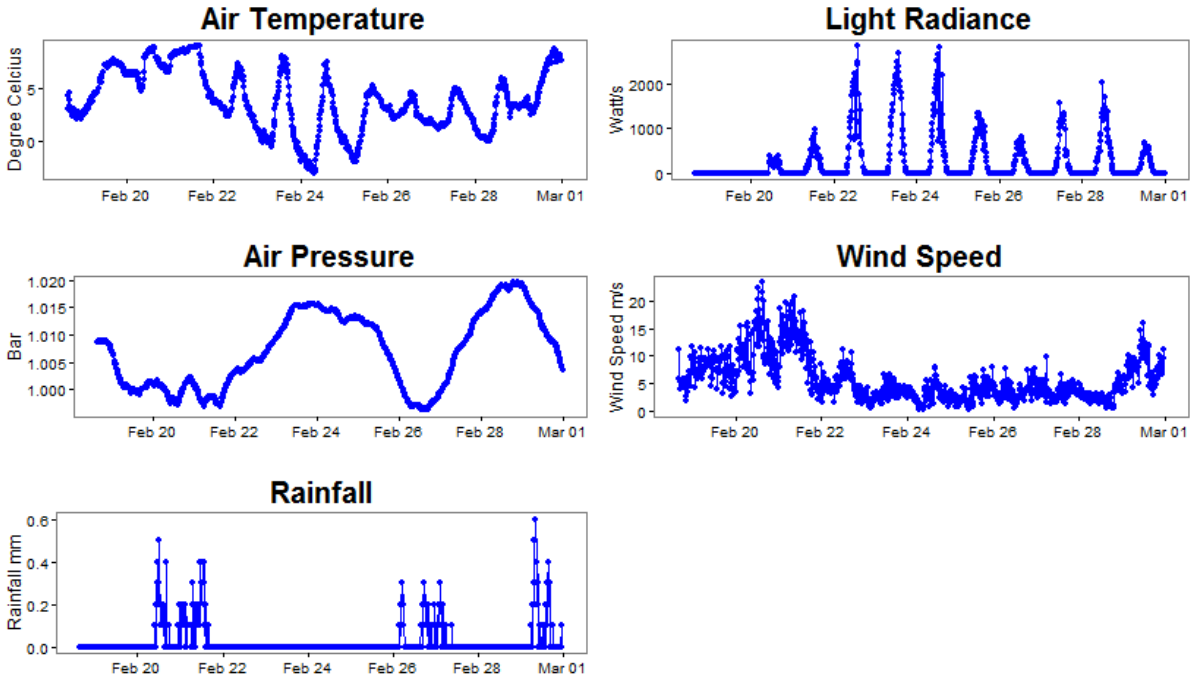

Figure 8: Data from MS02 (Whitegate) from installation to end February 2016.

2.6. T900 Plankton Survey

Analysis of chlorophyll *a* shows spikes in values during the late summer into early September (Figure 9). This was attributed to a high dominance of *Microcystis aeruginosa* across all sites. Other common species found in the lake include diatom species *Diatoma vulgaris, Melosira varians, Asterionella formosa,* and *Stephanodiscus astraea.* A dinoflagellate bloom of a species of *Peridinium/Peridiniopsis* spp. was noted near Kilgarvan quay in June lasting approximately 1 week.

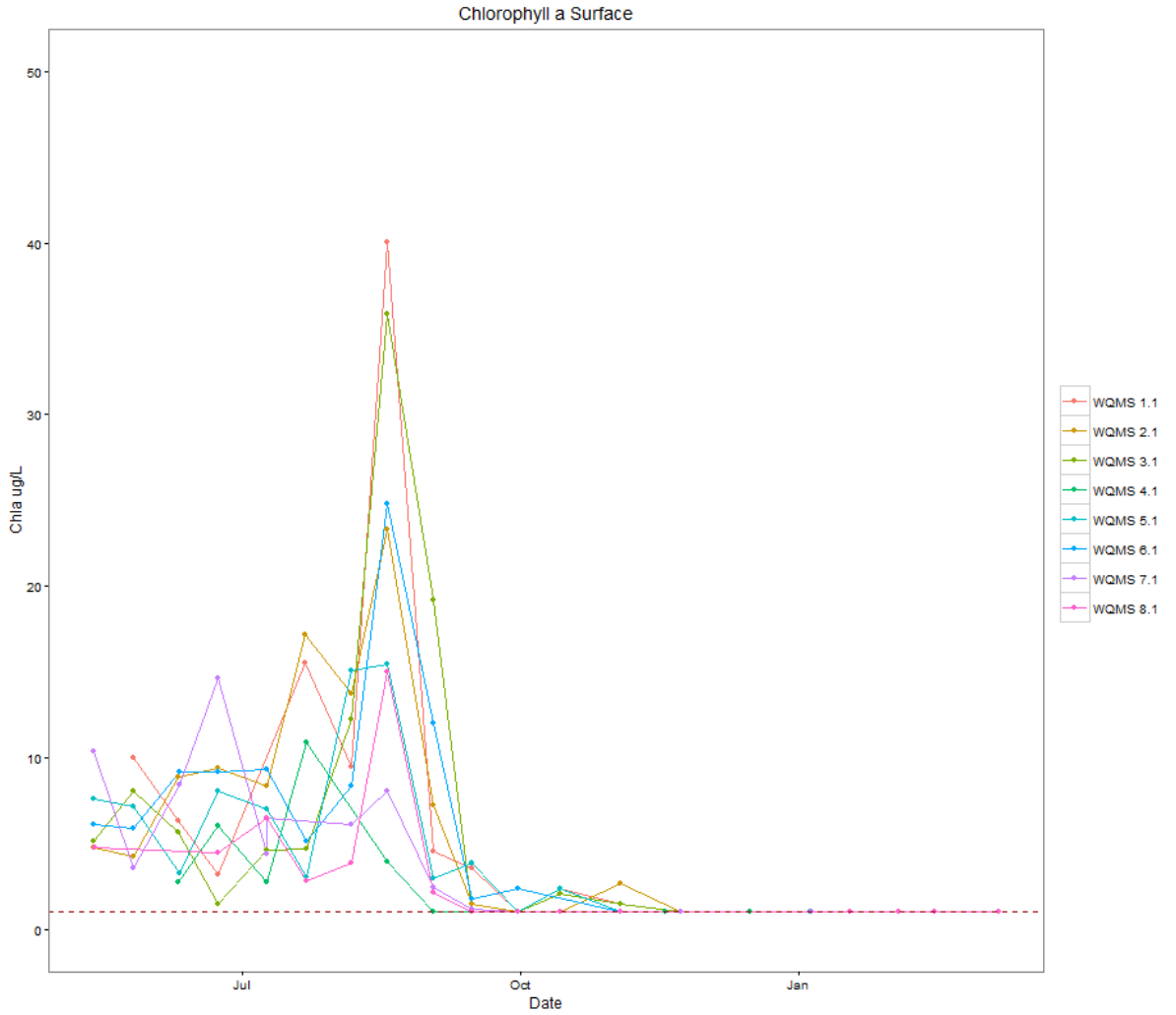

Figure 9: Surface chlorophyll a results from all sites from May 2015 - February 2016.

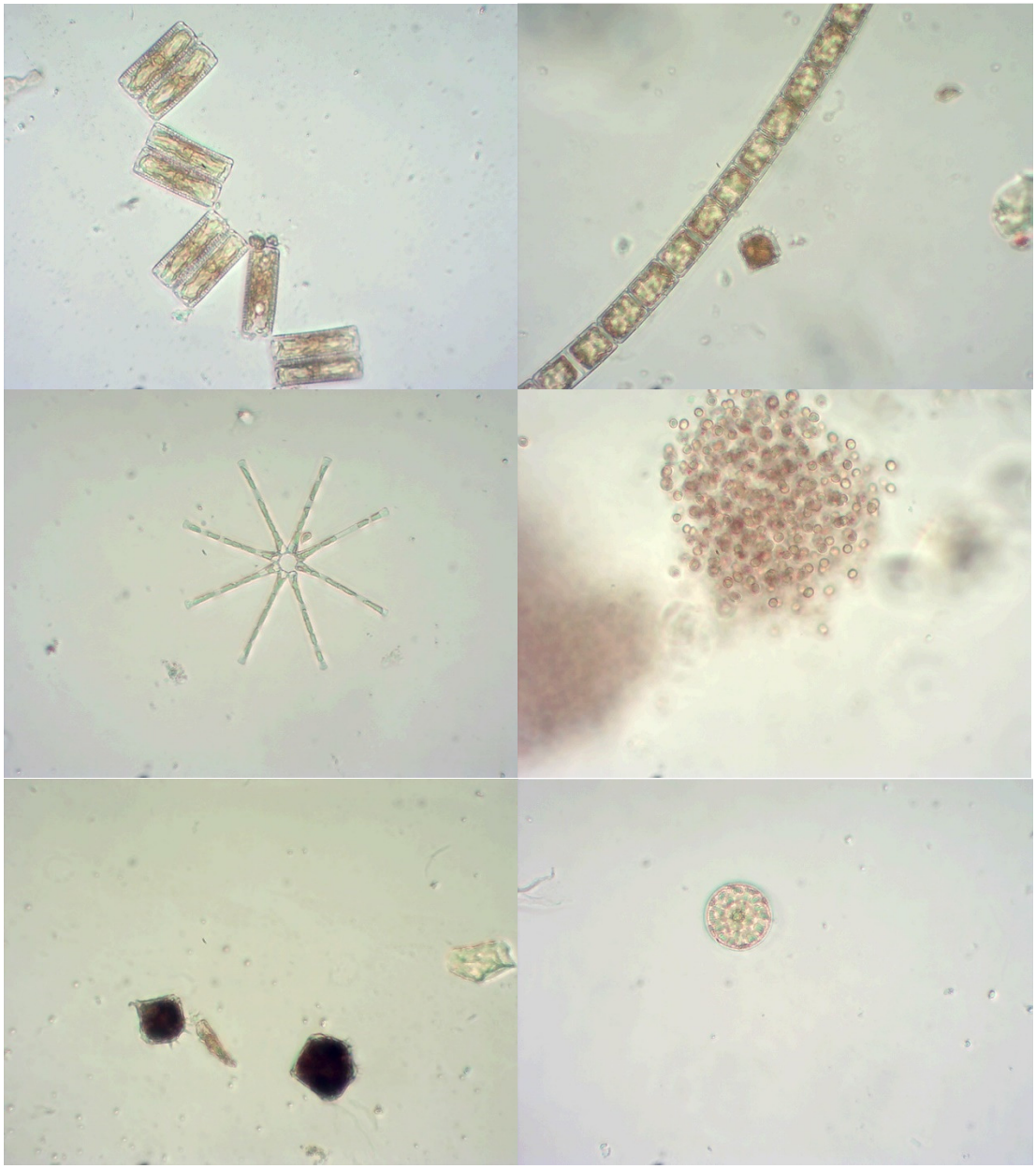

Figure 10: Examples of phytoplankton species from Lough Derg samples (Clockwise from the top left panel Diatoma vulgaris, *Melosira varians, Asterionella formosa, Microcystis aeruginosa, Peridinium/Peridiniopsis spp., and Stephanodiscus astraea*).

3. Comments on data gaps.

Some of the data - in particular the temperature data from the WQB's for 2015 which had not been transmitted to the server has now been recovered from the data loggers - and is in the process of being checked and verified prior to submission. Technical issues related to the original non-transmission have been fully resolved.

That leaves in general data gaps that relate to our fairly stringent QC on probe and auto-analyser data where we have rejected the stored values obtained, and data that is unavailable due to technical/ equipment fault reasons..

By way of providing context for the problem we would return to the roll out of the project in 2015 and review the chronology.

In early 2015 the project was late in obtaining permissions and as a result the progression was as follows

April - Project rolled out level sensors -this was satisfactory with some installation specific issues - 2015 data from level sensors was good until winter flooding knocked out 2 lake units - one since replaced - one outstanding (awaiting WI permissions).

May - Project rolled out lake thermistors - all satisfactory. These has been some servicing & maintenance issues (more regular battery replacements and one unit located in Parteen with a discharged battery was unapproachable due to very high flow for more than 1 month - now resolved.

July/**August** –Completed deployment of WQBs - we installed equipment and auto analysers and started the workup to full operation of the equipment. During this period we became aware that the original estimates of resources required to achieve the required standards were too low and we also had problems obtaining support from the Italian supplier. The Systea system and subcontract was therefore taken over in its entirety by WTL with transfer achieved in September.

In effect it has required 3 months to take over, train, fully re-calibrate all 7 auto-analysers to the required level - and included in this were a large number of manufacturer's faults with the units as well as manufacturers maintenance errors.

Data was collected during the roll out stage, but reporting of data for WQBs commences from September 1st

September Problems with units were still being resolved and we were running into a combination of commissioning problems with the equipment and severe power management problems. The power requirement for sampling from three depths, was originally underestimated - WTL who were late to discover this - immediately moved to add batteries and wind generators to the buoys - achieved in late October.

November – 100% of the generators were destroyed in Storm Barney and there followed a succession of storms which made maintaining power levels on the buoys extremely difficult.

To review the situation at this stage - In November we were battling severe storms - which knocked out equipment, the strict project weather exclusion prevented us from operating on the lake in wind conditions >F4 and because of the aforementioned problems, we require a lot of on-buoy time to get commissioning / bedding in of equipment achieved.

A typical scenario is where one brings in a unit ashore for maintenance - fix it - and need to bring it back out - but might have to wait a week to get back out to. This is not generally expected - but certainly arose a lot as we were bringing the units online in the aforementioned restructured system.

Where the engineer from Italy came onsite and we were unable to retrieve the equipment for him to work on, resulting in a situation where we moved to recover all of the system to allow him to service them, resulting in some down time.

The November flooding added considerably to the complexity of managing the data generation - we were now having problems working at Portumna and were completely locked out of Parteen - where the flows are at the "extreme" end of the scale and both survey vessels were upstream of the bridge - we pushed

right to the limit of safety to try to get to the equipment in Parteen – where the problem was exacerbated by a 10 knot current in the channel.

One consequence of the difficulty of access, and the power management issues is that we were forced to reduce the sampling intervals for some of the WQ parameters at various times, in order to save power and maintain the operation of the ADCP units on the buoys, which we considered as a more important parameter to maintain during the winter period.
There is no variation in the WQ data in these decreased frequency periods, and we believe that the data for the model could be achieved by interpolation.

We now have very high levels of uptime on the systems, very high levels of operational reliability on the Systeas, very high levels of in house knowledge of the units and how to maintain them.

We can also state clearly that we need to access the lake in up to F6 or we cannot guarantee sufficient lake time/on-buoy to hit our targets. To facilitate this we have purchased a new certified vessel (6.5m RIB) with a specific objective of accessing the buoys in inclement weather and have worked up what we believe to be a safe means of achieving this - and this is being submitted as a revised boat operation SOP with a switch from the project wind speed limit to a wave state/skippers discretion model.

In effect the chronology of events was such that the critical workup occurred during a period when we had limited access to our equipment because of weather and project wind restrictions, we had unforeseen technical issues with power management and a longer technical lead time on the Systea auto-analysers. We are confident that we have now excellent quality data coming in on a daily basis at the highest level since the commencement of the project.

ADCP's

There are some ADCP specific issues that arise in the project that have also contributed to a large maintenance overhead and issues with ADCP data.

In our submission the ADCPs were to be mounted on derricks lowered to the bottom of the lake. But in discussions with the other project partners we were asked to achieve a location as close to the bottom of the lake as possible. The reality of a lake bottom is that the sediment water interface makes the concept of the "bottom" a slightly nebulous concept. So at present the bottom mounted ADCP's are mounted on metal sleds with the buoyancy increased with floats such that they sit on the sediment. We did express reservations about this and it has proved to be difficult to implement - in effect the precise location of the sleds vertically cannot be assured and there is a tendency for both high levels of sedimentation and also tipping as it settles into the bottom.

Currently this implementation of the ADCP location strategy is unsatisfactory and requires review.

4. Appendices

Appendix 1: Summary of spot sampling for Water Quality, Water Treatability and Ecology.

Sample Date	WQMS - Fortnightly	WTMS- Fortnightly	WTMS- Quarterly	Ecological	Comments
13/05/2015	X	X	X		
15/05/2015				X	
26/05/2015	X	X		X	
10/06/2015	X	X		X	
23/06/2015	X	X		X	
09/07/2015	X	X		X	
22/07/2015	X	X		X	
06/08/2015	X	X	X	X	
12/08/2015-13/08/2015			X		
18/08/2015	X	X		X	
02/09/2015	X	X		X	
15/09/2015	X	X		X	
30/09/2015	X	X		X	
14/10/2015	X	X			
03/11/2015	X	X			
23/11/2015	X	X	X		Parteen basin and WQMS 5 were omitted due to severe weather and/or high flow
05/01/2016	X	X			Parteen basin was omitted due to high flow
18/01/2016	X	X			Parteen basin was omitted due to high flow and a sample was taken from the River Shannon at Kincora Marina
03/02/2016	X	X		X	
15/02/2016	X	X	X	X	
07/03/2016	X	X		X	
16/03/2016	X	X		X	
29/03/2016	X	X		X	

Appendix 2: Summary of sensors deployed on Lough Derg and deployment status

Station Type	Station Code	Station ID	Data Logger	Sensor type	Fully Deployed	Status
Level Station	LDMP-SS-03	Carraigahorrig River	Yes	DP	Yes	Live
Level Station	LDMP-SS-04	Woodford River	Yes	US	Yes	Live
Level Station	LDMP-SS-05	Coolbaun Quay	Yes	DP	Yes	Live
Level Station	LDMP-SS-06	Garrykennedy	Yes	DP	Yes	Removed due to flooding on 14.12.15, negotiations ongoing with Waterways Ireland regarding re-installation
Level Station	LDMP-SS-07	Kincora Marina	Yes	DP	Yes	Live
Level Station, Thermistor, ADCP, Water Quality	LDMP-SS-01	Portumna Bridge	Yes	DP	Yes	Live
Thermistor Buoy Unit	LDMP-OL-01	OL - 01 Carrigahorrig Bay	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-03	OL - 03 Near Drominagh Point	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-04	OL - 04 Off Brookfield Point	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m & 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-05	OL - 05 Edge of Coose Bay	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live

Station Type	Station Code	Station ID	Data Logger	Sensor type	Fully Deployed	Status
Thermistor Buoy Unit	LDMP-OL-06	OL - 06 NE of Illaunmore	Yes	2Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-07	OL - 07 NW tip of Illaunmore	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m & 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-08	OL- 08 North of Corrikeen Island	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m & 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-10	OL-10 Dromineer Bay	Yes	2 Nexsens T- Node. Attached at 0.5m, 2.5m,	Yes	Live
Thermistor Buoy Unit	LDMP-OL-11	OL -11 Youghal Bay	Yes	4 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m & 7.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-12	OL -12 Deep NE of Packers PT	Yes	8 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m, 9.5m, 14.5m, 19.5m, 29.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-13	OL -13 SE of Middle round Rocks	Yes	4 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m & 7.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-14	OL-14 Near Cahir Island	Yes	4 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m & 7.5m	Yes	Live

Station Type	Station Code	Station ID	Data Logger	Sensor type	Fully Deployed	Status
Thermistor Buoy Unit	LDMP-OL-16	OL-16 West of Derry Point	Yes	7 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m, 9.5m & 14.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-17	OL-17 Near Ballyvalley	Yes	5 Nexsens T- Node. Attached at 0.5m, 2.5m, 4.5m, 7.5m and 9.5m	Yes	Live
Thermistor Buoy Unit	LDMP-OL-18	OL-18 Top of Parteen Basin	Yes	3 Nexsens T- Node. Attached at 0.5m, 2.5m, & 4.5m	Yes	Live
ADCP Unit / Systea unit / Probes /Thermistor	LDMP-OL-02	OL - 02 East of Cloondauvan	Yes	3 Nexsens T- Node 0.5m, 4m & 6m,6 * Poncel WQ Sensors, (2 * DO, PH & Conductivity) - Deployed at 1m, & 6m, 1 * Turner Cyclops Chl-a, 1*Turner Cyclops Turbidity - Deployed at 1M, 1*Vertical ADCP, 1*Systea nutrient analyser	Yes	Live
ADCP Unit / Systea unit / Probes /Thermistor	LDMP-OL-09	OL-09 South East of Dromaan	Yes	3 Nexsens T- Node deployed @ 0.5m, 4m, 7m, 9.5m, 14.5m & 19.5m, 9 * Poncel WQ Sensors, (3 * DO, PH & Conductivity) - Deployed at 1m, 10m & 19m, 1 * Turner Cyclops Chl-a, 1 * Turner Cyclops Turbidity - Deployed at 1M, 1*Vertical ADCP, 1*Systea nutrient analyser	Yes	Live
ADCP Unit / Systea unit / Probes /Thermistor	LDMP-OL-15	OL-15 NW of Castlelough Beach	Yes	3 Nexsens T- Node deployed @ 0.5m, 2.5m, 4.5m, 7.5m, 9.5m & 14.5m, 9 * Poncel WQ Sensors, (3 * DO, PH & Conductivity) - Deployed at 1m, 6m & 15m, 1 * Turner Cyclops Chl-a, 1 * Turner Cyclops Turbidity - Deployed at 1M, 1*Vertical ADCP, 1*Systea nutrient analyser	Yes	Live

Station Type	**Station Code**	**Station ID**	**Data Logger**	**Sensor type**	**Fully Deployed**	**Status**
ADCP Unit	LDMP-SS-2	SS- 02 Horizontal ADCP Portumna	Yes	1*Horizontal ADCP	Yes	Live
Systea unit / Probes / Thermistor	LDMP-OL-19	OL-19 Parteen Basin	Yes	3 Nexsens T- Node 0.5m, 2.5m & 4.5m, 6 * Poncel WQ Sensors, (2 * DO, PH & Conductivity) - Deployed at 0.5m & 6m, 1 * Turner Cyclops Chl-a, 1 X Turner Cyclops Turbidity - Deployed at 1M, 1*Systea nutrient analyser	Yes	Live
Met Station	MS- 01	Ballinderry	Yes	Met Station- 1 * Airmar WX150, 1 * RM Young Tipping gauge, 1 * Licor Irradiance Sensor	Yes	Installed 17/02/2016 Live
Met Station	MS-02	Whitegate	Yes	Met Station - 1 * Airmar WX150, 1 * RM Young Tipping gauge, 1 * Licor Irradiance Sensor	Yes	Installed 18/02/2016 Live

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

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Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
Document Title:	**Data report for Lough Derg Monitoring Project (March 2016 – May 2016)**
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1. Introduction

The Lough Derg Monitoring Project technical partnership led by Water Technology Ltd. Are engaged in a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers. The project has been running since April 2015.

2. Results to date

2.1. T300 Water Flow and Current Survey

2.1.1. ADCP Survey

Figure *1* shows horizontal ADCP data from March 2015 – May 2015, the data has had a daily moving average applied to allow for interpretation. The top panel shows X axis flows across the river channel, from March to end of April high flows can be seen in the western channel of the river. From the end of April to the start of May this flow is shown to slow to speeds of between 10 – 20 cm/s. Y axis flows also show a sharp decline in May from a peaks of greater than 300 cm/s in March/April to speeds of approximately 100 cm/s from May onwards.

The vertical ADCP on OL15 has been subject to high levels of sedmentation during the reporting period resulting in errant data. Vertical ADCP's on both OL02 and OL09 have been monitoring continuously over the report period. Pitch and Roll data from both stations indicate they are within the defined settings as required by the equipment. Analysis of daily rolling average data shows that for both station high variability of flow are shown in the top 2 bins (bins 12 and 13 for OL02 and bins 11 and 12 for OL09) for both stations (Note: for OL02 the bin size is 0.5m and OL09 the bin size 2m). This is consistant in both the North-South axis and the East-West axis (**Figure *2*** and **Figure 3**). Comparison of the top bin data with wind direction data from the closest met stations shows a relationship between wind direction and flow in the these top bins. **Figure *4*** shows scatter plots of flow from the surface level bin with wind direction from the nearest weather station (Ballinderry- MS1 for OL02 and Whitegate – MS2 for OL09). A Lowess ((LOcally WEighted Scatter-plot Smoother) line has been imposed on the data to decipher any trends derived from wind direction data. Wind direction appears to be driving the flows in the top bins of the lake. There was no evidence of a direct wind effect on the lower bins of the lake.

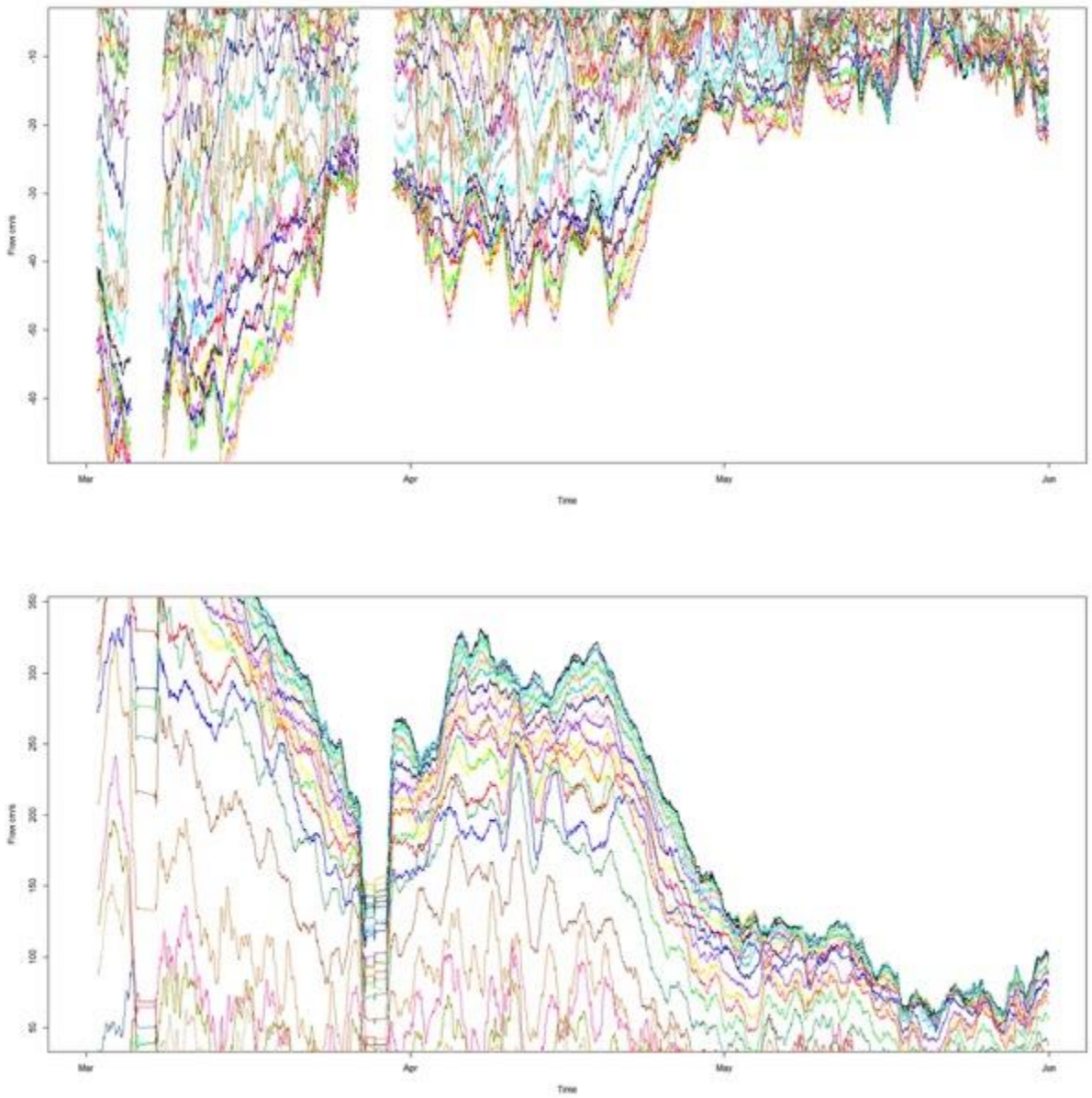

Figure 1: Daily moving average Flow data from Horizontal ADCP cm/s (Top panel shows X axis flows across all bins, Bottom panel shows Y axis flows) from March 2016 – May 2016. Note Data has been filtered to remove noisy data (>500, < -500).

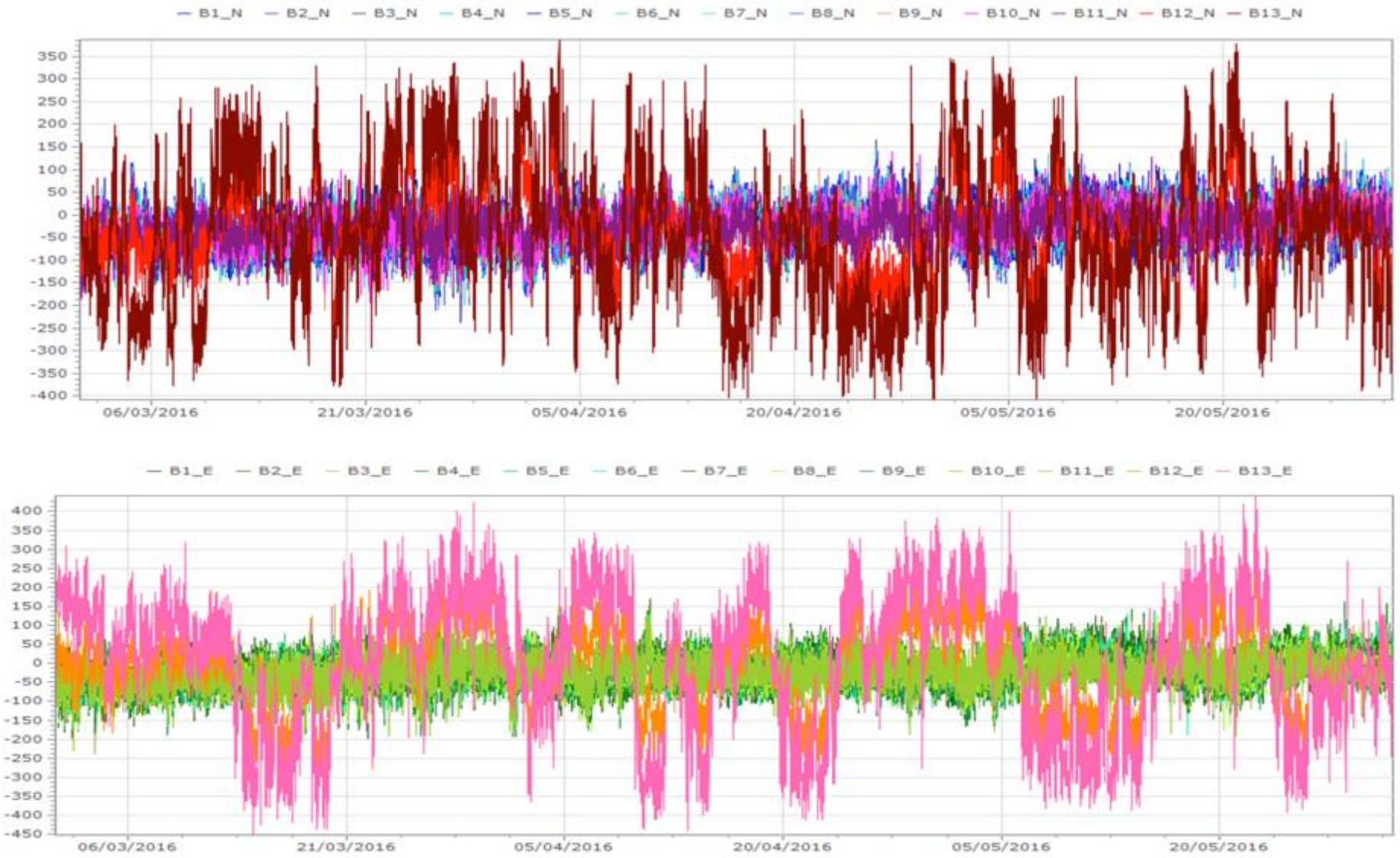

Figure 2: Flow data from OL02 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from March – May 2016.

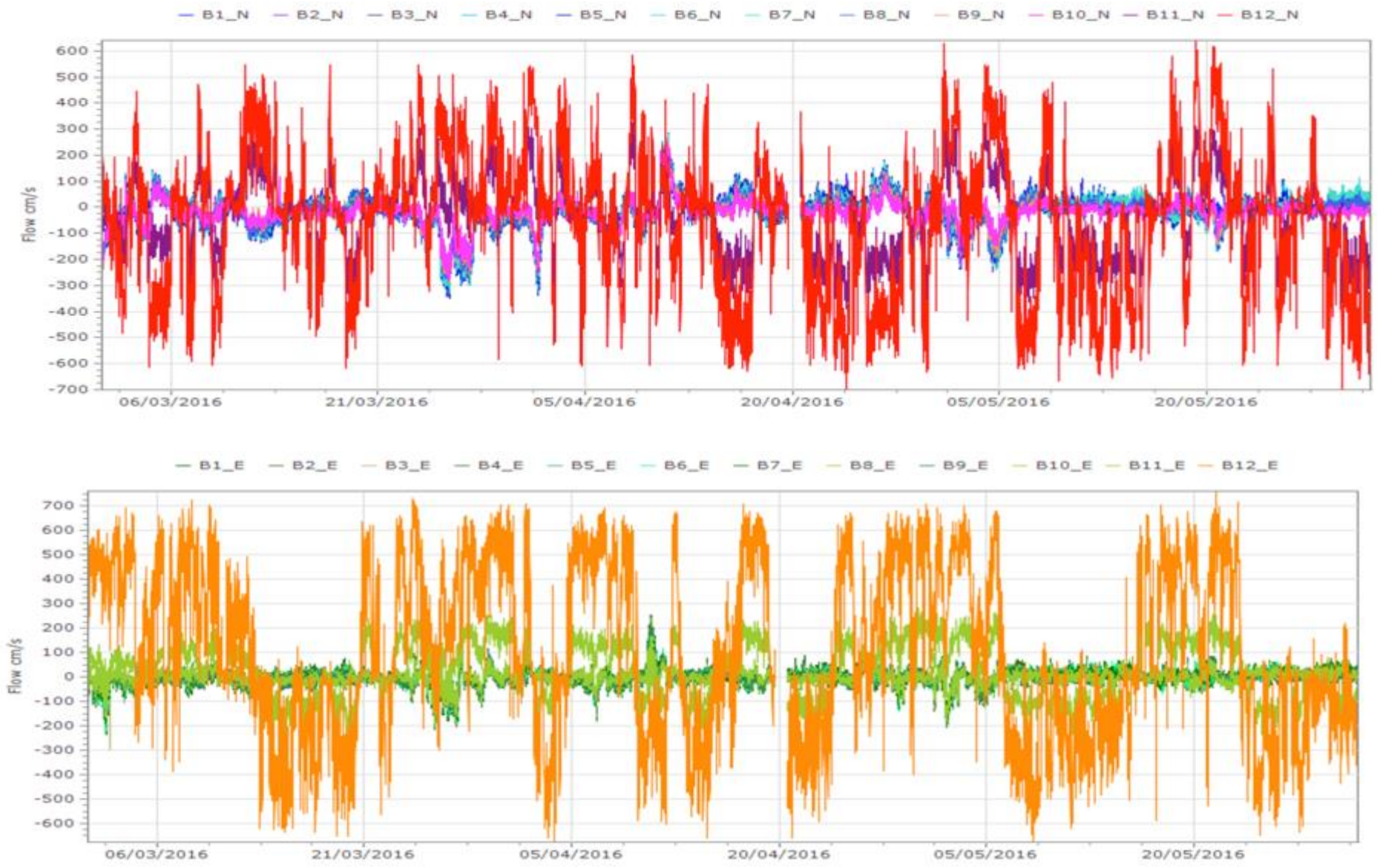

Figure 3: **Flow data from OL09 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from March – May 2016.**

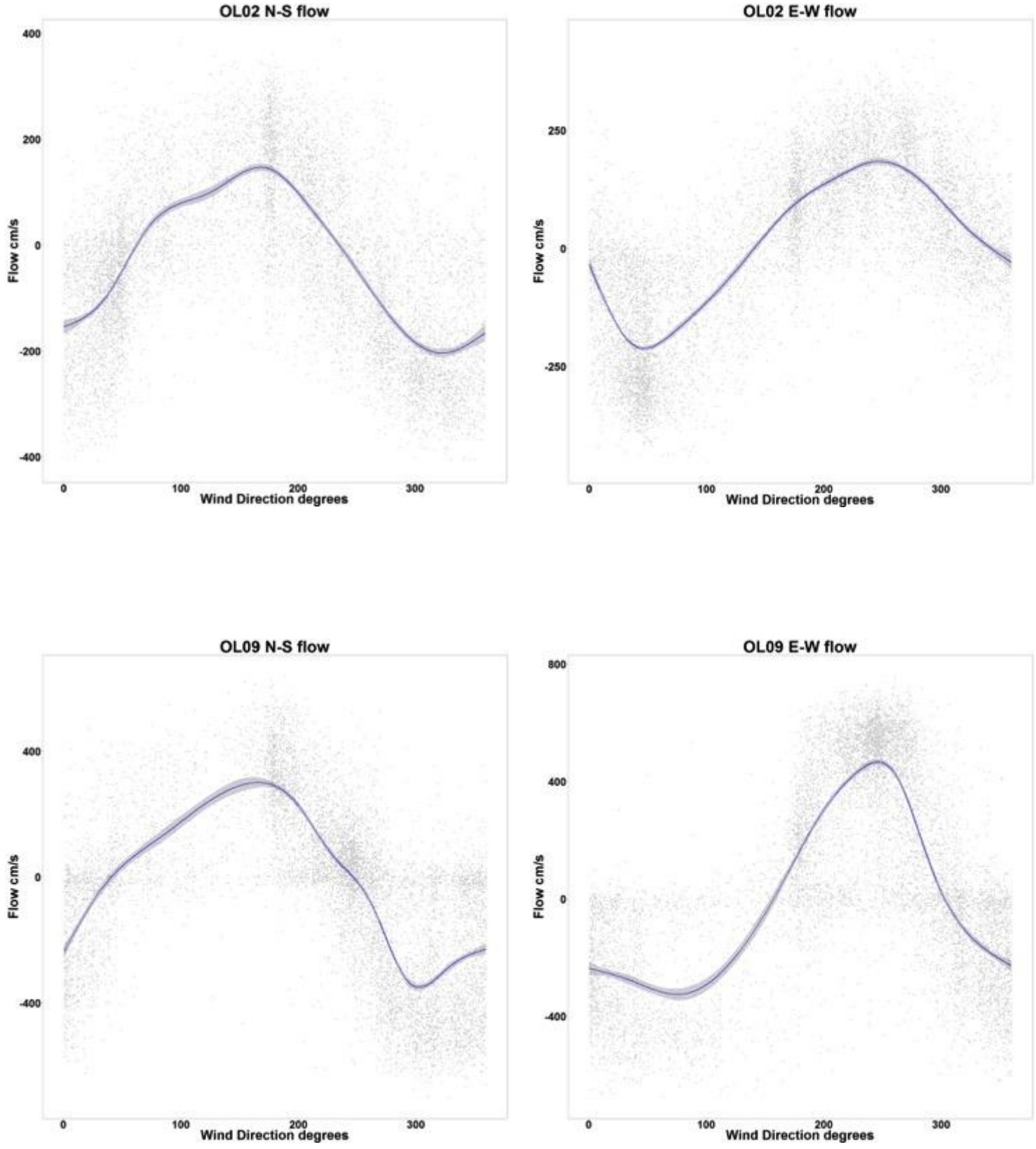

Figure 4: Scatterplots showing flow (y axis) versus Wind direction (x axis) from nearest Weather Station for Stations OL09 and OL02 with a lowess smoother line (blue) imposed.

2.2. T400 Water Level Survey

Level stations are installed at 6 locations (3 lake and 3 river sites), the level station at Garrykennedy marina was removed by Waterways Ireland staff on 14/12/15 as it was interfering with the pontoon rising during high floods. After negotiations with Waterways Ireland and a redesign of the installation of the station it was reinstalled on the 6th May 2016. All lake stations (SS05, SS06 and SS07) showed a similar pattern in level data declining from peaks in March (**Figure *5***). Lake stations showed similar patterns to the level data at Portumna Bridge (SS01).

Carraigahorrig (SS03) has shown a gradual decline in water levels from March to the end of May whereas water level data in the Woodford River (SS04) has been consistent across the reporting period.

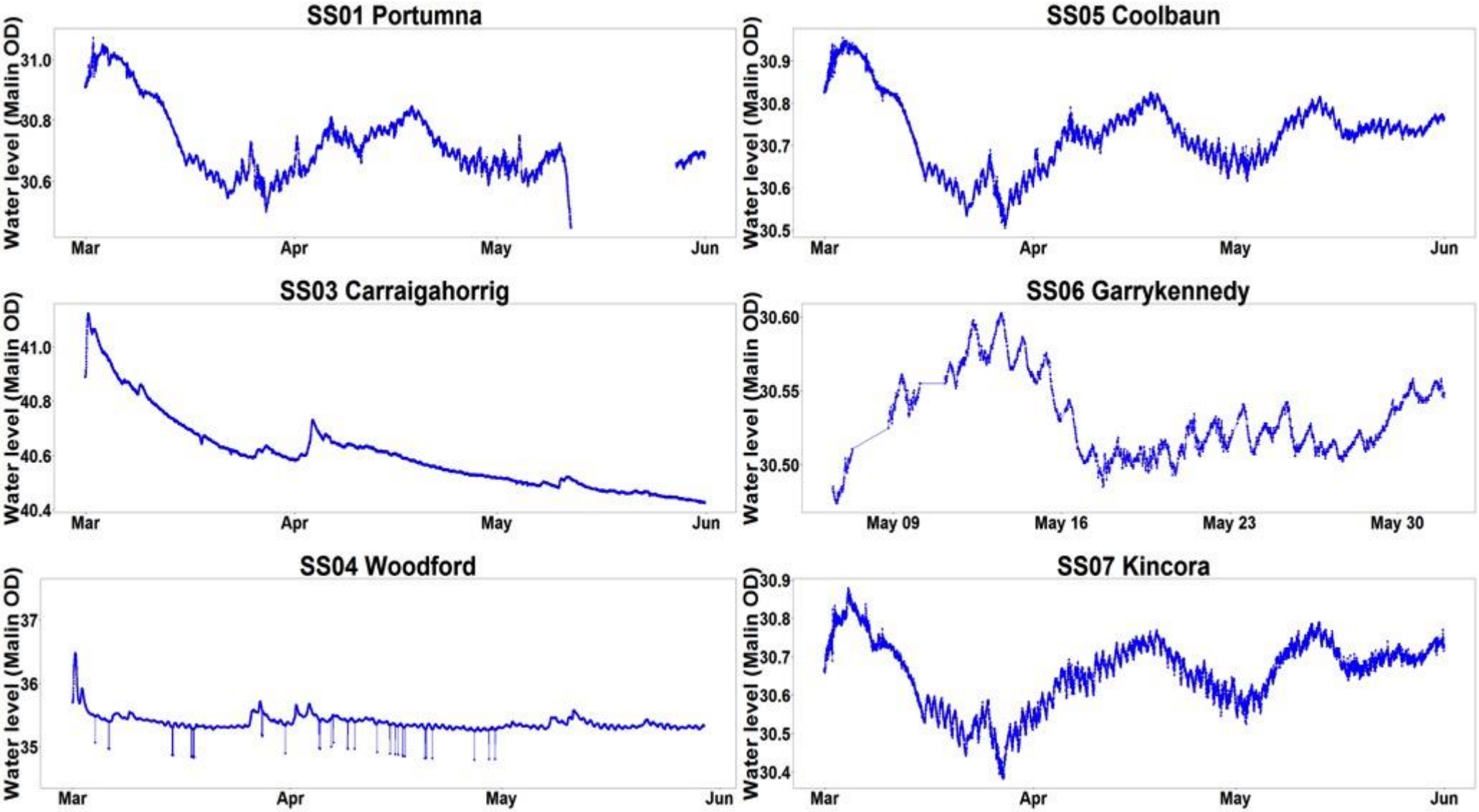

Figure 5: Water level data converted to Malin OD (m) from 6 stations from March 2016 - May 2016.

2.3. T500 Water Quality Survey

2.3.1. In-situ sampling

Five in-situ nutrient analysers are deployed, four at open lake sites and one on the inflowing River Shannon at Portumna Bridge. **Figure *6***, **Figure *7***, **Figure *8***, **Figure *9*** and **Figure *10*** show nutrient data from all 5 sites from March – May 2016 with all data below the limit of detection removed. All sites showed an increase in nitrate in March with the exception of Portumna Bridge which showed a decline across the sampling period. Phosphate showed a slight increase in March across all sites. Many nitrite and ammonia values were below the limit of detection

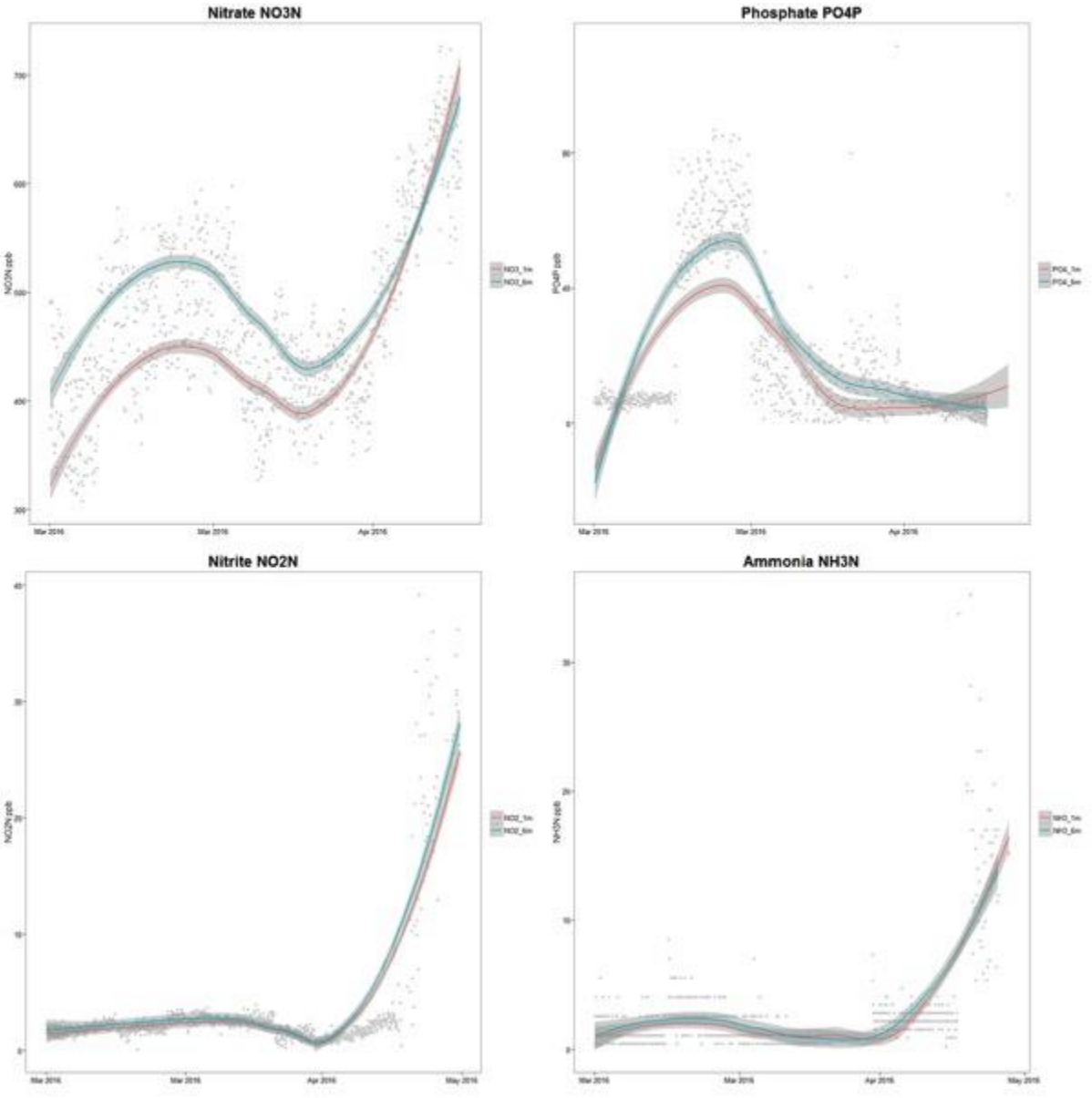

Figure 6: Nutrient Data from OL02 from March -May 2016 (Note some extreme outliers and data below the limit of detection were removed) .

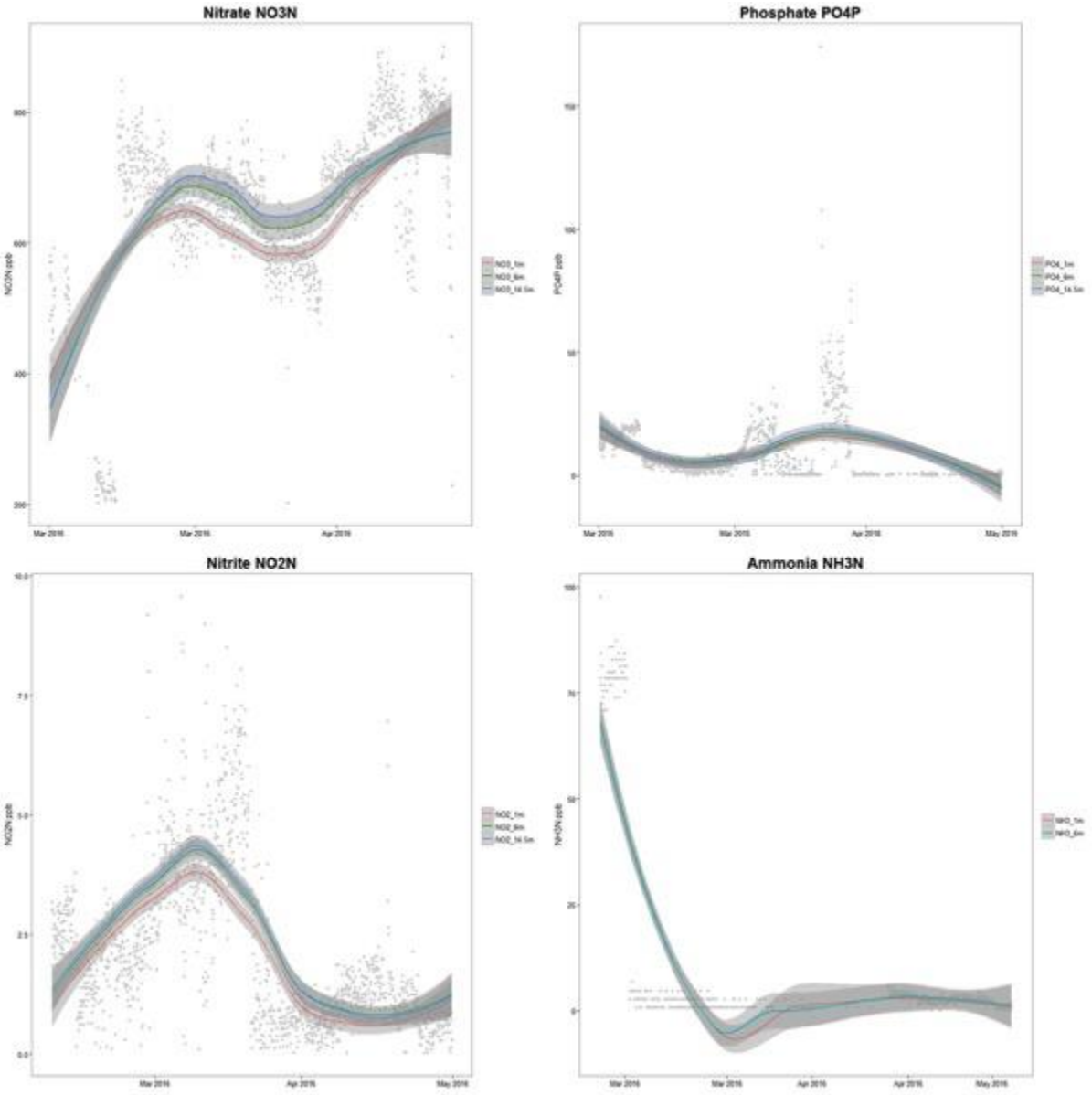

Figure 7: Nutrient Data from OL09 from March - May 2016 (Note some extreme outliers and data below the limit of detection were removed).

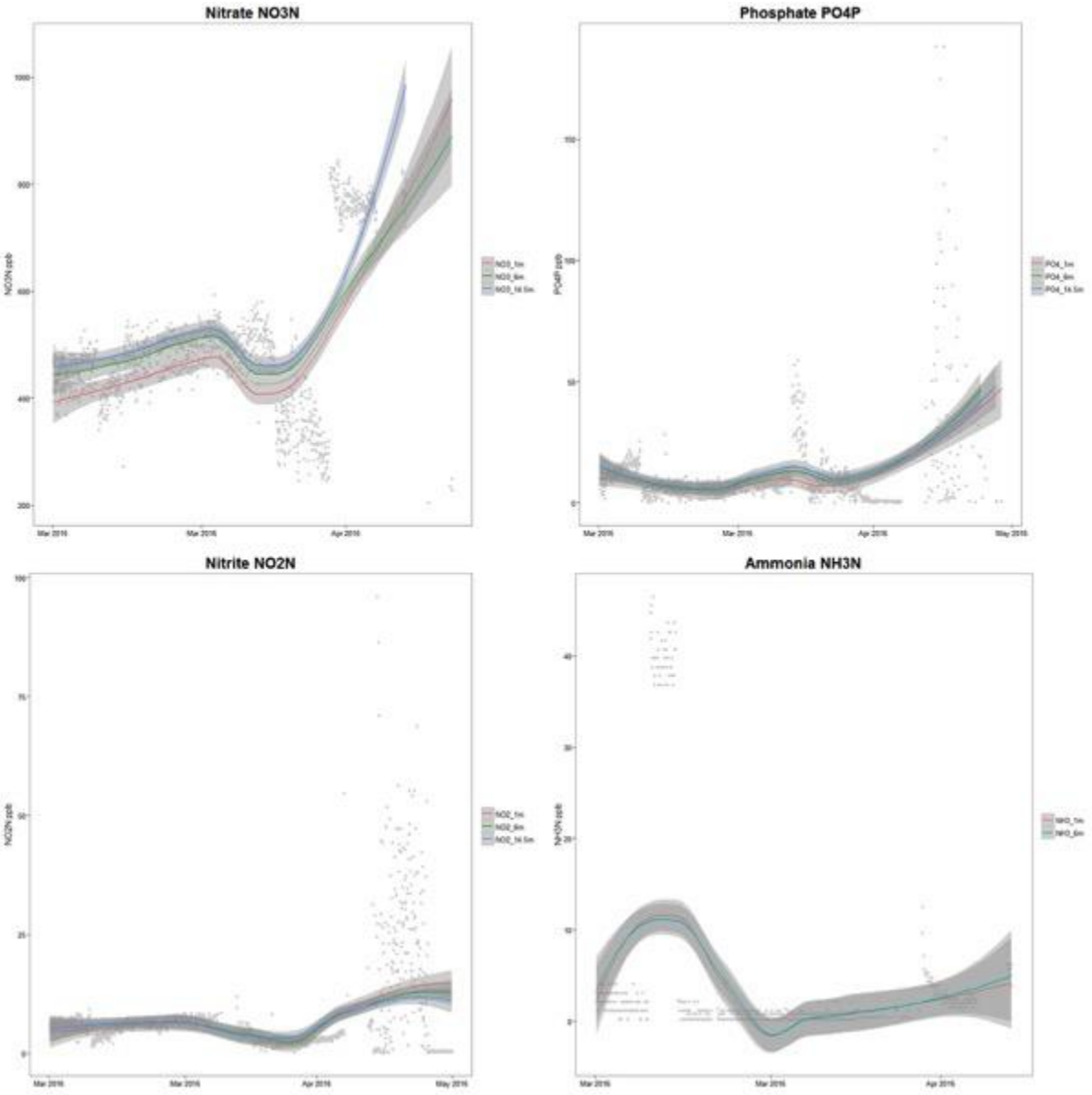

Figure 8: Nutrient Data from OL15 from March - May 2016 (Note some extreme outliers and data below the limit of detection were removed).

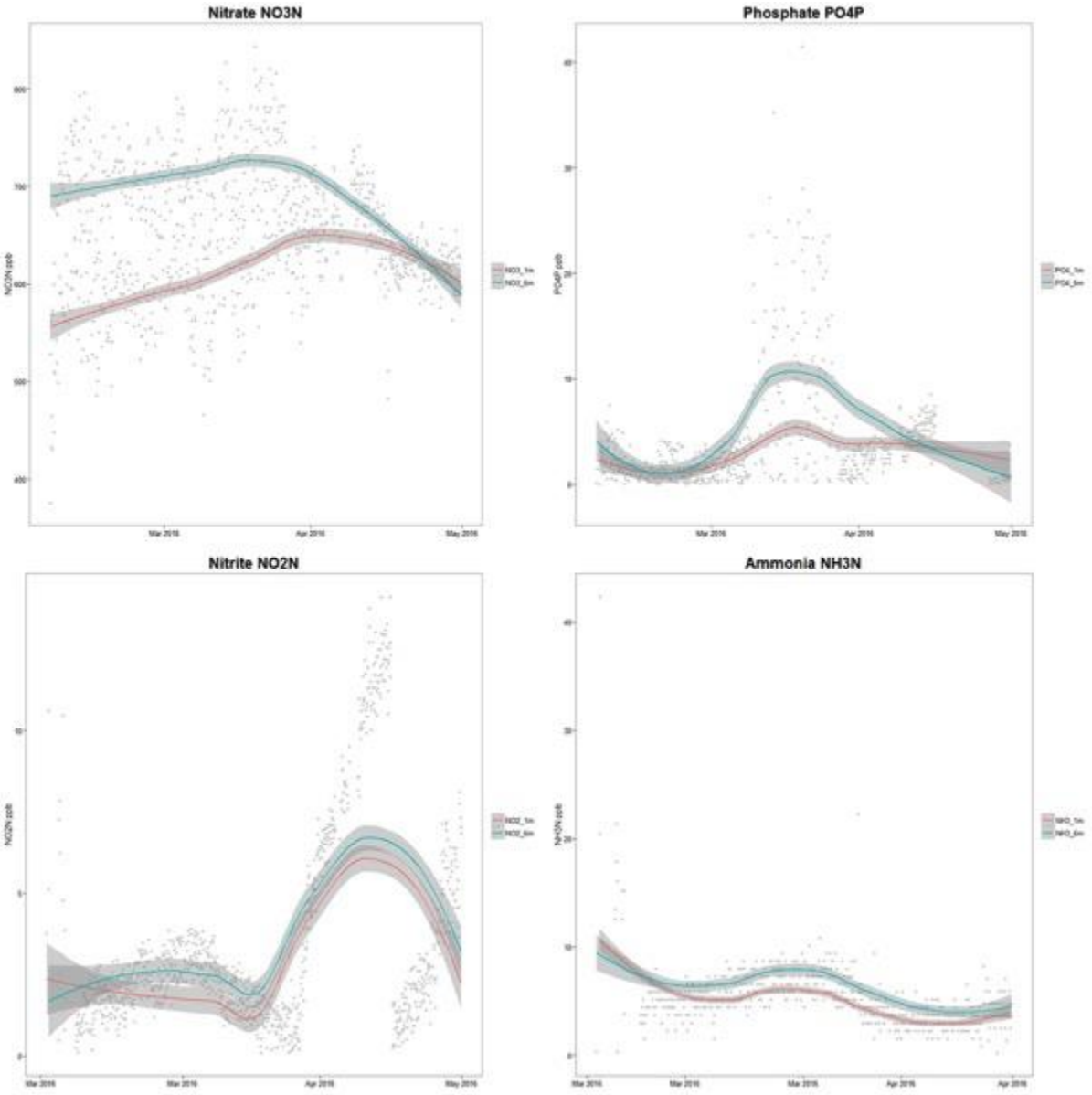

Figure 9: Nutrient Data from OL19 from March - May 2016 (Note some extreme outliers and data below the limit of detection were removed).

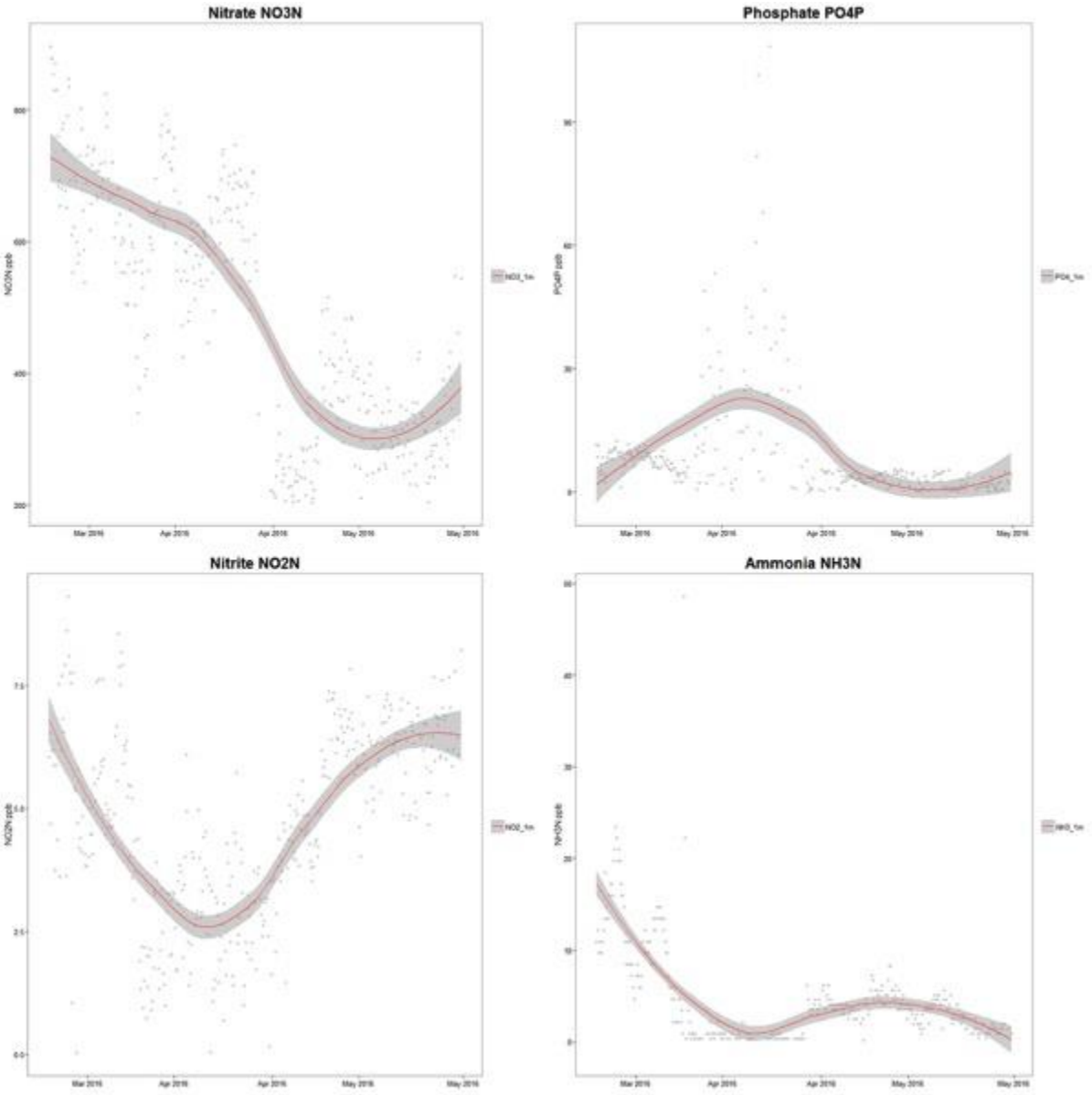

Figure 10: Nutrient Data from SS01 (Portumna Bridge) from March - May 2016 (Note some extreme outliers and data below the limit of detection were removed).

2.3.2. Spot sampling

Water quality surveying of the lake has been ongoing since May 13th 2015. **Figure *11***, **Figure *12***, and **Figure *13*** show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate and chlorophyll a from water quality sites on Lough Derg at all depths. **Figure *14*** shows the water quality data from all inflowing rivers into Lough Derg. Nitrate in the lake shows an increasing trend while phosphate shows a declining trend across all sites from the beginning of March through to end of May. Chlorophyll a levels are low in March but start to show an increase in April through to May indicating the beginning of primary productivity in the lake. Trends in river inputs were more difficult to detect but a general increase in nitrate and phosphate can be seen in the winter months before declining in Springtime.

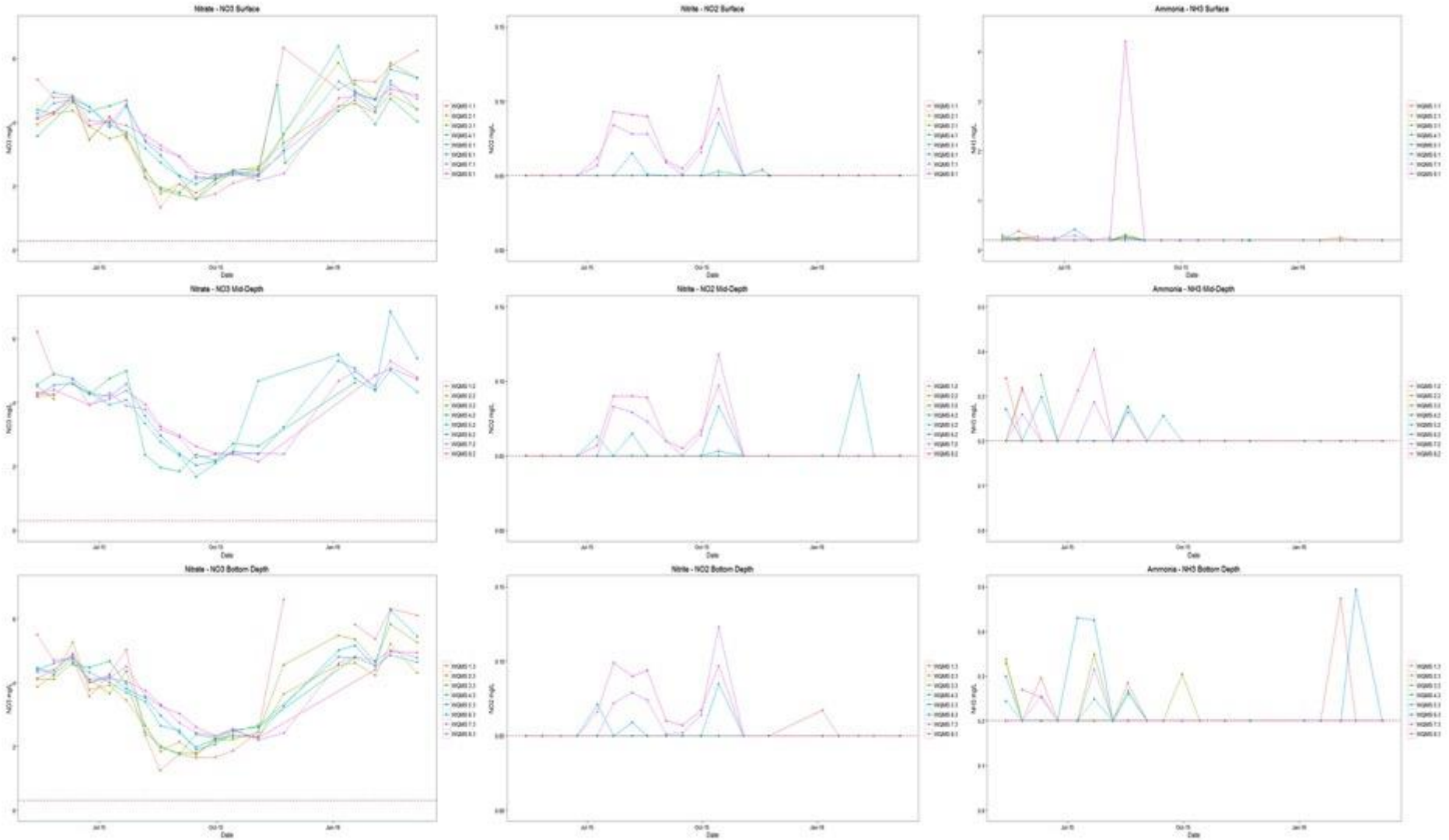

Figure 11: Survey results from all lake water quality sites of nitrate (NO3) nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicated limits of detection of analysis).

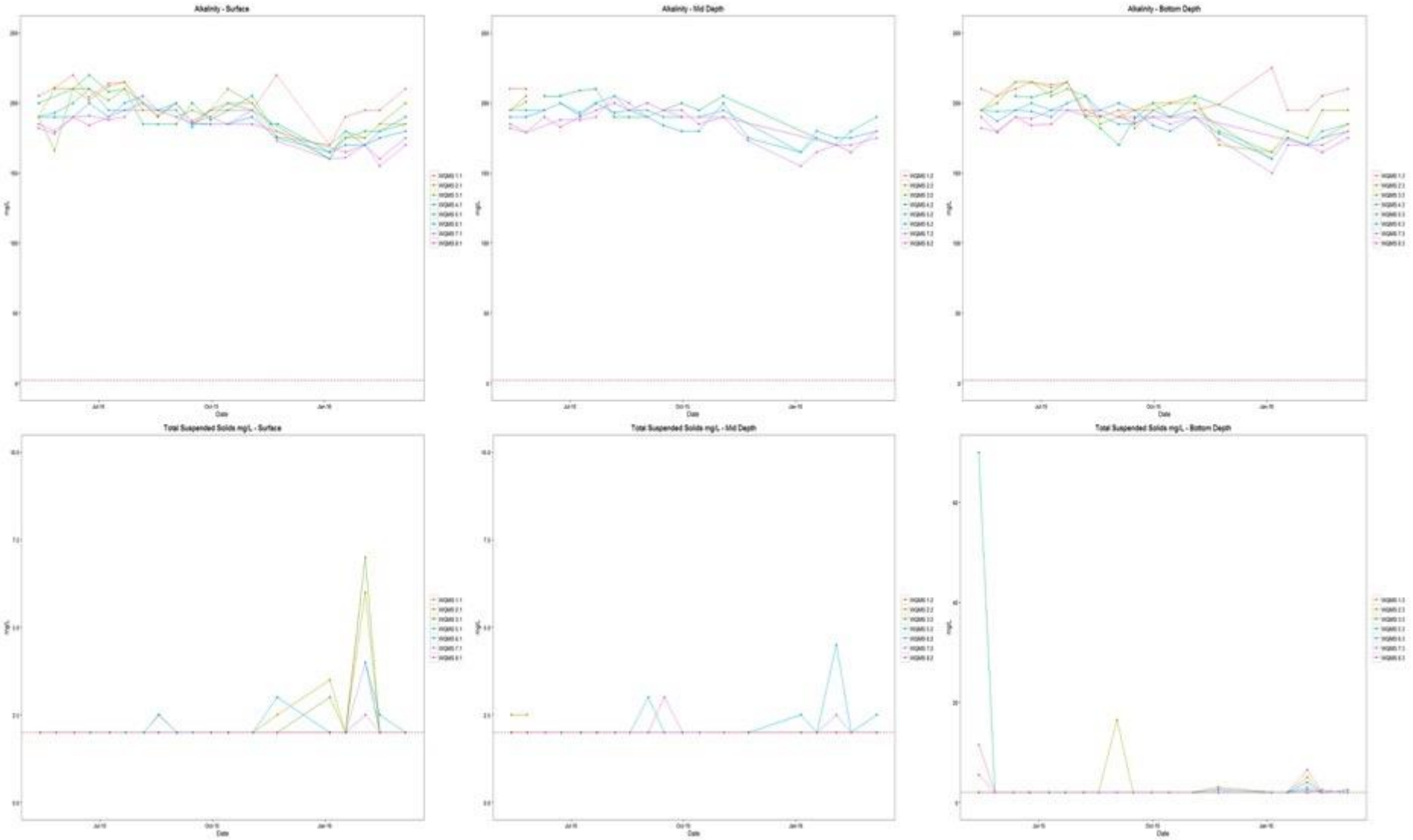

Figure 12: Survey results from all lake water quality sites of Alkalinity and Suspend Solids (Please note red dashed lines indicated limits of detection of analysis).

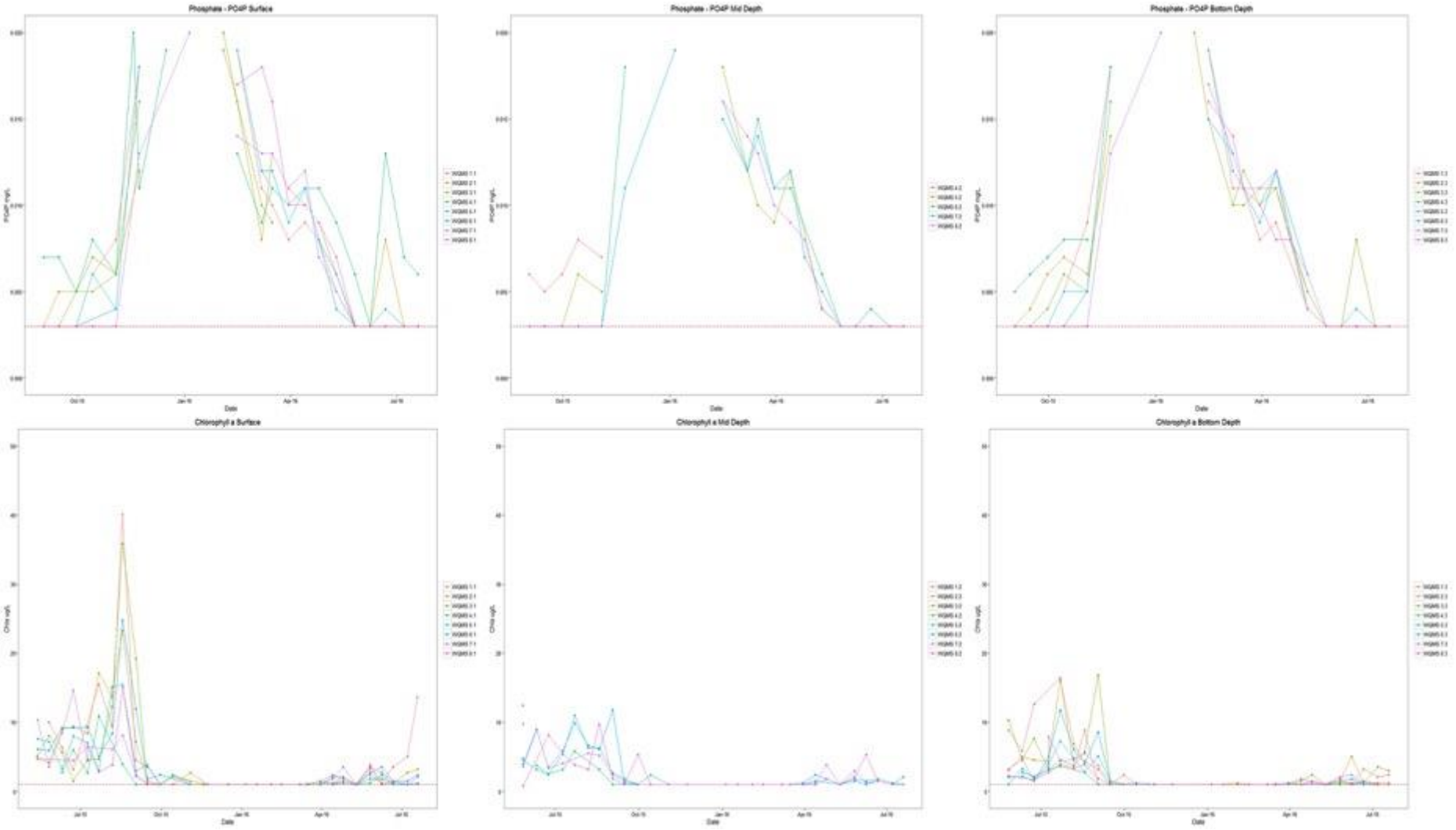

Figure 13: Survey results from all lake water quality sites of Chlorophyll a and Phosphate (PO4P) (Please note red dashed lines indicated limits of detection of analysis).

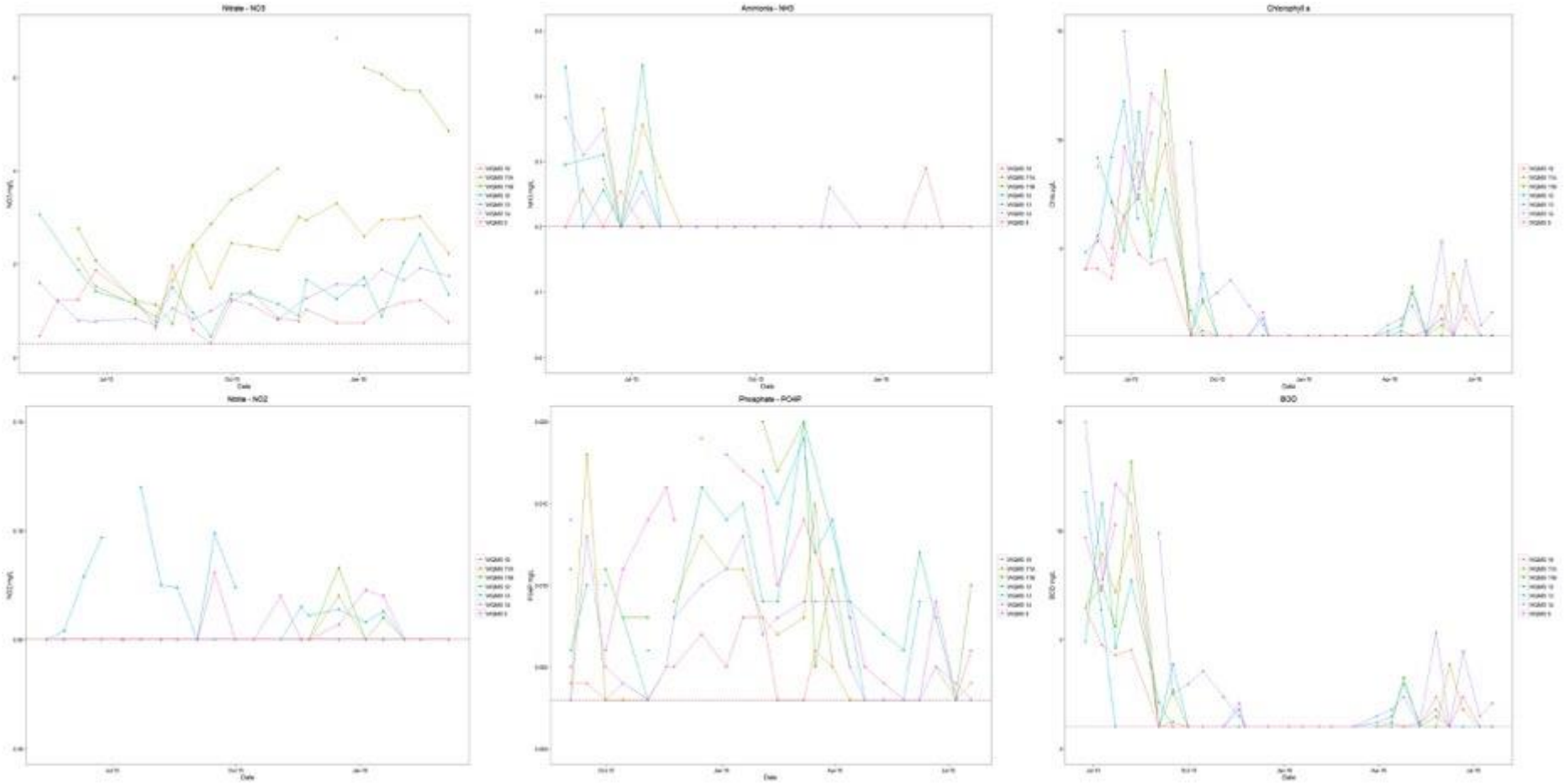

Figure 14: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll a and BOD (Please note red dashed lines indicated limits of detection of analysis).

2.4. T600 Temperature Survey

Nineteen temperature monitoring stations are deployed on Lough Derg. All sites showed similar patterns throughout the reporting period. Temperatures showed a steady increase across all depths from March to May. A steep increase was observed from the start of May until the end of the reporting period. There is some evidence of stratification beginning at the deeper depths (> 20m) towards the end of May (**Figure *15***). **Figure *16*** shows a boxplot of surface level temperatures from the inflow (Portumna) and outflow (Parteen) of the lake. Both sites show a similar mean temperature with Parteen exhibiting a slightly larger range in temperatures.

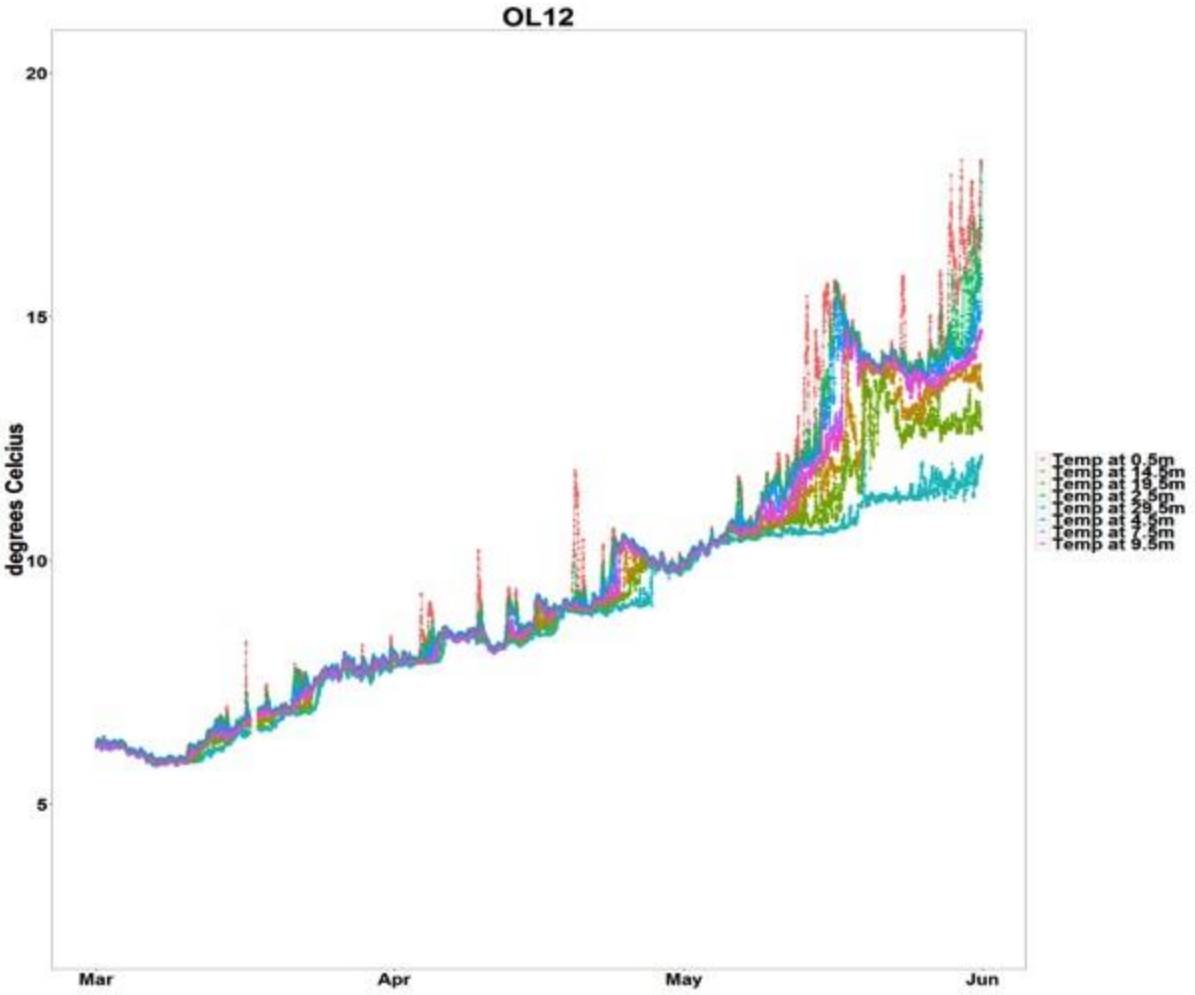

Figure 15: OL12 temperature data from all depths from March 2016 - May 2016.

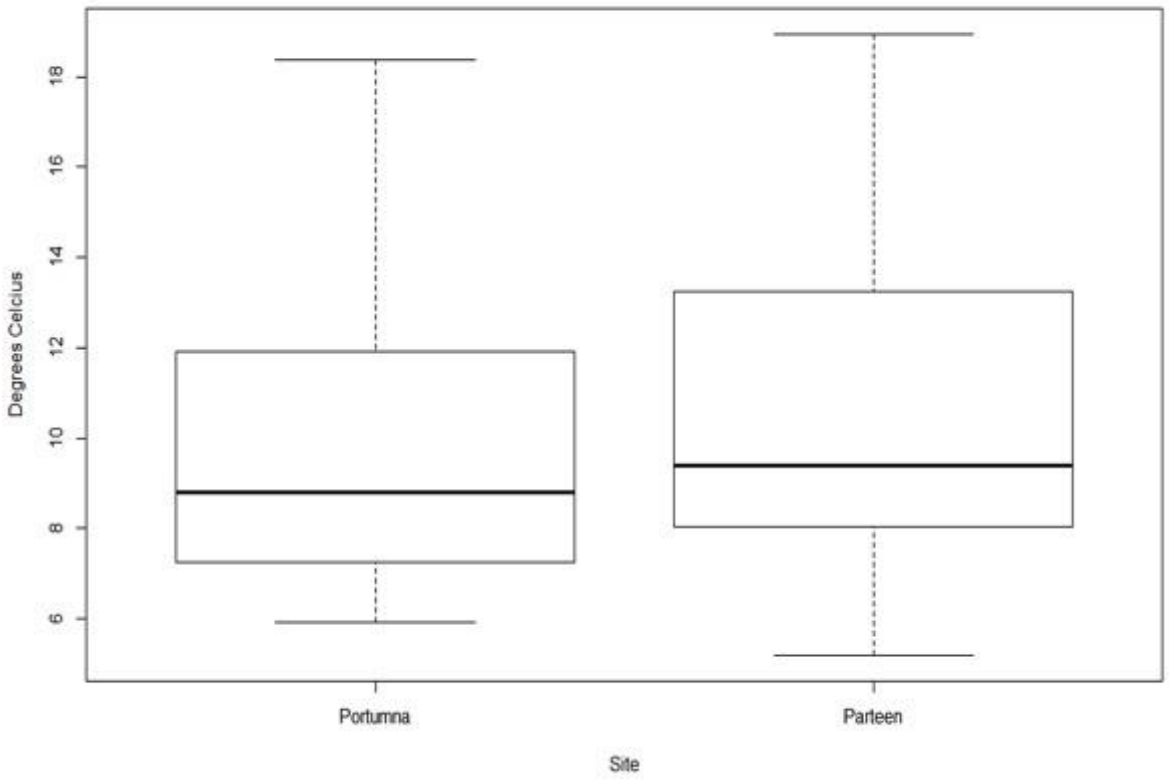

Figure 16: Boxplot showing surface temperatures from Portumna (inflow) and Parteen (outflow) from March 2016 - May 2016.

2.5. T800 Meteorological Survey

Two meteorological stations have been installed on the eastern and western shores of Lough Derg. **Figure *17*** and **Figure *18*** show meteorological data from both stations at Ballinderry and Whitegate. Both stations show similar values for all parameters.

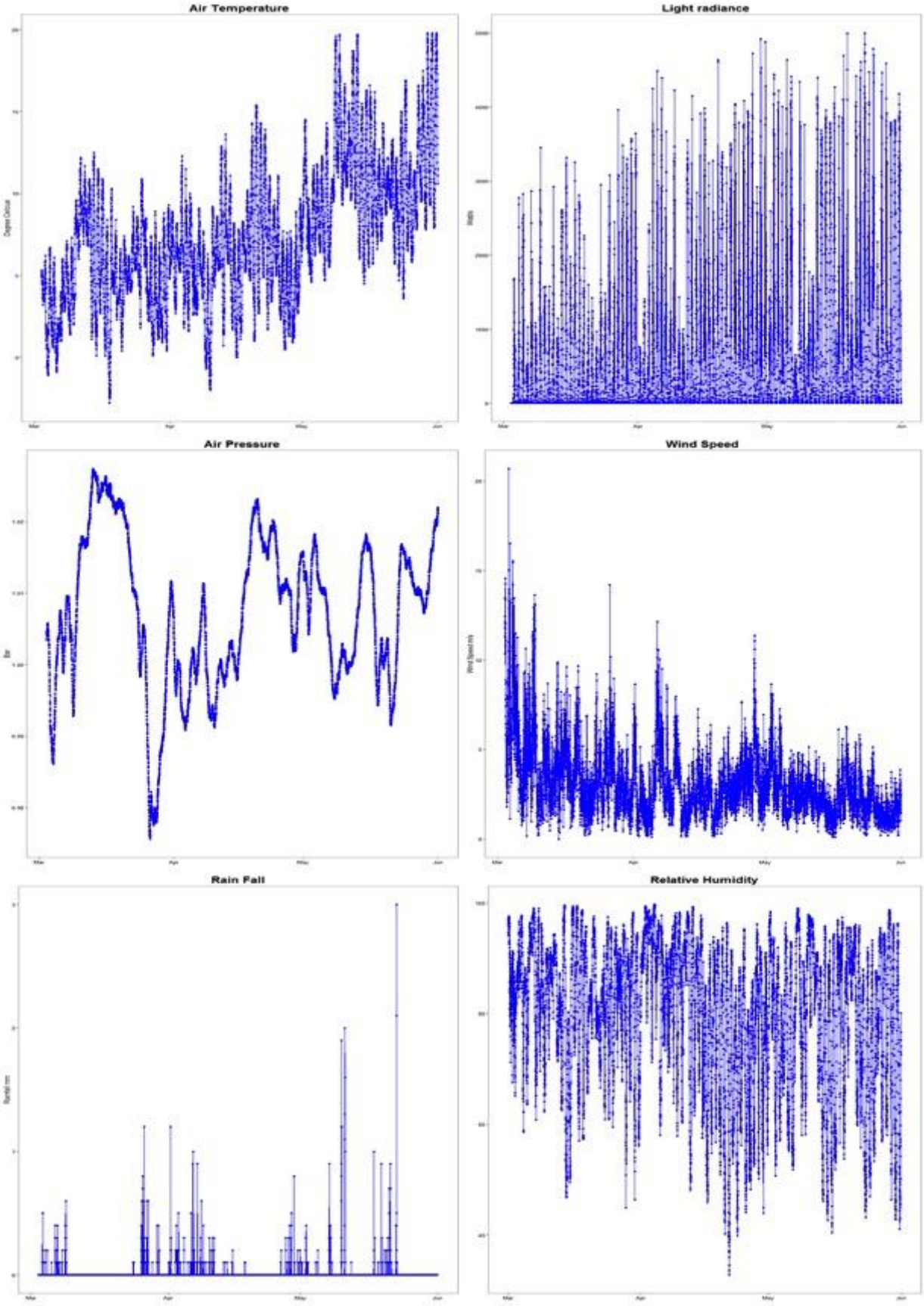

Figure 17: Data from MS01 (Ballinderry) from March 2016 - May 2016.

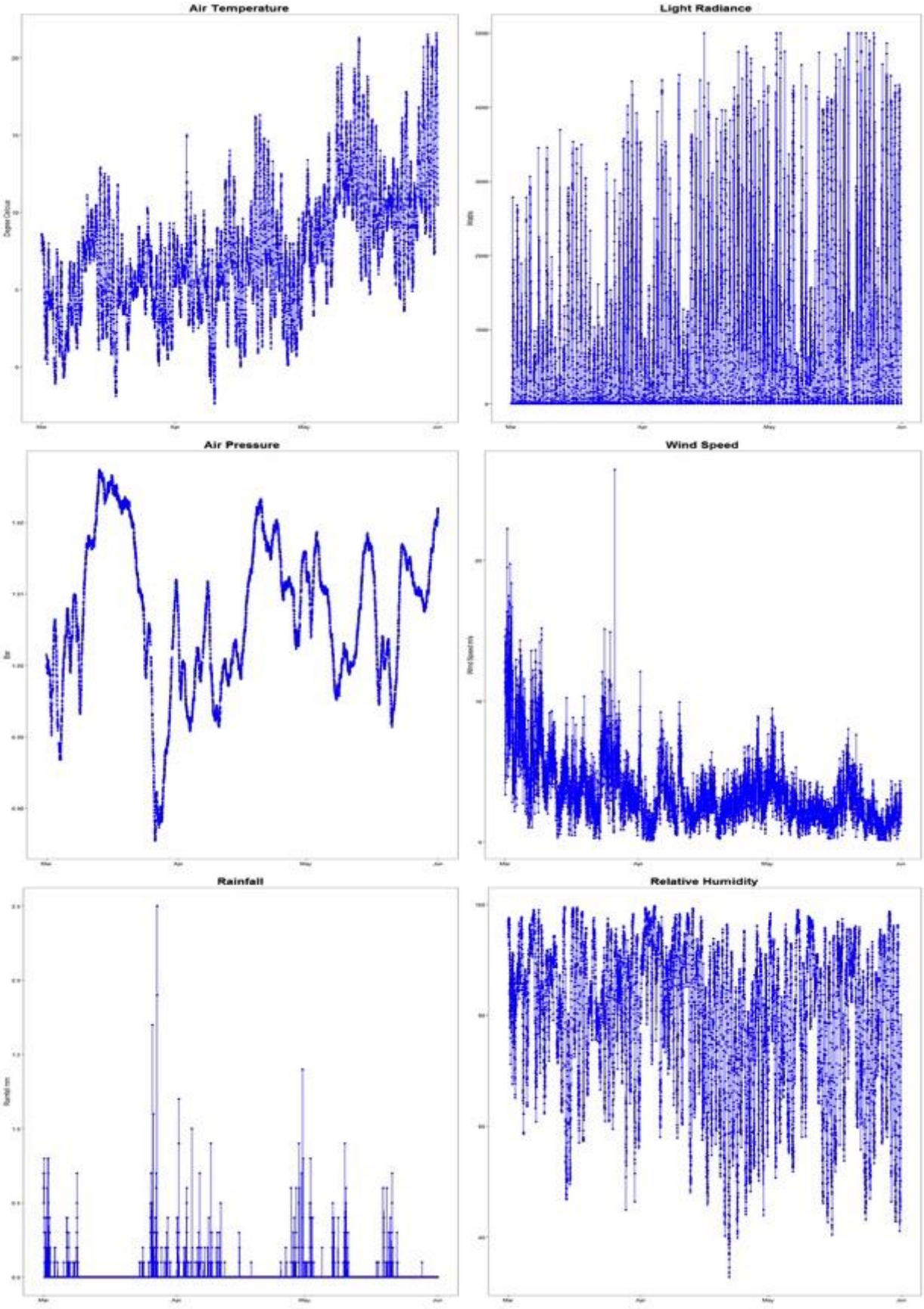

Figure 18: Data from MS02 (Whitegate) from March 2016 - May 2016.

2.6. T900 Plankton Survey

Analysis of plankton data is ongoing

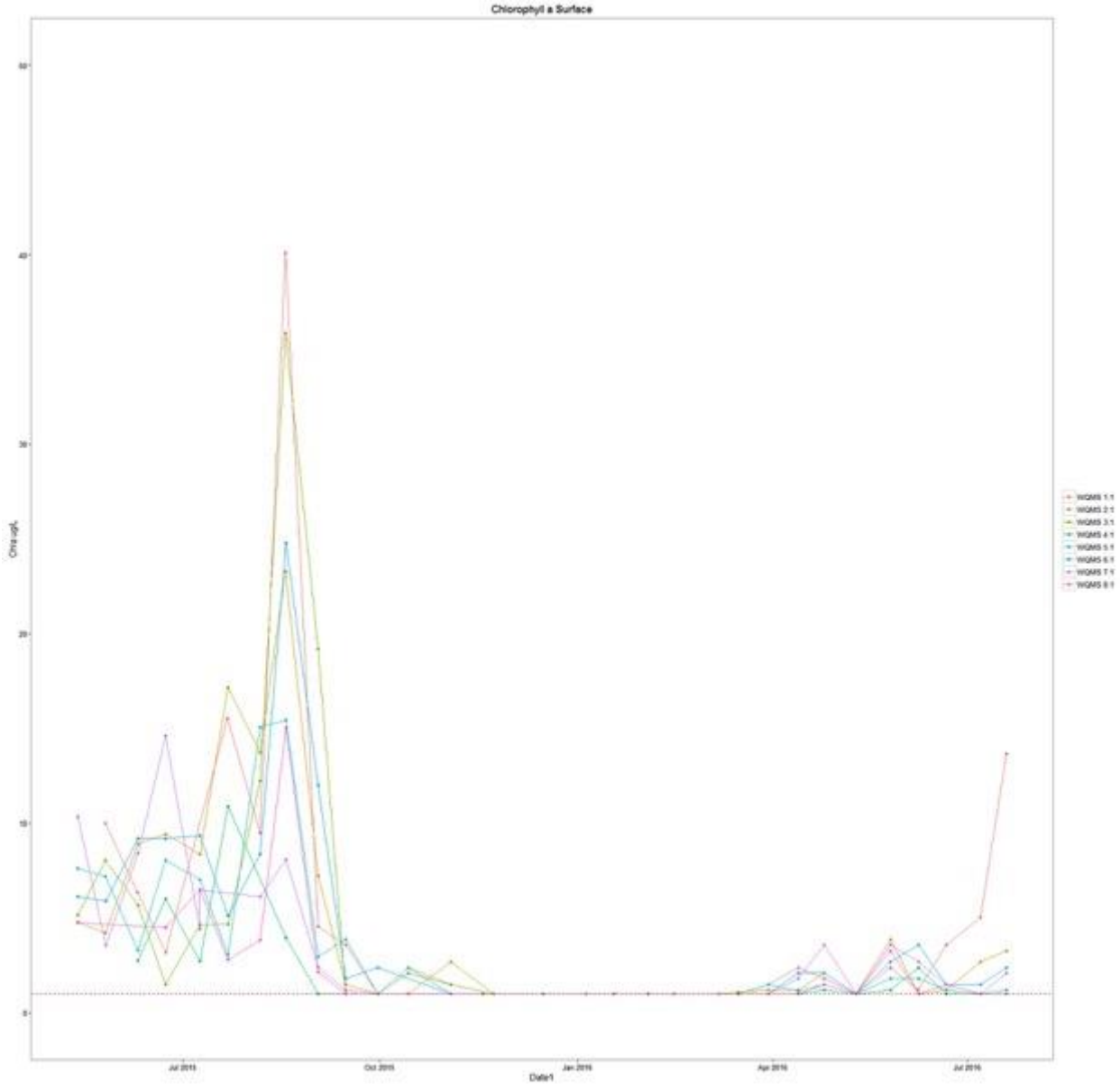

Figure 19: Surface chlorophyll a results from all sites from May 2015 - July 2016.

3. Appendices

Appendix 1: Summary of spot sampling for Water Quality, Water Treatability and Ecology.

Sample Date	WQMS - Fortnightly	WTMS- Fortnightly	WTMS- Quarterly	Ecological	Comments
13/05/2015	X	X	X		
15/05/2015				X	
26/05/2015	X	X		X	
10/06/2015	X	X		X	
23/06/2015	X	X		X	
09/07/2015	X	X		X	
22/07/2015	X	X		X	
06/08/2015	X	X	X	X	
12/08/2015-13/08/2015			X		
18/08/2015	X	X		X	
02/09/2015	X	X		X	
15/09/2015	X	X		X	
30/09/2015	X	X		X	
14/10/2015	X	X			
03/11/2015	X	X			
23/11/2015	X	X	X		Parteen basin and WQMS 5 were omitted due to severe weather and/or high flow
05/01/2016	X	X			Parteen basin was omitted due to high flow
18/01/2016	X	X			Parteen basin was omitted due to high flow and a sample was taken from the River Shannon at Kincora Marina
03/02/2016	X	X		X	
15/02/2016	X	X	X	X	
07/03/2016	X	X		X	
16/03/2016	X	X		X	
29/03/2016	X	X		X	
13/04/2016	X	X		X	
25/04/2016	X	X		X	
10/05/2016	X	X	X		
26/05/2016	X	X			

Appendix 2: List of quarterly water treatability parameters with limits of detection.

Test	Result Units	Limit of detection
Alkalinity, Total as CaCO3	mg/l	2
Bromine*	mg/l	0.1
COD, unfiltered	mg/l	7
Cyanide, Total	mg/l	0.05
Conductivity @ 20 deg.C	mS/cm	0.005
Total EPH (C6-C40) (aq)	µg/l	100
EPH Range >C10 - C40 (aq)	µg/l	46
Fluoride	mg/l	0.5
Benzene	µg/l	7
EPH (C6-C10)	µg/l	100
Ethylbenzene	µg/l	5
GRO >C5-C10	µg/l	10
m,p-Xylene	µg/l	8
Methyl tertiary butyl ether (MTBE)	µg/l	3
o-Xylene	µg/l	3
Sum of detected BTEX	µg/l	28
Toluene	µg/l	4
Mercury (diss.filt)	µg/l	0.01
Aluminium (diss.filt)	µg/l	2.9
Arsenic (diss.filt)	µg/l	0.12
Barium (diss.filt)	µg/l	0.03
Boron (diss.filt)	µg/l	9.4
Cadmium (diss.filt)	µg/l	0.1
Chromium (diss.filt)	µg/l	0.22
Copper (diss.filt)	µg/l	0.85
Lead (diss.filt)	µg/l	0.02
Manganese (diss.filt)	µg/l	0.04
Nickel (diss.filt)	µg/l	0.15
Selenium (diss.filt)	µg/l	0.39
Zinc (diss.filt)	µg/l	0.41
Nitrogen, Kjeldahl	mg/l	1
Chloride	mg/l	2
Sulphate	mg/l	2
Total Oxidised Nitrogen as N	mg/l	0.1
Surfactants, Anionic (MBAS)	mg/l	0.05
Calcium (diss.filt)	mg/l	0.012
Iron (diss.filt)	mg/l	0.019
Nitrogen, Total	mg/l	1
Acenaphthene (aq)	µg/l	0.015
Acenaphthylene (aq)	µg/l	0.011
Anthracene (aq)	µg/l	0.015

Appendix 2: cont'd

Test	Result Units	Limit of detection
Benzo(a)anthracene (aq)	µg/l	0.017
Benzo(a)pyrene (aq)	µg/l	0.009
Benzo(b)fluoranthene (aq)	µg/l	0.023
Benzo(g,h,i)perylene (aq)	µg/l	0.016
Benzo(k)fluoranthene (aq)	µg/l	0.027
Chrysene (aq)	µg/l	0.013
Dibenzo(a,h)anthracene (aq)	µg/l	0.016
Fluoranthene (aq)	µg/l	0.017
Fluorene (aq)	µg/l	0.014
Indeno(1,2,3-cd)pyrene (aq)	µg/l	0.014
Naphthalene (aq)	µg/l	0.1
PAH, Total Detected USEPA 16 (aq)	µg/l	0.344
Phenanthrene (aq)	µg/l	0.022
Pyrene (aq)	µg/l	0.015
Aldrin	µg/l	0.01
alpha-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Azinphos-ethyl	µg/l	0.01
Azinphos-methyl	µg/l	0.01
beta-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Carbophenothion	µg/l	0.01
Chlorfenvinphos	µg/l	0.01
Chlorothalonil	µg/l	0.01
Chlorpyriphos	µg/l	0.01
Chlorpyriphos methyl	µg/l	0.01
cis-Chlordane	µg/l	0.01
Diazinon	µg/l	0.01
Dichlorvos	µg/l	0.01
Dieldrin	µg/l	0.01
Dimethoate	µg/l	0.01
Disulfoton	µg/l	0.01
Endosulphan I	µg/l	0.01
Endosulphan II	µg/l	0.01
Endosulphan sulphate	µg/l	0.01
Endrin	µg/l	0.01
Ethion	µg/l	0.01
Etrimphos	µg/l	0.01
Fenitrothion	µg/l	0.01
Fenthion	µg/l	0.01
gamma-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Heptachlor	µg/l	0.01

Appendix 2: cont'd

Test	Result Units	Limit of detection
Heptachlor epoxide	µg/l	0.01
Hexachlorobenzene	µg/l	0.01
Isodrin	µg/l	0.01
Malathion	µg/l	0.01
Methyl parathion	µg/l	0.01
Mevinphos	µg/l	0.01
o,p-DDE	µg/l	0.01
o,p-DDT	µg/l	0.01
o,p-Methoxychlor	µg/l	0.01
o,p-TDE (DDD)	µg/l	0.01
p,p-DDE	µg/l	0.01
p,p-DDT	µg/l	0.01
p,p-Methoxychlor	µg/l	0.01
p,p-TDE (DDD)	µg/l	0.01
Parathion	µg/l	0.01
Pendimethalin	µg/l	0.01
Permethrin I	µg/l	0.01
Permethrin II	µg/l	0.01
Phosalone	µg/l	0.01
Pirimiphos-methyl	µg/l	0.01
Propetamphos	µg/l	0.01
Quintozene (PCNB)	µg/l	0.01
Tecnazene	µg/l	0.01
Telodrin	µg/l	0.01
Trans-chlordane	µg/l	0.01
Triadimefon	µg/l	0.01
Triallate	µg/l	0.01
Triazophos	µg/l	0.01
Trifluralin	µg/l	0.01
pH	pH Units	1
Cresols	mg/l	0.006
Phenol	mg/l	0.002
Phenols, Total Detected monohydric	mg/l	0.016
Xylenols	mg/l	0.008
Dissolved solids, Total (meter)	mg/l	5
Organic Carbon, Total	mg/l	3
Oxygen, dissolved	mg/l	0.3
BOD, unfiltered	mg/l	1
Langelier Index (derived) *	N/A	N/A

Appendix 2: cont'd

***Langelier Index (LSI)** LSI = pH – pHs pHs = (9.3 + A + B) – (C + D)

A = ($\log_{10}$[Total Dissolved Solids] – 1)/10

B = -13.12 * log10(Temp^{o}C + 273) + 34.55

C = $\log_{10}$[Ca^{2+} as $CaCO_3^{*}$] – 0.4

D = $\log_{10}$[Alkalinity as $CaCO_3$]

*Calcium was converted to Ca^{2+} as $CaCO_3$ using a conversion factor of 2.5.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

Client:	**Irish Water**
Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
Document Title:	**Data report for Lough Derg Monitoring Project (June 2016 – August 2016)**
Document Number:	**LDMP/R/08**
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1. Introduction

The Lough Derg Monitoring Project technical partnership led by Water Technology Ltd. Are engaged in a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers. The project has been running since April 2015.

2. Results to date

2.1. T300 Water Flow and Current Survey

2.1.1. ADCP Survey

Figure 1 shows horizontal ADCP data from June 2016 to end of August 2016. The data has a daily moving average applied to allow for interpretation. The top panel shows X axis flows across the river channel; consistent flows were seen across all months averaging between -30 to -20 cm/s. Y axis flows also show consistent flows across all three months, with a slight decline shown in August. Flows normally ranged from 0 – 100 cm/s.

Analysis of flow data from vertical ADCP stations show high variability of flow in the top two bins (bins 12 and 13 for OL2 and bins 11 and 12 on OL9) (Figure 2 and Figure 3). Bins for lower depths show little variation, and it appears that most of the water movement in the lake is confined to the surface depths. Comparison of the top bin data with wind direction data from the closest met stations show a relationship between wind direction and flow (Figure 4). Figure 4 shows scatter plots of flow from the surface level bin with wind direction from nearest weather station. A Lowess (LOcally WEighted Scatter-plot Smoother) line has been imposed on the data to decipher trends. Wind direction seems to be driving flows in the lake. This trend was also shown in data from March to May (see Data Report (March – May 2016).

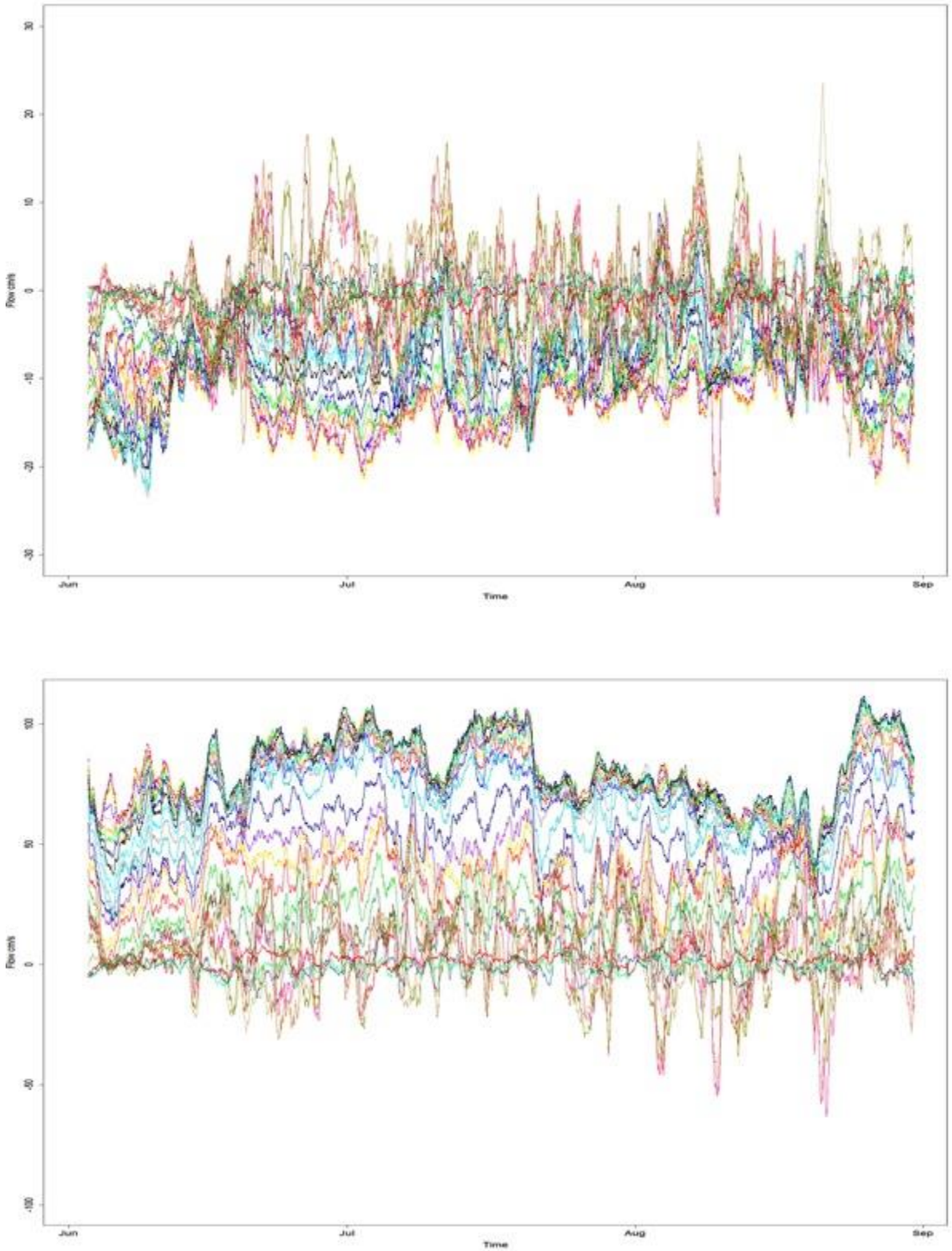


Figure 1: Daily moving average Flow data from Horizontal ADCP cm/s (Top panel shows X axis flows across all bins, Bottom panel shows Y axis flows) from June 2016 – August 2016. Note: Data has been filtered to remove noisy data (>500, < -500).

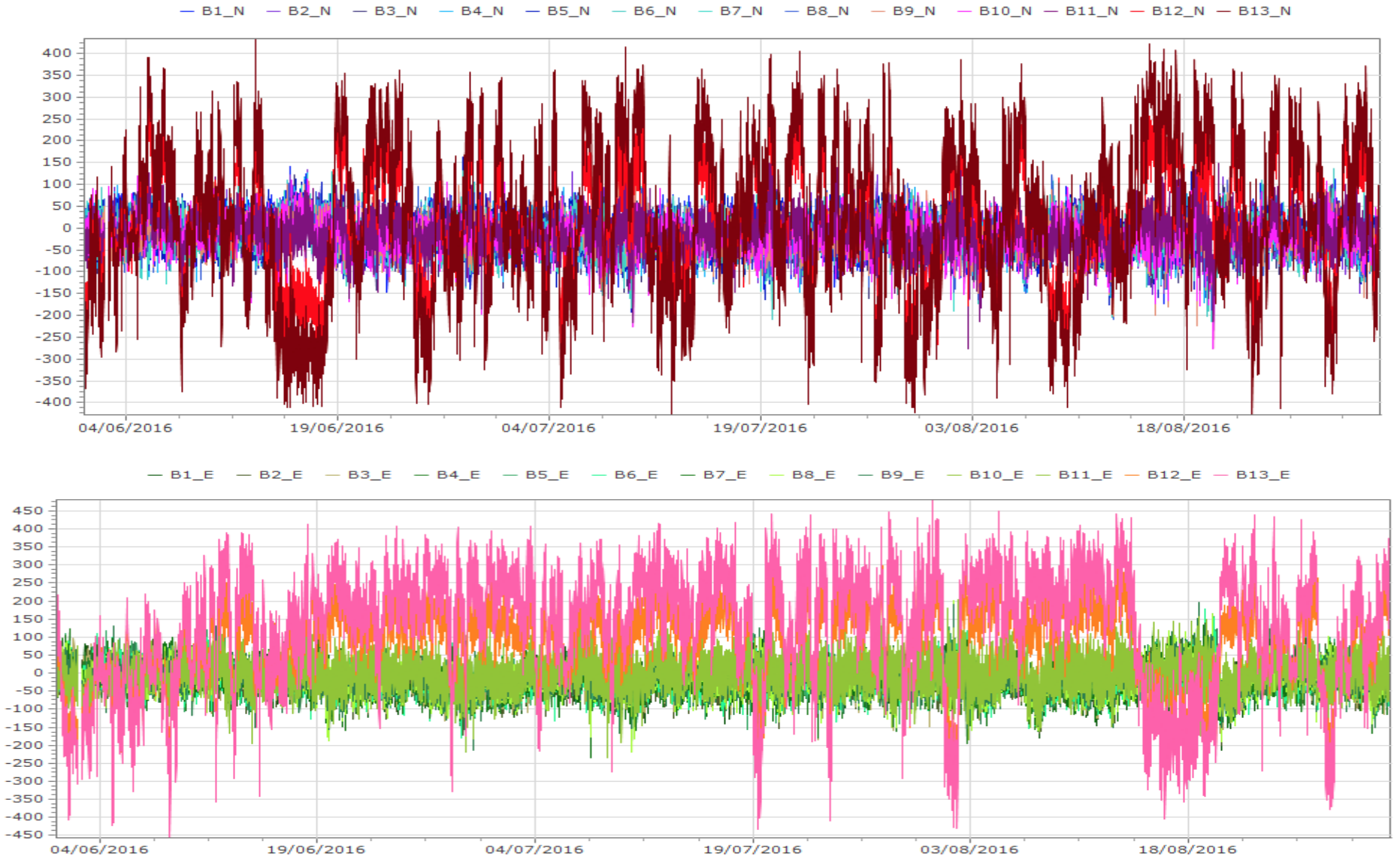


Figure 2: Flow data from OL02 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from June – August 2016.

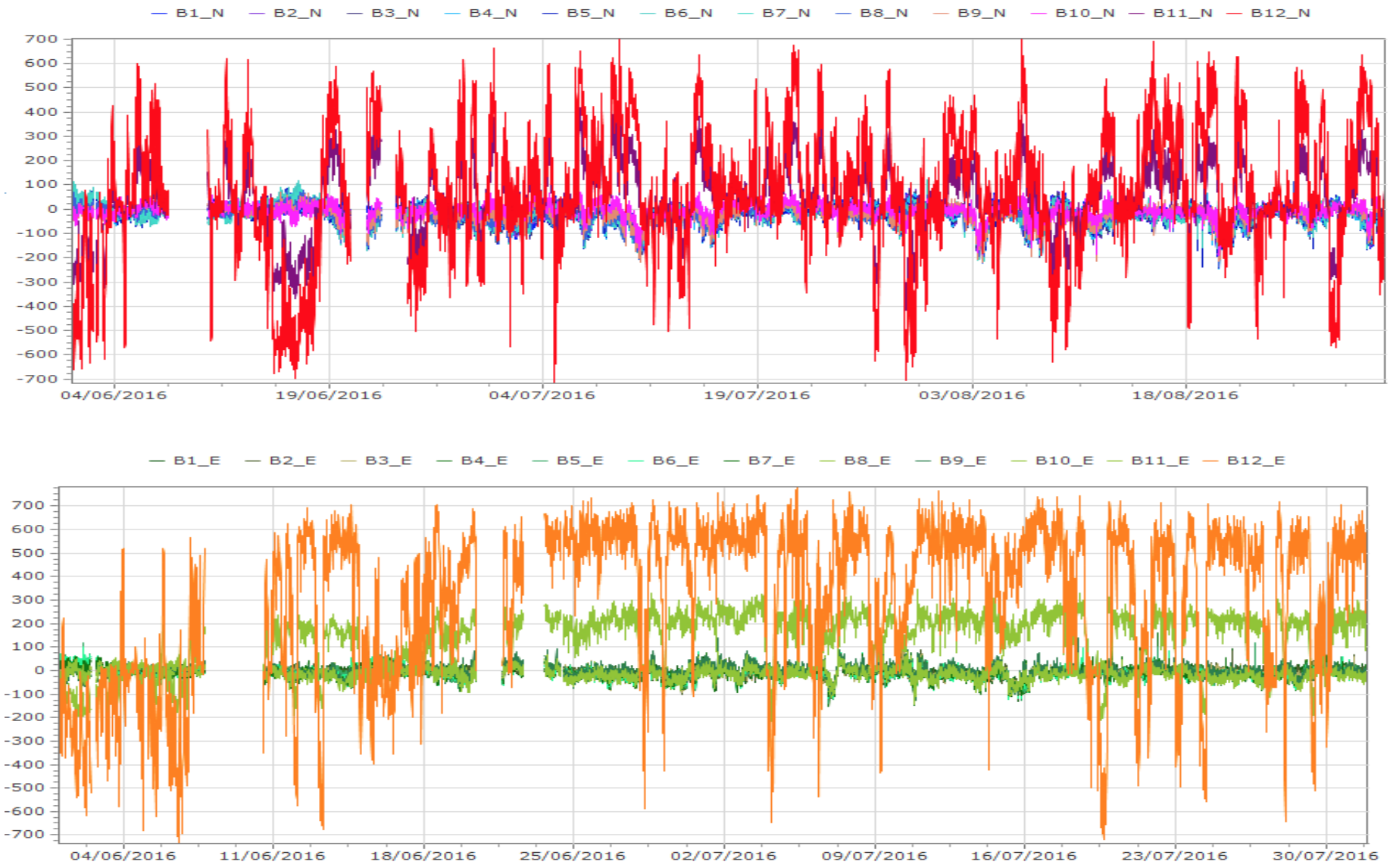


Figure 3: Flow data from OL09 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from June – August 2016.

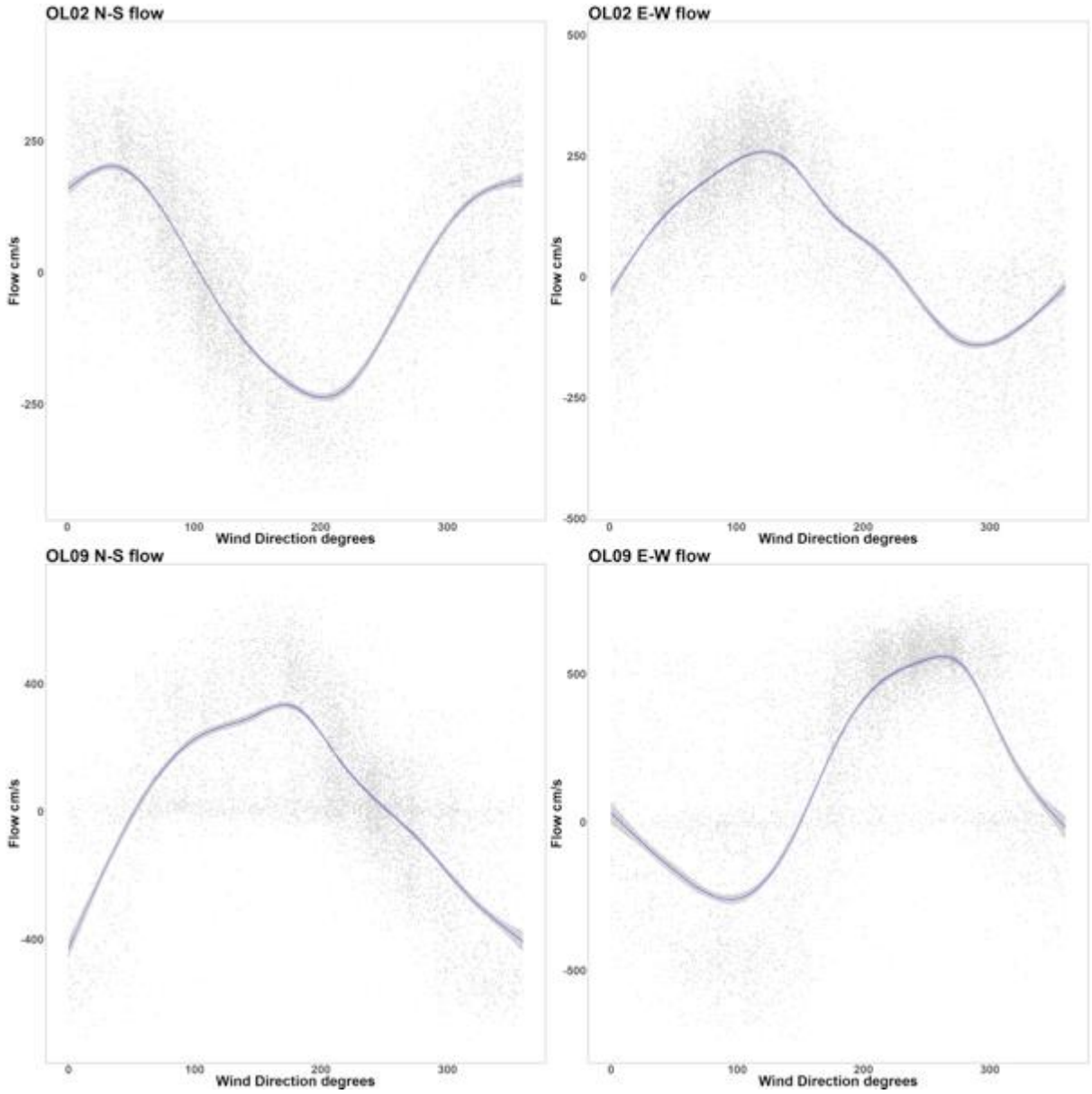


Figure 4: Scatterplots showing flow (y axis) versus Wind direction (x axis) from nearest Weather Station for Stations OL09 and OL02 with a lowess smoother line (blue) imposed.

2.2. T400 Water Level Survey

Level stations are installed at 6 locations (3 lake and 3 river sites). All lake stations show similar patterns of water levels. All stations show a slight dip in water levels in mid June, before increasing throughout July and August. A decrease in water levels occurred at the end of August. Woodford River (SS04) showed little variation throughout the reporting period, with the exception of a slight increase in August. Carraigahorrig River (SS03) displayed low water levels across the reporting period, due to low flow in the river throughout the summer months.

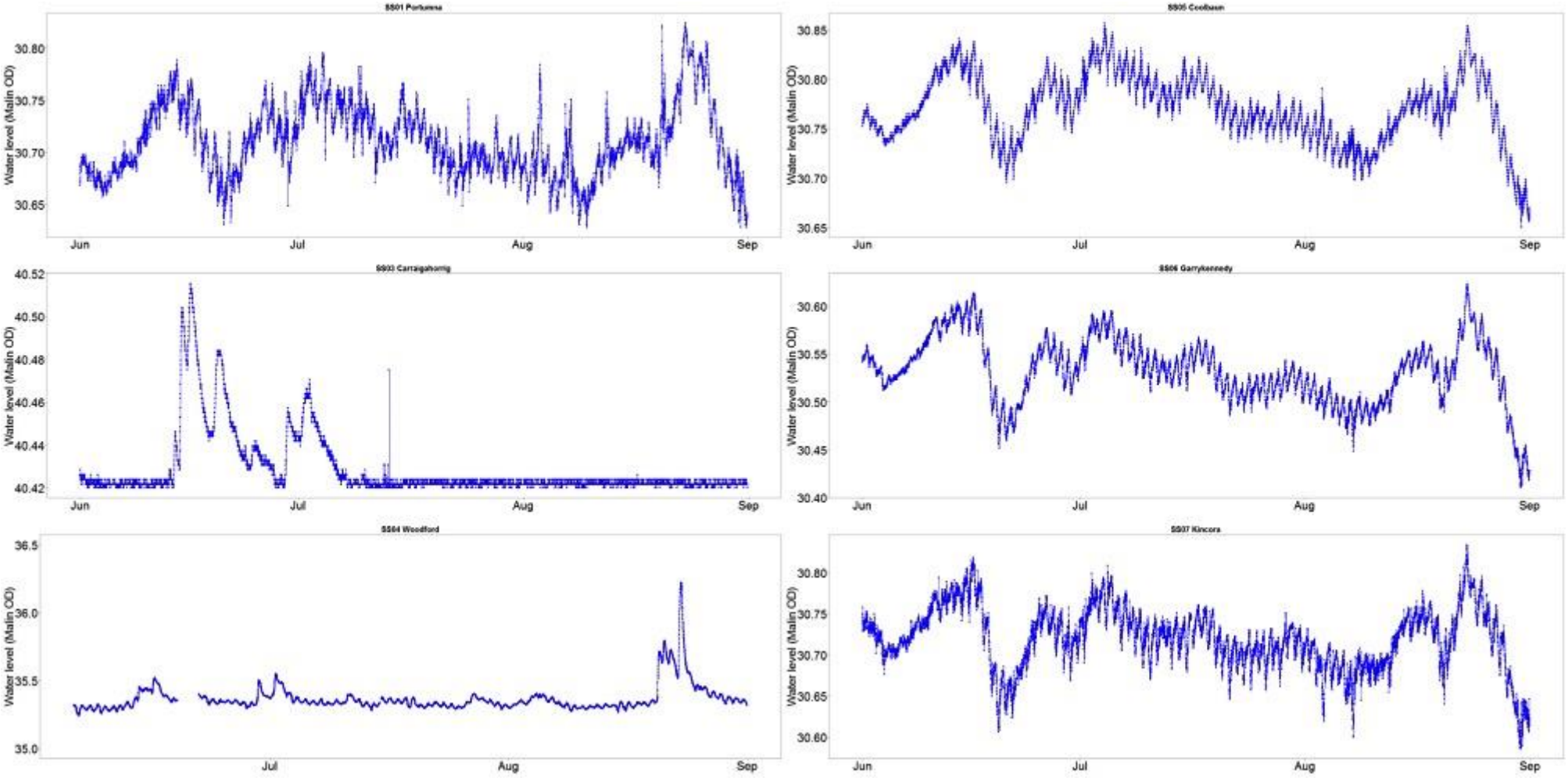


Figure 5: Water level data converted to Malin OD (m) from 6 stations from June 2016 - August 2016.

2.3. T500 Water Quality Survey

2.3.1. In-situ sampling

Five in-situ nutrient analysers are deployed, four at open lake sites and one on the inflowing River Shannon at Portumna Bridge. Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10 show nutrient data from all 5 sites from June – August 2016 with all data below the limit of detection removed. All stations showed a decline in dissolved nitrogen towards the end of the reporting period. This was in line with appearances of large numbers of phytoplankton blooms in the lake and may indicate uptake by algal populations. Phosphate also showed a decline in August across all stations. Many nitrite and ammonia values were below the limit of detection making observations on trends difficult.

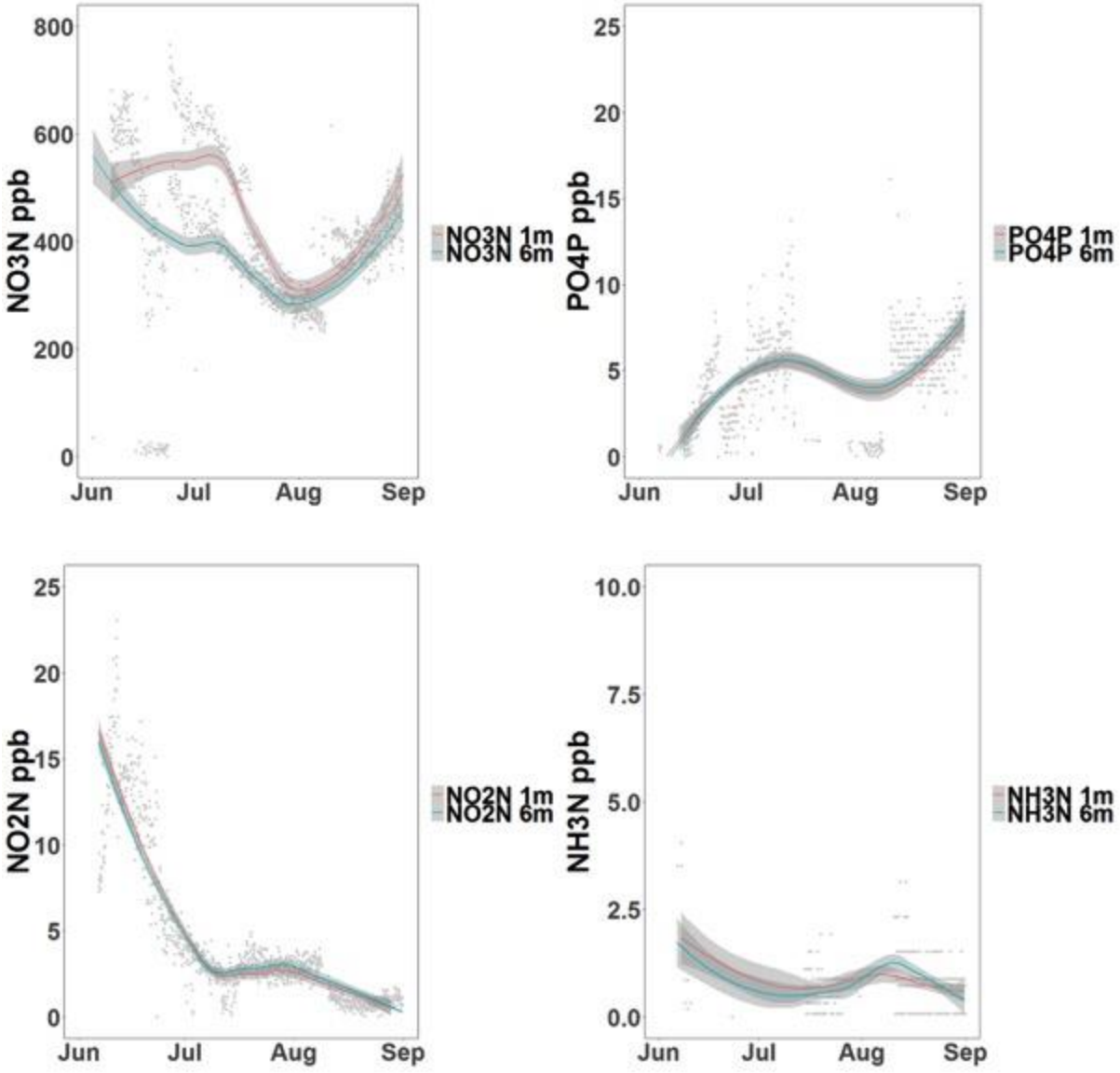


Figure 6: Nutrient Data from OL02 from June -August 2016 (Note some extreme outliers and data below the limit of detection were removed) .

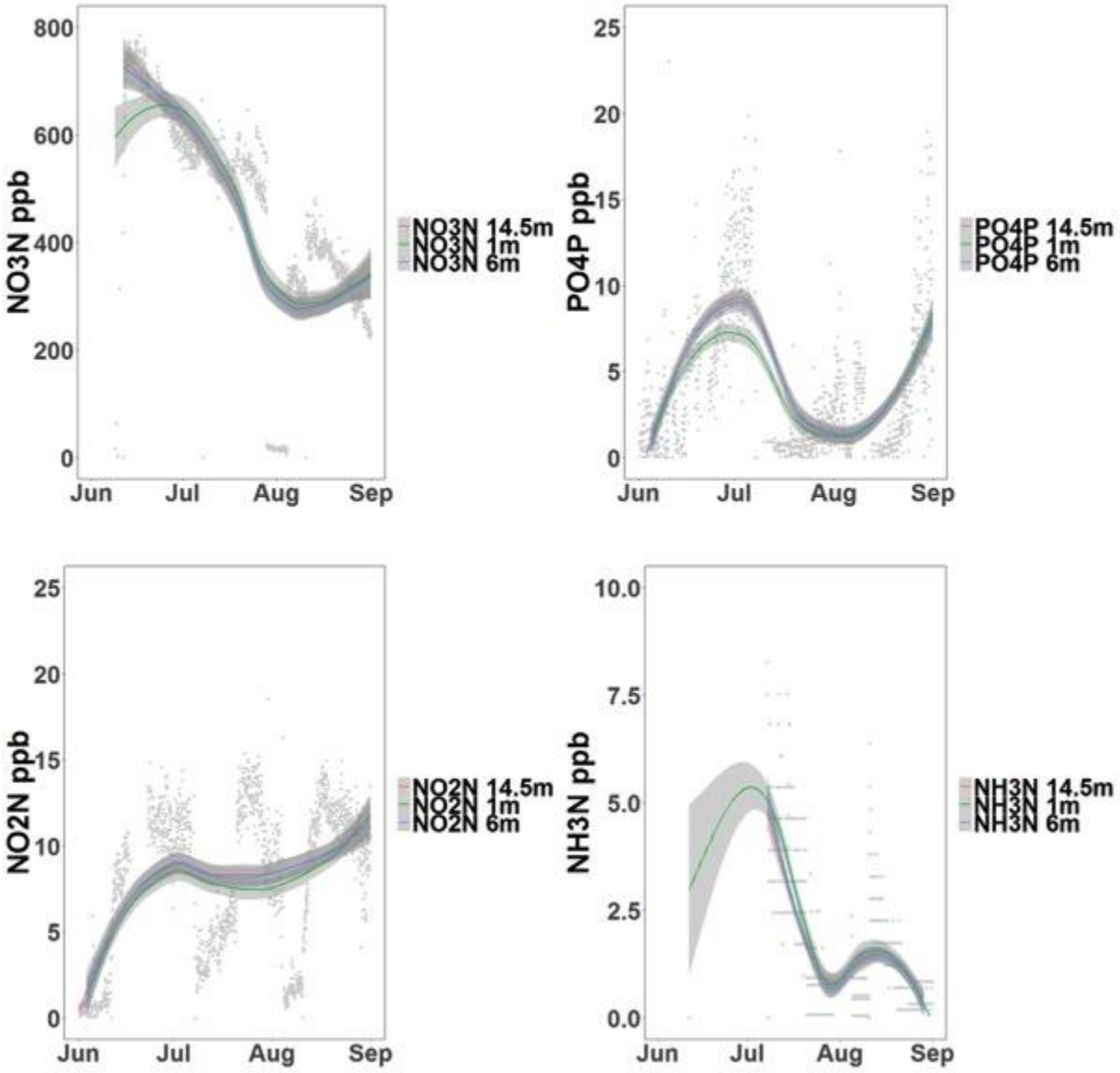


Figure 7: Nutrient Data from OL09 from June - August 2016 (Note some extreme outliers and data below the limit of detection were removed).

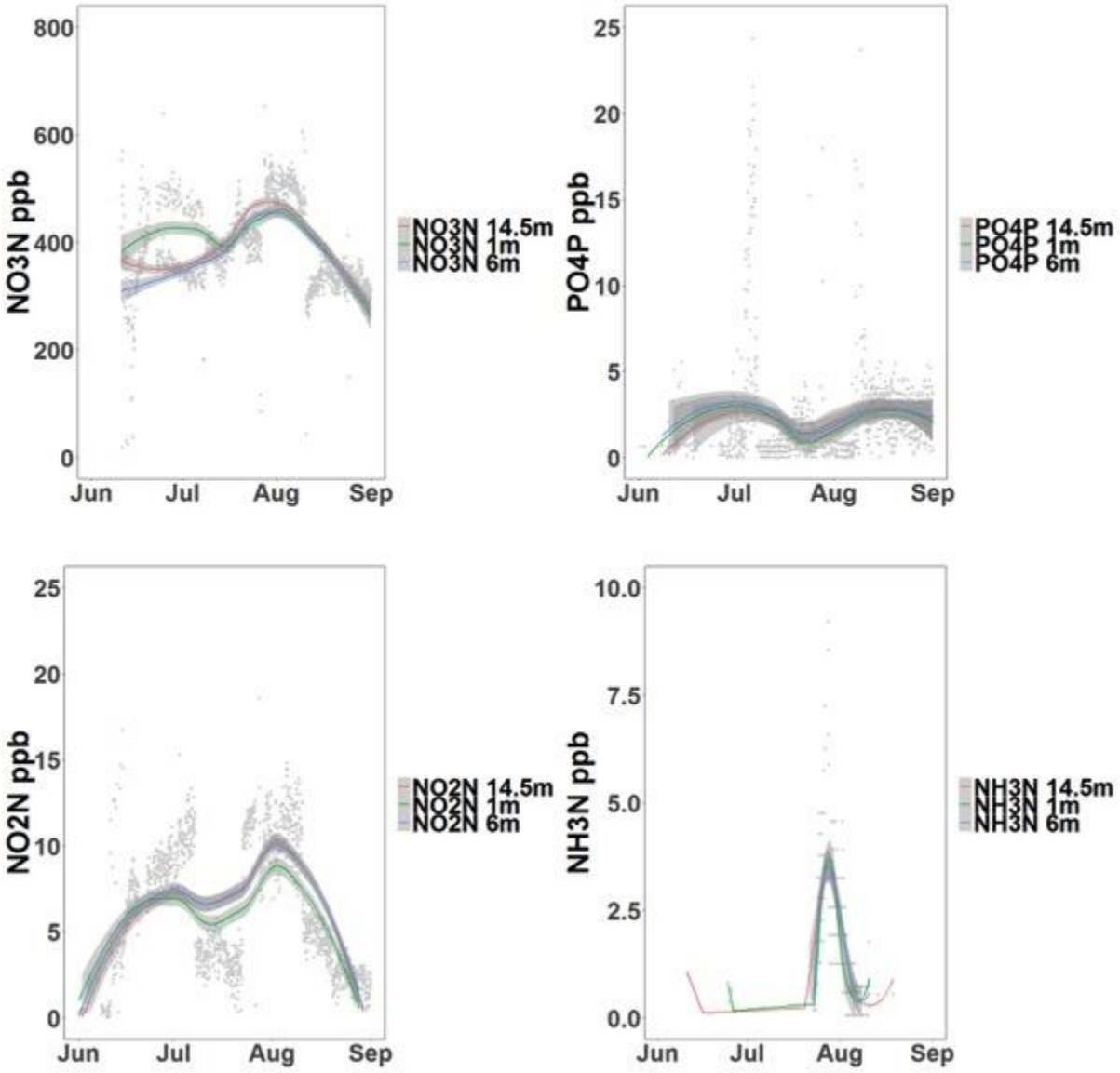


Figure 8: Nutrient Data from OL15 from June - August 2016 (Note some extreme outliers and data below the limit of detection were removed).

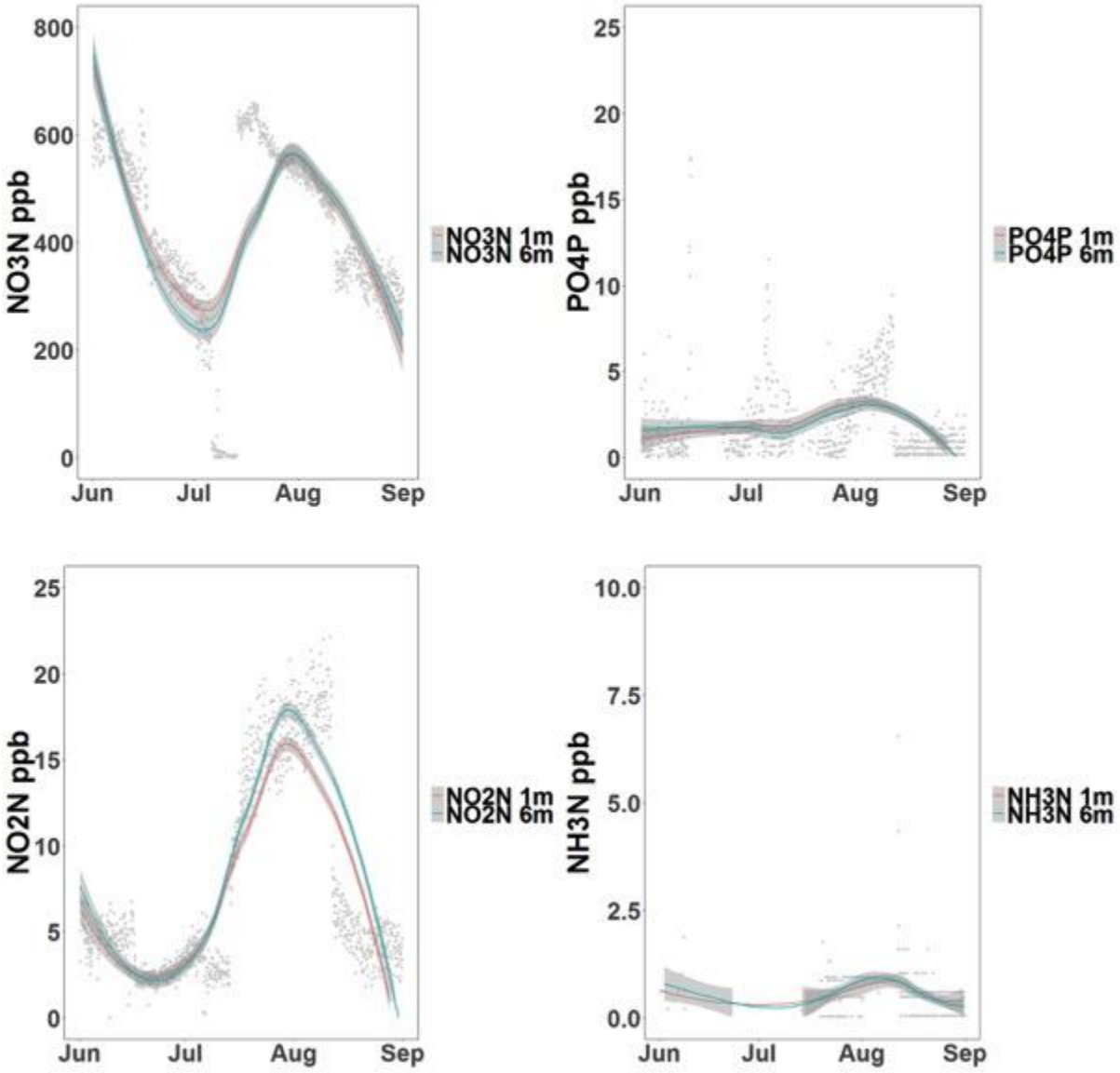


Figure 9: Nutrient Data from OL19 from June - August 2016 (Note some extreme outliers and data below the limit of detection were removed).

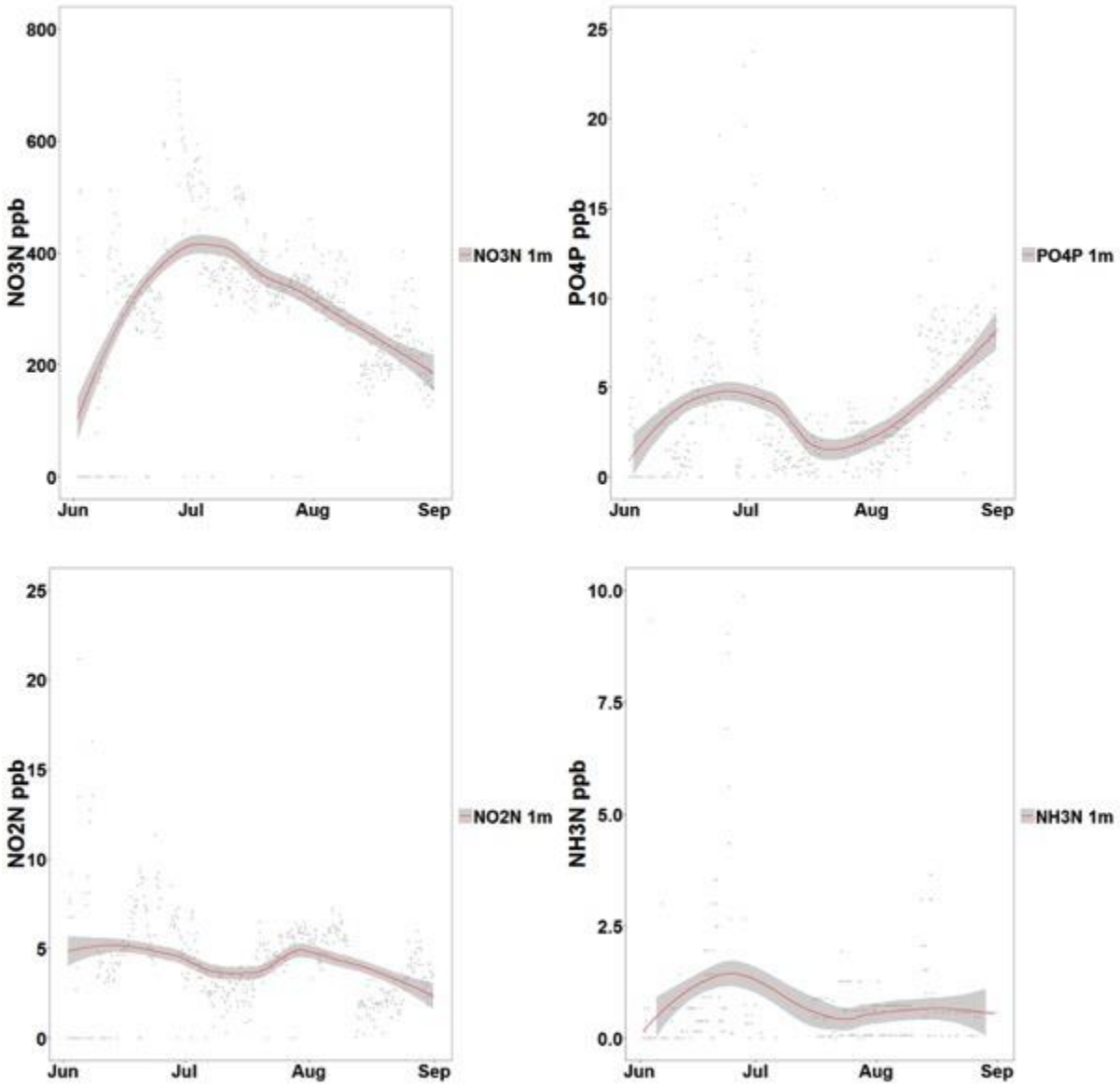


Figure 10: Nutrient Data from SS01 (Portumna Bridge) from June - August 2016 (Note some extreme outliers and data below the limit of detection were removed).

2.3.2. Spot sampling

Water quality surveying of the lake has been ongoing since May 13th 2015. **Figure 11**,

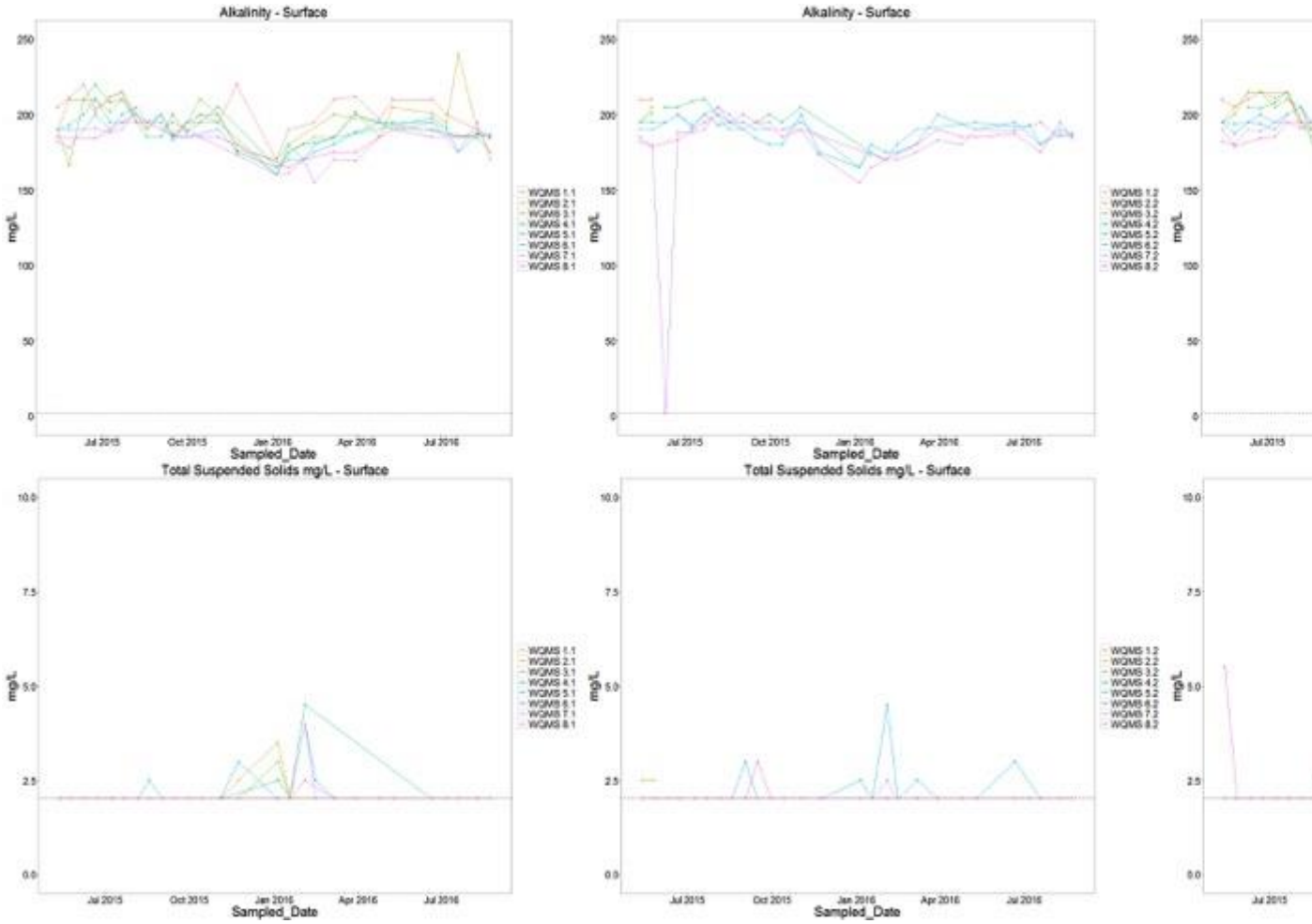


Figure 12*, and*

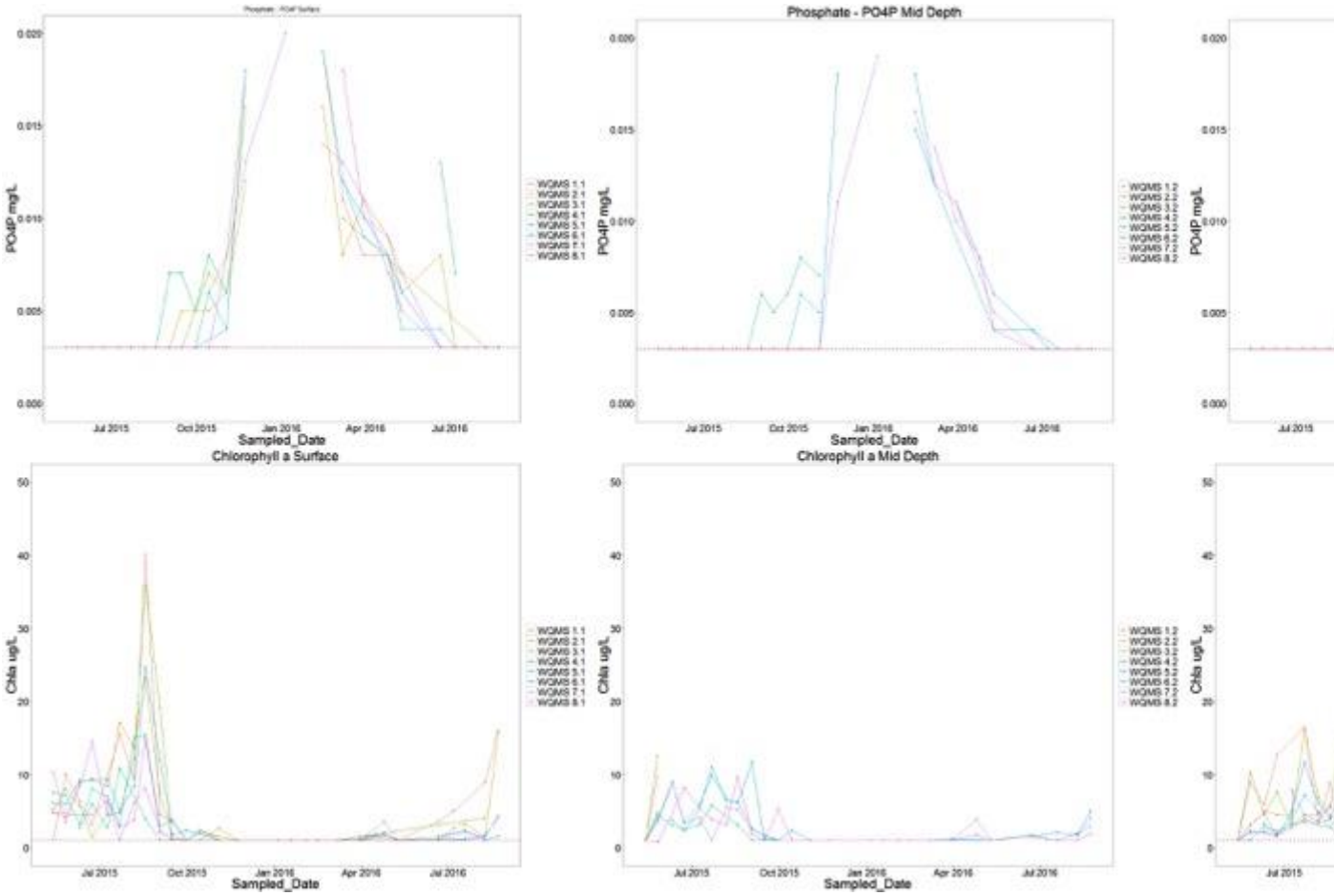


Figure 13 show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate and chlorophyll *a* from water quality sites on Lough Derg at all depths. **Figure *14*** shows the water quality data from all inflowing rivers into Lough Derg. Obvious trends can be seen in nitrate, phosphate and chlorophyll *a* in the lake. Both nitrate and phosphate increase in winter time which is as expected due to high run-off and flows from the surrounding catchments over the winter period. Chlorophyll *a* peaks in late summer/early autumn with higher levels observed at the surface.

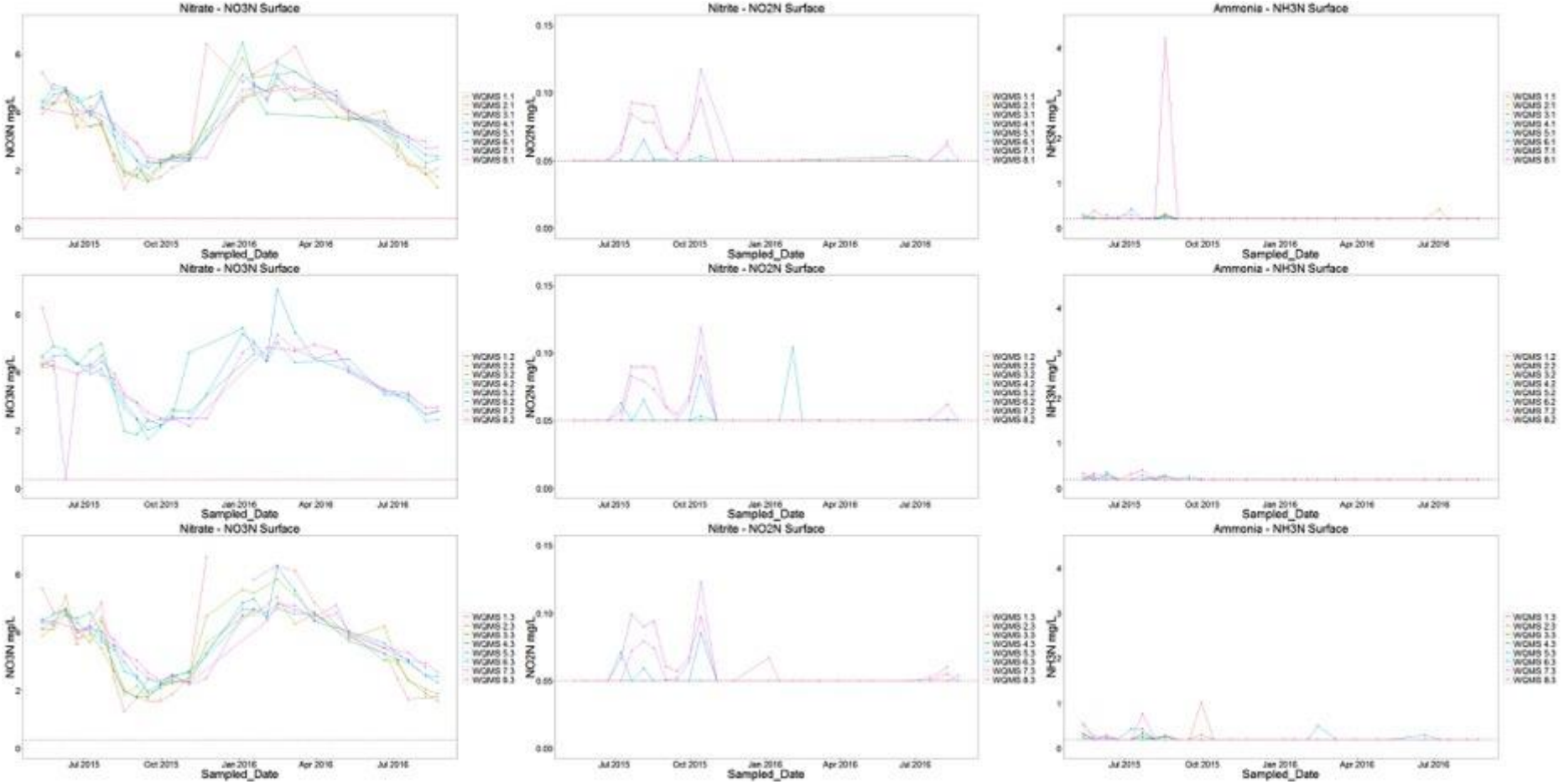


Figure 11: Survey results from all lake water quality sites of nitrate (NO3) nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicated limits of detection of analysis).

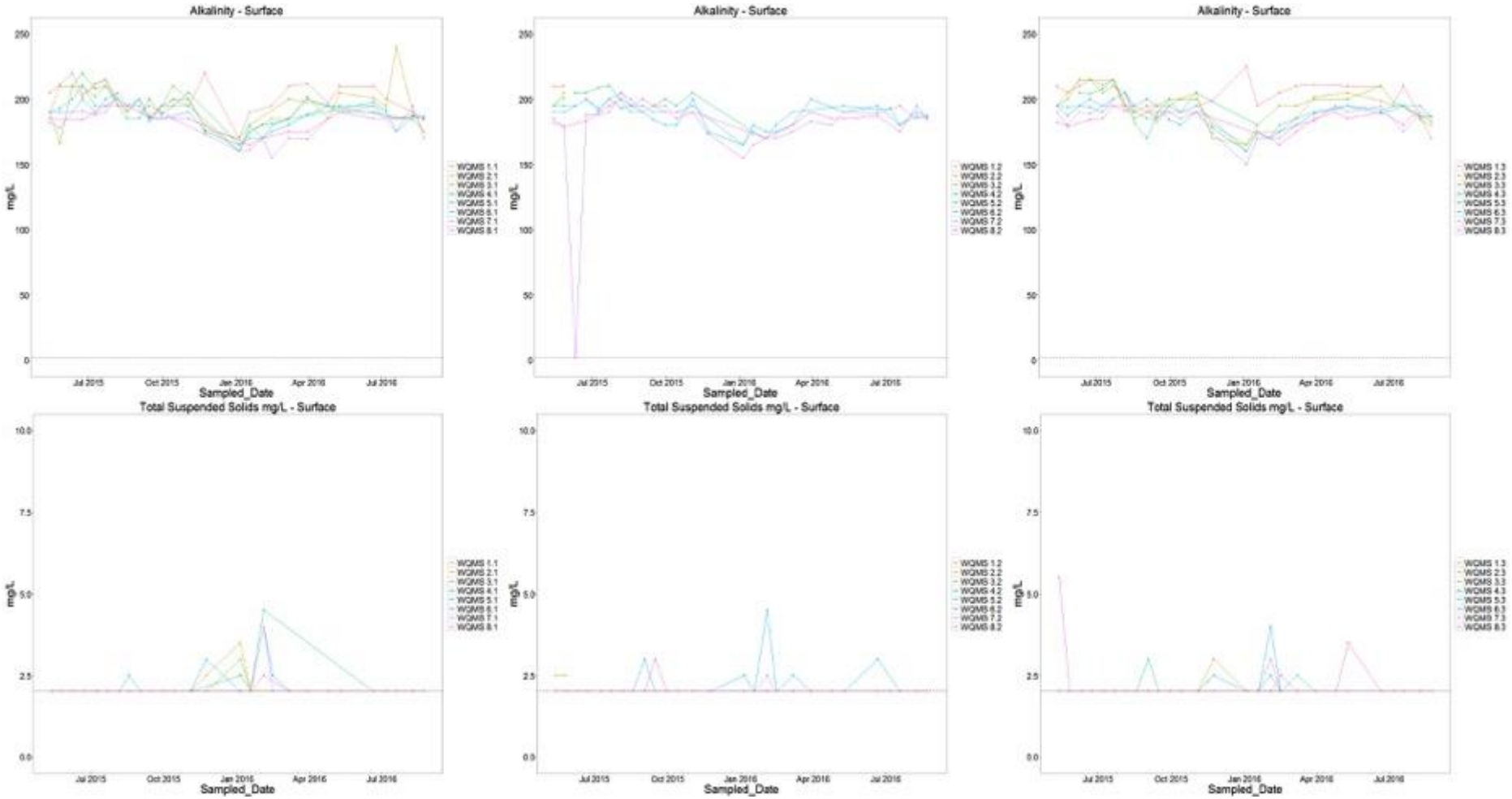


Figure 12: Survey results from all lake water quality sites of Alkalinity and Suspend Solids (Please note red dashed lines indicated limits of detection of analysis).

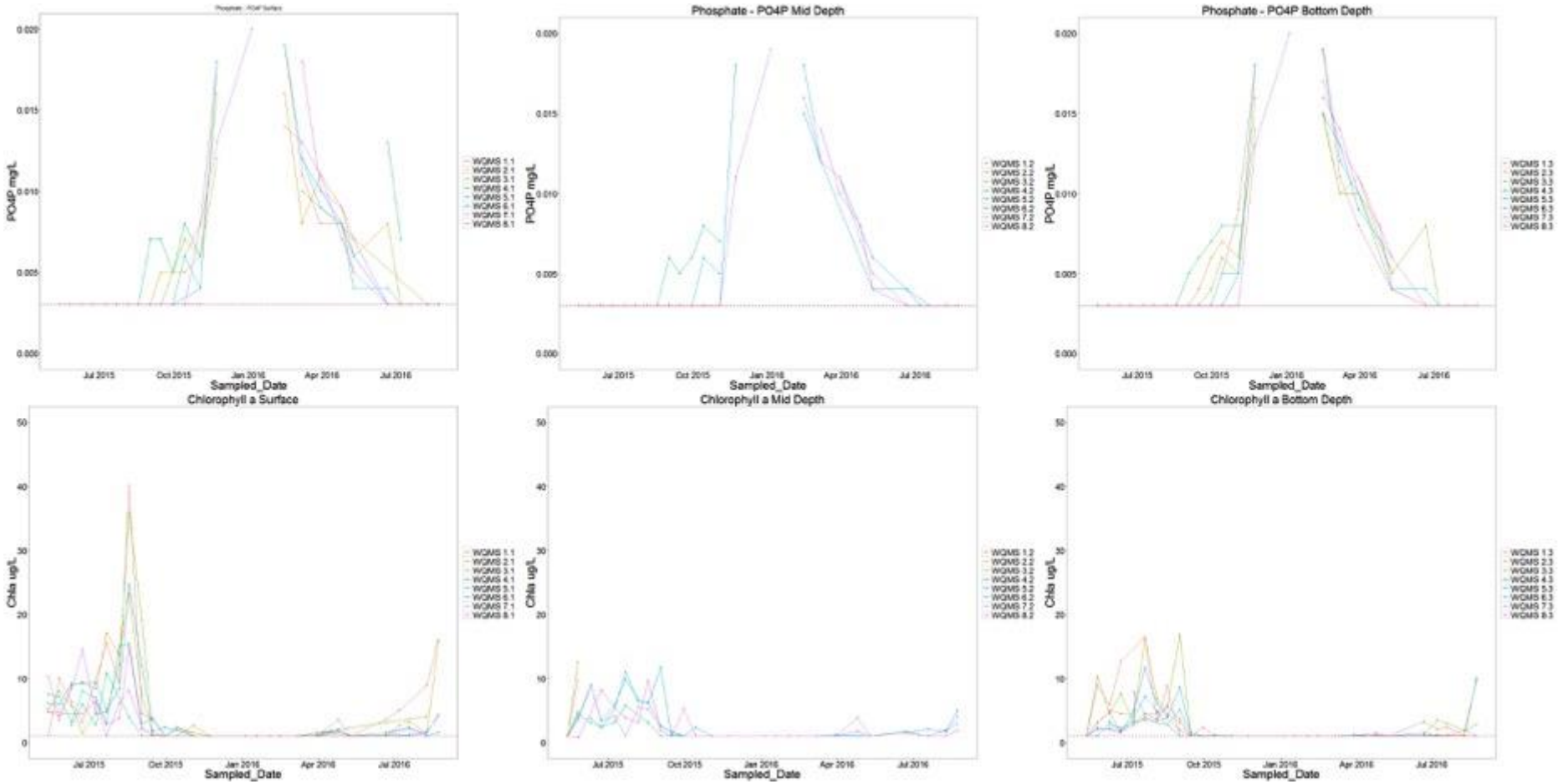


Figure 13: Survey results from all lake water quality sites of Chlorophyll *a* and Phosphate (PO4P) (Please note red dashed lines indicated limits of detection of analysis).

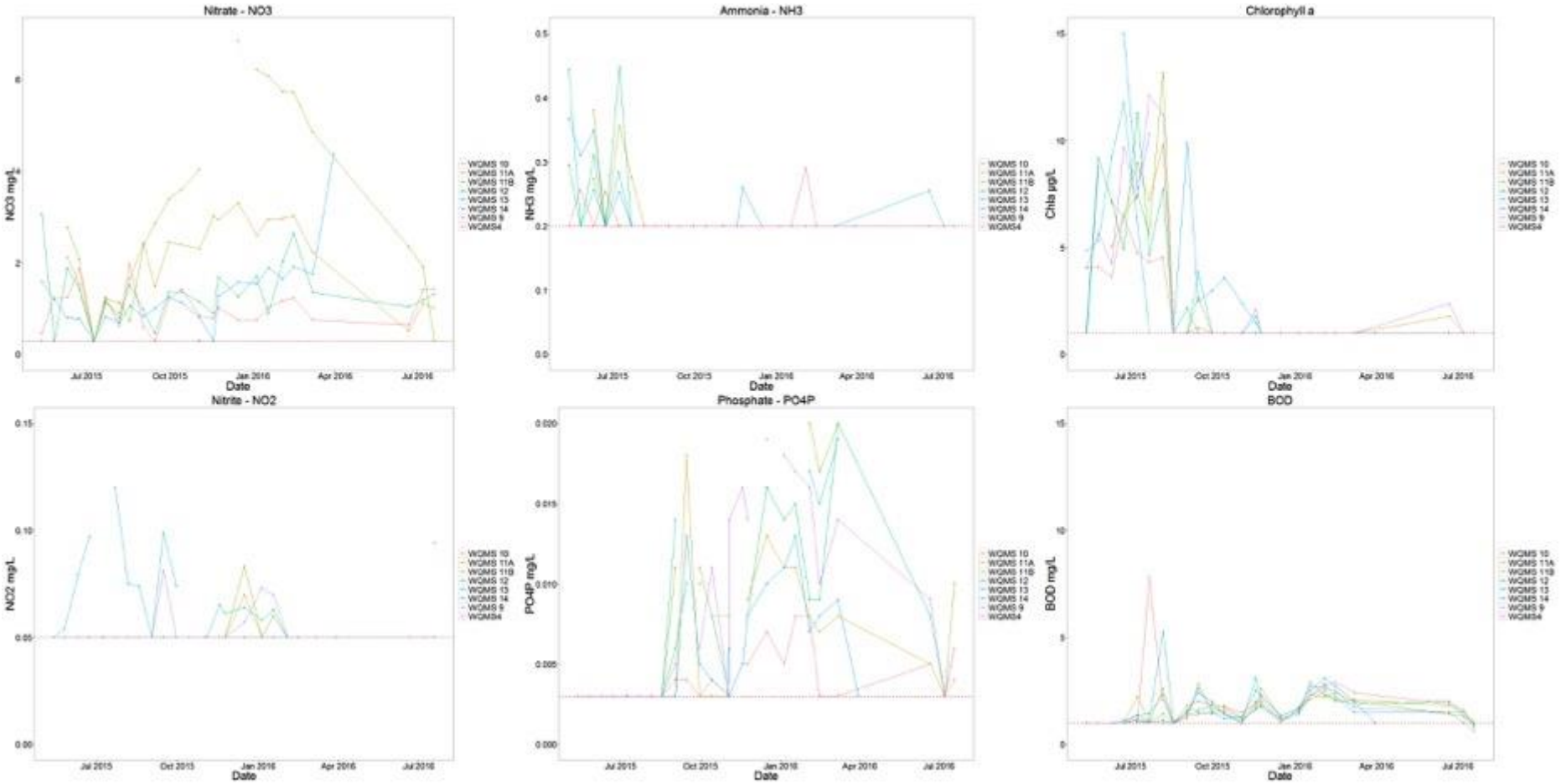


Figure 14: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll *a* and BOD (Please note red dashed lines indicated limits of detection of analysis).

2.4. T 600 Temperature Survey

Nineteen temperature monitoring stations are deployed on Lough Derg. All sites showed similar patterns throughout the reporting period. Figure 15 shows temperature data from OL12 which is located at the deepest location in the lake (~36m). A steep increase in temperature was observed from March to May (See LDMP Report March – May 2016), this trend of high temperature continued from June to August with temperatures at most depths above 15°C (Figure 15). Stratification was evident at the deeper depths (>20m) until mid July. Stratification broke down in mid-July, indicating a period of mixing, which persisted until the end of the reporting period. Figure 16 shows a boxplot of surface level temperatures from the inflow (Portumna) and outflow (Parteen) of the lake. Portumna showed a slightly lower mean temperature than Parteen.

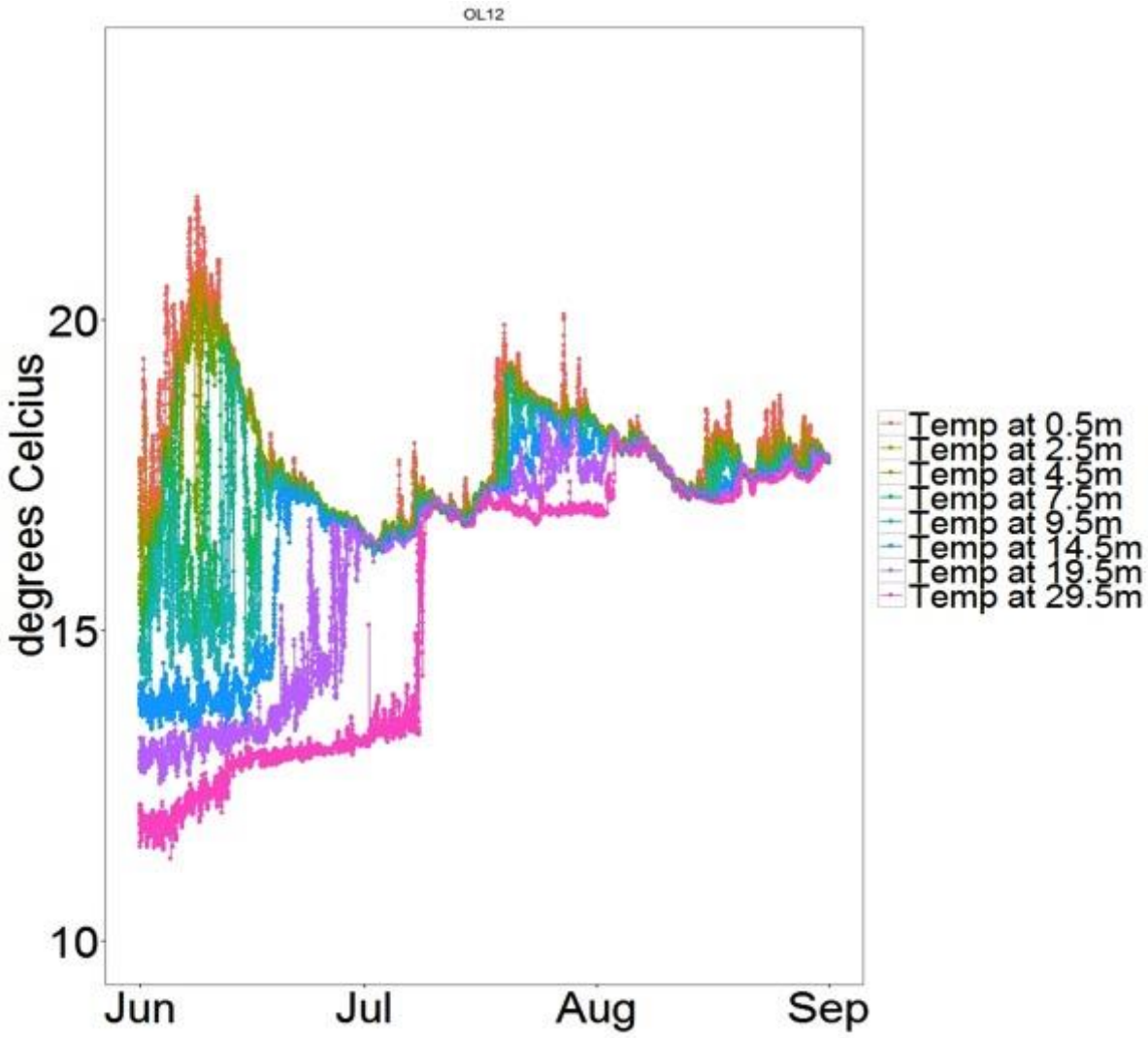


Figure 15: OL12 temperature data from all depths from June 2016 - August 2016.

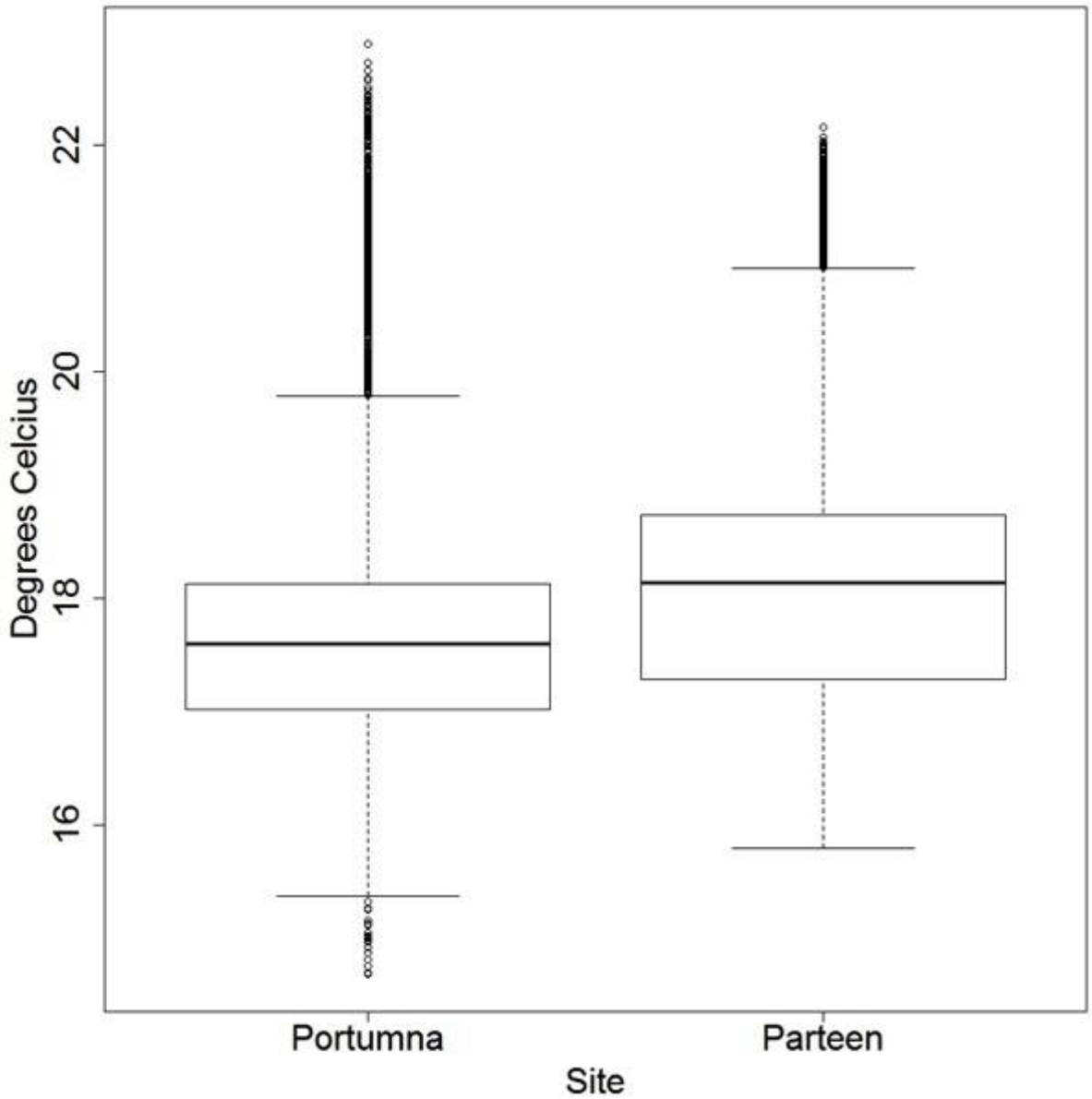


Figure 16: Boxplot showing surface temperatures from Portumna (inflow) and Parteen (outflow) from June 2016 - August 2016.

2.5. T800 Meteorological Survey

Two meteorological stations have been installed on the eastern and western shores of Lough Derg. **Figure *17*** and **Figure *18*** show meteorological data from both stations at Ballinderry and Whitegate. Both stations show similar values for all parameters.

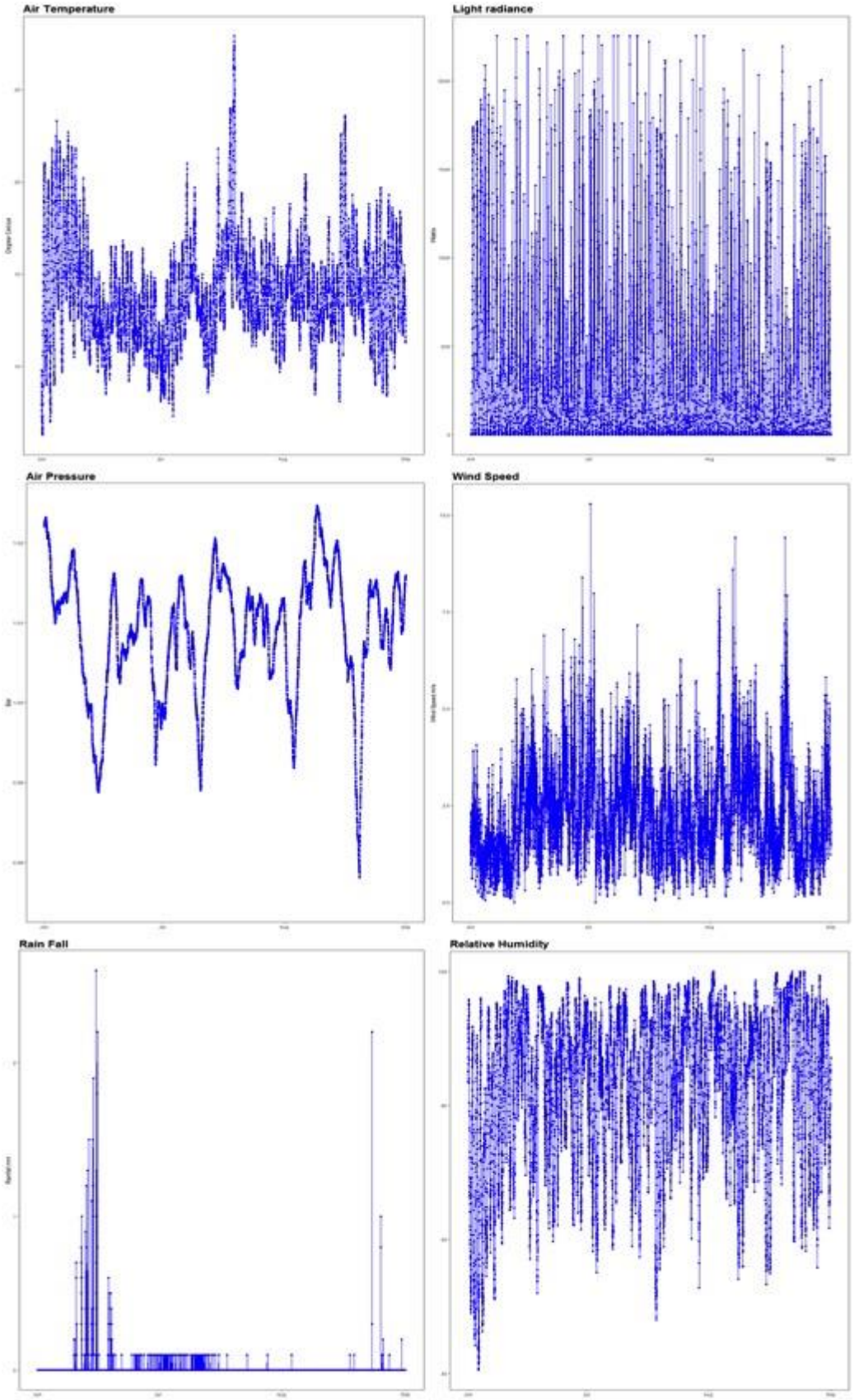


Figure 17: Data from MS01 (Ballinderry) from March 2016 - May 2016.

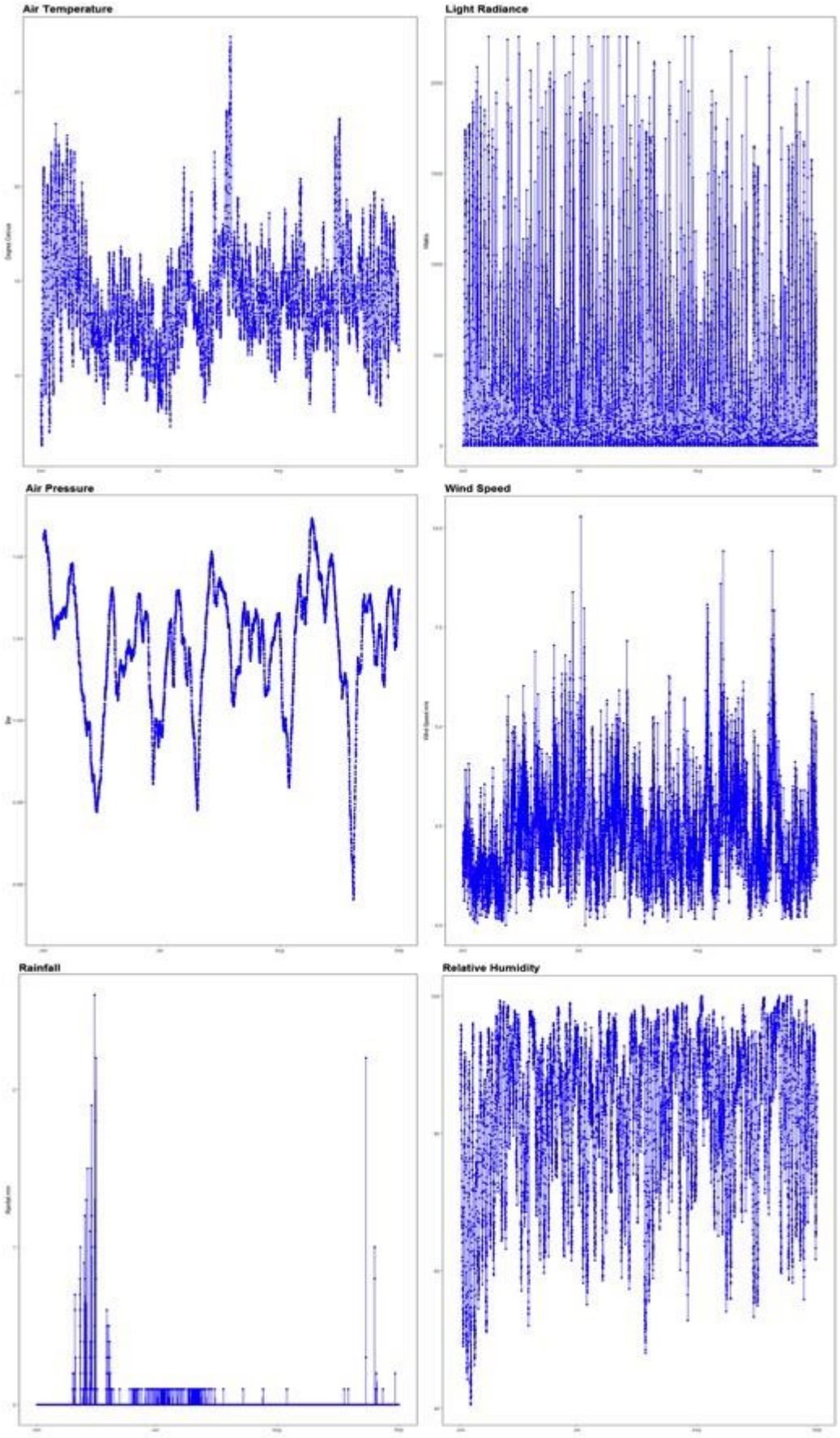


Figure 18: Data from MS02 (Whitegate) from March 2016 - May 2016.

2.6. T900 Plankton Survey

Analysis of plankton data is ongoing. Surface chlorophyll *a* values peaked in late summer/early autumn in 2015. In 2016 chlorophyll *a* values started to increase in April

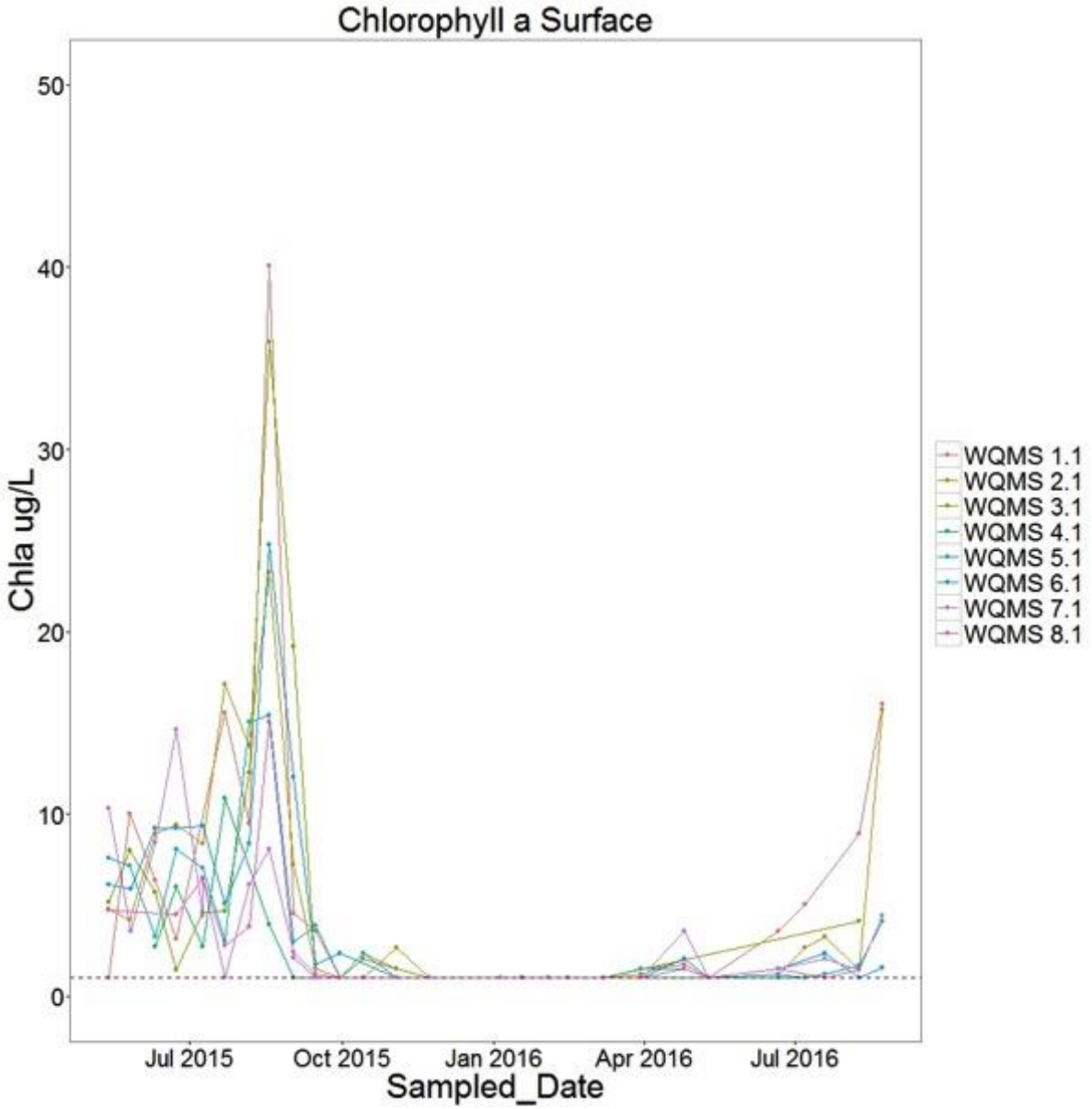


Figure 19: Surface chlorophyll *a* results from all sites from May 2015 - July 2016.

3. Appendices

Appendix 1: Summary of spot sampling for Water Quality, Water Treatability and Ecology.

Sample Date	WQMS - Fortnightly	WTMS- Fortnightly	WTMS- Quarterly	Ecological	Comments
13/05/2015	X	X	X		
15/05/2015				X	
26/05/2015	X	X		X	
10/06/2015	X	X		X	
23/06/2015	X	X		X	
09/07/2015	X	X		X	
22/07/2015	X	X		X	
06/08/2015	X	X	X	X	
12/08/2015-13/08/2015			X		
18/08/2015	X	X		X	
02/09/2015	X	X		X	
15/09/2015	X	X		X	
30/09/2015	X	X		X	
14/10/2015	X	X			
03/11/2015	X	X			
23/11/2015	X	X	X		Parteen basin and WQMS 5 were omitted due to severe weather and/or high flow
05/01/2016	X	X			Parteen basin was omitted due to high flow
18/01/2016	X	X			Parteen basin was omitted due to high flow and a sample was taken from the River Shannon at Kincora Marina
03/02/2016	X	X		X	
15/02/2016	X	X	X	X	
07/03/2016	X	X		X	
16/03/2016	X	X		X	
29/03/2016	X	X		X	
13/04/2016	X	X		X	
25/04/2016	X	X		X	
10/05/2016	X	X	X		
26/05/2016	X	X			
08/06/2016	X	X			
21/06/2016	X	X			
07/07/2016	X	X			
19/07/2016	X	X			
09/08/2016	X	X	X		
23/08/2016	X	X			

Appendix 2: List of quarterly water treatability parameters with limits of detection.

Test	Result Units	Limit of detection
Alkalinity, Total as CaCO3	mg/l	2
Bromine*	mg/l	0.1
COD, unfiltered	mg/l	7
Cyanide, Total	mg/l	0.05
Conductivity @ 20 deg.C	mS/cm	0.005
Total EPH (C6-C40) (aq)	µg/l	100
EPH Range >C10 - C40 (aq)	µg/l	46
Fluoride	mg/l	0.5
Benzene	µg/l	7
EPH (C6-C10)	µg/l	100
Ethylbenzene	µg/l	5
GRO >C5-C10	µg/l	10
m,p-Xylene	µg/l	8
Methyl tertiary butyl ether (MTBE)	µg/l	3
o-Xylene	µg/l	3
Sum of detected BTEX	µg/l	28
Toluene	µg/l	4
Mercury (diss.filt)	µg/l	0.01
Aluminium (diss.filt)	µg/l	2.9
Arsenic (diss.filt)	µg/l	0.12
Barium (diss.filt)	µg/l	0.03
Boron (diss.filt)	µg/l	9.4
Cadmium (diss.filt)	µg/l	0.1
Chromium (diss.filt)	µg/l	0.22
Copper (diss.filt)	µg/l	0.85
Lead (diss.filt)	µg/l	0.02
Manganese (diss.filt)	µg/l	0.04
Nickel (diss.filt)	µg/l	0.15
Selenium (diss.filt)	µg/l	0.39
Zinc (diss.filt)	µg/l	0.41
Nitrogen, Kjeldahl	mg/l	1
Chloride	mg/l	2
Sulphate	mg/l	2
Total Oxidised Nitrogen as N	mg/l	0.1
Surfactants, Anionic (MBAS)	mg/l	0.05
Calcium (diss.filt)	mg/l	0.012
Iron (diss.filt)	mg/l	0.019
Nitrogen, Total	mg/l	1
Acenaphthene (aq)	µg/l	0.015
Acenaphthylene (aq)	µg/l	0.011
Anthracene (aq)	µg/l	0.015

Appendix 2: cont'd

Test	Result Units	Limit of detection
Benzo(a)anthracene (aq)	µg/l	0.017
Benzo(a)pyrene (aq)	µg/l	0.009
Benzo(b)fluoranthene (aq)	µg/l	0.023
Benzo(g,h,i)perylene (aq)	µg/l	0.016
Benzo(k)fluoranthene (aq)	µg/l	0.027
Chrysene (aq)	µg/l	0.013
Dibenzo(a,h)anthracene (aq)	µg/l	0.016
Fluoranthene (aq)	µg/l	0.017
Fluorene (aq)	µg/l	0.014
Indeno(1,2,3-cd)pyrene (aq)	µg/l	0.014
Naphthalene (aq)	µg/l	0.1
PAH, Total Detected USEPA 16 (aq)	µg/l	0.344
Phenanthrene (aq)	µg/l	0.022
Pyrene (aq)	µg/l	0.015
Aldrin	µg/l	0.01
alpha-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Azinphos-ethyl	µg/l	0.01
Azinphos-methyl	µg/l	0.01
beta-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Carbophenothion	µg/l	0.01
Chlorfenvinphos	µg/l	0.01
Chlorothalonil	µg/l	0.01
Chlorpyriphos	µg/l	0.01
Chlorpyriphos methyl	µg/l	0.01
cis-Chlordane	µg/l	0.01
Diazinon	µg/l	0.01
Dichlorvos	µg/l	0.01
Dieldrin	µg/l	0.01
Dimethoate	µg/l	0.01
Disulfoton	µg/l	0.01
Endosulphan I	µg/l	0.01
Endosulphan II	µg/l	0.01
Endosulphan sulphate	µg/l	0.01
Endrin	µg/l	0.01
Ethion	µg/l	0.01
Etrimphos	µg/l	0.01
Fenitrothion	µg/l	0.01
Fenthion	µg/l	0.01
gamma-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Heptachlor	µg/l	0.01

Appendix 2: cont'd

Test	Result Units	Limit of detection
Heptachlor epoxide	µg/l	0.01
Hexachlorobenzene	µg/l	0.01
Isodrin	µg/l	0.01
Malathion	µg/l	0.01
Methyl parathion	µg/l	0.01
Mevinphos	µg/l	0.01
o,p-DDE	µg/l	0.01
o,p-DDT	µg/l	0.01
o,p-Methoxychlor	µg/l	0.01
o,p-TDE (DDD)	µg/l	0.01
p,p-DDE	µg/l	0.01
p,p-DDT	µg/l	0.01
p,p-Methoxychlor	µg/l	0.01
p,p-TDE (DDD)	µg/l	0.01
Parathion	µg/l	0.01
Pendimethalin	µg/l	0.01
Permethrin I	µg/l	0.01
Permethrin II	µg/l	0.01
Phosalone	µg/l	0.01
Pirimiphos-methyl	µg/l	0.01
Propetamphos	µg/l	0.01
Quintozene (PCNB)	µg/l	0.01
Tecnazene	µg/l	0.01
Telodrin	µg/l	0.01
Trans-chlordane	µg/l	0.01
Triadimefon	µg/l	0.01
Triallate	µg/l	0.01
Triazophos	µg/l	0.01
Trifluralin	µg/l	0.01
pH	pH Units	1
Cresols	mg/l	0.006
Phenol	mg/l	0.002
Phenols, Total Detected monohydric	mg/l	0.016
Xylenols	mg/l	0.008
Dissolved solids, Total (meter)	mg/l	5
Organic Carbon, Total	mg/l	3
Oxygen, dissolved	mg/l	0.3
BOD, unfiltered	mg/l	1
Langelier Index (derived) *	N/A	N/A

Appendix 2: cont'd

***Langelier Index (LSI)** LSI = pH – pHs pHs = (9.3 + A + B) – (C + D)

A = ($\log_{10}$[Total Dissolved Solids] – 1)/10

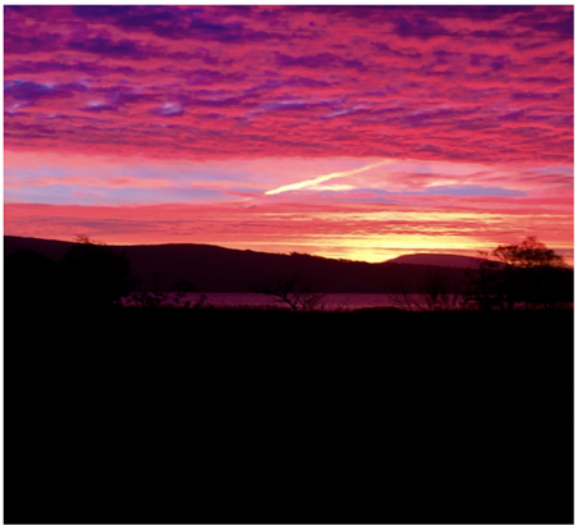
B = -13.12 * log10(Temp°C + 273) + 34.55

C = $\log_{10}$[Ca^{2+} as $CaCO_3^*$] – 0.4

D = $\log_{10}$[Alkalinity as $CaCO_3$]

*Calcium was converted to Ca^{2+} as $CaCO_3$ using a conversion factor of 2.5.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)



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1. Introduction

The Lough Derg Monitoring Project technical partnership led by Water Technology Ltd. Are engaged in a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers. The project has been running since April 2015.

2. Results to date

2.1. T300 Water Flow and Current Survey

2.1.1. ADCP Survey

Figure 1 shows horizontal ADCP data from September 2016 to end of November 2016.

As with previous reporting periods analysis of flow data from vertical ADCP stations show high variability of flow in the top two bins (bins 12 and 13 for OL2 and bins 11 and 12 on OL9) (
Figure *2* and **Figure 3**). Bins for lower depths show little variation, and it appears that most of the water movement in the lake is confined to the surface depths. Comparison of the top bin data with wind direction data from the closest met stations show a relationship between wind direction and flow (
Figure *4*).
Figure *4* shows scatter plots of flow from the surface level bin with wind direction from nearest weather station. A Lowess (LOcally WEighted Scatter-plot Smoother) line has been imposed on the data to decipher trends. Wind direction seems to be driving surface flows in the lake. This trend was also shown in data from previous reporting periods.

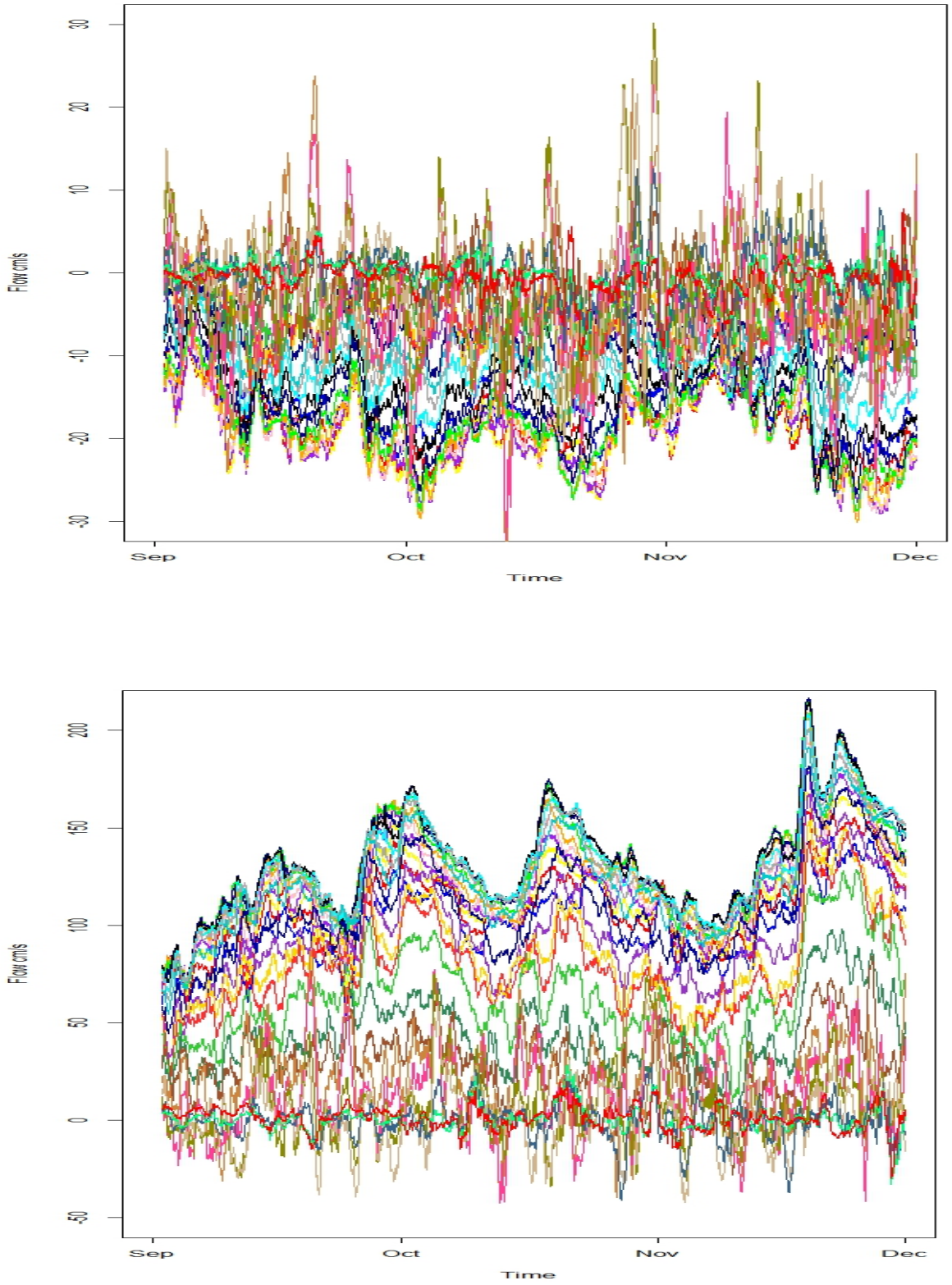

Figure 1: Daily moving average Flow data from Horizontal ADCP cm/s (Top panel shows X axis flows across all bins, Bottom panel shows Y axis flows) from September 2016 – November 2016. Note: Data has been filtered to remove noisy data (>500, < -500).

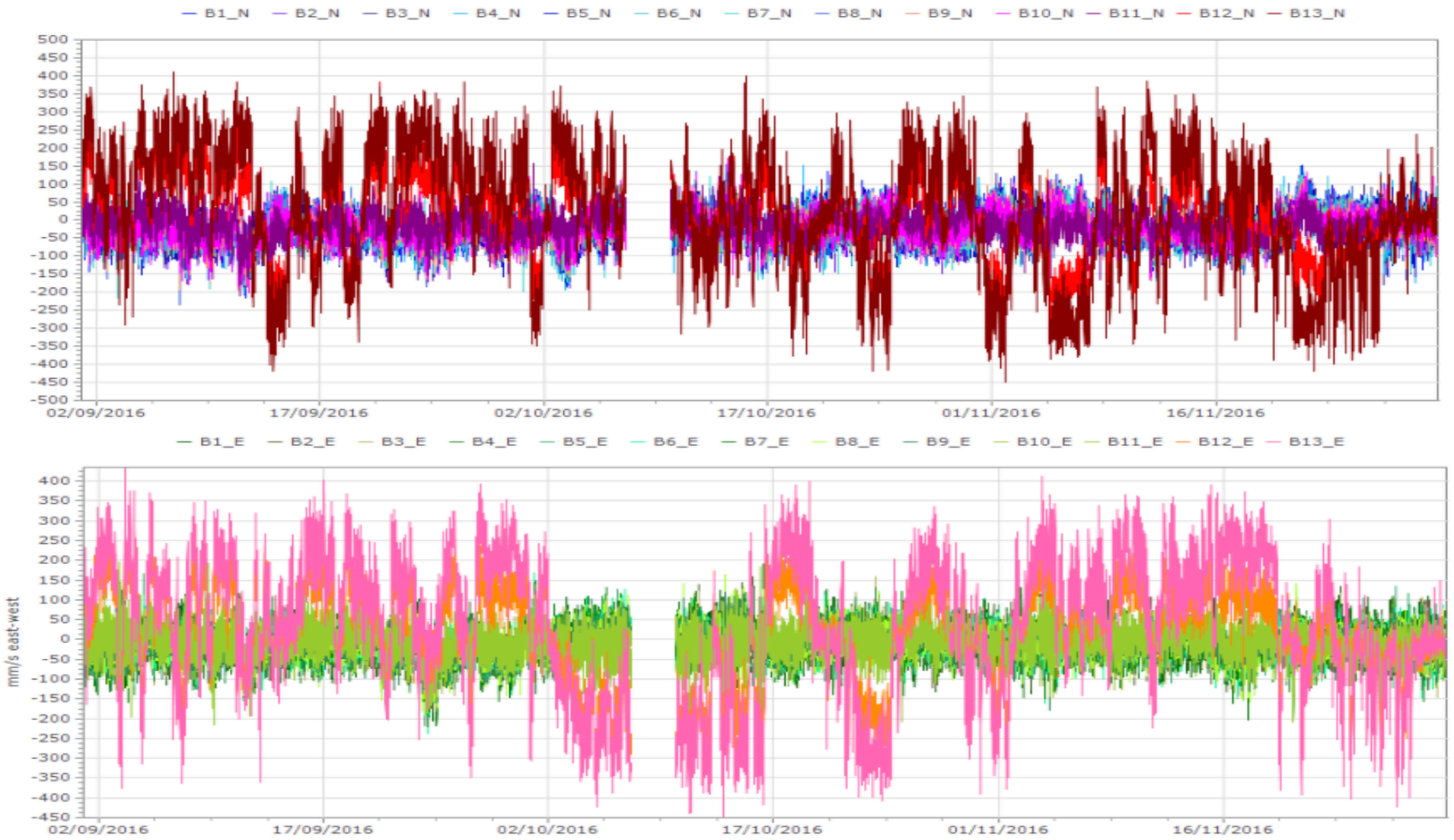

Figure 2: Flow data from OL02 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from September – November 2016.

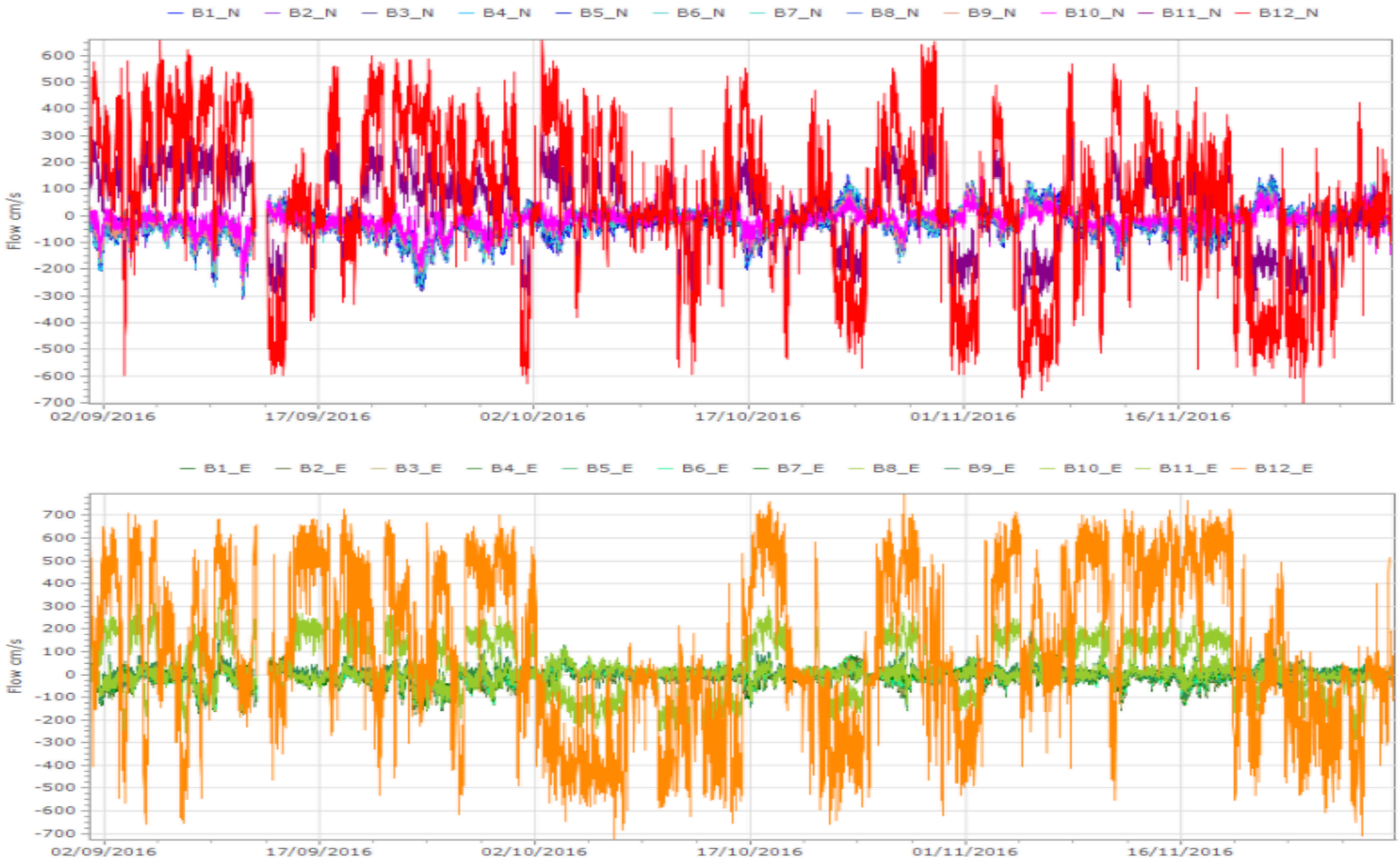

Figure 3: Flow data from OL09 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from September – November 2016.

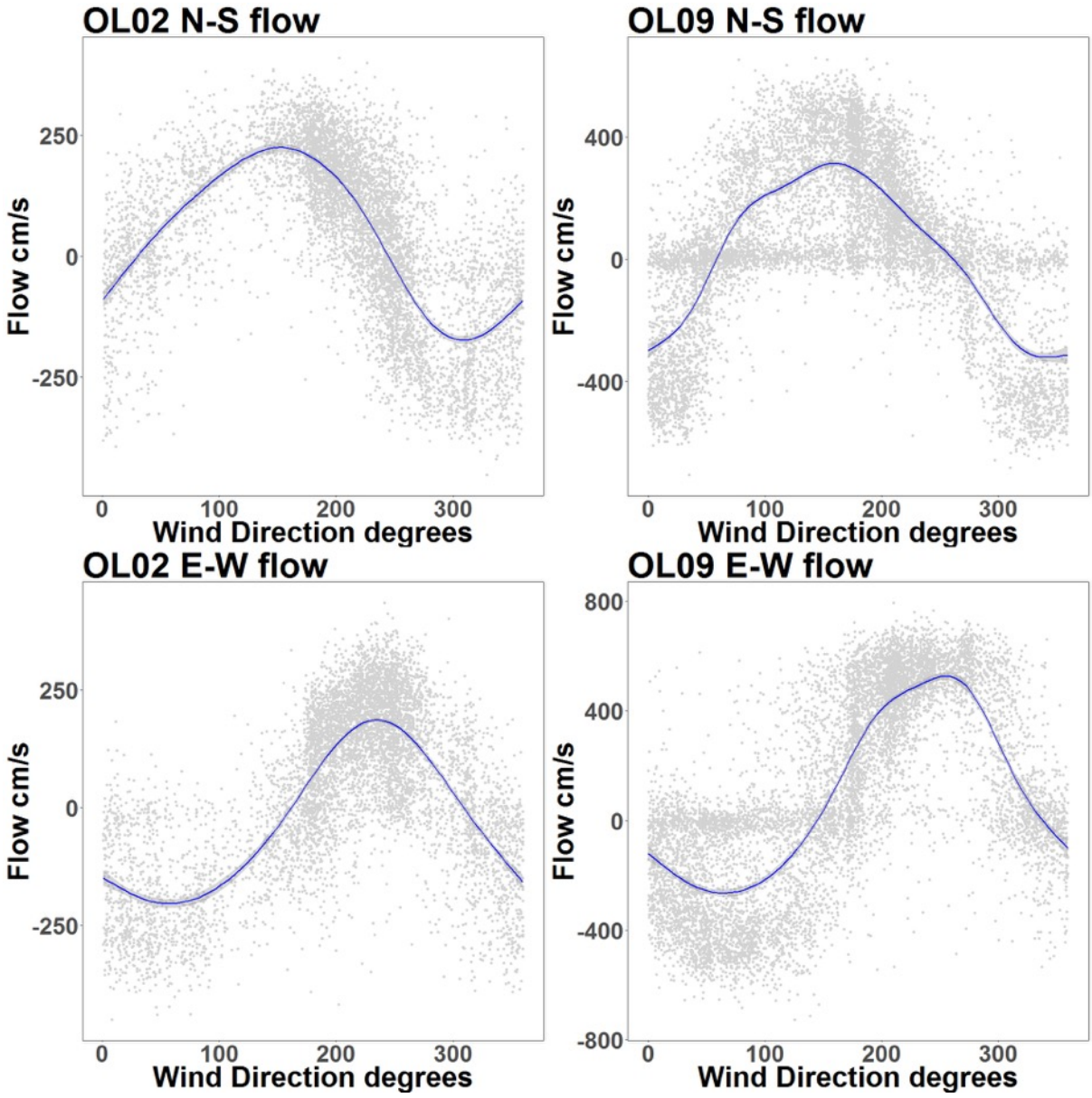

Figure 4: Scatterplots showing flow (y axis) versus Wind direction (x axis) from nearest Weather Station for Stations OL09 and OL02 with a lowess smoother line (blue) imposed.

2.2. T400 Water Level Survey

Level stations are installed at 6 locations (3 lake and 3 river sites). All lake stations show similar patterns of water levels. Carraigahorrig showed low levels until approx. mid October when levels started to increase (**Figure 5**). Woodford levels remain relatively static with intermittent rainfall events causing levels to increase rapidly over short periods of time.

Woodford level station

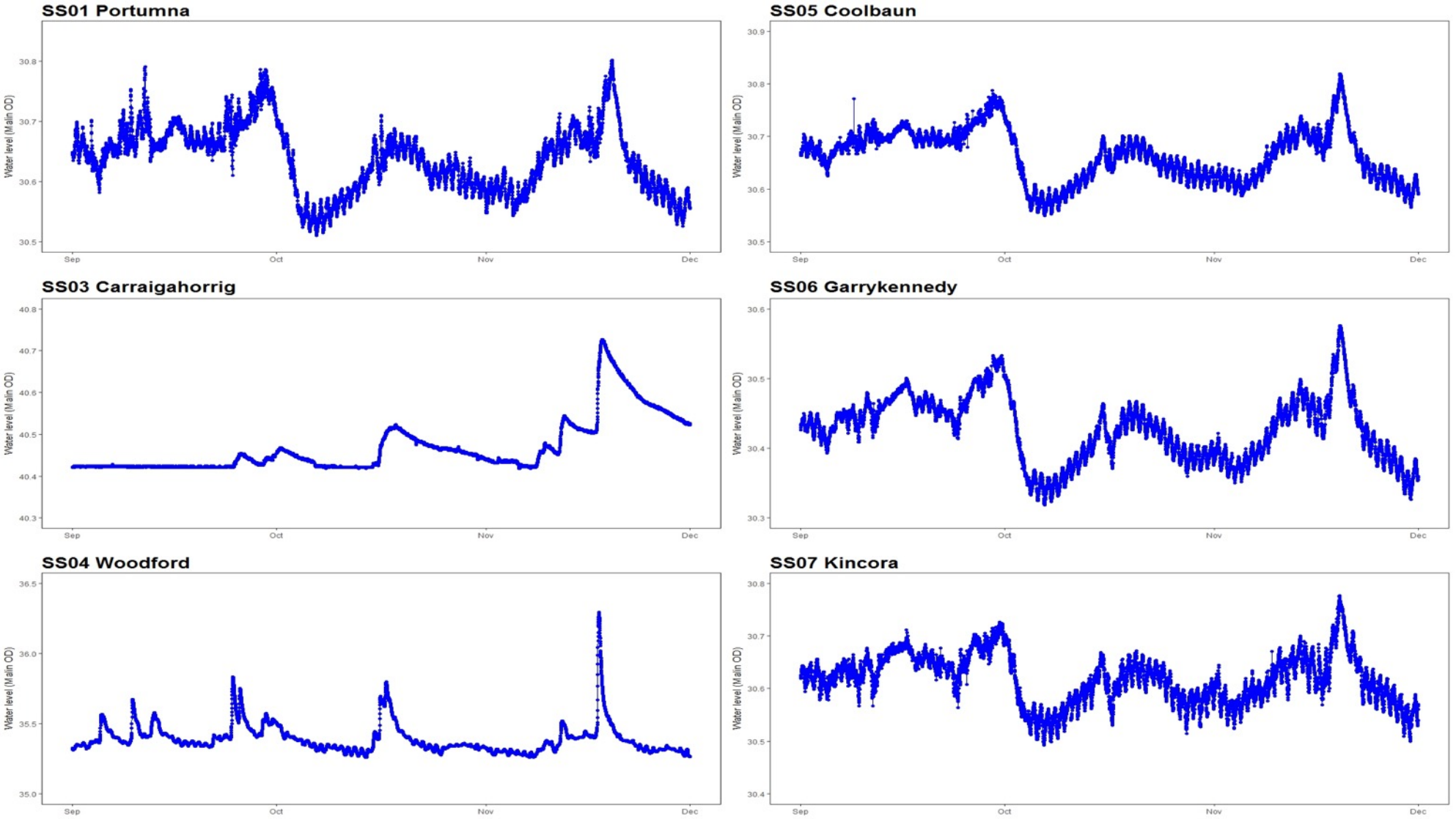

Figure 5: Water level data converted to Malin OD (m) from 6 stations from September – November 2016.

2.3. T500 Water Quality Survey

2.3.1. In-situ sampling

Five in-situ nutrient analysers are deployed, four at open lake sites and one on the inflowing River Shannon at Portumna Bridge**. Figure 6**, **Figure 7**, **Figure 8**, **Figure 9** and **Figure 10** show nutrient data from all 5 sites from September – November 2016 with all data below the limit of detection removed. Phosphate showed an increase in most stations towards the end of the reporting period. This increase is also reflected in the manual sampling data. This increase is most notable in OL09, OL15 and SS01 (Portumna Bridge). All stations showed a decline in dissolved nitrogen towards the end of the reporting period. Many nitrite and ammonia values were below the limit of detection making observations on trends difficult.

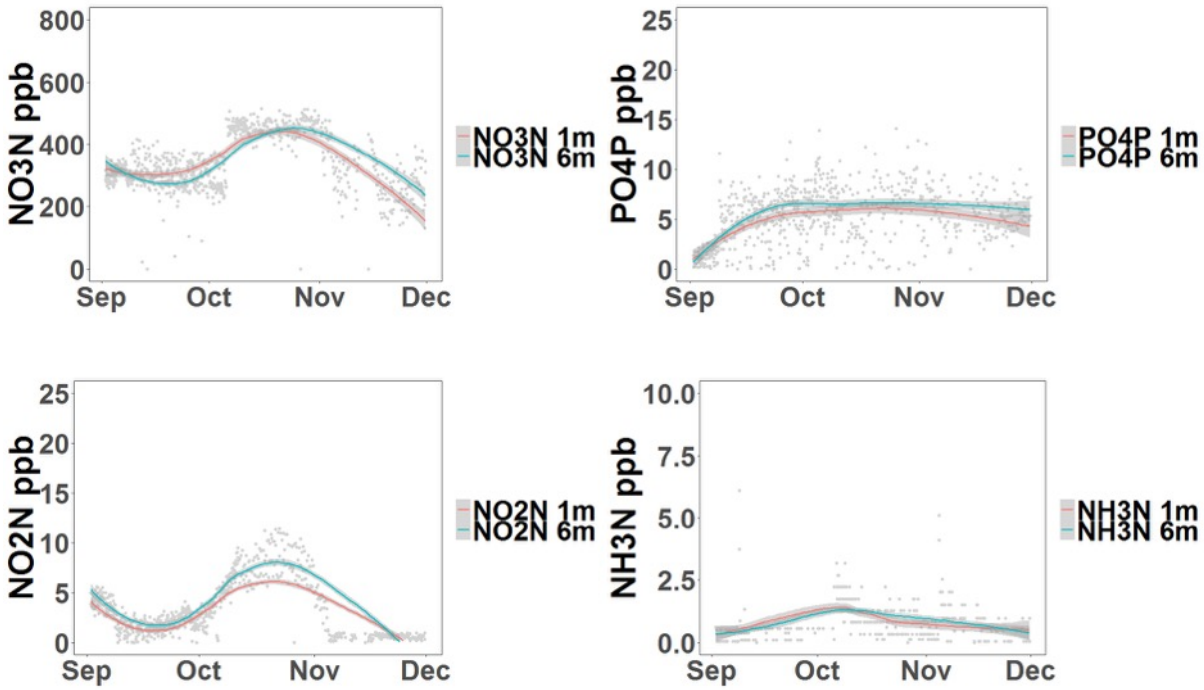

Figure 6: Nutrient Data from OL02 from September – November 2016 (Note some extreme outliers and data below the limit of detection were removed) .

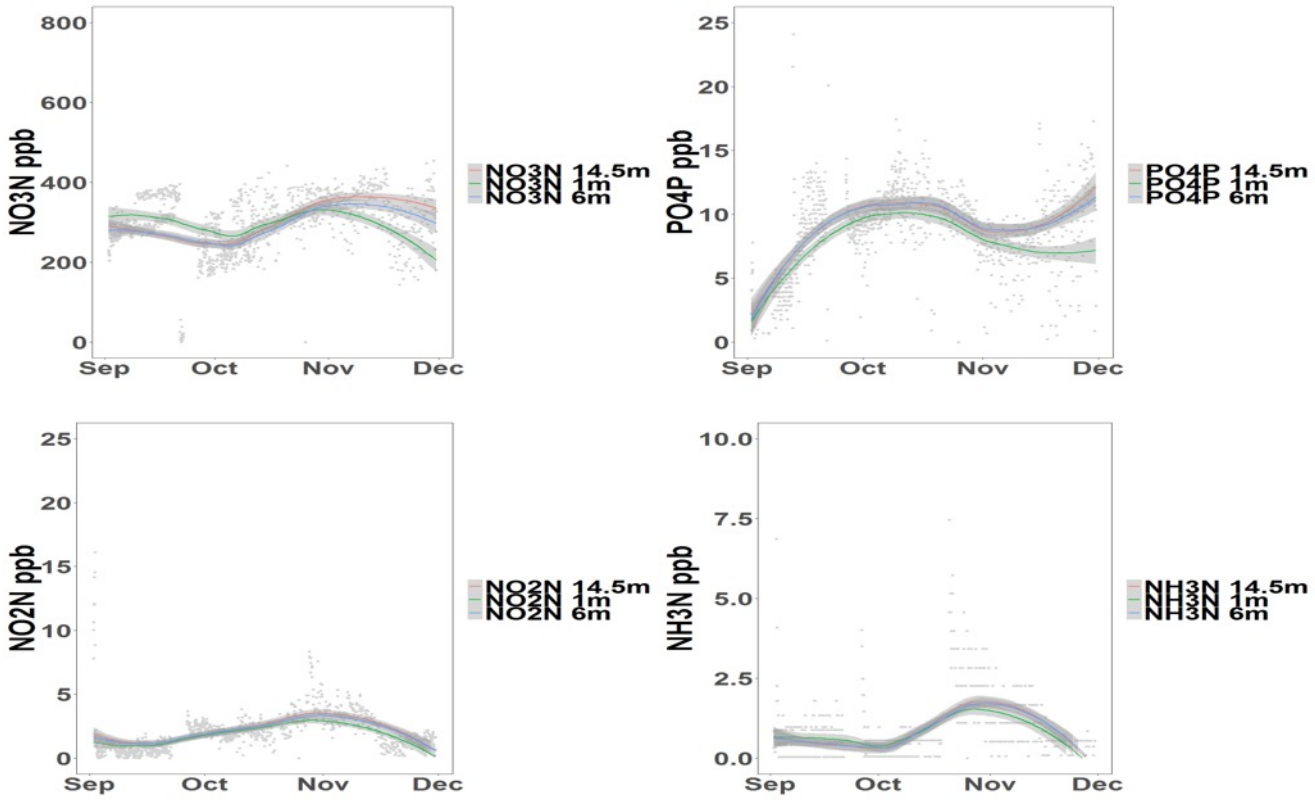

Figure 7: Nutrient Data from OL09 from September – November 2016 (Note some extreme outliers and data below the limit of detection were removed).

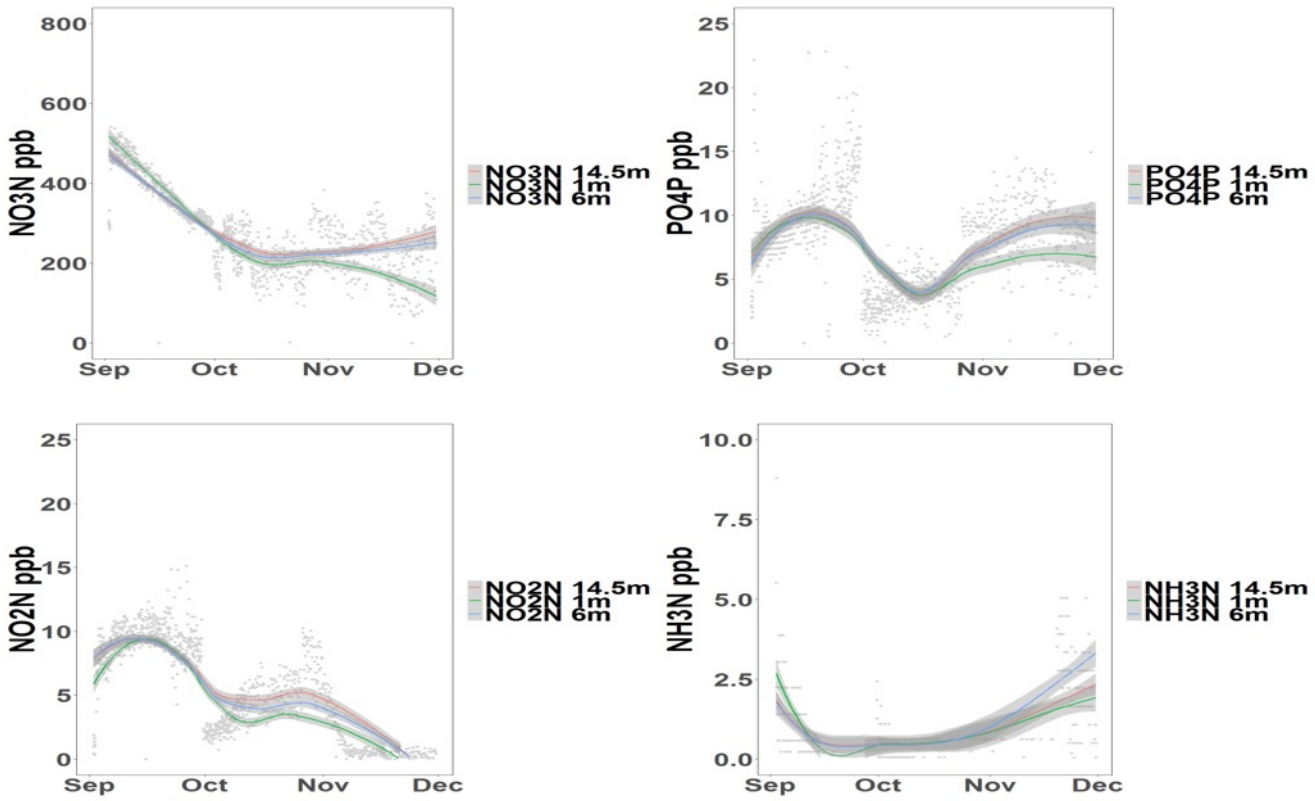

Figure 8: Nutrient Data from OL15 from September – November 2016 (Note some extreme outliers and data below the limit of detection were removed).

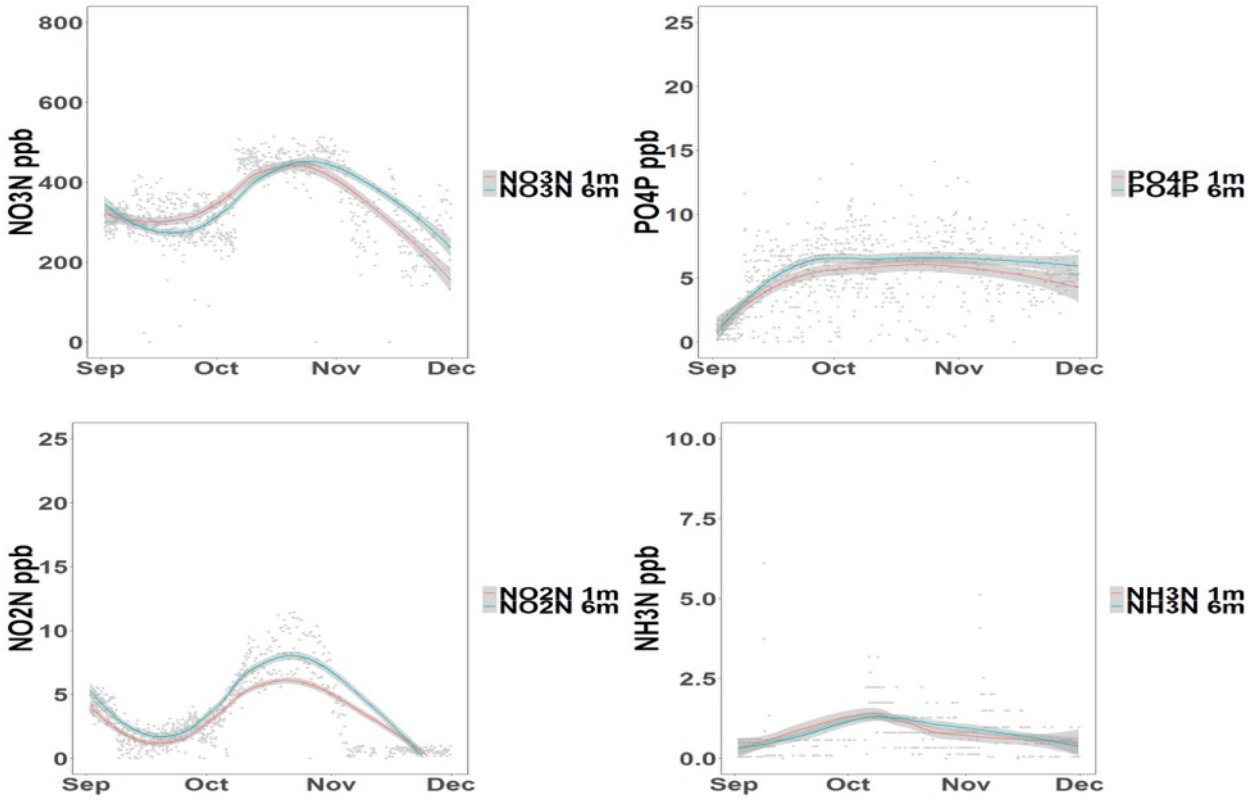

Figure 9: Nutrient Data from OL19 from September – November 2016 (Note some extreme outliers and data below the limit of detection were removed).

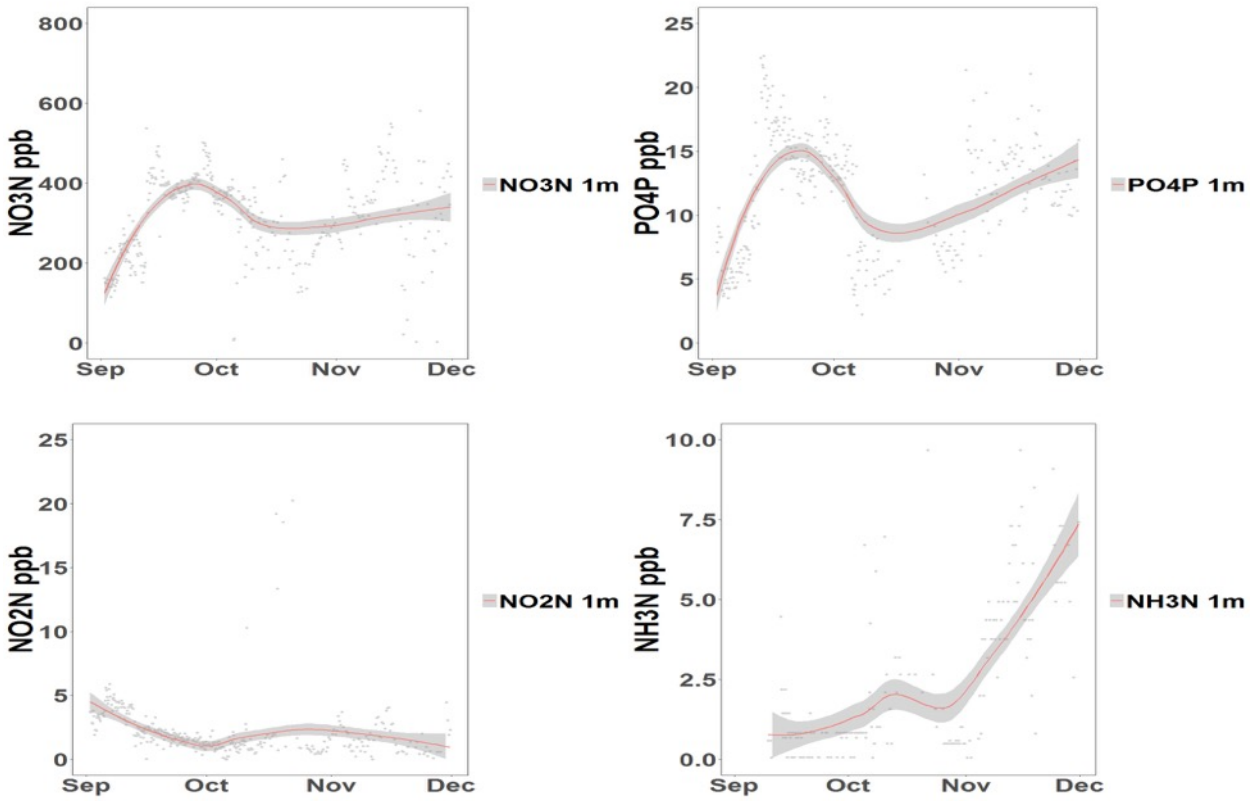

Figure 10: Nutrient Data from SS01 (Portumna Bridge) from September – November 2016 (Note some extreme outliers and data below the limit of detection were removed).

2.3.2. Spot sampling

Figure 11, Figure 12 and Figure 13 show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate and chlorophyll a from water quality sites on Lough Derg at all depths. Figure 14 shows the water quality data from all inflowing rivers into Lough Derg. Obvious trends can be seen in nitrate, phosphate and chlorophyll a in the lake. Both nitrate and phosphate increase in winter time which is as expected due to high run-off and flows from the surrounding catchments over the winter period. Chlorophyll a peaks in late summer/early autumn with higher levels observed at the surface. For the current reporting period chlorophyll a levels dropped from October onwards suggesting a decline in phytoplankton levels in the lake over this period. Phosphate levels in contrast started to increase in the lake from October onwards.

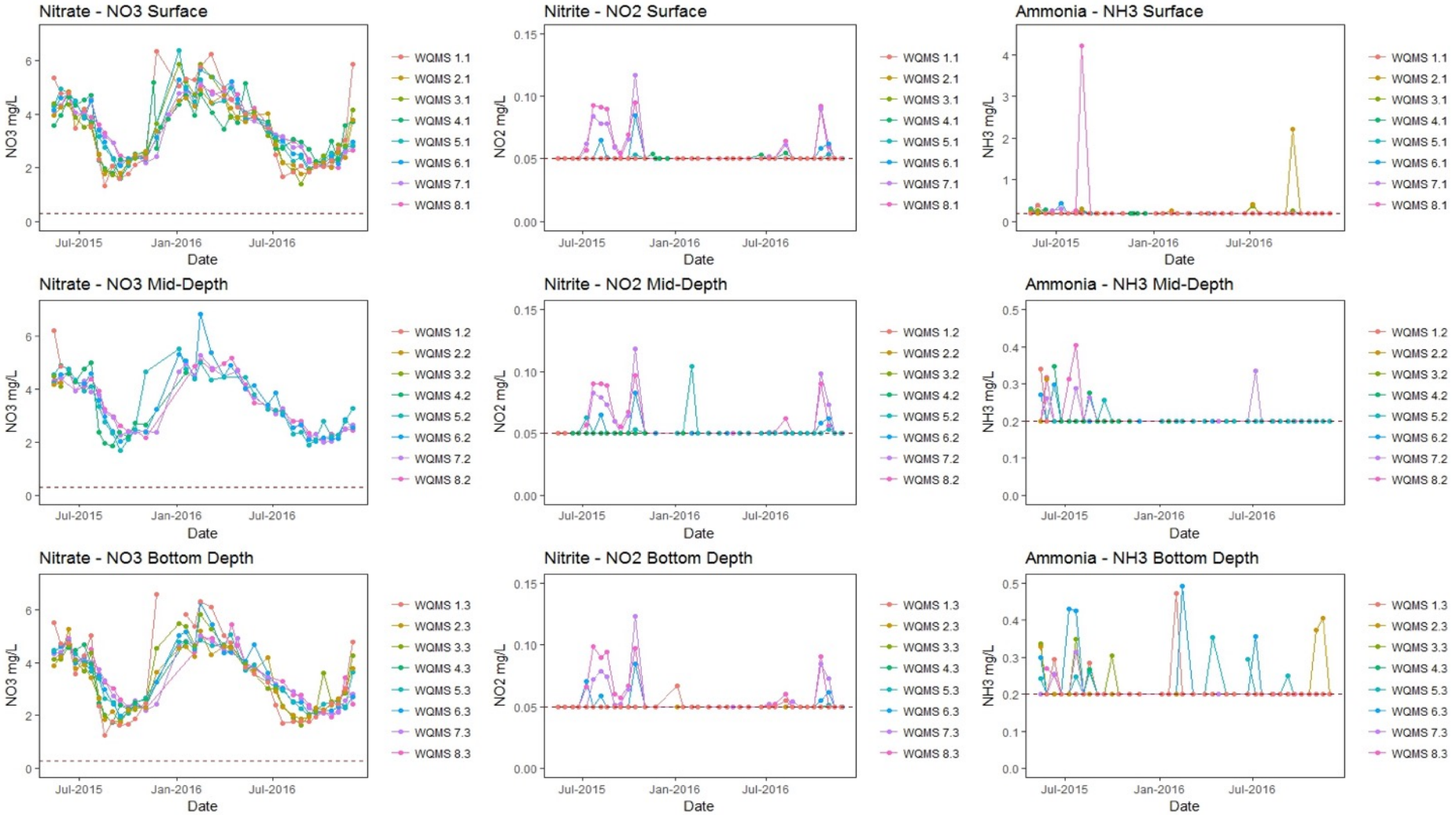

Figure 11: Survey results from all lake water quality sites of nitrate (NO3) nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – Nov 2016.

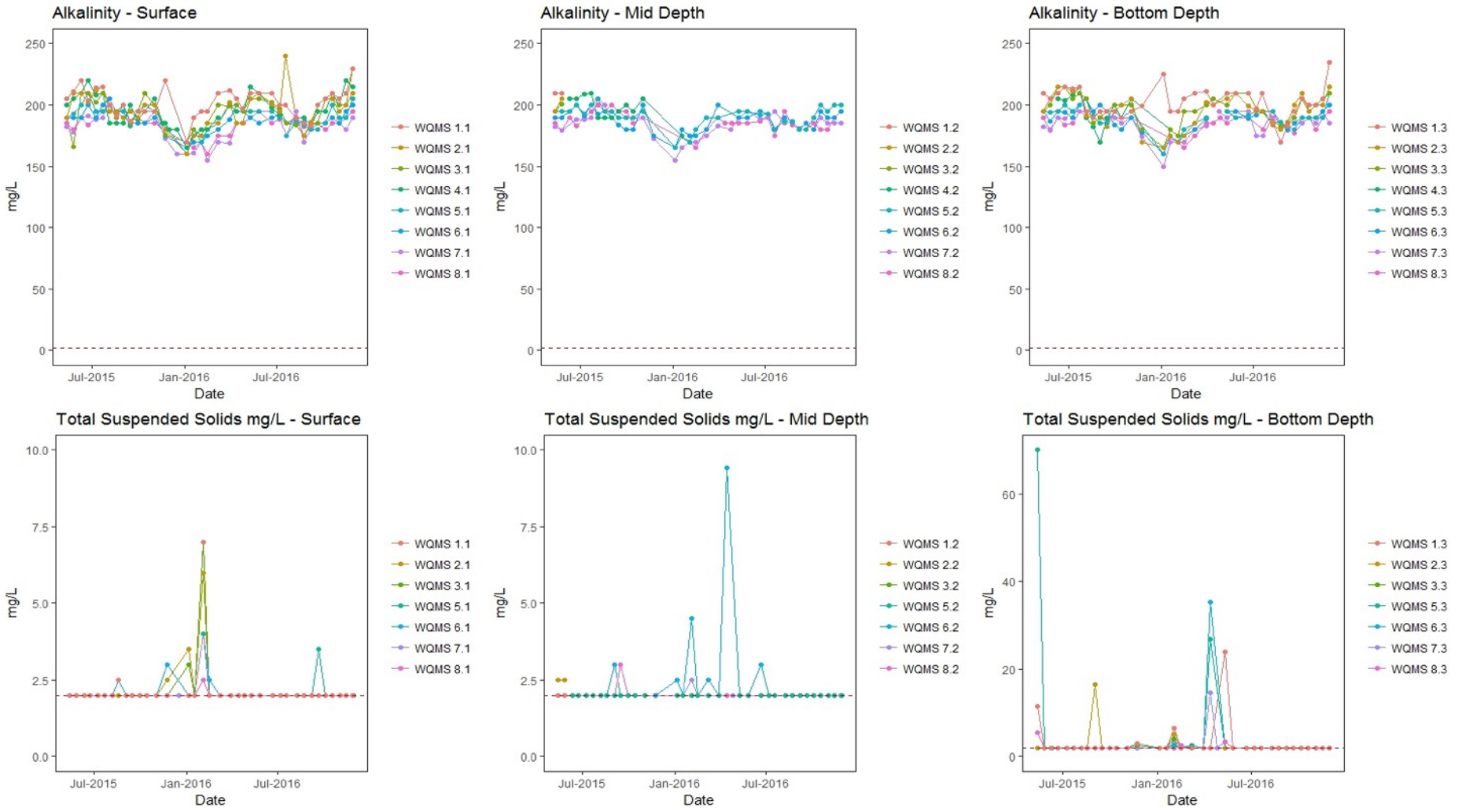

Figure 12: Survey results from all lake water quality sites of Alkalinity and Suspend Solids (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – Nov 2016.

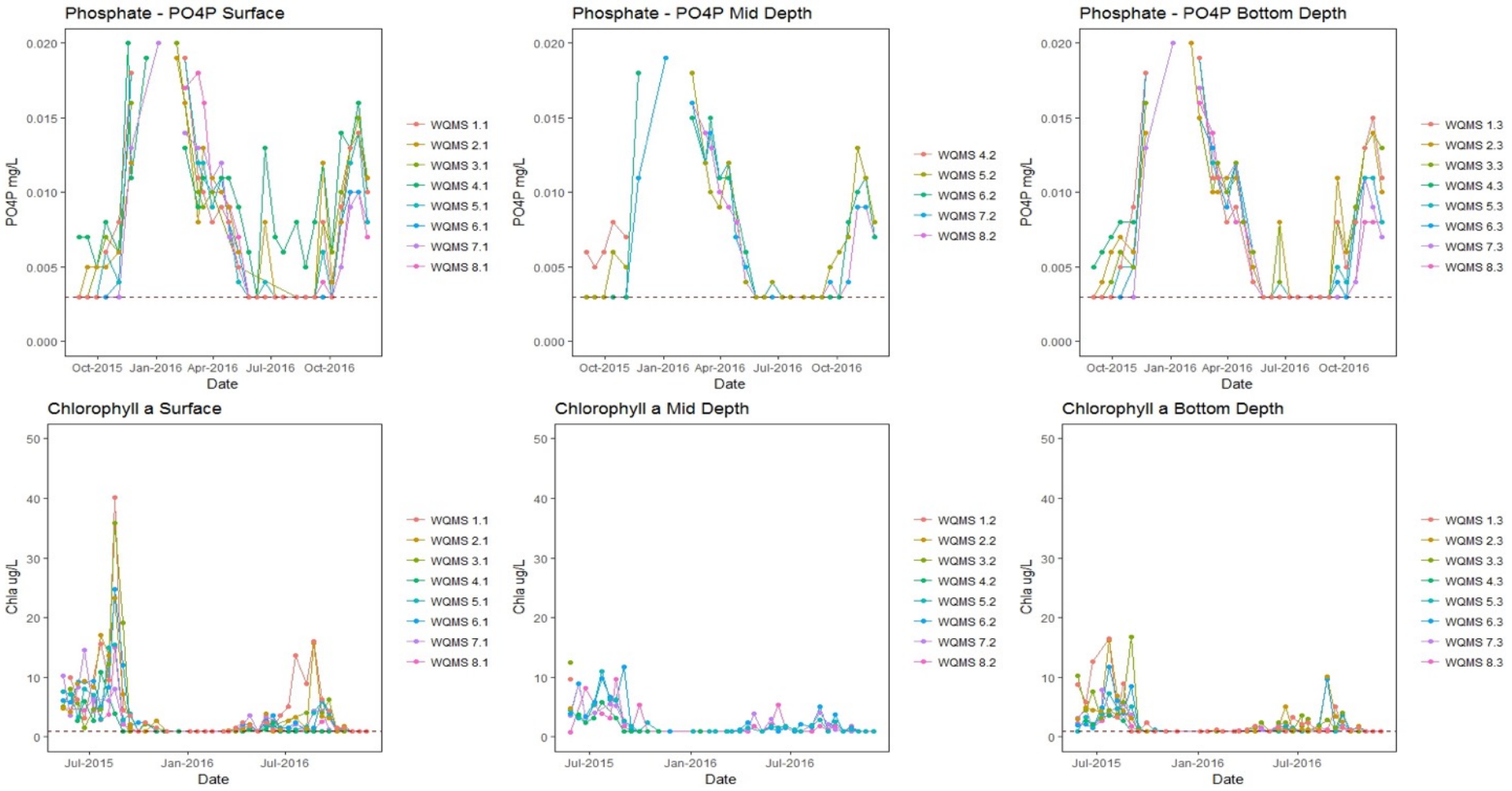

Figure 13: Survey results from all lake water quality sites of Chlorophyll *a* and Phosphate (PO4P) (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – Nov 2016.

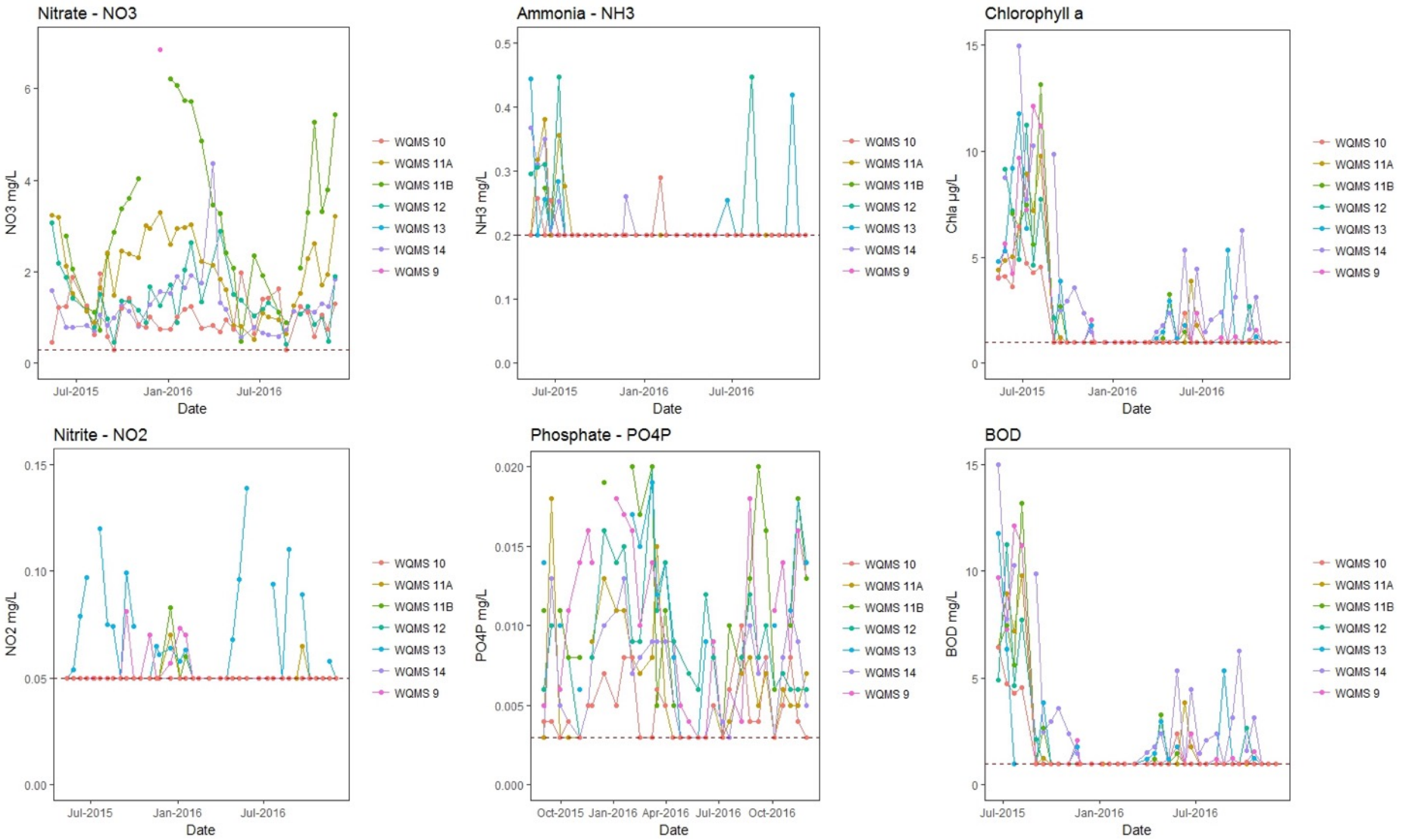

Figure 14: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll *a* and BOD (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – Nov 2016

2.4. T600 Temperature Survey

Nineteen temperature monitoring stations are deployed on Lough Derg. All sites showed similar patterns throughout the reporting period. **Figure 15** shows temperature data from OL12 which is located at the deepest location in the lake (~36m). A steep increase in temperature was observed from June to August Stratification was evident at the deeper depths (>20m) until mid July (See LDMP Report June – August 2016).. Stratification broke down in mid-July, indicating a period of mixing, which persisted until August. All evidence of stratification at OL12 disappeared from September onwards coinciding with a sharp decline in temperatures at all depths continuing until the end of the reporting period. **Figure 16** shows a boxplot of surface level temperatures from the inflow (Portumna) and outflow (Parteen) of the lake. Portumna showed a slightly higher mean temperature than Parteen. This is in contrast to the previous reporting period where Parteen had a higher mean temperature than Portumna.

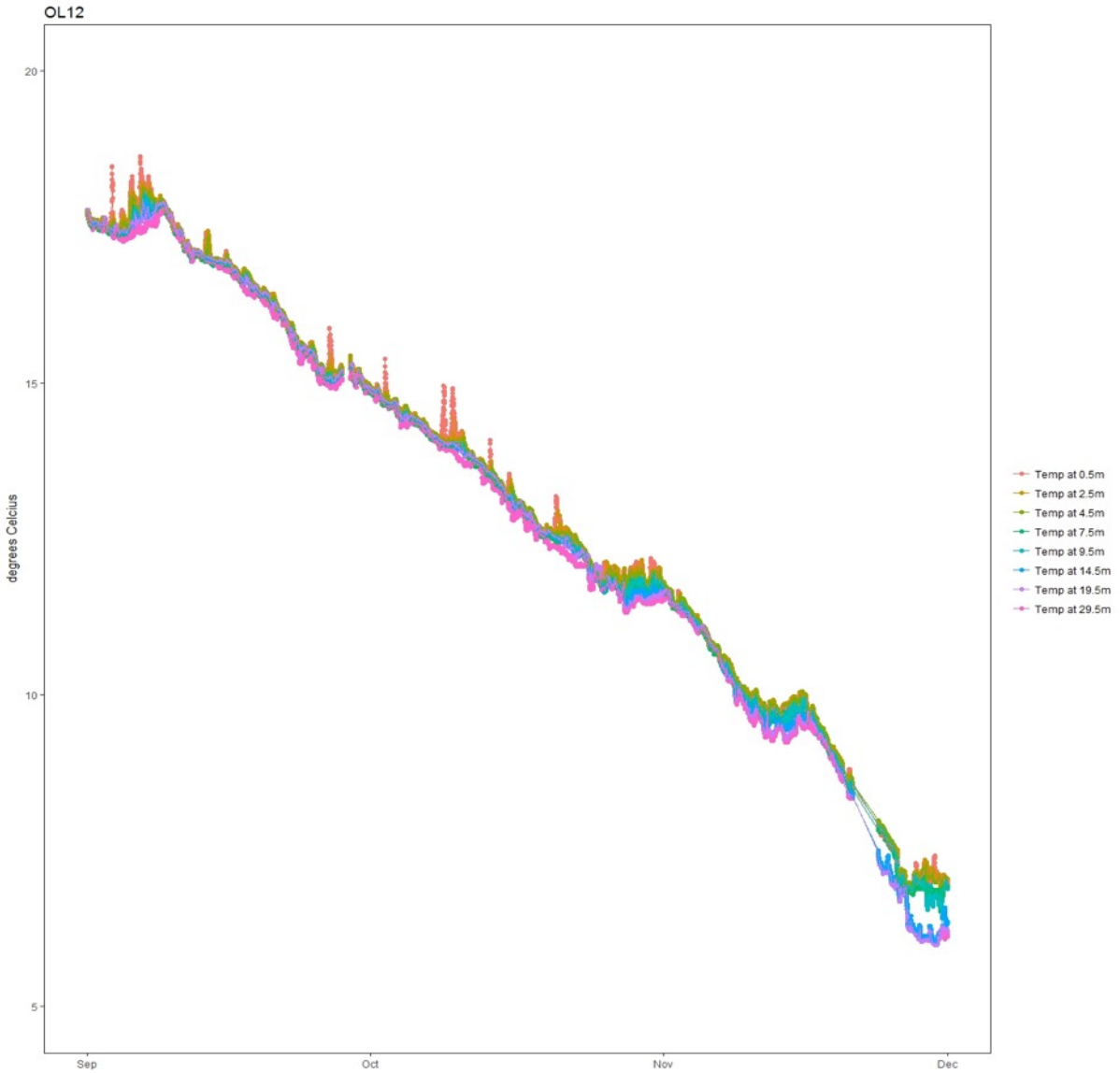

Figure 15: OL12 temperature data from all depths from September – November 2016.

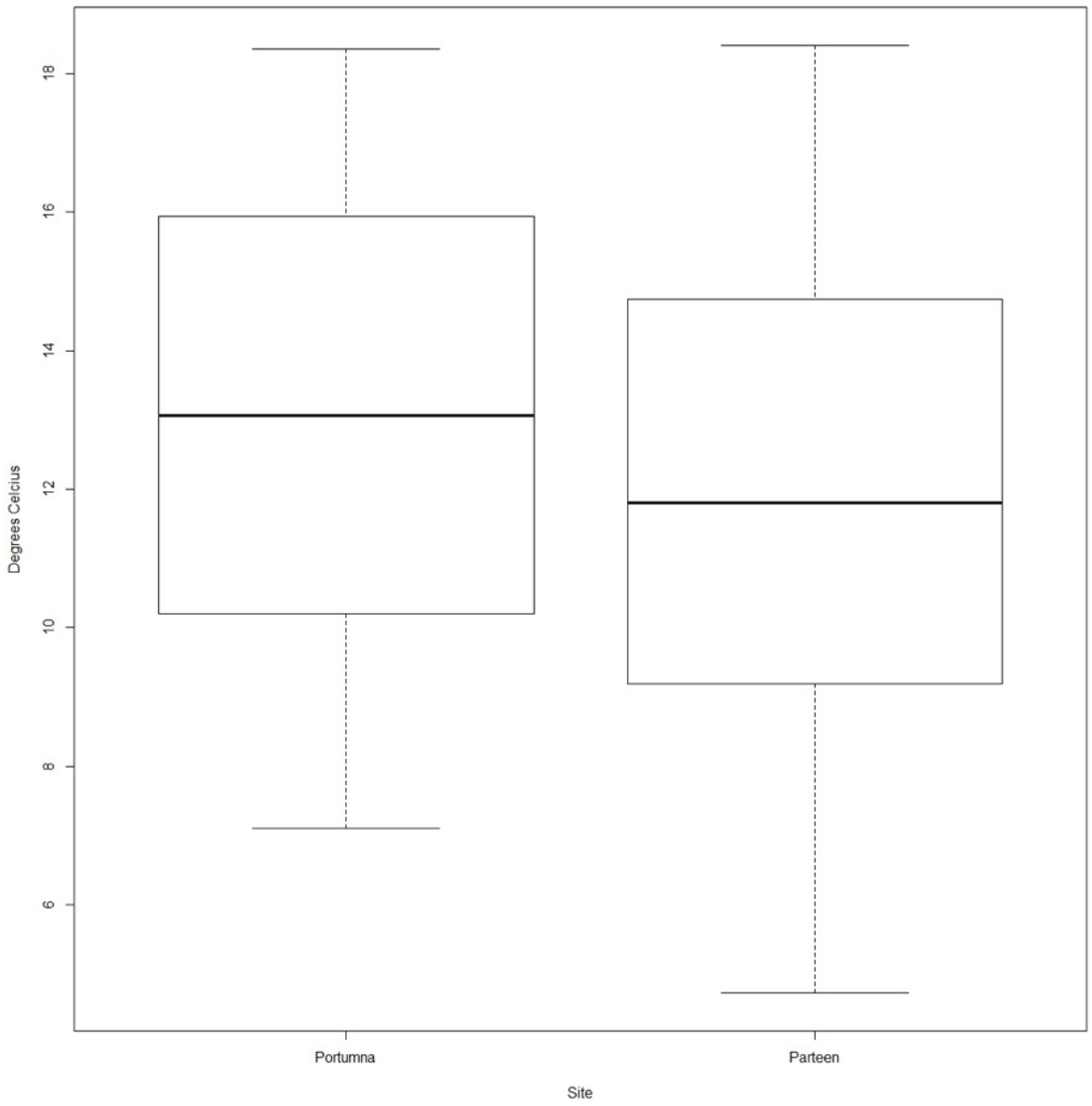

Figure 16: Boxplot showing surface temperatures from Portumna (inflow) and Parteen (outflow) from September – November 2016.

2.5. T800 Meteorological Survey

Two meteorological stations have been installed on the eastern and western shores of Lough Derg. **Figure 17** and **Figure 18** show meteorological data from both stations at Ballinderry and Whitegate. Both stations show similar values for all parameters. Whitegate station was offline from 18/11/16 – 24/11/16 and 30/11/16 – 15/12/16. **Figure 19** shows windrose diagrams of both weather stations, prevailing winds for both stations was south-westerly.

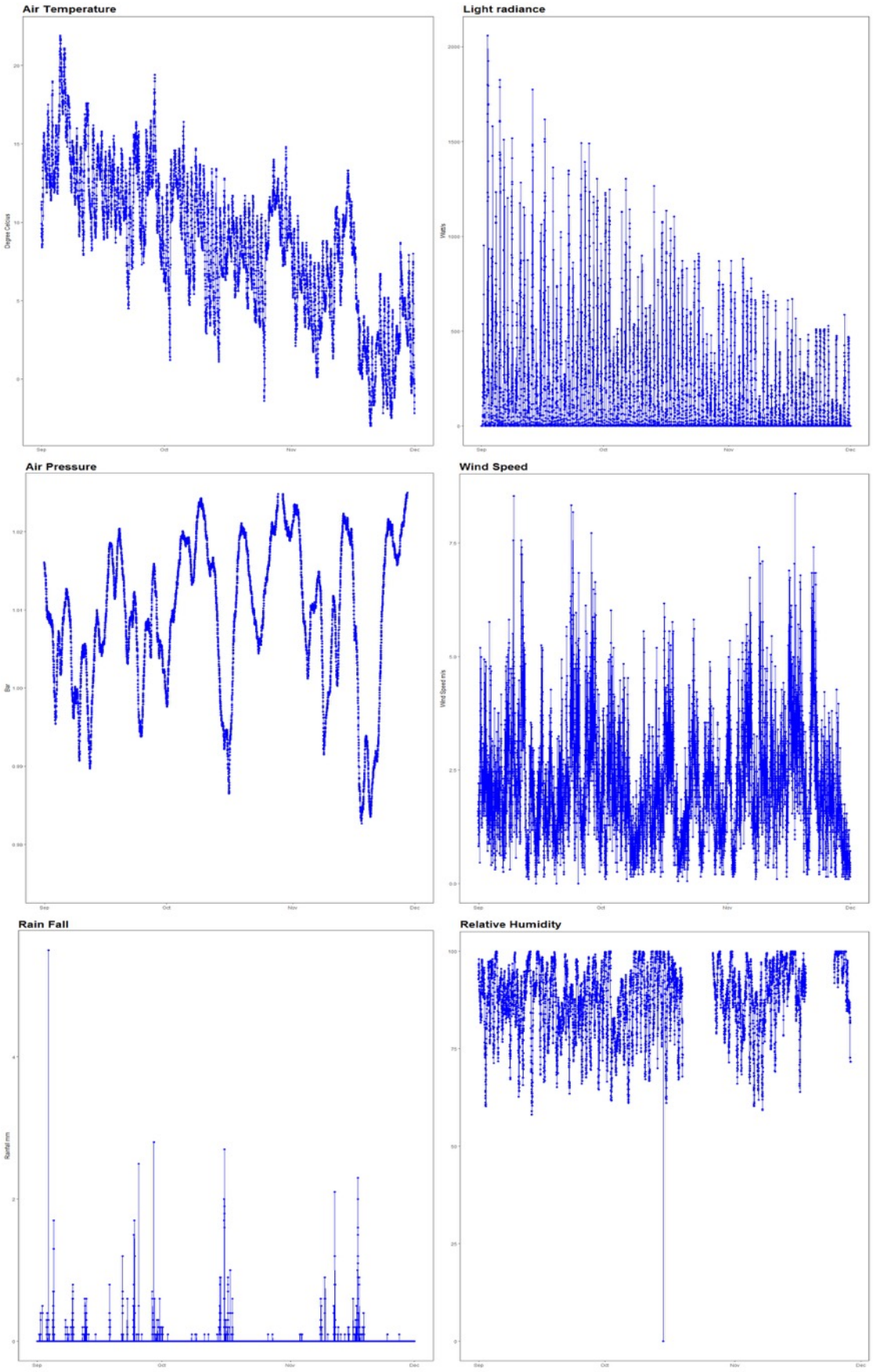

Figure 17: Data from MS01 (Ballinderry) from September – November 2016.

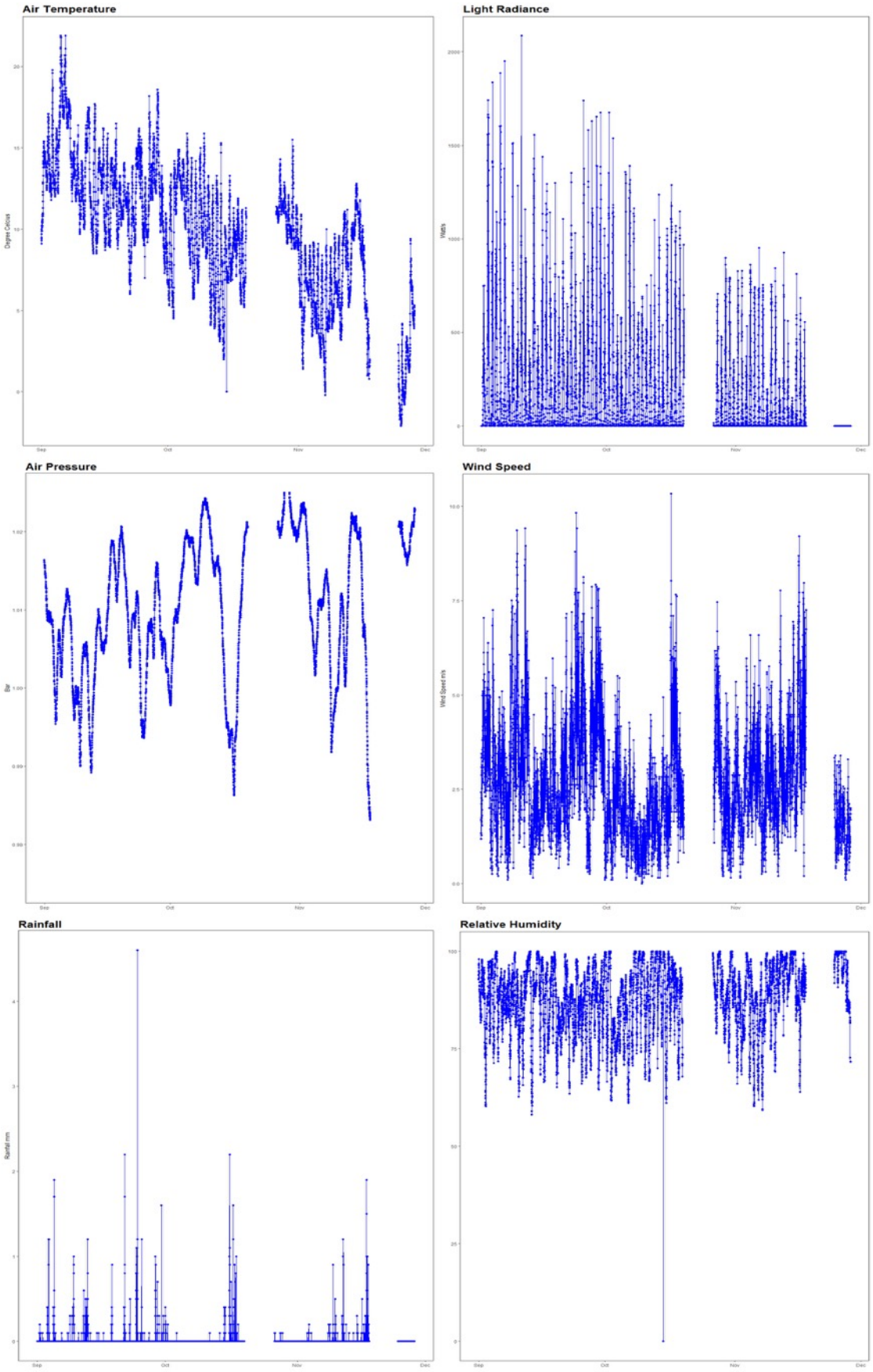

Figure 18: Data from MS02 (Whitegate) from September – November 2016.

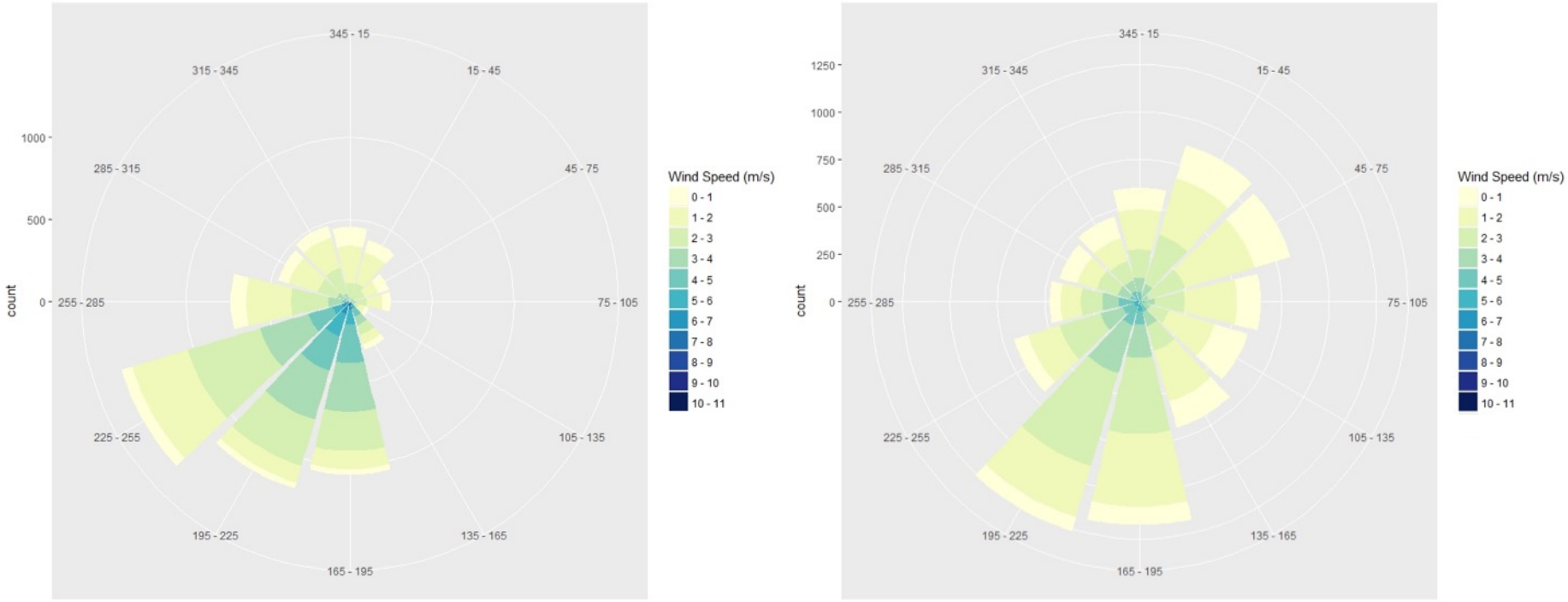

Figure 19: Windrose diagram for Whitegate (left pane) and Ballinderry (right pane) weather stations from September – November 2016.

2.6. T900 Plankton Survey

Figure 20 shows all surface level chlorophyll *a* values from all sites from May 2015 – November. For the current reporting period chlorophyll *a* levels have dropped with the majority of sample being below the limit of detection.

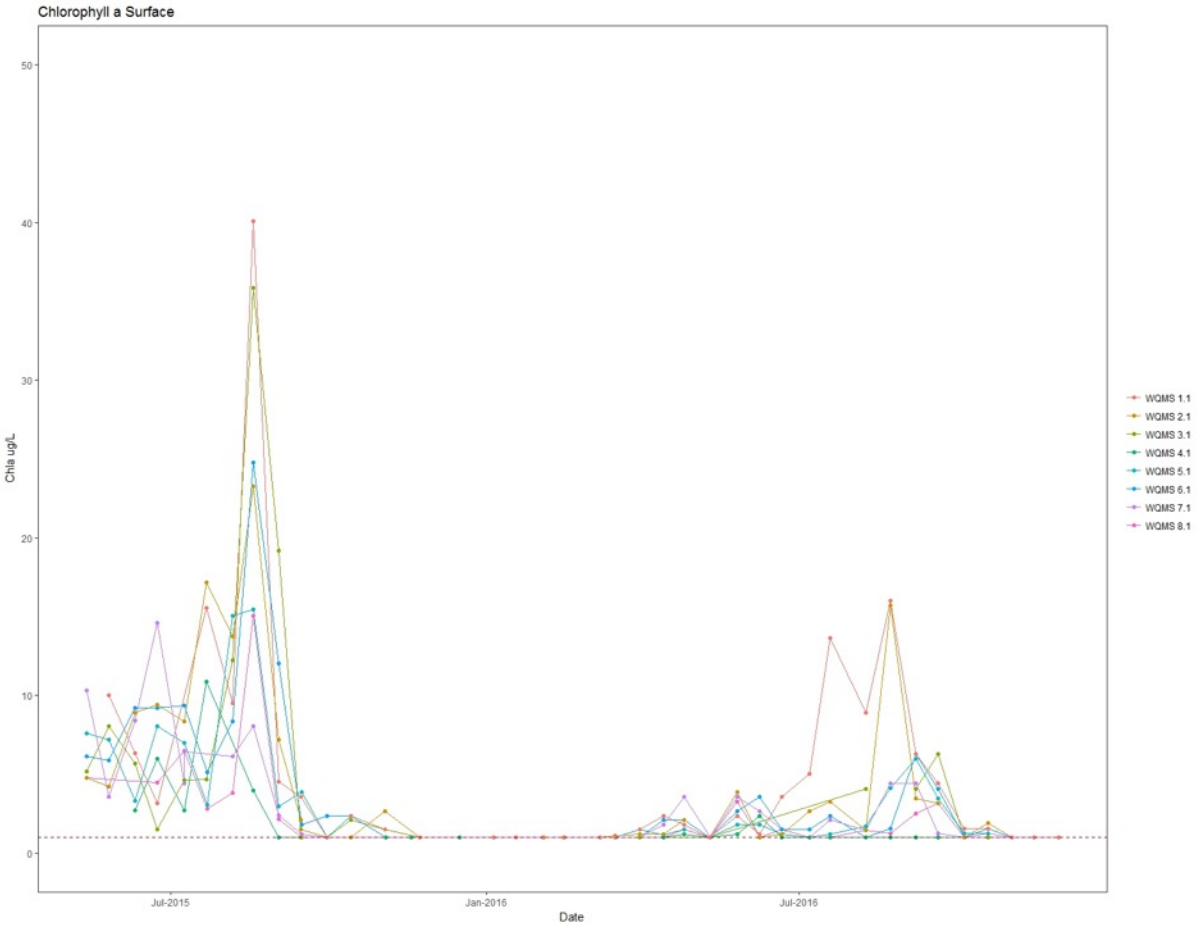

Figure 20: Surface chlorophyll a results from all sites from May 2015 – November 2016.

3. Appendices

Appendix 1: Summary of spot sampling for Water Quality, Water Treatability and Ecology from September –November 2016.

Sample Date	WQMS - Fortnightly	WTMS-Monthly *	WTMS-Quarterly *	Comments
07/09/2016	X	X		
20/09/2016	X	X		
05/10/2016	X			
19/10/2016	X	X		
02/11/2016	X			
15/11/2016	X	X	X	
29/11/2016	X			

* As per clients instruction from August 2016 onwards samples for Water Treatability sampling will only be taken from WTMS 4. Fortnightly sampling will be reduced to monthly.

Appendix 2: List of quarterly water treatability parameters with limits of detection.

Test	Result Units	Limit of detection
Alkalinity, Total as CaCO3	mg/l	2
Bromine*	mg/l	0.1
COD, unfiltered	mg/l	7
Cyanide, Total	mg/l	0.05
Conductivity @ 20 deg.C	mS/cm	0.005
Total EPH (C6-C40) (aq)	µg/l	100
EPH Range >C10 - C40 (aq)	µg/l	46
Fluoride	mg/l	0.5
Benzene	µg/l	7
EPH (C6-C10)	µg/l	100
Ethylbenzene	µg/l	5
GRO >C5-C10	µg/l	10
m,p-Xylene	µg/l	8
Methyl tertiary butyl ether (MTBE)	µg/l	3
o-Xylene	µg/l	3
Sum of detected BTEX	µg/l	28
Toluene	µg/l	4
Mercury (diss.filt)	µg/l	0.01
Aluminium (diss.filt)	µg/l	2.9
Arsenic (diss.filt)	µg/l	0.12
Barium (diss.filt)	µg/l	0.03
Boron (diss.filt)	µg/l	9.4
Cadmium (diss.filt)	µg/l	0.1
Chromium (diss.filt)	µg/l	0.22
Copper (diss.filt)	µg/l	0.85
Lead (diss.filt)	µg/l	0.02
Manganese (diss.filt)	µg/l	0.04
Nickel (diss.filt)	µg/l	0.15
Selenium (diss.filt)	µg/l	0.39
Zinc (diss.filt)	µg/l	0.41
Nitrogen, Kjeldahl	mg/l	1
Chloride	mg/l	2
Sulphate	mg/l	2
Total Oxidised Nitrogen as N	mg/l	0.1
Surfactants, Anionic (MBAS)	mg/l	0.05
Calcium (diss.filt)	mg/l	0.012
Iron (diss.filt)	mg/l	0.019
Nitrogen, Total	mg/l	1
Acenaphthene (aq)	µg/l	0.015
Acenaphthylene (aq)	µg/l	0.011
Anthracene (aq)	µg/l	0.015

Appendix 2: cont'd

Test	Result Units	Limit of detection
Benzo(a)anthracene (aq)	µg/l	0.017
Benzo(a)pyrene (aq)	µg/l	0.009
Benzo(b)fluoranthene (aq)	µg/l	0.023
Benzo(g,h,i)perylene (aq)	µg/l	0.016
Benzo(k)fluoranthene (aq)	µg/l	0.027
Chrysene (aq)	µg/l	0.013
Dibenzo(a,h)anthracene (aq)	µg/l	0.016
Fluoranthene (aq)	µg/l	0.017
Fluorene (aq)	µg/l	0.014
Indeno(1,2,3-cd)pyrene (aq)	µg/l	0.014
Naphthalene (aq)	µg/l	0.1
PAH, Total Detected USEPA 16 (aq)	µg/l	0.344
Phenanthrene (aq)	µg/l	0.022
Pyrene (aq)	µg/l	0.015
Aldrin	µg/l	0.01
alpha-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Azinphos-ethyl	µg/l	0.01
Azinphos-methyl	µg/l	0.01
beta-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Carbophenothion	µg/l	0.01
Chlorfenvinphos	µg/l	0.01
Chlorothalonil	µg/l	0.01
Chlorpyriphos	µg/l	0.01
Chlorpyriphos methyl	µg/l	0.01
cis-Chlordane	µg/l	0.01
Diazinon	µg/l	0.01
Dichlorvos	µg/l	0.01
Dieldrin	µg/l	0.01
Dimethoate	µg/l	0.01
Disulfoton	µg/l	0.01
Endosulphan I	µg/l	0.01
Endosulphan II	µg/l	0.01
Endosulphan sulphate	µg/l	0.01
Endrin	µg/l	0.01
Ethion	µg/l	0.01
Etrimphos	µg/l	0.01
Fenitrothion	µg/l	0.01
Fenthion	µg/l	0.01
gamma-Hexachlorocyclohexane (HCH / Lindane)	µg/l	0.01
Heptachlor	µg/l	0.01

Appendix 2: cont'd

Test	Result Units	Limit of detection
Heptachlor epoxide	µg/l	0.01
Hexachlorobenzene	µg/l	0.01
Isodrin	µg/l	0.01
Malathion	µg/l	0.01
Methyl parathion	µg/l	0.01
Mevinphos	µg/l	0.01
o,p-DDE	µg/l	0.01
o,p-DDT	µg/l	0.01
o,p-Methoxychlor	µg/l	0.01
o,p-TDE (DDD)	µg/l	0.01
p,p-DDE	µg/l	0.01
p,p-DDT	µg/l	0.01
p,p-Methoxychlor	µg/l	0.01
p,p-TDE (DDD)	µg/l	0.01
Parathion	µg/l	0.01
Pendimethalin	µg/l	0.01
Permethrin I	µg/l	0.01
Permethrin II	µg/l	0.01
Phosalone	µg/l	0.01
Pirimiphos-methyl	µg/l	0.01
Propetamphos	µg/l	0.01
Quintozene (PCNB)	µg/l	0.01
Tecnazene	µg/l	0.01
Telodrin	µg/l	0.01
Trans-chlordane	µg/l	0.01
Triadimefon	µg/l	0.01
Triallate	µg/l	0.01
Triazophos	µg/l	0.01
Trifluralin	µg/l	0.01
pH	pH Units	1
Cresols	mg/l	0.006
Phenol	mg/l	0.002
Phenols, Total Detected monohydric	mg/l	0.016
Xylenols	mg/l	0.008
Dissolved solids, Total (meter)	mg/l	5
Organic Carbon, Total	mg/l	3
Oxygen, dissolved	mg/l	0.3
BOD, unfiltered	mg/l	1
Langelier Index (derived) *	N/A	N/A

Appendix 2: cont'd

***Langelier Index (LSI)** LSI = pH – pHs pHs = (9.3 + A + B) – (C + D)

A = $(\log_{10}[\text{Total Dissolved Solids}] - 1)/10$

B = $-13.12 * \log10(\text{Temp}^{o}\text{C} + 273) + 34.55$

C = $\log_{10}[Ca^{2+} \text{ as } CaCO_3^{*}] - 0.4$

D = $\log_{10}[\text{Alkalinity as } CaCO_3]$

*Calcium was converted to Ca^{2+} as $CaCO_3$ using a conversion factor of 2.5.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

Client:	**Irish Water**
Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
Document Title:	**Data report for Lough Derg Monitoring Project (December 2016 – February 2017)**
Document Number:	**LDMP/R/10**
Text Pages:	**33**

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1. Introduction

The Lough Derg Monitoring Project technical partnership led by Water Technology Ltd. Are engaged in a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers. The project has been running since April 2015.

2. Results to date

2.1. T300 Water Flow and Current Survey

2.1.1. ADCP Survey

Figure 1 shows daily moving average flow data from the horizontal ADCP installed at Portumna.

As with previous reporting periods the flow data from the vertical ADCP's installed at lake stations OL02, OL09 and OL15 show a high variability in flow in the top bins (**Figure 2**, **Figure 3** and **Figure 4**). Comparison of the top bin data with wind direction data from the closest met stations show a relationship between wind direction and flow in the surface water of the lake (**Figure 5**). **Figure 5** shows scatter plots of flow from the surface level bin with wind direction from nearest weather station. A Lowess (LOcally WEighted Scatter-plot Smoother) line has been imposed on the data to decipher trends. Wind direction seems to be driving surface flows in the lake at OL09 and OL02. This trend was also shown in data from previous reporting periods. The relationship between surface flows and wind direction is less obvious at station OL15, this may be due to the stations proximity from the weather station or a lesser influence of wind on flow at this station.

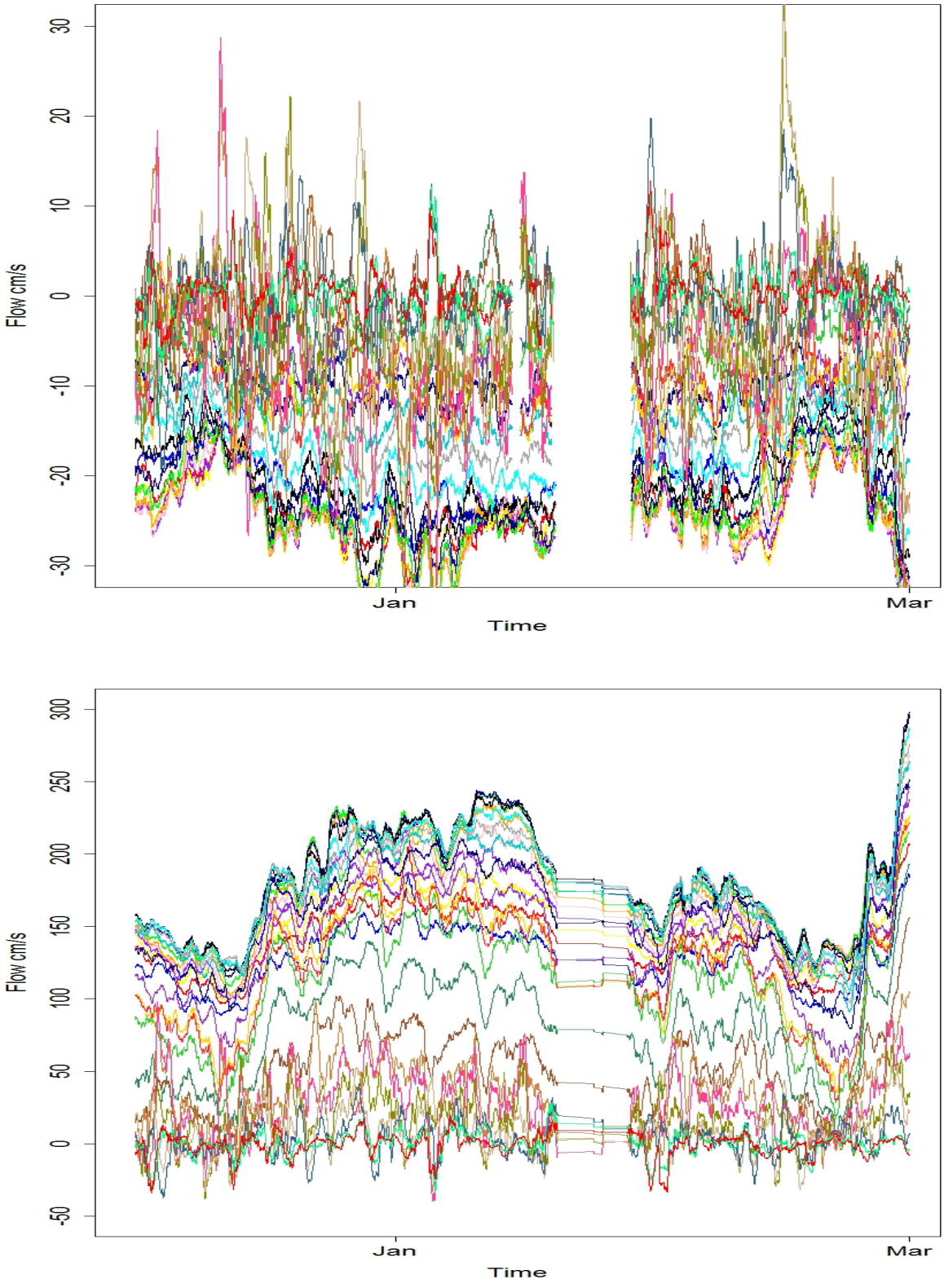

Figure 1: Daily moving average Flow data from Horizontal ADCP cm/s (Top panel shows X axis flows across all bins, Bottom panel shows Y axis flows) from December 2016 – February 2017. Note: Data has been filtered to remove noisy data (>500, < -500).

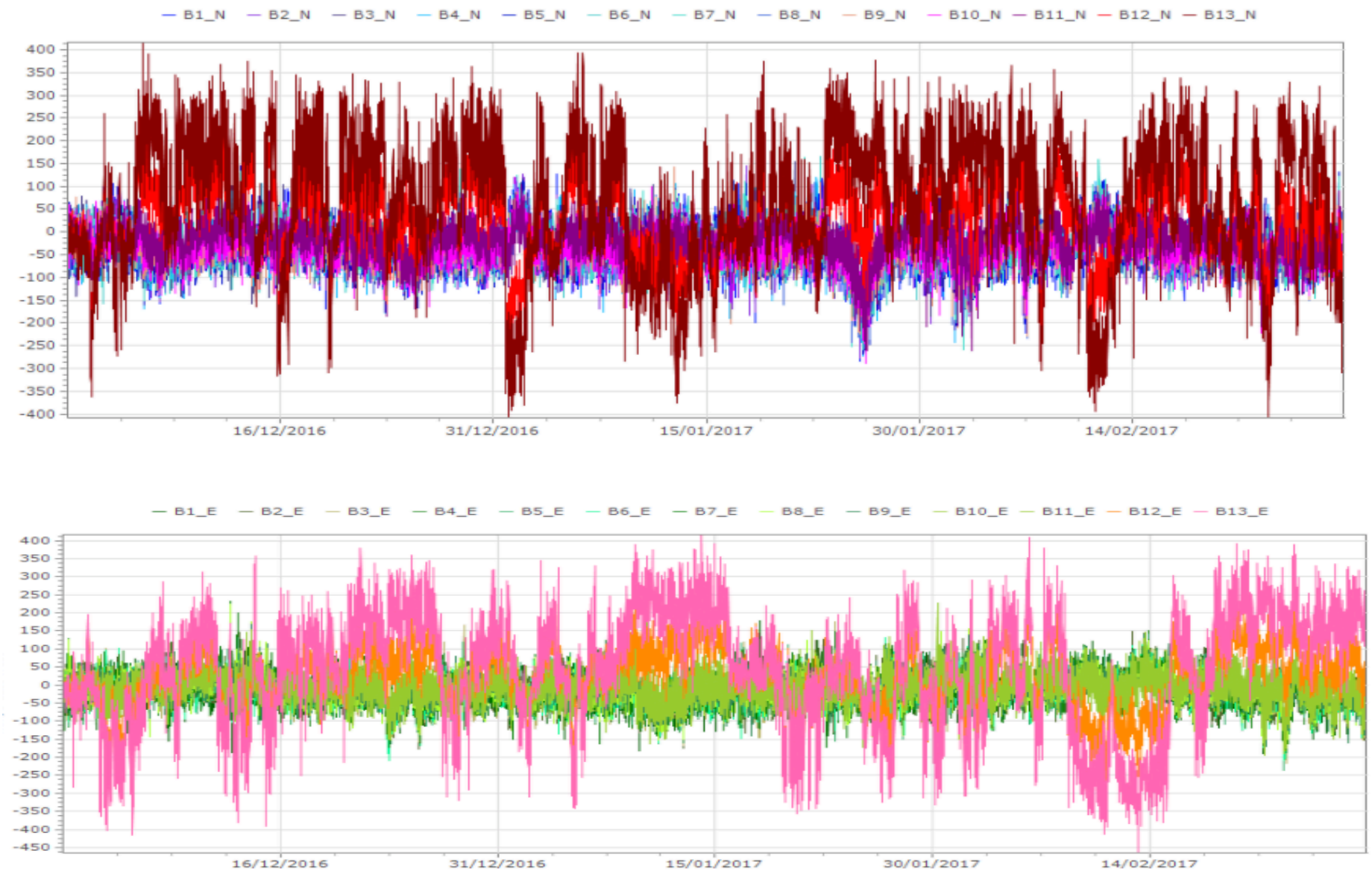

Figure 2: Flow data from OL02 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from December 2016 – February 2017

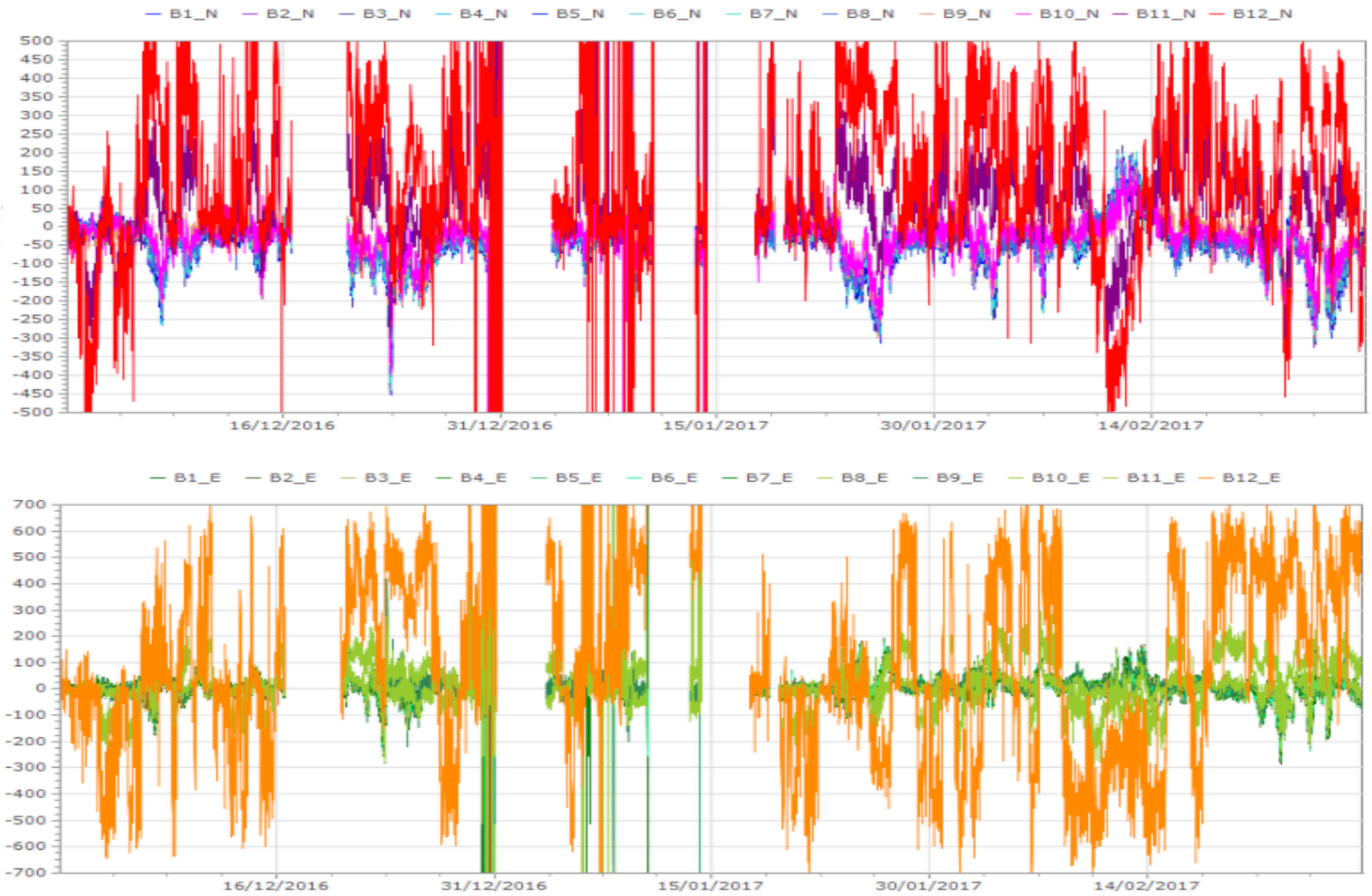

Figure 3: Flow data from OL09 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from December 2016 – February 2017

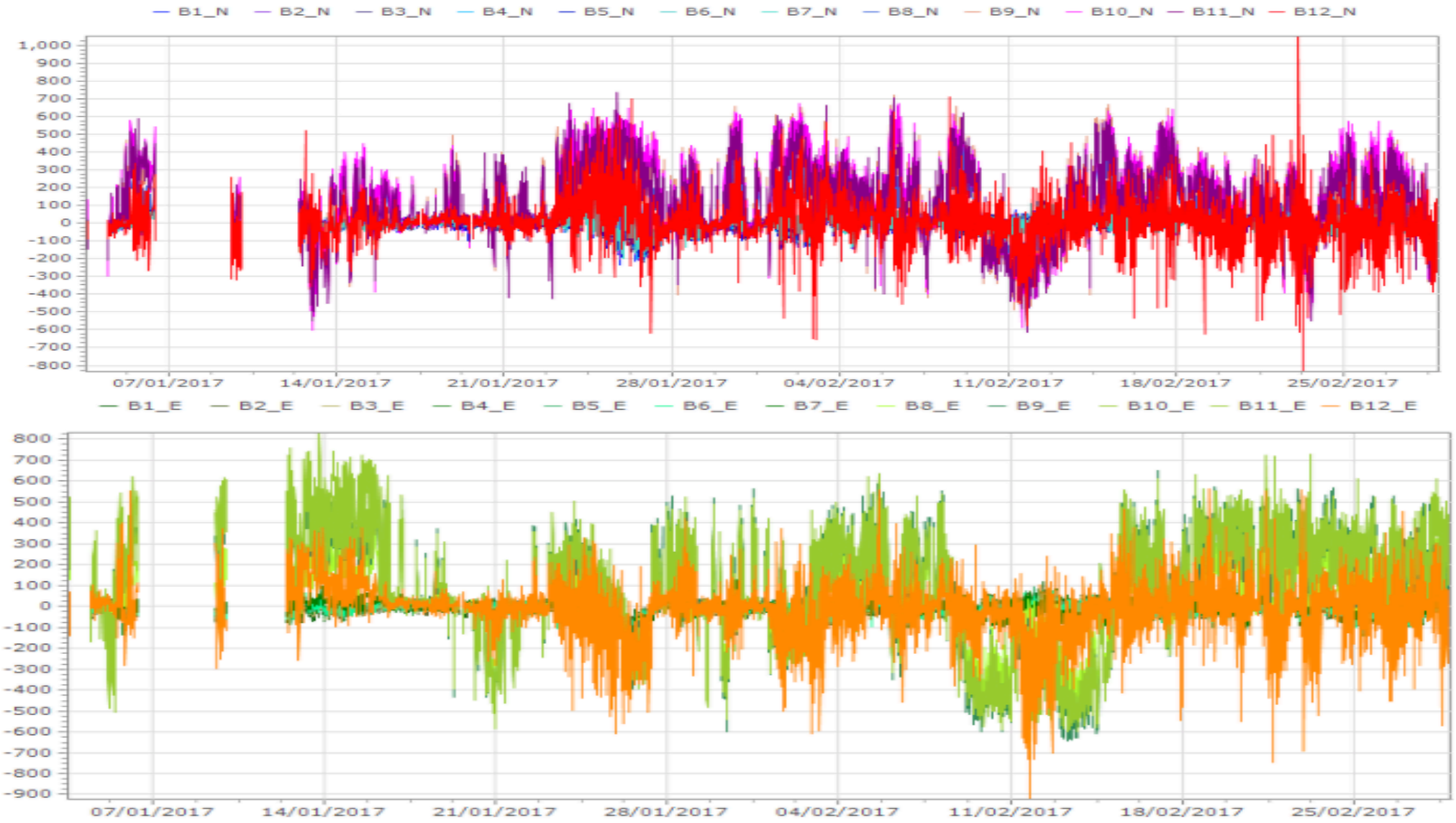

Figure 4: Flow data from OL15 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from January – February 2017.

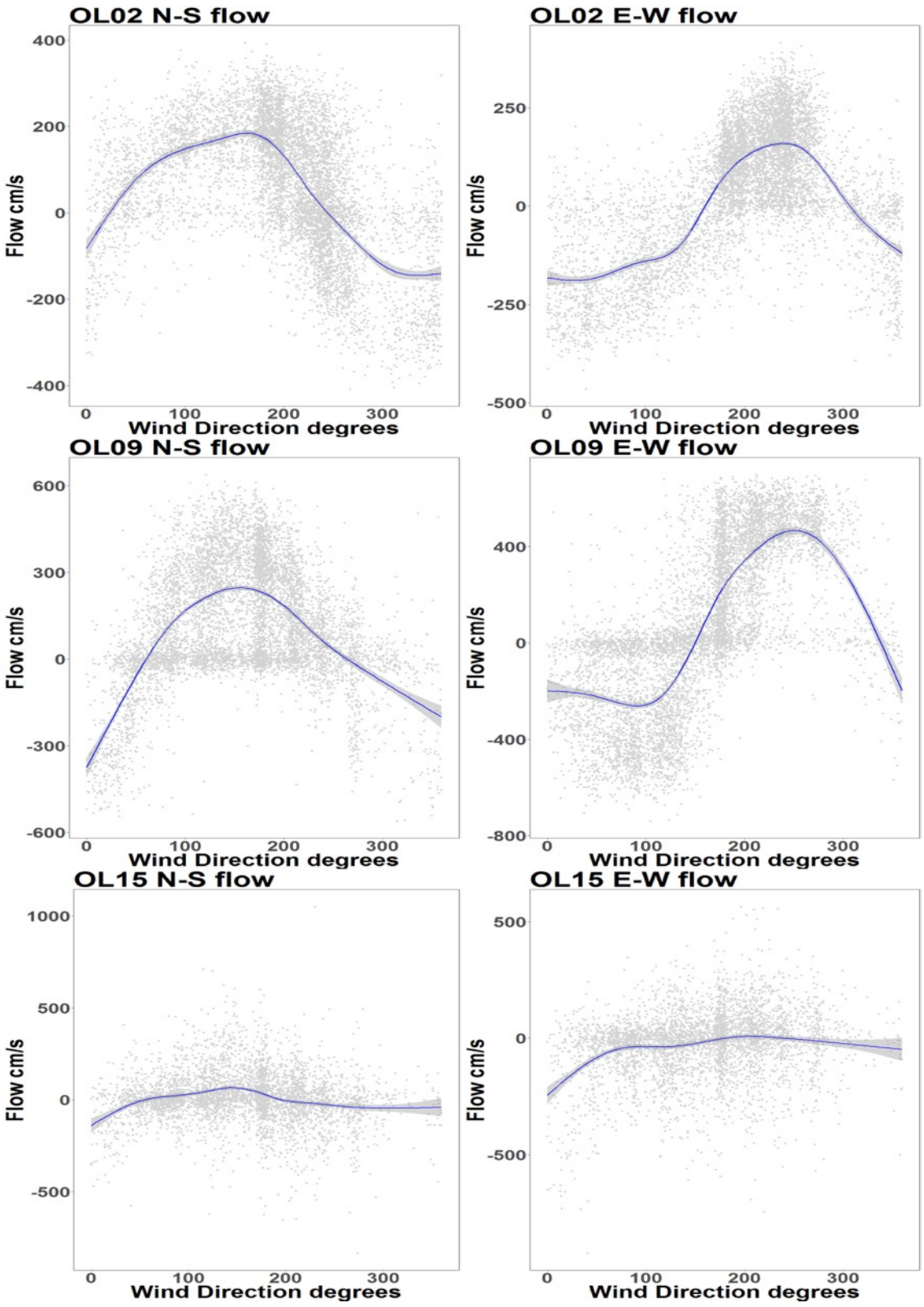

Figure 5: Scatterplots showing flow (y axis) versus Wind direction (x axis) from nearest Weather Station for Stations OL09, OL02 and OL15 with a lowess smoother line (blue) imposed.

2.2. T400 Water Level Survey

Level stations are installed at 6 locations (3 lake and 3 river sites). All lake stations show similar patterns of water levels throughout the reporting period (**Figure 6**). All stations showed a similar increase towards the end of the reporting period. Carraigahorrig River water levels started to increase in mid-December, levels remained high throughout the reporting period. Woodford levels remain relatively static with intermittent rainfall events causing levels to increase rapidly over short periods of time.

Carraigahorrig River

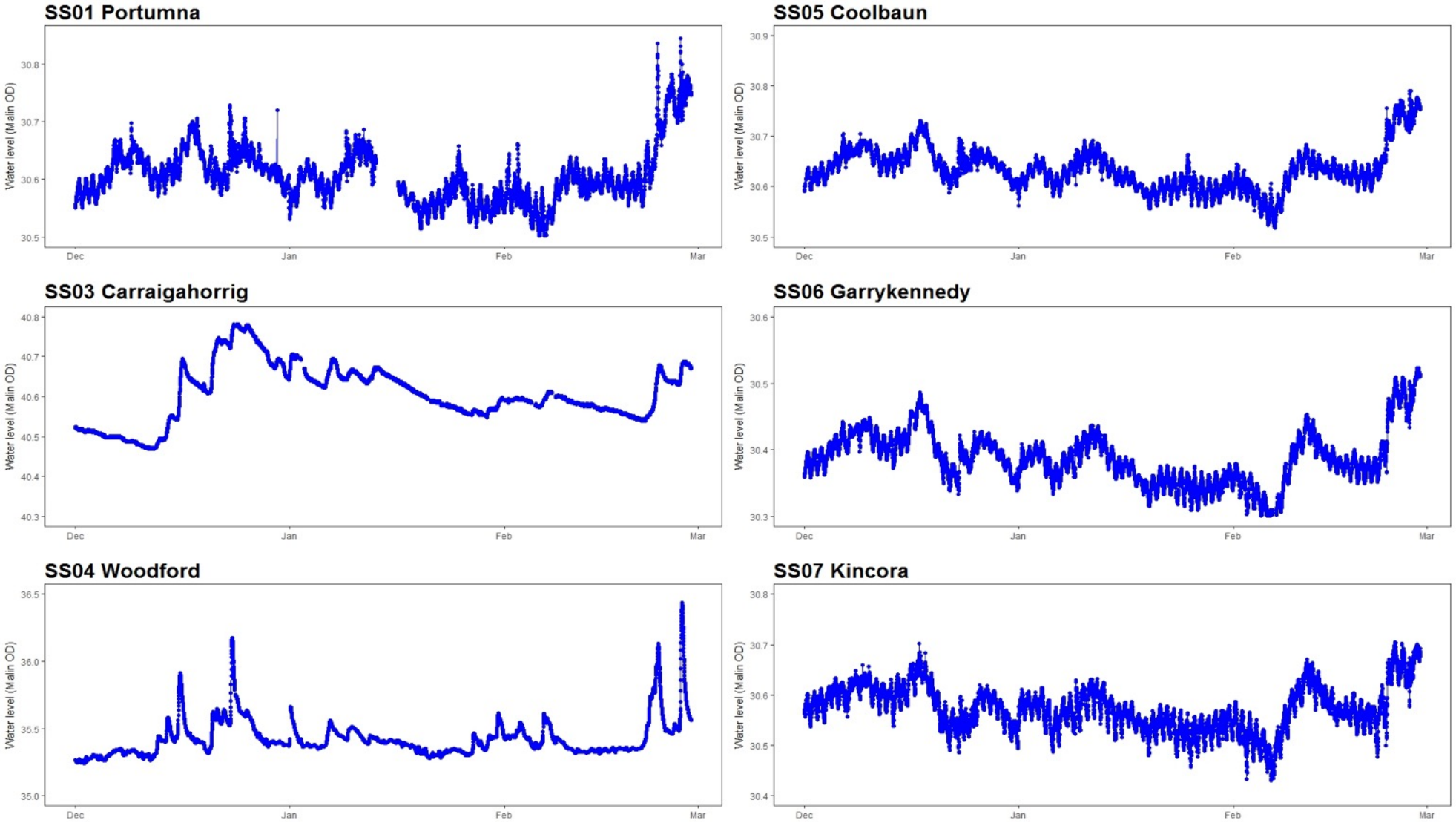

Figure 6: Water level data converted to Malin OD (m) from 6 stations from December 2016 – February 2017

2.3. T500 Water Quality Survey

2.3.1. In-situ sampling

Five in-situ nutrient analysers are deployed, four at open lake sites and one on the inflowing River Shannon at Portumna Bridge. **Figure 7**, **Figure 8**, **Figure 9**, **Figure 10** and **Figure 11** show nutrient data from all 5 sites from September – November 2016 with all data below the limit of detection removed. Many nitrite and ammonia values were below the limit of detection making observations on trends difficult. Nitrate showed an increase across all sites throughout the reporting period. Phosphate showed an increase across all sites with the exception of OL09 which decreased in values from the start of February.

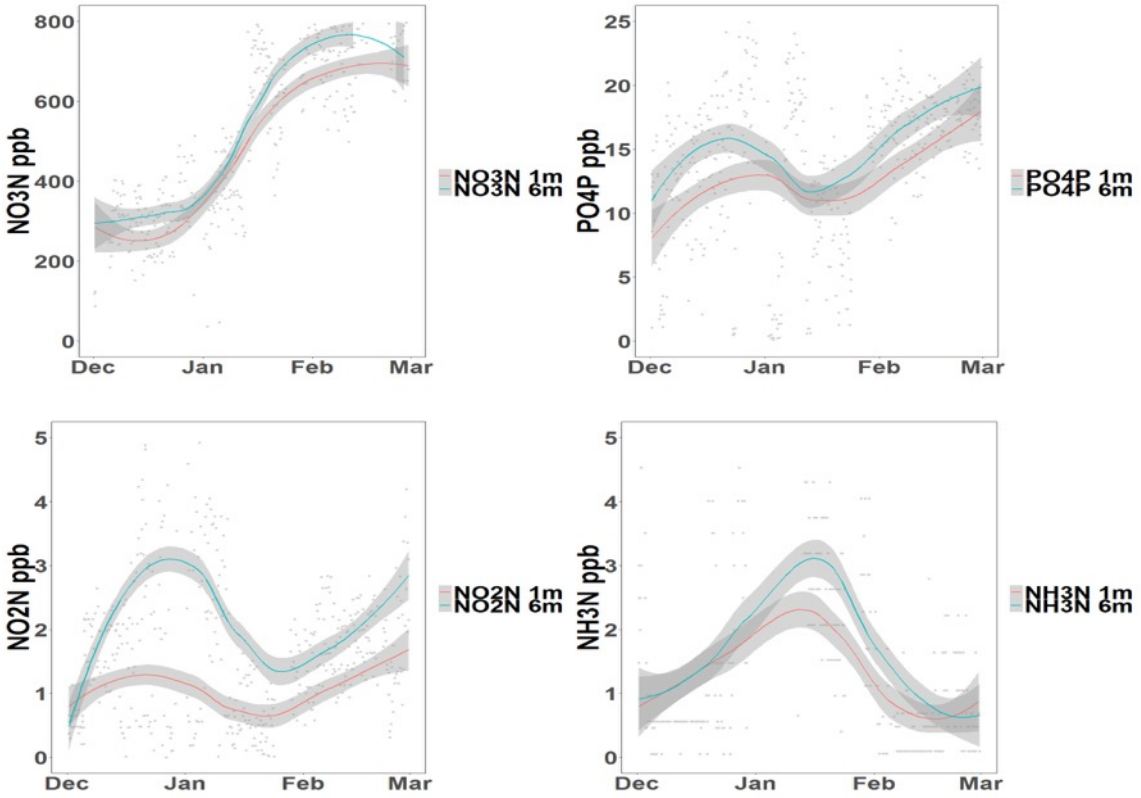

Figure 7: Nutrient Data from OL02 from December 2016 – February 2017 (Note some extreme outliers and data below the limit of detection were removed) .

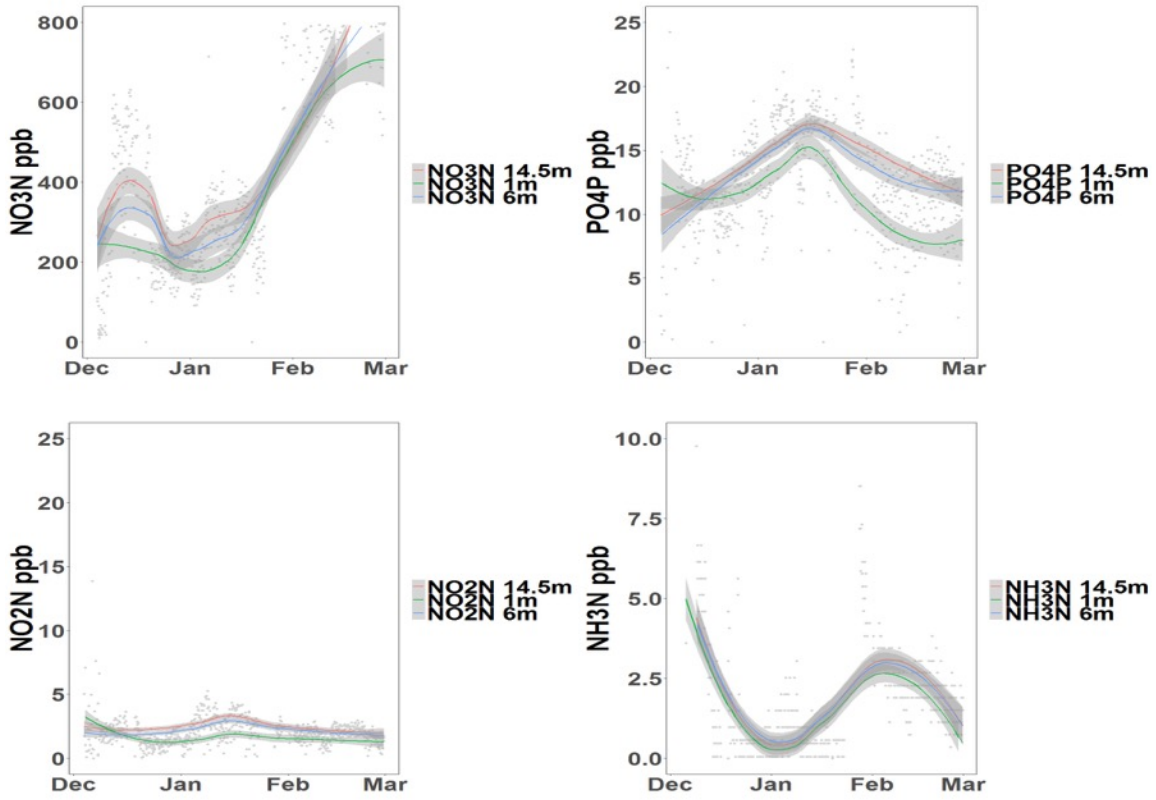

Figure 8: Nutrient Data from OL09 from December 2016 – February 2017 (Note some extreme outliers and data below the limit of detection were removed).

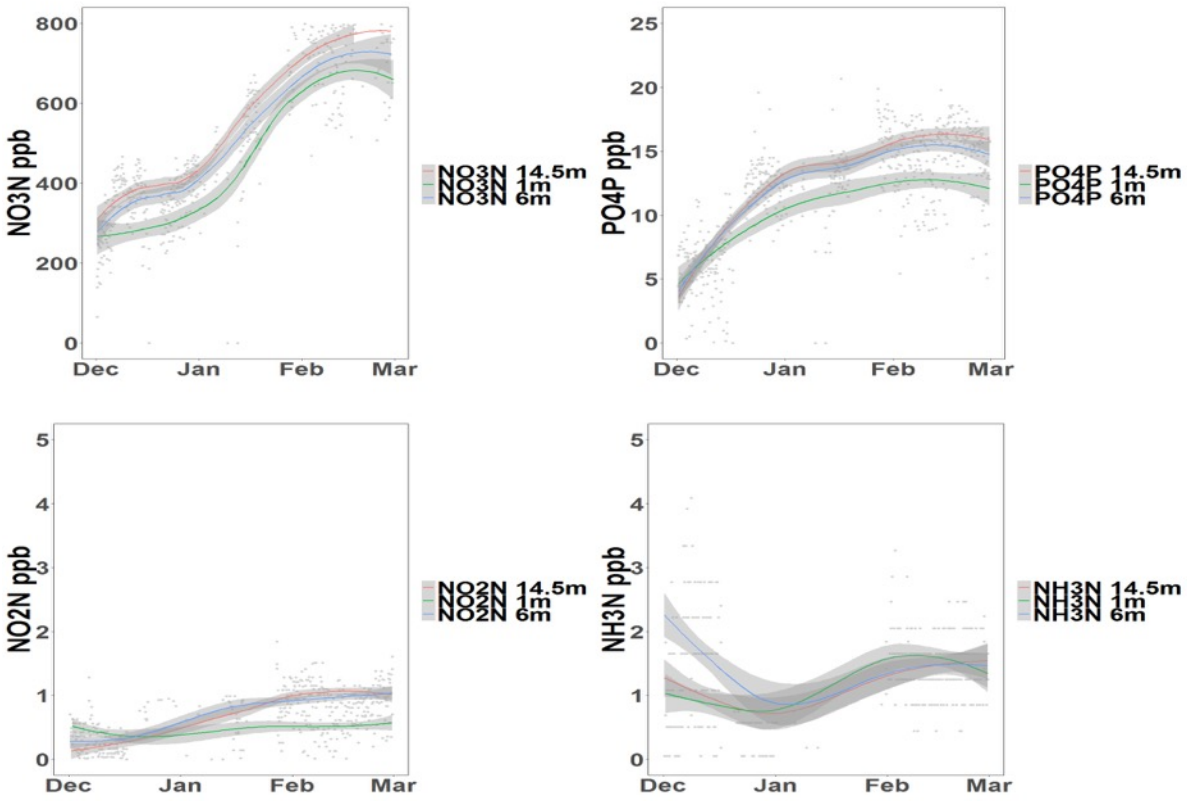

Figure 9: Nutrient Data from OL15 from December 2016 – February 2017 (Note some extreme outliers and data below the limit of detection were removed).

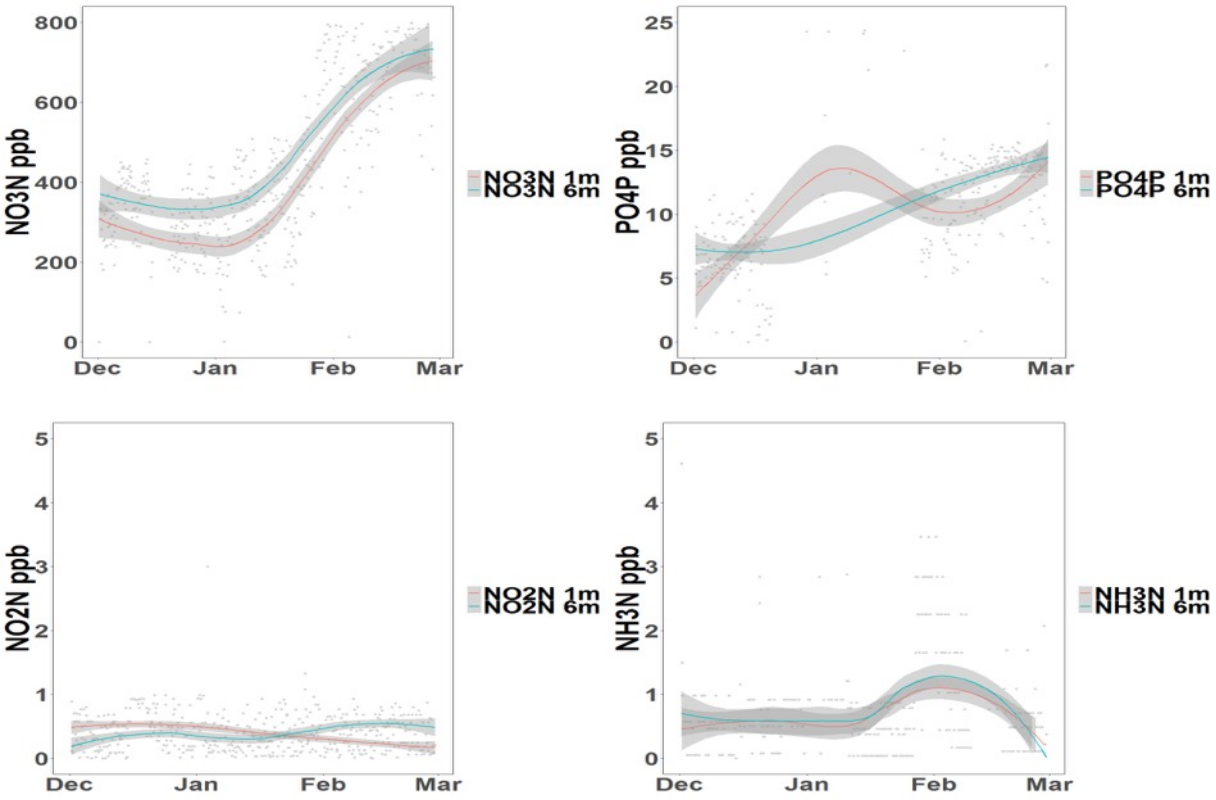

Figure 10: Nutrient Data from OL19 from December 2016 – February 2017 (Note some extreme outliers and data below the limit of detection were removed).

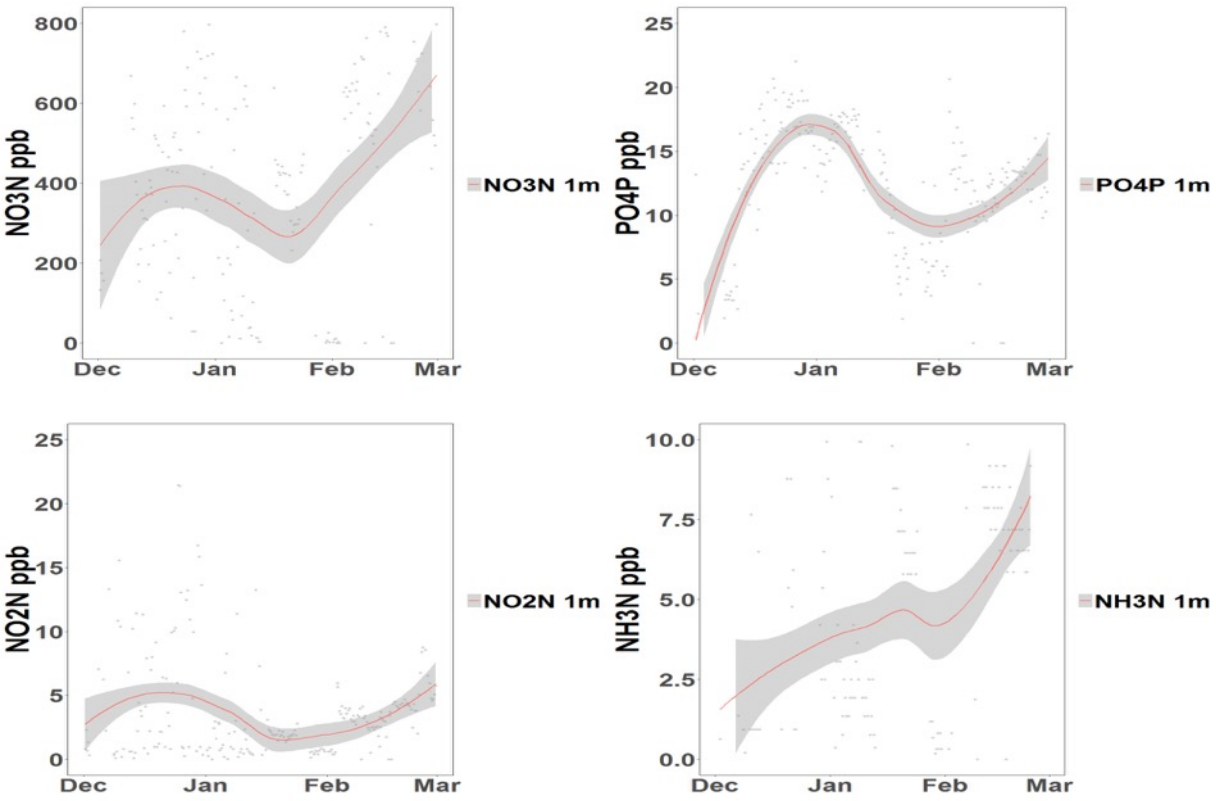

Figure 11: Nutrient Data from SS01 (Portumna Bridge) from December 2016 – February 2017 (Note some extreme outliers and data below the limit of detection were removed).

2.3.2. Spot sampling

Spot sampling has been undertaken since May 2015, **Appendix 1** summarises sampling undertaken for the current reporting period. Extensive water treatability analysis is ongoing on a quarterly basis at the sample site WTMS-4 (Parteen basin). **Appendix 2** lists all chemical parameters measured for Quarterly analysis including the results. Microbiological samples showed evidence of *Cryptosporidium* sp. in a sample taken on 16/02/17. One oocyst was isolated from the sample. No oocysts of *Cryptosporidium* sp. was discovered in any previous samples undertaken during the sampling program.

Figure 12 shows the survey results of fortnightly/monthly[1]coliform bacteria sampling at WTMS 4 (Parteen basin). The presence of thermotolerant coliforms indicates the presence of Escherichia coli which in itself is indicative of traces of human or animal sewage in the water source. Mean values of total coliforms and thermotolerant coliforms in Parteen basin were 31.36 and 16.17 CFU/100ml. Under the Bathing Water Quality Regulations 2008 inland water bodies are classified as excellent status if E. coli numbers are below 500 CFU/100ml (based on a 95-percentile evaluation). Maximum thermotolerant coliform values from WTMS 4 were 294 CFU/ml below the guideline value of the bathing water regulations. Under drinking water legislation water supplies are obliged to have zero coliforms present indicating microbiological treatment would be required of these waters.

Figure 13, **Figure 14** and **Figure 15** show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate and chlorophyll a from water quality sites on Lough Derg at all depths. **Figure 16** shows the water quality data from all inflowing rivers into Lough Derg. Obvious trends can be seen in nitrate, phosphate and chlorophyll a in the lake. Nitrate and phosphate increased at all stations and depths across the reporting period peaking in January/February 2017. Chlorophyll *a* levels remained low across all sites throughout the reporting period. It was difficult to discern trends in the river parameters however both nitrate and phosphate both showed an increase over the winter months. Nitrite and ammonia levels remained low across most samples with many samples falling below the limits of detection.

[1] *As per clients instruction from August 2016 onwards samples for Water Treatability sampling was taken from WTMS 4. Fortnightly sampling was reduced to monthly.*

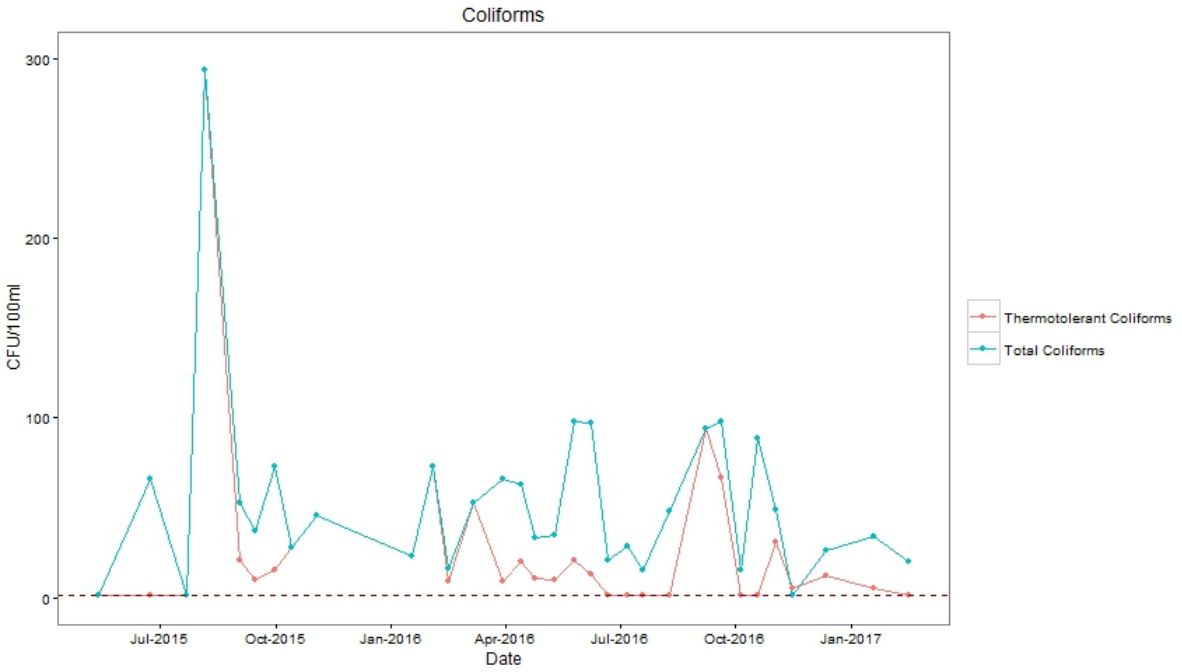

Figure 12: Survey results of Coliforms bacteria (CFU/100ml) at WTMS 4 (Parteen basin) from May 2015 – February 2017.

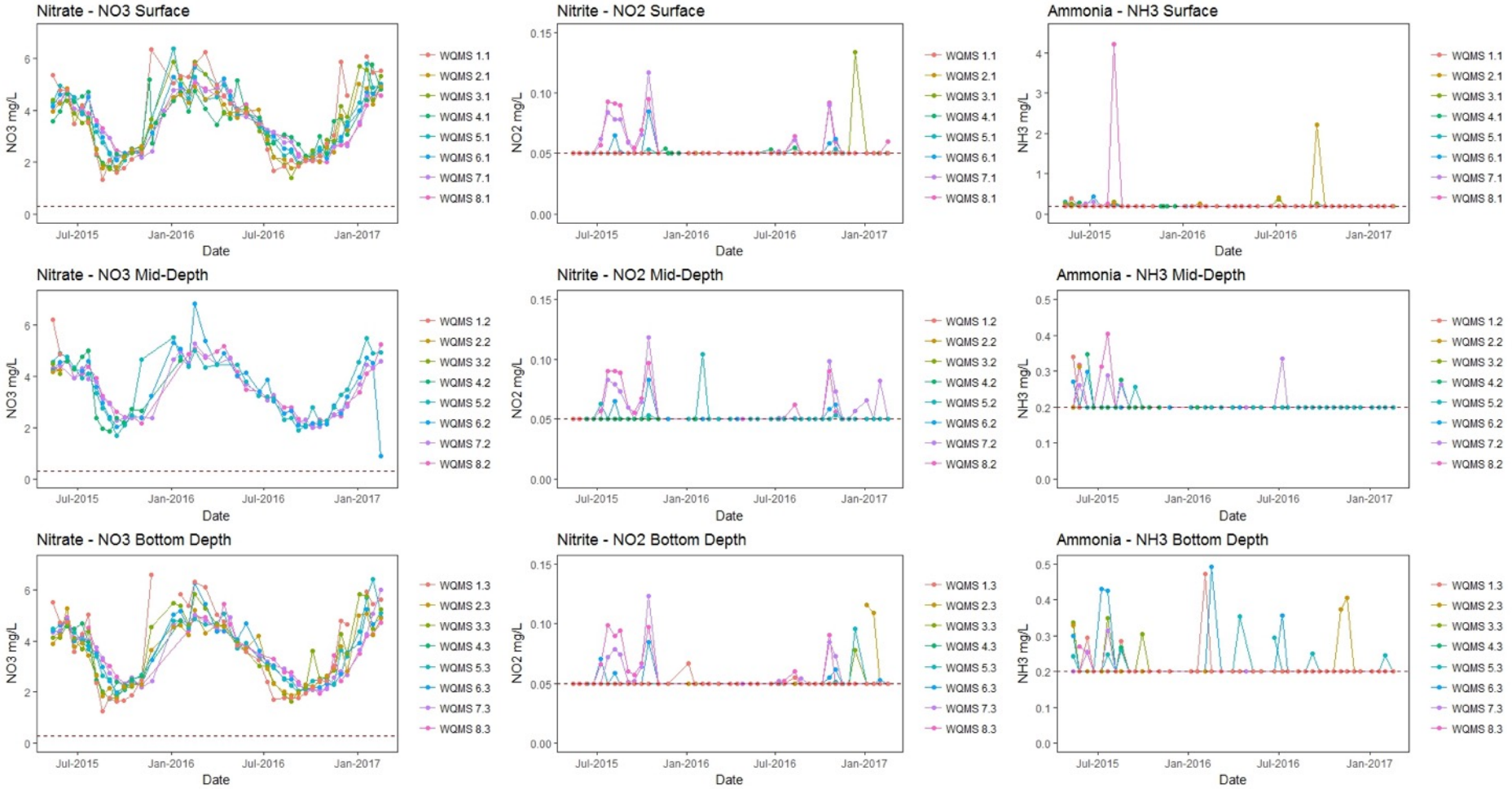

Figure 13: Survey results from all lake water quality sites of nitrate (NO3) nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – February 2017.

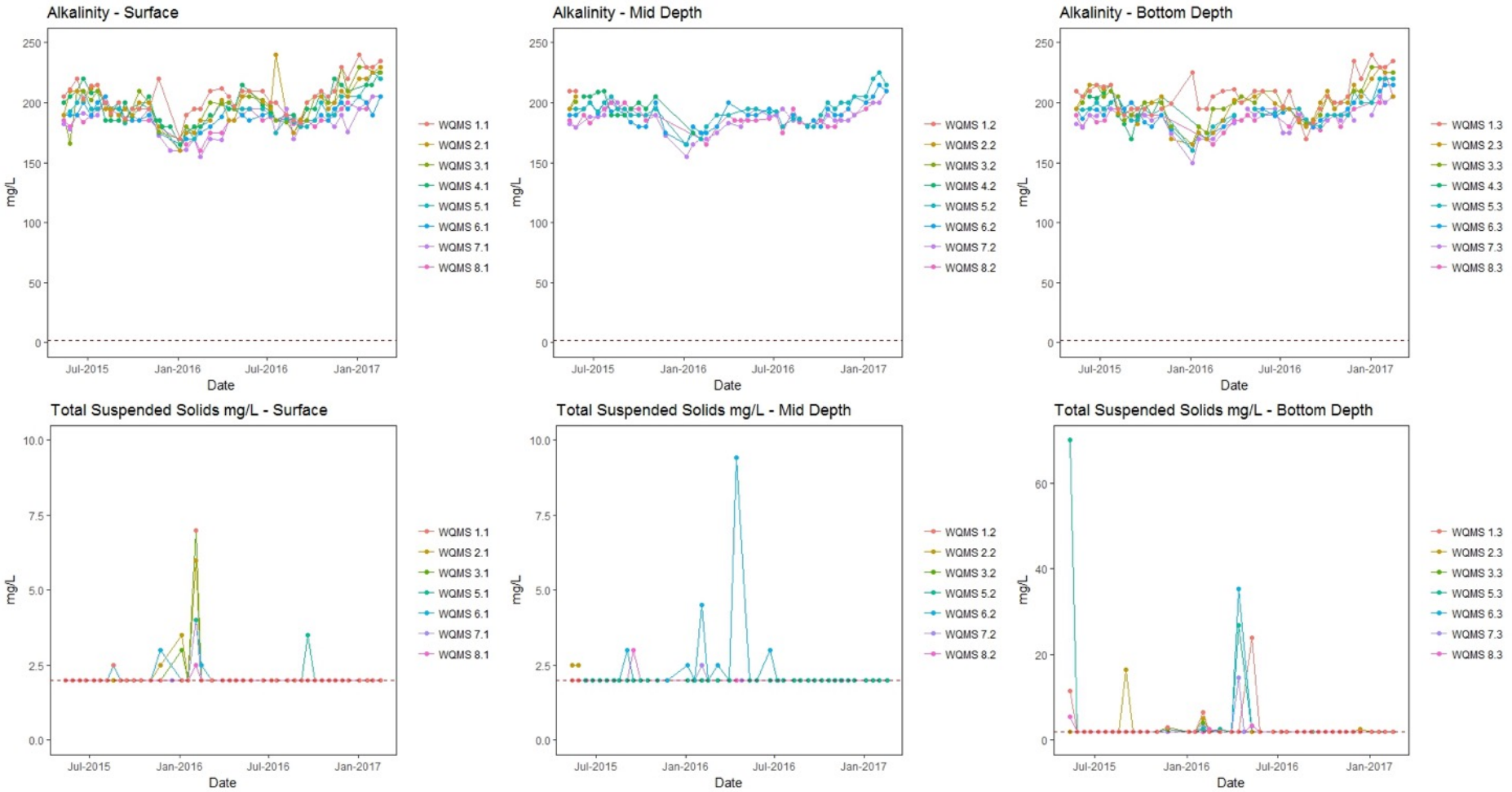

Figure 14: Survey results from all lake water quality sites of Alkalinity and Suspend Solids (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – February 2017.

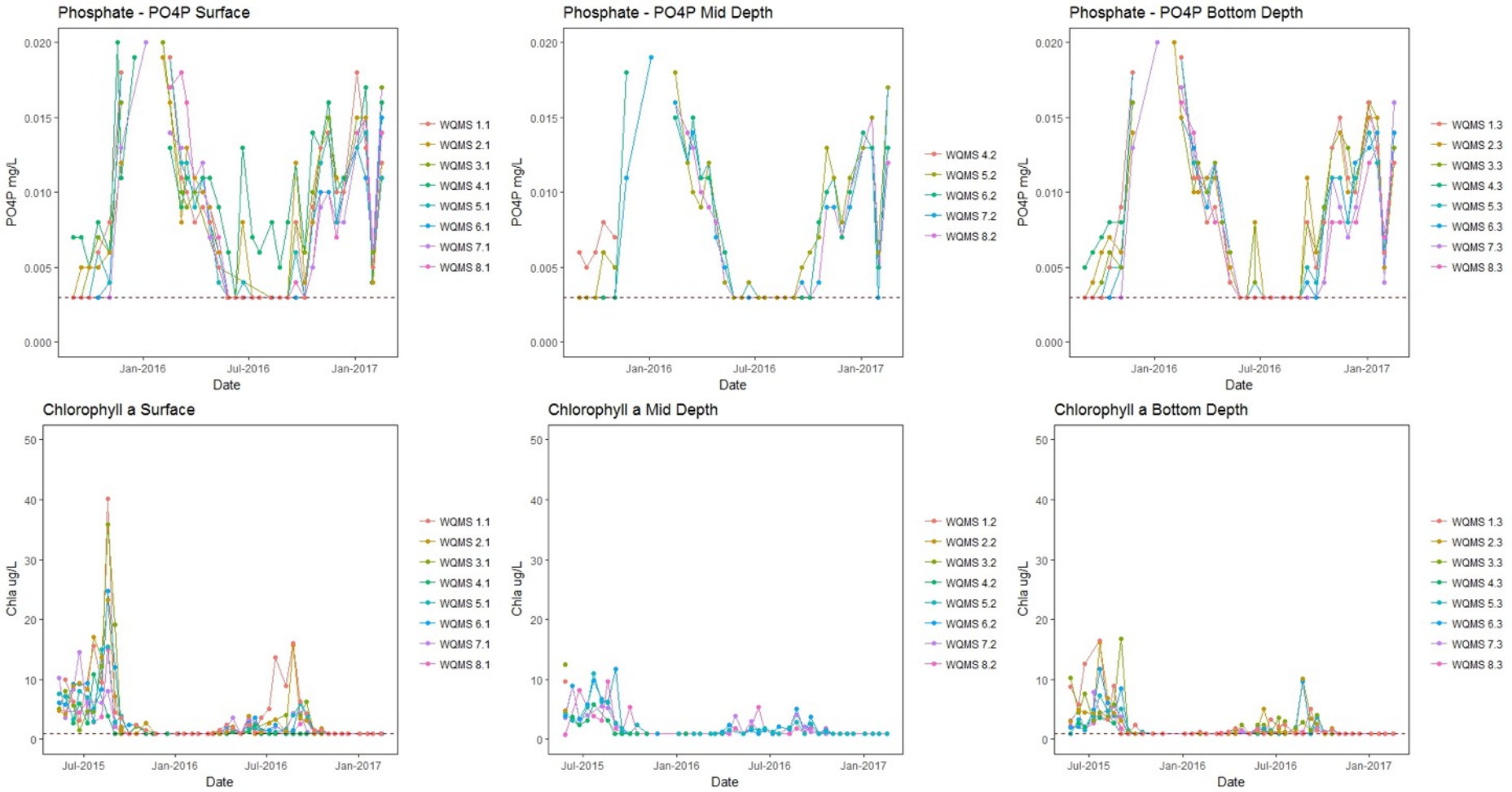

Figure 15: Survey results from all lake water quality sites of Chlorophyll *a* and Phosphate (PO4P) (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – February 2017.

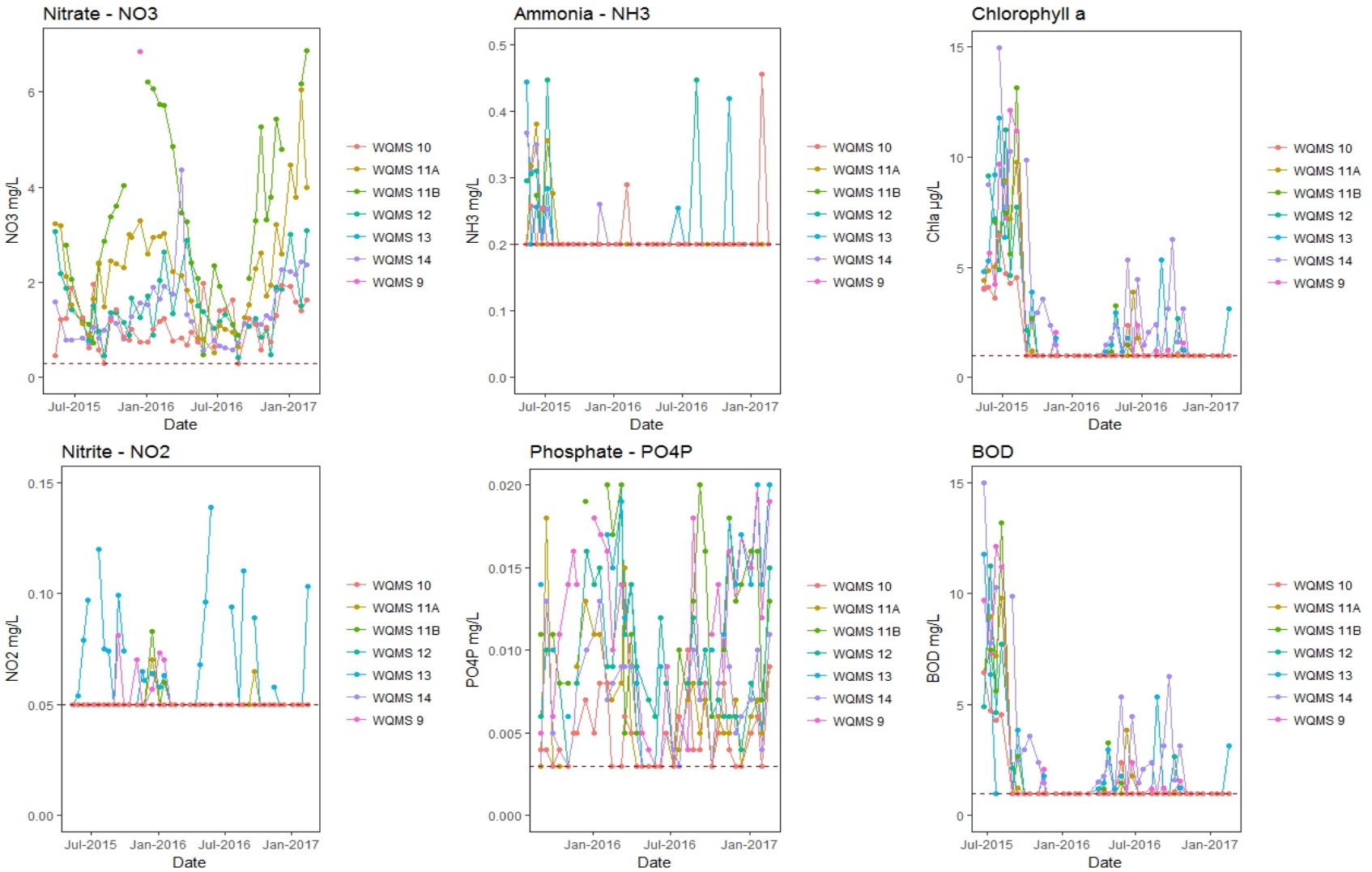

Figure 16: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll *a* and BOD (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – February 2017.

2.4. T600 Temperature Survey

Nineteen temperature monitoring stations are deployed on Lough Derg. All sites showed similar patterns throughout the reporting period. OL12 located at the deepest location on the lake broke it's mooring in early January, it was removed from the lake to avoid it becoming a navigation hazard and redeployed 28th March 2017 with a new mooring. **Figure 17** shows temperature data from OL16 which is located at a deep location in the lake (~25m). No evidence of stratification was seen throughout the reporting period, lowest temperatures were seen in mid-February before steadily increasing to above 7°C toward the end of the month.

Figure *18* shows a boxplot of surface level temperatures from the inflow (Portumna) and outflow (Parteen) of the lake. Mean temperatures at both the inflow and outflow of the lake were similar with Parteen showing a wider range of temperatures than Portumna.

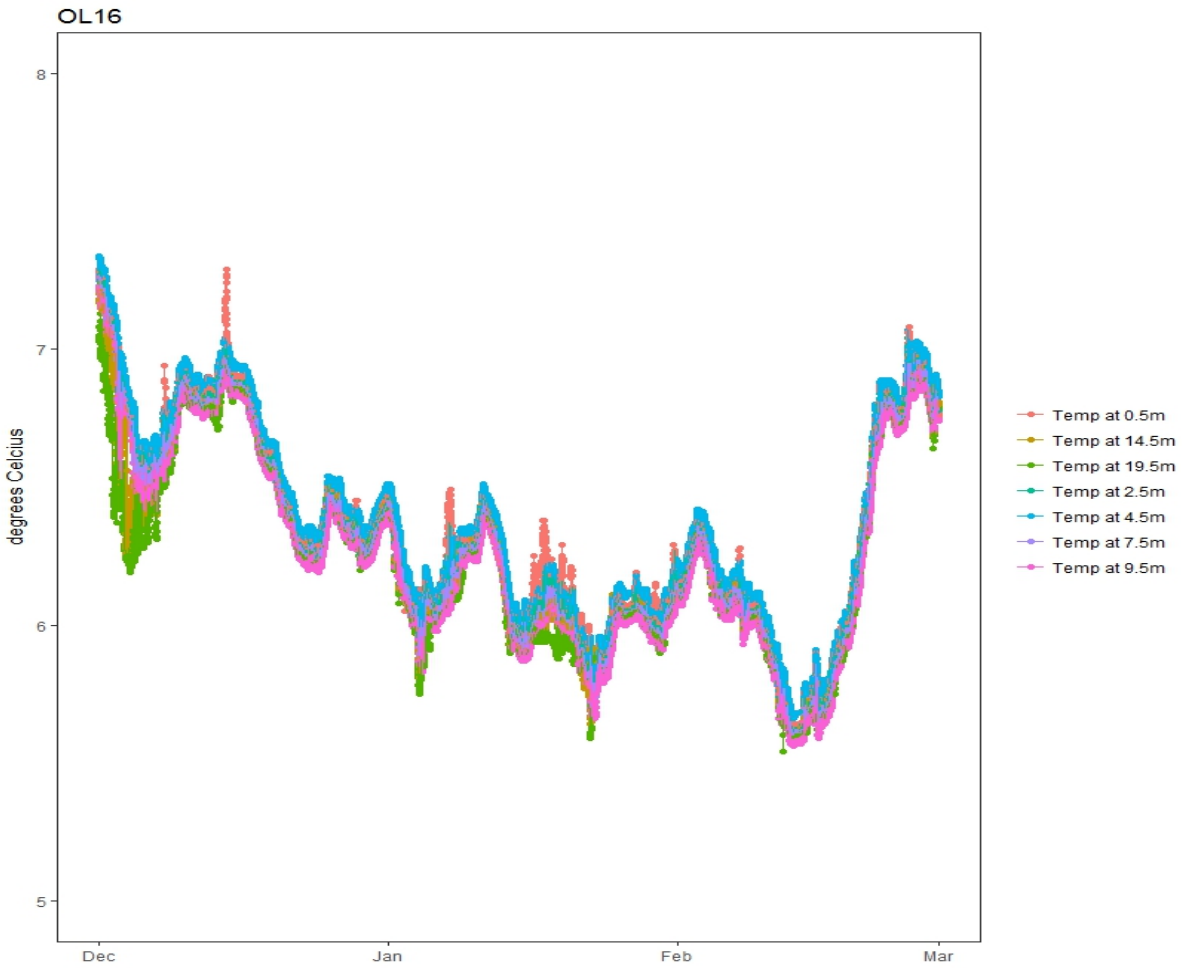

Figure 17: OL16 temperature data from all depths from December 2016 – February 2017.

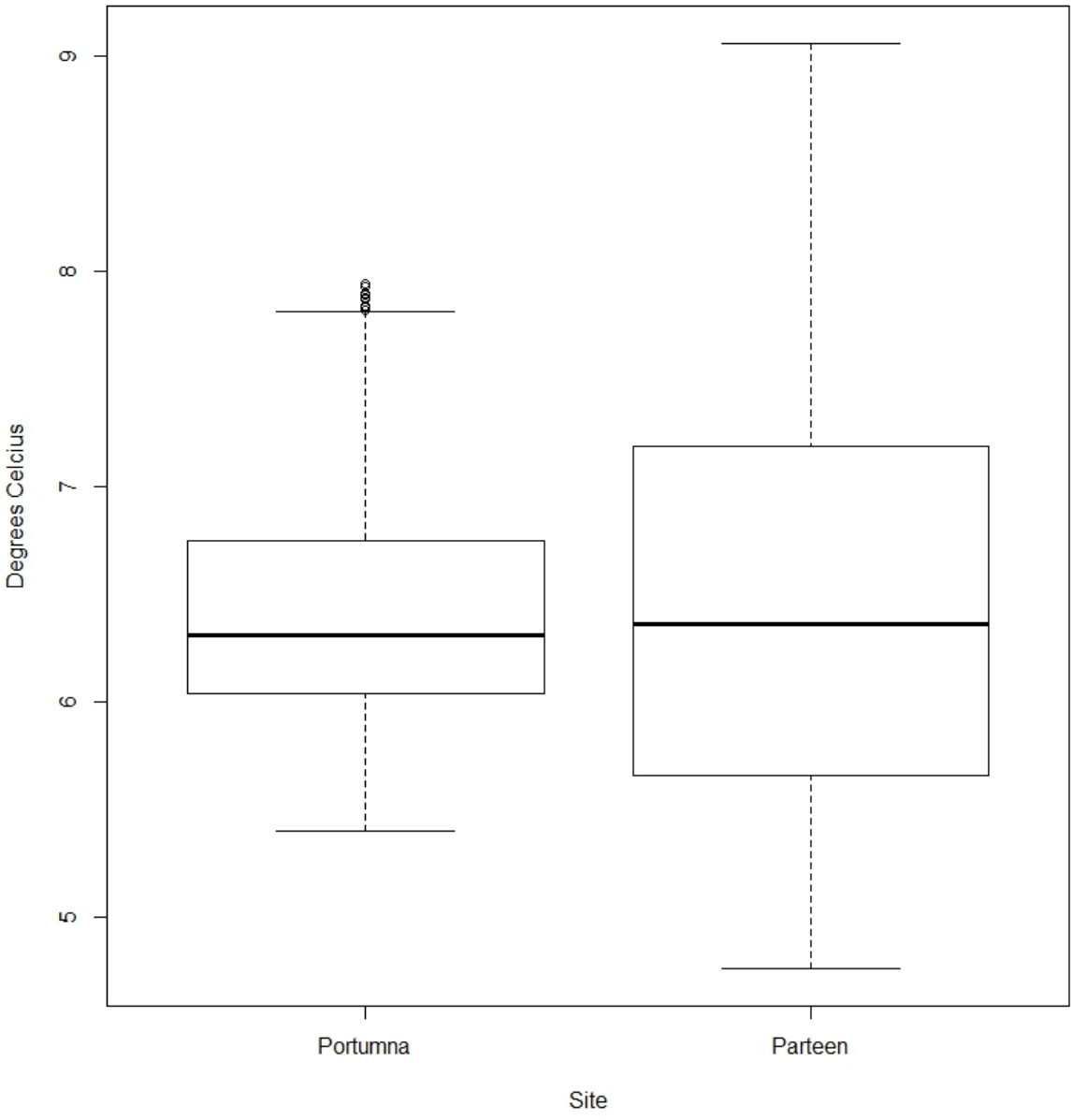

Figure 18: Boxplot showing surface temperatures from Portumna (inflow) and Parteen (outflow) from December 2016 – February 2017.

2.5. T800 Meteorological Survey

Two meteorological stations have been installed on the eastern and western shores of Lough Derg. **Figure 19** and **Figure 20** show meteorological data from both stations at Ballinderry and Whitegate. Both stations show similar values for all parameters. **Figure 21** shows windrose diagrams for both met stations, prevailing winds for Whitegate over the reporting period was predominantly southerly while for Ballinderry it was south – south westerly.

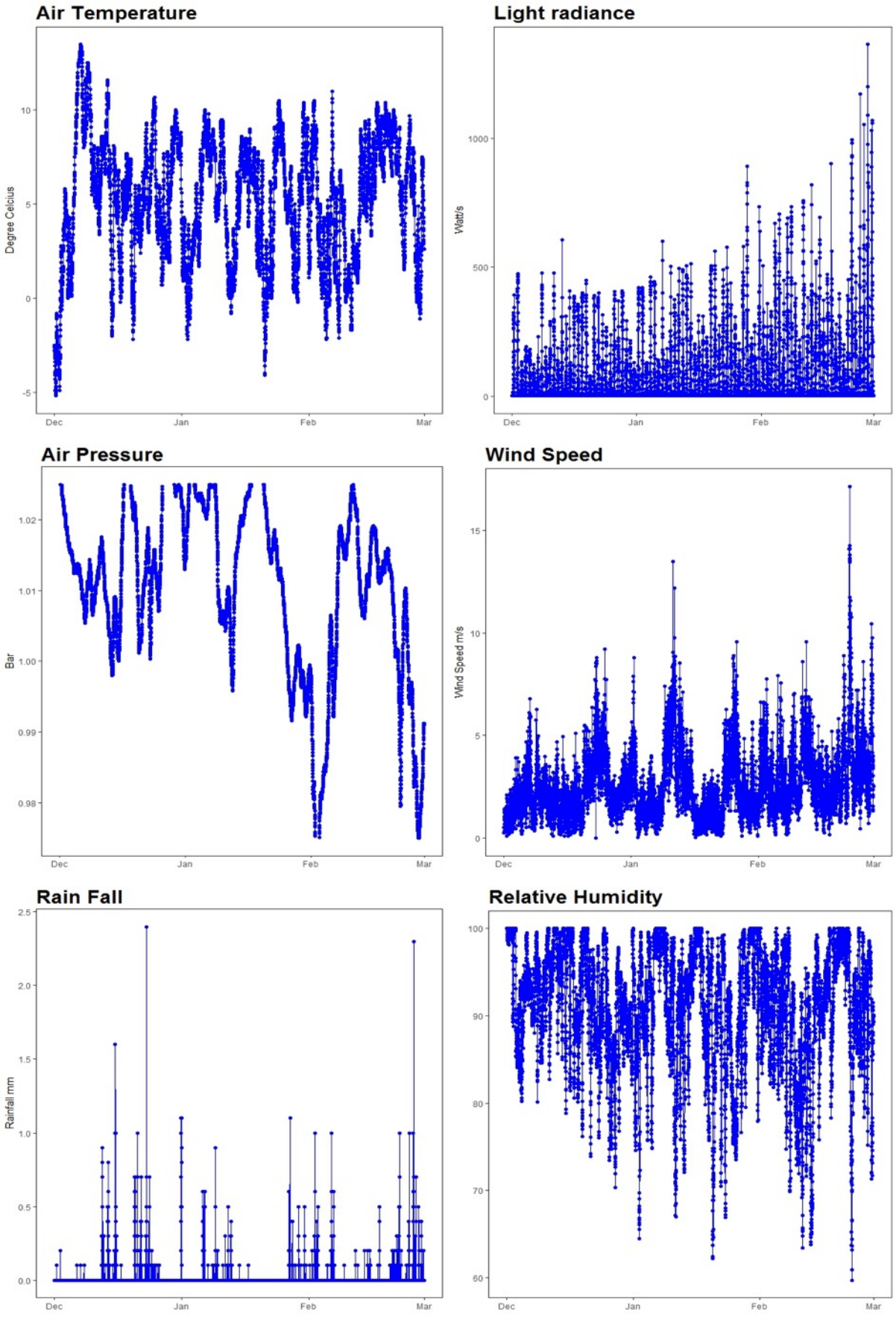

Figure 19: Data from MS01 (Ballinderry) from December 2016 – February 2017.

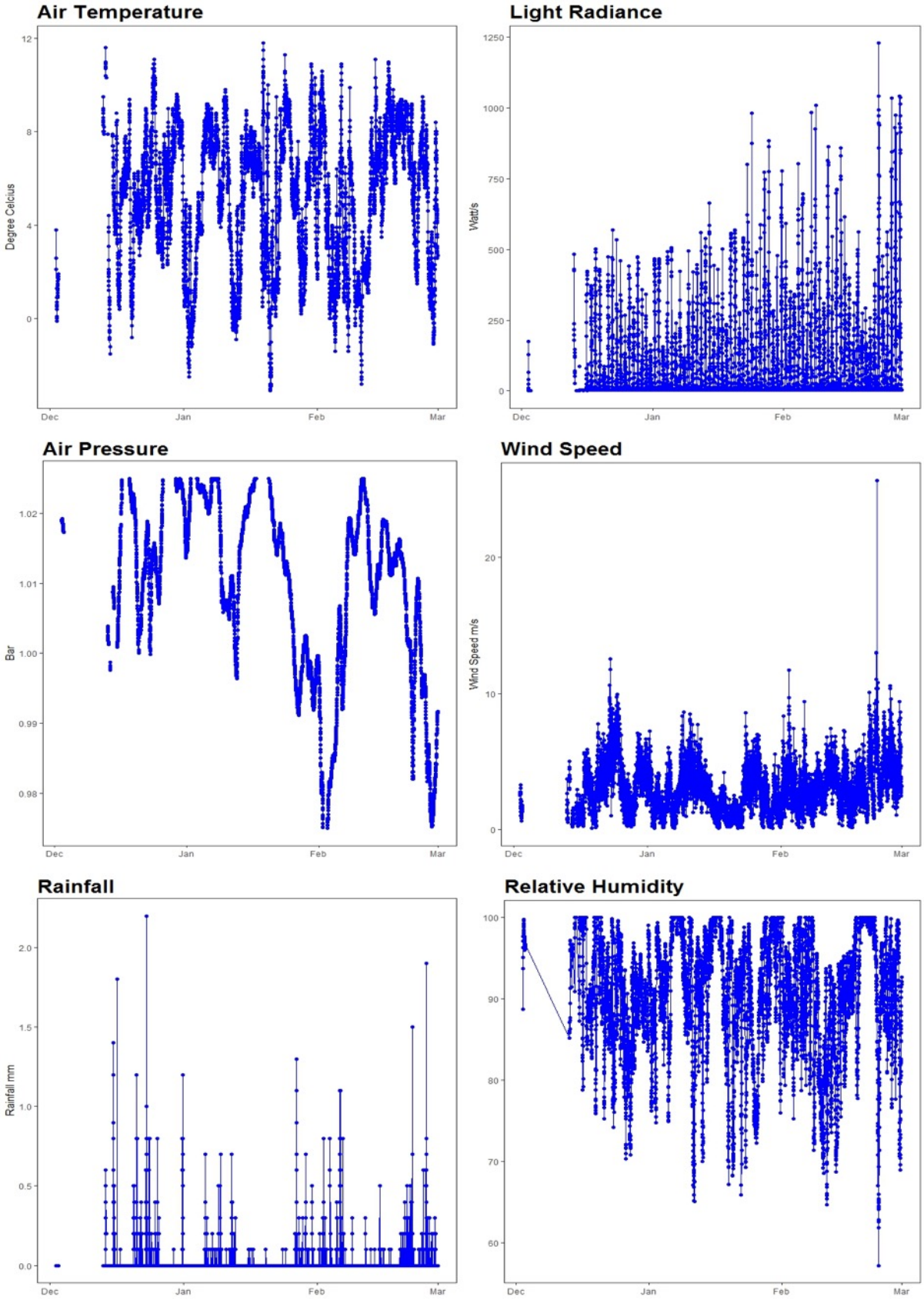

Figure 20: Data from MS02 (Whitegate) from December 2016 – February 2017.

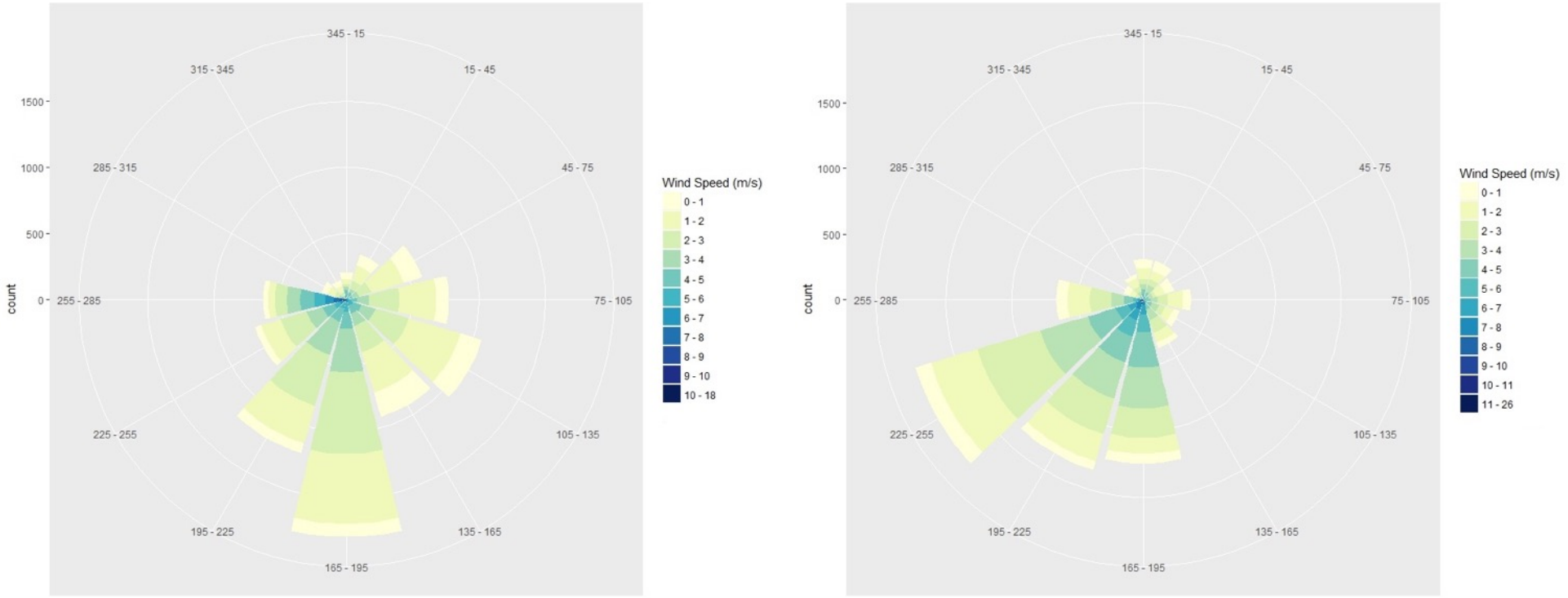

Figure 21: Windrose Diagram for Whitegate (left pane) and Ballinderry (right pane) weather stations from December 2016 – February 2017.

2.6. T900 Plankton Survey

Figure 22 shows all surface level chlorophyll *a* values from all sites from May 2015 – February 2017. For the current reporting period, values of chlorophyll *a* remained low indicating very little primary productivity in the lake.

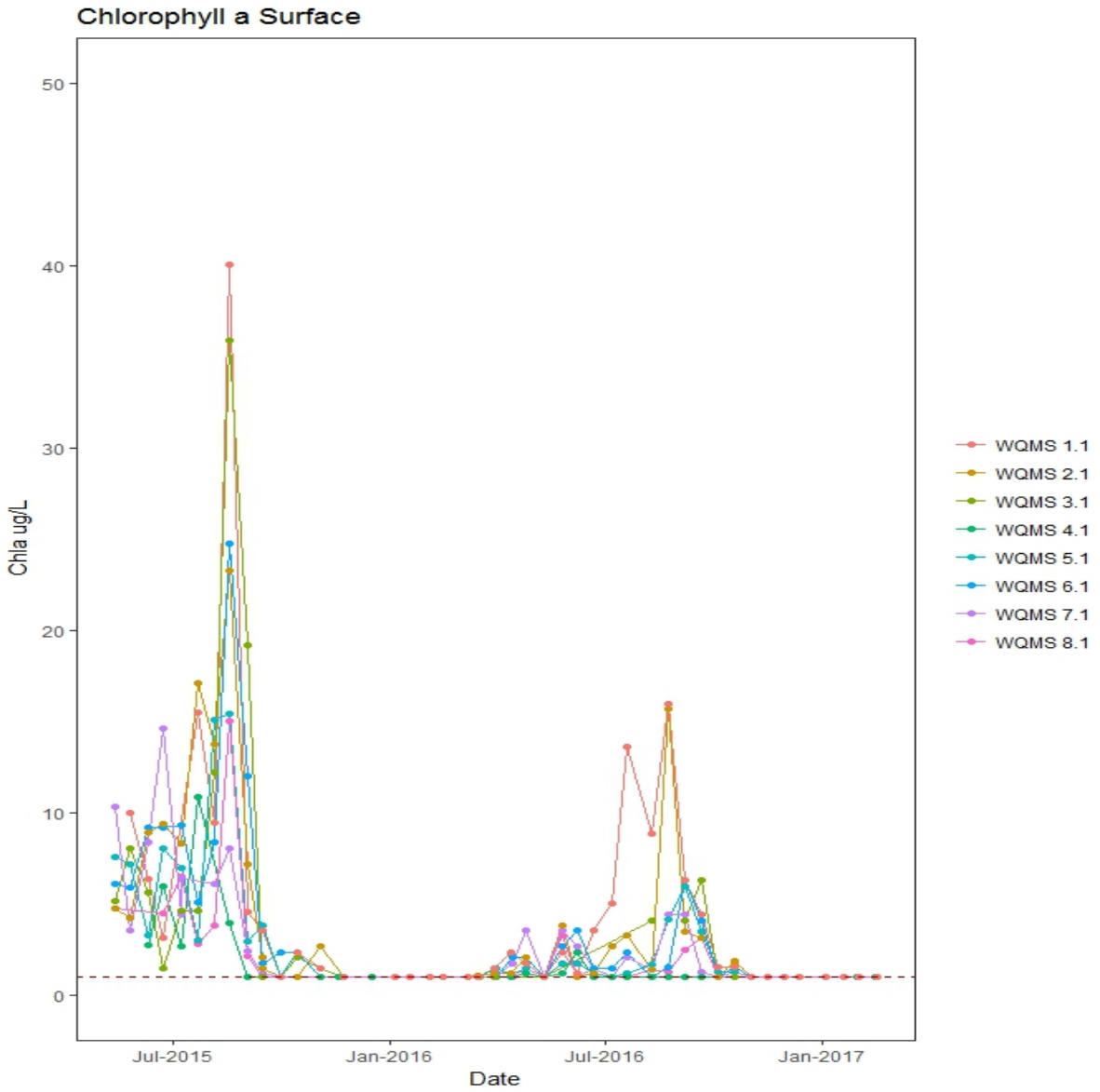

Figure 22: Surface chlorophyll *a* results from all sites from May 2015 – February 2017.

3. Appendices

Appendix 1: Summary of spot sampling for Water Quality, Water Treatability and Ecology from September –November 2016.

Sample Date	WQMS - Fortnightly	WTMS-Monthly [2]	WTMS-Quarterly *	Comments
12/12/2016	X	X		
04/01/2017	X			
19/01/2017	X	X		
31/01/2017	X	X		
16/02/2017	X	X	X	

[2] As per clients instruction from August 2016 onwards samples for Water Treatability sampling was taken from WTMS 4. Fortnightly sampling was reduced to monthly.

Appendix 2: List of quarterly water treatability parameters with results (values prefixed with < denotes below limit of detection).

Parameter	Sample Date						
	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017
Acenaphthene (aq) µg/l	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Acenaphthylene (aq) µg/l	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
Aldrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Alkalinity, Total as CaCO3 mg/l	190	195	170	195	185	190	205
alpha-Hexachlorocyclohexane (HCH / Lindane) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Aluminium (diss.filt) µg/l	6.14	4	13.7	8.62	<2	3.96	5.46
Anthracene (aq) µg/l	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Arsenic (diss.filt) µg/l	0.796	0.676	0.47	0.219	1.21	1.17	1.16
Azinphos-ethyl µg/l	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Azinphos-methyl µg/l	<0.01	0.02	<0.01	<0.01	<0.01	<0.05	<0.01
Barium (diss.filt) µg/l	35.5	41.5	31.8	37.2	40	37.3	41.7
Benzene µg/l	<7	<7	<7	<7	<7	<7	<7
Benzo(a)anthracene (aq) µg/l	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
Benzo(a)pyrene (aq) µg/l	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Benzo(b)fluoranthene (aq) µg/l	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023
Benzo(g,h,i)perylene (aq) µg/l	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016
Benzo(k)fluoranthene (aq) µg/l	<0.027	<0.027	<0.027	<0.027	<0.027	<0.027	<0.027
beta-Hexachlorocyclohexane (HCH / Lindane) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD, unfiltered mg/l	NA	NA	<1	<1	<1	<1.07	<1
Boron (diss.filt) µg/l	11	12.9	<9.4	<9.4	9.84	11	9.28
Bromine* mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium (diss.filt) µg/l	<0.1	<0.1	<0.1	<0.1	<0.08	<0.08	<0.08
Calcium (diss.filt) mg/l	70.4	70.1	60.8	68.4	66.1	73.2	74.9
Carbophenothion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorfenvinphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017
Chloride mg/l	19	18.4	14.8	15.3	16.3	16	15.2
Chlorothalonil µg/l	<0.01	0.02	<0.01	<0.01	<0.01	<0.05	<0.01
Chlorpyriphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorpyriphos methyl µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium (diss.filt) µg/l	1.36	2.91	2.37	1.75	<1.2	<1.2	<1.2
Chrysene (aq) µg/l	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
cis-Chlordane µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD, unfiltered mg/l	23.5	20.2	31	12.4	19.3	28.9	30.7
Conductivity @ 20 deg.C mS/cm	0.383	0.382	0.326	0.378	0.371	0.367	0.379
Copper (diss.filt) µg/l	1.04	1.26	1.11	1.21	1.79	<0.85	<0.85
Cresols mg/l	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Cyanide, Total mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Diazinon µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dibenzo(a,h)anthracene (aq) µg/l	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016
Dichlorvos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dieldrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dimethoate µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dissolved solids, Total (meter) mg/l	287	313	262	293	282	278	300
Disulfoton µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endosulphan I µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endosulphan II µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endosulphan sulphate µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
EPH (C6-C10) µg/l	<100	<100	<100	<100	<100	<100	<100
EPH Range >C10 - C40 (aq) µg/l	<46	<46	<46	<46	<46	<46	<46
Ethion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethylbenzene µg/l	<5	<5	<5	<5	<5	<5	<5

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017
Etrimphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenitrothion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenthion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene (aq) µg/l	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
Fluorene (aq) µg/l	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Fluoride mg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
gamma-Hexachlorocyclohexane (HCH / Lindane) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
GRO >C5-C10 µg/l	<10	<10	<10	<10	<10	<10	<10
Heptachlor µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Heptachlor epoxide µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hexachlorobenzene µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Indeno(1,2,3-cd)pyrene (aq) µg/l	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Iron (diss.filt) mg/l	0.0242	<0.019	0.103	0.0356	<0.019	0.0208	0.0514
Isodrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead (diss.filt) µg/l	<0.02	0.031	0.059	<0.02	<0.1	<0.1	<0.1
m,p-Xylene µg/l	<8	<8	<8	<8	<8	<8	<8
Malathion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Manganese (diss.filt) µg/l	0.549	3.15	2.22	3.01	1.43	3.64	2.73
Mercury (diss.filt) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methyl parathion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methyl tertiary butyl ether (MTBE) µg/l	<3	<3	<3	<3	<3	<3	<3
Mevinphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Naphthalene (aq) µg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel (diss.filt) µg/l	2.06	2.43	1.88	2.88	1.33	1.31	1.37
Nitrogen, Kjeldahl mg/l	<1	<1	<1	1.12	<1	<1	<1
Nitrogen, Total mg/l	1.91	1.37	1.48	2.06	1.59	1.29	1.86
o-Xylene µg/l	<3	<3	<3	<3	<3	<3	<3

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017
o,p-DDE µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
o,p-DDT µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
o,p-Methoxychlor µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
o,p-TDE (DDD) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Organic Carbon, Total mg/l	9.19	8.86	11.1	9.51	4.08	9.21	10.8
Oxygen, dissolved mg/l	10.4	9.43	10.1	10.2	9.82	9.74	9.96
p,p-DDE µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p,p-DDT µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p,p-Methoxychlor µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p,p-TDE (DDD) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH, Total Detected USEPA 16 (aq) µg/l	<0.344	<0.344	<0.344	<0.344	<0.344	<0.344	<0.344
Parathion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pendimethalin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Permethrin I µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Permethrin II µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
pH pH Units	8.25	8.41	8.32	8.27	8.38	8.28	8.41
Phenanthrene (aq) µg/l	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Phenol mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Phenols, Total Detected monohydric mg/l	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016
Phosalone µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pirimiphos-methyl µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propetamphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pyrene (aq) µg/l	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Quintozene (PCNB) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium (diss.filt) µg/l	<0.39	0.661	<0.39	<0.39	0.981	<0.81	<0.81
Sulphate mg/l	14.1	12.4	<2	<2	<2	<2	<2
Sum of detected BTEX µg/l	<28	<28	<28	<28	<28	<28	<28

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017
Surfactants, Anionic (MBAS) mg/l	<0.05	<0.05	<0.05	<0.05	0.45	0.0624	<0.05
Tecnazene µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Telodrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Toluene µg/l	<4	<4	<4	<4	<4	<4	<4
Total EPH (C6-C40) (aq) µg/l	<100	<100	<100	<100	<100	<100	<100
Total Oxidised Nitrogen as N mg/l	1.01	0.882	1.13	0.941	0.685	0.495	1.04
Trans-chlordane µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triadimefon µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triallate µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triazophos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trifluralin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Xylenols mg/l	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Zinc (diss.filt) µg/l	0.46	0.537	1.29	1.47	1.69	<1.3	2.12
Langelier Index (LSI) *	0.59722	0.84136	0.41247	0.60290	0.78656	0.59866	0.67297

***Langelier Index (LSI)** LSI = pH – pHs

pHs = (9.3 + A + B) – (C + D)

A = $(\log_{10}[\text{Total Dissolved Solids}] - 1)/10$

B = $-13.12 * \log10(\text{Temp}^{o}\text{C} + 273) + 34.55$

C = $\log_{10}[Ca^{2+} \text{ as } CaCO_3^{*}] - 0.4$

D = $\log_{10}[\text{Alkalinity as } CaCO_3]$

*Calcium was converted to Ca^{2+} as $CaCO_3$ using a conversion factor of 2.5.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

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Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
Document Title:	**Data report for Lough Derg Monitoring Project (March 2017 – May 2017)**
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1. Introduction

The Lough Derg Monitoring Project led by Water Technology Ltd. are engaged in a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers. The project has been running since April 2015.

2. Results to date

2.1. T300 Water Flow and Current Survey

2.1.1. ADCP Survey

Figure 1 shows daily moving average flow data from the horizontal ADCP installed at Portumna. High levels of flow were seen in March with a gradual decline across all bins shown through until the end of May.

As with previous reporting periods the flow data from the vertical ADCP's installed at lake stations OL02, OL09 and OL15 show a high variability in flow in the top bins (**Figure 2**, **Figure 3** and **Figure 4**). Comparison of the top bin data with wind direction data from the closest met stations show a relationship between wind direction and flow in the surface water of the lake (**Figure 5**). **Figure 5** shows scatter plots of flow from the surface level bin with wind direction from nearest weather station. A Lowess (LOcally WEighted Scatter-plot Smoother) line has been imposed on the data to decipher trends. Wind direction seems to be driving surface flows in the lake at OL09 and OL02. This trend was also shown in data from previous reporting periods. As stated in previous reports the relationship between surface flows and wind direction is less obvious at station OL15, this may be due to the stations proximity from the weather station or a lesser influence of wind direction on flow at this station.

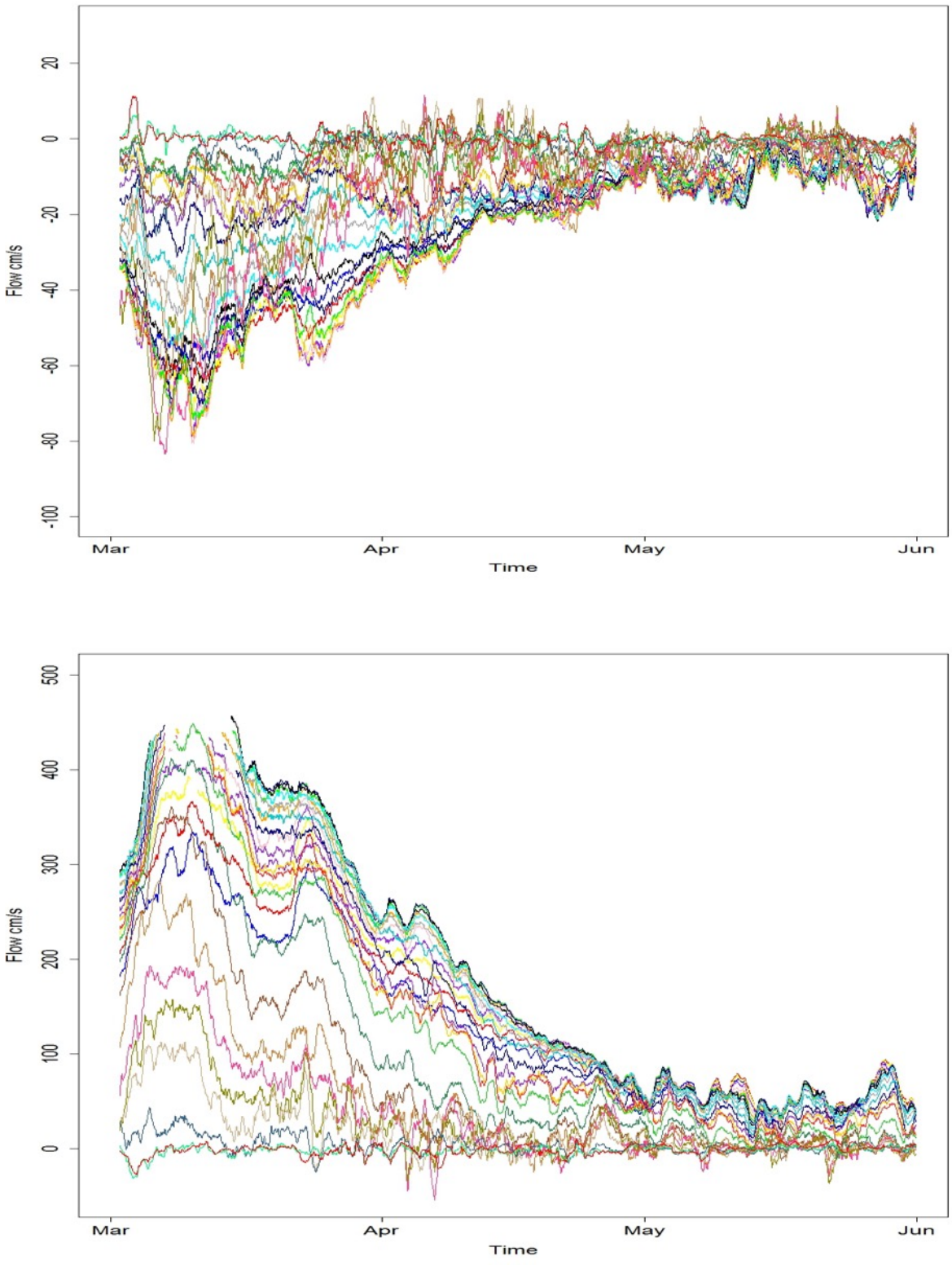

Figure 1: Daily moving average Flow data from Horizontal ADCP cm/s (Top panel shows X axis flows across all bins, Bottom panel shows Y axis flows) from March 2017 – May 2017. Note: Data has been filtered to remove noisy data (>500, < -500).

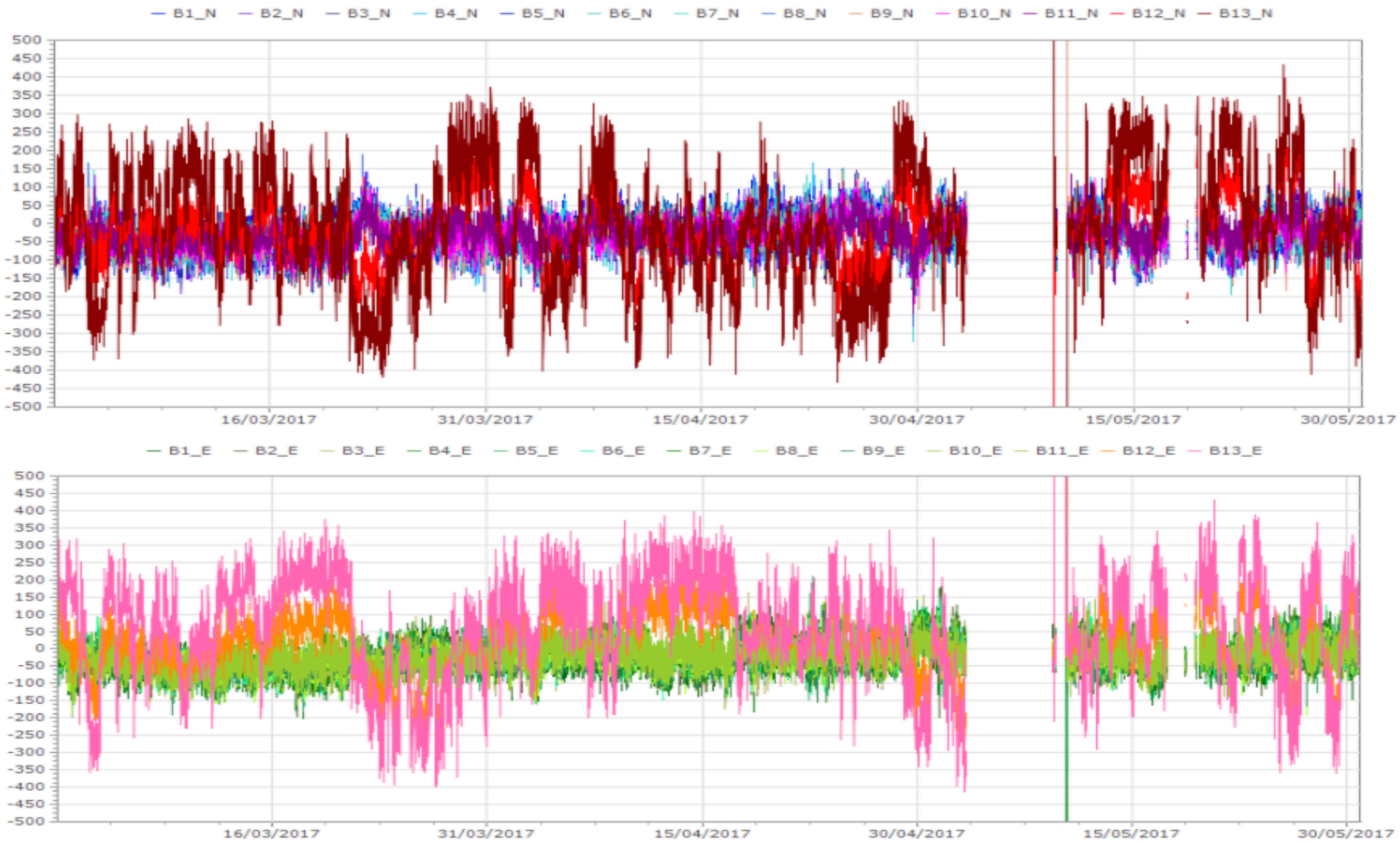

Figure 2: Flow data from OL02 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from March 2017 – May 2017

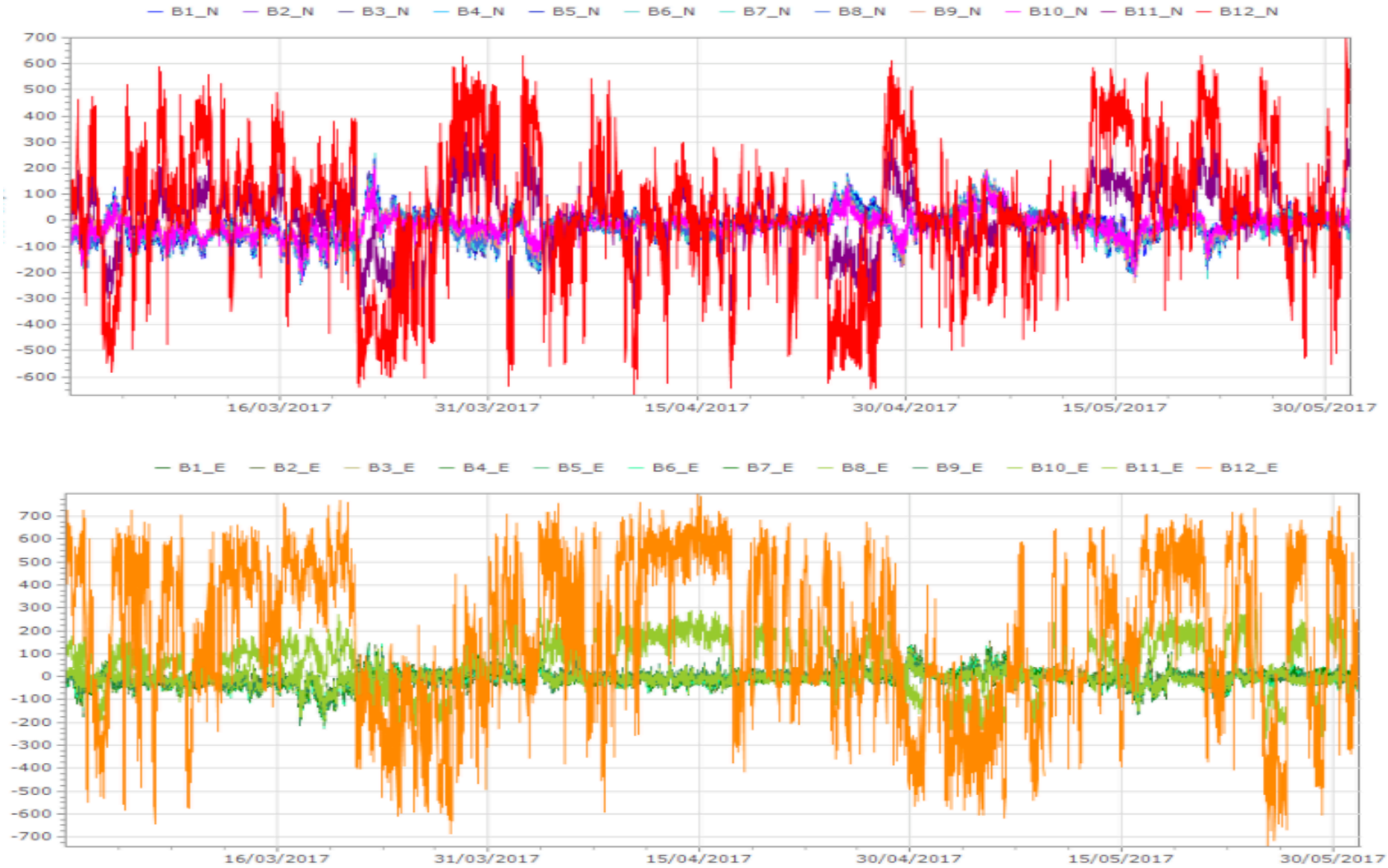

Figure 3: Flow data from OL09 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from March 2017 – May 2017

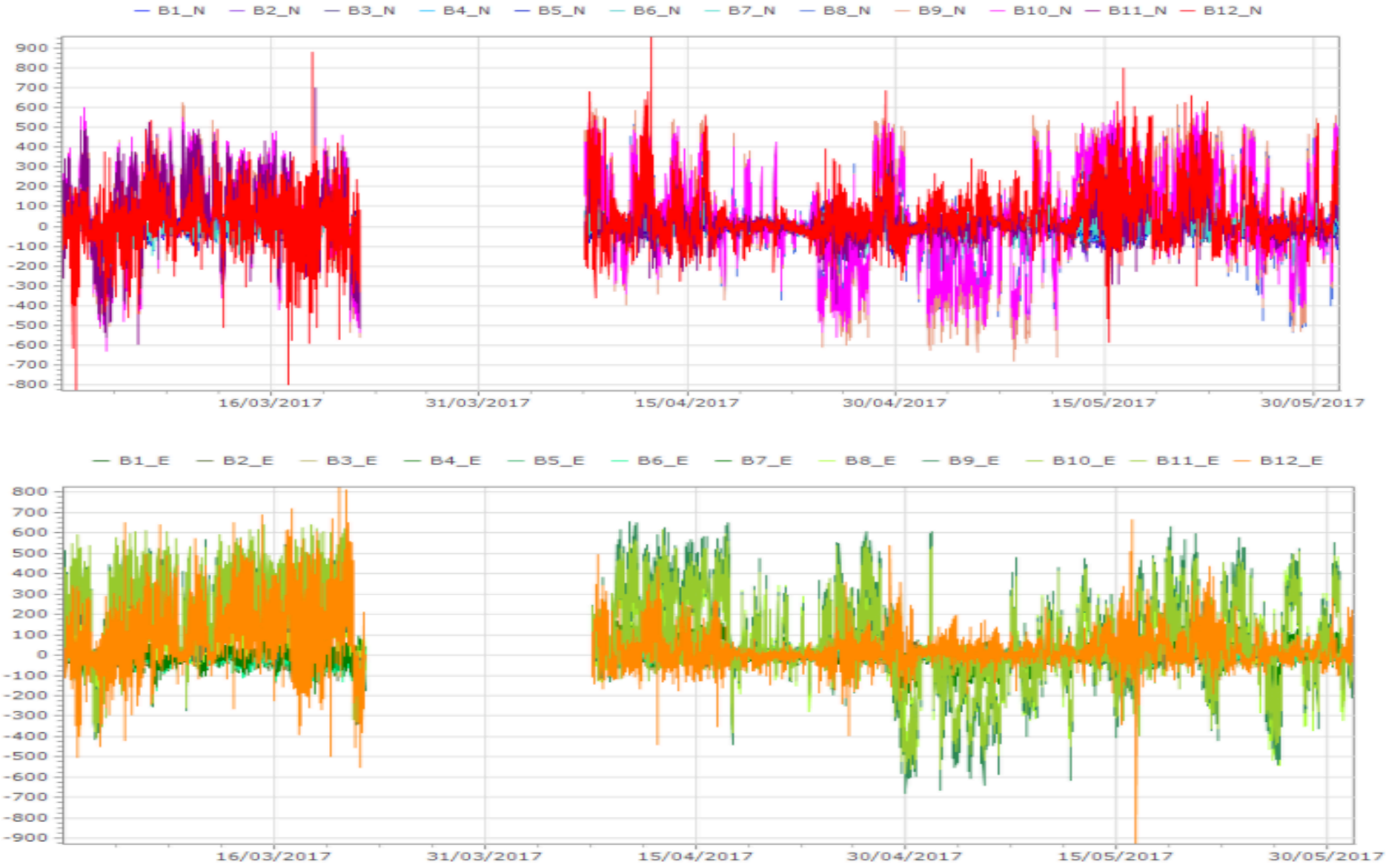

Figure 4: Flow data from OL15 cm/s (Top Panel – North South Flows, Bottom Panel – East West flows) from March 2017 – May 2017.

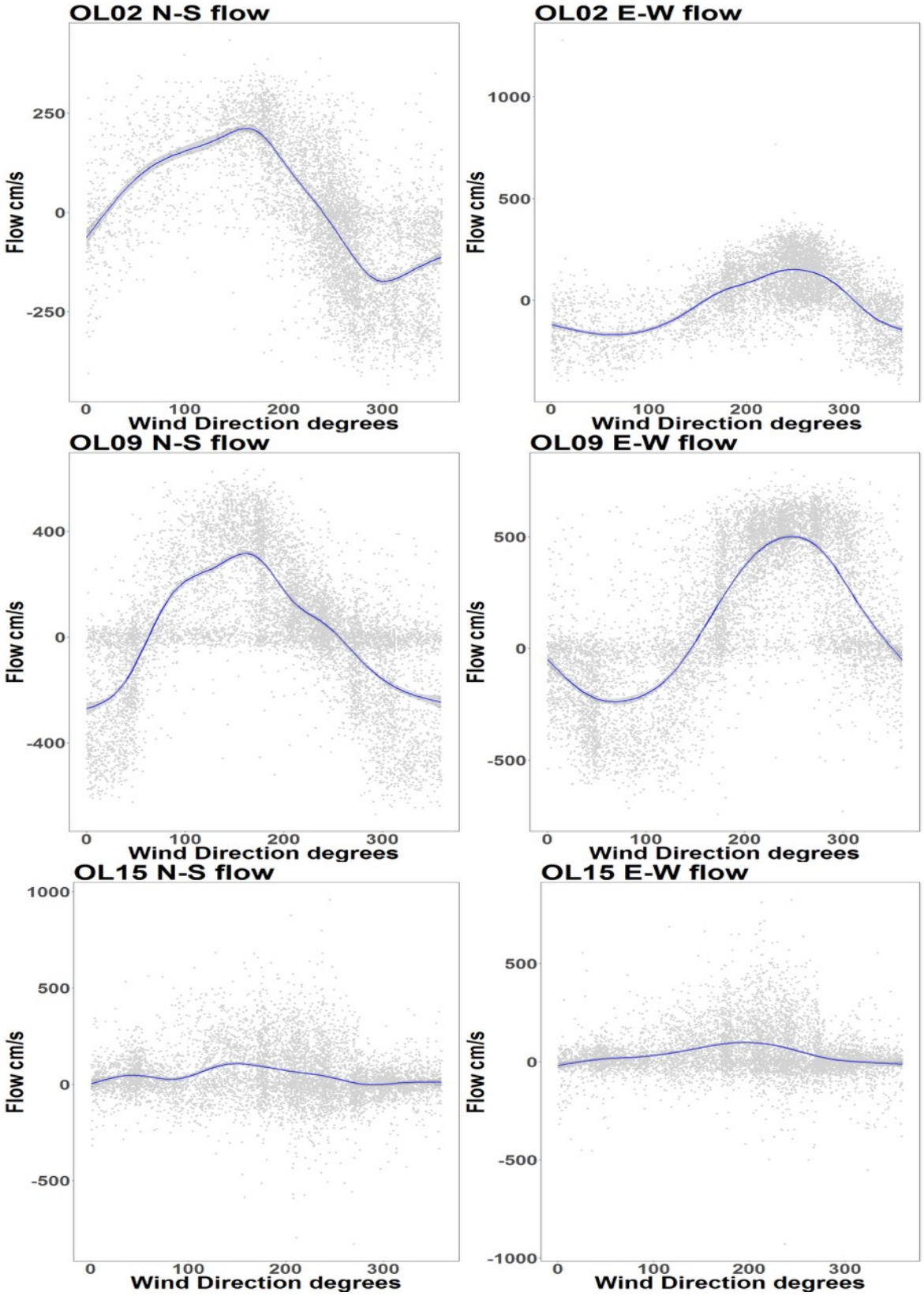

Figure 5: Scatterplots showing flow (y axis) versus Wind direction (x axis) from nearest Weather Station for Stations OL09, OL02 and OL15 with a lowess smoother line (blue) imposed.

2.2. T400 Water Level Survey

Level stations are installed at 6 locations (3 lake and 3 river sites). All lake stations show similar patterns of water levels throughout the reporting period (**Figure 6**). Levels in the lake decreased at all stations from March through to April. A slight increase in lake levels is seen from April through to the end of May. Both river stations have shown a gradual decline in levels across the reporting period. Woodford River has been shown to rise sharply in response to rainfall events however it will quickly return to a baseline level.

Woodford Bridge and River

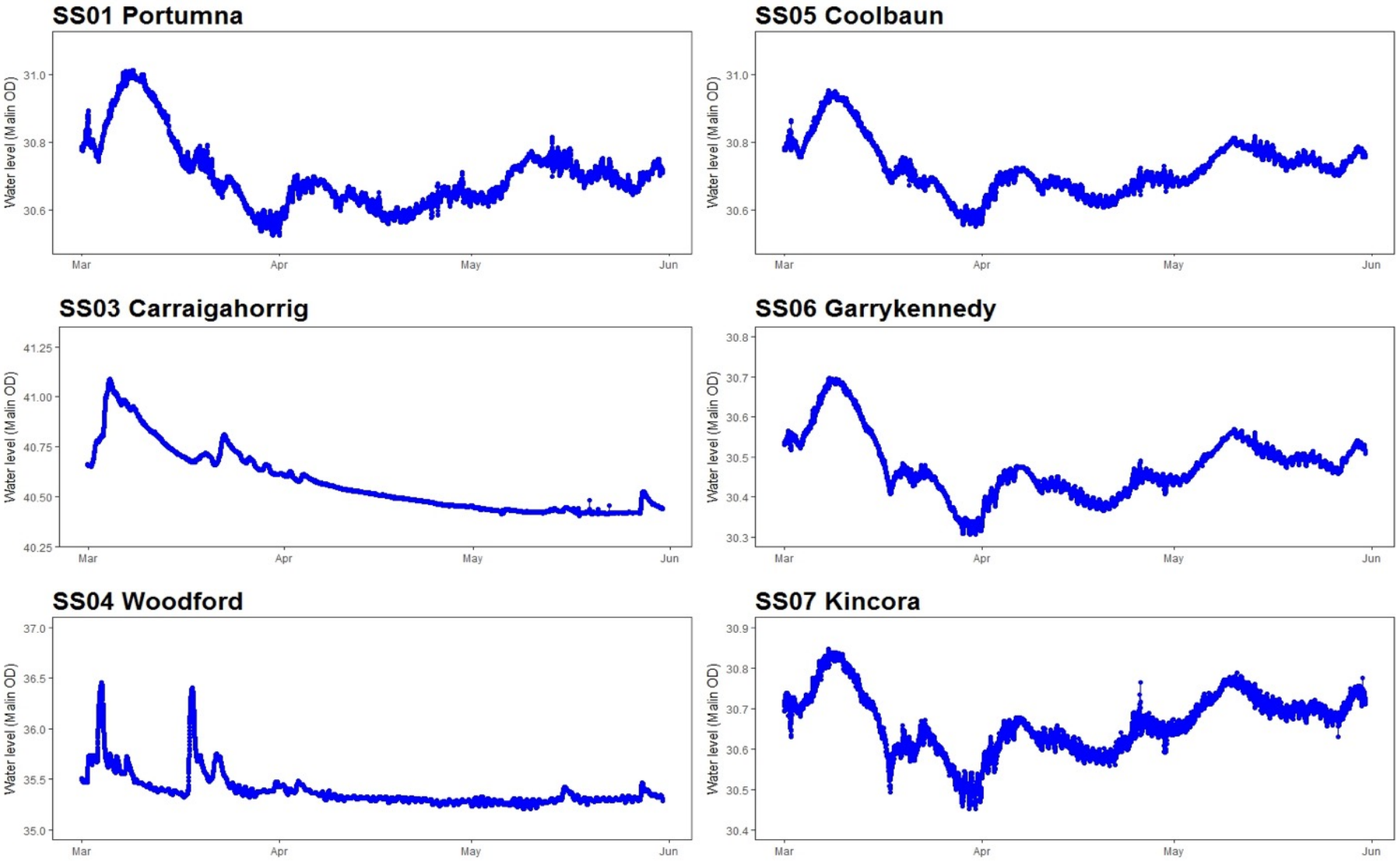

Figure 6: Water level data converted to Malin OD (m) from 6 stations from March 2017 – May 2017

2.3. T500 Water Quality Survey

2.3.1. In-situ sampling

Five in-situ nutrient analysers are deployed, four at open lake sites and one on the inflowing River Shannon at Portumna Bridge. **Figure 7**, **Figure 8**, **Figure 9**, **Figure 10** and **Figure 11** show nutrient data from all 5 sites from March – May 2017 with all data below the limit of detection removed. Many nitrite and ammonia values were below the limit of detection making observations on trends difficult. Nitrate and Phosphate values showed a decline across most stations from March through to May, this may indicate the beginning of the growing season in the lake with available dissolved nutrients being taken up by phytoplankton. This decline in dissolved nitrate and phosphate values is also noted in the spot sampling undertaken on a fortnightly basis in the lake (**Figure 13** and **Figure 15**).

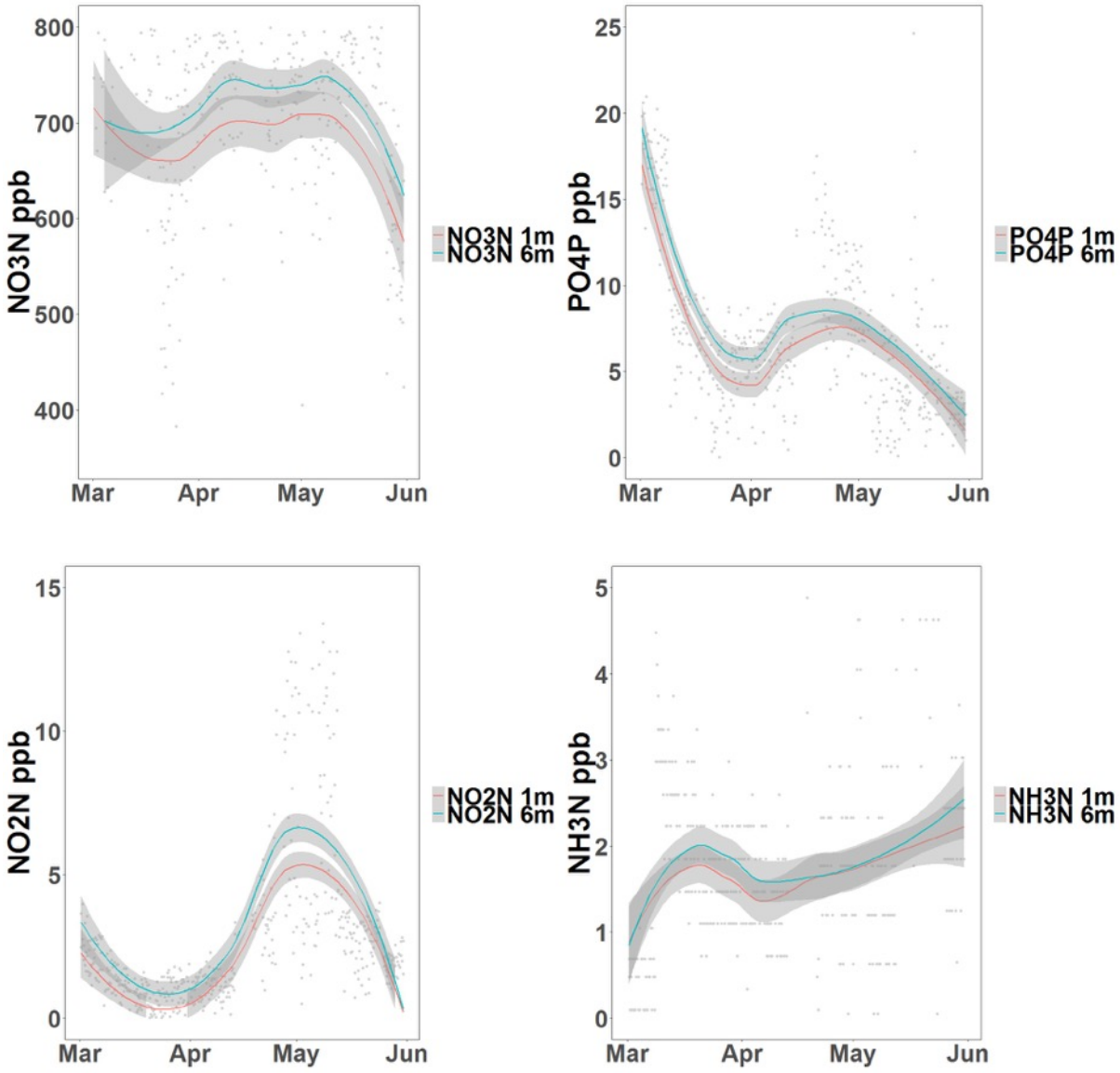

Figure 7: Nutrient Data from OL02 from March 2017 – May 2017 (Note some extreme outliers and data below the limit of detection were removed) .

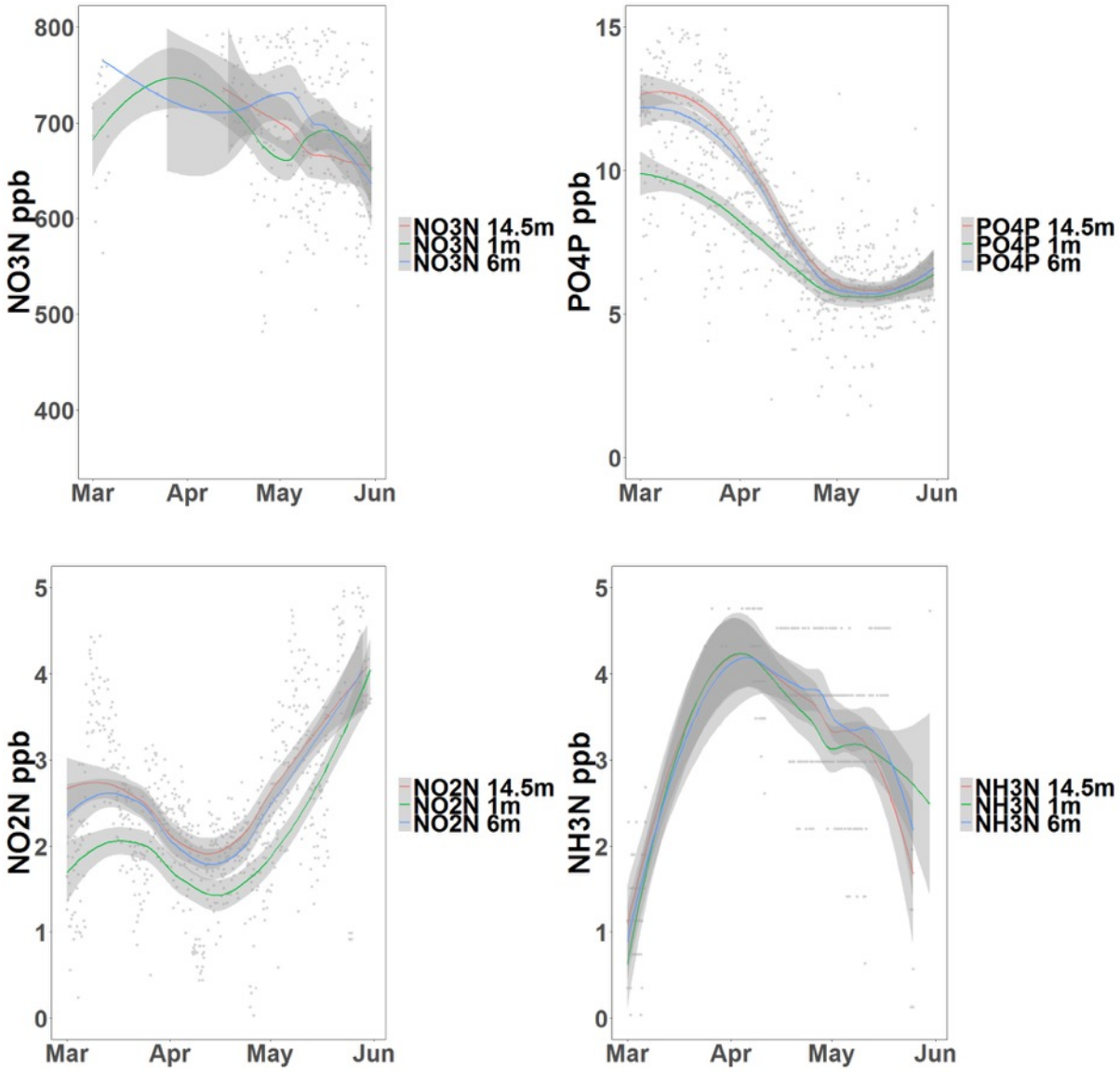

Figure 8: Nutrient Data from OL09 from March 2017 – May 2017 (Note some extreme outliers and data below the limit of detection were removed).

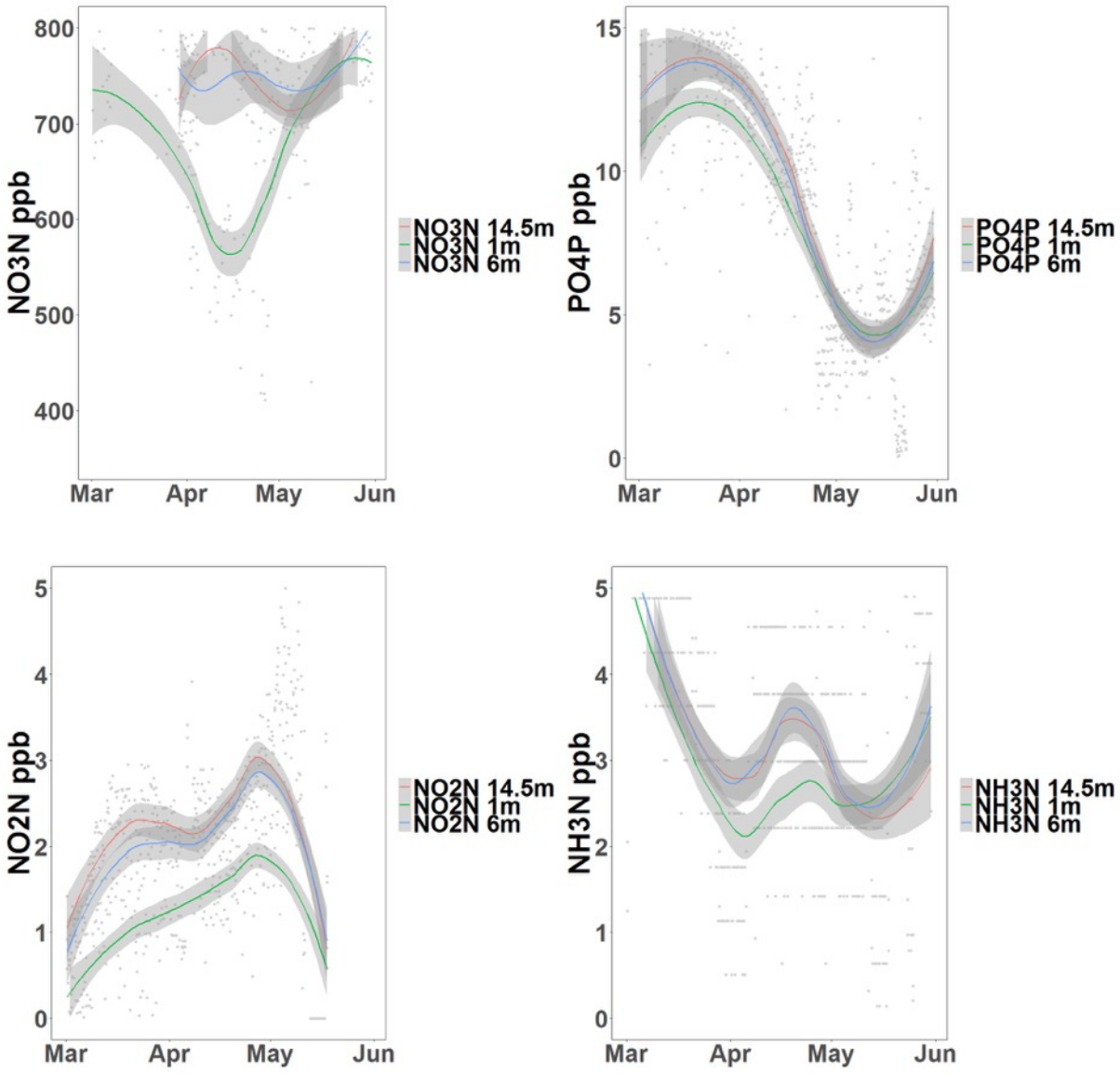

Figure 9: Nutrient Data from OL15 from March 2017 – May 2017 (Note some extreme outliers and data below the limit of detection were removed).

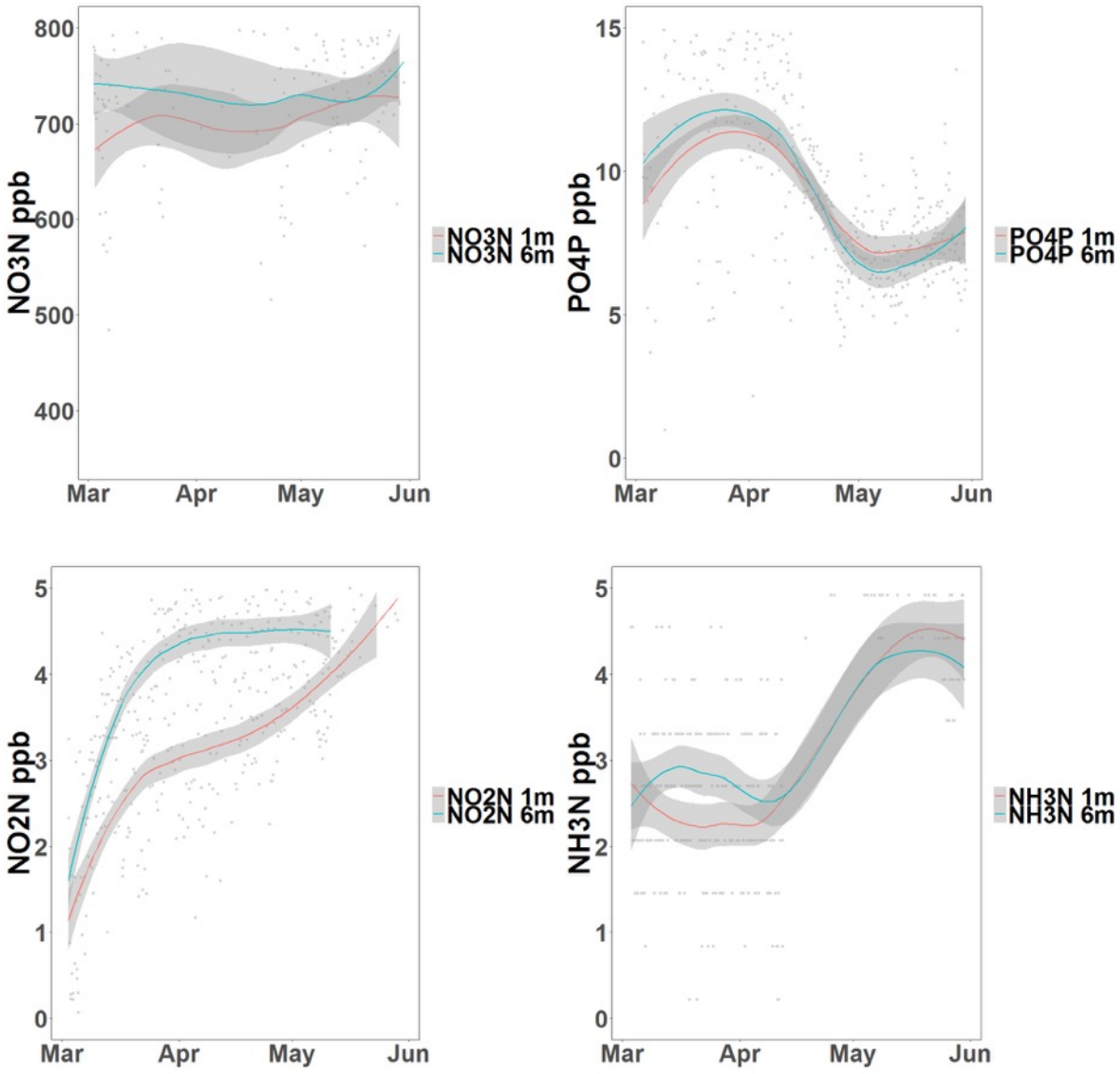

Figure 10: Nutrient Data from OL19 from March 2017 – May 2017 (Note some extreme outliers and data below the limit of detection were removed).

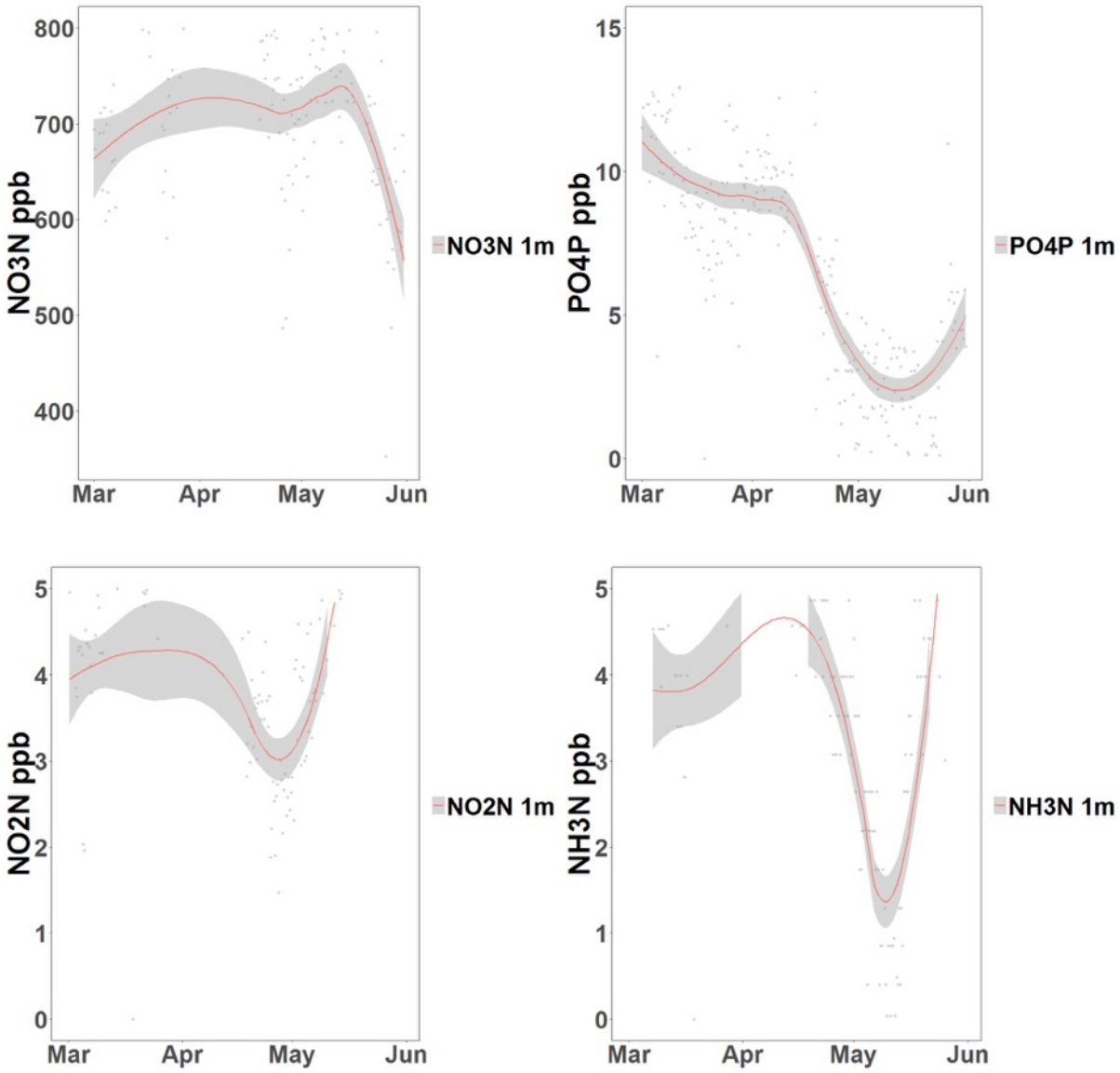

Figure 11: Nutrient Data from SS01 (Portumna Bridge) from March 2017 – May 2017 (Note some extreme outliers and data below the limit of detection were removed).

2.3.2. Spot sampling

Spot sampling has been undertaken since May 2015, **Appendix 1** summarises sampling undertaken for the current reporting period. Extensive water treatability analysis is ongoing on a quarterly basis at the sample site WTMS-4 (Parteen basin). **Appendix 2** lists all chemical parameters measured for Quarterly analysis including results.

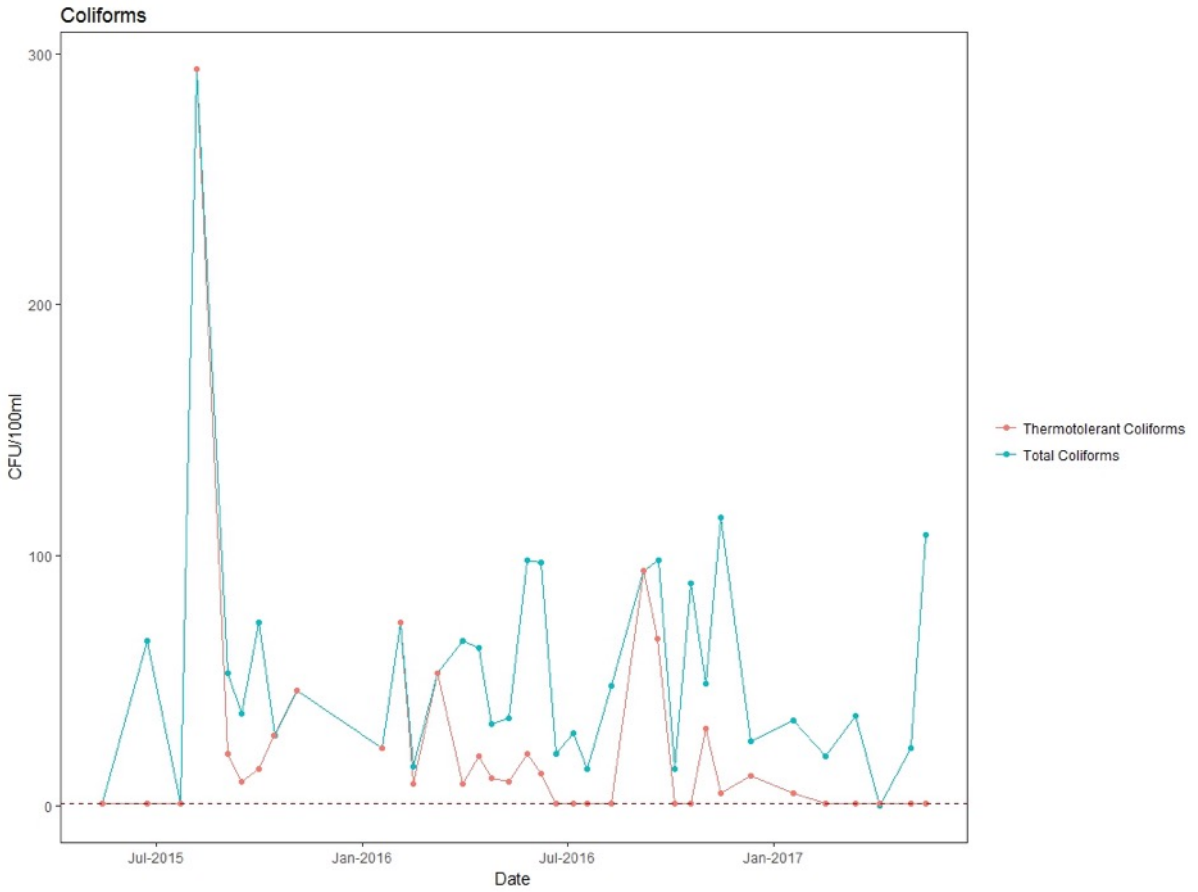

Figure *12* shows the survey results of fortnightly/monthly[1]coliform bacteria sampling at WTMS 4 (Parteen basin). The presence of thermotolerant coliforms indicates the presence of Escherichia coli which in itself is indicative of traces of human or animal sewage in the water source. Mean values of total coliforms and thermotolerant coliforms in Parteen basin were 54.89 and 24.56 CFU/100ml. Under the Bathing Water Quality Regulations 2008 inland water bodies are classified as excellent status if *E. coli* numbers are below 500 CFU/100ml (based on a 95-percentile evaluation). Maximum thermotolerant coliform values from WTMS 4 were 294 CFU/ml below the guideline value of the bathing water regulations. Under drinking water legislation water supplies are obliged to have zero coliforms present indicating microbiological treatment would be required of these waters.

Figure 13, **Figure 14** and **Figure 15** show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate and chlorophyll *a* from water quality sites on Lough Derg at all depths. **Figure 16** shows the water quality data from all inflowing rivers into Lough Derg. Obvious trends can be seen in nitrate, phosphate and chlorophyll *a* in the lake. Nitrate and phosphate decreased at all stations and depths across the reporting period similar to the in-situ nutrient results. Chlorophyll *a* levels remained low across all sites throughout the reporting period but started to show an increase in May indicating the beginning of some primary productivity in the lake. It was difficult to discern trends in the river parameters however both nitrate and phosphate showed a slight decrease over the spring period.

[1] *As per clients instruction from August 2016 onwards samples for Water Treatability sampling was taken from WTMS 4 only. Fortnightly sampling was reduced to monthly.*

Nitrite and ammonia levels remained low across most samples with many samples falling below the limits of detection.

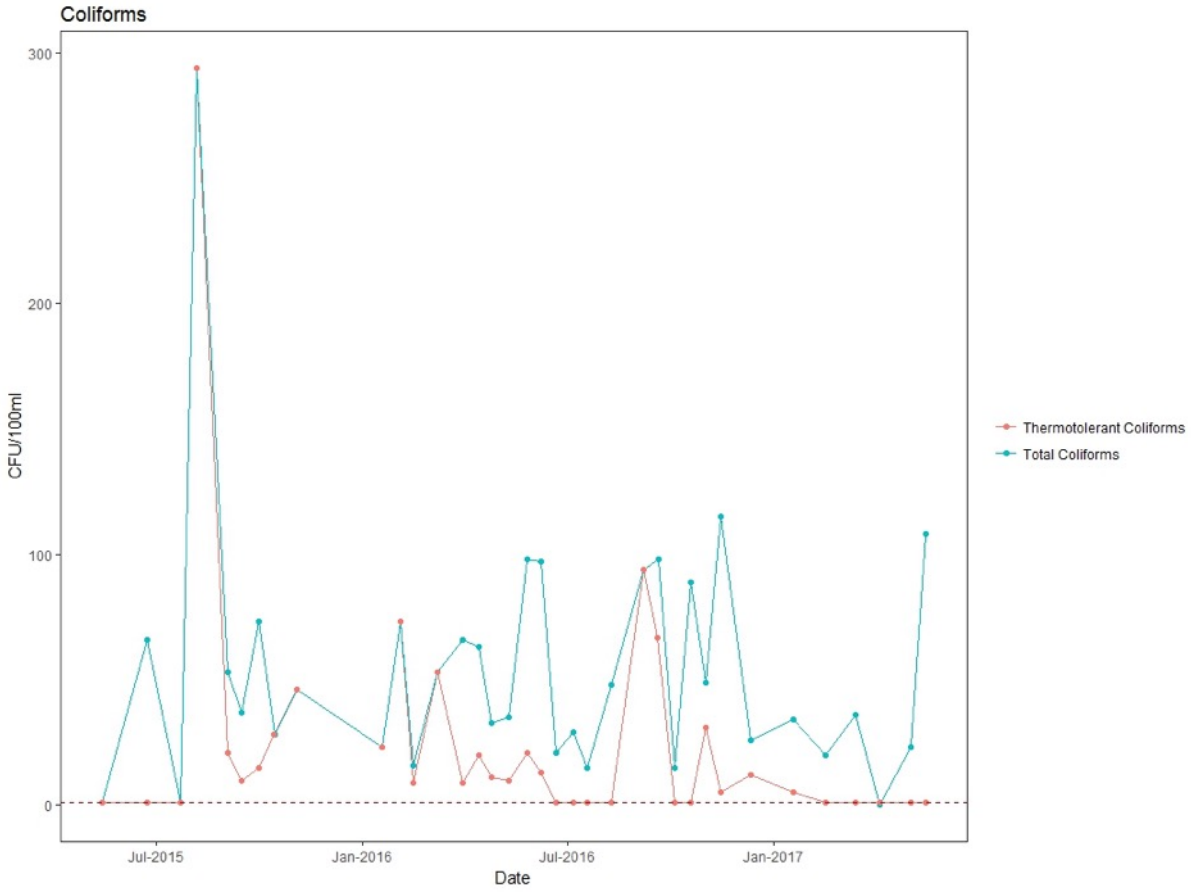

Figure 12: Survey results of Coliforms bacteria (CFU/100ml) at WTMS 4 (Parteen basin) from May 2015 – May 2017.

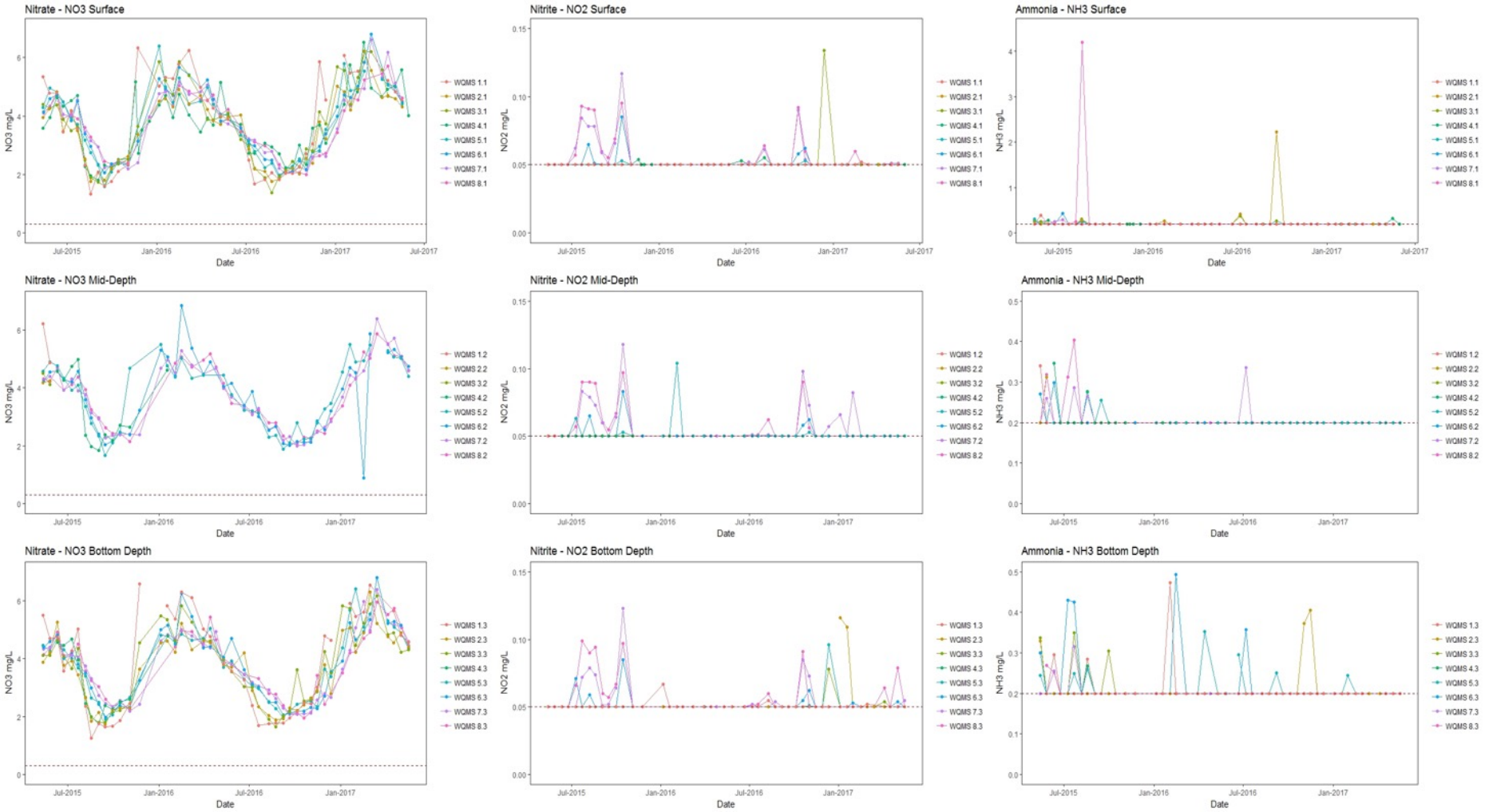

Figure 13: Survey results from all lake water quality sites of nitrate (NO3) nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – May 2017.

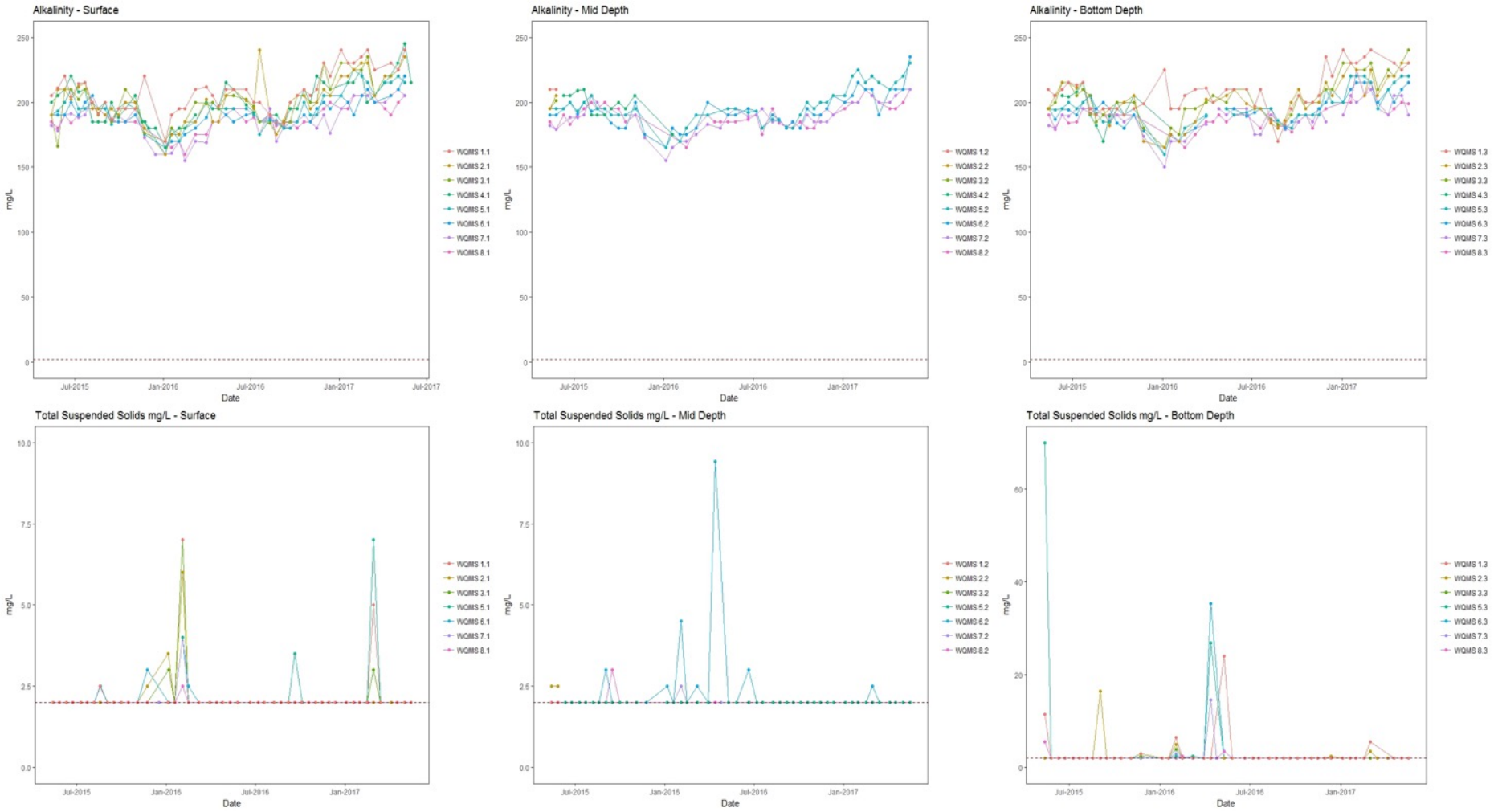

Figure 14: Survey results from all lake water quality sites of Alkalinity and Suspend Solids (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – May 2017.

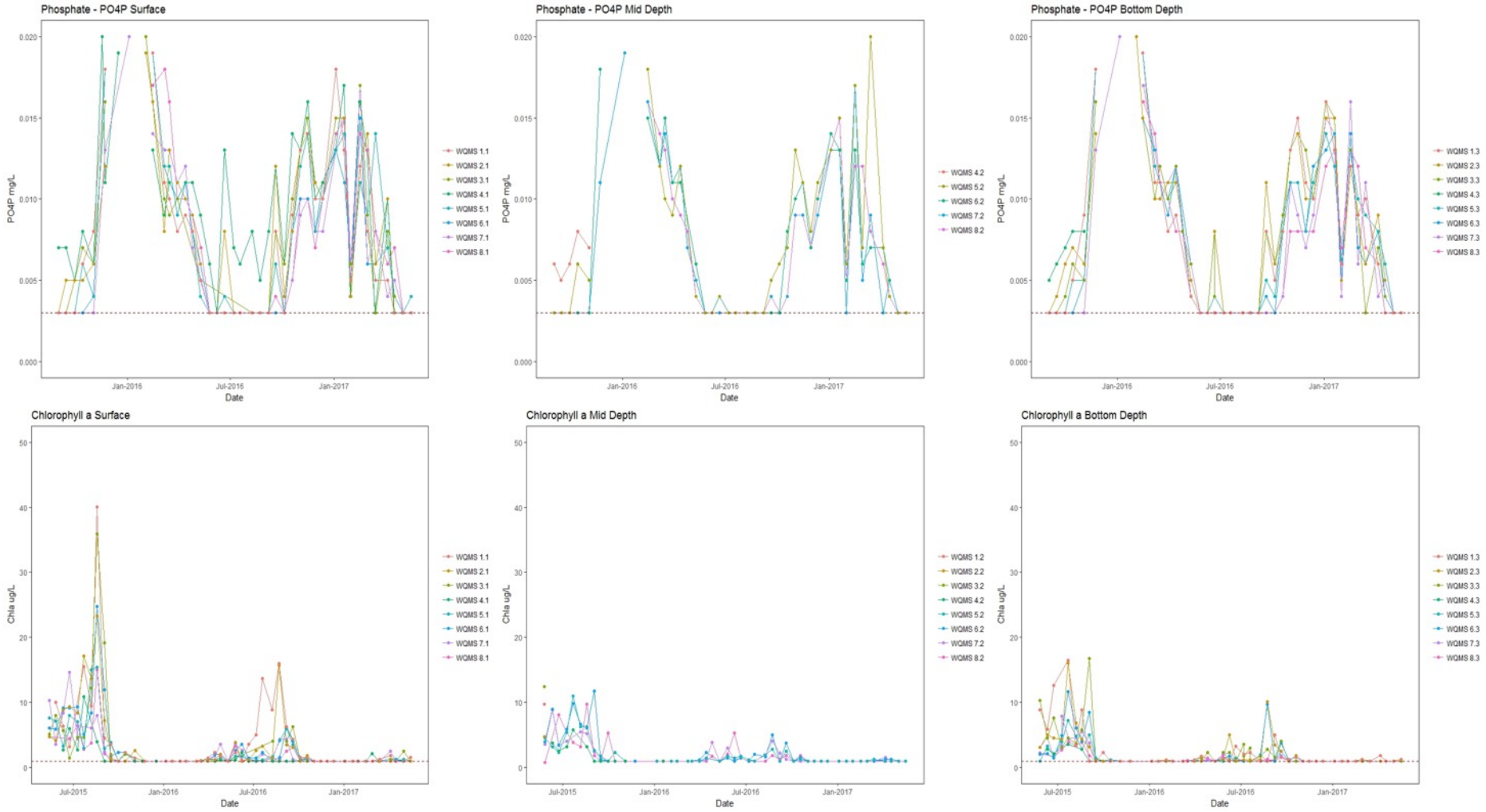

Figure 15: Survey results from all lake water quality sites of Chlorophyll *a* and Phosphate (PO4P) (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – May 2017.

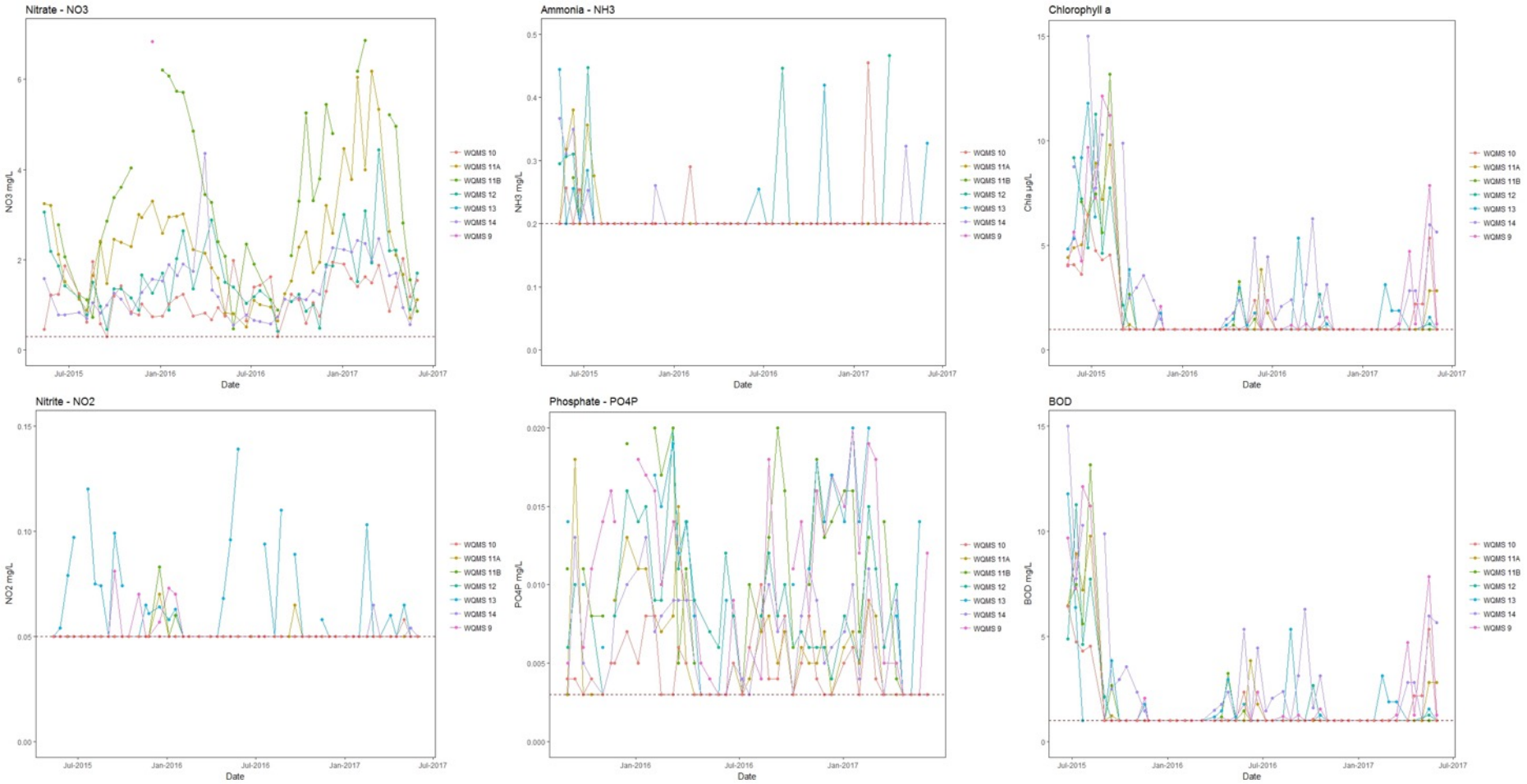

Figure 16: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll *a* and BOD (Please note red dashed lines indicated limits of detection of analysis) from May 2015 – May 2017.

2.4. T600 Temperature Survey

Nineteen temperature monitoring stations are deployed on Lough Derg. All sites showed similar patterns throughout the reporting period. OL12 located at the deepest location on the lake broke it's mooring in early January, it was removed from the lake to avoid it becoming a navigation hazard and redeployed 28th March 2017 with a new mooring.

Figure 17 shows temperature data from OL12 from March onwards. All depths show a steady increase in temperature throughout the reporting period however no stratification was noted.

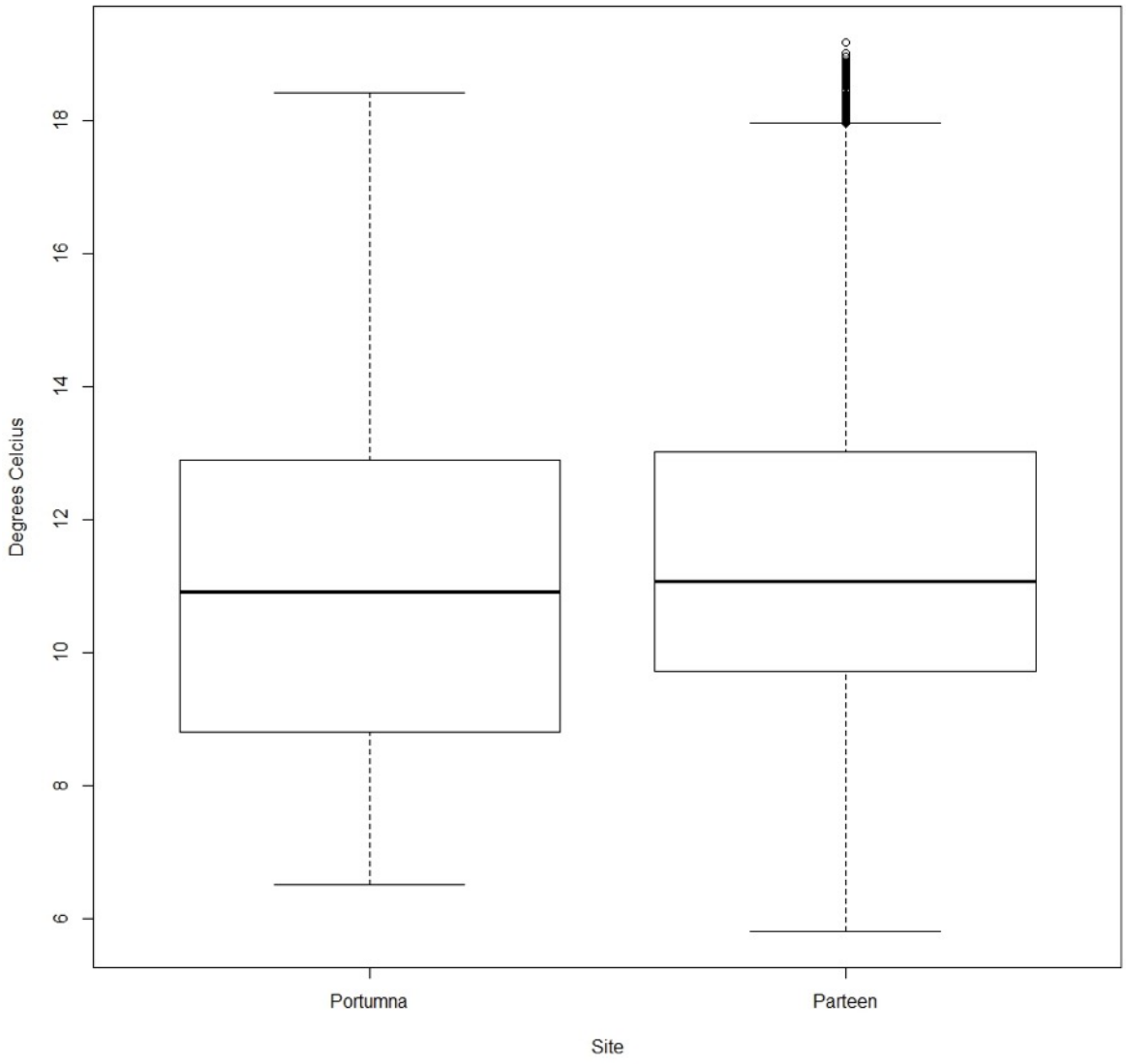

Figure 18 shows a boxplot of surface level temperatures from the inflow (Portumna) and outflow (Parteen) of the lake. Mean temperatures at both the inflow and outflow of the lake were similar.

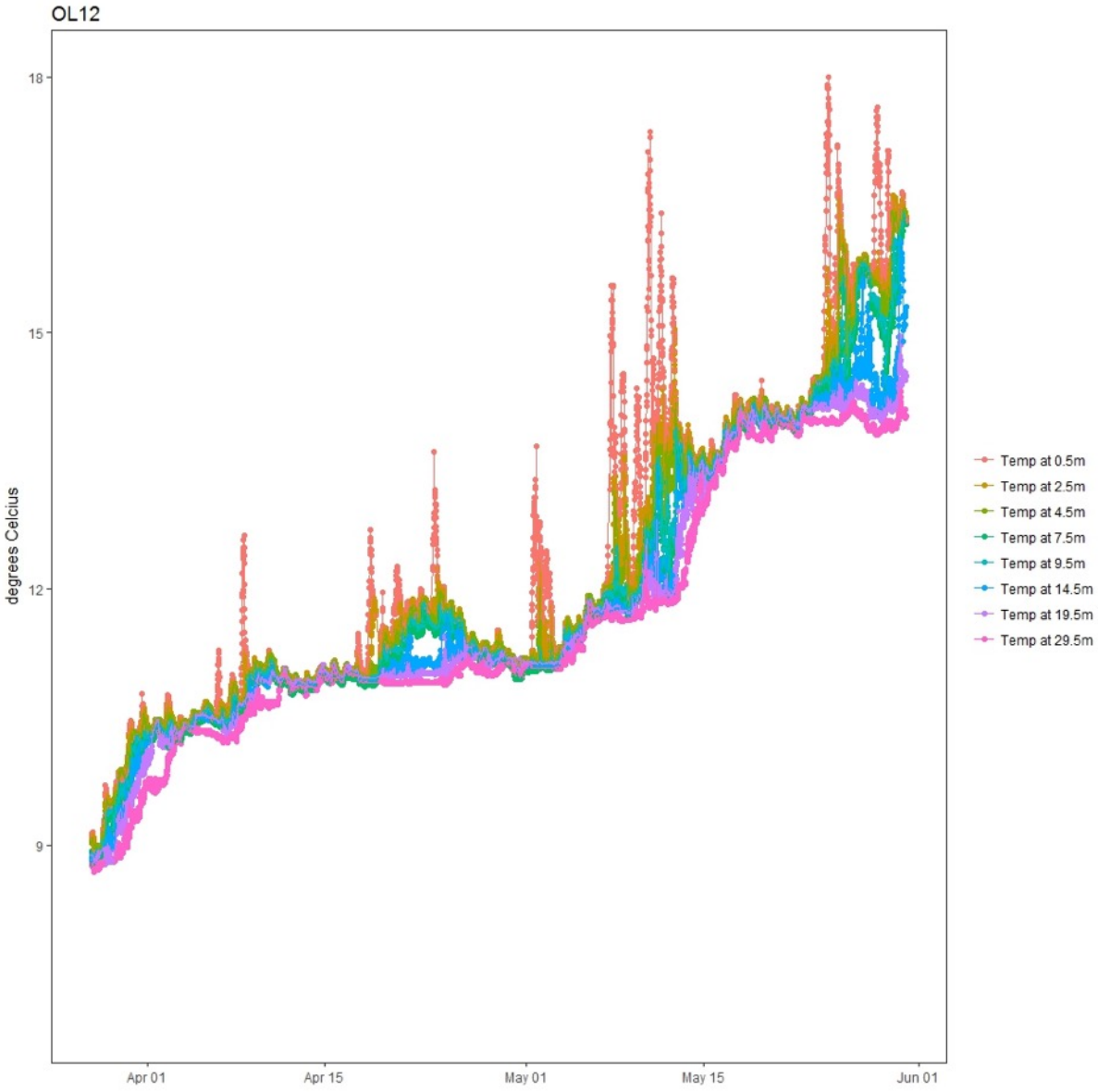

Figure 17: OL12 temperature data from all depths from March 2017 – May 2017.

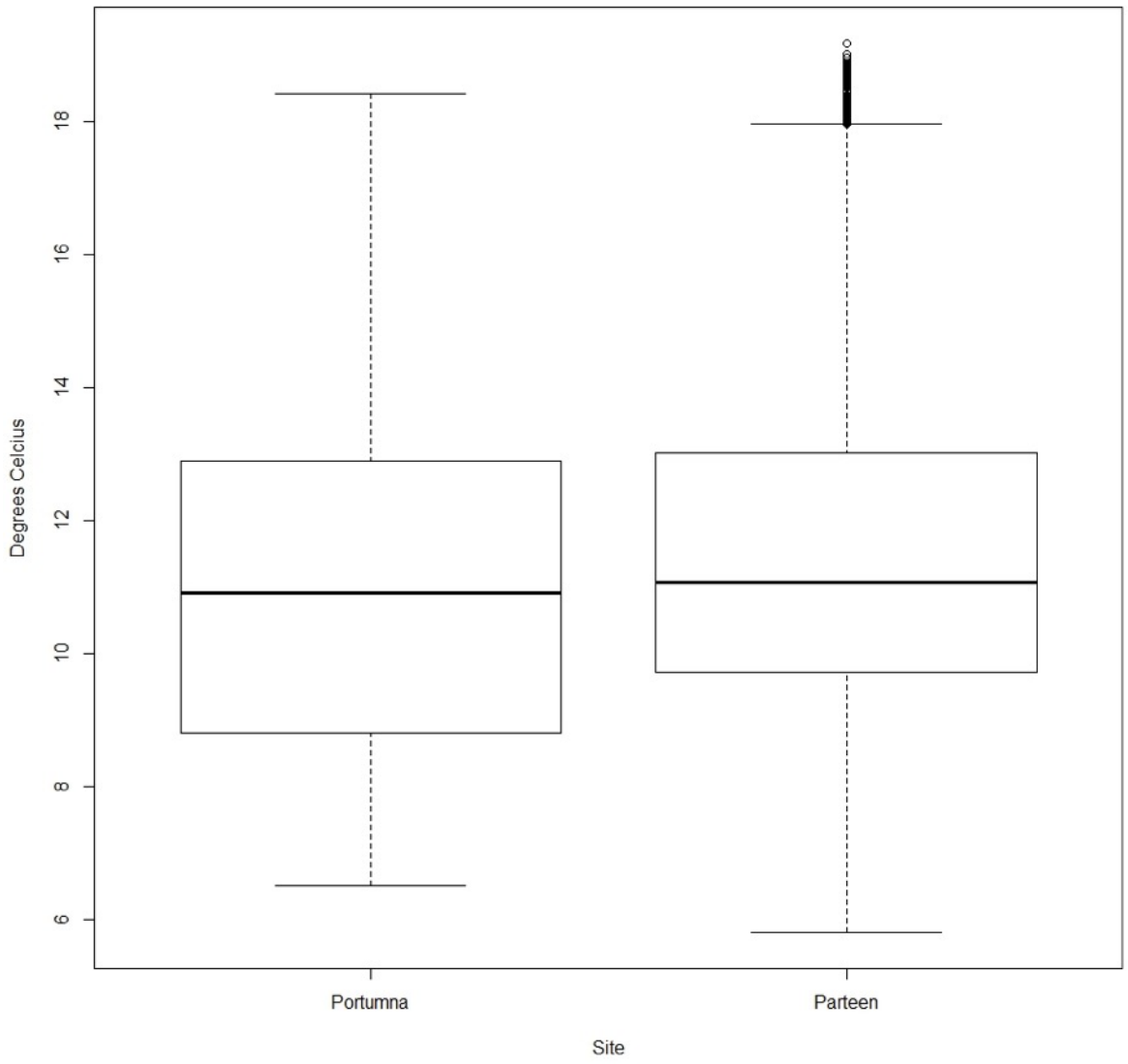

Figure 18: Boxplot showing surface temperatures from Portumna (inflow) and Parteen (outflow) from March 2017 – May 2017.

2.5. T800 Meteorological Survey

Two meteorological stations have been installed on the eastern and western shores of Lough Derg. **Figure 19** and

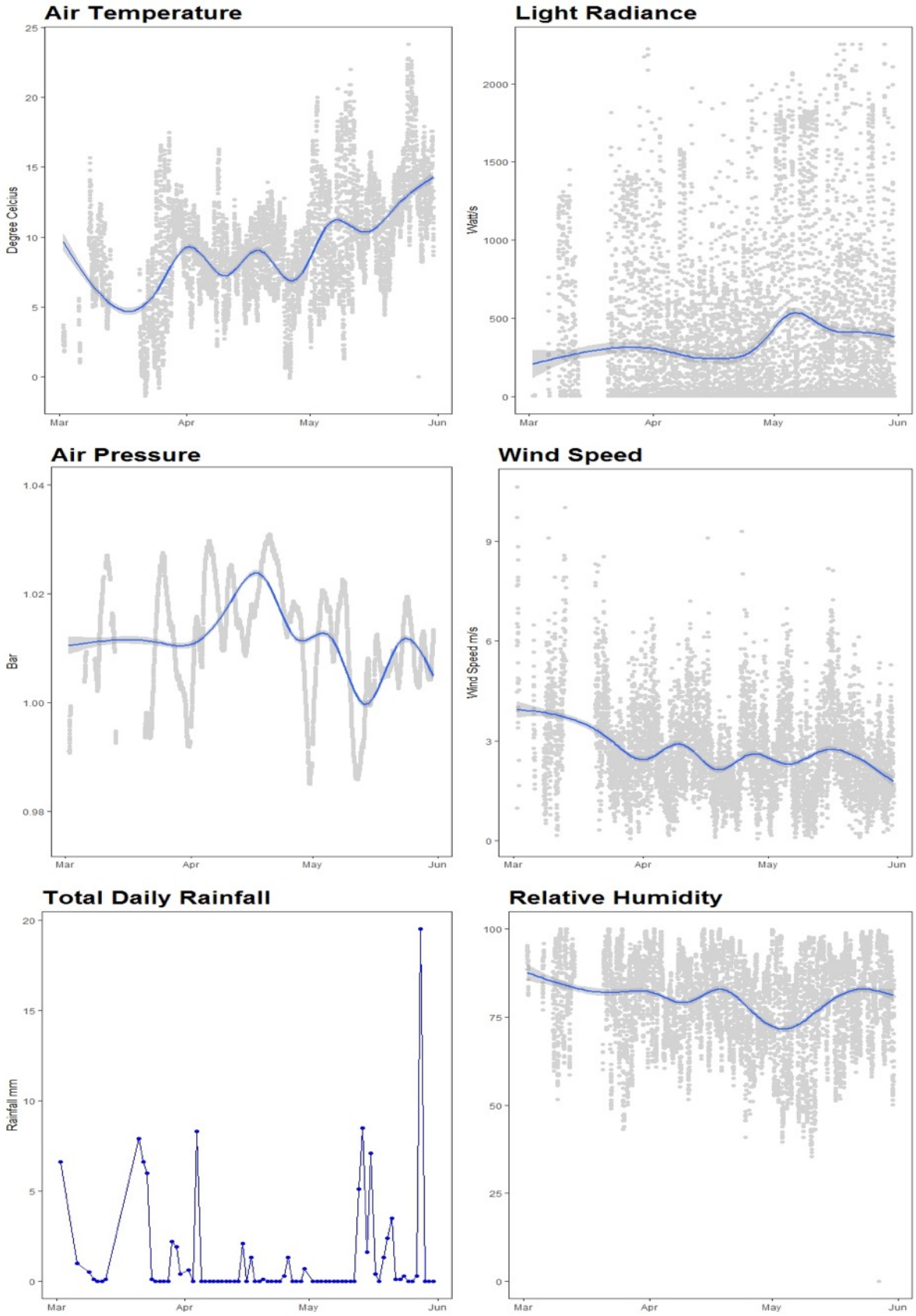

Figure 20 show meteorological data from both stations at Ballinderry and Whitegate. Both stations show similar values for all parameters. **Figure 21** shows windrose diagrams for both met stations, prevailing winds for Whitegate over the reporting period was predominantly

westerly. Ballinderry showed more varied wind direction with the predominant wind direction being south – south westerly.

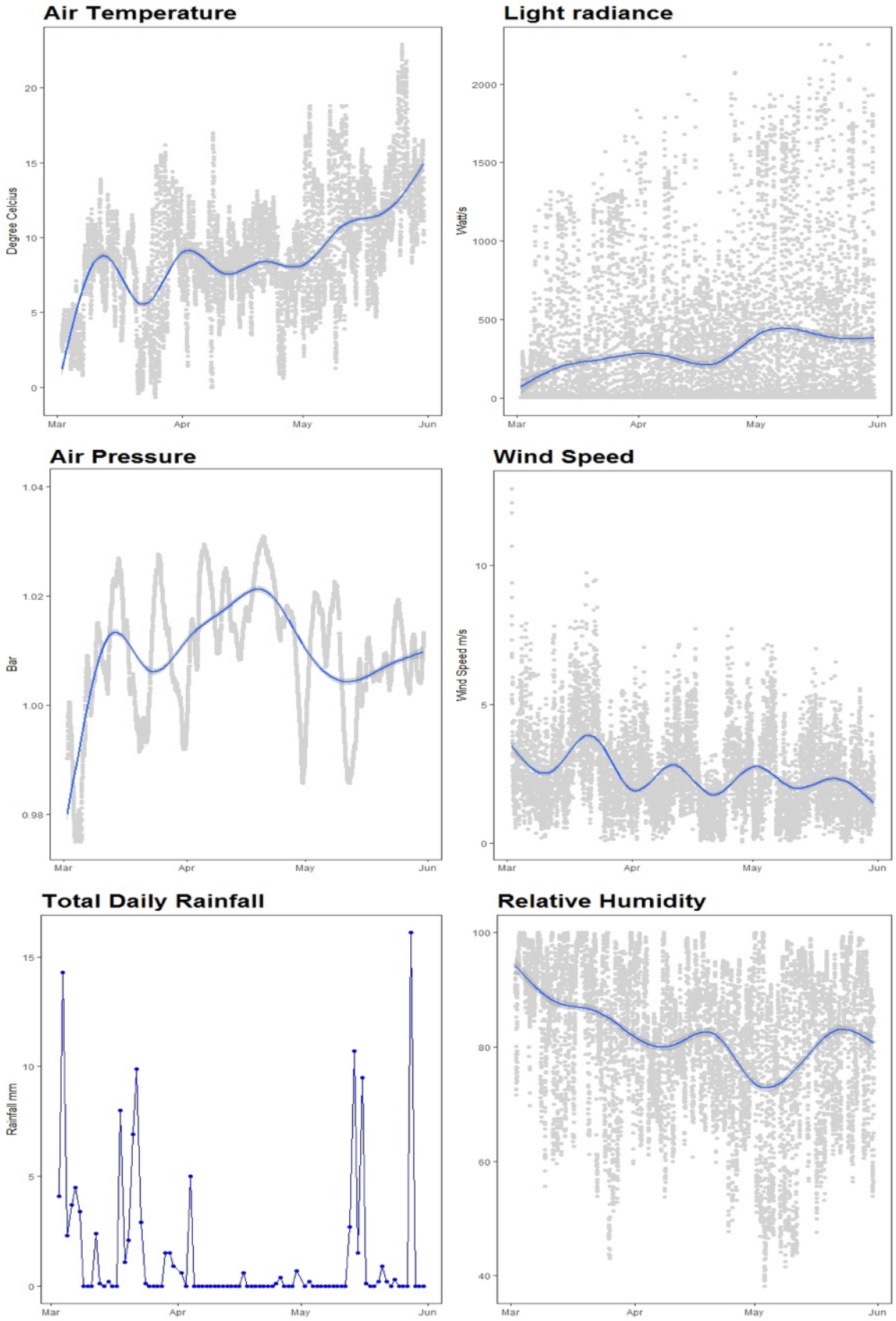

Figure 19: Data from MS01 (Ballinderry) from March 2017 – May 2017.

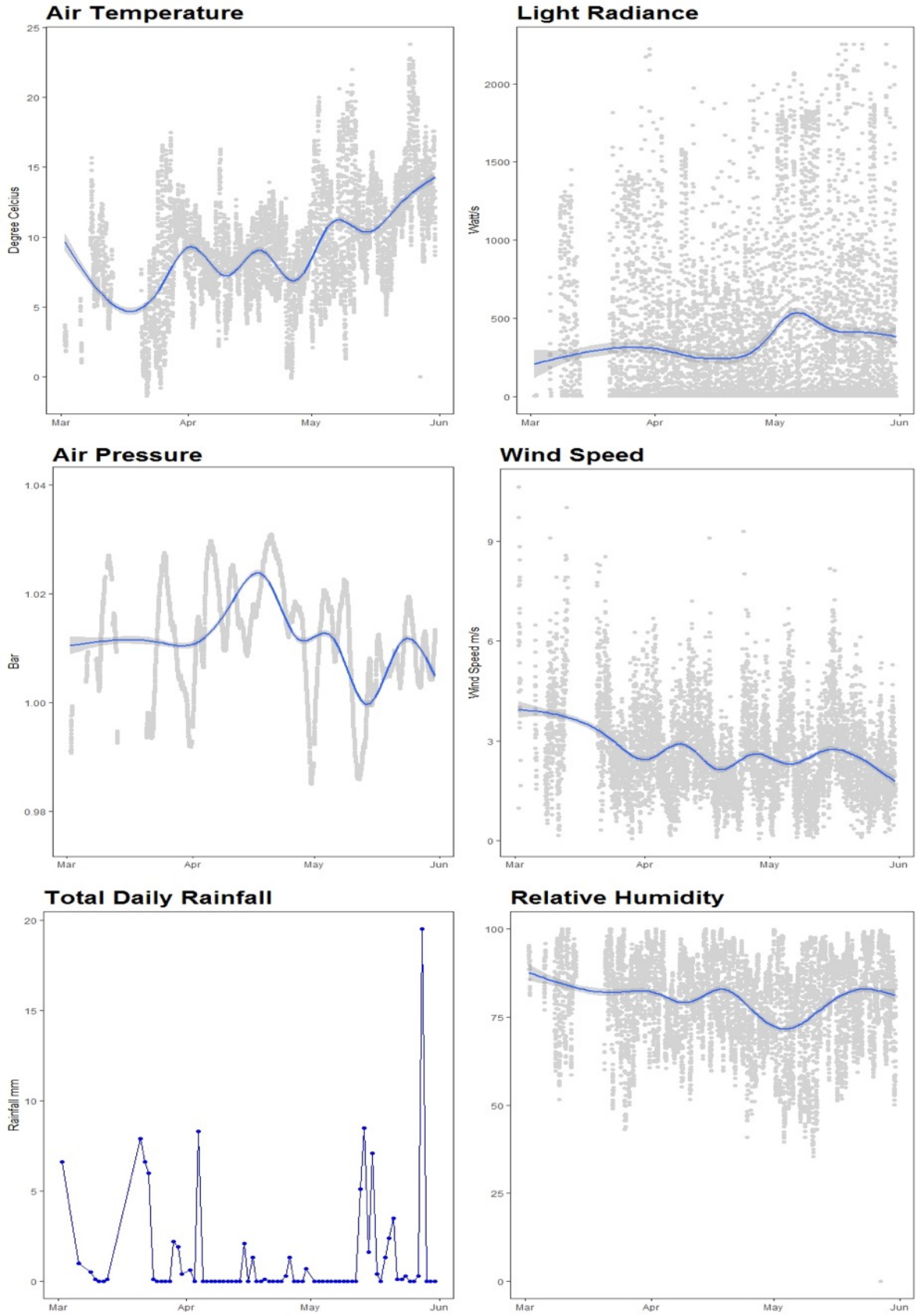

Figure 20: Data from MS02 (Whitegate) from March 2017 – May 2017.

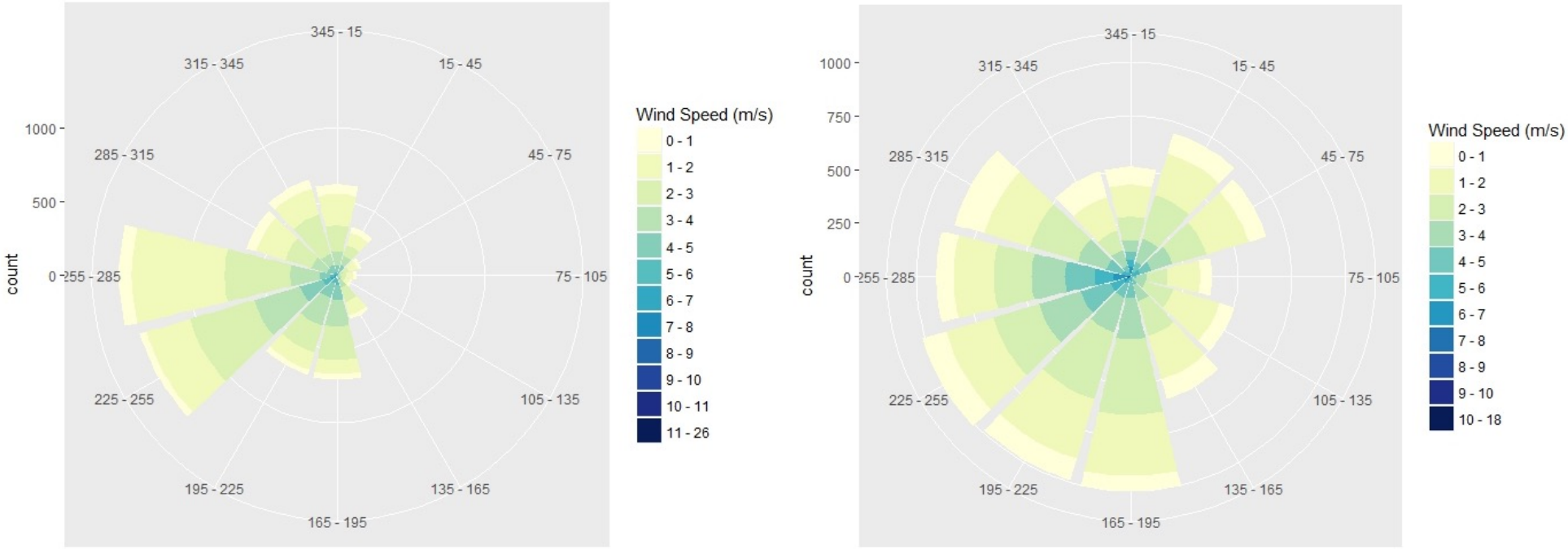

Figure 21: Windrose Diagram for Whitegate (left pane) and Ballinderry (right pane) weather stations from March 2017 – May 2017.

2.6. T900 Plankton Survey

Figure 22 shows all surface level chlorophyll *a* values from all sites from May 2015 – May 2017. Summer 2015 showed high levels of chlorophyll *a* compared to summer 2016. High levels of *Microcystis aeruginosa* were noted during September 2015. For the current reporting period, values of chlorophyll *a* started to show an increase during spring indicating the beginning of the growth season in the lake.

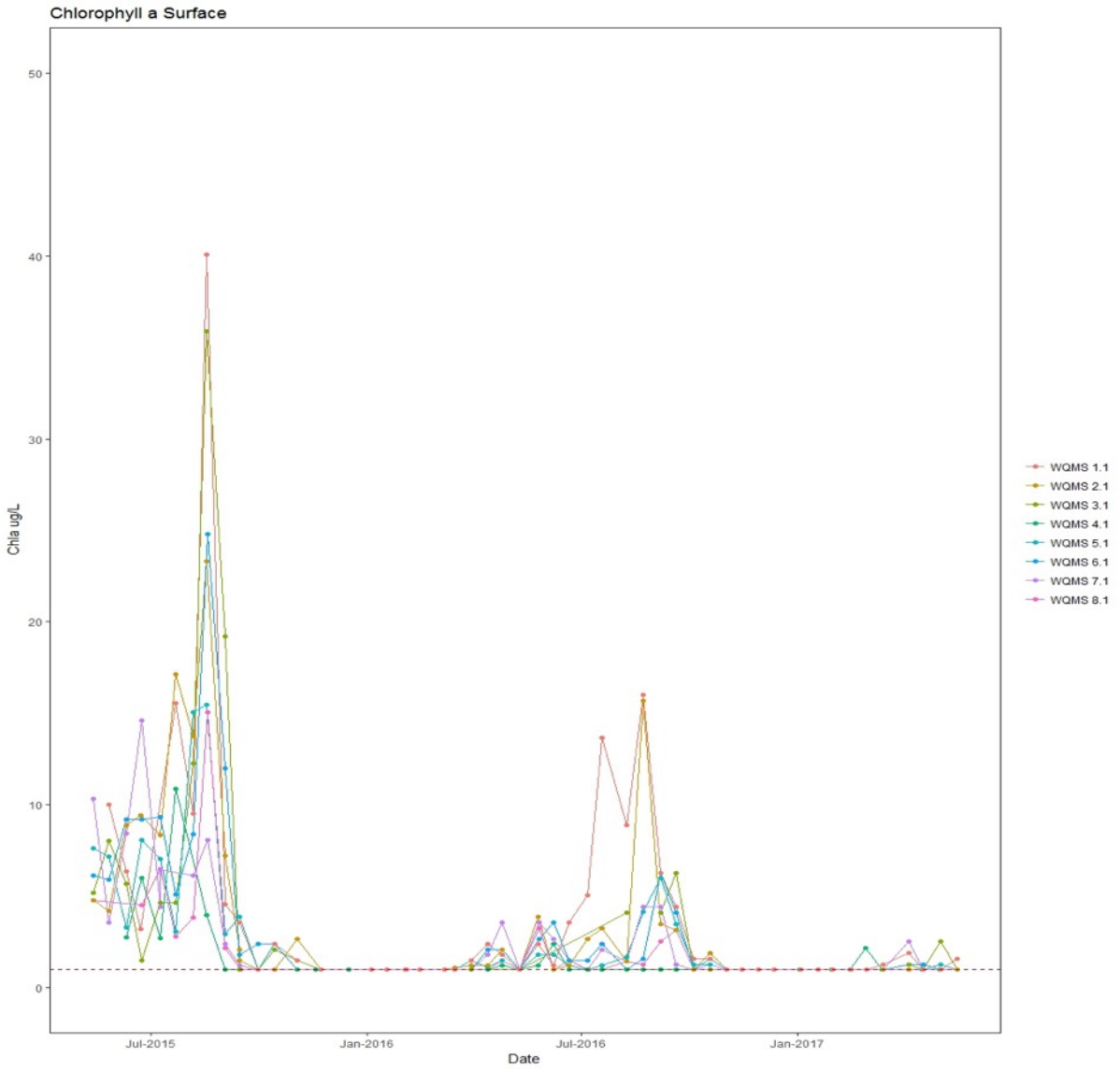

Figure 22: Surface chlorophyll *a* results from all sites from May 2015 – May 2017.

3. Appendices

Appendix 1: Summary of spot sampling for Water Quality, Water Treatability and Ecology from September –November 2016.

Sample Date	WQMS - Fortnightly	WTMS-Monthly [2]	WTMS-Quarterly *	Comments
01/03/2017	X			
15/03/2017	X	X		
06/04/2017	X	X		
18/04/2018	X			
03/05/2017	X	X		
17/05/2017	X	X	X	
31/05/2017	X			

[2] As per clients instruction from August 2016 onwards samples for Water Treatability sampling was taken from WTMS 4 only. Fortnightly sampling was reduced to monthly.

Appendix 2: List of quarterly water treatability parameters with results (values prefixed with < denotes below limit of detection).

Parameter	Sample Date							
	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017	17/05/2017
Acenaphthene (aq) µg/l	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Acenaphthylene (aq) µg/l	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
Aldrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Alkalinity, Total as CaCO3 mg/l	190	195	170	195	185	190	205	210
alpha-Hexachlorocyclohexane (HCH / Lindane) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Aluminium (diss.filt) µg/l	6.14	4	13.7	8.62	<2	3.96	5.46	100
Anthracene (aq) µg/l	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Arsenic (diss.filt) µg/l	0.796	0.676	0.47	0.219	1.21	1.17	1.16	0.574
Azinphos-ethyl µg/l	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Azinphos-methyl µg/l	<0.01	0.02	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01
Barium (diss.filt) µg/l	35.5	41.5	31.8	37.2	40	37.3	41.7	42.7
Benzene µg/l	<7	<7	<7	<7	<7	<7	<7	<7
Benzo(a)anthracene (aq) µg/l	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
Benzo(a)pyrene (aq) µg/l	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Benzo(b)fluoranthene (aq) µg/l	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023
Benzo(g,h,i)perylene (aq) µg/l	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016
Benzo(k)fluoranthene (aq) µg/l	<0.027	<0.027	<0.027	<0.027	<0.027	<0.027	<0.027	<0.027
beta-Hexachlorocyclohexane (HCH / Lindane) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD, unfiltered mg/l	NA	NA	<1	<1	<1	<1.07	<1	<1
Boron (diss.filt) µg/l	11	12.9	<9.4	<9.4	9.84	11	9.28	11.6
Bromine* mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium (diss.filt) µg/l	<0.1	<0.1	<0.1	<0.1	<0.08	<0.08	<0.08	<0.08
Calcium (diss.filt) mg/l	70.4	70.1	60.8	68.4	66.1	73.2	74.9	86
Carbophenothion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorfenvinphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017	17/05/2017
Chloride mg/l	19	18.4	14.8	15.3	16.3	16	15.2	16.8
Chlorothalonil µg/l	<0.01	0.02	<0.01	<0.01	<0.01	<0.05	<0.01	<0.02
Chlorpyriphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorpyriphos methyl µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium (diss.filt) µg/l	1.36	2.91	2.37	1.75	<1.2	<1.2	<1.2	<1
Chrysene (aq) µg/l	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
cis-Chlordane µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD, unfiltered mg/l	23.5	20.2	31	12.4	19.3	28.9	30.7	22.9
Conductivity @ 20 deg.C mS/cm	0.383	0.382	0.326	0.378	0.371	0.367	0.379	0.397
Copper (diss.filt) µg/l	1.04	1.26	1.11	1.21	1.79	<0.85	<0.85	1.52
Cresols mg/l	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Cyanide, Total mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Diazinon µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dibenzo(a,h)anthracene (aq) µg/l	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016
Dichlorvos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dieldrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dimethoate µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dissolved solids, Total (meter) mg/l	287	313	262	293	282	278	300	299
Disulfoton µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endosulphan I µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endosulphan II µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endosulphan sulphate µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
EPH (C6-C10) µg/l	<100	<100	<100	<100	<100	<100	<100	<100
EPH Range >C10 - C40 (aq) µg/l	<46	<46	<46	<46	<46	<46	<46	<46
Ethion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethylbenzene µg/l	<5	<5	<5	<5	<5	<5	<5	<5

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017	17/05/2017
Etrimphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenitrothion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenthion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene (aq) µg/l	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
Fluorene (aq) µg/l	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Fluoride mg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
gamma-Hexachlorocyclohexane (HCH / Lindane) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
GRO >C5-C10 µg/l	<10	<10	<10	<10	<10	<10	<10	<10
Heptachlor µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Heptachlor epoxide µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hexachlorobenzene µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Indeno(1,2,3-cd)pyrene (aq) µg/l	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Iron (diss.filt) mg/l	0.0242	<0.019	0.103	0.0356	<0.019	0.0208	0.0514	0.0358
Isodrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead (diss.filt) µg/l	<0.02	0.031	0.059	<0.02	<0.1	<0.1	<0.1	0.214
m,p-Xylene µg/l	<8	<8	<8	<8	<8	<8	<8	<8
Malathion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Manganese (diss.filt) µg/l	0.549	3.15	2.22	3.01	1.43	3.64	2.73	4.98
Mercury (diss.filt) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methyl parathion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methyl tertiary butyl ether (MTBE) µg/l	<3	<3	<3	<3	<3	<3	<3	<3
Mevinphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Naphthalene (aq) µg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel (diss.filt) µg/l	2.06	2.43	1.88	2.88	1.33	1.31	1.37	1.48
Nitrogen, Kjeldahl mg/l	<1	<1	<1	1.12	<1	<1	<1	<1
Nitrogen, Total mg/l	1.91	1.37	1.48	2.06	1.59	1.29	1.86	1.71
o-Xylene µg/l	<3	<3	<3	<3	<3	<3	<3	<3

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017	17/05/2017
o,p-DDE µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
o,p-DDT µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
o,p-Methoxychlor µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
o,p-TDE (DDD) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Organic Carbon, Total mg/l	9.19	8.86	11.1	9.51	4.08	9.21	10.8	9.19
Oxygen, dissolved mg/l	10.4	9.43	10.1	10.2	9.82	9.74	9.96	10.1
p,p-DDE µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p,p-DDT µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p,p-Methoxychlor µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
p,p-TDE (DDD) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH, Total Detected USEPA 16 (aq) µg/l	<0.344	<0.344	<0.344	<0.344	<0.344	<0.344	<0.344	<0.344
Parathion µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pendimethalin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Permethrin I µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Permethrin II µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
pH pH Units	8.25	8.41	8.32	8.27	8.38	8.28	8.41	8.37
Phenanthrene (aq) µg/l	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022
Phenol mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Phenols, Total Detected monohydric mg/l	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016
Phosalone µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pirimiphos-methyl µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propetamphos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pyrene (aq) µg/l	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Quintozene (PCNB) µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium (diss.filt) µg/l	<0.39	0.661	<0.39	<0.39	0.981	<0.81	<0.81	<0.5
Sulphate mg/l	14.1	12.4	<2	<2	<2	<2	<2	<2
Sum of detected BTEX µg/l	<28	<28	<28	<28	<28	<28	<28	<28

Appendix 2: cont'd

Parameter	13/05/2015	06/08/2015	15/02/2016	10/05/2016	09/08/2016	15/11/2016	16/02/2017	17/05/2017
Surfactants, Anionic (MBAS) mg/l	<0.05	<0.05	<0.05	<0.05	0.45	0.0624	<0.05	<0.05
Tecnazene µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Telodrin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Toluene µg/l	<4	<4	<4	<4	<4	<4	<4	<4
Total EPH (C6-C40) (aq) µg/l	<100	<100	<100	<100	<100	<100	<100	<100
Total Oxidised Nitrogen as N mg/l	1.01	0.882	1.13	0.941	0.685	0.495	1.04	1.12
Trans-chlordane µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triadimefon µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triallate µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triazophos µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trifluralin µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Xylenols mg/l	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Zinc (diss.filt) µg/l	0.46	0.537	1.29	1.47	1.69	<1.3	2.12	8.45
Langelier Index (LSI) *	0.59722	0.84136	0.41247	0.6029	0.78656	0.59866	0.67297	0.87132

***Langelier Index (LSI)** LSI = pH – pHs

pHs = (9.3 + A + B) – (C + D)

A = $(\log_{10}[\text{Total Dissolved Solids}] - 1)/10$

B = $-13.12 * \log10(\text{Temp}^{o}\text{C} + 273) + 34.55$

C = $\log_{10}[Ca^{2+} \text{ as } CaCO_3^{*}] - 0.4$

D = $\log_{10}[\text{Alkalinity as } CaCO_3]$

*Calcium was converted to Ca^{2+} as $CaCO_3$ using a conversion factor of 2.5.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

Client:	**Irish Water**
Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
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water technology limited

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1. Introduction

1.1. Lough Derg Monitoring Project

Irish Water, via a transferred contract originally procured by Dublin City Council, have engaged Jacobs-Tobin ("the Main Consultant") to provide consultancy services in respect of the Water Supply Project-Dublin Region (WSP-DR) ("the Project"), which is a strategic national project. The overall aim of the Project is to ensure that, in combination with other projects within the Greater Dublin Area (GDA), the long-term (2050+) water supply needs of the Dublin Region (Water Supply Area) are met in a sustainable manner. Jacobs-Tobins have engaged Water Technology Ltd to complete an environmental survey of Lough Derg and its surrounding catchment. Table 1 gives a breakdown of all aspects of the survey. **Appendix *1*** shows the locations of all sites from the original survey.

Table 1: Lough Derg Monitoring Project, Specification of Works.

Work Area	Title	Equipment
T300	Water Flow and Current Survey	4 Acoustic Doppler Current Profilers installed (1 horizontal on River Shannon inflow and 3 vertical on the lake).
T400	Water Level Survey	6 water level recorders installed (3 on inflowing rivers and 3 on lake).
T500	Water Quality Survey	5 moored sampling stations. Spot sampling at 8 sample sites on the lake and 7 river sites in the surrounding catchment.
T600	Water Treatability Survey	Spot sampling at 4 locations on the lake for 12 months followed by spot sampling at 1 site.
T700	Temperature Survey	Thermistor chains installed at 20 locations on the lake.
T800	Meteorological Survey	2 Meteorological Stations are to be deployed to measure wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity and compass.
T900	Plankton Survey	Phytoplankton and zooplankton samples to be taken at 11 sites on the lake over a 12 month period.

1.2. Site decommissioning

The temperature survey (T700) of the Lough Derg monitoring project completed on 31/10/2017. Fifteen thermistor sites were decommissioned and all equipment was removed from the lake. As per client instruction the vertical Acoustic Doppler Current Profiler (ADCP) was removed from the site at OL15 (below Parkers Point) was moved to OL19 (Parteen Basin). The new ADCP site was confirmed operational on 04/02/2018.

The main phase of the project ended on the 30th July 2018 with most sites decommissioned by this date. A reduced sampling programme was introduced with only the two weather stations and two nutrient analysers being maintained going forward. The spot sampling programme will also continue on a monthly basis. Locations of current stations can be seen in **Appendix 2**.

Table 2: Status of remaining LDMP stations as of 30th July 2018.

Station	Station Type	Status
MS01 (Ballinderry)	Weather Station	Live
MS02 (Whitegate)	Weather Station	Live
OL19 (Parteen Basin)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Level Station/Water Quality	Decommissioned
SS02 (Portumna River)	Horizontal ADCP	Decommissioned
SS03 (Carraigahorig River)	Level Station	Decommissioned
SS04 (Woodford River)	Level Station	Decommissioned
SS05 (Coolbaun)	Level Station	Decommissioned
SS06 (Garrykennedy)	Level Station	Decommissioned
SS07 (Killaloe)	Level Station	Decommissioned
OL02 (North of lake)	Water Quality/Nutrients/ADCP	Decommissioned
OL09 (Outside Dromineer Bay)	Water Quality/Nutrients/ADCP	Decommissioned
OL15 (Parkers Point)	Water Quality/Nutrients/ADCP	Decommissioned
OL19 (Parteen Basin)	Water Quality/ADCP	Decommissioned

1.3. Study Area

Lough Derg is an alkaline lake located on the River Shannon (**Figure 1**) between counties Clare, Tipperary and Galway. The main inflowing river is the Shannon which enters the lough at Portumna and flows out of the lake at the southern end at Killaloe. The lake is 40km long and 13km at it widest point. The majority of the lake lies on Carboniferous limestone with the exception of the narrow southern section which is underlain by Silurian strata. The surrounding catchment of the northern end of the lake is mainly flat agricultural land while the southern end of the lake is bordered by the Slieve Aughty Mountains to the west and the Arra Mountains to the east. The northern end of the lake has an average depth of 6m. Two deep trenches occur in the lake, one in the middle portion and one at the southern end with average depths of >34m and >25m respectively.

Under the WaterFramework Directive monitoring the lake is classified as mesotrophic with moderate water quality (Lough Derg Management Plan 2009 – 2015). Blue-green algae blooms of *Microcystis aeruginosa* are frequent occurrences during the summer months (*L. Vaughan, personal observation*). The lake is home to several invasive species including the invasive bivalve species the zebra mussel (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminea*). Several invasive macrophyte species have also been identified on the lake, these are Water Fern *Azolla filiculoides*, Canadian Pondweed *Elodea canadensis*,

Nuttall's waterweed *Elodea nuttalli*, Water Violet *Hottonia palustris*, Common Duckweed *Lemna minuta*, and water soldier *Stratiotes aloides* (Minchin and Boelens 2011).

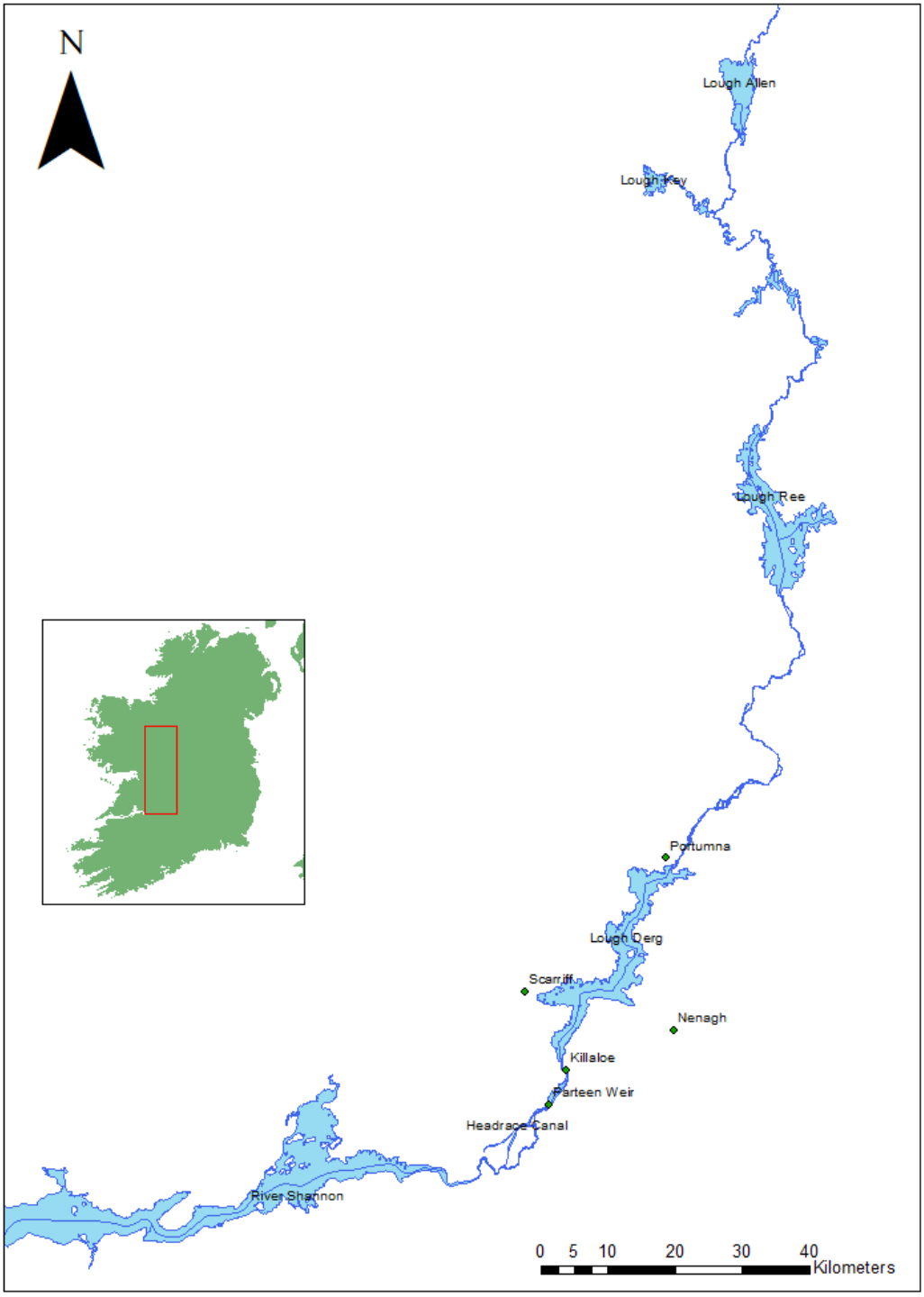


Figure 1: Shannon Catchment showing study area Lough Derg.

2. Results to date

2.1. T300 Water Flow and Current Survey

2.1.1. ADCP Survey

Four Acoustic Doppler Current Profilers were installed as part of the project at sites SS02, OL02, OL09 and OL15 (See **Appendix 1** for maps of all site locations on the lake and surrounding catchment). ADCPs produce a time series of vertical profiles of velocity in both the North/South and East/West axis. Internal processing resolves the acoustic Doppler signal into a set of "bins", each of which represents a layer of water defined by the acoustic travel time from the head of the transducer. On the vertical ADCP's this can be translated into depth layers (Note: for OL02 the bin size is 0.5m and OL09/15 the bin size 2m) while on the horizontal ADCP this translated to sections of the water column across the river.

At SS02 a horizontal ADCP has been installed with 24 bins of velocity. **Figure 2** shows monthly average flow data from each bin throughout the year.

As per clients instructions the ADCP survey underwent some changes in January 2018. A new ADCP station was set up at OL19 (Parteen Basin) and the ADCP on OL15 was removed. The new station is located approximately 15m south of the buoy at OL19 in 13.5m of water. The bin width was set to 0.5m with 25 bins (bin 25 at the surface and bin 1 at the lake bed). An additional 26th bin is available should the lake experience a rise in water levels.

The ADCP on OL02 was reinstalled on 02/02/2018 to fix an issue with sedimentation on the device which was causing errant results. The instrument was relocated to a site approximately 20m south of the bouy in 12.5m of water. The bin size remains at 0.5m however the number of bins have increased to 21 (bin 21 at the surface and bin 1 at the lake bed). Data presented below from OL02 is from 02/02/2018 onwards.

The ADCP on OL09 was serviced and cleaned on 02/02/2018. It was redeployed at a location 10m south of the buoy in 24m of water. The bin size and number remained as previous.

Figure 2 shows monthly average flow data from the horizontal ADCP installed at Portumna. Flows in January are the highest seen across the reporting period with a steady decline seen as the year progresses to July. Flows were highest on the western shore of the river during the study period.

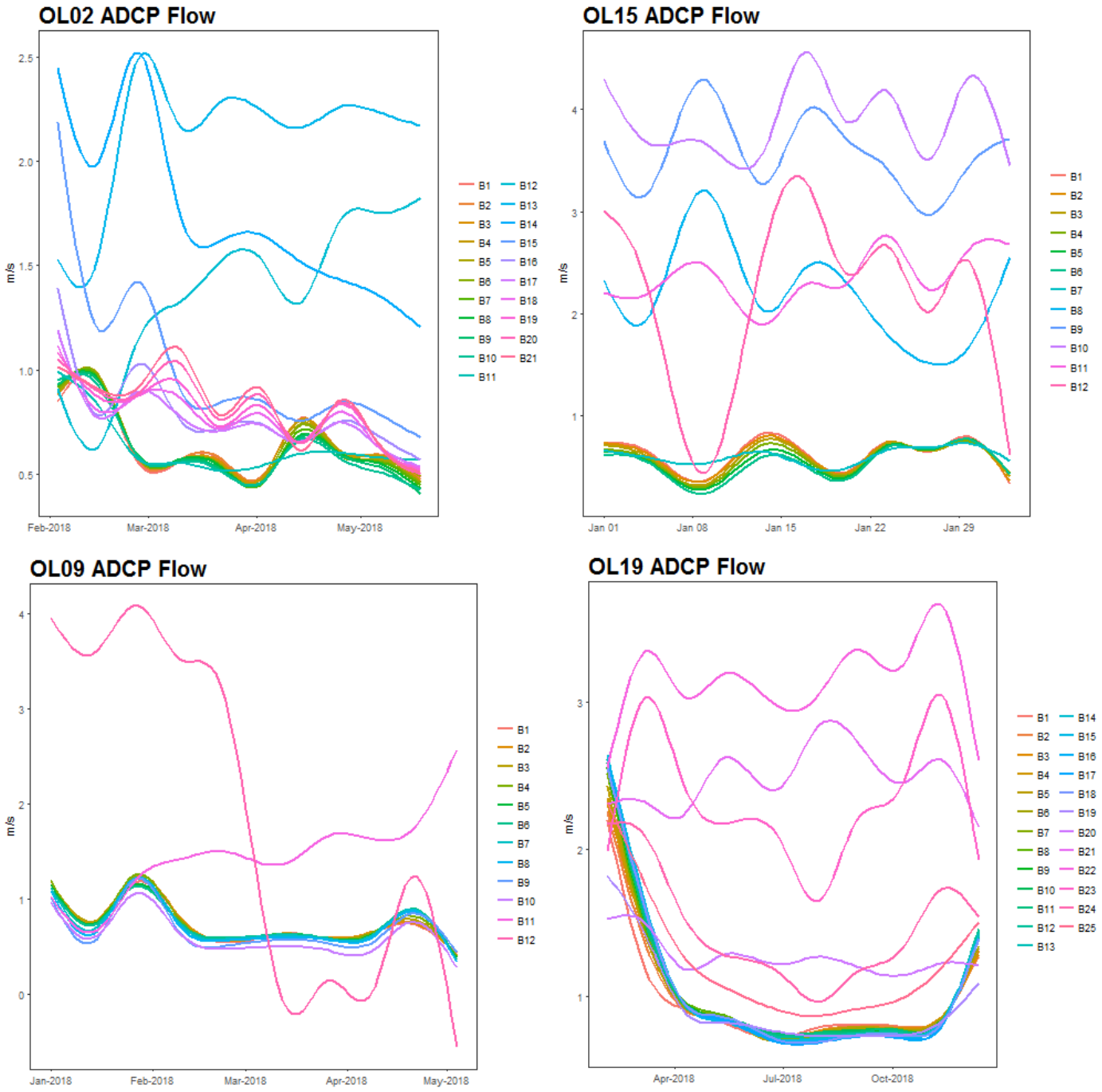


Figure *3* shows flow from vertical ADCP's installed at OL02, OL09, OL15 and OL19. The station at OL15 was removed in January 2018 so data presented is from this period only.

With the exception of the surface bins (Bins 23 – 24) all bins on OL19 show similar patterns with high flows seen in winter followed by lower levels from April through to October. Higher flows begin to be seen again in October with a gradual increase towards the end of the year. OL09 and OL15 flows show little variation in flow (excluding surface bins) throughout the study period.

OL19 data shows a much more varied pattern in surface flows than the other stations. Errant data from surface bins may be due to ghost levels above the water surface that result from reflection of the beams at the surface.

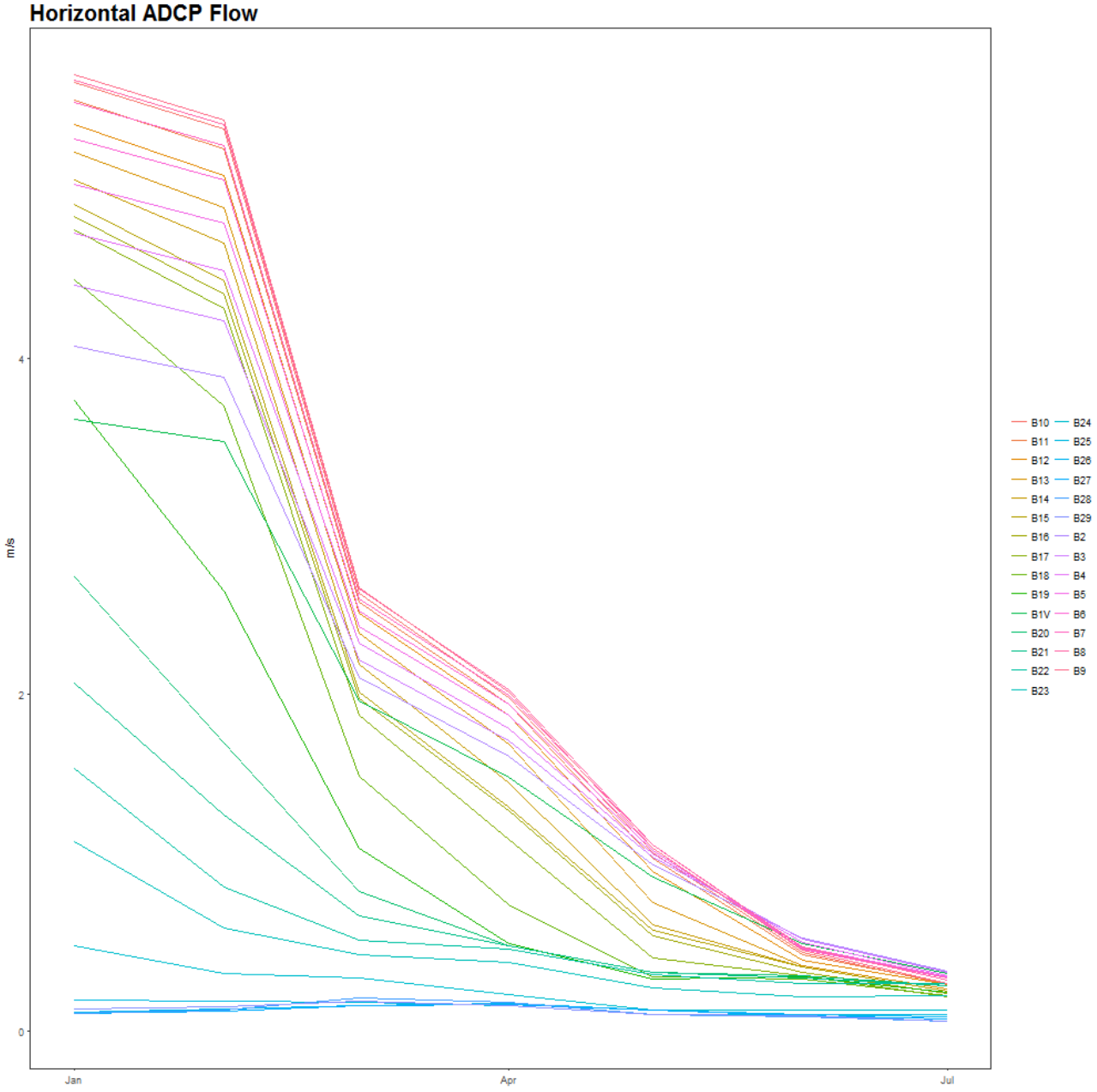


Figure 2: Monthly average flow data from Horizontal ADCP (m/s) (Flow calculated using Pythagoras theorem ((N-S flow)^2 + (E-W flow)^2 = (Overall flow)^2)) from January 2018 – July 2018. Note: Data has been filtered to remove noisy data.

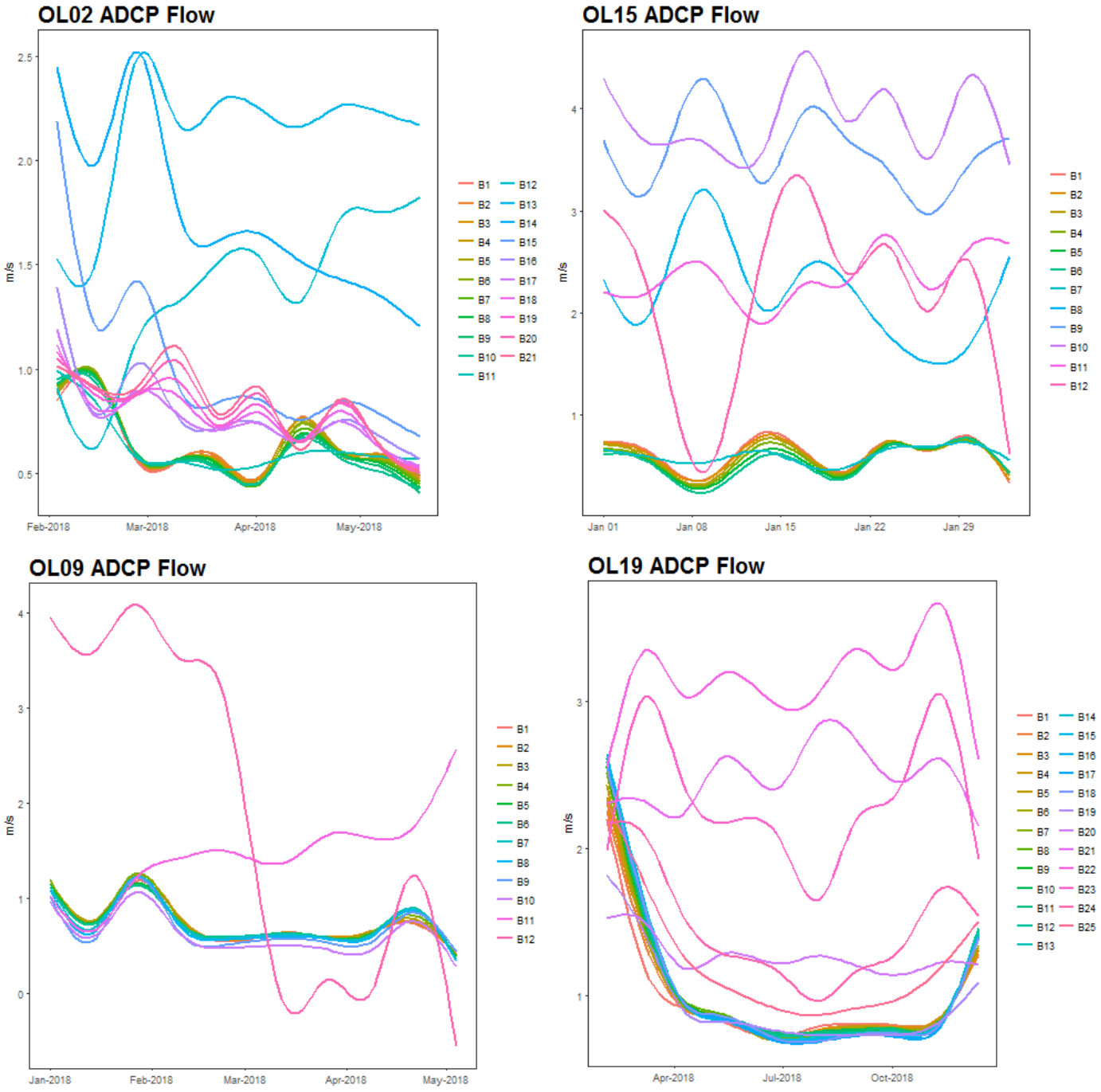


Figure 3: Flow data from all sites m/s (with a lowess smoother lines imposed on all bins) from January 2018 – July 2018 (m/s). Flow calculated using Pythagoras theorem ((N-S flow)^2 + (E-W flow)^2 = (Overall flow)^2)

2.2. T400 Water Level Survey

Level stations were installed at 6 locations (3 lake and 3 river sites). All lake stations show similar patterns of water levels throughout the reporting period and follow the pattern shown by the level station installed on Portumna Bridge at the inflow of the Shannon River. Higher levels are seen during the winter months with levels declining as the year progressed. The remaining river stations showed higher levels during the winter. Carraigahorrig River displayed a gradual decline over the year. Woodford River shows a much more variable pattern with sharp increases in water levels coinciding with periods of heavy rain.

Carraigahorrig River

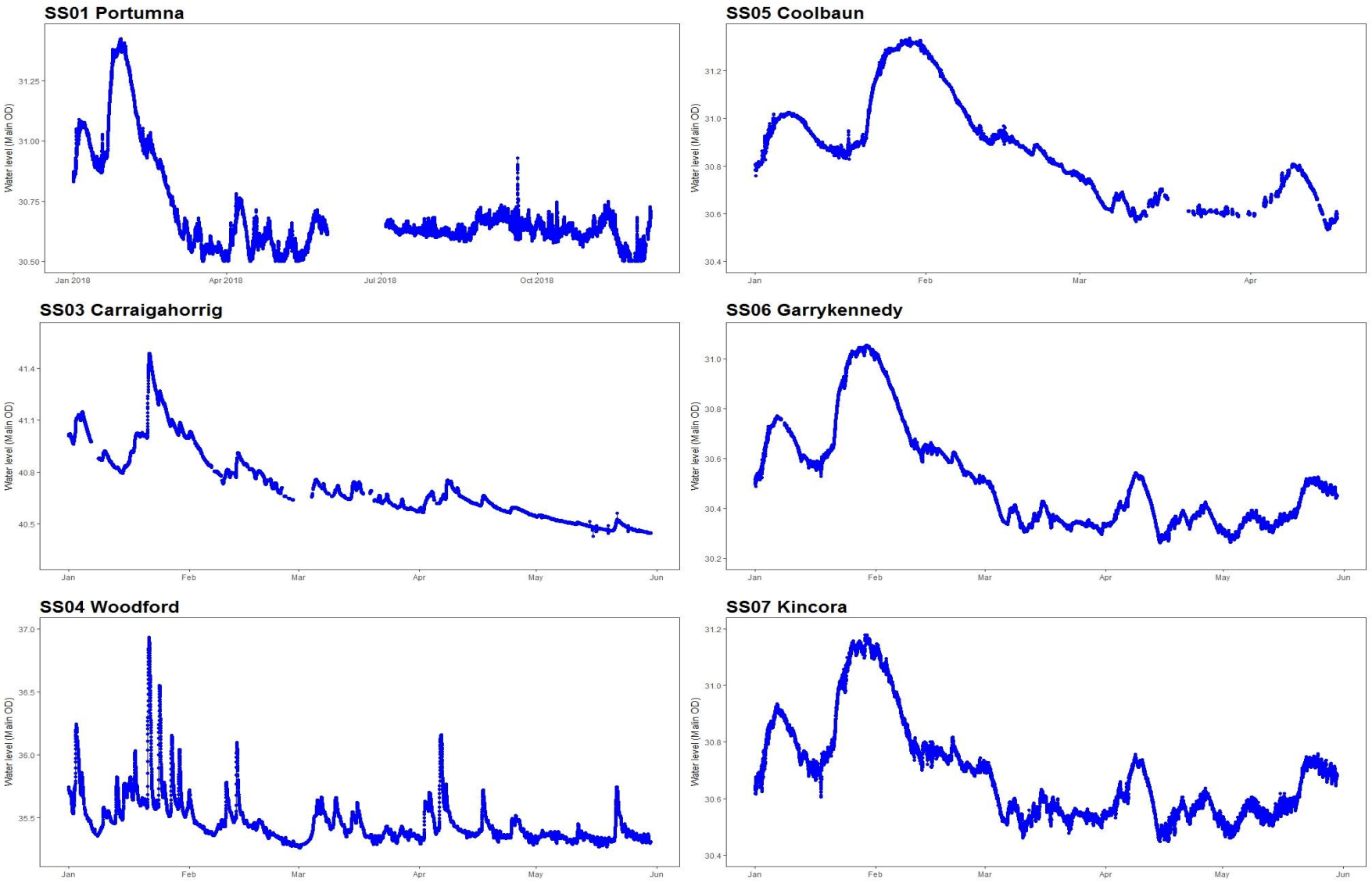


Figure 4: Water level data converted to Malin OD (m) from 6 stations from January 2018 – July 2018.

2.3. T500 Water Quality Survey

2.3.1. In-situ sampling

Five in-situ nutrient analysers were deployed, four at open lake sites and one on the inflowing River Shannon at Portumna Bridge.

Figure 5,

Figure *6*, **Figure *7***,
Figure 8, and
Figure 9 show nutrient data from all 5 sites from Jan – Jul 2018 (OL02, OL09, OL15) and Jan – Dec 2018 (SS01 and OL19) with all data below the limit of detection removed. Many nitrite and ammonia values were below the limit of detection making observations on trends difficult.

OL02, OL09 and OL15 all show an increase in NO_3N values in May. PO_4P values show a decline coming into the summer months. Values declined from spring through the summer months. This may indicate the beginning of the growing season in the lake with available dissolved nutrients being taken up by phytoplankton. This decline in dissolved nitrate and phosphate values is also noted in the spot sampling undertaken on a fortnightly basis in the lake. Stations OL02, OL09 and OL15 were decommissioned in June 2018. Nutrient analysers were maintained on stations OL19 and Portumna Bridge (SS01). Both stations showed an increase in NO_3N during November 2018. This coincided with a periods of heavy rain and was likely the result of increased runoff from the catchment.

Water Quality Buoy on Lough Derg

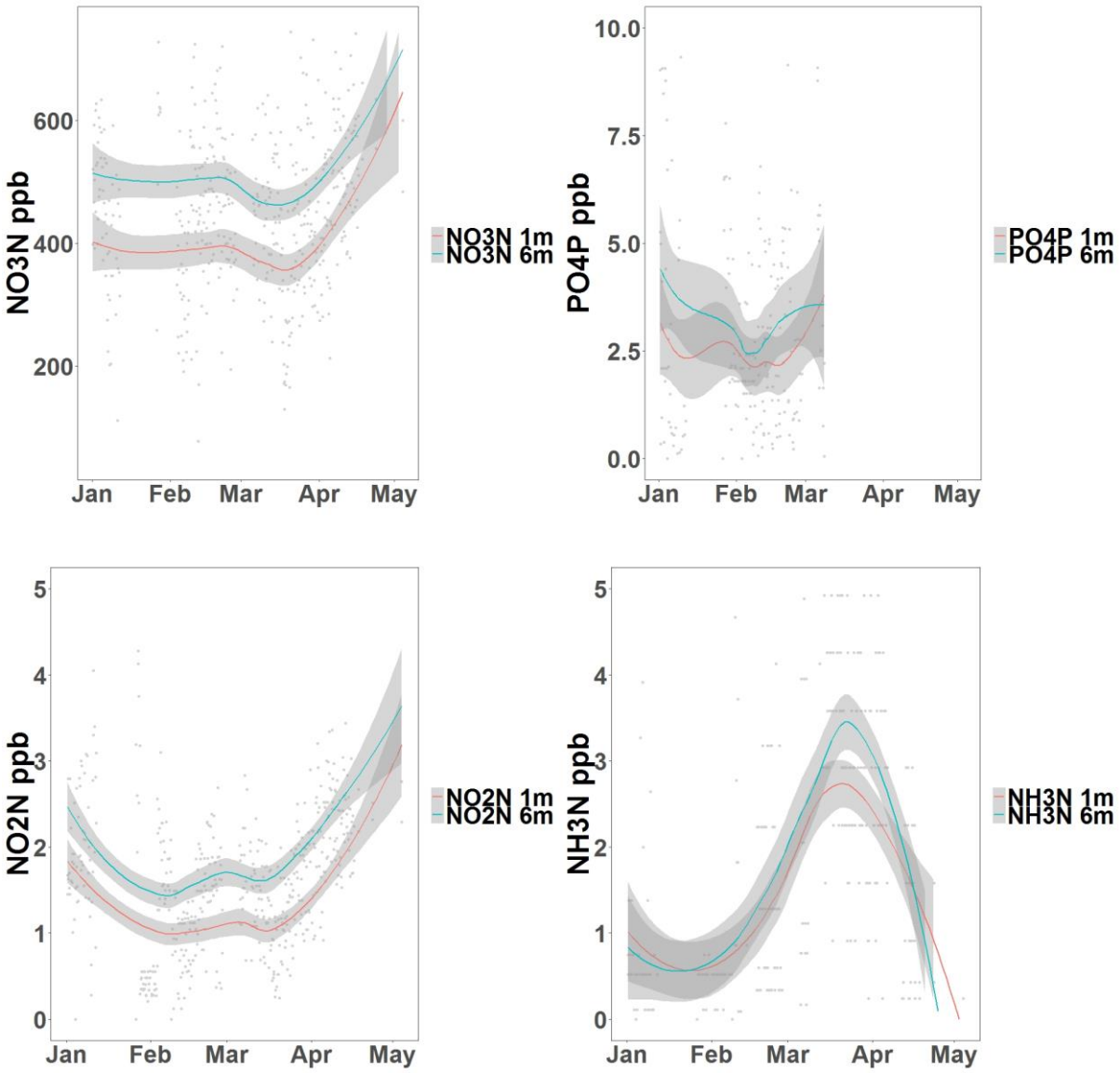


Figure 5: Nutrient Data from OL02 from January 2018 – July 2018 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed).

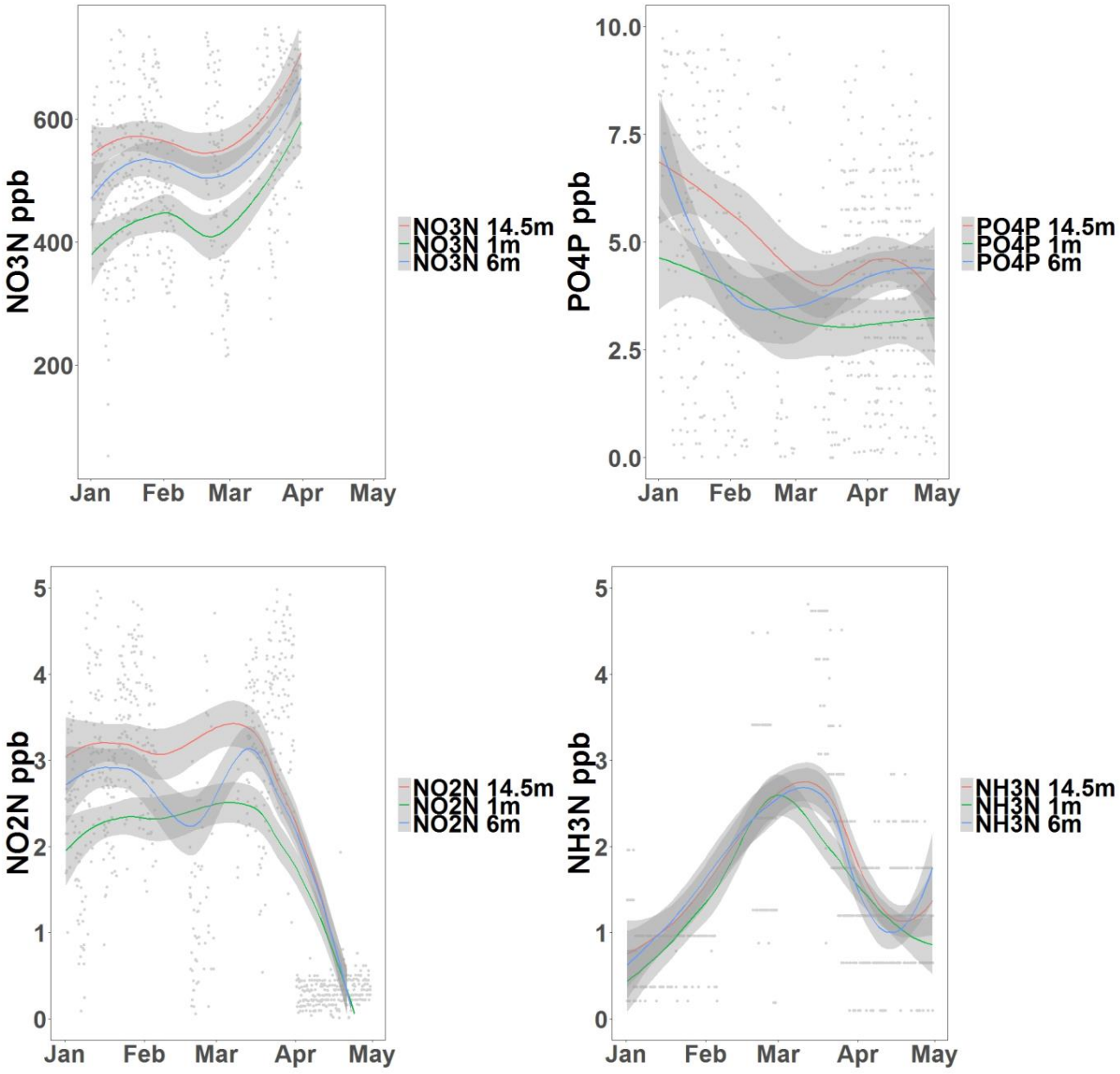


Figure 6: Nutrient Data from OL09 from January 2018 – July 2018 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed).

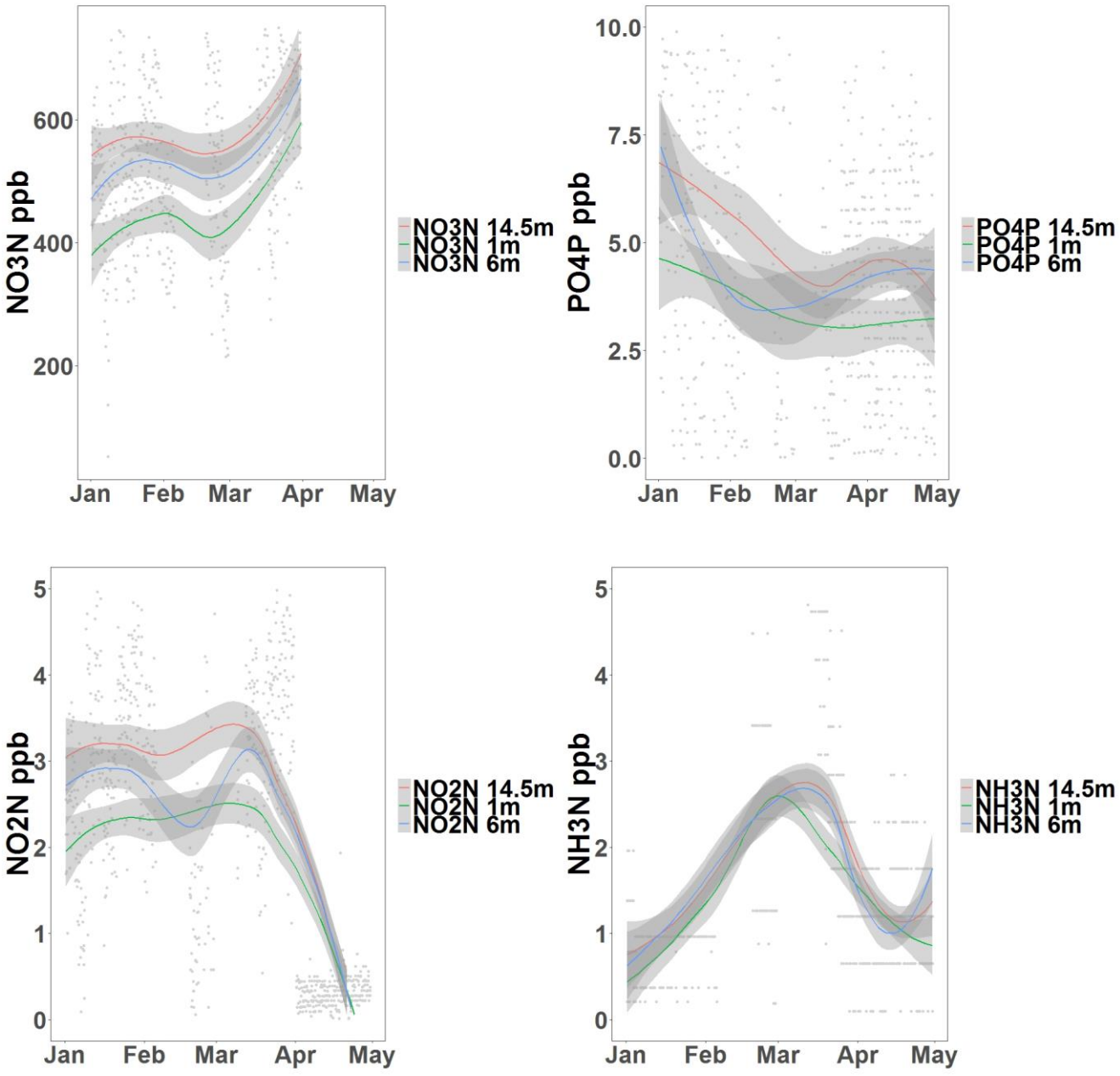


Figure 7: Nutrient Data from OL15 from January 2018 – July 2018 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed).

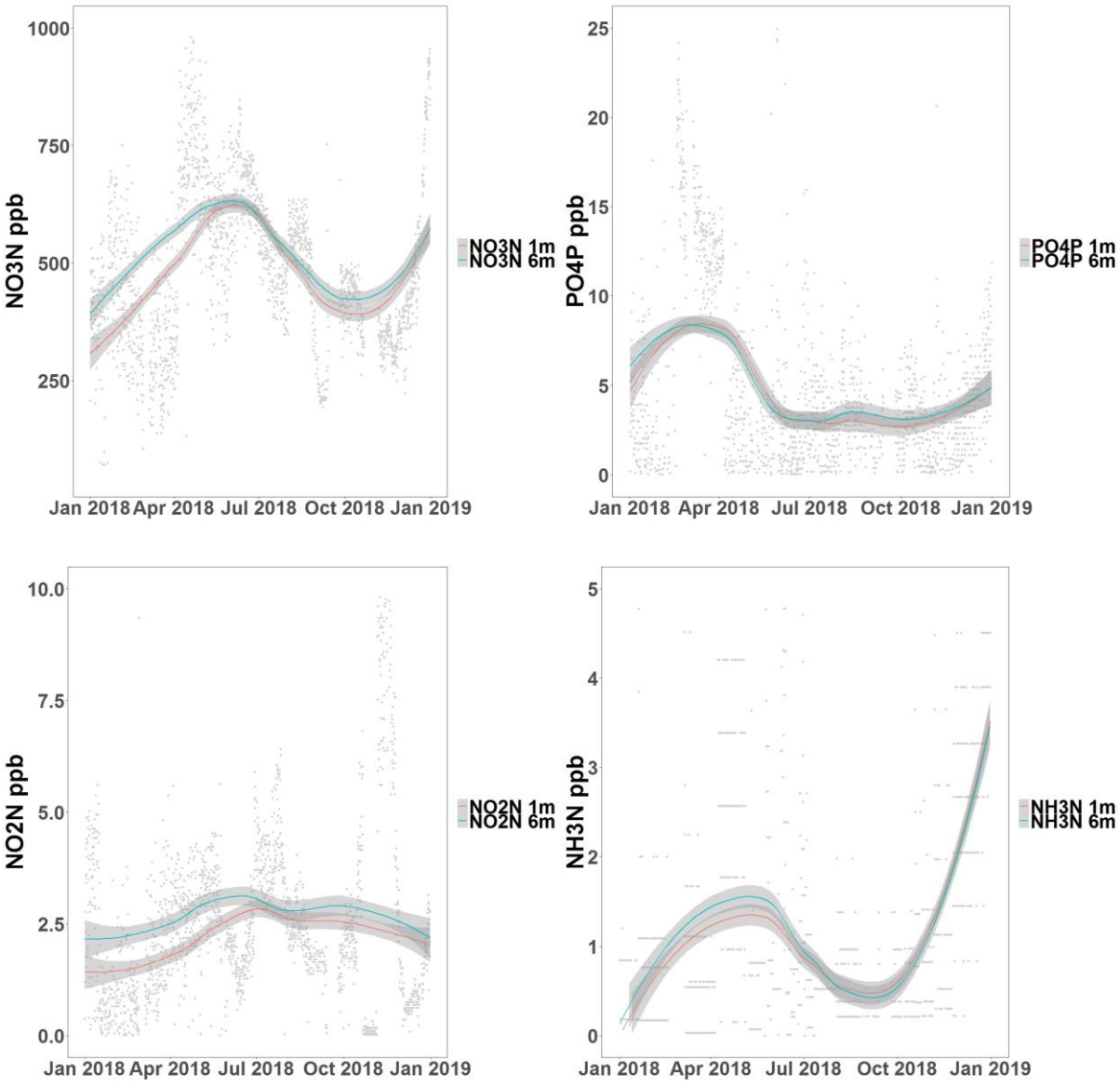


Figure 8: Nutrient Data from OL19 from January 2018 – December 2018 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed).

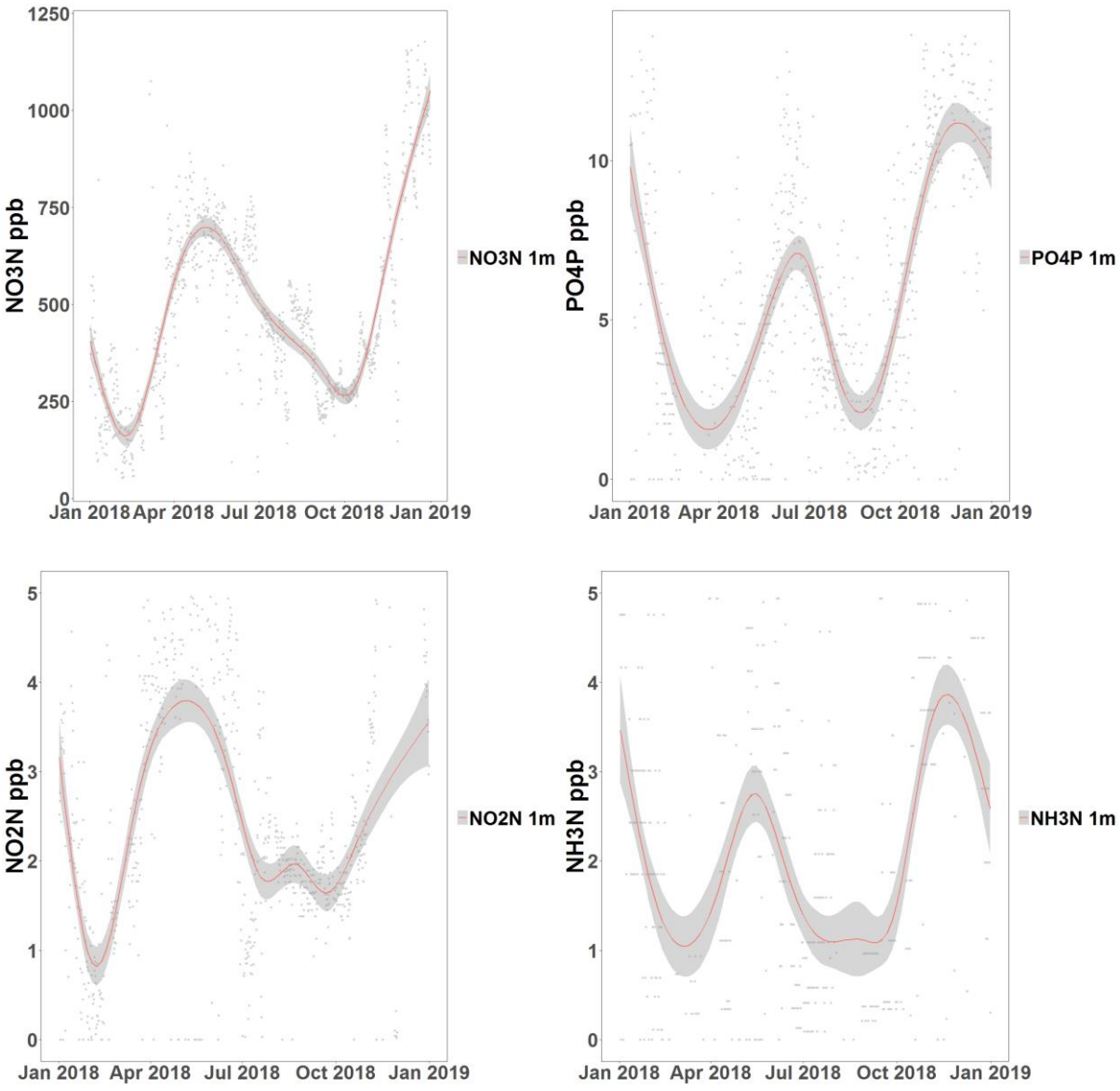


Figure 9: Nutrient Data from SS01 from January 2018 – December 2018 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed).

2.3.2. Spot Sampling

The current spot sampling programme commenced in January 2018 and includes parameters for water quality only. **Table 3** details the parameters collected at each site under the water quality monitoring programme. The water treatability spot sampling survey ceased in July 2017. Samples are collected on a monthly basis from the sites located in **Appendix *1***. At the request of the client a new test for ammonia (NH_3N) was sourced which allowed for a lower limit of detection. This was due to the low levels of ammonia found in the lake from the previous survey. Depending on the depth of the water column samples are taken at the surface, mid water depth and bottom depth (just above the lake bed). At shallow water site (< 5m) samples are taken at the surface and bottom depths. All lake sites showed similar patterns for all parameters measured across all depths.

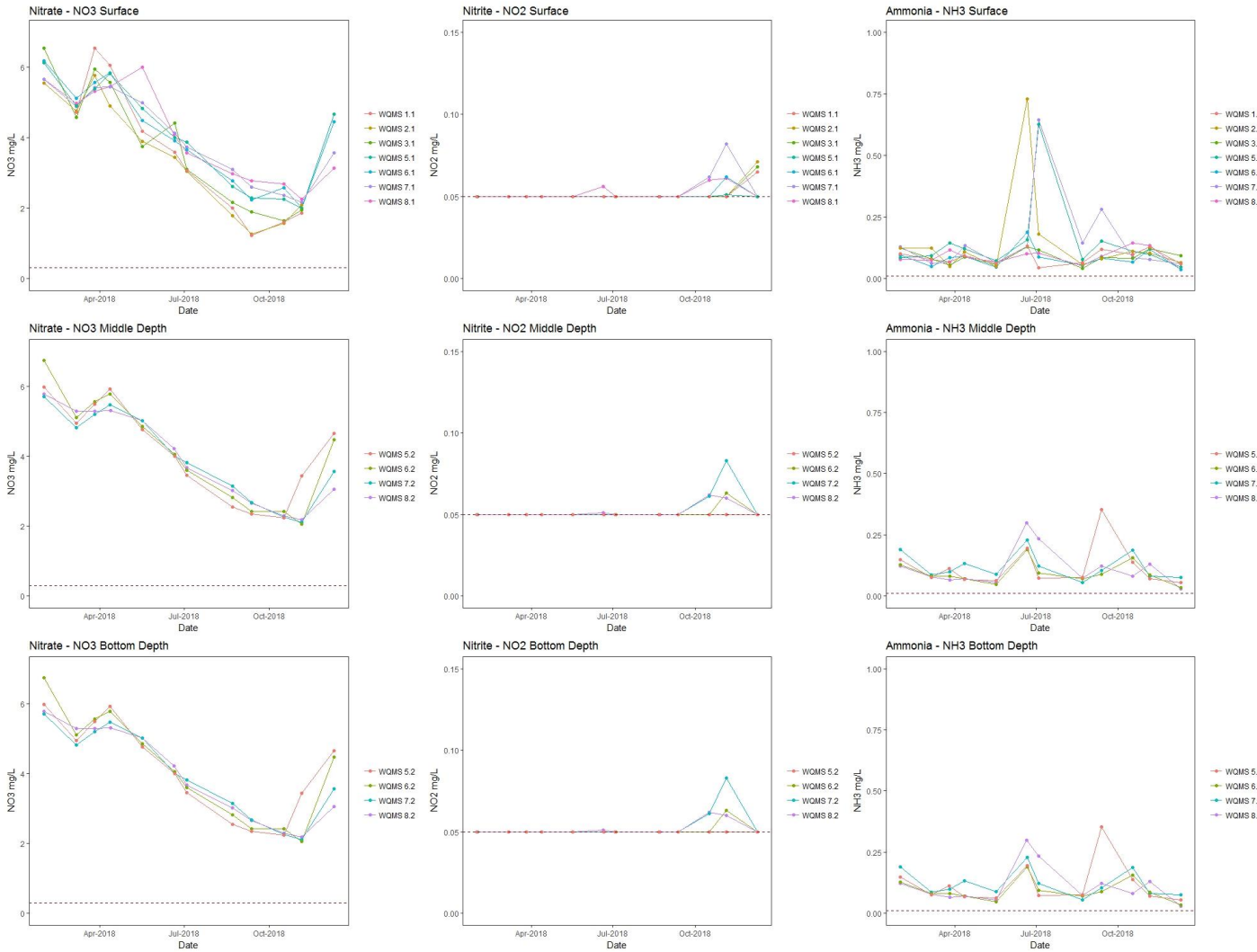


Figure 10, **Figure 11** and **Figure 12** show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate and chlorophyll *a* from water quality sites on Lough Derg at all

depths.

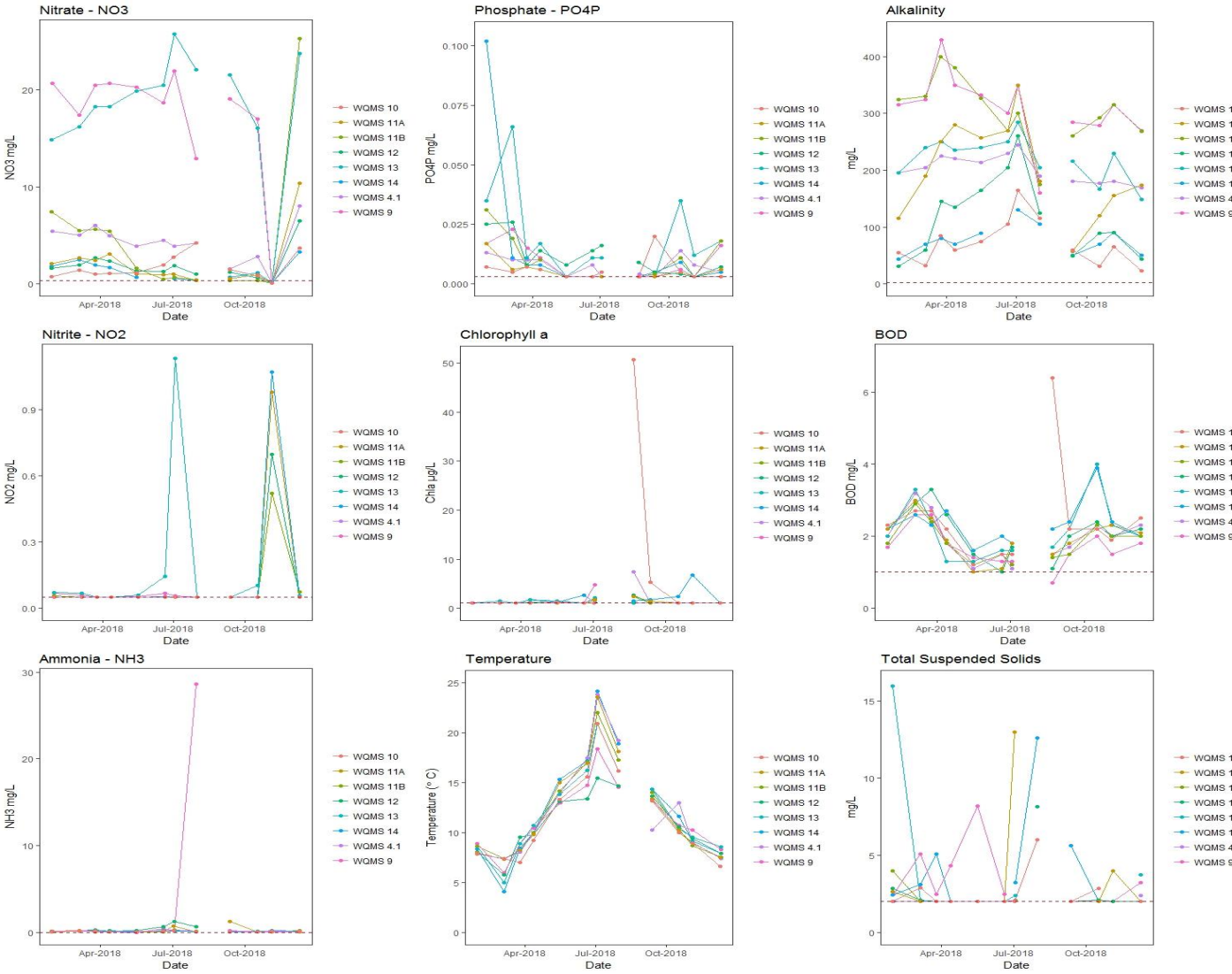


Figure 13 shows the water quality data from all inflowing rivers into Lough Derg.

As with previous years NO_3 showed a peak at the start of the year before declining through the summer months, this trend was seen across all sites and depths. All lake sites showed similar patterns for all parameters measured across all depths. Lake nitrate and phosphate values showed a steady decline from January to October although phosphate showed a slight increase across all sites in October. Chlorophyll *a* values are low until April where an increase can be seen particularly in the surface samples. This coincides with increased water temperatures and indicates the start of the growing season in the lake. From September onwards a decline in chlorophyll *a* is seen correlating with a similar declines in water temperatures.

The river parameters showed much more variability between sites, particularly for the nutrients NO_3 and PO_4P with WQMS 9 and WQMS 13 showing much higher NO_3 values than the other rivers. Both these sites are located on the eastern shore of the lake indicating a higher nutrient status on the eastern side of the catchment. Temperature levels at all river sites showed a decline in September and October.

Table 3: List of parameters collected under the spot sampling programme.

Parameter	**Units**
Alkalinity, Total as $CaCO_3$	mg/l
Ammoniacal Nitrogen as NH_3	mg/l
Nitrate as NO_3	mg/l
Nitrite as NO_2	mg/l
Phosphate (Ortho as P)	mg/l
Suspended solids, Total	mg/l
BOD	mg/l
Chlorophyll *a*	µg/l
Temperature	ºC
Dissolved Oxygen %	%/mg/l
pH	pH units
Conductivity	µS/cm

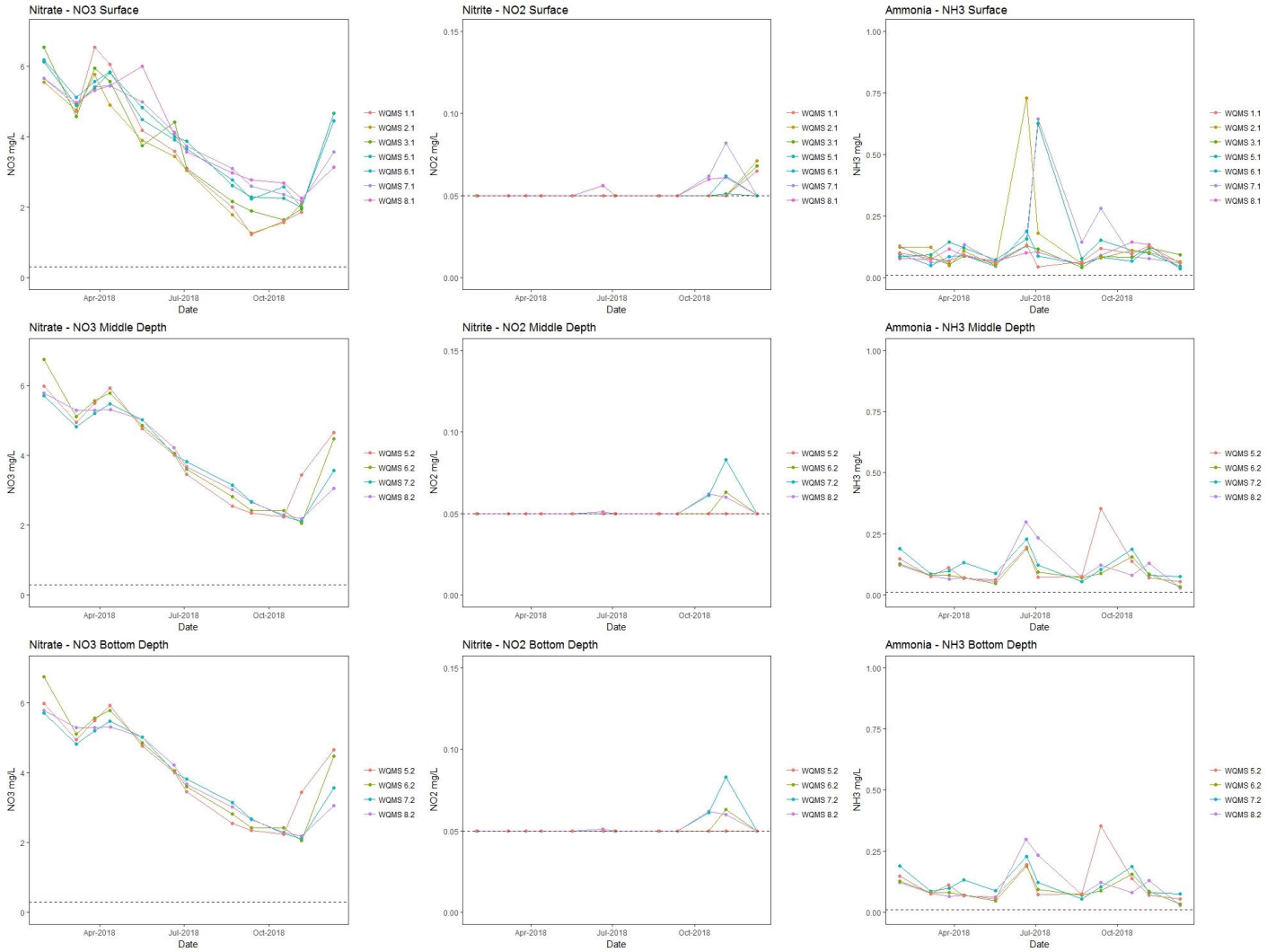


Figure 10: Survey results from all lake water quality sites of nitrate (NO3) nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicated limits of detection of analysis) from January 2018 – December 2018.

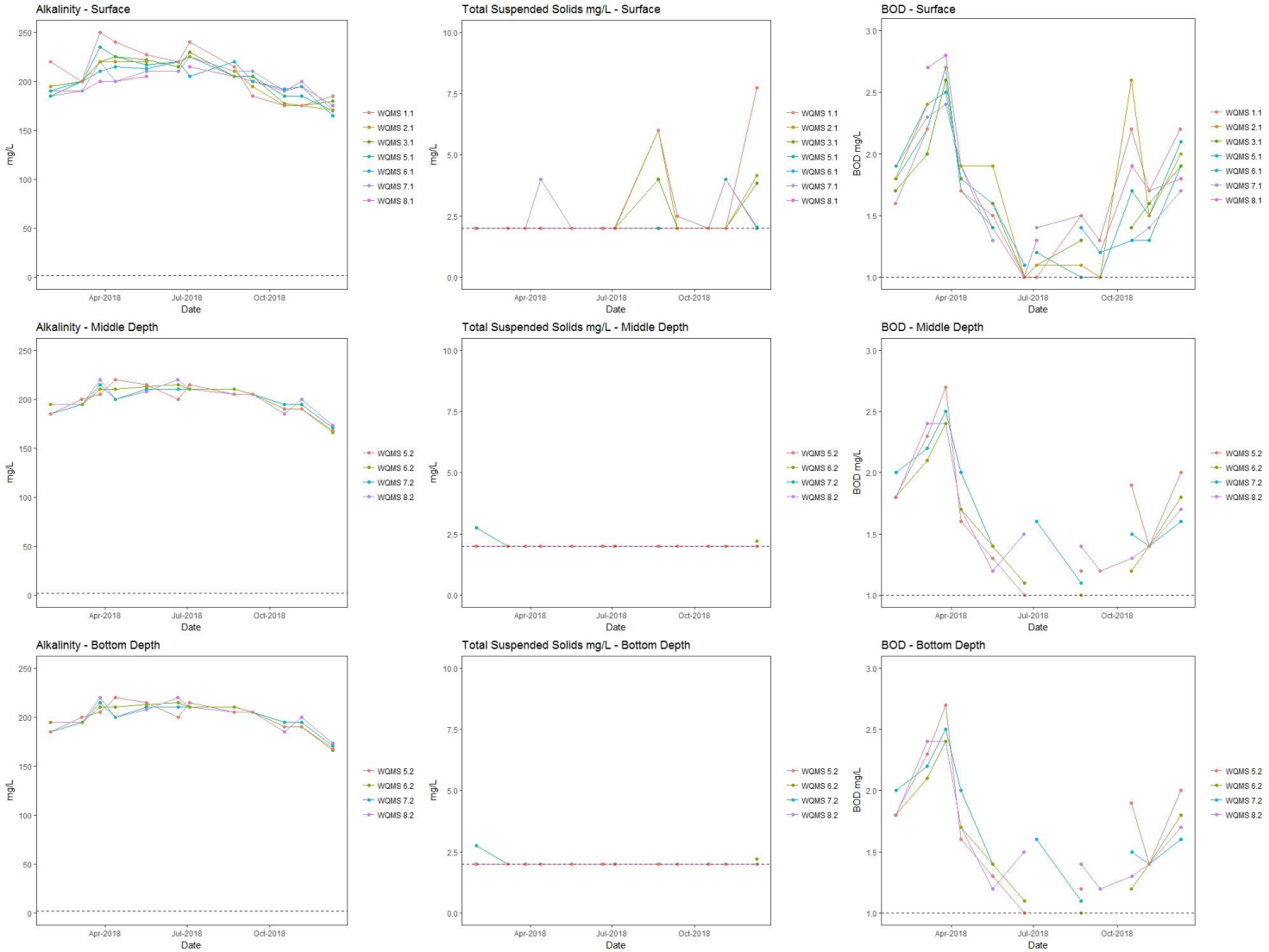


Figure 11: Survey results from all lake water quality sites of Alkalinity and Suspend Solids (Please note red dashed lines indicated limits of detection of analysis) from January 2018 – December 2018.

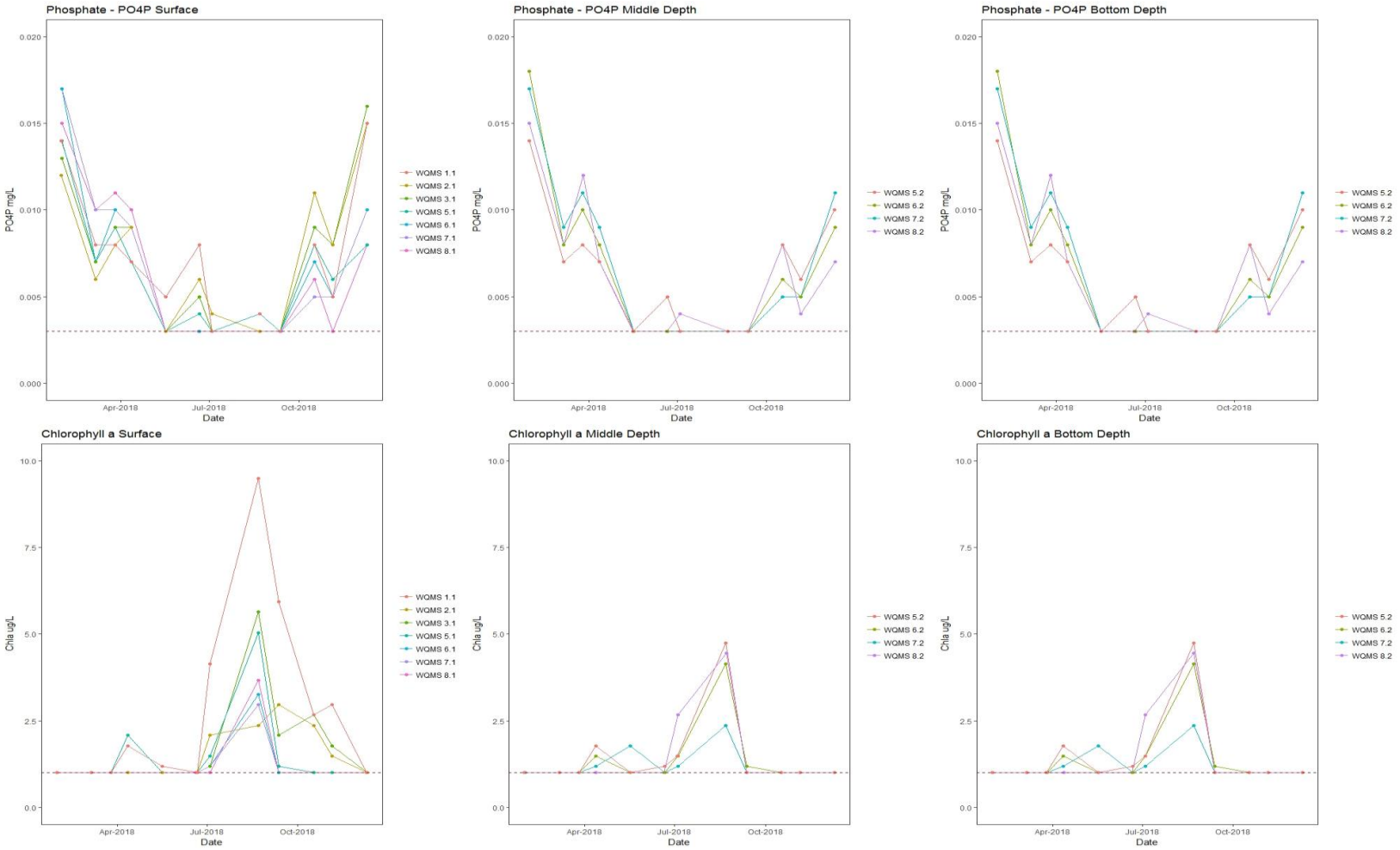


Figure 12: Survey results from all lake water quality sites of Chlorophyll *a* and Phosphate (PO4P) (Please note red dashed lines indicated limits of detection of analysis) from January 2018 – December 2018.

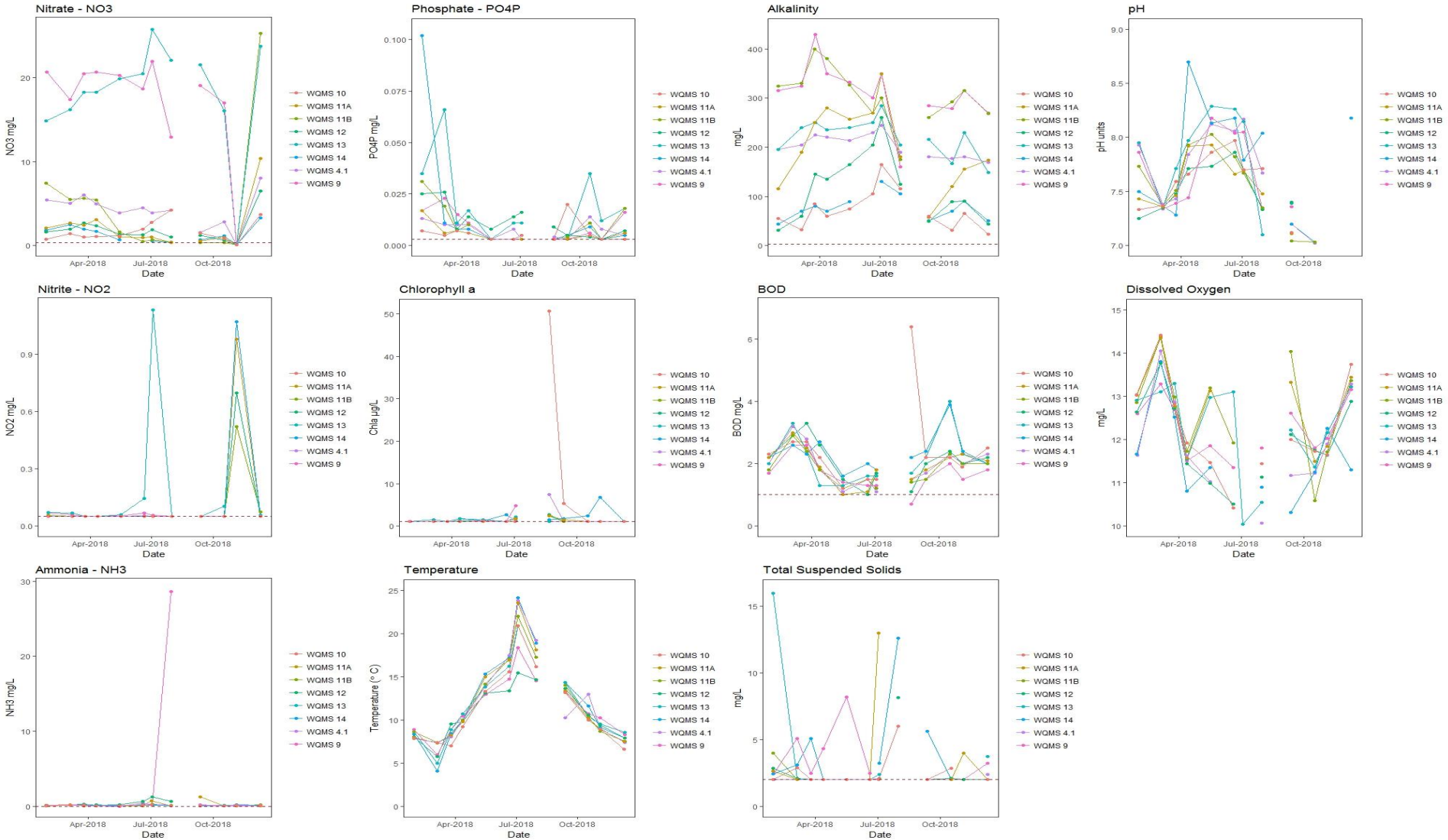


Figure 13: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll *a* and temperature, Alkalinity, pH, and Dissolved Oxygen (Please note red dashed lines indicated limits of detection of analysis) from January 2018 – December 20

2.4. T700 Temperature Survey

Nineteen temperature monitoring stations were deployed on Lough Derg as part of the original survey. The temperature survey on Lough Derg concluded at the end of October 2017. All thermistor buoys were removed from the lake by end of November 2017. Temperature sensors were still deployed on the large water quality buoys until they were decommissioned in July 2018.

2.5. T800 Meteorological Survey

Two meteorological stations were installed on the eastern and western shore of Lough Derg on the 17th/18th February 2016. Stations were deployed with sensors measuring wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity. Both stations show similar patterns over 2018. June and July 2018 was characterised by lower levels of rainfall and high temperatures. A maximum temperature of 32°C was recorded at Shannon Airport on the 28th of June. Maximum temperatures for MS01 (Ballinderry) and MS02 (Whitegate) over the study period were 29.9 °C and 30.7°C. Both these temperatures were recorded on the 27th June. Relative humidity for all of July were lower in comparison with the rest of the year.

Figure 16 shows windrose diagrams for both met stations, the prevailing winds for both stations varied from westerly to south westerly.

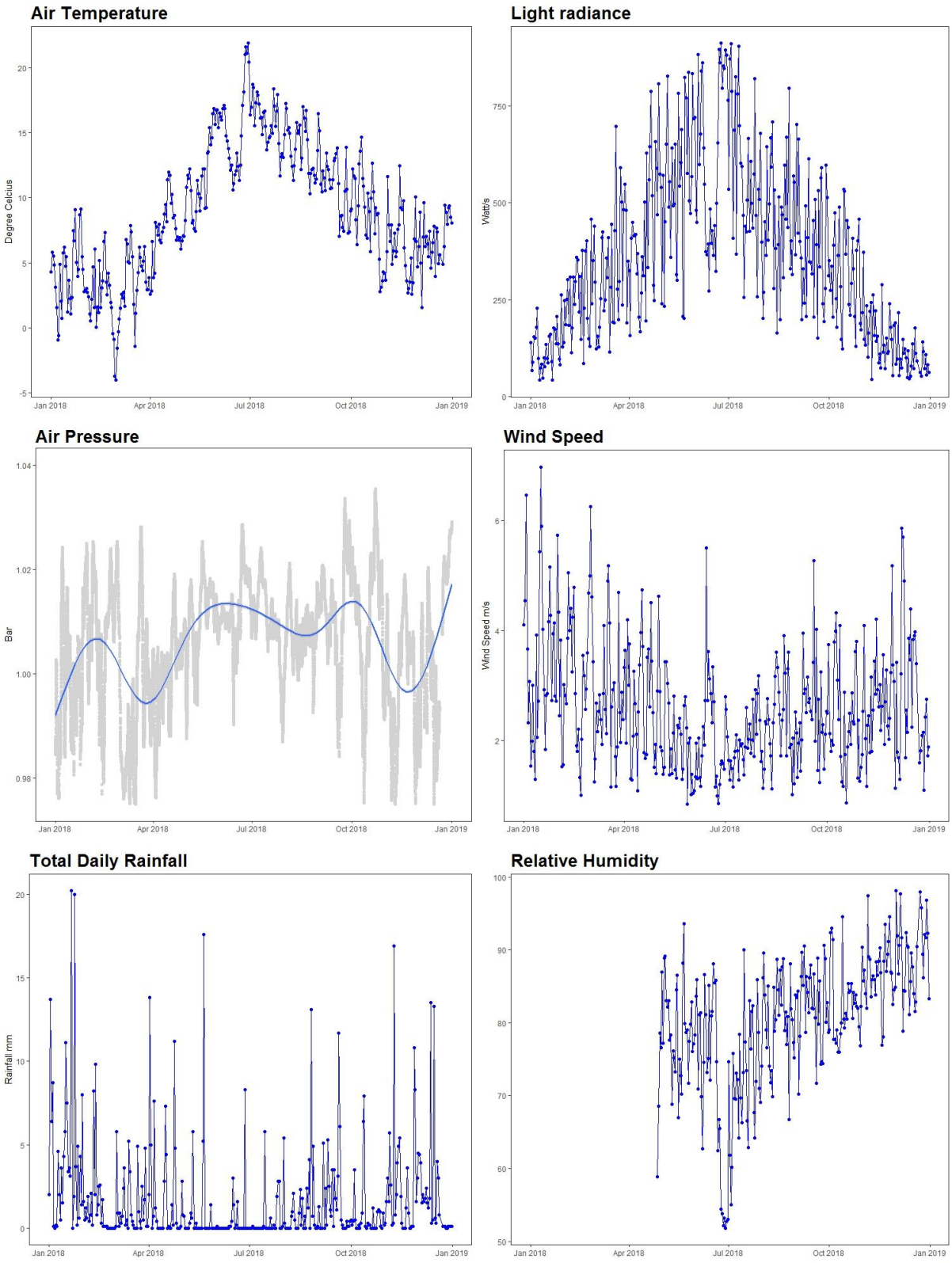


Figure 14: Data from MS01 (Ballinderry) from January 2018 – December 2018 (Air temperature and Air Pressure show observations with a loess smoother lines imposed, Light radiance (day time values only), Wind Speed and Relative Humidity show monthly average values).

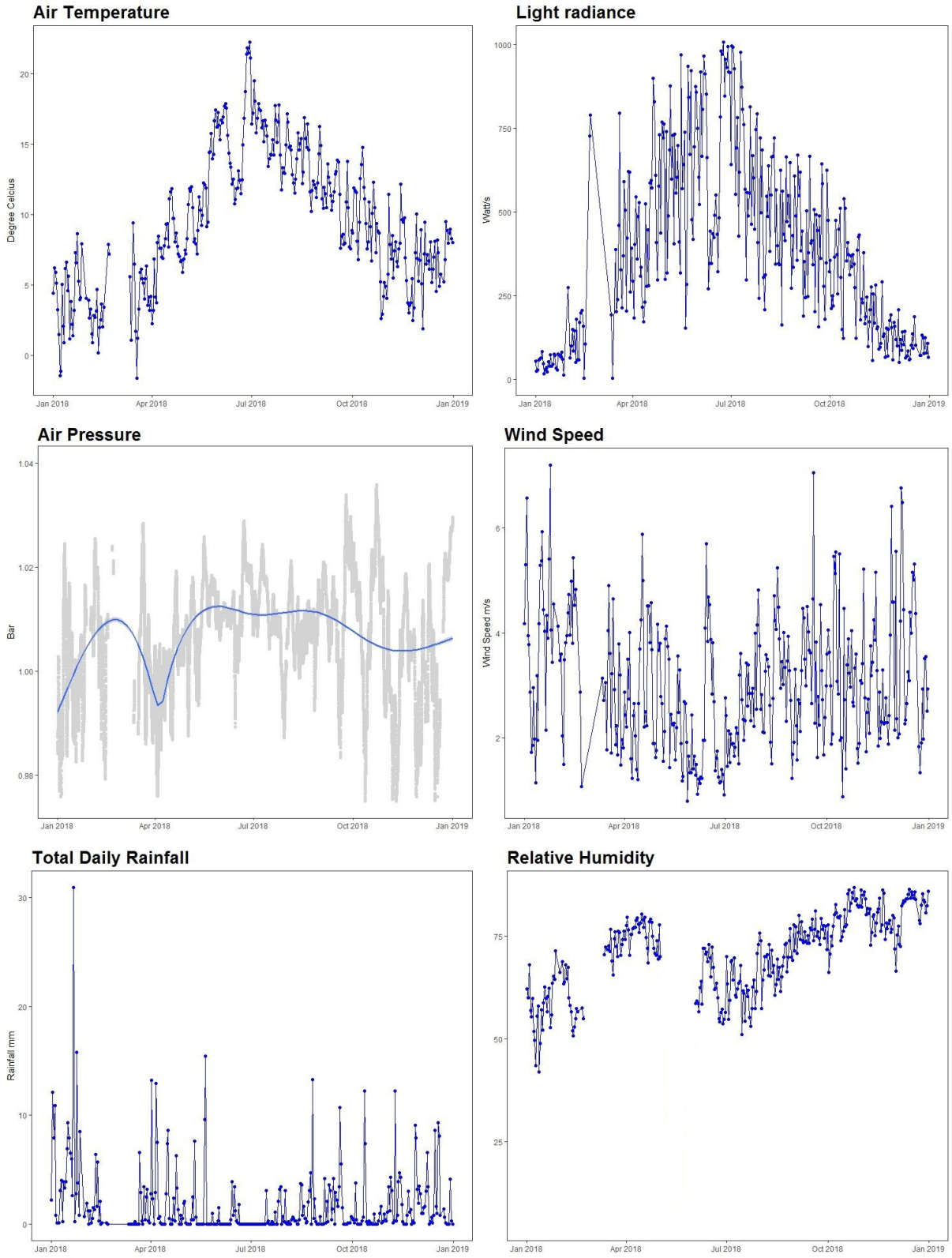


Figure 15: Data from MS02 (Whitegate) from January 2018 – December 2018 (Air temperature and Air Pressure show observations with a loess smoother lines imposed, Light radiance (day time values only), Wind Speed and Relative Humidity show monthly average values).

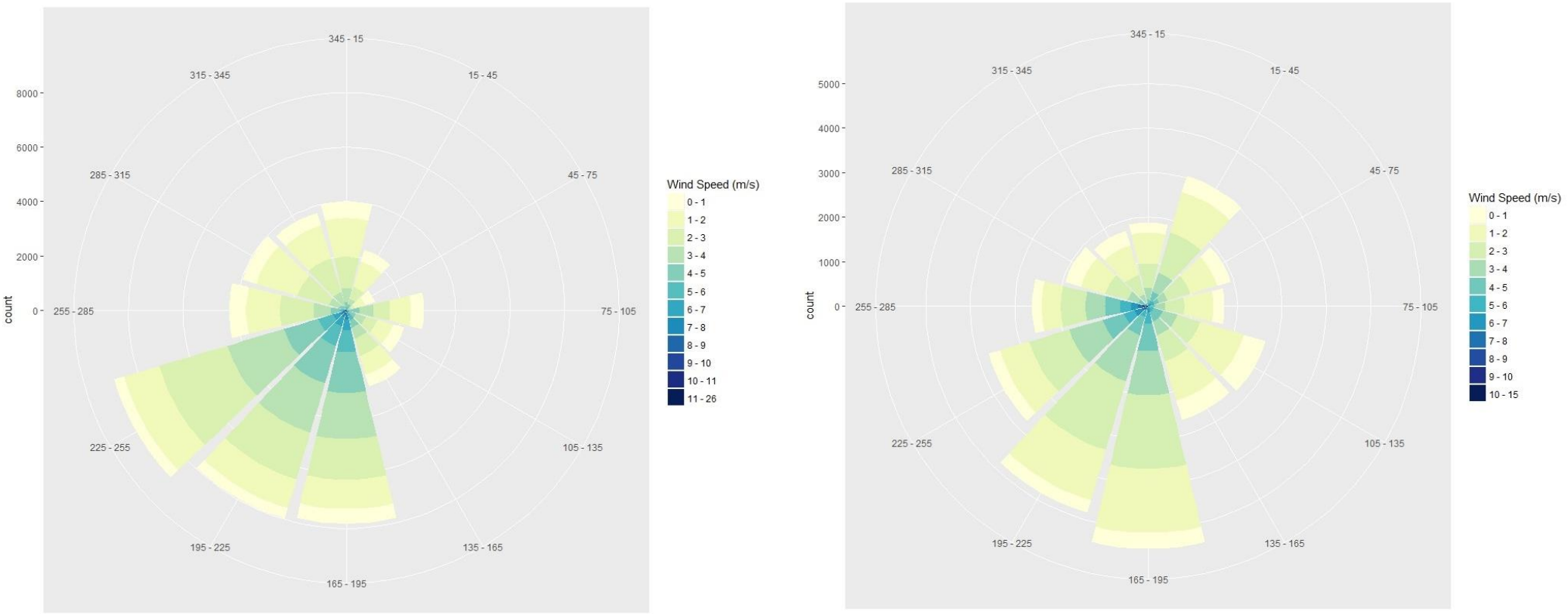
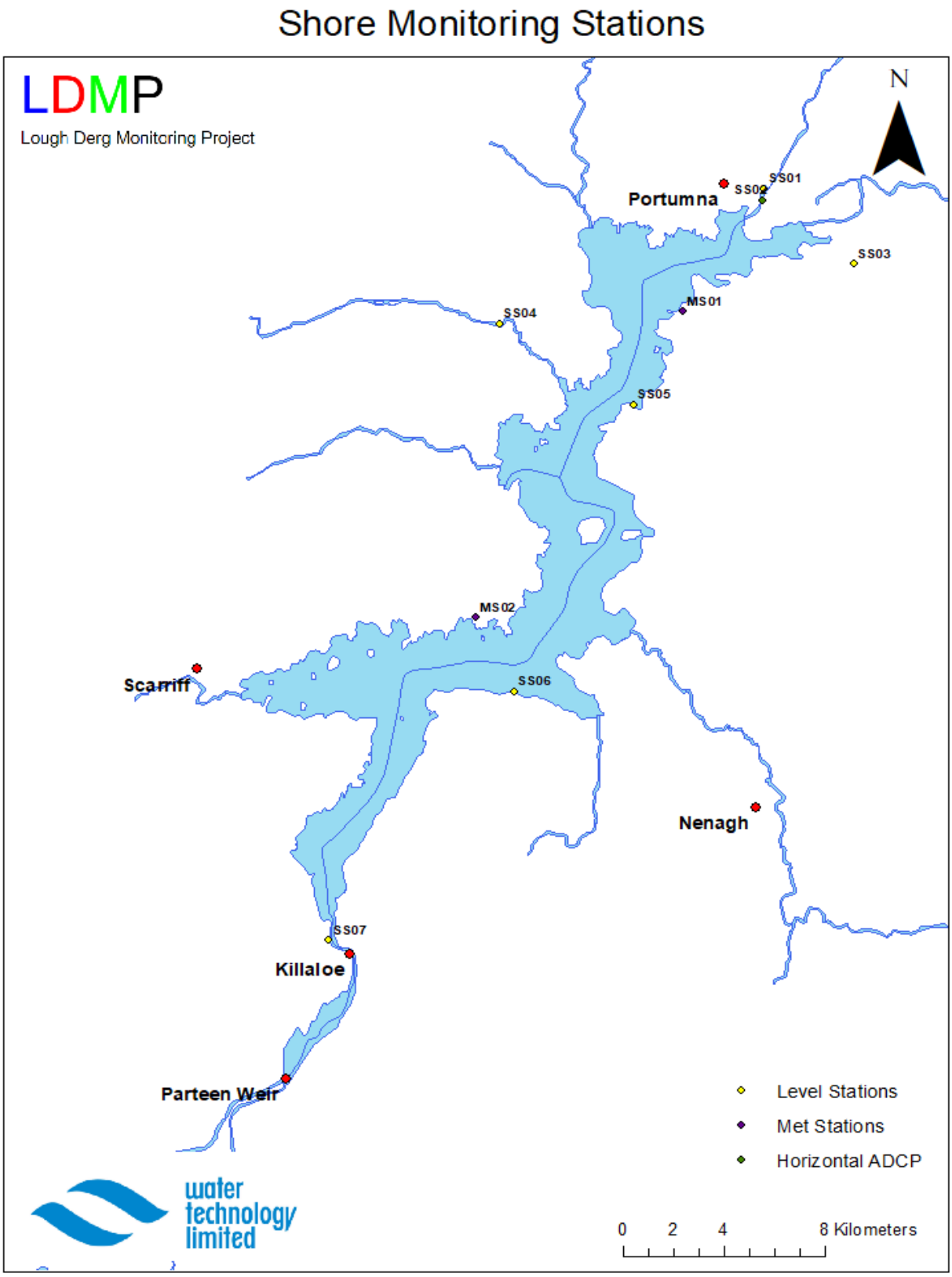


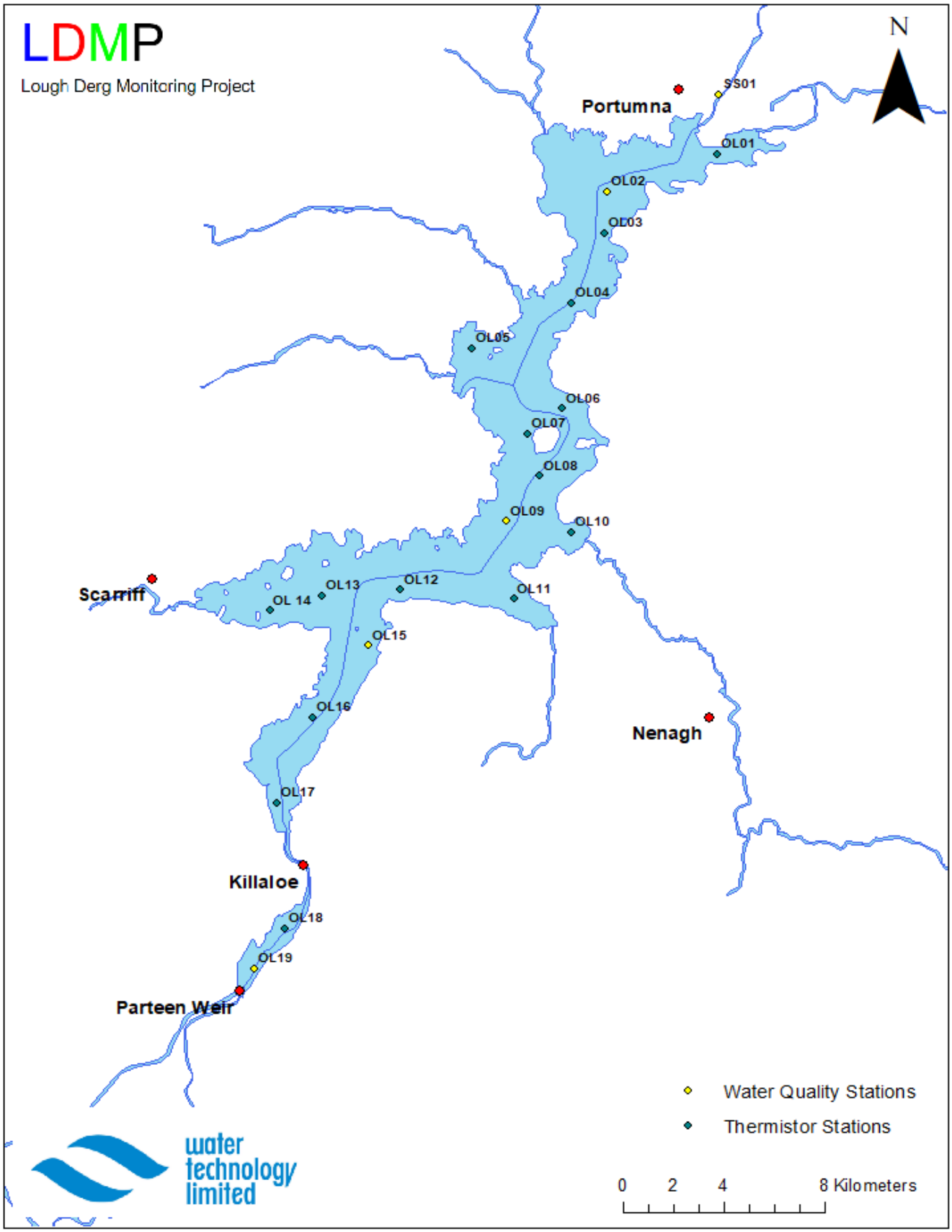
Figure 16: Windrose Diagram for Whitegate MS02 (left pane) and Ballinderry MS01 (right pane) weather stations from January 2018 – December 2018.

3. Appendices

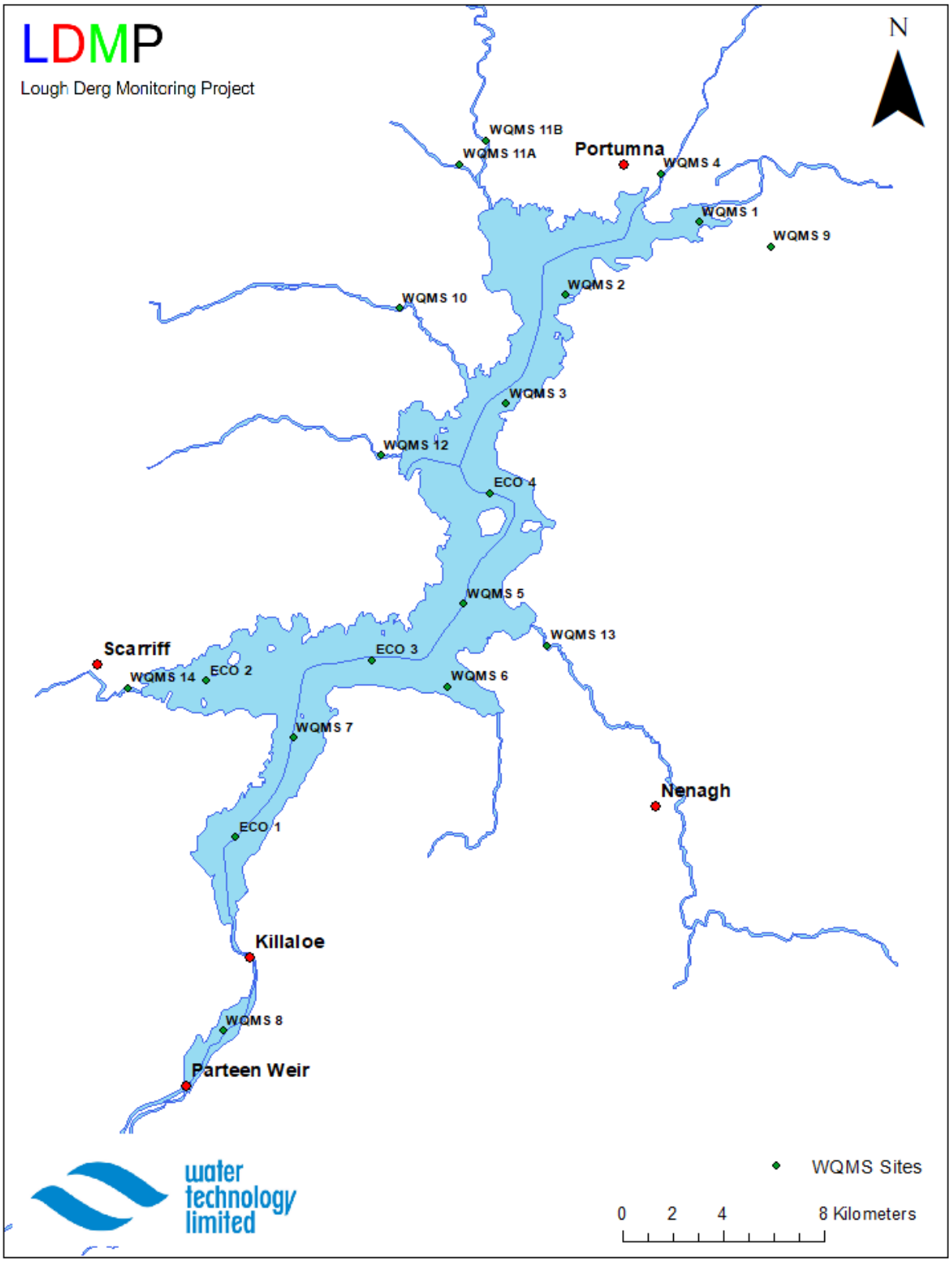
Appendix 1: Maps showing original survey site locations.



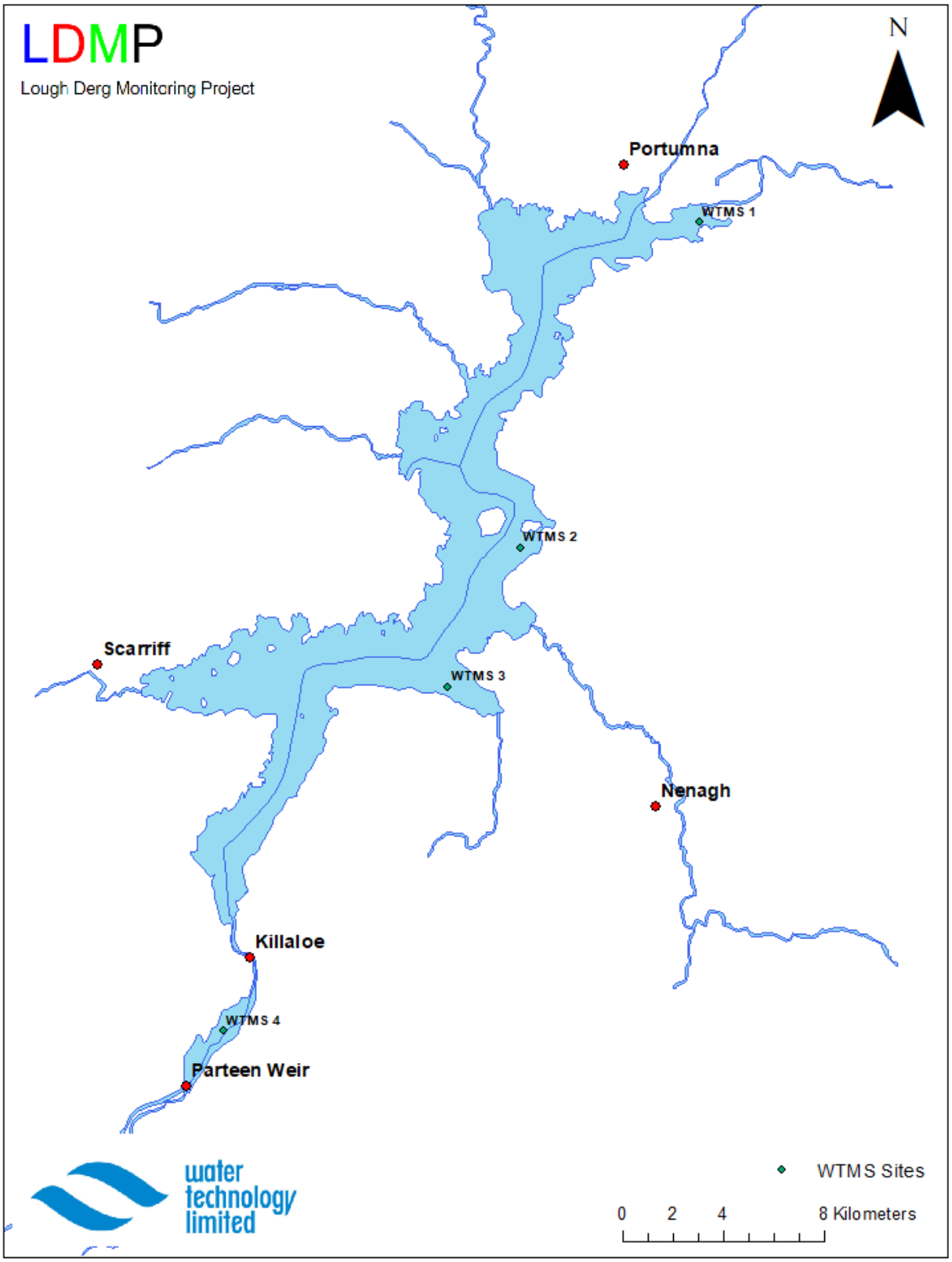
Open Water Monitoring Stations



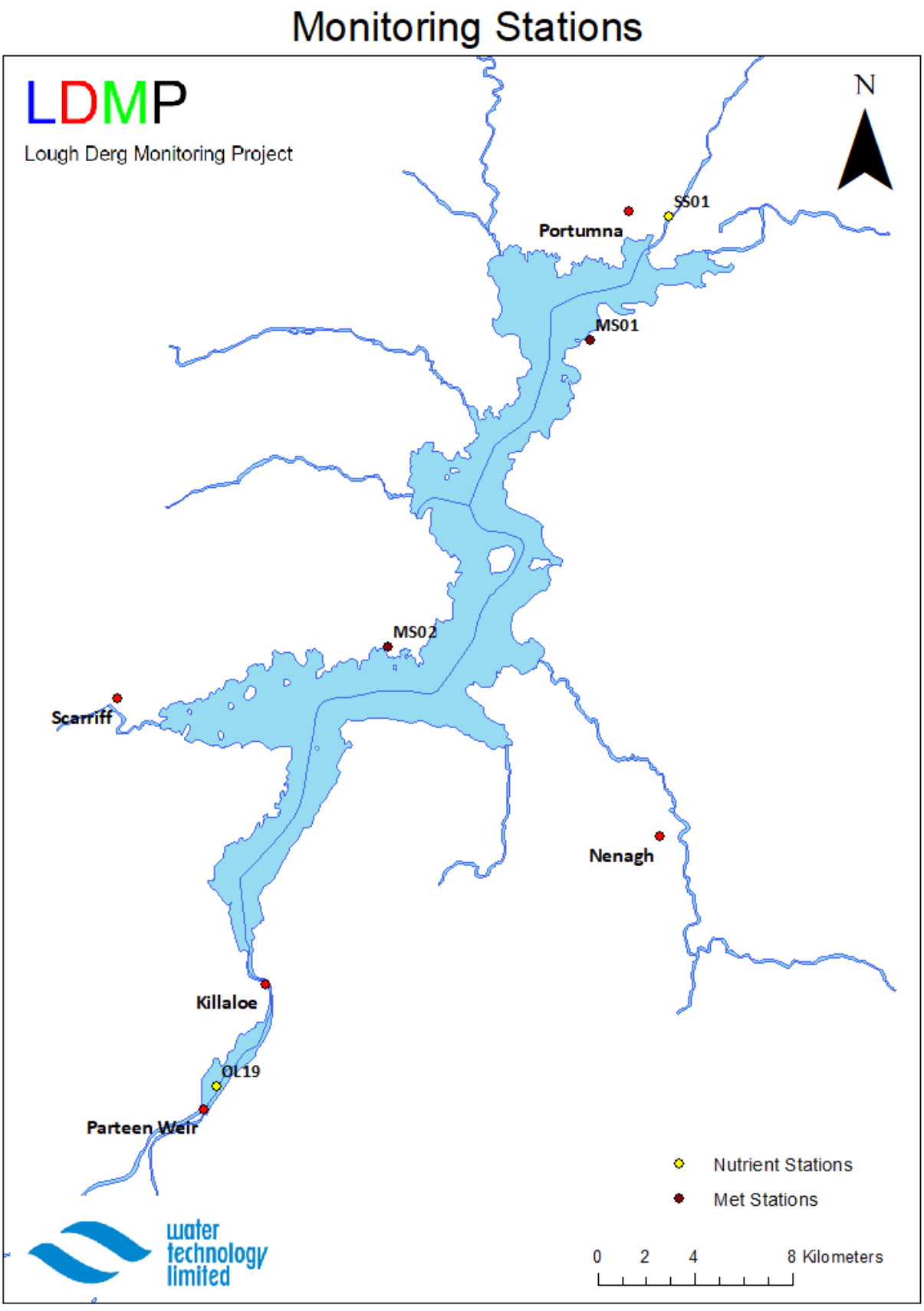
Water Quality Monitoring Site Locations



Water Treatability Monitoring Site Locations



Appendix 2: Maps showing current survey monitoring site locations.



4. References

Minchin, D. and R. Boelens (2011). "The Distribution and Expansion of Ornamental Plants on the Shannon Navigation." Biology and Environment-Proceedings of the Royal Irish Academy **Vol IIIB**(3): 1-9.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

Client:	**Irish Water**
Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
Document Title:	**Data report for Lough Derg Monitoring Project (Annual Report 2019)**
Document Number:	**LDMP/R/22**
Text Pages:	**25**

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1. Introduction

1.1. Lough Derg Monitoring Project

Irish Water, via a transferred contract originally procured by Dublin City Council, have engaged Jacobs-Tobin ("the Main Consultant") to provide consultancy services in respect of the Water Supply Project-Dublin Region (WSP-DR) ("the Project"), which is a strategic national project. The overall aim of the Project is to ensure that, in combination with other projects within the Greater Dublin Area (GDA), the long-term (2050+) water supply needs of the Dublin Region (Water Supply Area) are met in a sustainable manner. Jacobs-Tobins have engaged Water Technology Ltd to complete an environmental survey of Lough Derg and its surrounding catchment. Table 1 gives a breakdown of all aspects of the survey. **Appendix *1*** shows the locations of all sites from the original survey.

Table 1: Lough Derg Monitoring Project, Specification of Works.

Work Area	Title	Equipment
T300	Water Flow and Current Survey	4 Acoustic Doppler Current Profilers installed (1 horizontal on River Shannon inflow and 3 vertical on the lake).
T400	Water Level Survey	6 water level recorders installed (3 on inflowing rivers and 3 on lake).
T500	Water Quality Survey	5 moored sampling stations. Spot sampling at 8 sample sites on the lake and 7 river sites in the surrounding catchment.
T600	Water Treatability Survey	Spot sampling at 4 locations on the lake for 12 months followed by spot sampling at 1 site.
T700	Temperature Survey	Thermistor chains installed at 20 locations on the lake.
T800	Meteorological Survey	2 Meteorological Stations are to be deployed to measure wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity and compass.
T900	Plankton Survey	Phytoplankton and zooplankton samples to be taken at 11 sites on the lake over a 12 month period.

1.2. Site decommissioning

The temperature survey (T700) of the Lough Derg monitoring project completed on 31/10/2017. Fifteen thermistor sites were decommissioned and all equipment was removed from the lake. As per client instruction the vertical Acoustic Doppler Current Profiler (ADCP) was removed from the site at OL15 (below Parkers Point) was moved to OL19 (Parteen Basin). The new ADCP site was confirmed operational on 04/02/2018.

The main phase of the project ended on the 30th July 2018 with most sites decommissioned by this date. A reduced sampling programme was introduced with only the two weather stations and two nutrient analysers being maintained going forward. The spot sampling programme will also continue on a monthly basis. Locations of current stations can be seen in **Appendix 2**.

Table 2: Status of remaining LDMP stations as of 30th July 2018.

Station	Station Type	Status
MS01 (Ballinderry)	Weather Station	Live
MS02 (Whitegate)	Weather Station	Live
OL19 (Parteen Basin)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Level Station/Water Quality	Decommissioned
SS02 (Portumna River)	Horizontal ADCP	Decommissioned
SS03 (Carraigahorig River)	Level Station	Decommissioned
SS04 (Woodford River)	Level Station	Decommissioned
SS05 (Coolbaun)	Level Station	Decommissioned
SS06 (Garrykennedy)	Level Station	Decommissioned
SS07 (Killaloe)	Level Station	Decommissioned
OL02 (North of lake)	Water Quality/Nutrients/ADCP	Decommissioned
OL09 (Outside Dromineer Bay)	Water Quality/Nutrients/ADCP	Decommissioned
OL15 (Parkers Point)	Water Quality/Nutrients/ADCP	Decommissioned
OL19 (Parteen Basin)	Water Quality/ADCP	Decommissioned

1.3. Study Area

Lough Derg is an alkaline lake located on the River Shannon (**Figure 1**) between counties Clare, Tipperary and Galway. The main inflowing river is the Shannon which enters the lough at Portumna and flows out of the lake at the southern end at Killaloe. The lake is 40km long and 13km at it widest point. The majority of the lake lies on Carboniferous limestone with the exception of the narrow southern section which is underlain by Silurian strata. The surrounding catchment of the northern end of the lake is mainly flat agricultural land while the southern end of the lake is bordered by the Slieve Aughty Mountains to the west and the Arra Mountains to the east. The northern end of the lake has an average depth of 6m. Two deep trenches occur in the lake, one in the middle portion and one at the southern end with average depths of >34m and >25m respectively.

Under the WaterFramework Directive monitoring the lake is classified as mesotrophic with moderate water quality (Lough Derg Management Plan 2009 – 2015). Blue-green algae blooms of *Microcystis aeruginosa* are frequent occurrences during the summer months (*L. Vaughan, personal observation*). The lake is home to several invasive species including the invasive bivalve species the zebra mussel (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminea*). Several invasive macrophyte species have also been identified on the lake, these are Water Fern *Azolla filiculoides*, Canadian Pondweed *Elodea canadensis*, Nuttall's waterweed *Elodea nuttalli*, Water Violet *Hottonia palustris*, Common Duckweed *Lemna minuta*, and water soldier *Stratiotes aloides* (Minchin and Boelens 2011).

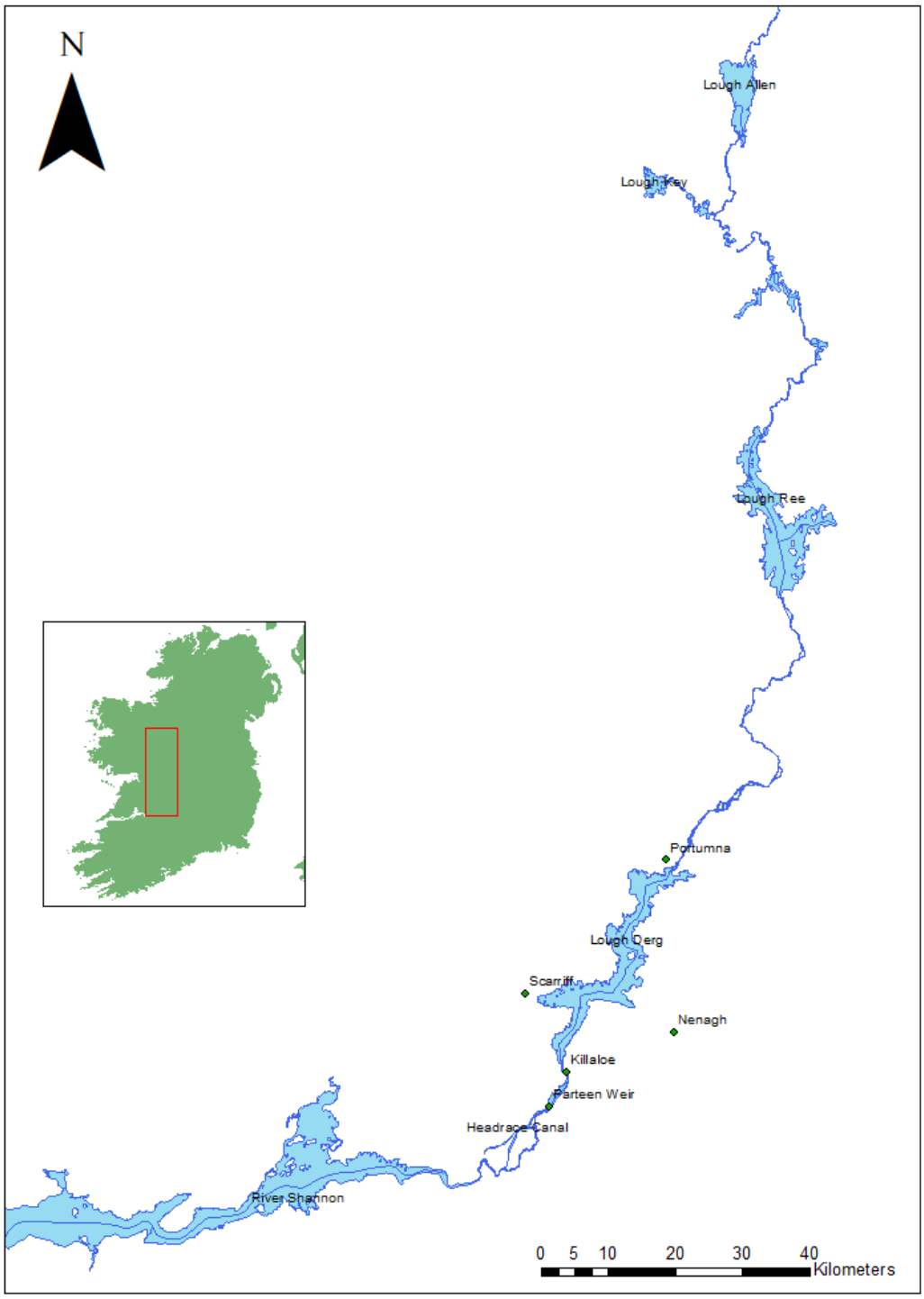


Figure 1: Shannon Catchment showing study area Lough Derg.

2. Results to date

2.1. T500 Water Quality Survey

2.1.1. In-situ sampling

Two in-situ nutrient analysers were deployed, one at an open lake site located near Parteen Weir and one on the inflowing River Shannon at Portumna Bridge (Appendix 2). **Figure *2*** and **Figure 3** show nutrient data from both sites from January 2019 – December 2019 with all data below the limit of detection removed. Many NO_2N and NH_3N values were below the limit of detection making observations on trends difficult. Both stations showed an increase in nitrate values in the early months of the year (January – March). Higher levels of nutrients is expected over the winter months due to higher levels of runoff from the catchment. OL19 showed a declining trend in nitrate values from May onwards coinciding with the beginning of the growing season in the lake and an uptake of dissolved nutrients by phytoplankton.

Water Quality Buoy on Lough Derg

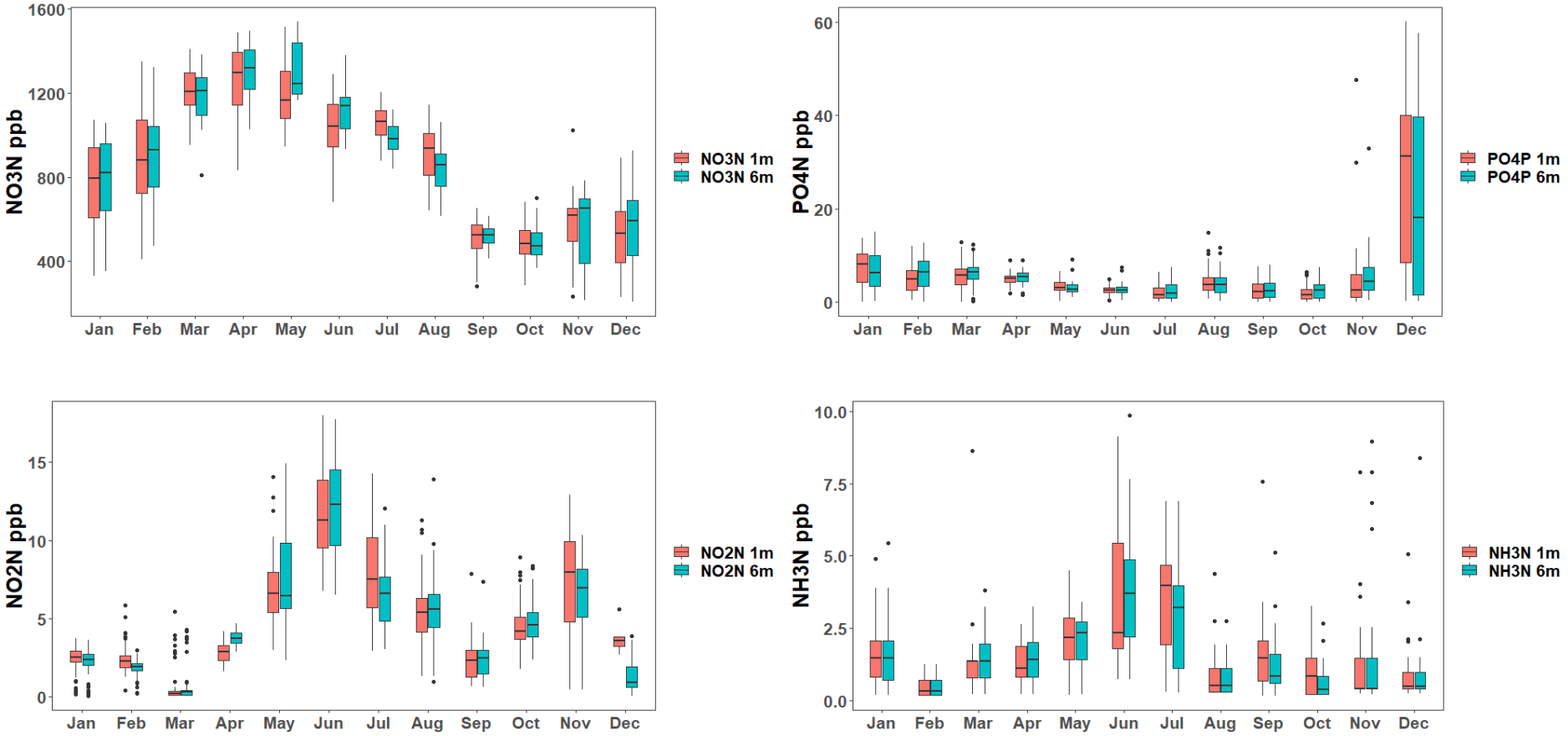


Figure 2: Nutrient Data from OL19 from January 2019 – December 2019 (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range. Outliers are marked by black points.

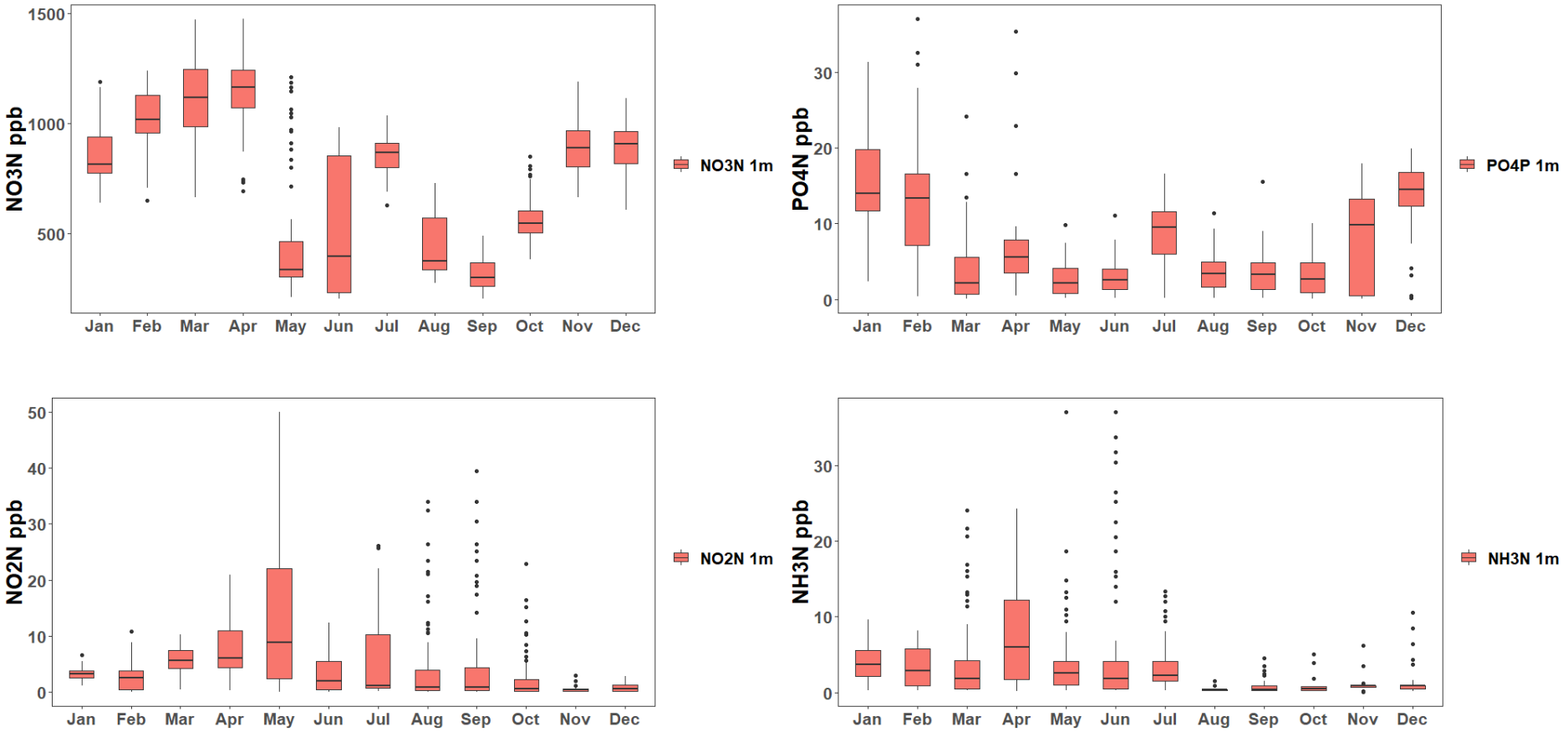


Figure 3: Nutrient Data from SS01 from January 2019 – December 2019 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range. Outliers are marked by black points.

2.1.2. Spot Sampling

The current spot sampling programme commenced in January 2018 and includes parameters for water quality only. **Table 3** details the parameters collected at each site under the water quality monitoring programme. Depending on the depth of the water column samples are taken at the surface, mid water depth and bottom depth (just above the lake bed). At shallow water site (< 5m) samples are taken at the surface and bottom depths. All lake sites showed similar patterns for all parameters measured across all depths. **Figure 4**, **Figure 5** and **Figure 6***:* show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate, BOD, temperature and chlorophyll *a* from water quality sites on Lough Derg at all depths. **Figure 7** shows the water quality data from all inflowing rivers into Lough Derg. As with previous years nitrate (NO_3)showed a peak at the start of the year before declining through the summer months, this trend was seen across all sites and depths. All lake sites showed similar patterns for all parameters measured across all depths. Lake nitrate and phosphate values showed a steady decline from January to October. Chlorophyll *a* values are low until April where an increase can be seen particularly in the surface samples. This coincides with increased water temperatures and indicates the start of the growing season in the lake. Highest levels of chlorophyll a were seen at sites WQMS 1 and WQMS 7. From September onwards a decline in chlorophyll *a* is seen correlating with a similar declines in water temperatures. The river parameters showed much more variability between sites, particularly for the nutrients NO_3 and PO_4P with WQMS 9 and WQMS 13 showing much higher NO_3 values than the other rivers. Both these sites are located on the eastern shore of the lake indicating a higher nutrient status on the eastern side of the catchment.

Table 3: List of parameters collected under the spot sampling programme.

Parameter	**Units**
Alkalinity, Total as $CaCO_3$	mg/l
Ammoniacal Nitrogen as NH_3	mg/l
Nitrate as NO_3	mg/l
Nitrite as NO_2	mg/l
Phosphate (Ortho as P)	mg/l
Suspended solids, Total	mg/l
BOD	mg/l
Chlorophyll *a*	µg/l
Temperature	ºC
Dissolved Oxygen %	%/mg/l
pH	pH units
Conductivity	µS/cm

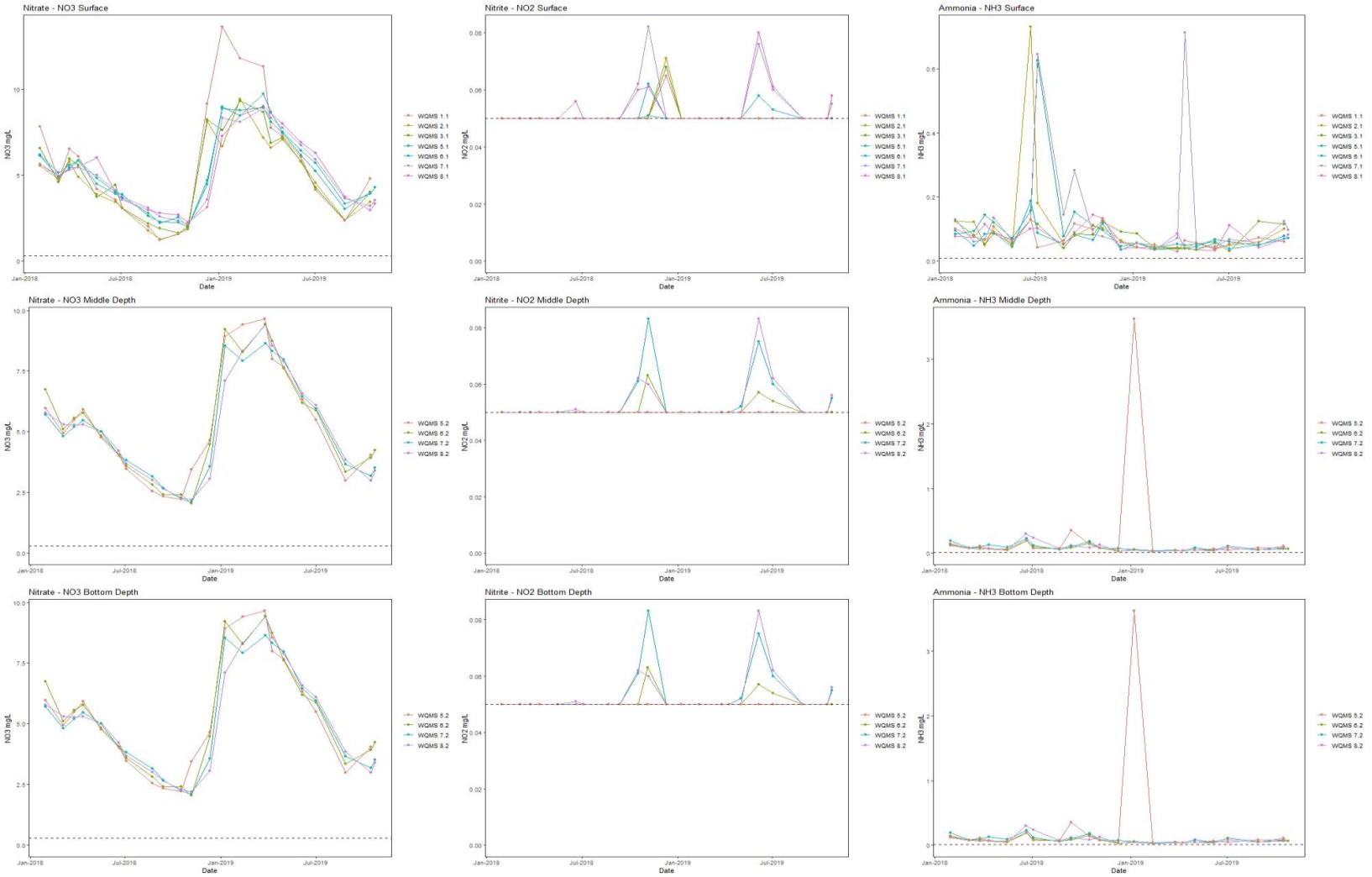


Figure 4: Survey results from all lake water quality sites of nitrate (NO3) nitrite (NO2), and ammonia (NH3) (Please note red dashed lines indicated limits of detection of analysis) from January 2019 – December 2019.

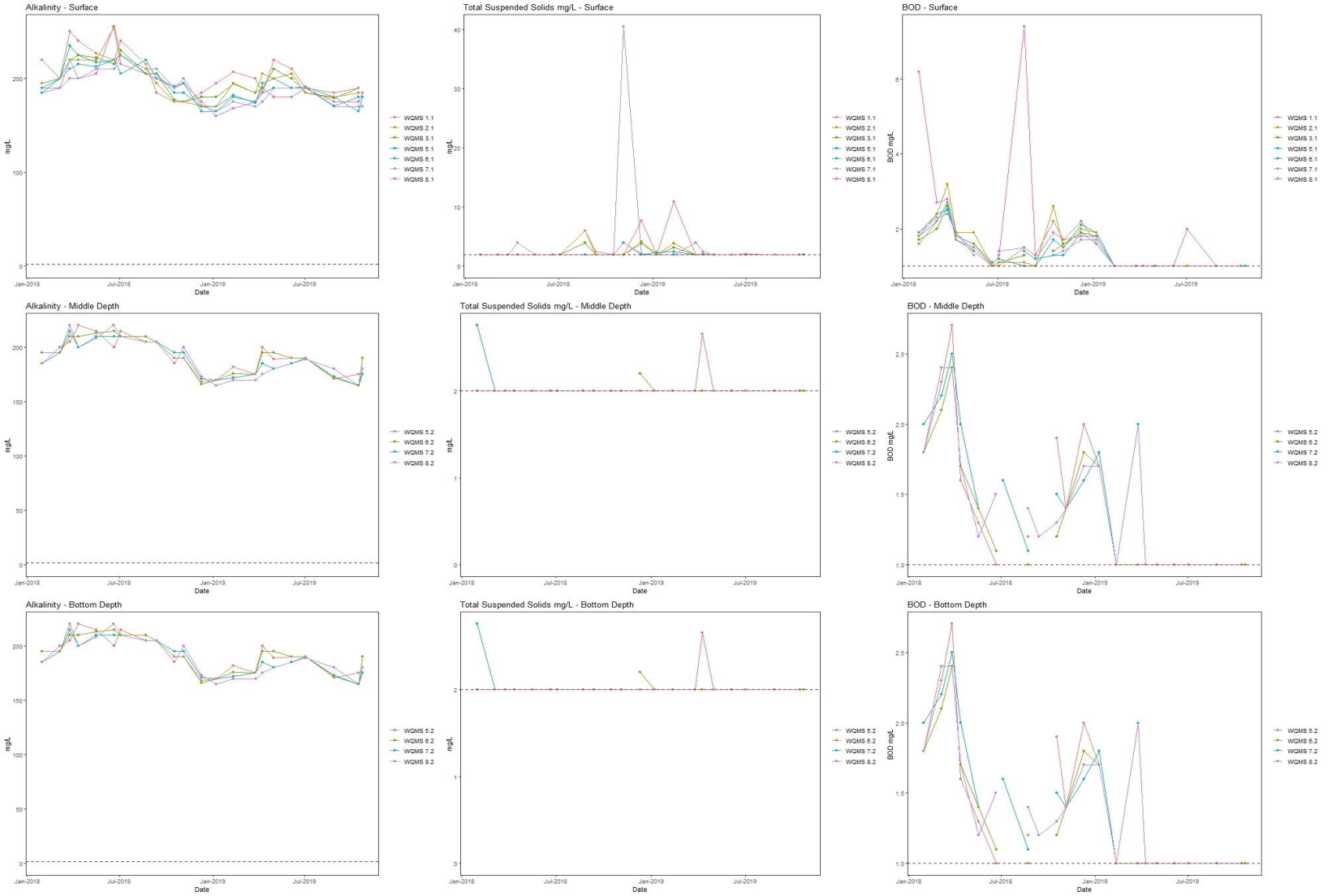


Figure 5: Survey results from all lake water quality sites of Alkalinity and Suspend Solids (Please note red dashed lines indicated limits of detection of analysis) from January 2019 – December 2019.

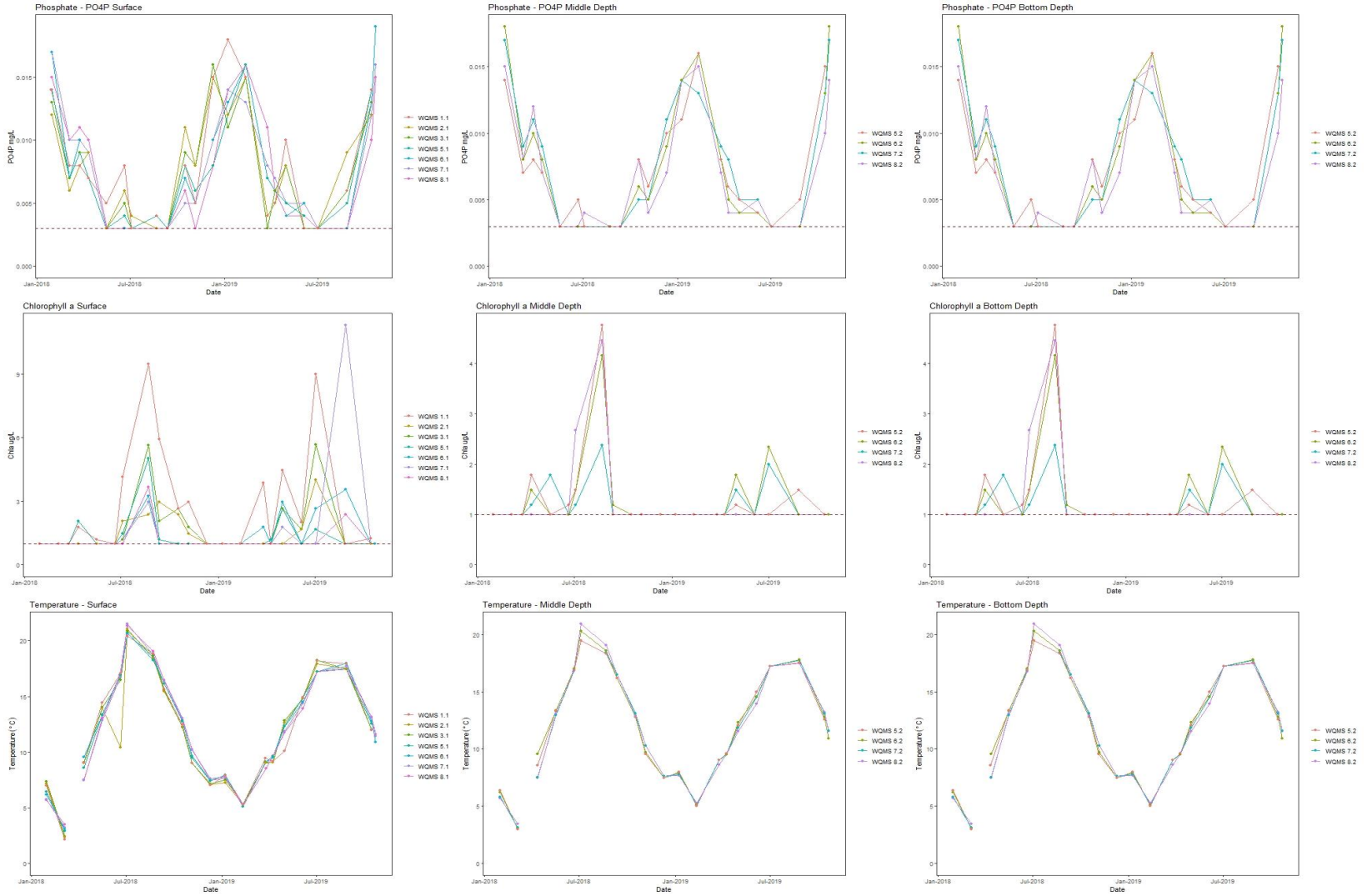


Figure 6: Survey results from all lake water quality sites of Chlorophyll a and Phosphate (PO4P) (Please note red dashed lines indicated limits of detection of analysis) from January 2019 – December 2019.

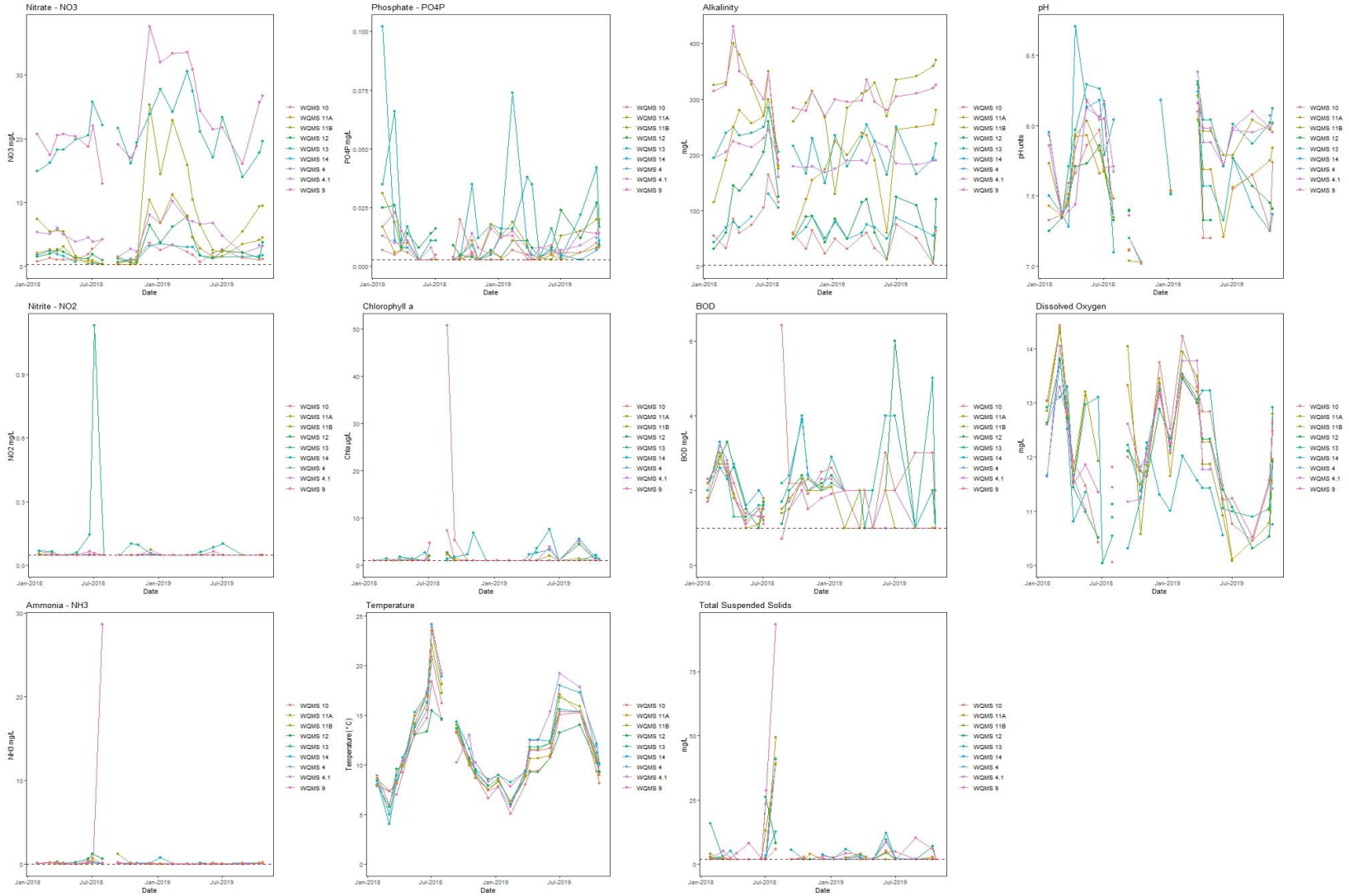


Figure 7: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll a and temperature, Alkalinity, pH, and Dissolved Oxygen (Please note red dashed lines indicated limits of detection of analysis) from January 2019 – December 2019.

2.2. T800 Meteorological Survey

Two meteorological stations were installed on the eastern and western shore of Lough Derg on the 17th/18th February 2016. Stations were deployed with sensors measuring wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity. Both stations showed similar patterns over 2019. Maximum 2019 air temperatures for stations were 23.2°C and 25°C at MS01 and MS02 respectively.

Figure 10: shows windrose diagrams for both met stations, the prevailing winds for both stations varied from westerly to south westerly. Wind direction for the MS01 (Ballinderry) was more variable than MS02 (Whitegate).

Whitegate Met Station

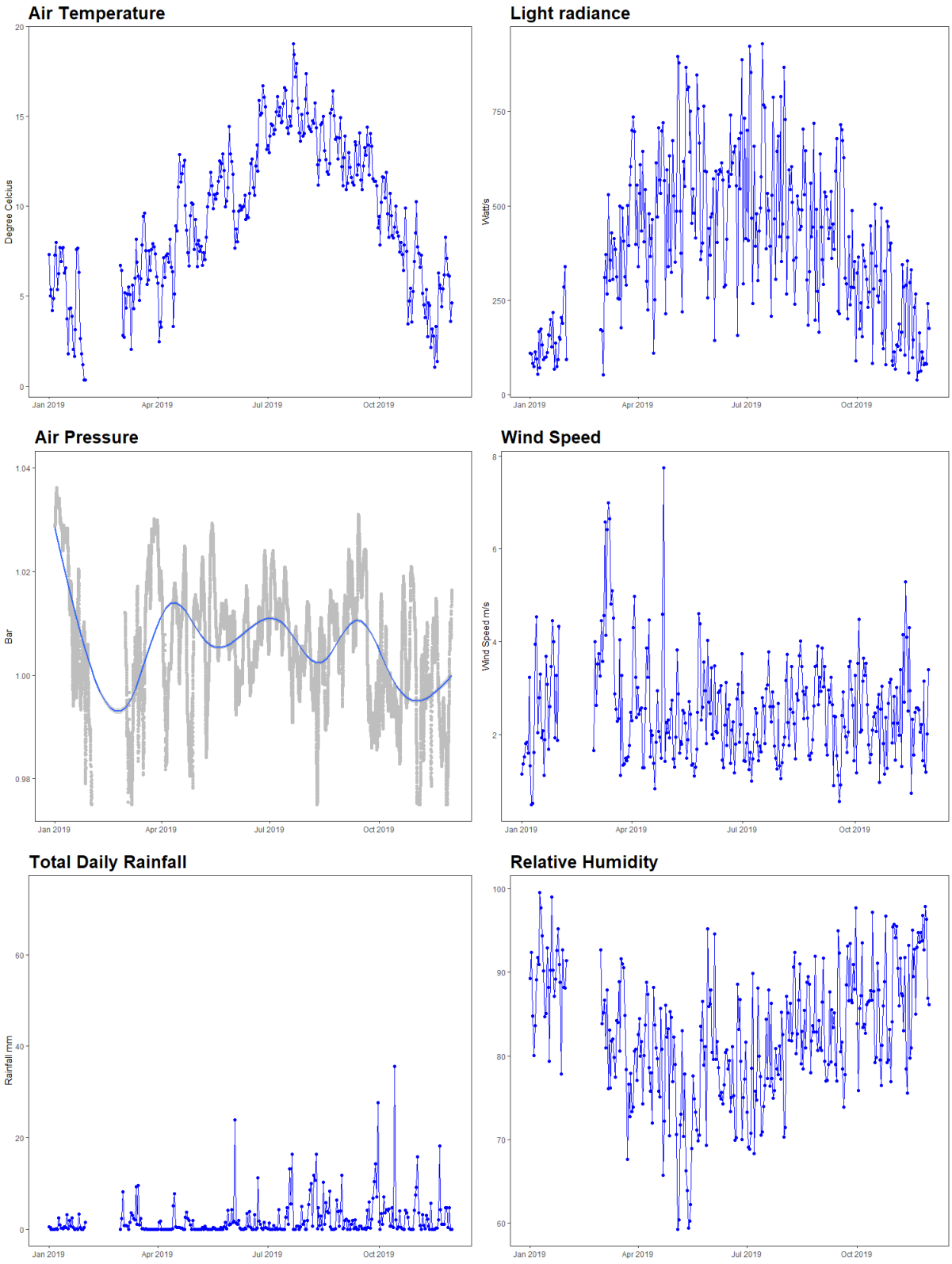


Figure 8: Data from MS01 (Ballinderry) from January 2019 – December 2019 (Air Pressure show observations with a loess smoother lines imposed, Light radiance (day time values only), Air Temperature, Wind Speed and Relative Humidity show daily average values).

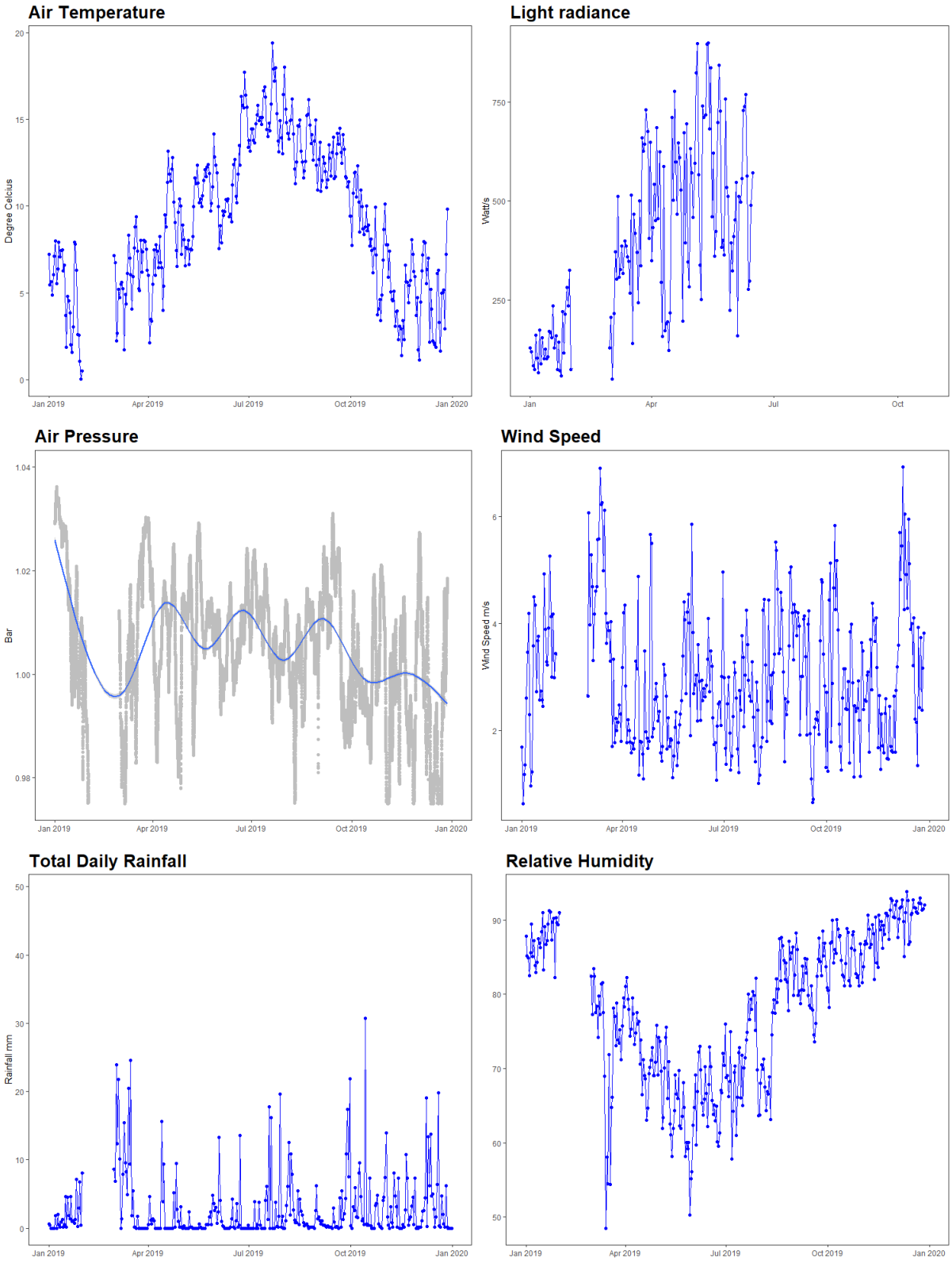
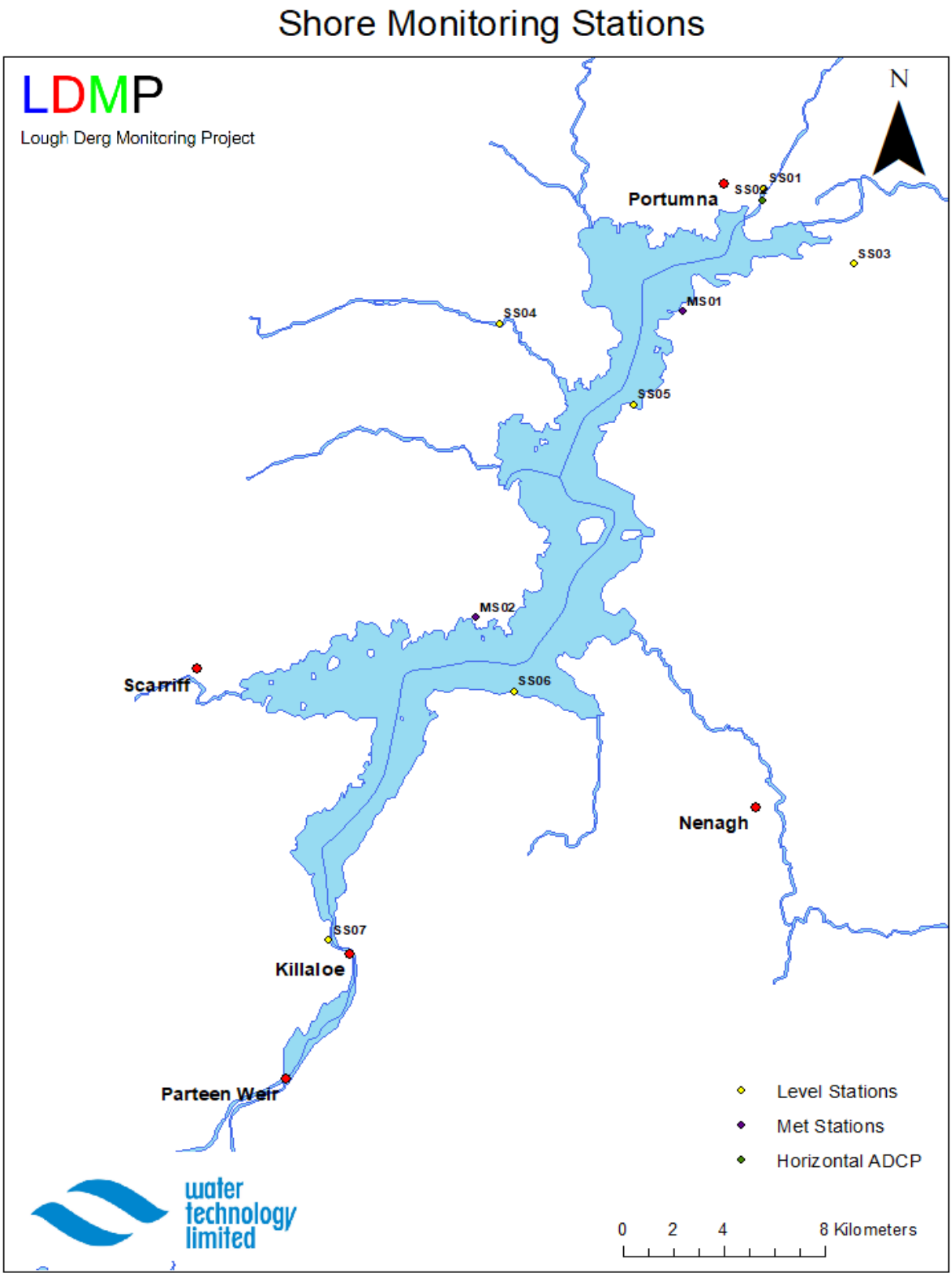


Figure 9: Data from MS02 (Whitegate) from January 2019 – December 2019 (Air Pressure show observations with a loess smoother lines imposed, Light radiance (day time values only), Air Temperature, Wind Speed and Relative Humidity show daily average values).

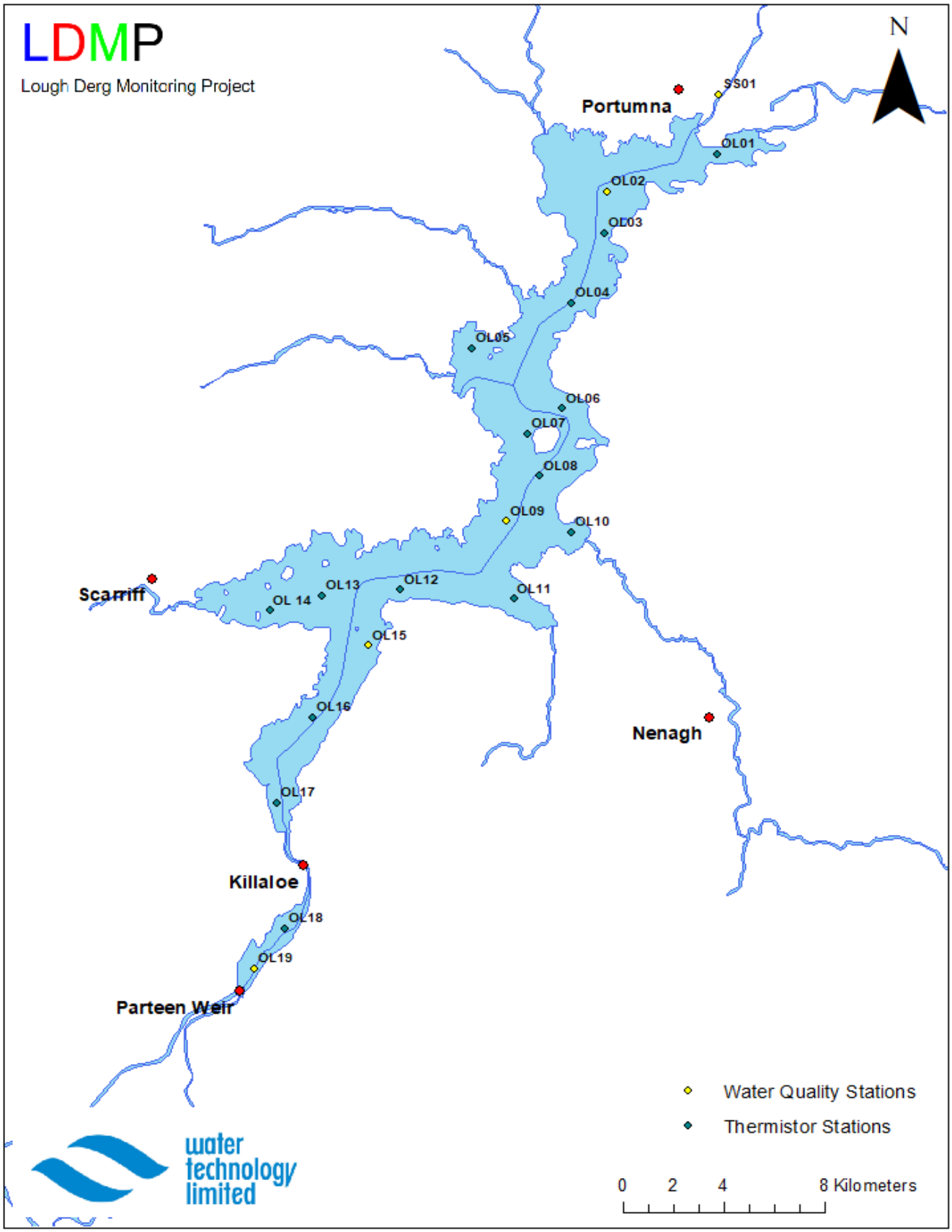
Figure 10: Windrose Diagram for Whitegate MS02 (right pane) and Ballinderry MS01 (left pane) weather stations from January 2019 – December 2019.

3. Appendices

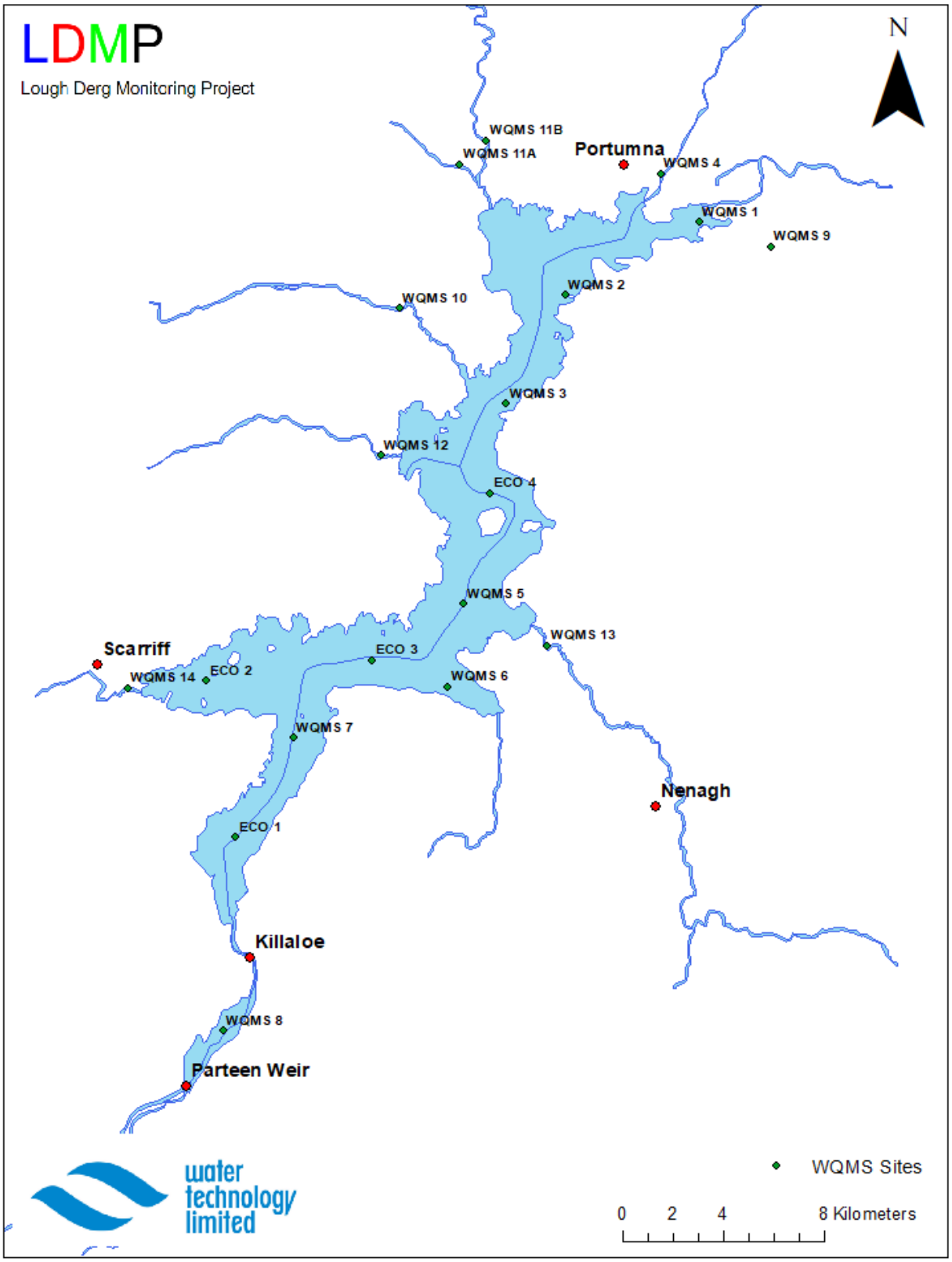
Appendix 1: Maps showing original survey site locations.



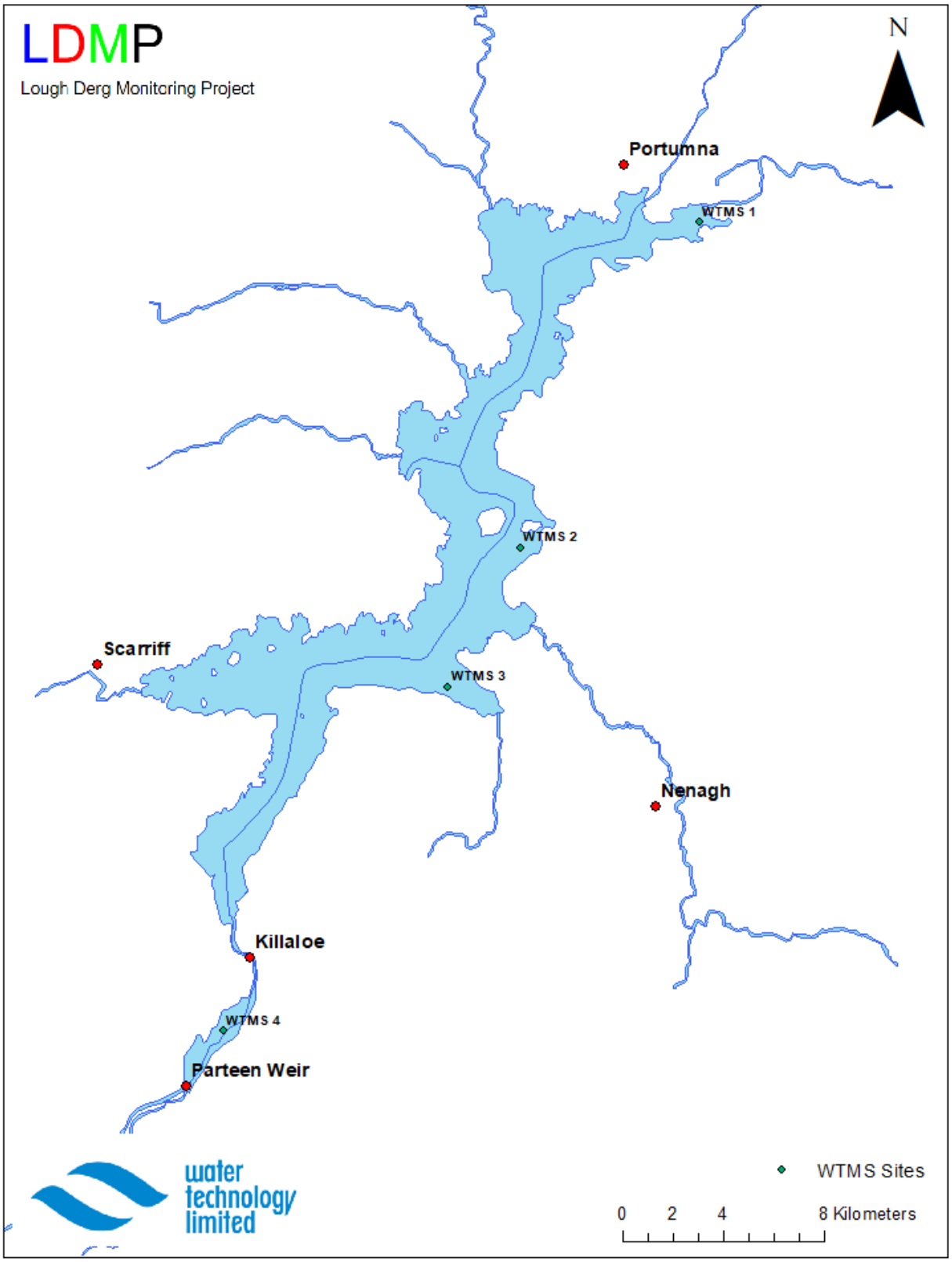
Open Water Monitoring Stations



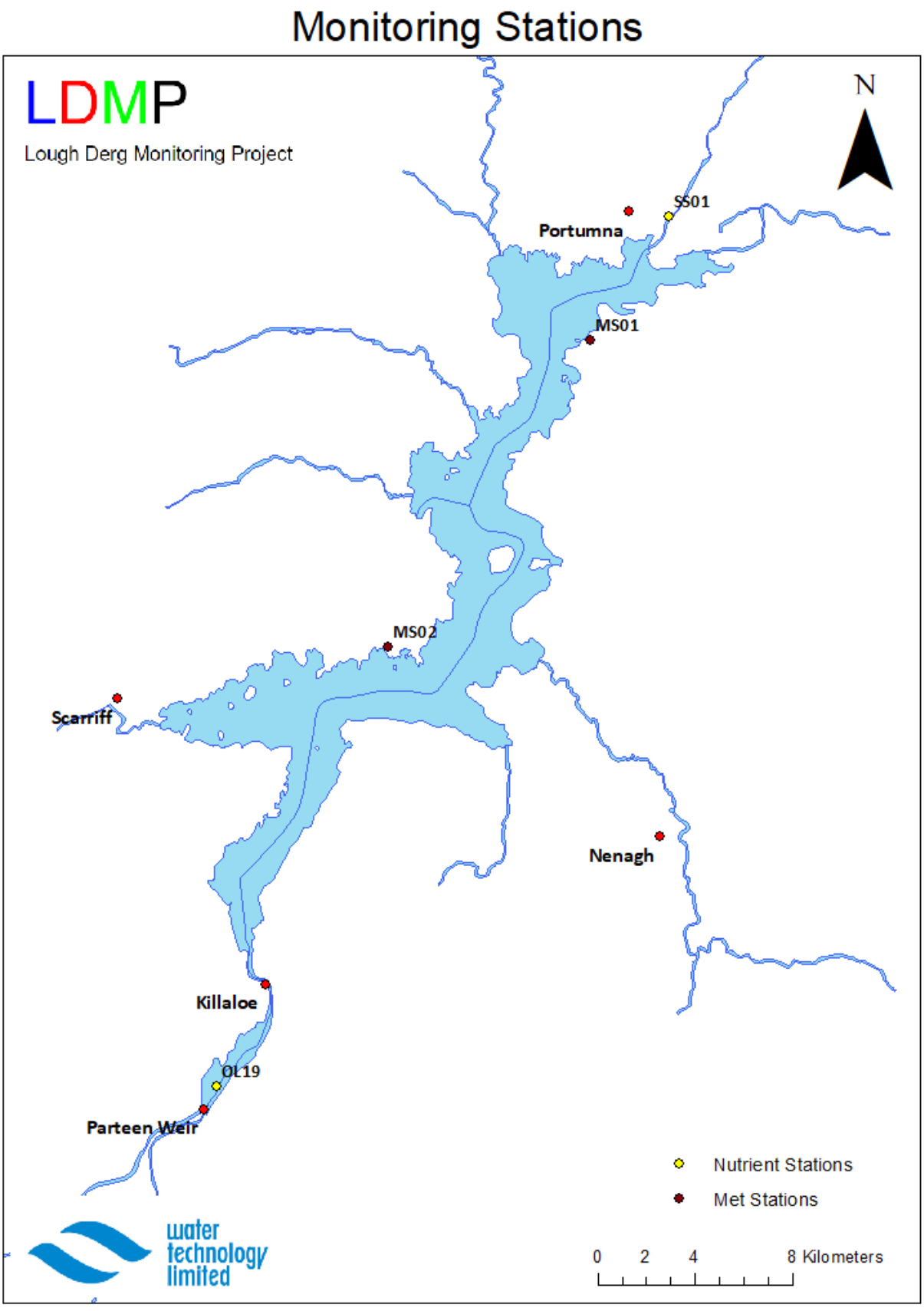
Water Quality Monitoring Site Locations



Water Treatability Monitoring Site Locations



Appendix 2: Maps showing current survey monitoring site locations.



4. References

Minchin, D. and R. Boelens (2011). "The Distribution and Expansion of Ornamental Plants on the Shannon Navigation." Biology and Environment-Proceedings of the Royal Irish Academy **Vol IIIB**(3): 1-9.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

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Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
Document Title:	**Data report for Lough Derg Monitoring Project (Annual Report 2020)**
Document Number:	**LDMP/R/27**
Text Pages:	**25**

water technology limited

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Figure 3: Nutrient Data from SS01 from January 2020 – December 2020 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range. Outliers are marked by black points. 10

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1. Introduction

1.1. Lough Derg Monitoring Project

Irish Water, via a transferred contract originally procured by Dublin City Council, have engaged Jacobs-Tobin ("the Main Consultant") to provide consultancy services in respect of the Water Supply Project-Dublin Region (WSP-DR) ("the Project"), which is a strategic national project. The overall aim of the Project is to ensure that, in combination with other projects within the Greater Dublin Area (GDA), the long-term (2050+) water supply needs of the Dublin Region (Water Supply Area) are met in a sustainable manner. Jacobs-Tobins have engaged Water Technology Ltd to complete an environmental survey of Lough Derg and its surrounding catchment. Table 1 gives a breakdown of all aspects of the survey. **Appendix *1*** shows the locations of all sites from the original survey.

Table 1: Lough Derg Monitoring Project, Initial Specification of Works.

Work Area	Title	Equipment
T300	Water Flow and Current Survey	4 Acoustic Doppler Current Profilers installed (1 horizontal on River Shannon inflow and 3 vertical on the lake).
T400	Water Level Survey	6 water level recorders installed (3 on inflowing rivers and 3 on lake).
T500	Water Quality Survey	5 moored sampling stations. Spot sampling at 8 sample sites on the lake and 7 river sites in the surrounding catchment.
T600	Water Treatability Survey	Spot sampling at 4 locations on the lake for 12 months followed by spot sampling at 1 site.
T700	Temperature Survey	Thermistor chains installed at 20 locations on the lake.
T800	Meteorological Survey	2 Meteorological Stations are to be deployed to measure wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity and compass.
T900	Plankton Survey	Phytoplankton and zooplankton samples to be taken at 11 sites on the lake over a 12 month period.

1.2. Site decommissioning

The temperature survey (T700) of the Lough Derg monitoring project completed on 31/10/2017. Fifteen thermistor sites were decommissioned and all equipment was removed from the lake. As per client instruction the vertical Acoustic Doppler Current Profiler (ADCP) was removed from the site at OL15 (below Parkers Point) was moved to OL19 (Parteen Basin). The new ADCP site was confirmed operational on 04/02/2018.

The main phase of the project ended on the 30th July 2018 with most sites decommissioned by this date. A reduced sampling programme was introduced with only the two weather stations and two nutrient analysers being maintained going forward. The spot sampling programme will also continue on a monthly basis. Locations of current stations can be seen in **Appendix 2**.

Table 2: Status of remaining LDMP stations as of 30th July 2018.

Station	Station Type	Status
MS01 (Ballinderry)	Weather Station	Live
MS02 (Whitegate)	Weather Station	Live
OL19 (Parteen Basin)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Level Station/Water Quality	Decommissioned
SS02 (Portumna River)	Horizontal ADCP	Decommissioned
SS03 (Carraigahorig River)	Level Station	Decommissioned
SS04 (Woodford River)	Level Station	Decommissioned
SS05 (Coolbaun)	Level Station	Decommissioned
SS06 (Garrykennedy)	Level Station	Decommissioned
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OL02 (North of lake)	Water Quality/Nutrients/ADCP	Decommissioned
OL09 (Outside Dromineer Bay)	Water Quality/Nutrients/ADCP	Decommissioned
OL15 (Parkers Point)	Water Quality/Nutrients/ADCP	Decommissioned
OL19 (Parteen Basin)	Water Quality/ADCP	Decommissioned

1.3. Covid 19

The emergence of the novel strain of coronavirus (Covid 19) and subsequent national lockdown due to the pandemic caused significant disruption to the sampling and servicing programme. Access to the weather stations at Ballinderry and Whitegate for servicing was discontinued from 25/03/2020 to 14/08/2020. Data from this time period should be viewed with caution.

1.4. Study Area

Lough Derg is an alkaline lake located on the River Shannon (**Figure 1**) between counties Clare, Tipperary and Galway. The main inflowing river is the Shannon which enters the lough at Portumna and flows out of the lake at the southern end at Killaloe. The lake is 40km long and 13km at it widest point. The majority of the lake lies on Carboniferous limestone with the exception of the narrow southern section which is underlain by Silurian strata. The surrounding catchment of the northern end of the lake is mainly flat agricultural land while the southern end of the lake is bordered by the Slieve Aughty Mountains to the west and the Arra Mountains to the east. The northern end of the lake has an average depth of 6m. Two deep trenches occur in the lake, one in the middle portion and one at the southern end with average depths of >34m and >25m respectively.

Under the WaterFramework Directive monitoring the lake is classified as mesotrophic with moderate water quality (Lough Derg Management Plan 2009 – 2015). Blue-green algae blooms of *Microcystis aeruginosa* are frequent occurrences during the summer months (*L. Vaughan, personal observation*). The lake is home to several invasive species including the invasive bivalve species the zebra mussel (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminea*). Several invasive macrophyte species have also been identified on the lake, these are Water Fern *Azolla filiculoides*, Canadian Pondweed *Elodea canadensis*, Nuttall's waterweed *Elodea nuttalli*, Water Violet *Hottonia palustris*, Common Duckweed *Lemna minuta*, and water soldier *Stratiotes aloides* (Minchin and Boelens 2011).

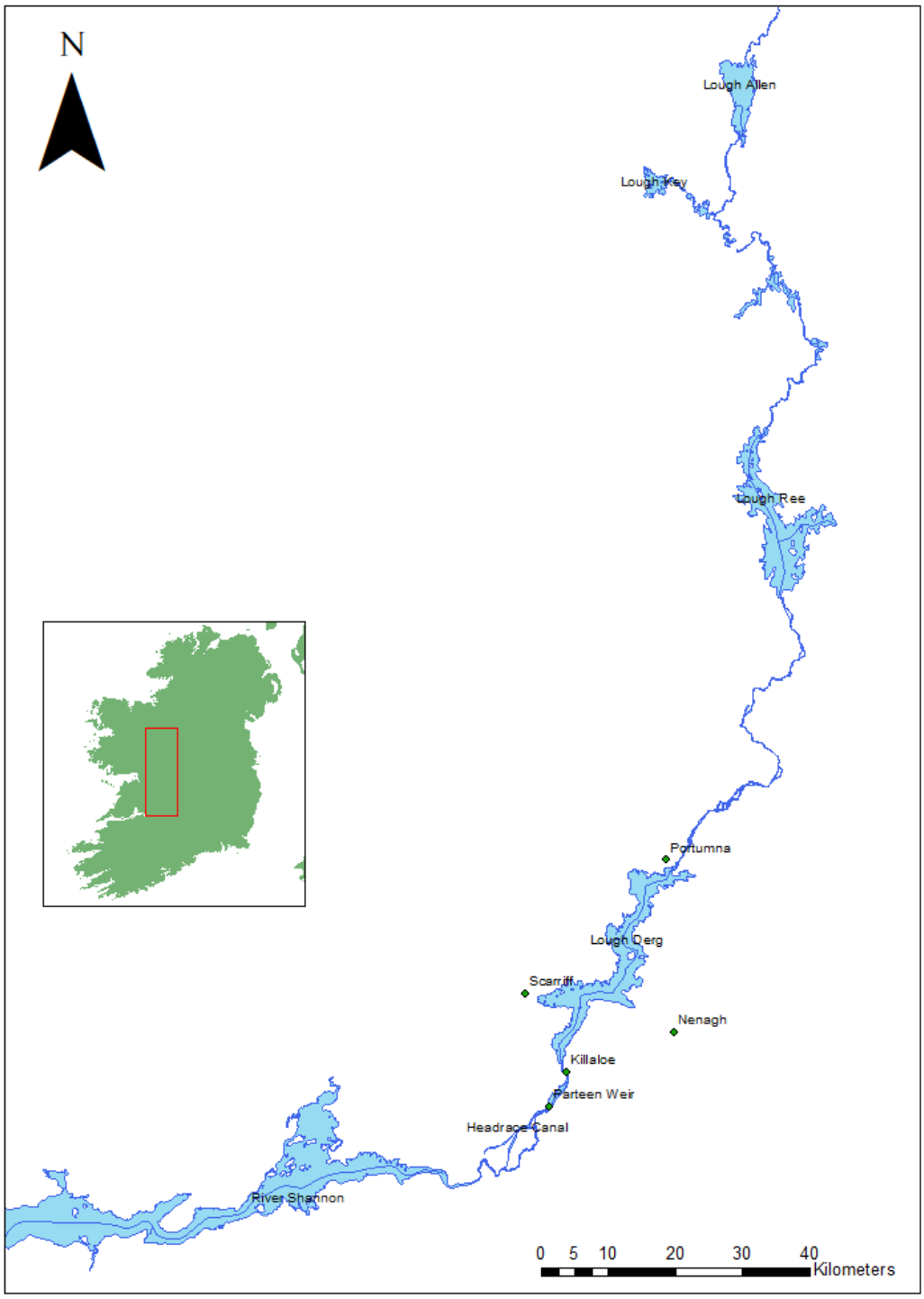


Figure 1: Shannon Catchment showing study area Lough Derg.

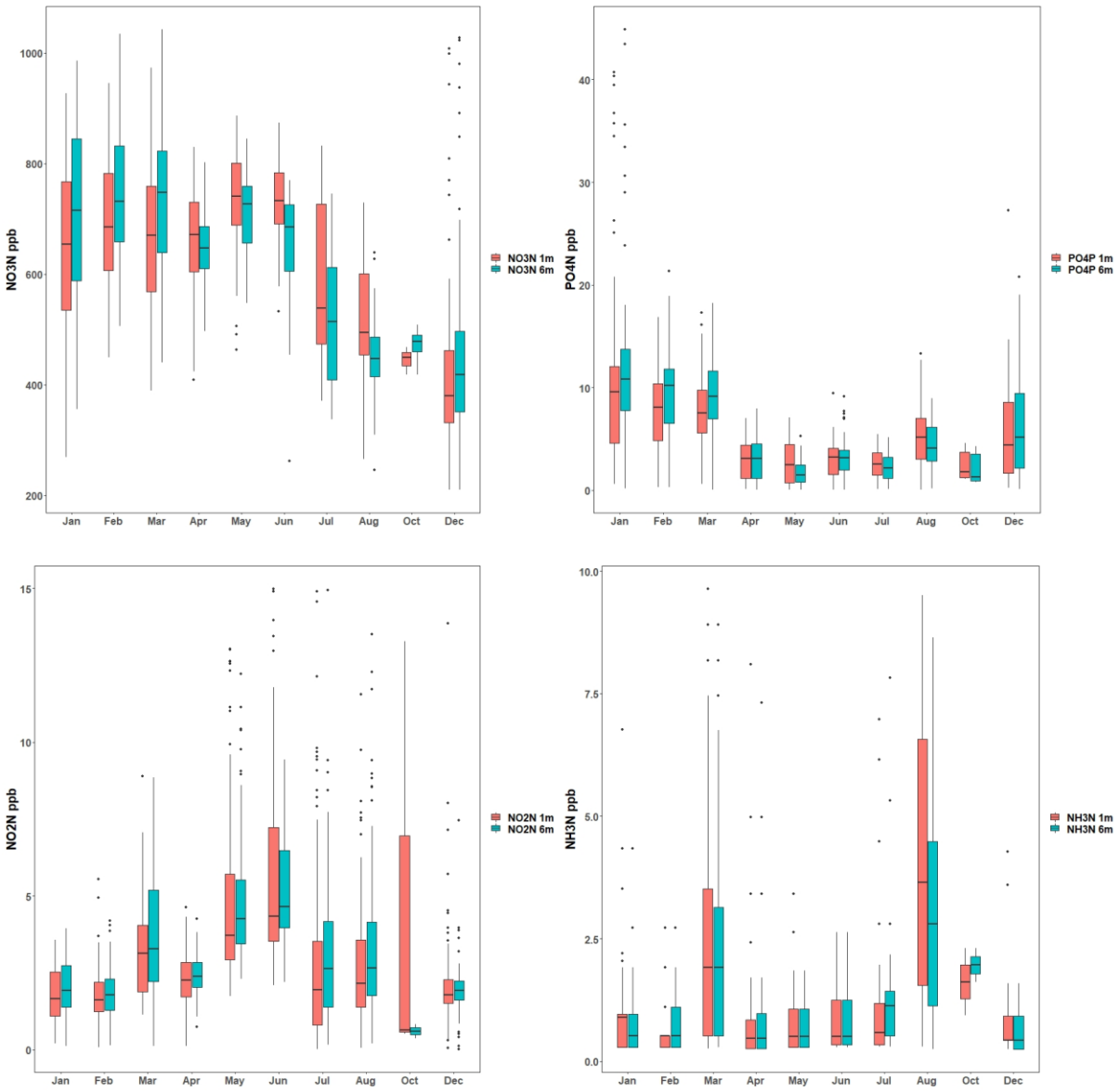
2. Results to date

2.1. T500 Water Quality Survey

2.1.1. In-situ sampling

Two in-situ nutrient analysers were deployed, one at an open lake site located near Parteen Weir and one on the inflowing River Shannon at Portumna Bridge (Appendix 2). **Figure *2*** and **Figure 3** show nutrient data from both sites from January 2020 – December 2020 with all data below the limit of detection removed. Many NO_2N and NH_3N values were below the limit of detection making observations on trends difficult. A malfunction in the instrument meant there were no nutrient values from OL19 in September. Higher levels of NO3N were seen in the months January – June. This was followed by a decline from July onwards. Declining nutrients is to be expected with increased primary production in the lake over the summer months. Higher levels of nutrients is expected over the winter months due to higher levels of runoff from the catchment with higher rainfall. PO_4P showed an earlier decline in values than NO_3N with values declining from April onwards at both stations.

Water quality monitoring buoy on the lake



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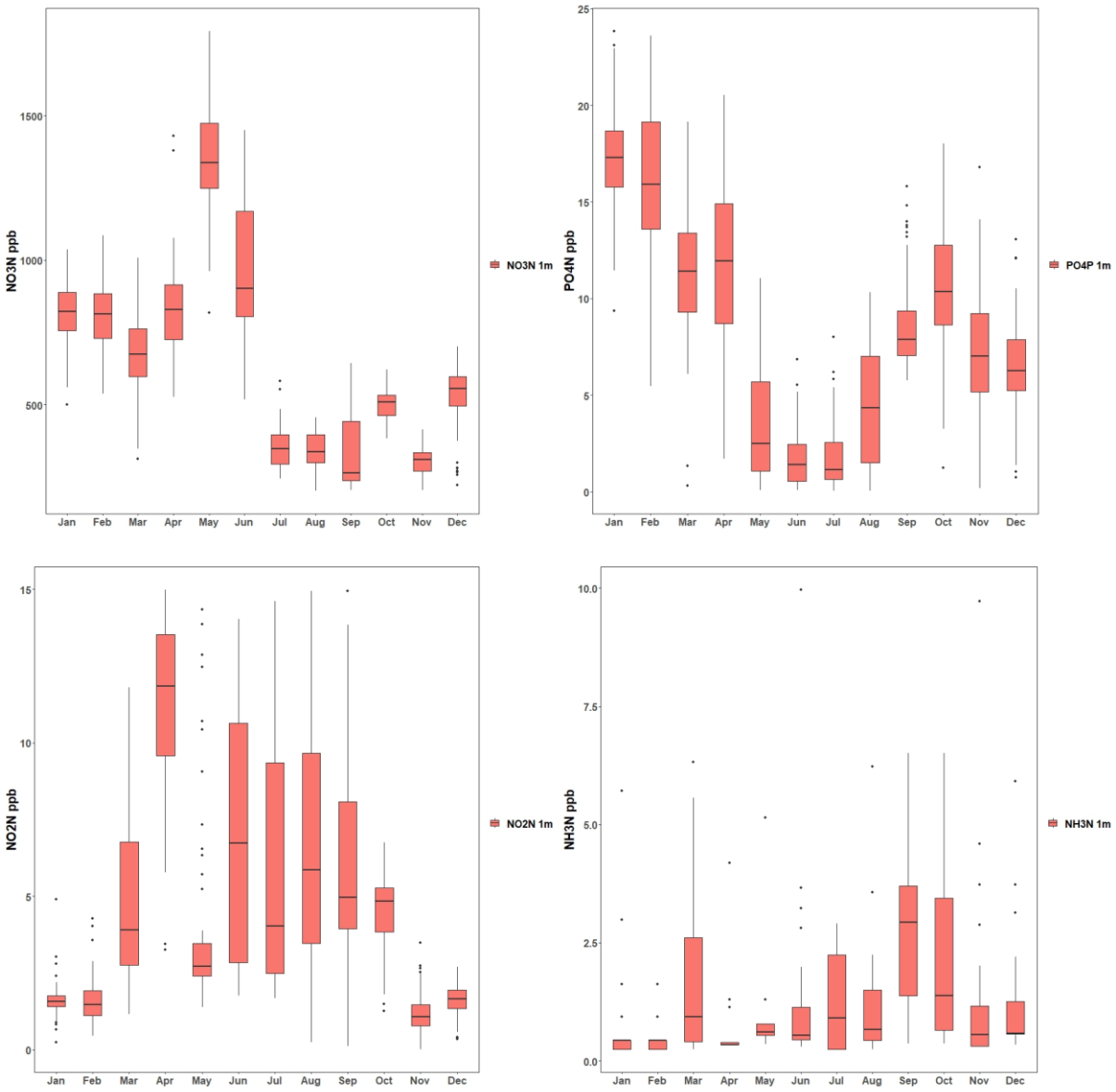

Figure 3: Nutrient Data from SS01 from January 2020 – December 2020 with loess smoother lines imposed (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range. Outliers are marked by black points.

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The current spot sampling programme commenced in January 2018 and includes parameters for water quality only. **Table 3** details the parameters collected at each site under the water quality monitoring programme. Depending on the depth of the water column samples are taken at the surface, mid water depth and bottom depth (just above the lake bed). At shallow water site (< 5m) samples are taken at the surface and bottom depths. All lake sites showed similar patterns for all parameters measured across all depths. **Figure 4**, **Figure 5** and **Figure 6***:* show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate, BOD, temperature and chlorophyll *a* from water quality sites on Lough Derg at all depths. **Figure 7** shows the water quality data from all inflowing rivers into Lough Derg. As with previous years nitrate (NO_3)showed a peak at the start of the year before declining through the summer months, this trend was seen across all sites and depths. All lake sites showed similar patterns for all parameters measured across all depths. NO_3 values from Quarter 1 (Jan-Mar) were lower in 2020 (6.33mg/L) than in 2019 (9.04mg/L). Lake nitrate and phosphate values showed a steady decline from January to October. Chlorophyll *a* values are low until April where an increase can be seen particularly in the surface samples. This coincides with increased water temperatures and indicates the start of the growing season in the lake. Highest levels of chlorophyll a were seen at sites WQMS 1 and WQMS 3 in August. From September onwards a decline in chlorophyll *a* is seen correlating with a similar declines in water temperatures. The river parameters showed much more variability between sites, particularly for the nutrients NO_3 and PO_4P with WQMS 9 and WQMS 13 showing much higher NO_3 values than the other rivers. Both these sites are located on the eastern shore of the lake indicating a higher nutrient status on the eastern side of the catchment.

Table 3: List of parameters collected under the spot sampling programme.

Parameter	**Units**
Alkalinity, Total as $CaCO_3$	mg/l
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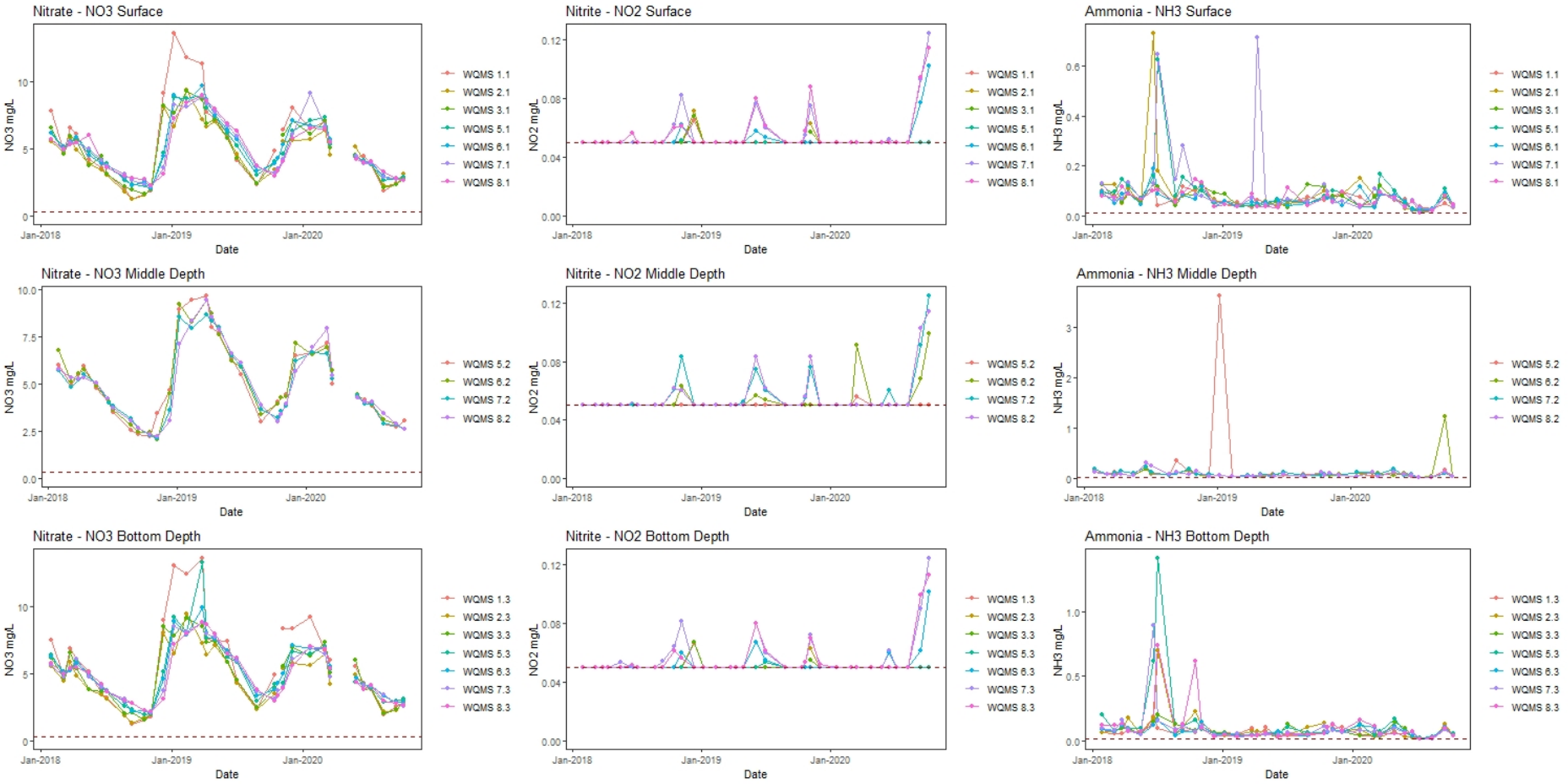
Nitrate as NO_3	mg/l
Nitrite as NO_2	mg/l
Phosphate (Ortho as P)	mg/l
Suspended solids, Total	mg/l
BOD	mg/l
Chlorophyll *a*	µg/l
Temperature	ºC
Dissolved Oxygen %	%/mg/l
pH	pH units
Conductivity	µS/cm



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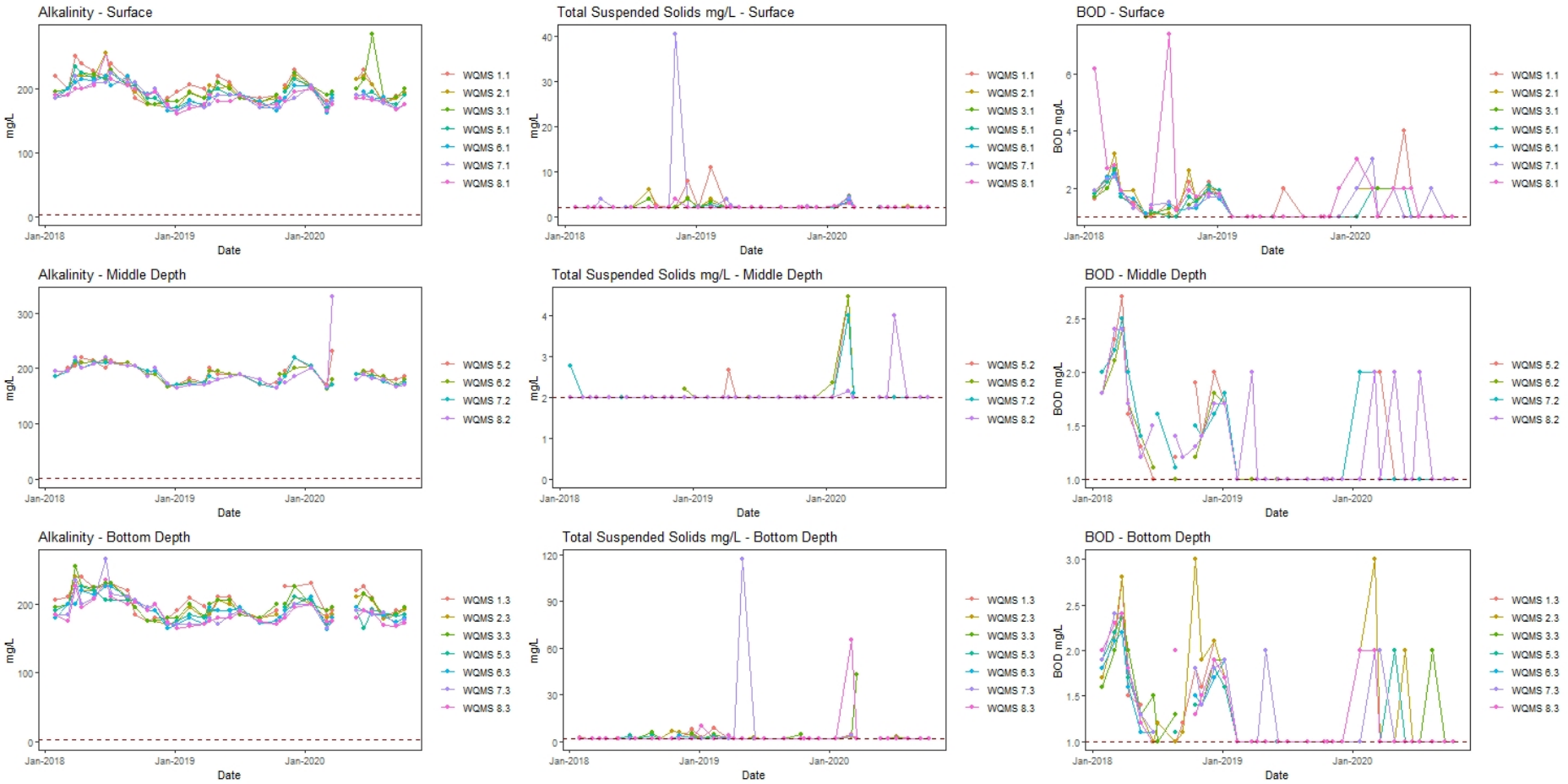


Figure 5: Survey results from all lake water quality sites of alkalinity, suspended solids and BOD (Please note red dashed lines indicated limits of detection of analysis) from January 2019 – December 2020.

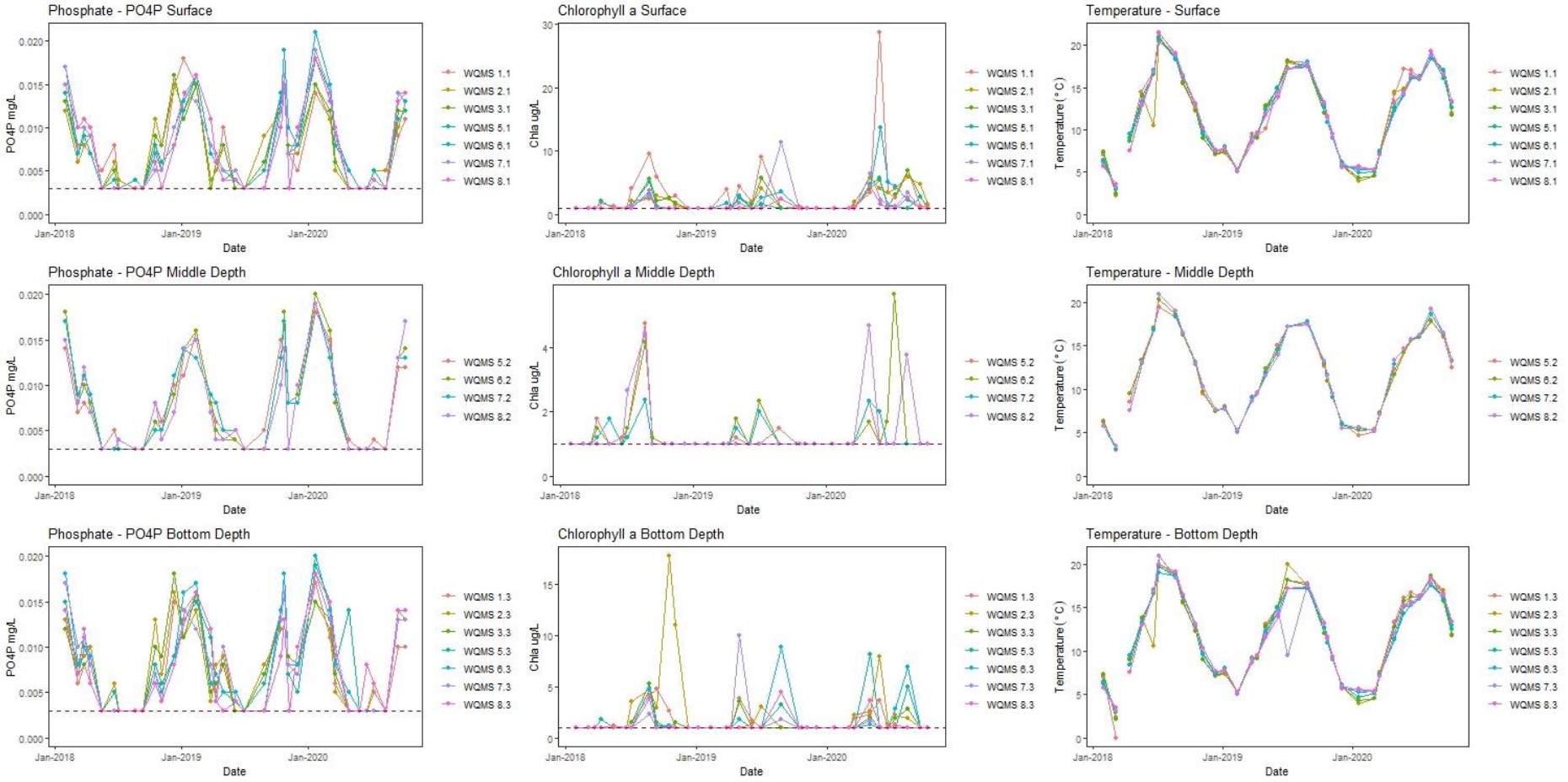


Figure 6: Survey results from all lake water quality sites of chlorophyll a, phosphate (PO4P) and temperature (Please note red dashed lines indicated limits of detection of analysis) from January 2019 – December 2020.

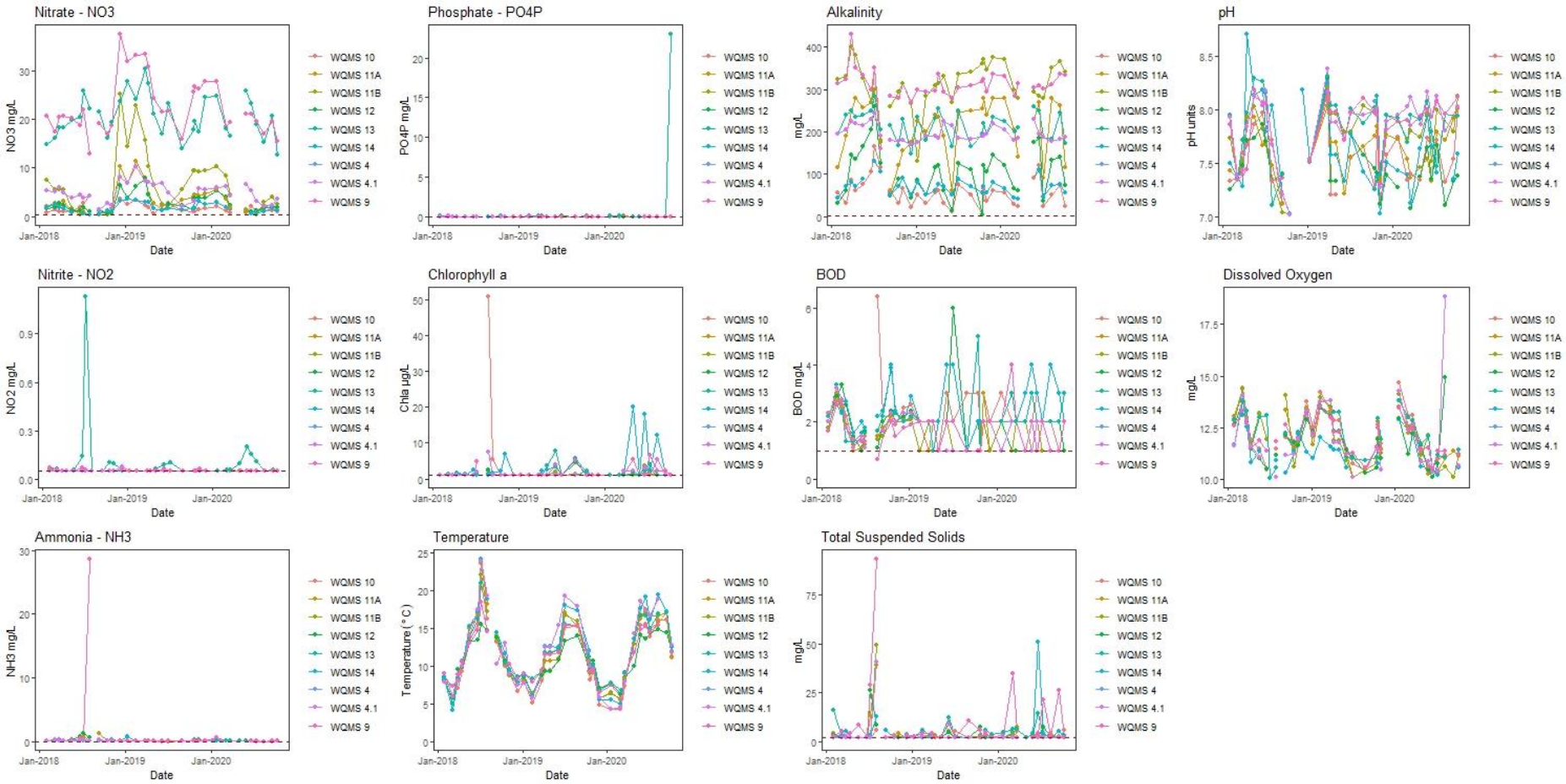


Figure 7: Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll a, temperature, alkalinity, BOD, total suspended solids, pH and dissolved oxygen (Please note red dashed lines indicated limits of detection of analysis) from January 2019 – December 2020.

2.2. T800 Meteorological Survey

Two meteorological stations were installed on the eastern and western shore of Lough Derg on the 17th/18th February 2016. Stations were deployed with sensors measuring wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity. Restrictions put in place by the client due to the Covid 19 pandemic meant that neither weather station could be serviced from March 2020 to August 2020. All values for the stations from this time period should be treated as suspect. In particular average daily irradiance values from both stations show a noticeable decline over this period and both rain gauges were blocked upon return to regular scheduled servicing. Both stations showed similar patterns over 2020. Maximum 2020 air temperatures for stations were 24.9°C and 27.2°C at MS01 and MS02 respectively. **Figure 10:** shows windrose diagrams for both met stations, the prevailing winds for both stations varied from westerly to southerly.

Ballinderry Met Station (MS1)

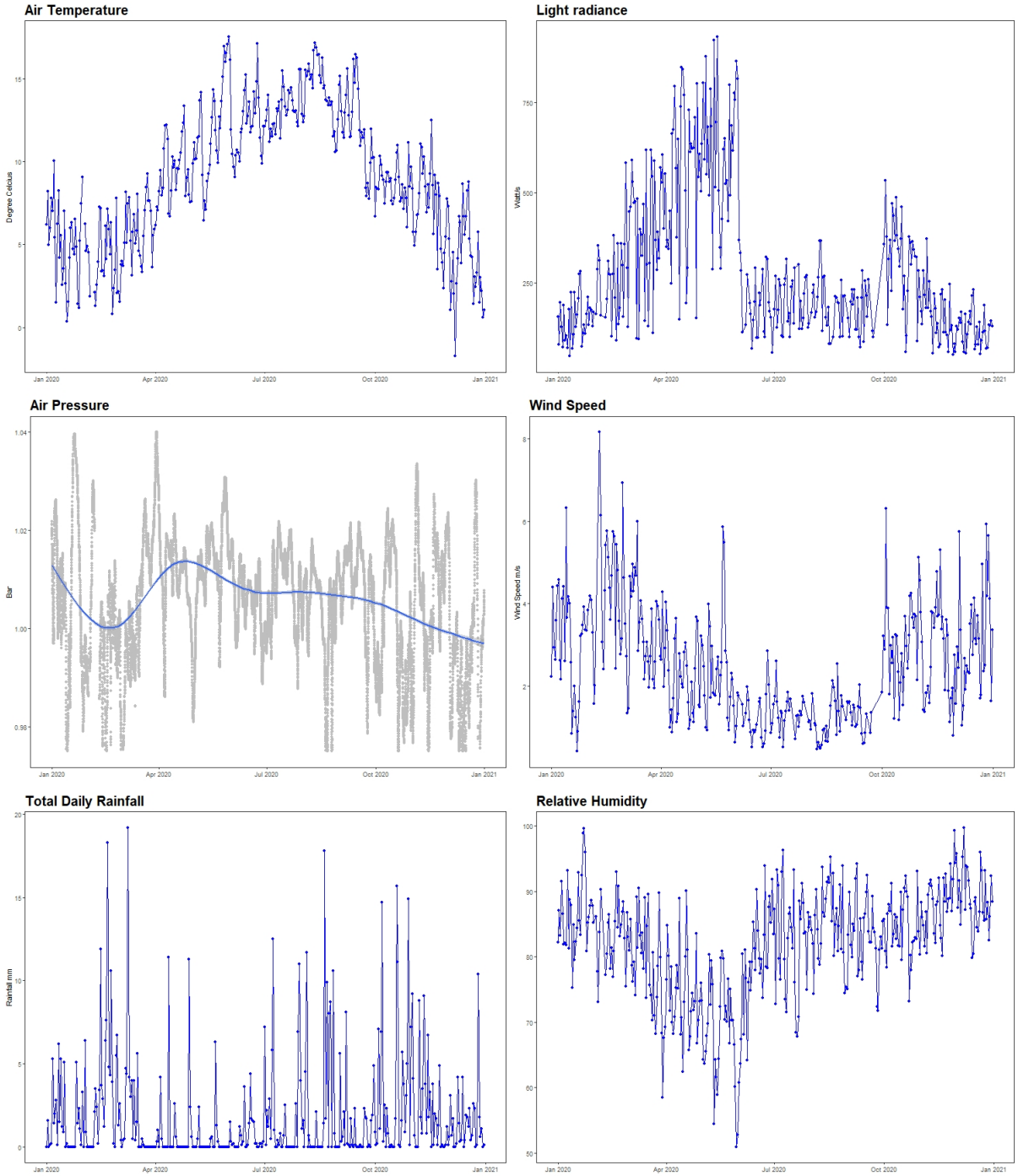


Figure 8: Data from MS01 (Ballinderry) from January 2020 – December 2020 (Air Pressure show observations with a loess smoother lines imposed, Light radiance (day time values only), Air Temperature, Wind Speed and Relative Humidity show daily average values).

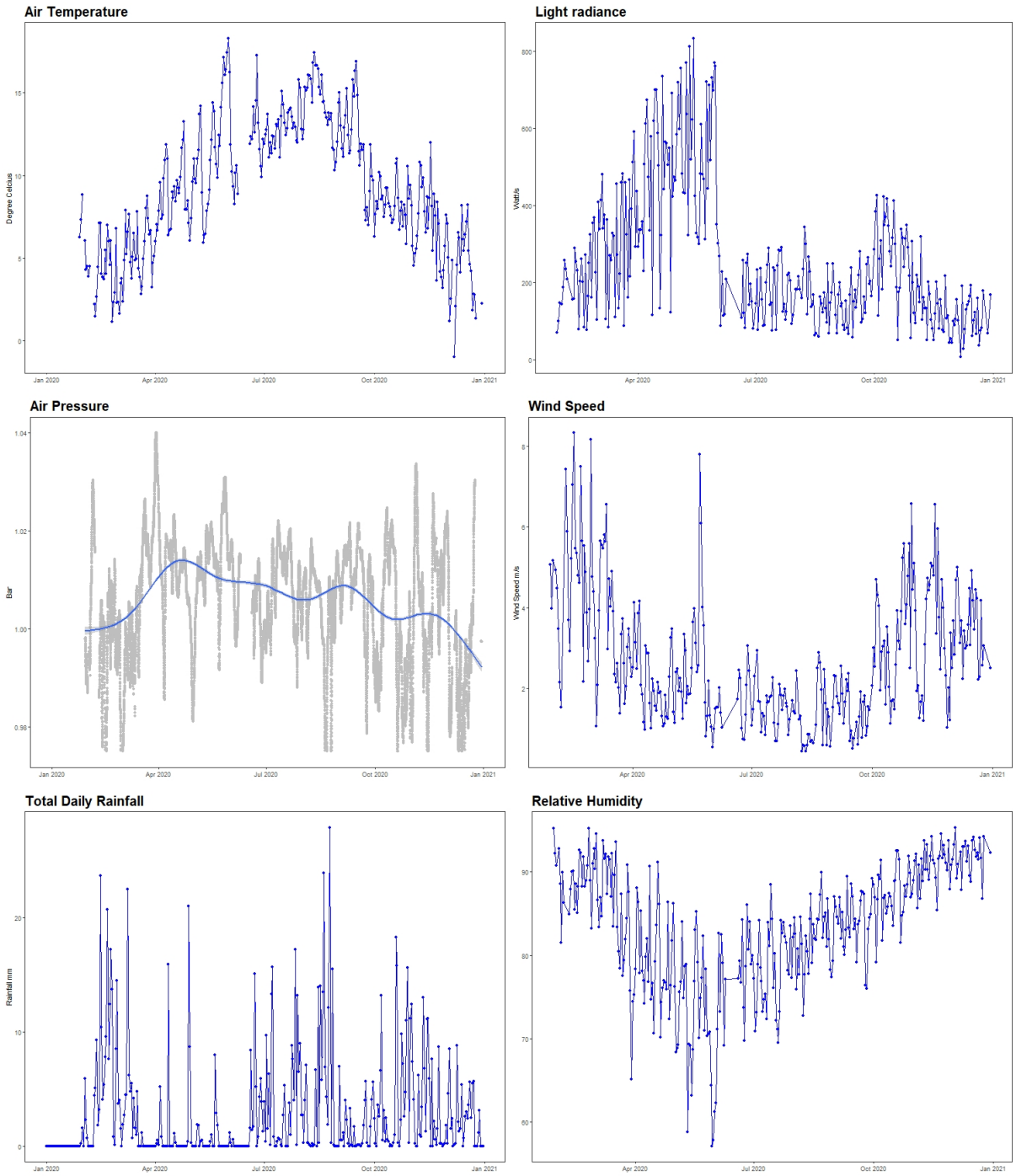


Figure 9: Data from MS02 (Whitegate) from January 2020 – December 2020 (Air Pressure show observations with a loess smoother lines imposed, Light radiance (day time values only), Air Temperature, Wind Speed and Relative Humidity show daily average values).

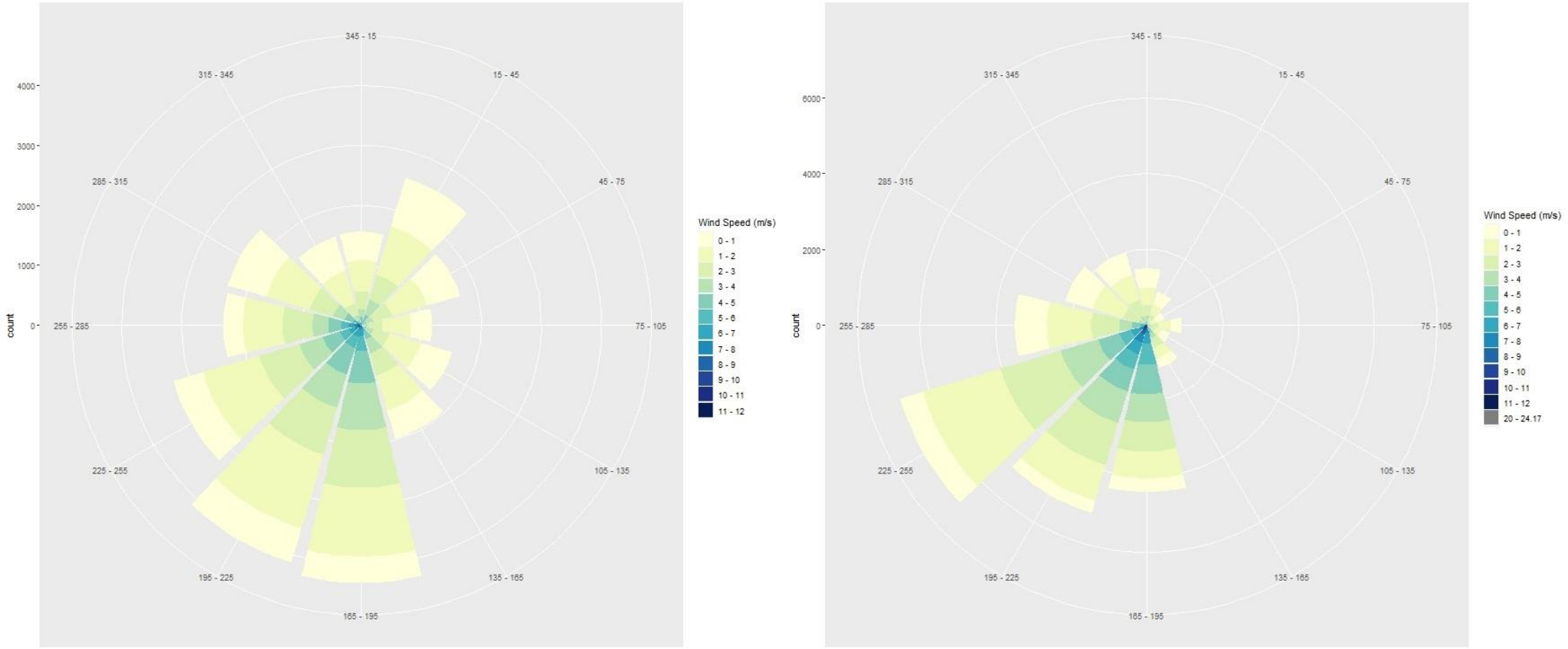
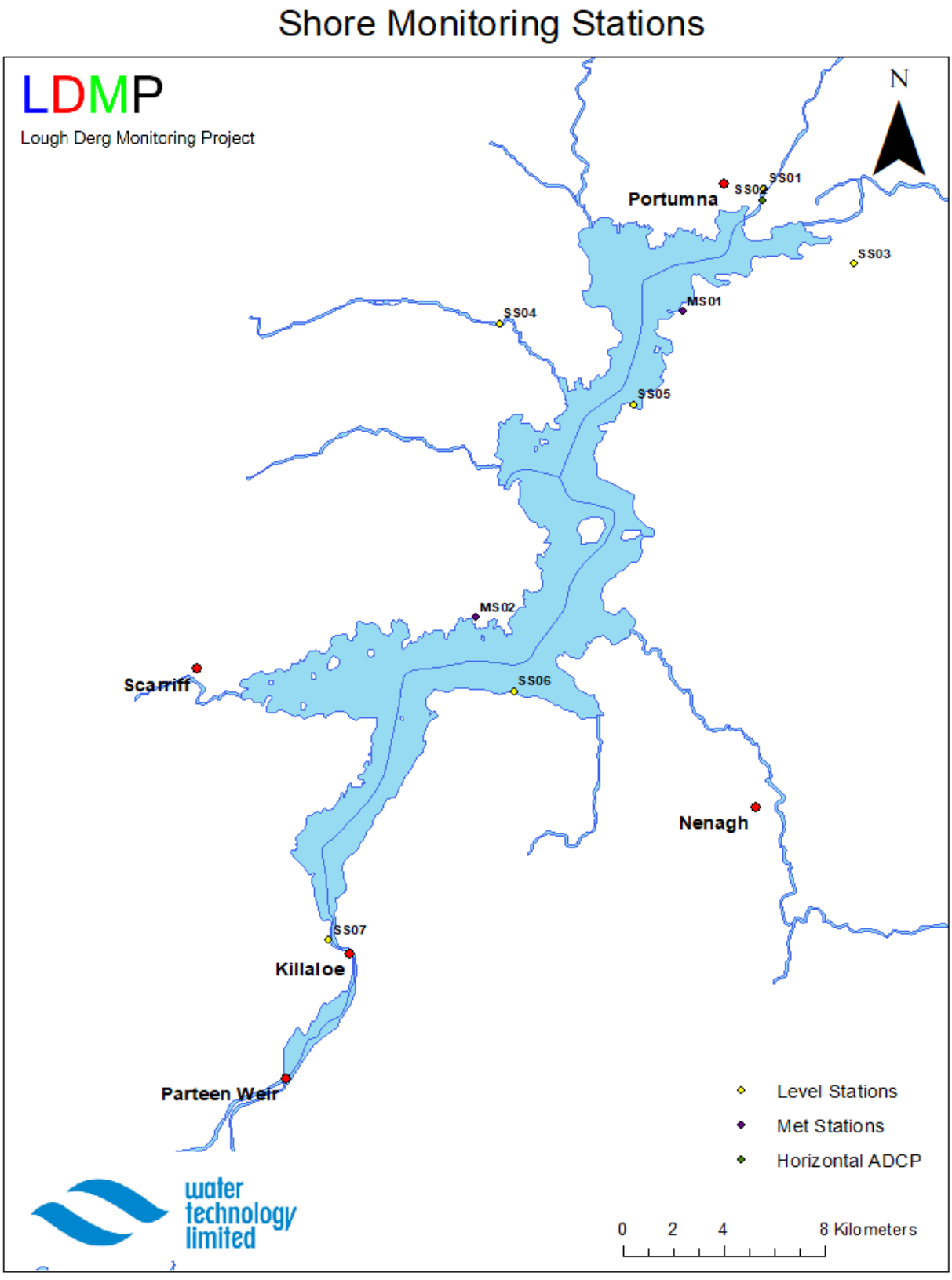


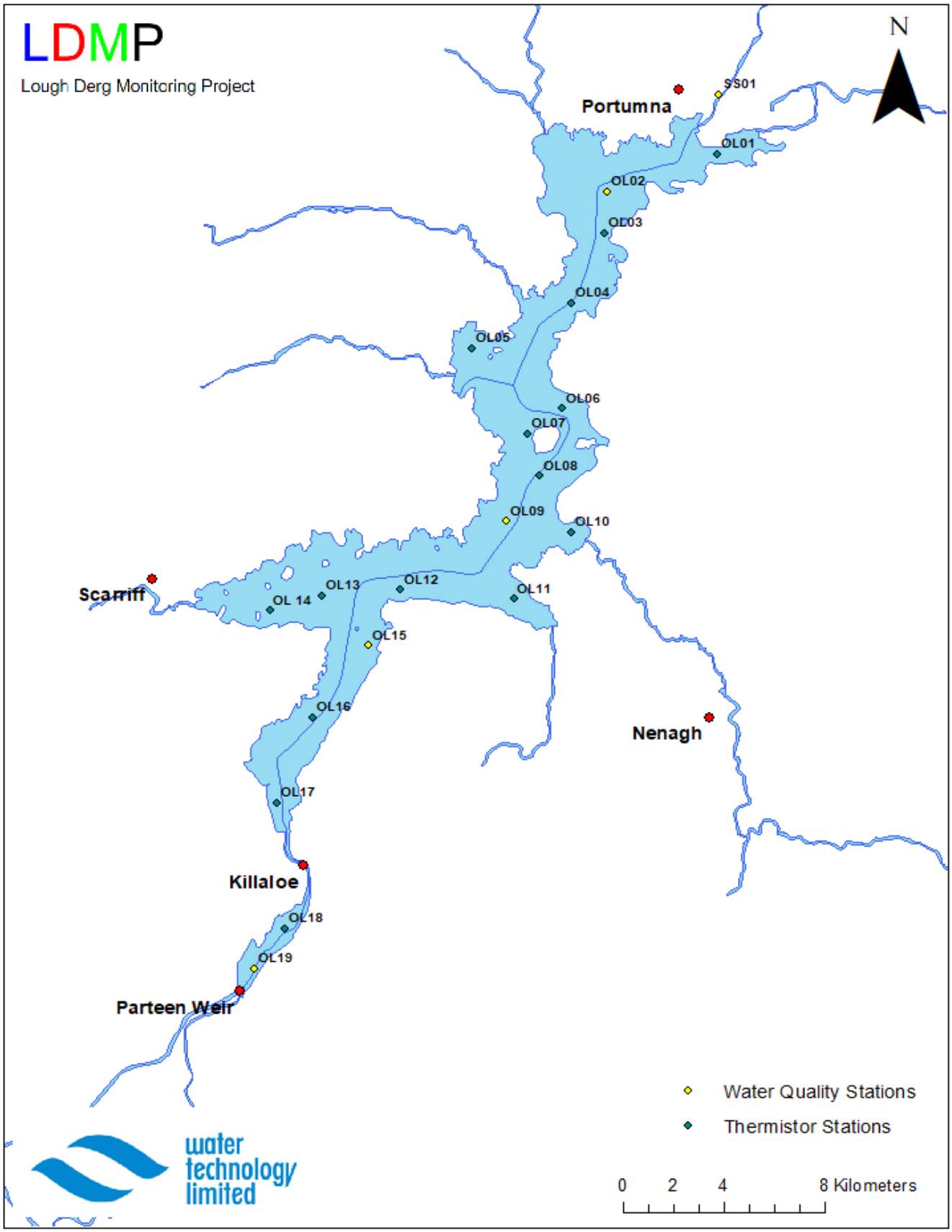
Figure 10: Windrose Diagram for Whitegate MS02 (right pane) and Ballinderry MS01 (left pane) weather stations from January 2020 – December 2020.

3. Appendices

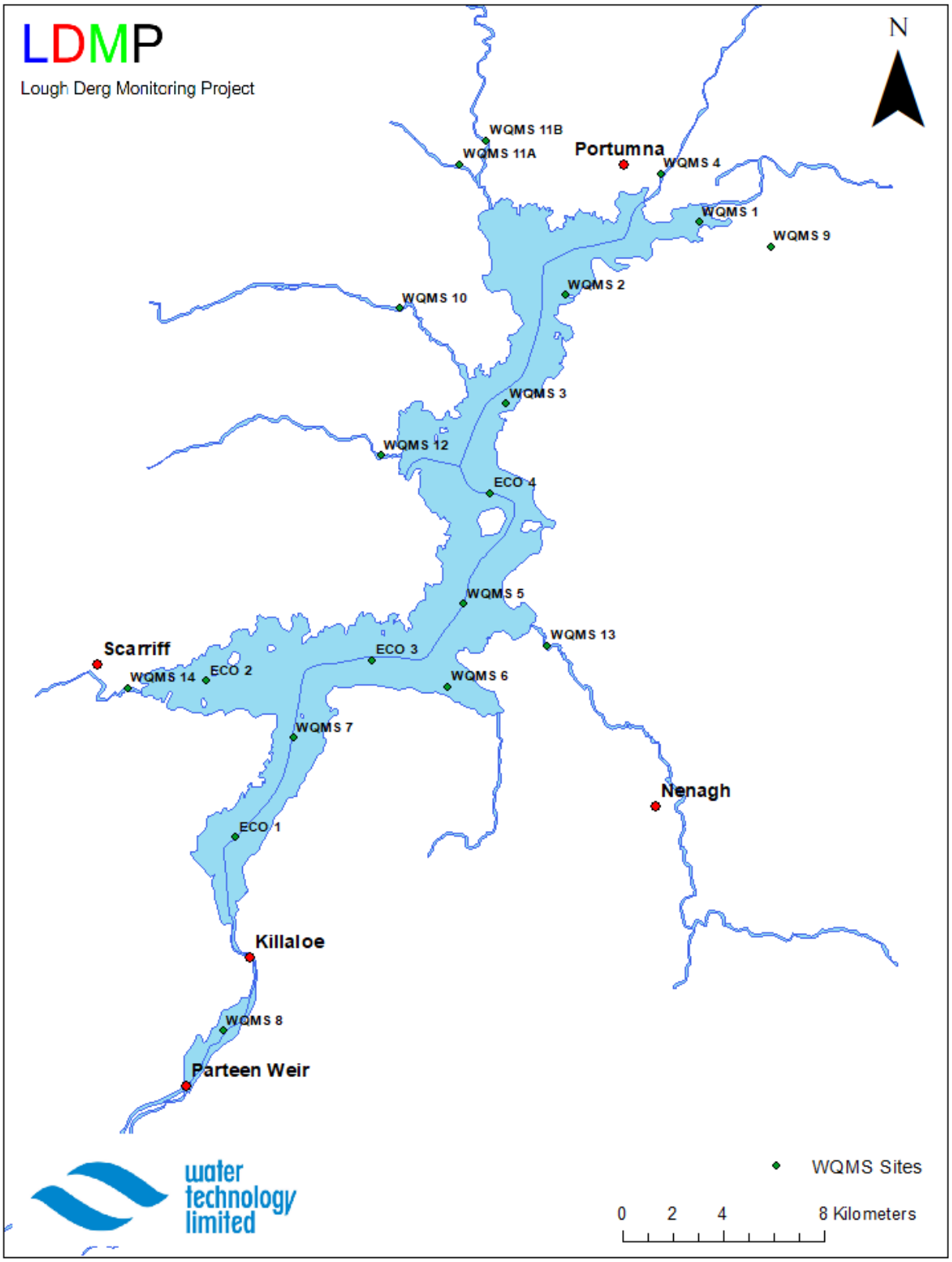
Appendix 1: Maps showing original survey site locations.



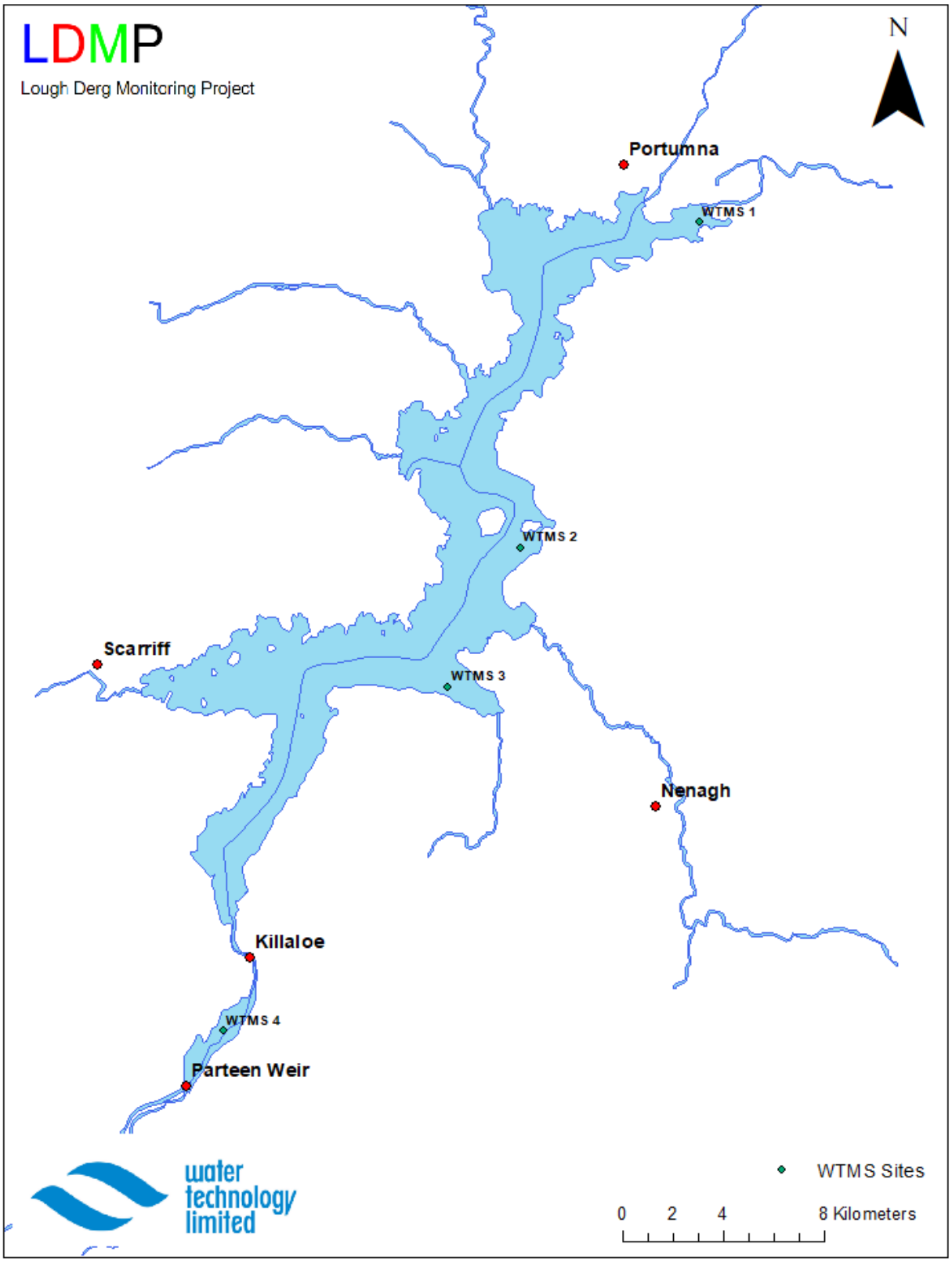
Open Water Monitoring Stations



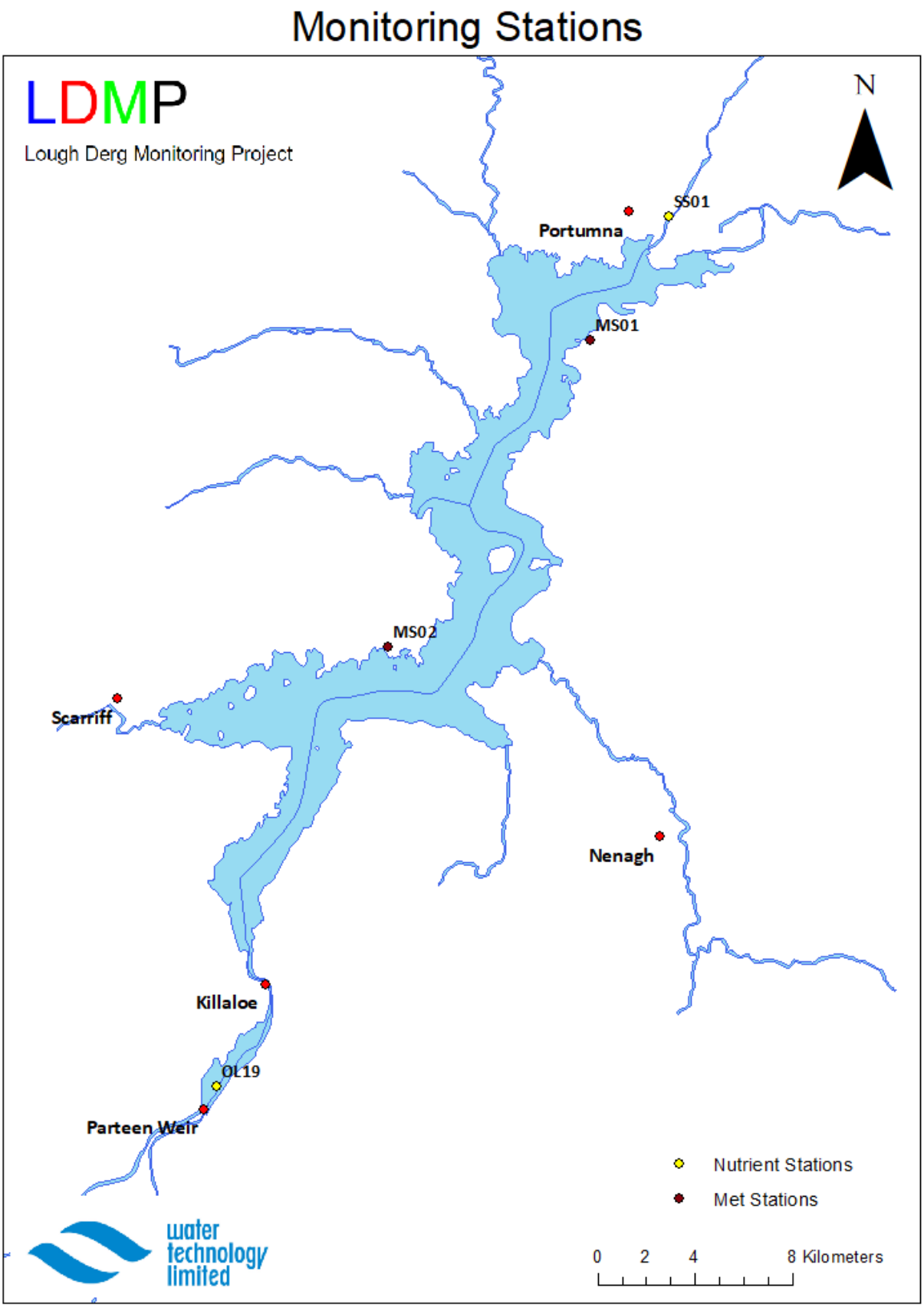
Water Quality Monitoring Site Locations



Water Treatability Monitoring Site Locations



Appendix 2: Maps showing current survey monitoring site locations.



4. References

Minchin, D. and R. Boelens (2011). "The Distribution and Expansion of Ornamental Plants on the Shannon Navigation." Biology and Environment-Proceedings of the Royal Irish Academy **Vol IIIB**(3): 1-9.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

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Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
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1. Introduction

1.1. Lough Derg Monitoring Project

Irish Water, via a transferred contract originally procured by Dublin City Council, have engaged Jacobs-Tobin ("the Main Consultant") to provide consultancy services in respect of the Water Supply Project-Dublin Region (WSP-DR) ("the Project"), which is a strategic national project. The overall aim of the Project is to ensure that, in combination with other projects within the Greater Dublin Area (GDA), the long-term (2050+) water supply needs of the Dublin Region (Water Supply Area) are met in a sustainable manner. Jacobs-Tobins have engaged Water Technology Ltd to complete an environmental survey of Lough Derg and its surrounding catchment. Table 1 gives a breakdown of all aspects of the survey. **Appendix *1*** shows the locations of all sites from the original survey.

Table 1: Lough Derg Monitoring Project, Specification of Works.

Work Area	Title	Equipment
T300	Water Flow and Current Survey	4 Acoustic Doppler Current Profilers installed (1 horizontal on River Shannon inflow and 3 vertical on the lake).
T400	Water Level Survey	6 water level recorders installed (3 on inflowing rivers and 3 on lake).
T500	Water Quality Survey	5 moored sampling stations. Spot sampling at 8 sample sites on the lake and 7 river sites in the surrounding catchment.
T600	Water Treatability Survey	Spot sampling at 4 locations on the lake for 12 months followed by spot sampling at 1 site.
T700	Temperature Survey	Thermistor chains installed at 20 locations on the lake.
T800	Meteorological Survey	2 Meteorological Stations are to be deployed to measure wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity and compass.
T900	Plankton Survey	Phytoplankton and zooplankton samples to be taken at 11 sites on the lake over a 12 month period.

1.2. Site decommissioning

The temperature survey (T700) of the Lough Derg monitoring project completed on 31/10/2017. Fifteen thermistor sites were decommissioned and all equipment was removed from the lake. As per client instruction the vertical Acoustic Doppler Current Profiler (ADCP) was removed from the site at OL15 (below Parkers Point) was moved to OL19 (Parteen Basin). The new ADCP site was confirmed operational on 04/02/2018.

The main phase of the project ended on the 30th July 2018 with most sites decommissioned by this date. A reduced sampling programme was introduced with only the two weather stations and two nutrient analysers being maintained going forward. The spot sampling programme will also continue on a monthly basis. Locations of current stations can be seen in **Appendix 2**.

Table 2: Status of remaining LDMP stations as of 21st Dec 2021.

Station	Station Type	Status
MS01 (Ballinderry)	Weather Station	Live
MS02 (Whitegate)	Weather Station	Live
OL19 (Parteen Basin)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Level Station/Water Quality	Decommissioned
SS02 (Portumna River)	Horizontal ADCP	Decommissioned
SS03 (Carraigahorig River)	Level Station	Decommissioned
SS04 (Woodford River)	Level Station	Decommissioned
SS05 (Coolbaun)	Level Station	Decommissioned
SS06 (Garrykennedy)	Level Station	Decommissioned
SS07 (Killaloe)	Level Station	Decommissioned
OL02 (North of lake)	Water Quality/Nutrients/ADCP	Decommissioned
OL09 (Outside Dromineer Bay)	Water Quality/Nutrients/ADCP	Decommissioned
OL15 (Parkers Point)	Water Quality/Nutrients/ADCP	Decommissioned
OL19 (Parteen Basin)	Water Quality/ADCP	Decommissioned

1.3. Study Area

Lough Derg is an alkaline lake located on the River Shannon (**Figure 1**) between counties Clare, Tipperary and Galway. The main inflowing river is the Shannon which enters the lough at Portumna and flows out of the lake at the southern end at Killaloe. The lake is 40km long and 13km at it widest point. The majority of the lake lies on Carboniferous limestone with the exception of the narrow southern section which is underlain by Silurian strata. The surrounding catchment of the northern end of the lake is mainly flat agricultural land while the southern end of the lake is bordered by the Slieve Aughty Mountains to the west and the Arra Mountains to the east. The northern end of the lake has an average depth of 6m. Two deep trenches occur in the lake, one in the middle portion and one at the southern end with average depths of >34m and >25m respectively.

Under the WaterFramework Directive monitoring the lake is classified as mesotrophic with moderate water quality (Lough Derg Management Plan 2009 – 2015). Blue-green algae blooms of *Microcystis aeruginosa* are frequent occurrences during the summer months (*L. Vaughan, personal observation*). The lake is home to several invasive species including the invasive bivalve species the zebra mussel (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminea*). Several invasive macrophyte species have also been identified on the lake, these are Water Fern *Azolla filiculoides*, Canadian Pondweed *Elodea canadensis*, Nuttall's waterweed *Elodea nuttalli*, Water Violet *Hottonia palustris*, Common Duckweed *Lemna minuta*, and water soldier *Stratiotes aloides* (Minchin and Boelens 2011).

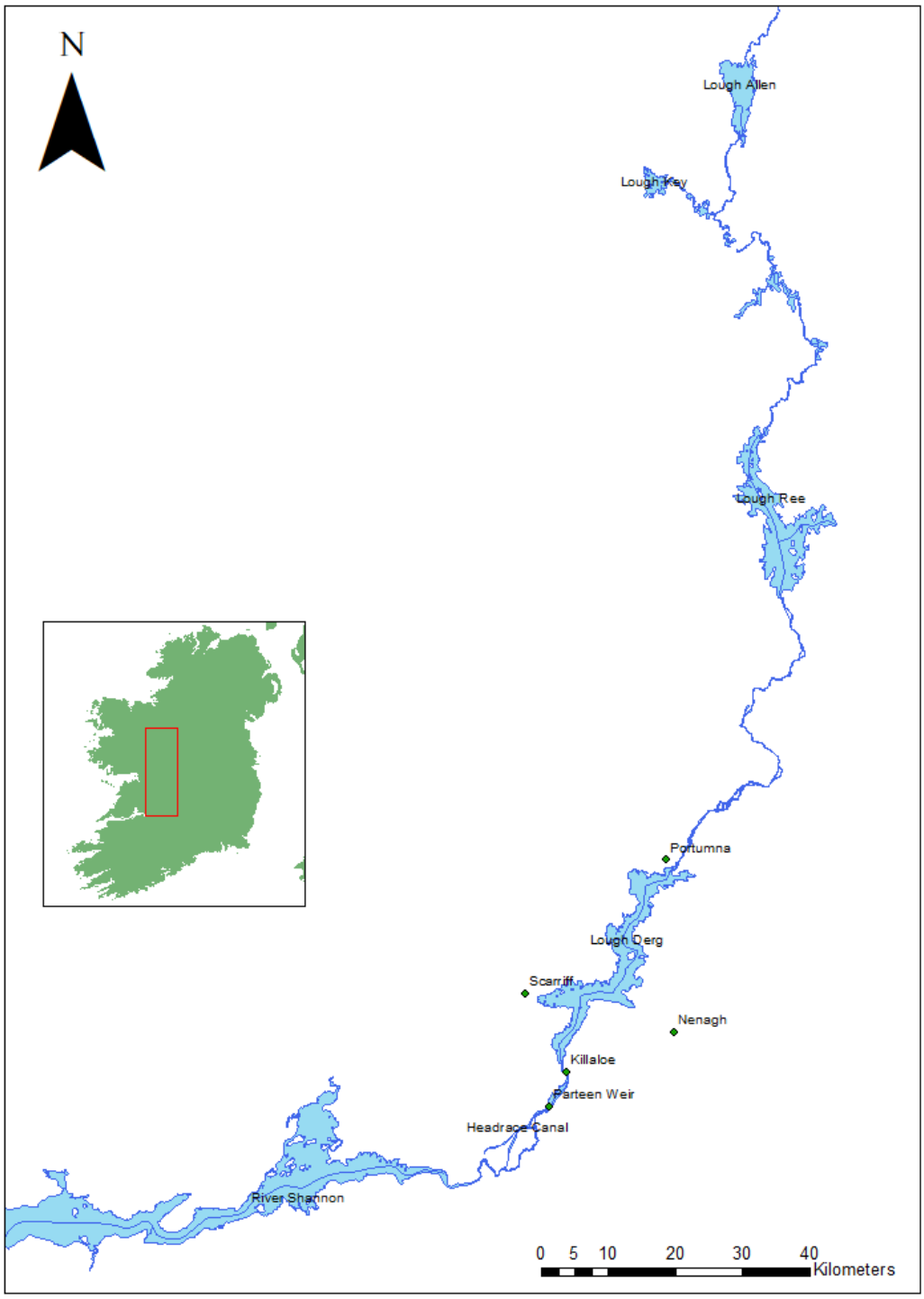


Figure 1: Shannon Catchment showing study area Lough Derg.

2. Results to date

2.1. T500 Water Quality Survey

2.1.1. In-situ sampling

Two in-situ nutrient analysers were deployed, one at an open lake site located near Parteen Weir and one on the inflowing River Shannon at Portumna Bridge (Appendix 2). **Figure *2*** and **Figure 3** show nutrient data from both sites from January 2021 – December 2021 with all data below the limit of detection removed. Many NO_2N and NH_3N values were below the limit of detection making observations on trends difficult. Both stations showed an increase in nitrate values in the early months of the year (January – April). Higher levels of nutrients is expected over the winter months due to higher levels of runoff from the catchment. OL19 showed a declining trend in nitrate values from May onwards coinciding with the beginning of the growing season in the lake and an uptake of dissolved nutrients by phytoplankton.

Water Quality Buoy on Lough Derg

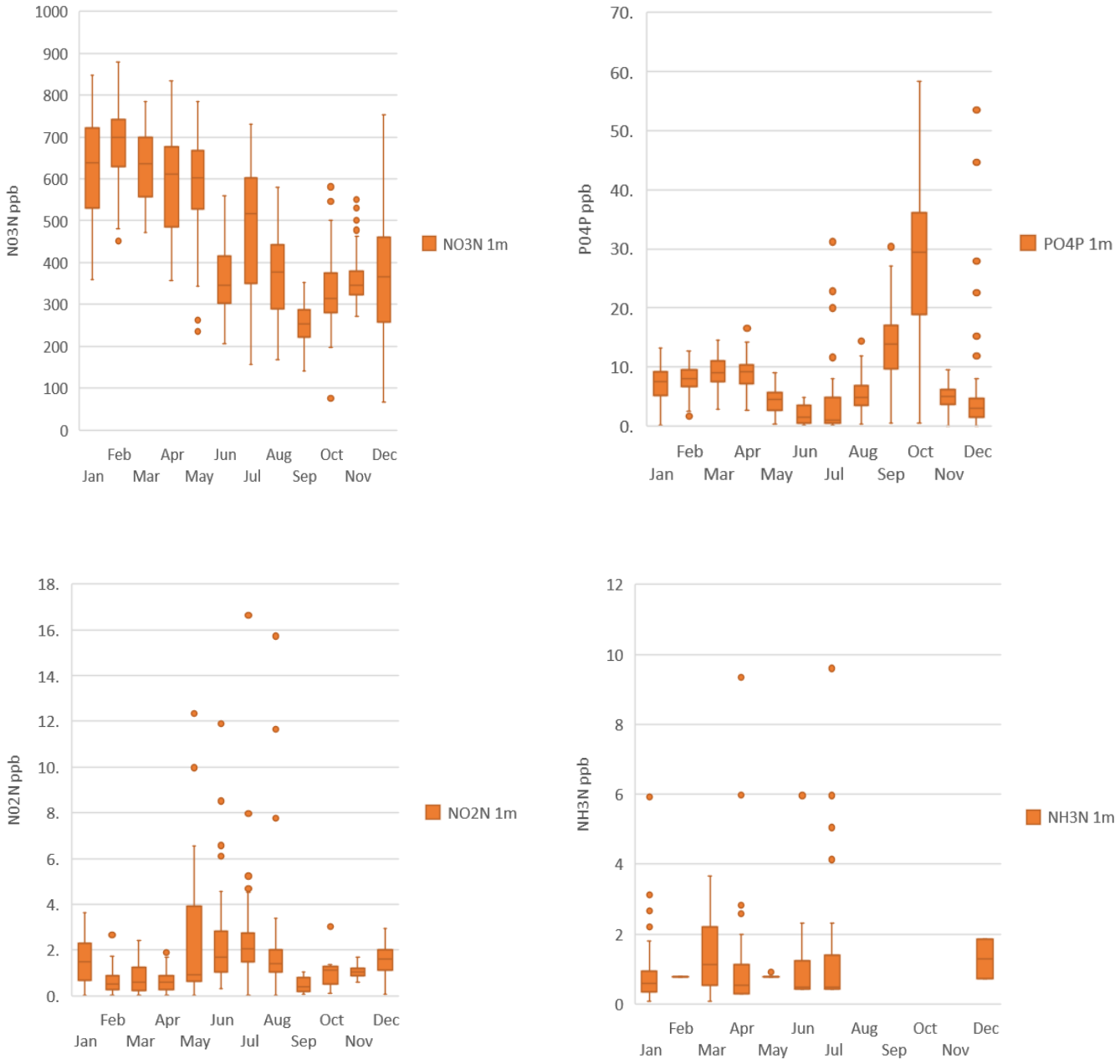


Figure 2: Nutrient Data from SS01 from January 2021 – December 2021 (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range..

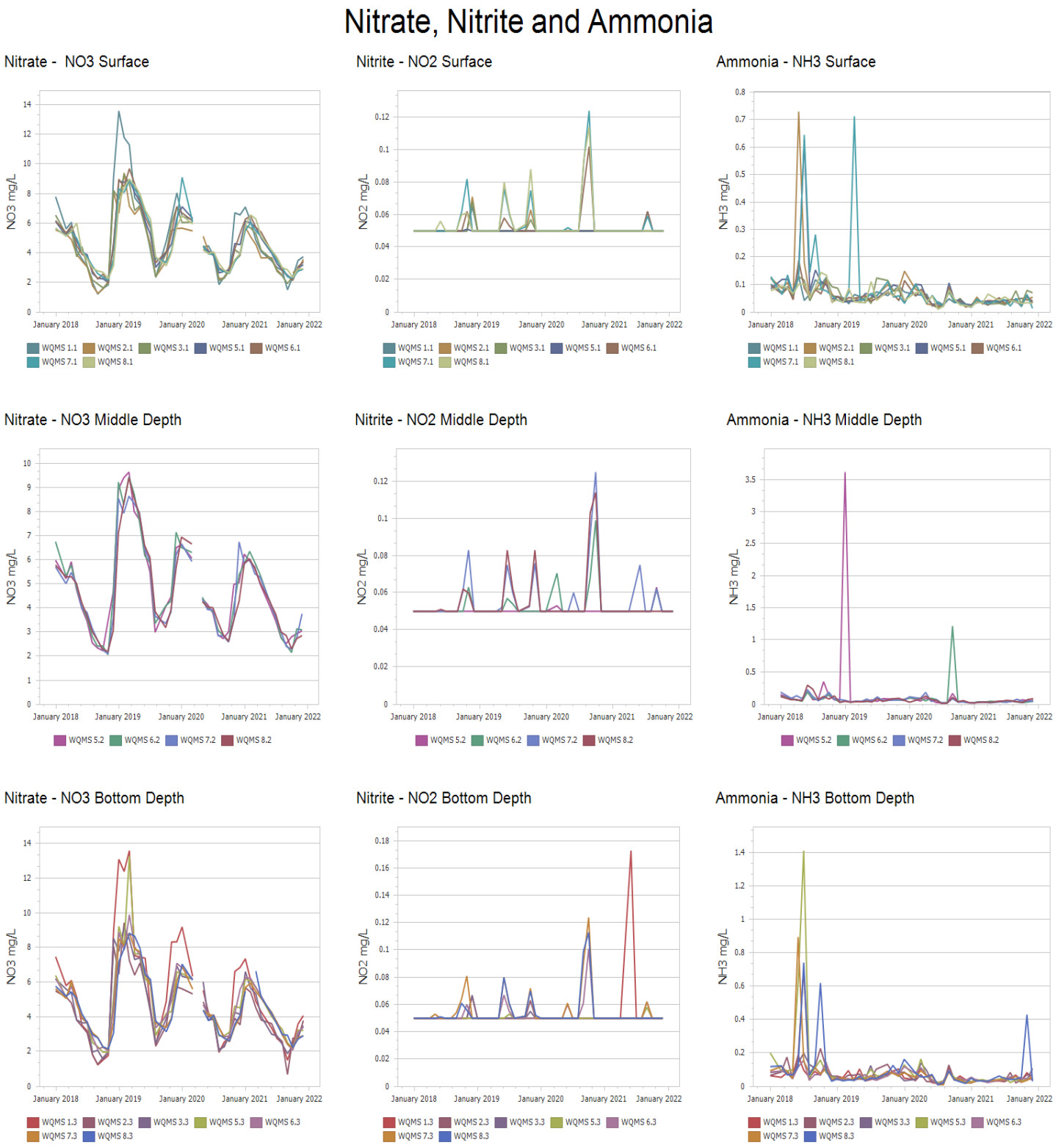
Figure 3: Nutrient Data from OL19 from January 2021 – December 2021 (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range.

2.1.2. Spot Sampling

The current spot sampling programme commenced in January 2018 and includes parameters for water quality only. **Table 3** details the parameters collected at each site under the water quality monitoring programme. Depending on the depth of the water column samples are taken at the surface, mid water depth and bottom depth (just above the lake bed). At shallow water site (< 5m) samples are taken at the surface and bottom depths. All lake sites showed similar patterns for all parameters measured across all depths. **Figure 4**, **Figure 5** and **Figure 6***:* show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate, BOD, temperature and chlorophyll *a* from water quality sites on Lough Derg at all depths. **Figure 7** shows the water quality data from all inflowing rivers into Lough Derg. As with previous years nitrate (NO_3)showed a peak at the start of the year before declining through the summer months, this trend was seen across all sites and depths. All lake sites showed similar patterns for all parameters measured across all depths. Lake nitrate and phosphate values showed a steady decline from January to October however a spike in lake phosphate level was detected in December. Chlorophyll *a* values are low until April where an increase can be seen particularly in the surface samples. This coincides with increased water temperatures and indicates the start of the growing season in the lake. The river parameters showed much more variability between sites, particularly for the nutrients NO_3 and PO_4P with WQMS 9 and WQMS 13 showing much higher NO_3 values than the other rivers. Both these sites are located on the eastern shore of the lake indicating a higher nutrient status on the eastern side of the catchment.

Table 3: List of parameters collected under the spot sampling programme.

Parameter	**Units**
Alkalinity, Total as $CaCO_3$	mg/l
Ammoniacal Nitrogen as NH_3	mg/l
Nitrate as NO_3	mg/l
Nitrite as NO_2	mg/l
Phosphate (Ortho as P)	mg/l
Suspended solids, Total	mg/l
BOD	mg/l
Chlorophyll *a*	µg/l
Temperature	ºC
Dissolved Oxygen %	%/mg/l
pH	pH units
Conductivity	µS/cm



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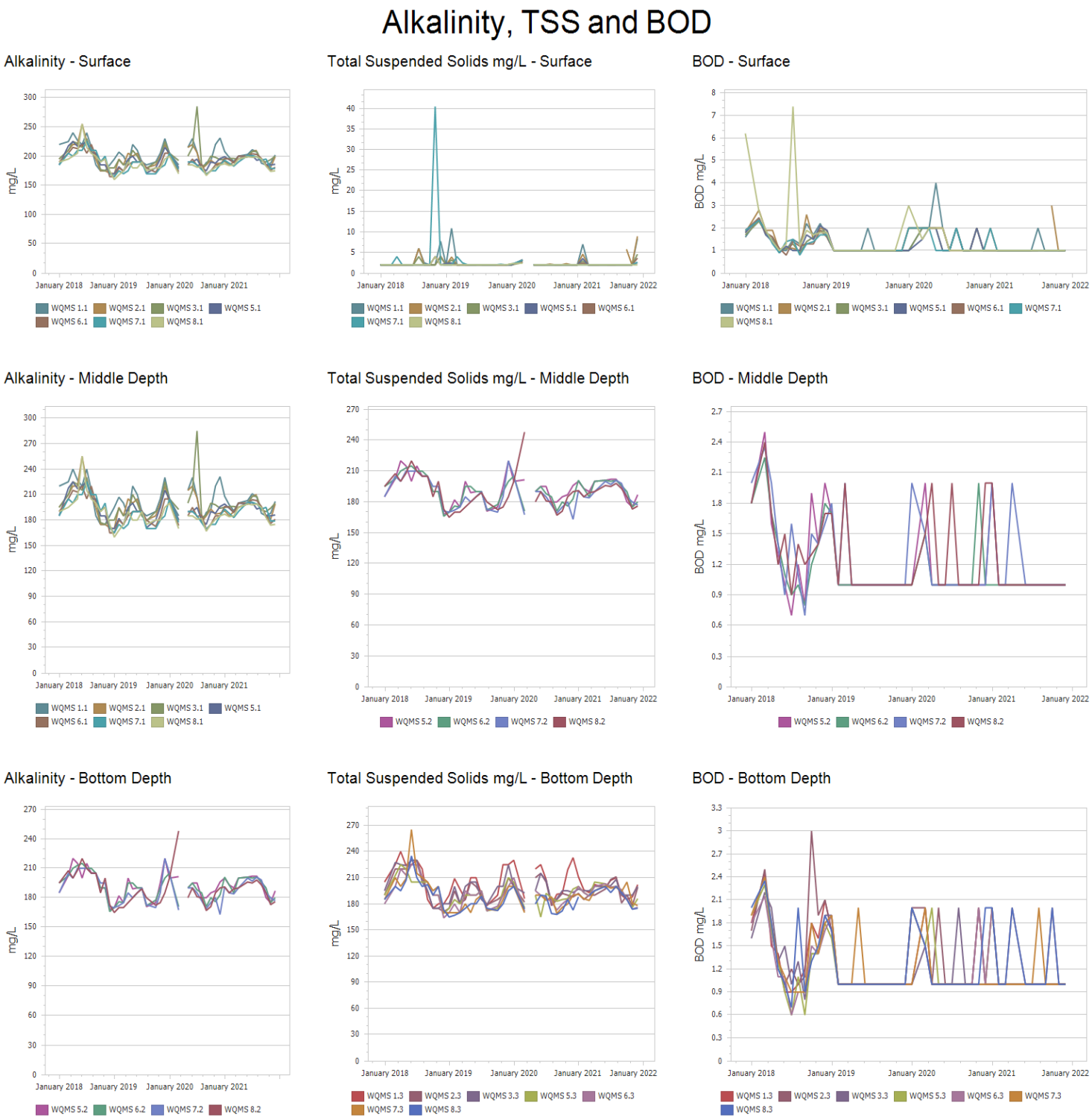

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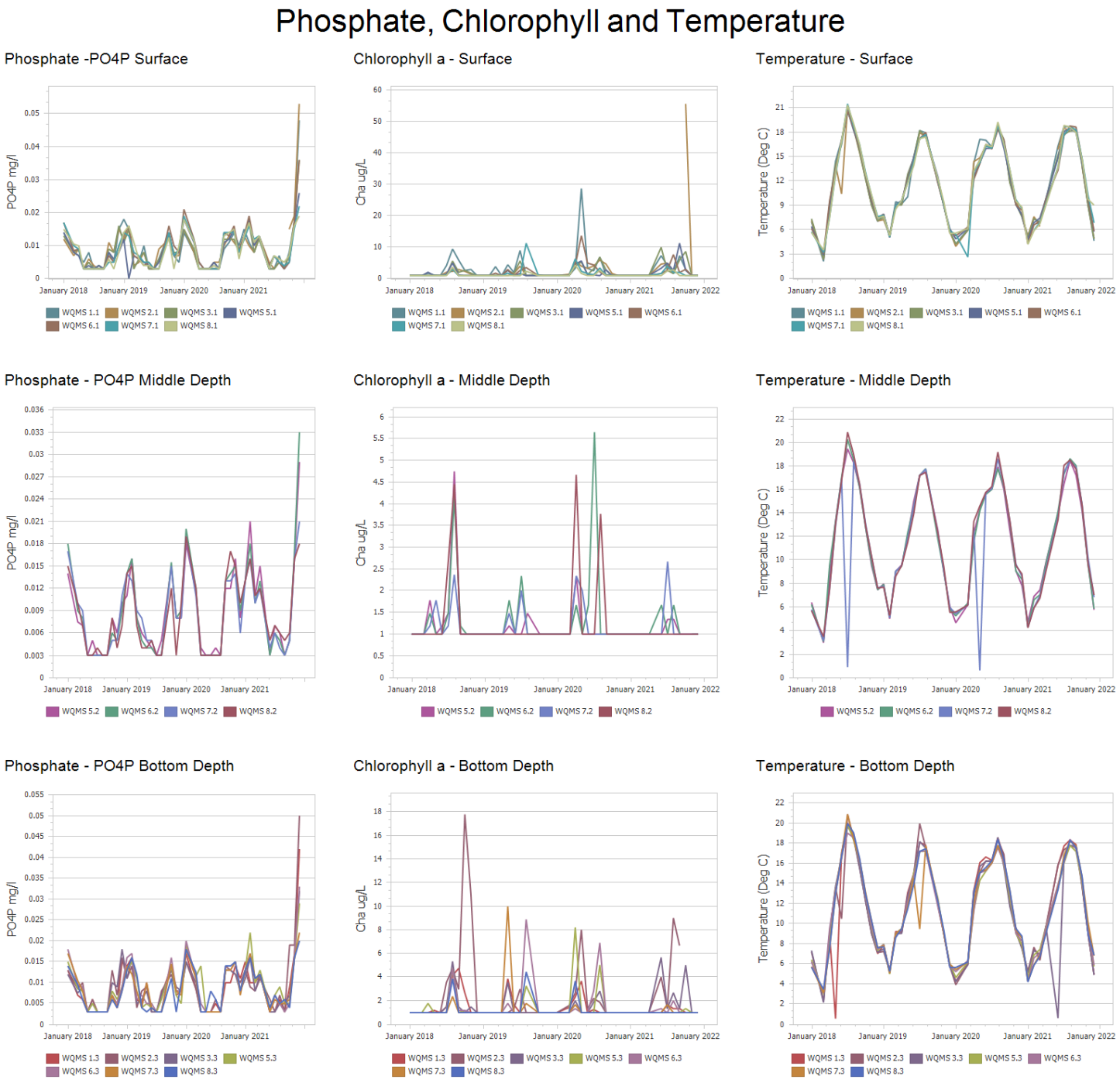

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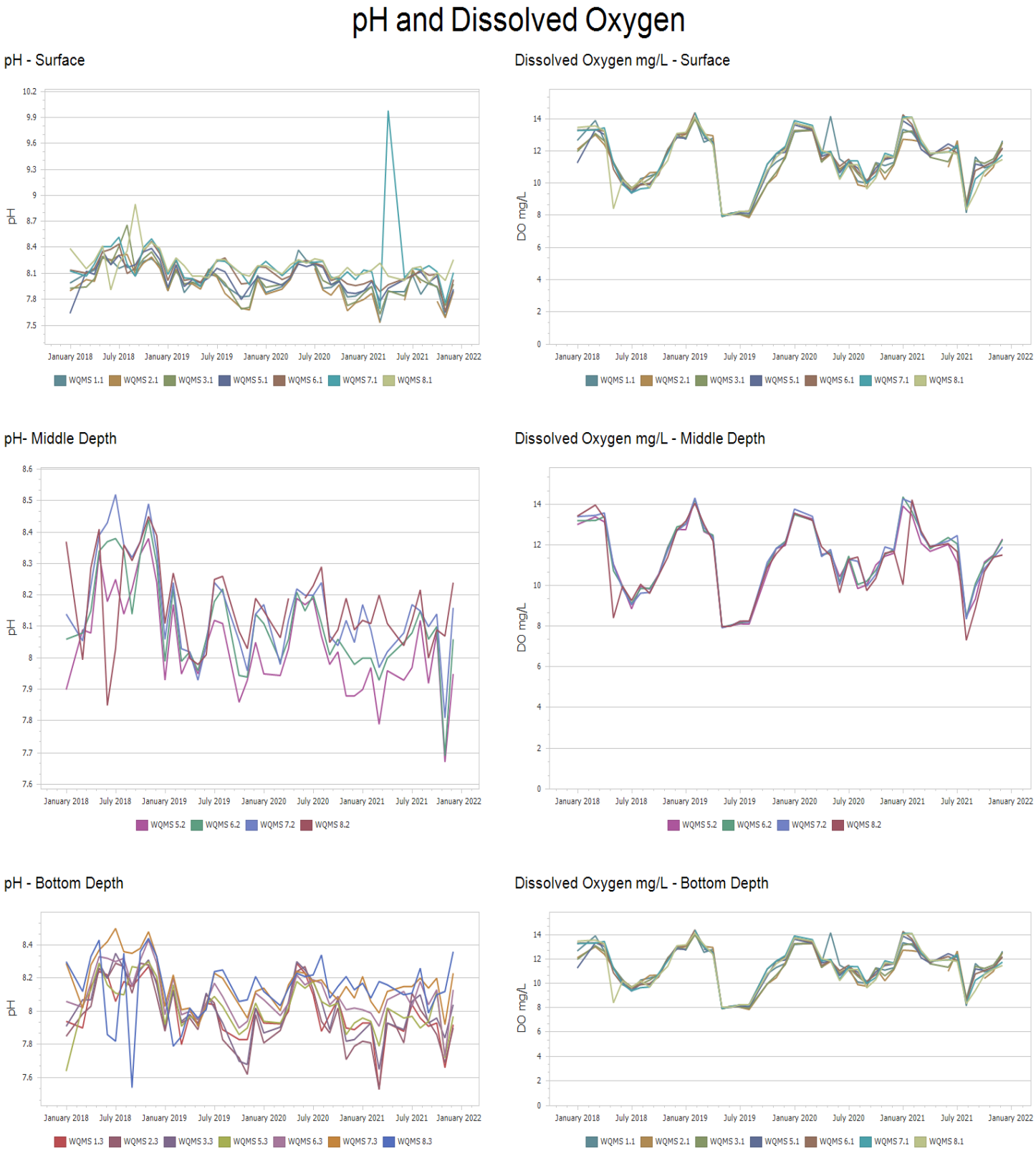


Figure 7: Survey results from all lake water quality sites of pH and Dissolved Oxygen from January 2021 – December 2021.

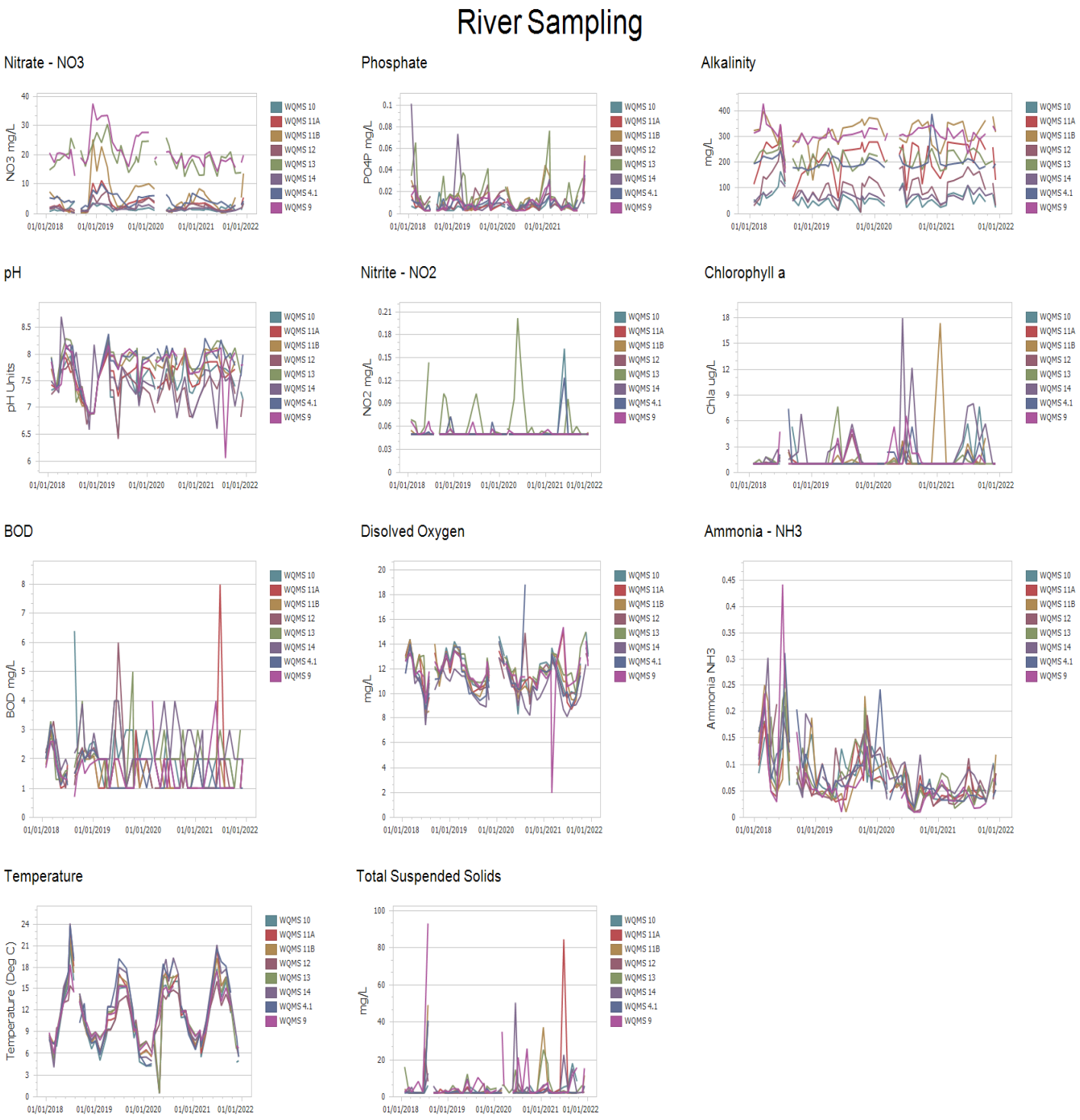


Figure 8 Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll a and temperature, Alkalinity, pH, and Dissolved Oxygen from January 2021 – December 2021

2.2. T800 Meteorological Survey

Two meteorological stations were installed on the eastern and western shore of Lough Derg on the 17th/18th February 2016. Stations were deployed with sensors measuring wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity. Both stations showed similar patterns over 2021. Maximum 2021 air temperatures for stations were 22.5.2°C and 22.9°C at MS01 and MS02 respectively.

Whitegate Met Station

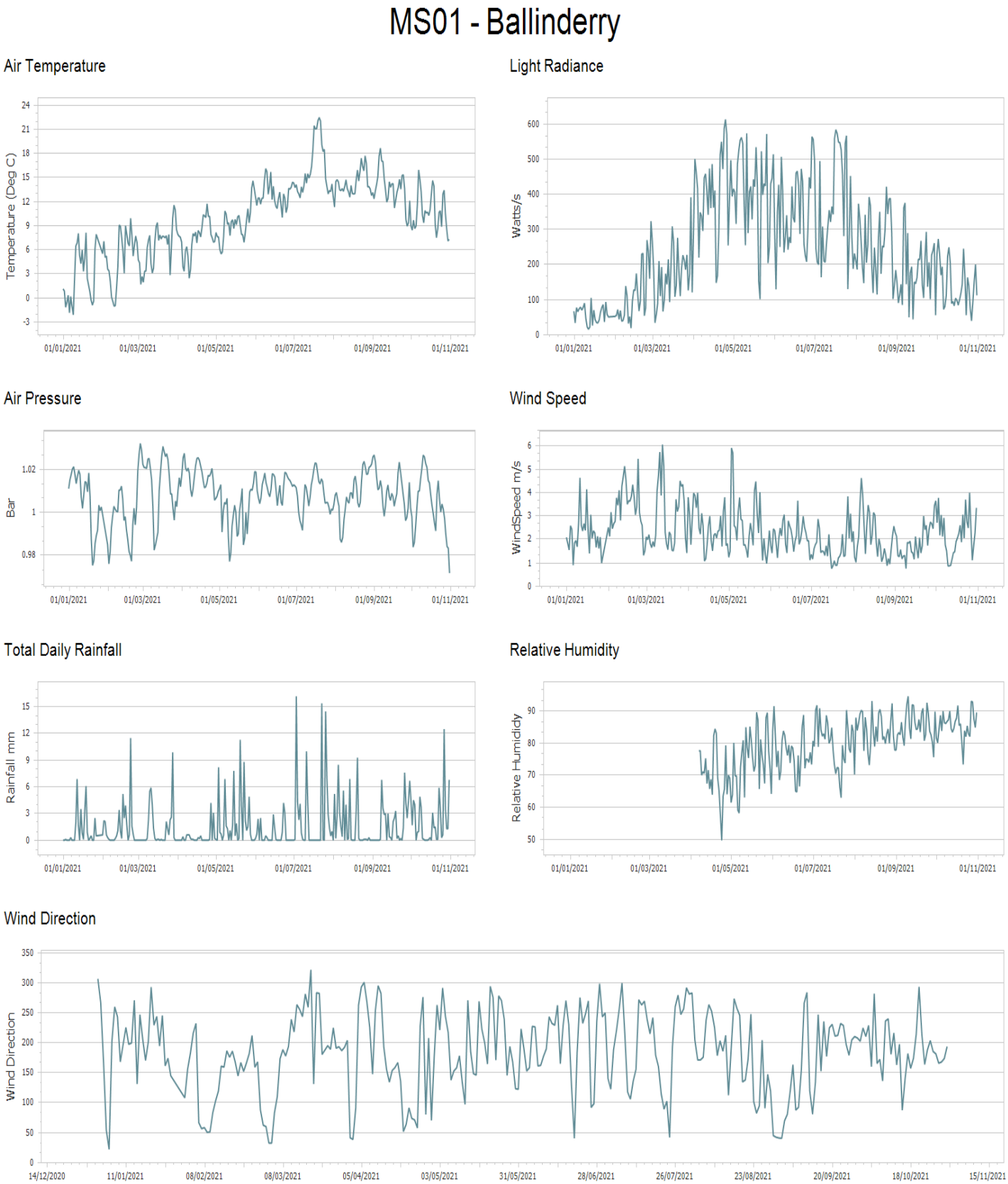


Figure 9: Data from MS01 (Ballinderry) from January 2021 – December 2021 (Air Pressure show observations with a loess smoother lines imposed, Light radiance (day time values only), Air Temperature, Wind Speed and Relative Humidity show daily average values).

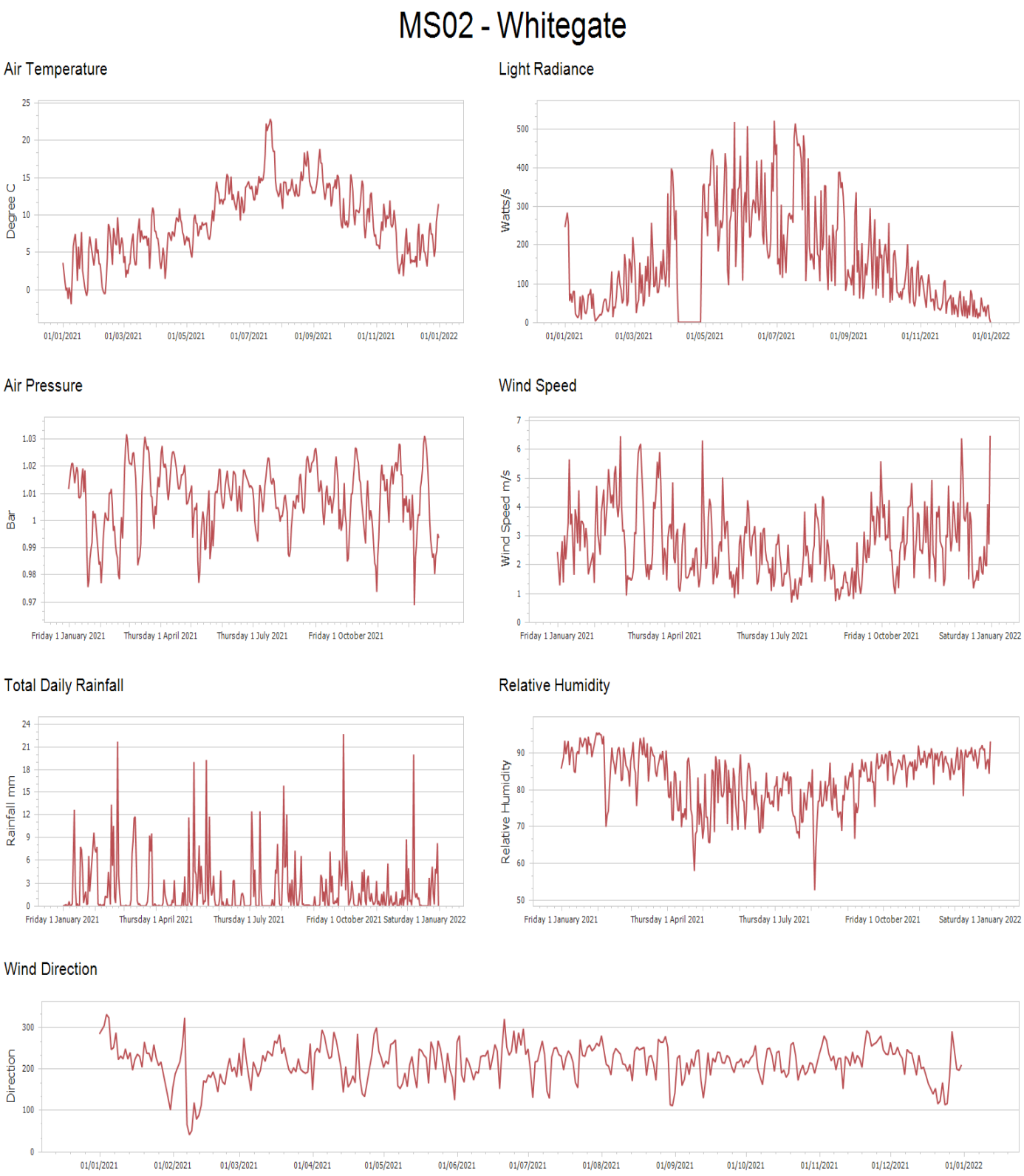
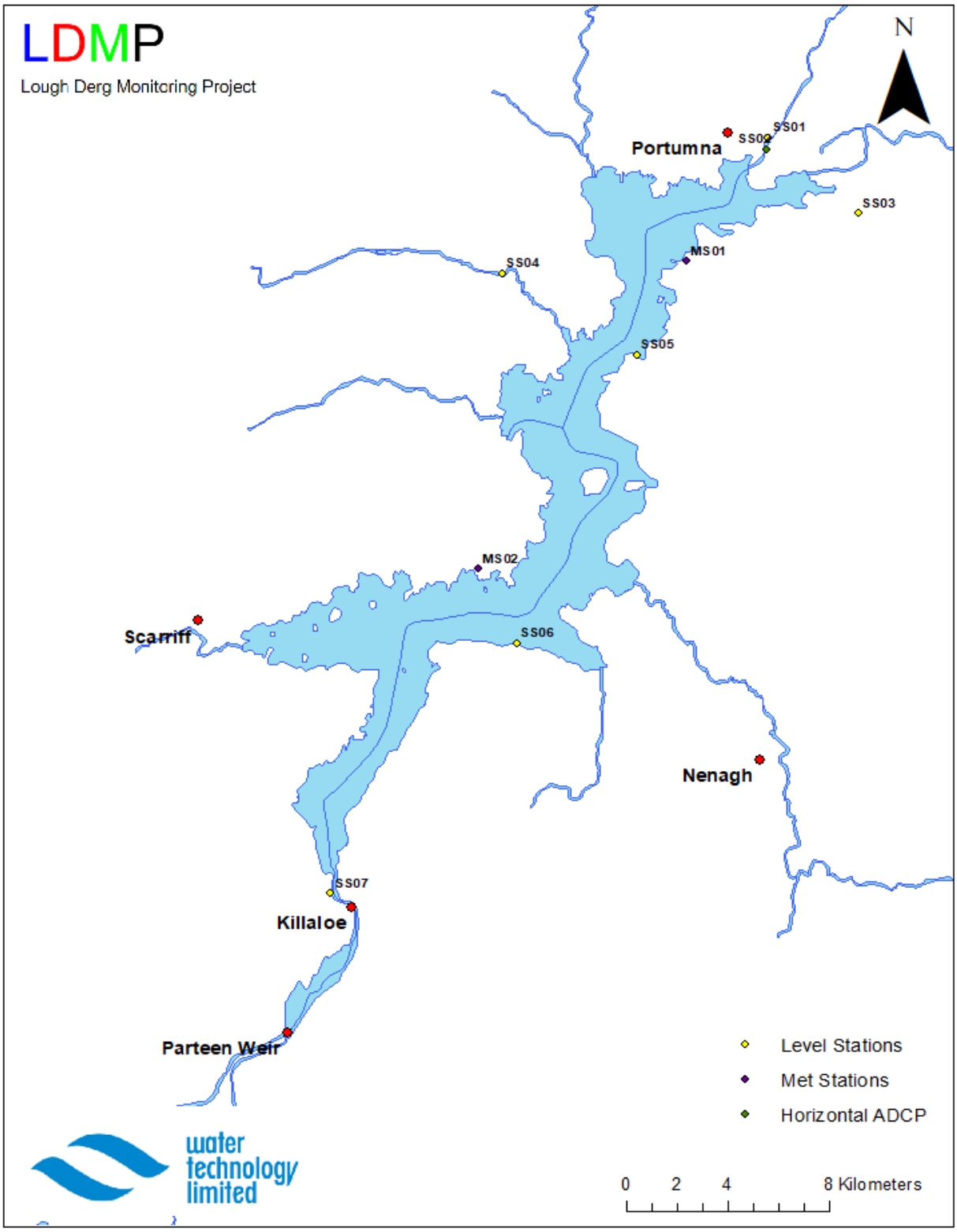


Figure 10 Data from MS02 (Whitegate) from January 2021 – December 2021 (, Light radiance (day time values only), Air Temperature, Wind Speed and Relative Humidity show daily average values).

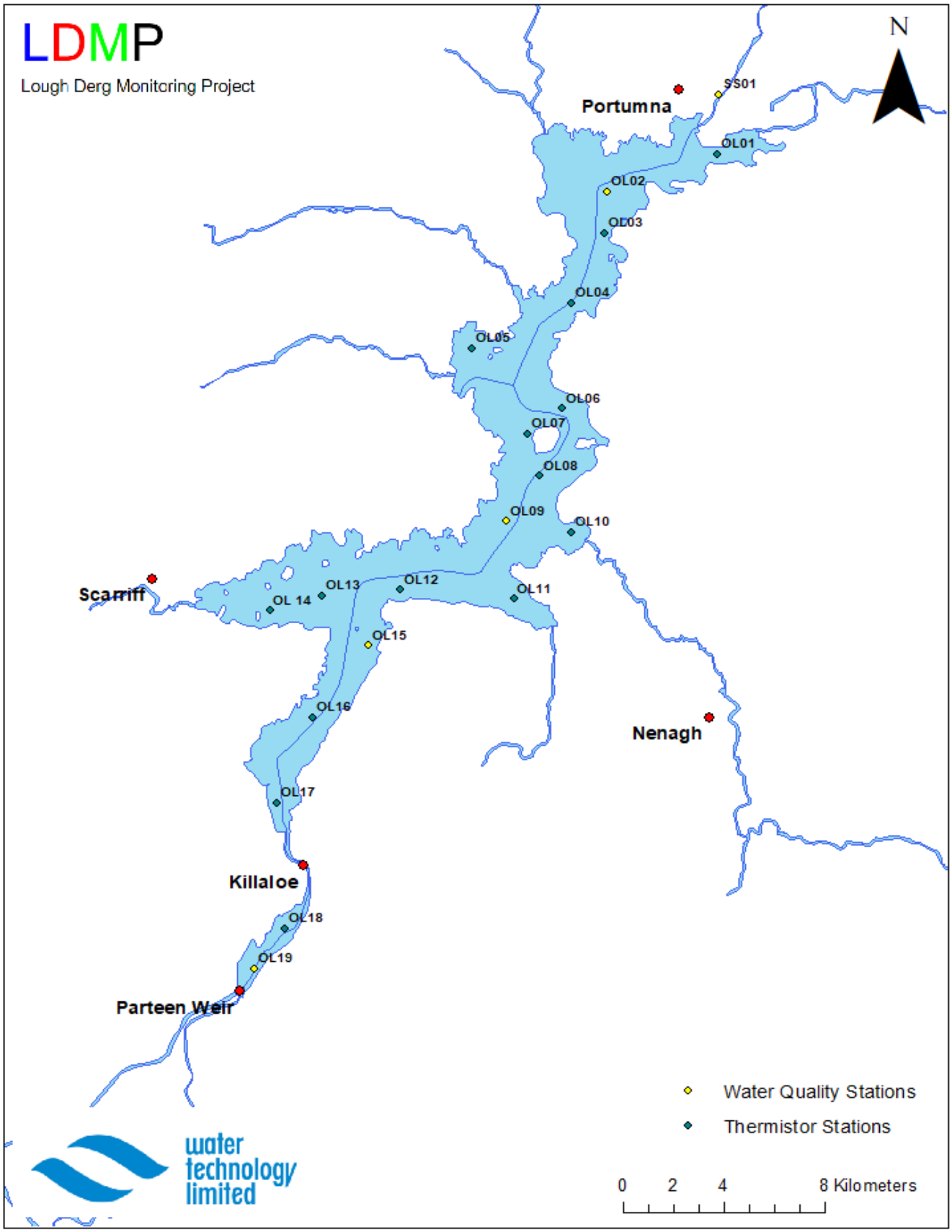
3. Appendices

Appendix 1: Maps showing original survey site locations.

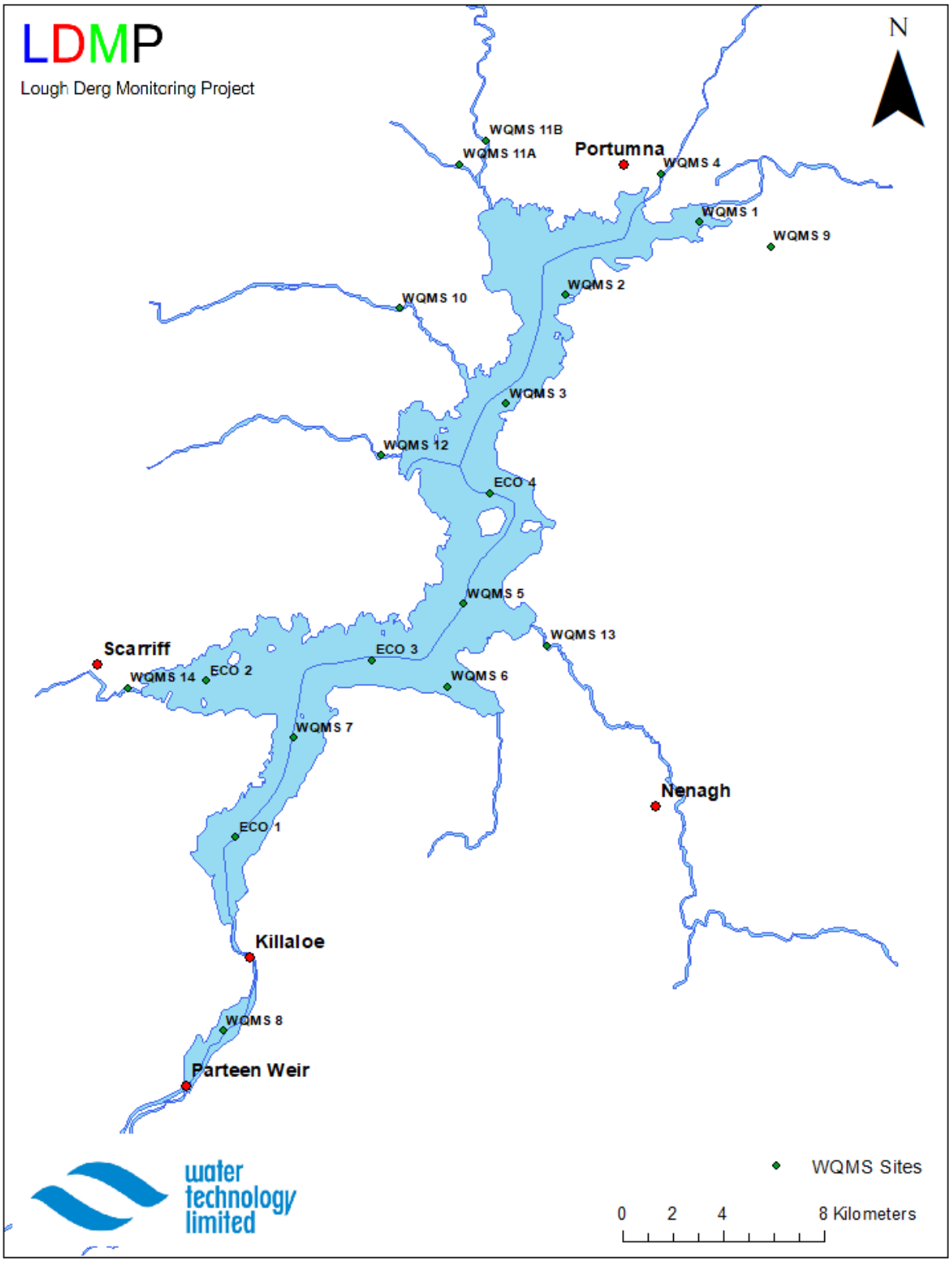
Shore Monitoring Stations



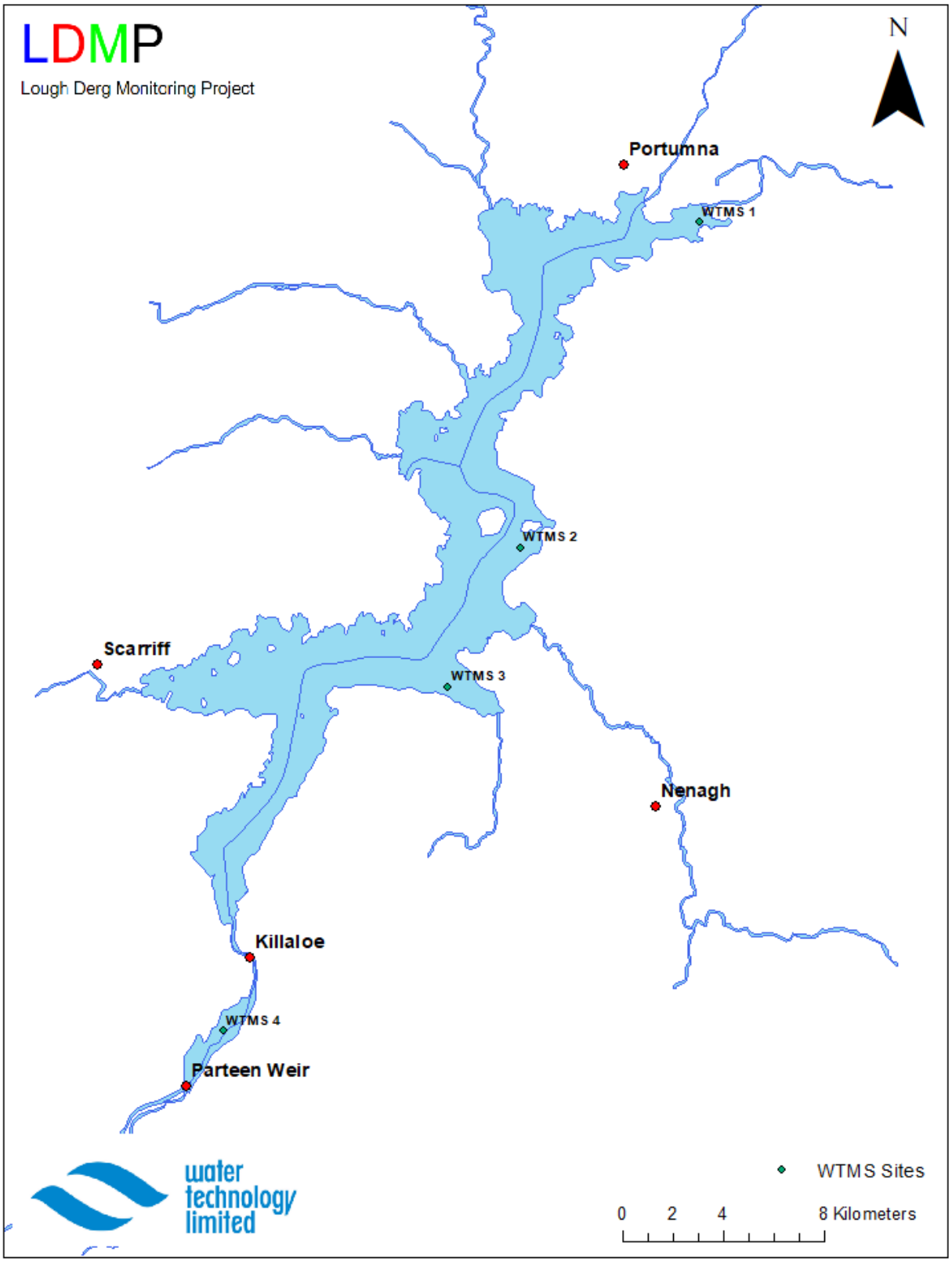
Open Water Monitoring Stations



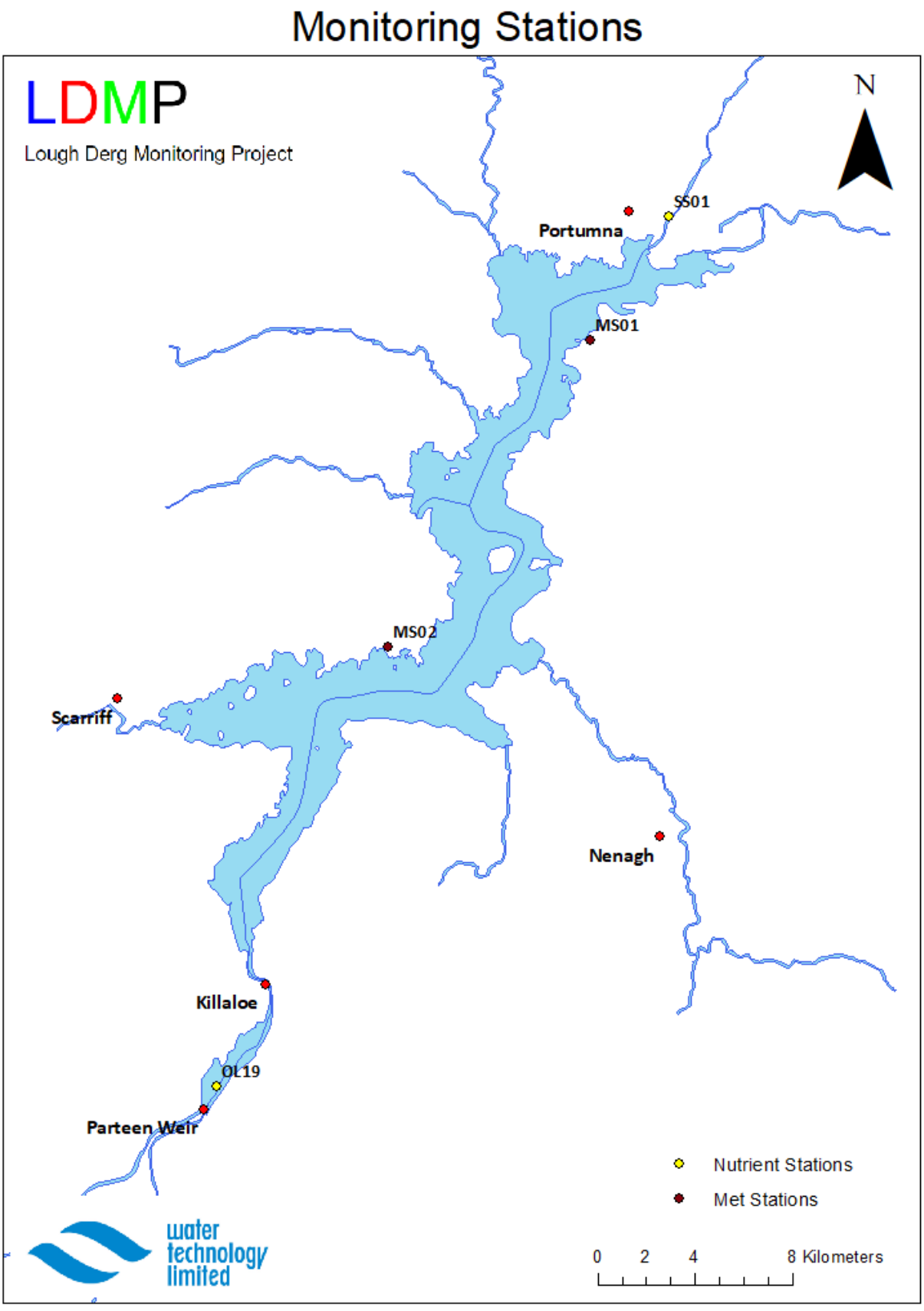
Water Quality Monitoring Site Locations



Water Treatability Monitoring Site Locations



Appendix 2: Maps showing current survey monitoring site locations.



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1. Introduction

1.1. Lough Derg Monitoring Project

Irish Water, via a transferred contract originally procured by Dublin City Council, have engaged Jacobs-Tobin ("the Main Consultant") to provide consultancy services in respect of the Water Supply Project-Dublin Region (WSP-DR) ("the Project"), which is a strategic national project. The overall aim of the Project is to ensure that, in combination with other projects within the Greater Dublin Area (GDA), the long-term (2050+) water supply needs of the Dublin Region (Water Supply Area) are met in a sustainable manner. Jacobs-Tobins have engaged Water Technology Ltd to complete an environmental survey of Lough Derg and its surrounding catchment. Table 1 gives a breakdown of all aspects of the survey. **Appendix *1*** shows the locations of all sites from the original survey.

Table 1: Lough Derg Monitoring Project, Specification of Works.

Work Area	Title	Equipment
T300	Water Flow and Current Survey	4 Acoustic Doppler Current Profilers installed (1 horizontal on River Shannon inflow and 3 vertical on the lake).
T400	Water Level Survey	6 water level recorders installed (3 on inflowing rivers and 3 on lake).
T500	Water Quality Survey	5 moored sampling stations. Spot sampling at 8 sample sites on the lake and 7 river sites in the surrounding catchment.
T600	Water Treatability Survey	Spot sampling at 4 locations on the lake for 12 months followed by spot sampling at 1 site.
T700	Temperature Survey	Thermistor chains installed at 20 locations on the lake.
T800	Meteorological Survey	2 Meteorological Stations are to be deployed to measure wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity and compass.
T900	Plankton Survey	Phytoplankton and zooplankton samples to be taken at 11 sites on the lake over a 12 month period.

1.2. Site decommissioning

The temperature survey (T700) of the Lough Derg monitoring project completed on 31/10/2017. Fifteen thermistor sites were decommissioned and all equipment was removed from the lake. As per client instruction the vertical Acoustic Doppler Current Profiler (ADCP) was removed from the site at OL15 (below Parkers Point) was moved to OL19 (Parteen Basin). The new ADCP site was confirmed operational on 04/02/2018.

The main phase of the project ended on the 30th July 2018 with most sites decommissioned by this date. A reduced sampling programme was introduced with only the two weather stations and two nutrient analysers being maintained going forward. The spot sampling programme will also continue on a monthly basis. Locations of current stations can be seen in **Appendix 2**.

Table 2: Status of remaining LDMP stations as of 21st Dec 2022.

Station	Station Type	Status
MS01 (Ballinderry)	Weather Station	Live
MS02 (Whitegate)	Weather Station	Live
OL19 (Parteen Basin)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Level Station/Water Quality	Decommissioned
SS02 (Portumna River)	Horizontal ADCP	Decommissioned
SS03 (Carraigahorig River)	Level Station	Decommissioned
SS04 (Woodford River)	Level Station	Decommissioned
SS05 (Coolbaun)	Level Station	Decommissioned
SS06 (Garrykennedy)	Level Station	Decommissioned
SS07 (Killaloe)	Level Station	Decommissioned
OL02 (North of lake)	Water Quality/Nutrients/ADCP	Decommissioned
OL09 (Outside Dromineer Bay)	Water Quality/Nutrients/ADCP	Decommissioned
OL15 (Parkers Point)	Water Quality/Nutrients/ADCP	Decommissioned
OL19 (Parteen Basin)	Water Quality/ADCP	Decommissioned

1.3. Study Area

Lough Derg is an alkaline lake located on the River Shannon (**Figure 1**) between counties Clare, Tipperary and Galway. The main inflowing river is the Shannon which enters the lough at Portumna and flows out of the lake at the southern end at Killaloe. The lake is 40km long and 13km at it widest point. The majority of the lake lies on Carboniferous limestone with the exception of the narrow southern section which is underlain by Silurian strata. The surrounding catchment of the northern end of the lake is mainly flat agricultural land while the southern end of the lake is bordered by the Slieve Aughty Mountains to the west and the Arra Mountains to the east. The northern end of the lake has an average depth of 6m. Two deep trenches occur in the lake, one in the middle portion and one at the southern end with average depths of >34m and >25m respectively.

Under the WaterFramework Directive monitoring the lake is classified as mesotrophic with moderate water quality (Lough Derg Management Plan 2009 – 2015). Blue-green algae blooms of *Microcystis aeruginosa* are frequent occurrences during the summer months (*L. Vaughan, personal observation*). The lake is home to several invasive species including the invasive bivalve species the zebra mussel (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminea*). Several invasive macrophyte species have also been identified on the lake, these are Water Fern *Azolla filiculoides*, Canadian Pondweed *Elodea canadensis*, Nuttall's waterweed *Elodea nuttalli*, Water Violet *Hottonia palustris*, Common Duckweed *Lemna minuta*, and water soldier *Stratiotes aloides* (Minchin and Boelens 2011).

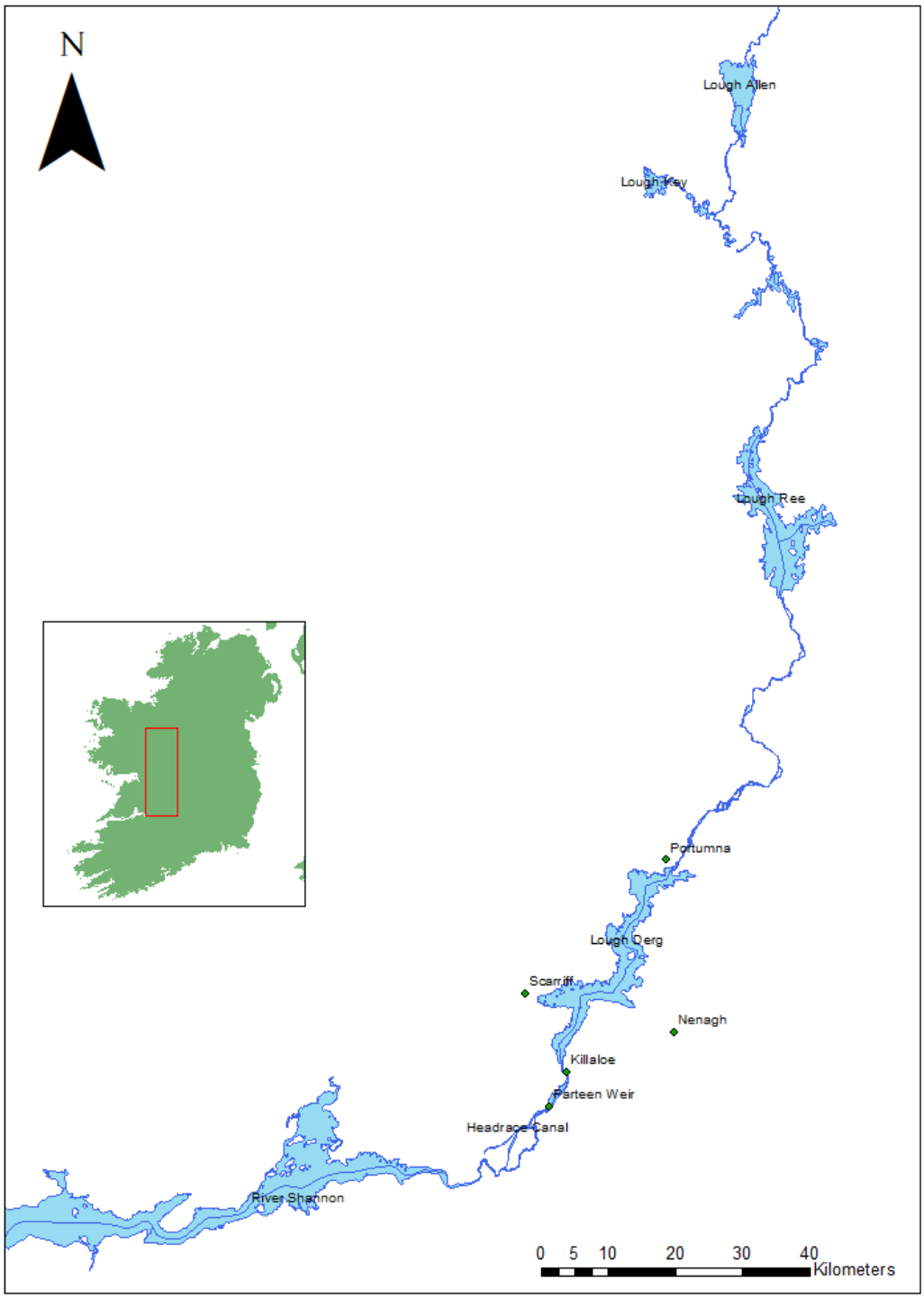


Figure 1: Shannon Catchment showing study area Lough Derg.

2. Results to date

2.1. T500 Water Quality Survey

2.1.1. In-situ sampling

Two in-situ nutrient analysers were deployed, one at an open lake site located near Parteen Weir and one on the inflowing River Shannon at Portumna Bridge (Appendix 2). **Figure *2*** and **Figure 3** show nutrient data from both sites from January 2022 – December 2022 with all data below the limit of detection removed. Many NO_2N and NH_3N values were below the limit of detection making observations on trends difficult. Both stations showed an increase in nitrate values in the early months of the year (January – April). Higher levels of nutrients is expected over the winter months due to higher levels of runoff from the catchment. Some technical issues on OL19 were encountered during both May and August which may affected certain readings of phosphate and ammonia however all parameter measurements fell between the typical low levels of previous years levels.

Water Quality Buoy on Lough Derg

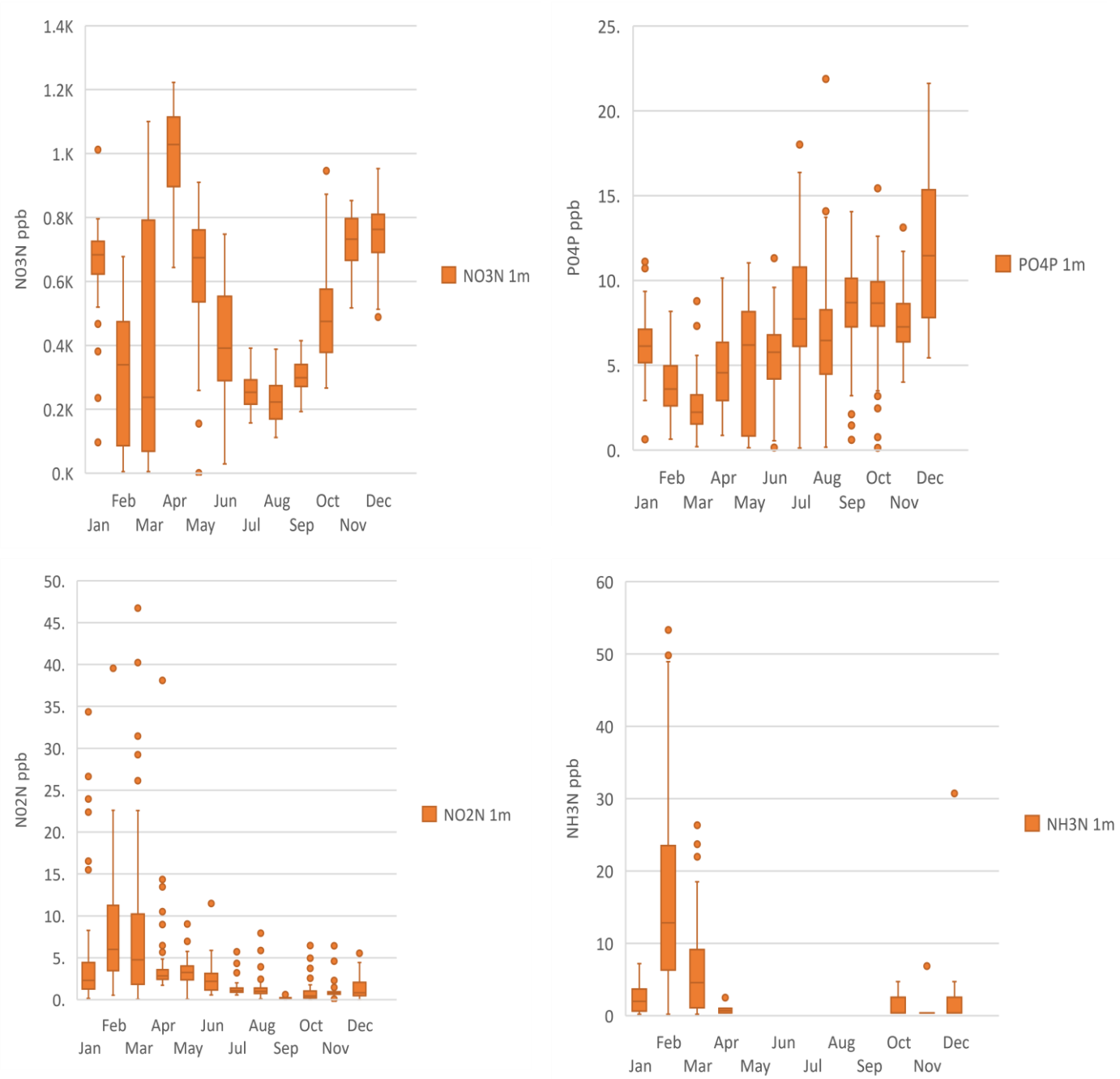


Figure 2: Nutrient Data from SS01 from January 2022 – December 2022 (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range..

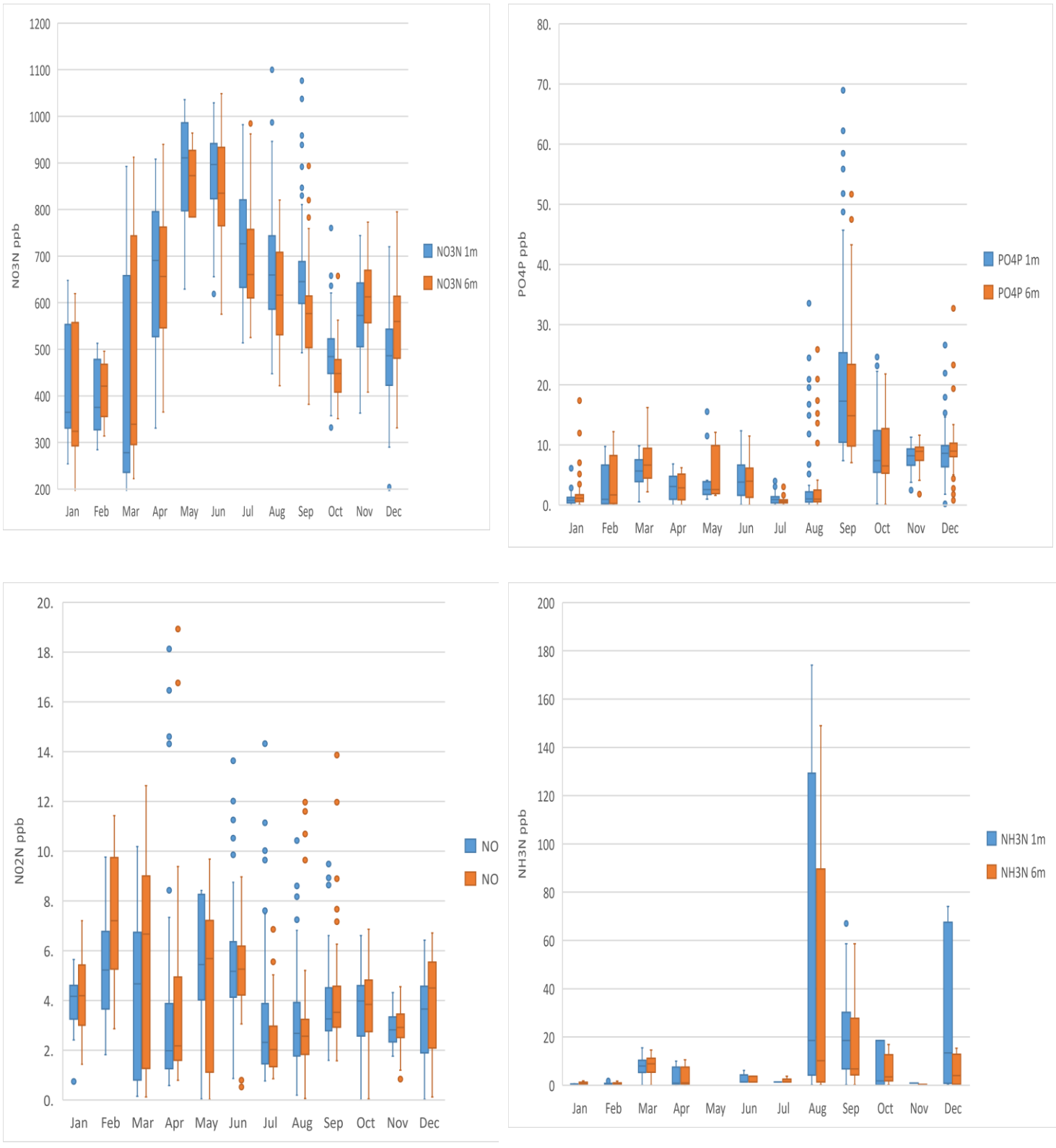


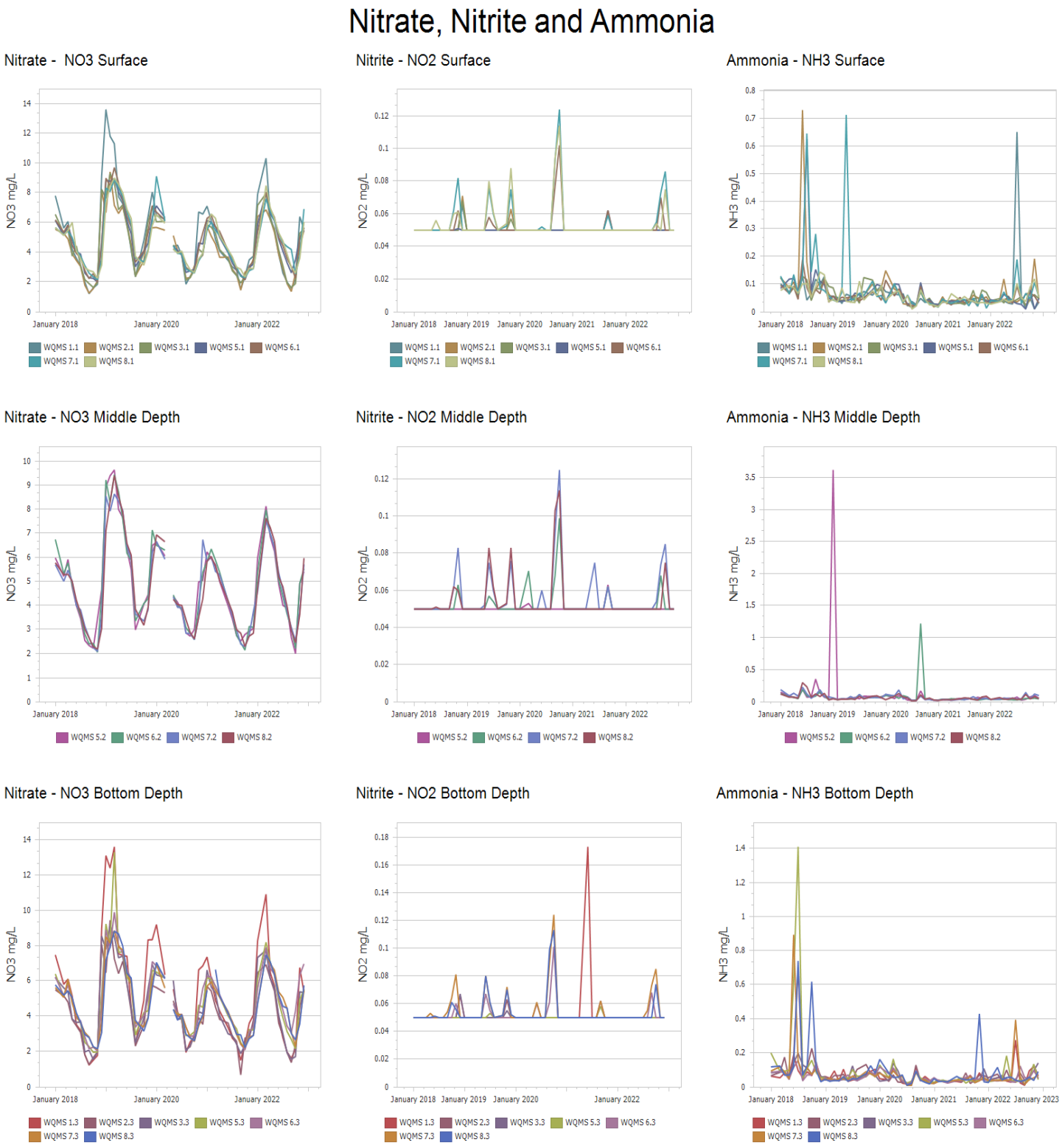
Figure 3: Nutrient Data from OL19 from January 2022 – December 2022 (Note some extreme outliers and data below the limit of detection were removed). Central boxes indicate the interquartile percentile range (IQR), the horizontal line mark the median, the whiskers mark 1.5 * interquartile range.

2.1.2. Spot Sampling

The current spot sampling programme commenced in January 2018 and includes parameters for water quality only. **Table 3** details the parameters collected at each site under the water quality monitoring programme. Depending on the depth of the water column samples are taken at the surface, mid water depth and bottom depth (just above the lake bed). At shallow water site (< 5m) samples are taken at the surface and bottom depths. All lake sites showed similar patterns for all parameters measured across all depths. **Figure 4**, **Figure 5** and **Figure 6***:* show the results of nitrate, nitrite, ammonia, alkalinity, suspended solids, phosphate, BOD, temperature and chlorophyll *a* from water quality sites on Lough Derg at all depths. **Figure 7** shows the water quality data from all inflowing rivers into Lough Derg. As with previous years nitrate (NO_3) showed a peak at the start of the year before declining through the summer months, this trend was seen across all sites and depths. All lake sites showed similar patterns for all parameters measured across all depths. Lake nitrate and phosphate values showed a steady decline from January to October and the observed spike in lake phosphate level in December did not repeat itself in 2022. Chlorophyll *a* values are low until April where an increase can be seen particularly in the surface samples. This coincides with increased water temperatures and indicates the start of the growing season in the lake. The river parameters showed much more variability between sites, particularly for the nutrients NO_3 and PO_4P with WQMS 9 and WQMS 13 showing much higher NO_3 values than the other rivers. Both these sites are located on the eastern shore of the lake indicating a higher nutrient status on the eastern side of the catchment.

Table 3: List of parameters collected under the spot sampling programme.

Parameter	**Units**
Alkalinity, Total as $CaCO_3$	mg/l
Ammoniacal Nitrogen as NH_3	mg/l
Nitrate as NO_3	mg/l
Nitrite as NO_2	mg/l
Phosphate (Ortho as P)	mg/l
Suspended solids, Total	mg/l
BOD	mg/l
Chlorophyll *a*	µg/l
Temperature	ºC
Dissolved Oxygen %	%/mg/l
pH	pH units
Conductivity	µS/cm



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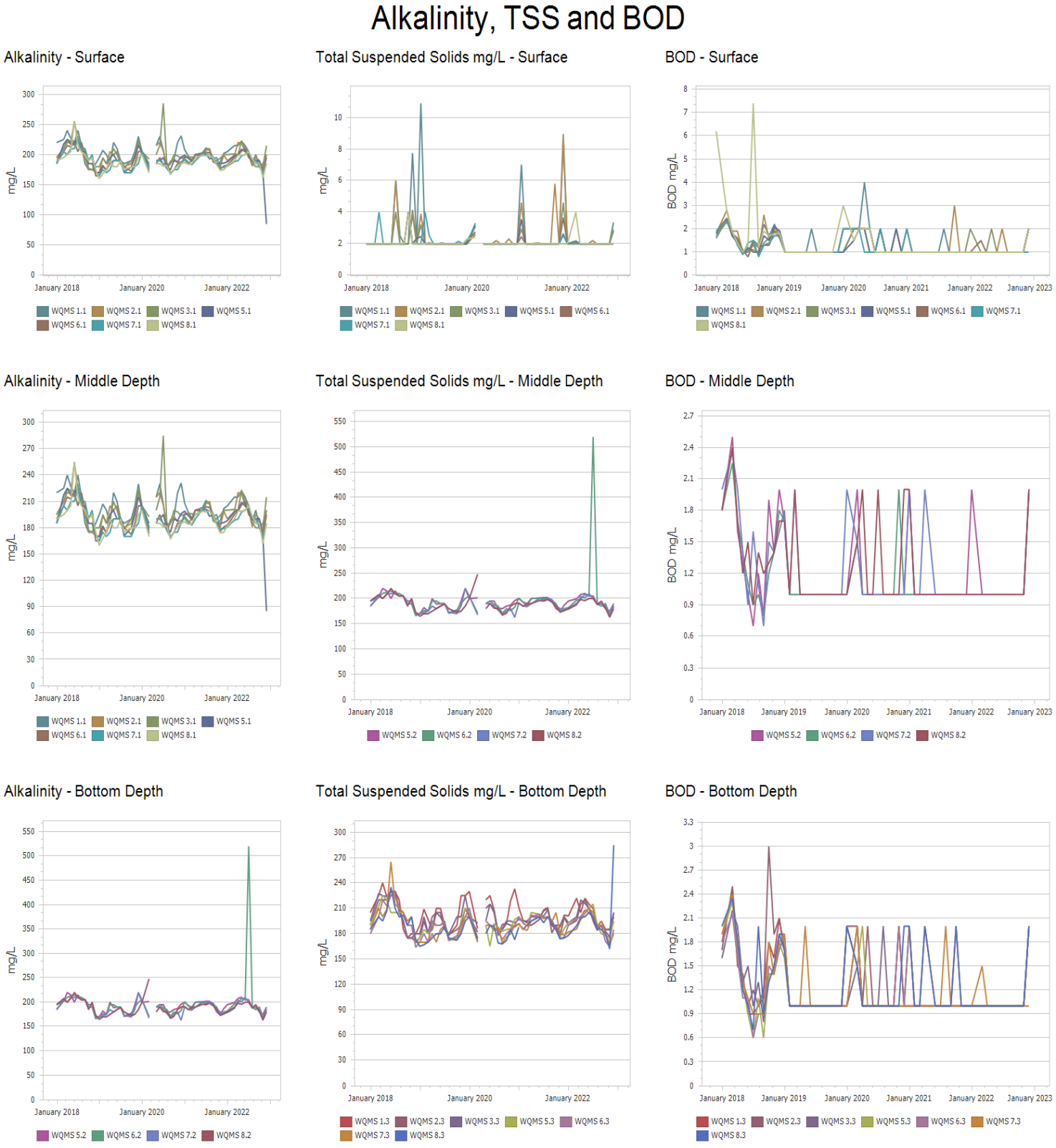


Figure 5: Survey results from all lake water quality sites of Alkalinity, Suspended Solids and BOD from January 2018– December 2022.

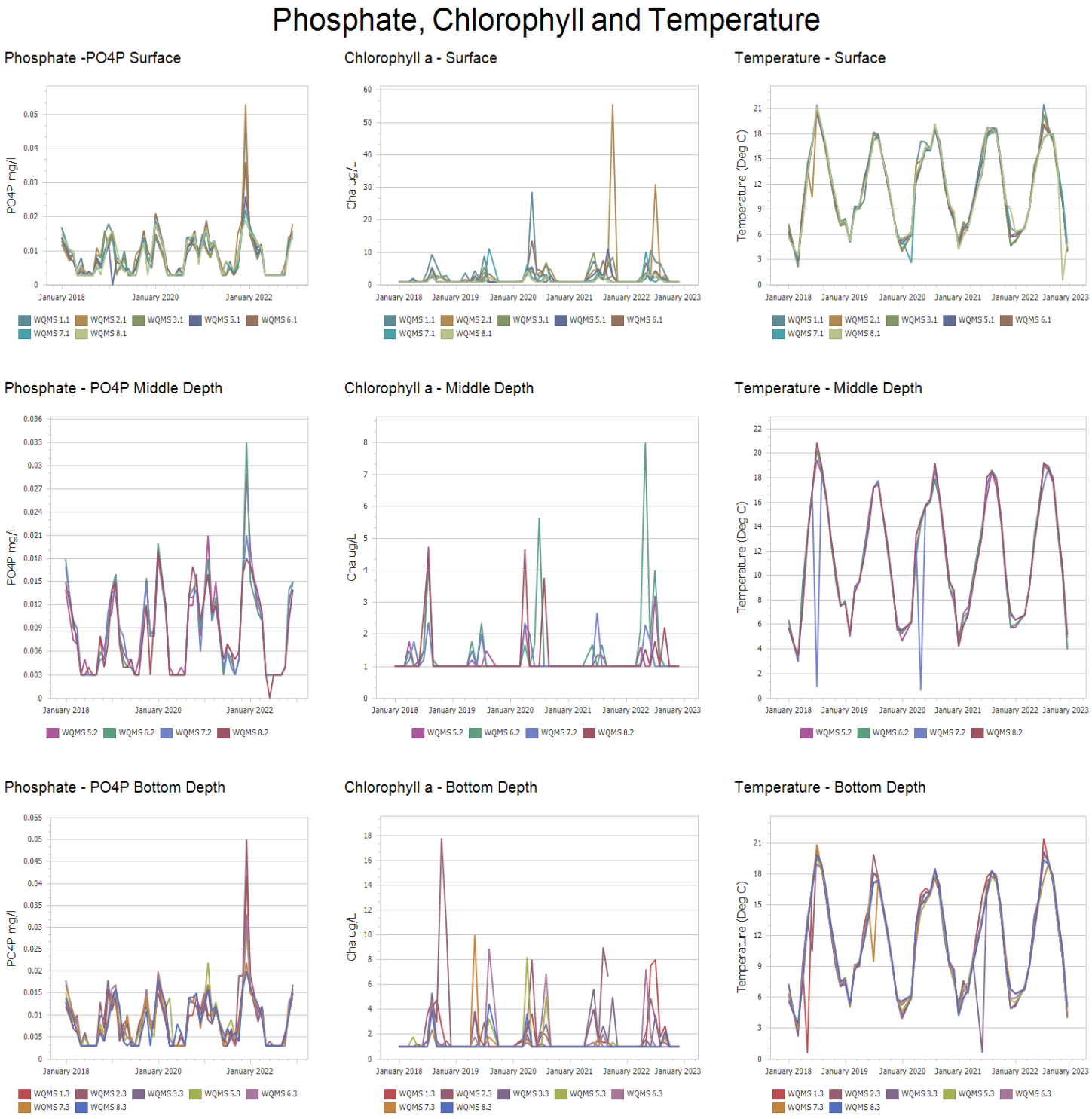


Figure 6: Survey results from all lake water quality sites of Chlorophyll a and Phosphate (PO4P) and Temperature from January 2018– December 2022.

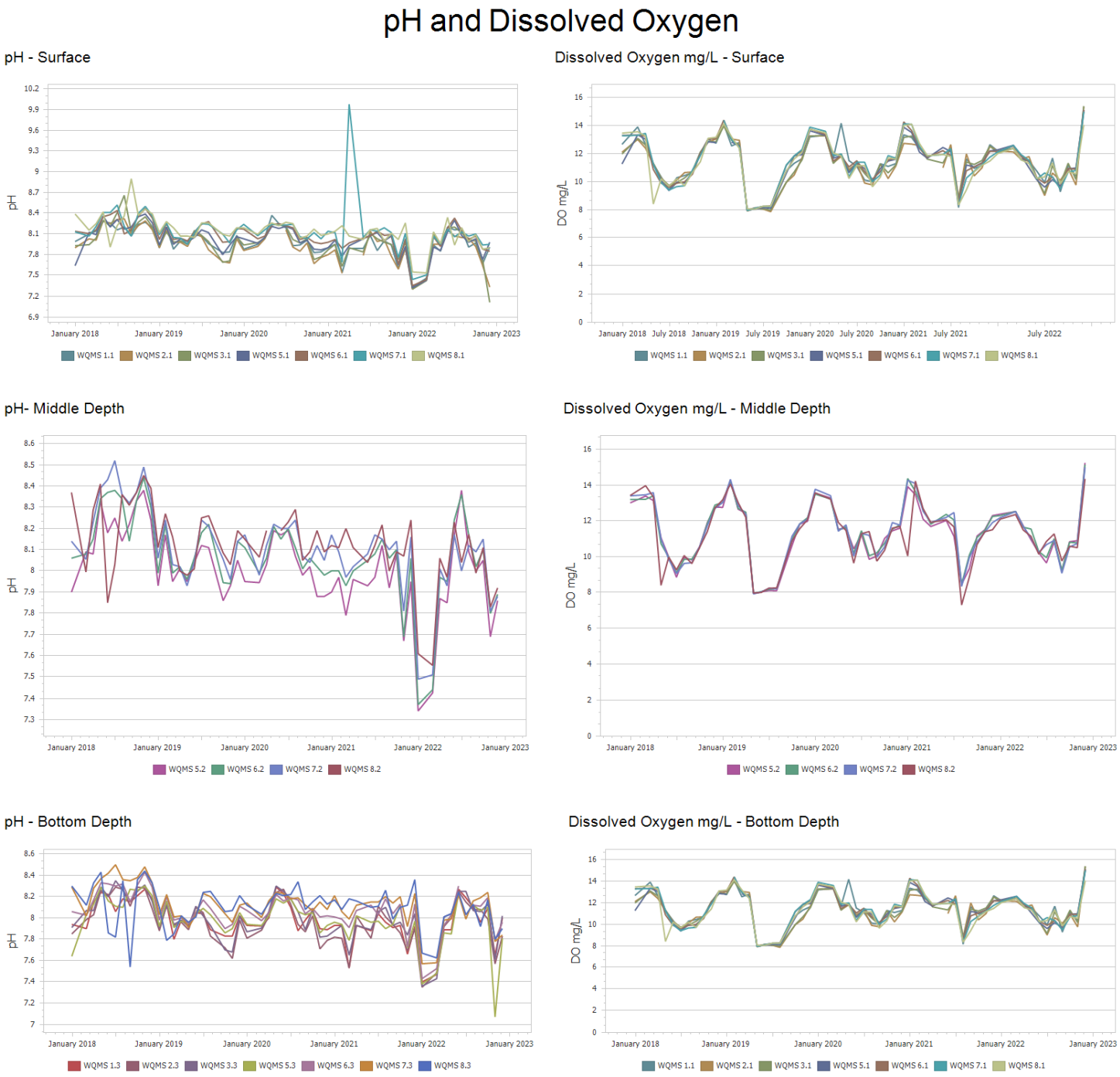


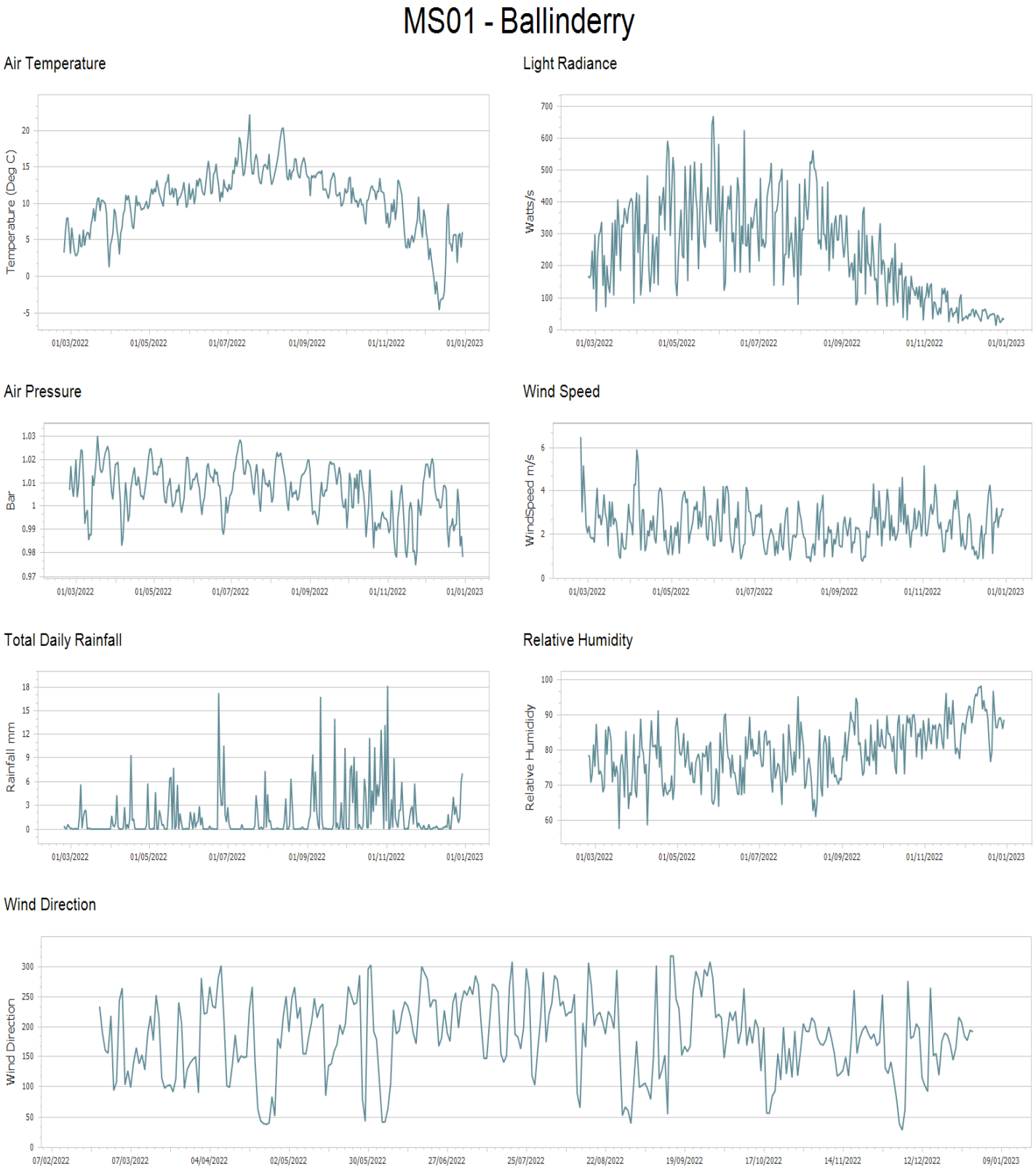
Figure 7: Survey results from all lake water quality sites of pH and Dissolved Oxygen from January 2018– December 2022.

Figure 8 Survey results from all river water quality sites of nitrate (NO3), nitrite (NO2), ammonia (NH3), phosphate (PO4P), chlorophyll a and temperature, Alkalinity, pH, and Dissolved Oxygen from January 2018– December 2022

2.2. T800 Meteorological Survey

Two meteorological stations were installed on the eastern and western shore of Lough Derg on the 17th/18th February 2016. Stations were deployed with sensors measuring wind speed, wind direction, precipitation, barometric pressure, air temperature, solar radiance, relative humidity. The station at Whitegate MS02 suffered from technical issues in the first quarter of 2022 however after repairs it returned to full operational status for the remaining portion of the study period. Both stations showed similar patterns to 2021 with no remarkable changes in weather patterns. Both sites exhibited similar weather measurements for all parameters except for Wind direction which have more localised variations.

Whitegate Met Station



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3. Appendices

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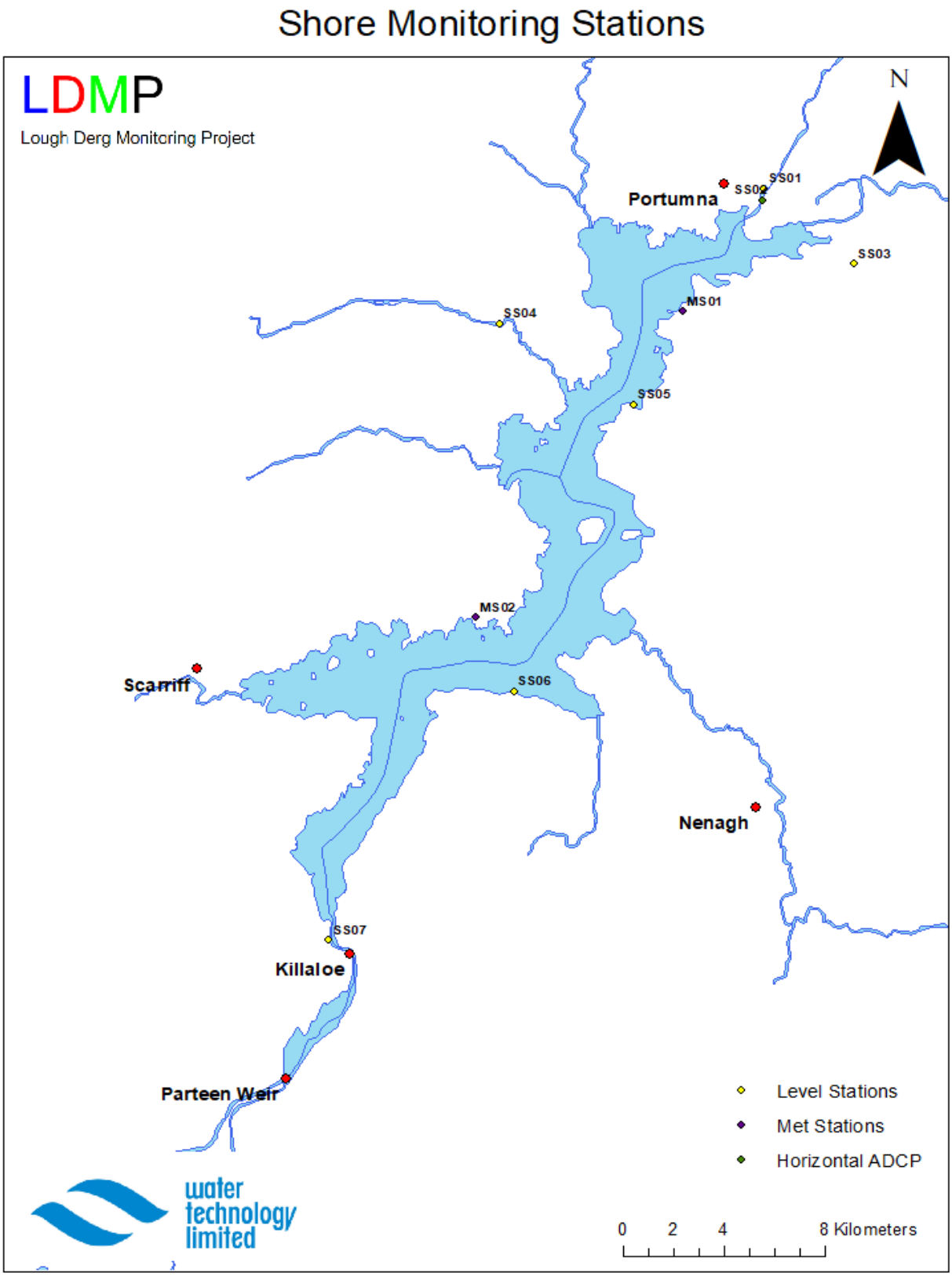
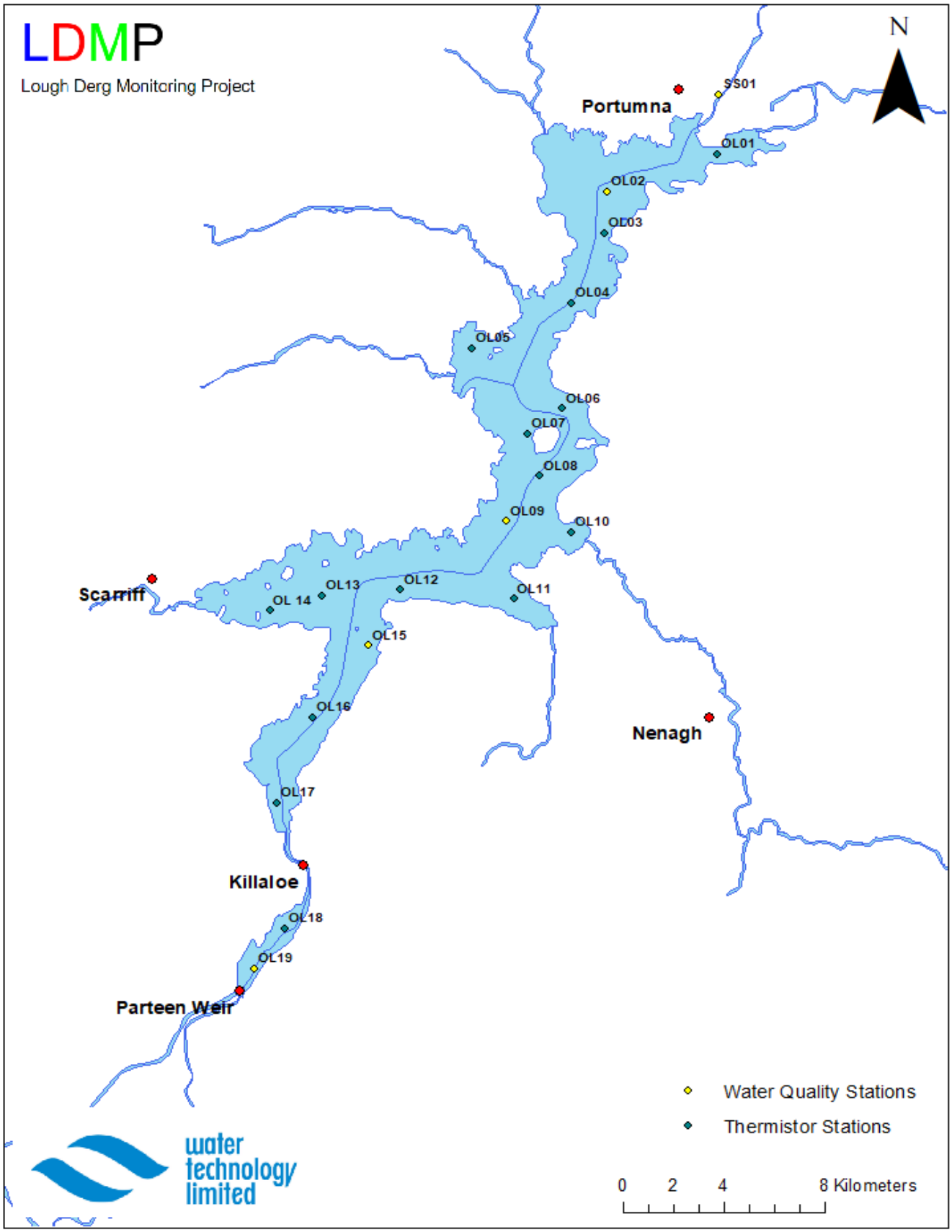
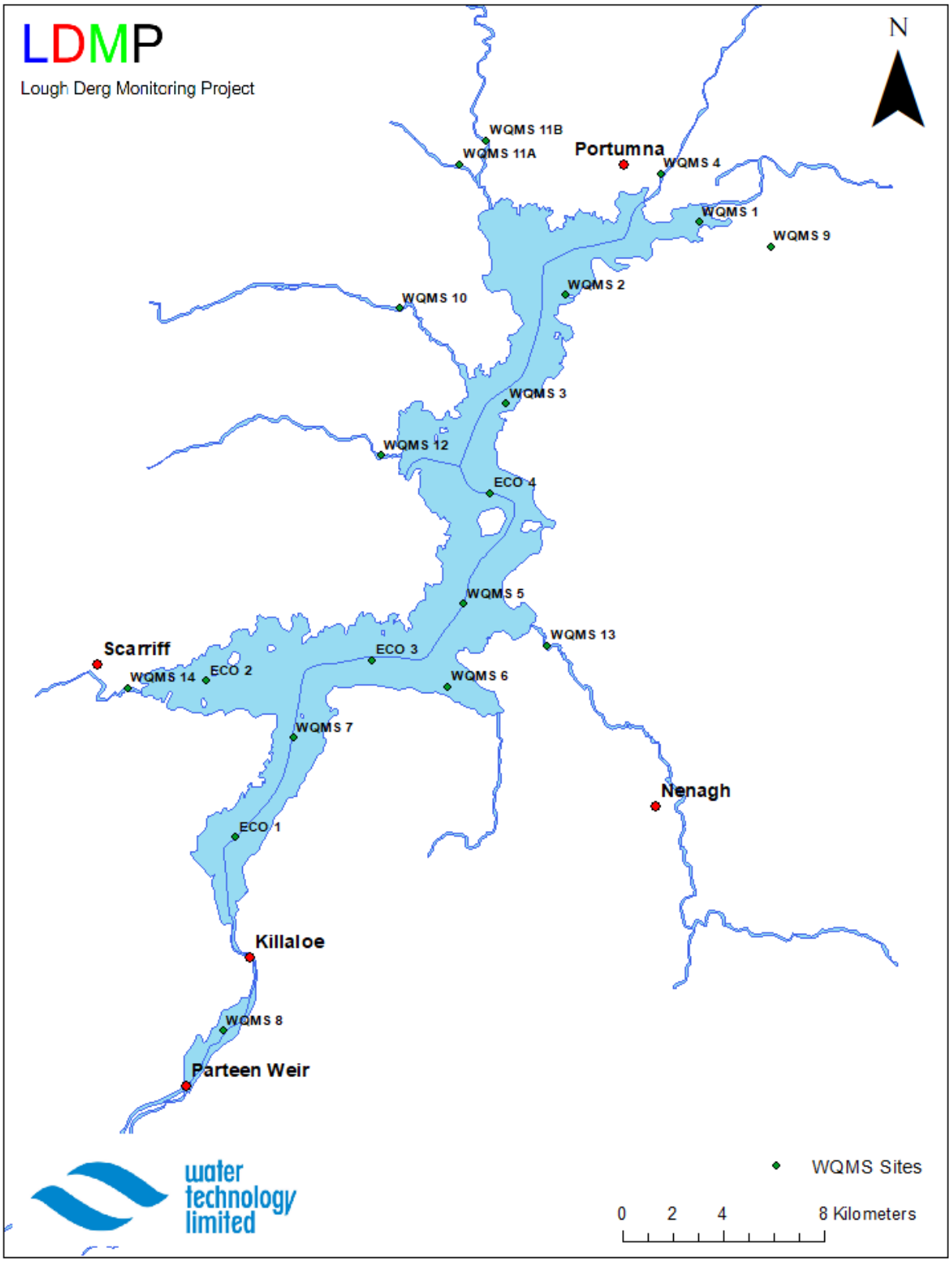


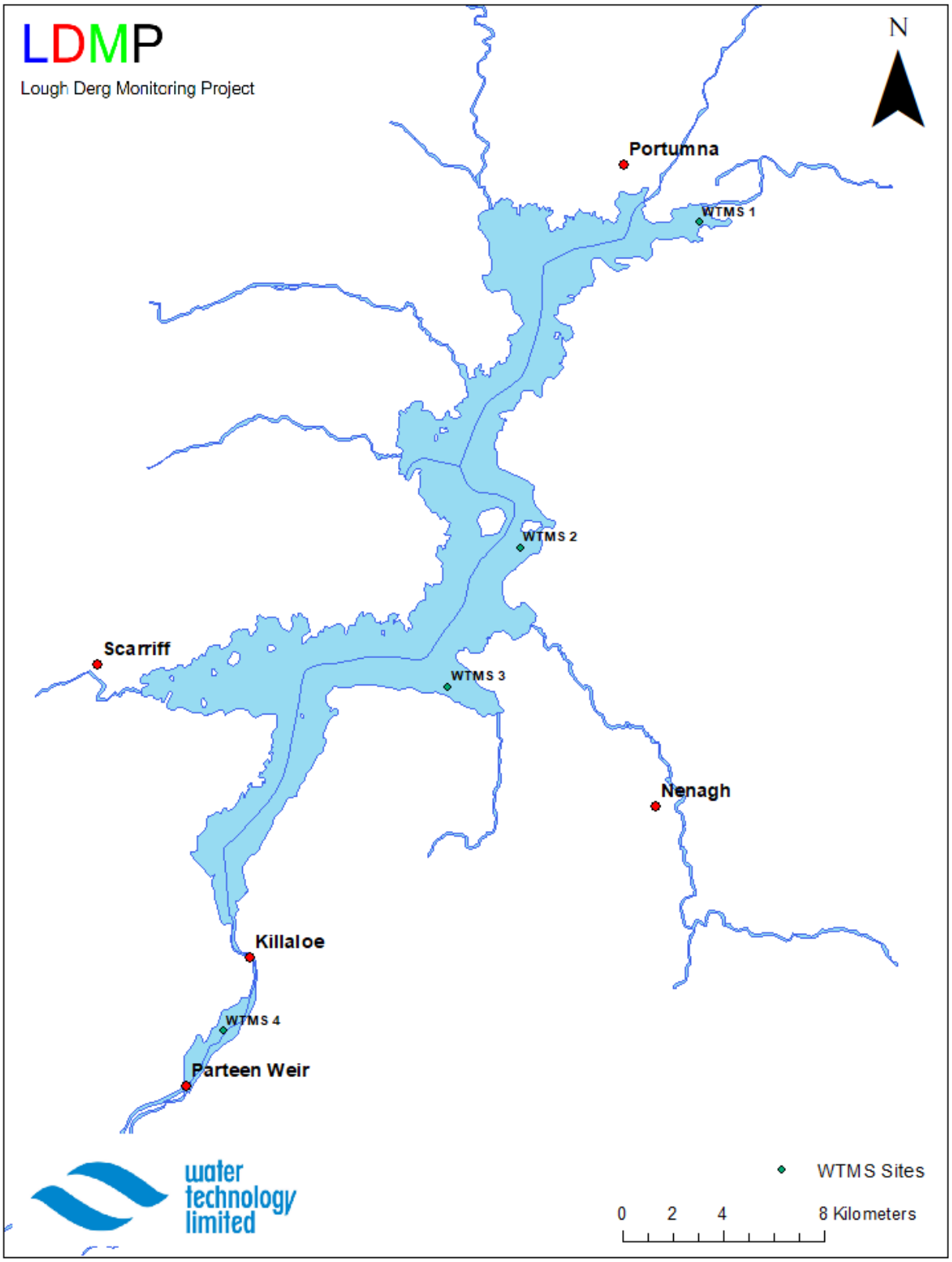
Open Water Monitoring Stations



Water Quality Monitoring Site Locations



Water Treatability Monitoring Site Locations



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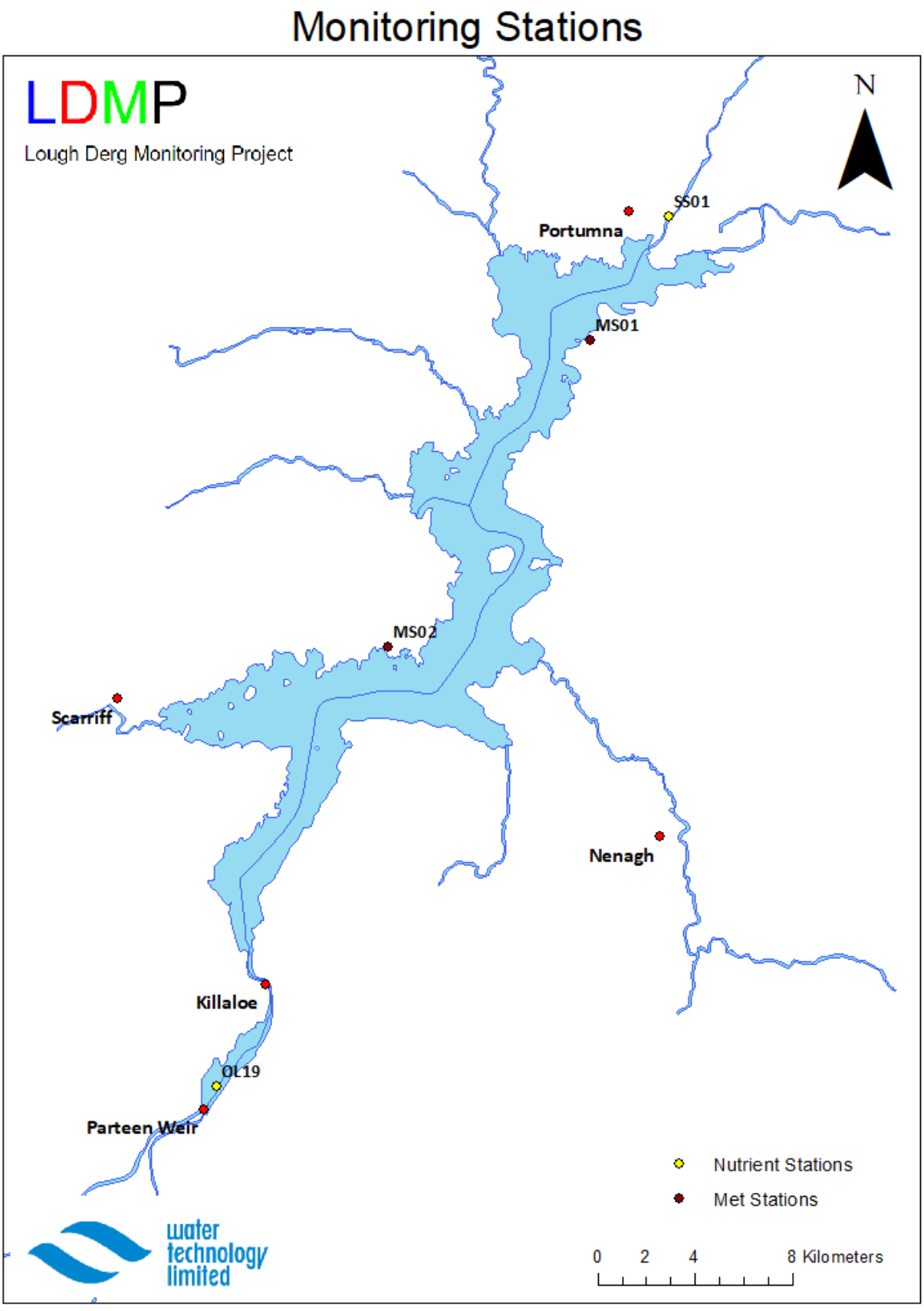

4. References

Minchin, D. and R. Boelens (2011). "The Distribution and Expansion of Ornamental Plants on the Shannon Navigation." Biology and Environment-Proceedings of the Royal Irish Academy **Vol IIIB**(3): 1-9.

Water Supply Project Eastern and Midlands Region – Lough Derg Monitoring Project (LDMP)

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Client Representative	**Jacobs Engineering Ireland Ltd**
Project Title:	**Water Supply Project Eastern and Midlands Region**
Document Title:	**Annual data report for Lough Derg Monitoring Project (Jan 2023 – Dec 2023)**
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1. Introduction

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The Lough Derg Monitoring Project undertaken by Water Technology Ltd. consists of a limnological data collection project based in Lough Derg which involves the use of installed instruments and sampling on a multiyear basis and delivery of specific data collection objectives to their client Jacobs Consulting Engineers. The project has been running since April 2015.

1.1. Study Area

Lough Derg is an alkaline lake located on the River Shannon (**Figure 1**) between counties Clare, Tipperary and Galway. The main inflowing river is the Shannon which enters the lough at Portumna and flows out of the lake at the southern end at Killaloe. The lake is 40km long and 13km at it widest point. The majority of the lake lies on Carboniferous limestone with the exception of the narrow southern section which is underlain by Silurian strata. The surrounding catchment of the northern end of the lake is mainly flat agricultural land while the southern end of the lake is bordered by the Slieve Aughty Mountains to the west and the Arra Mountains to the east. The northern end of the lake has an average depth of 6m. Two deep trenches occur in the lake, one in the middle portion and one at the southern end with average depths of >34m and >25m respectively.

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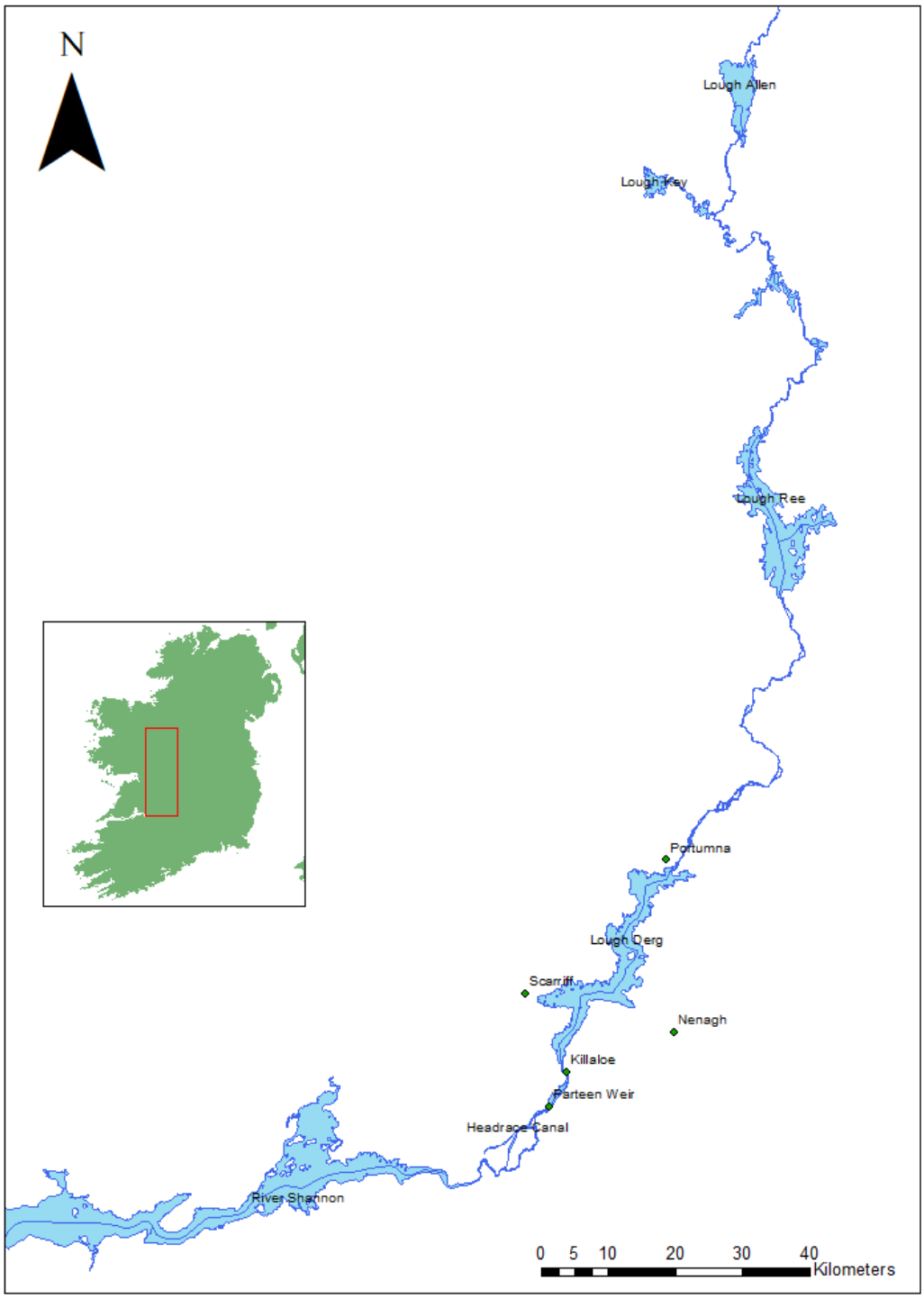

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1.2. Site decommissioning

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Table 1: Status of remaining LDMP stations as of 31st Dec 2023.

Station	Station Type	Status
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MS02 (Whitegate)	Weather Station	Live
OL19 (Parteen Basin)	Nutrient Analyser	Live
SS01 (Portumna Bridge)	Nutrient Analyser	Live
PLS001 (Ballina WWTP)	Level Station	Live
PLS002 (Forthenry)	Level Station	Live
PLS003 (Clonfada Upper)	Level Station	Live
PLS005 (Ardclooney Upper)	Level Station	Live
LS101 (Portumna Bridge)	Level Station	Live
LS102 (Cloondavaun)	Level Station	Live
LS103 (TwoMileGate)	Level Station	Live
SS01 (Portumna Bridge)	Level Station/Water Quality	Decommissioned
SS02 (Portumna River)	Horizontal ADCP	Decommissioned
SS03 (Carraigahorig River)	Level Station	Decommissioned
SS04 (Woodford River)	Level Station	Decommissioned
SS05 (Coolbaun)	Level Station	Decommissioned
SS06 (Garrykennedy)	Level Station	Decommissioned
SS07 (Killaloe)	Level Station	Decommissioned
OL02 (North of lake)	Water Quality/Nutrients/ADCP	Decommissioned
OL09 (Outside Dromineer Bay)	Water Quality/Nutrients/ADCP	Decommissioned
OL15 (Parkers Point)	Water Quality/Nutrients/ADCP	Decommissioned
OL19 (Parteen Basin)	Water Quality/ADCP	Decommissioned

2. Results to date

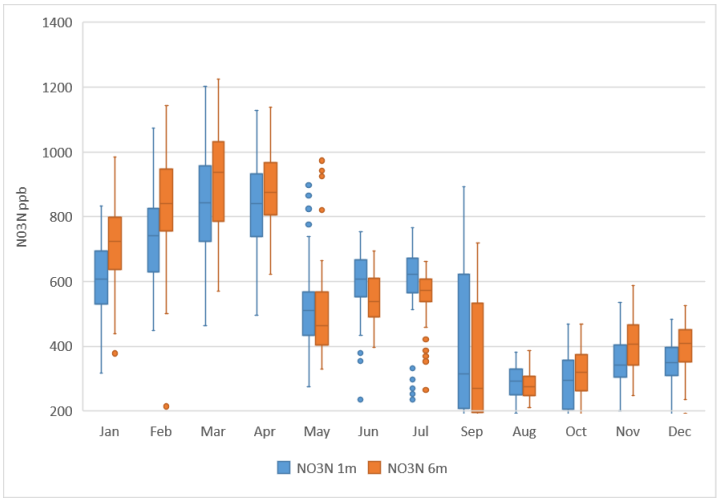
2.1. T500 Water Quality Survey

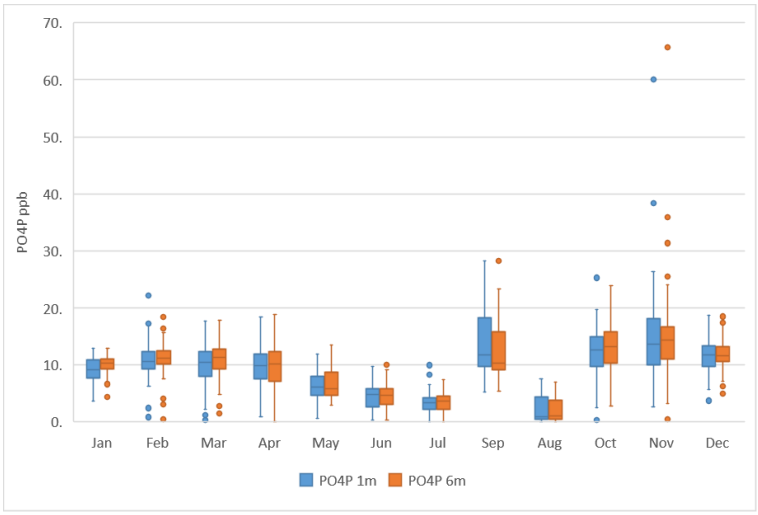
2.1.1. In-situ sampling

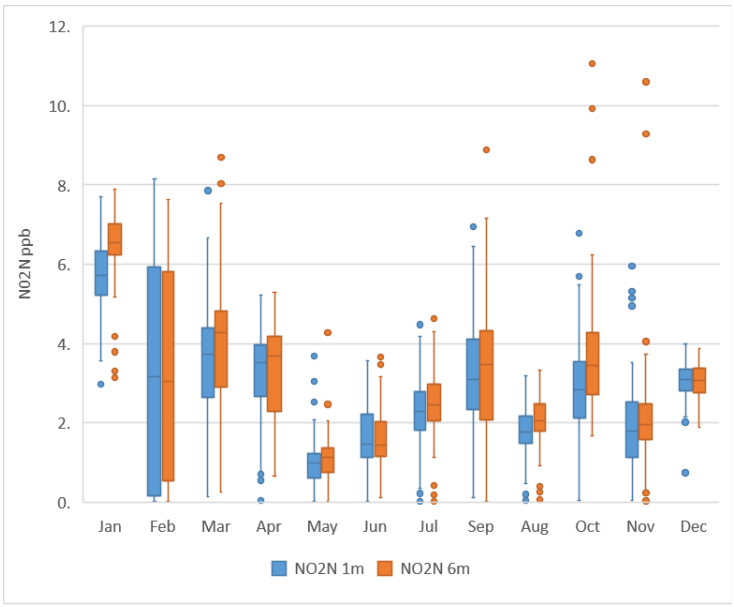
Two in-situ nutrient analysers are deployed one at Parteen Basin near the outflow of the River Shannon (OL19) and one on the inflow of the River Shannon at Portumna Bridge (SS01). **Figure 2**, and **Figure 3** show nutrients data from both sites from Jan 2023 –Dec 2023. **Table 2** shows the mean value of all nutrients from each site and depth across the study period Many of the NH_3N results were below the limit of detection and is considered to be zero. Nitrate levels at both sites noticeably decreased during the second half of the year.

Table 2: Mean values of nutrients in parts per billion (ppb) from Jan 2023 - Dec 2023. Note: Many values of NH3N were below limit of detection of the device, mean values may not be accurate.

Site	Depth (m)	NO_3N	NO_2N	PO_4P	NH_3N
OL19	1	526	2.8	9.2	1.6
	6	548	3.1	9.5	1.2
SS01	1	530	2.2	8.6	2.6







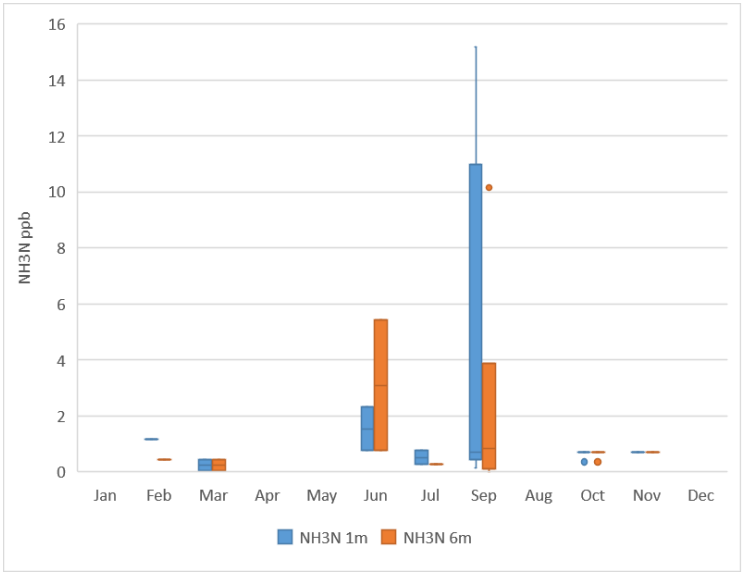


Figure 2: Nutrient Data from OL19 from Jan 2023 – Dec 2023 (Note some extreme outliers and data below the limit of detection were removed. Most NH_3N readings below Limit of Detection).

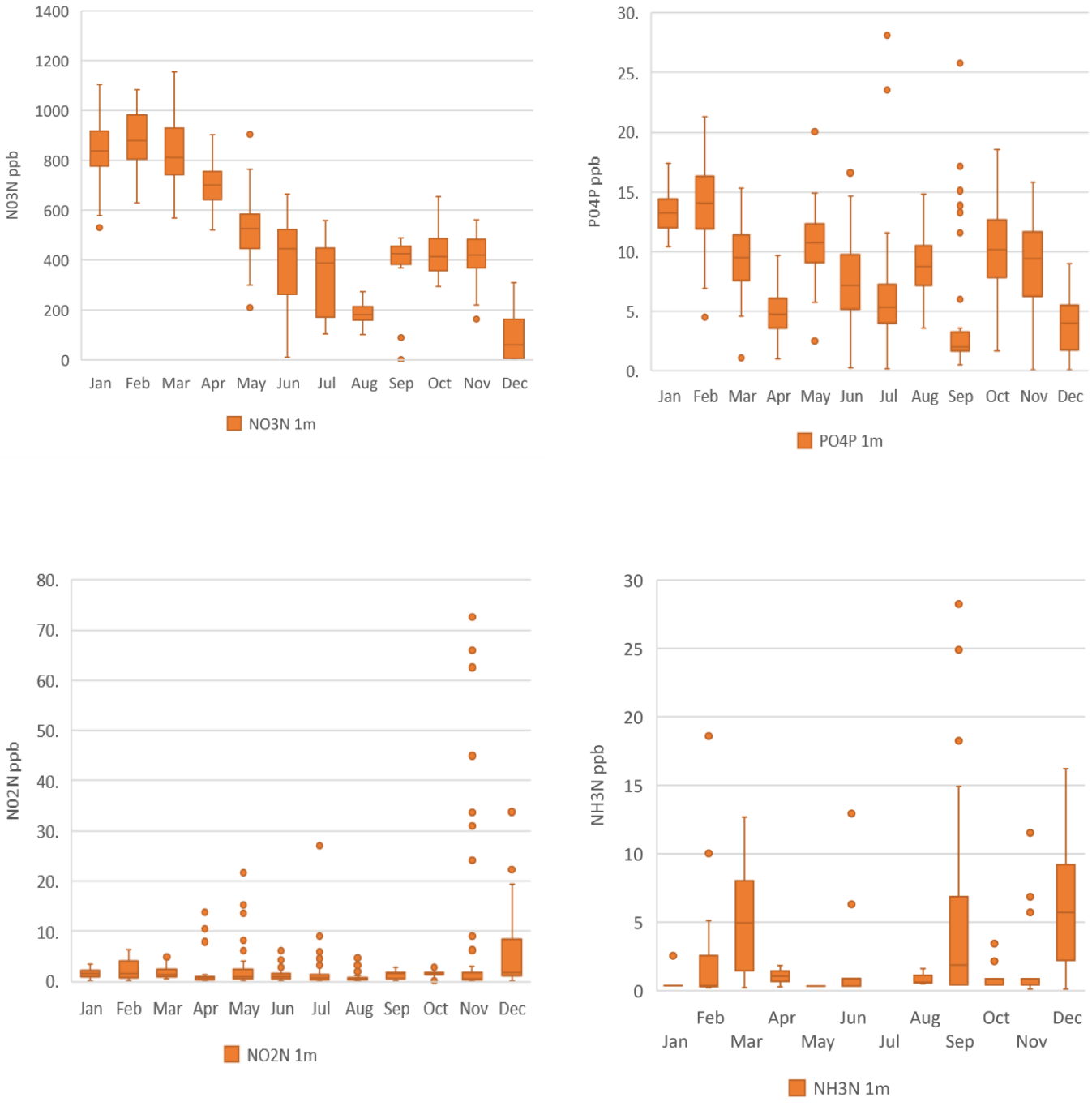


Figure 3: Nutrient Data from SS01 from Jan 2023 – Dec 2023 (Note some extreme outliers and data below the limit of detection were removed. Many NH_3N readings below Limit of Detection).

2.1.2. Spot Sampling

The spot sampling programme restarted in January 2018. **Table 3** details the parameters collected at each site under the water quality monitoring programme. A new test was sourced for Ammoniacal Nitrogen (NH_3) with a lower limit of detection in line with the values expected within the lake. **Appendix 1** shows the locations of all sites sampled. Depending on the depth of the water column samples are taken at the surface, mid water depth and bottom depth (just above the lake bed). At shallow water site (< 5m) samples are taken at the surface and bottom depths.

Table 3: List of parameters collected under the spot sampling programme.

Parameter	**Units**
Alkalinity, Total as $CaCO_3$	mg/l
Ammoniacal Nitrogen as NH_3	mg/l
Nitrate as NO_3	mg/l
Nitrite as NO_2	mg/l
Phosphate (Ortho as P)	mg/l
Suspended solids, Total	mg/l
BOD	mg/l
Chlorophyll *a*	µg/l
Temperature	ºC
Dissolved Oxygen %	%/mg/l
pH	pH units
Conductivity	µS/cm

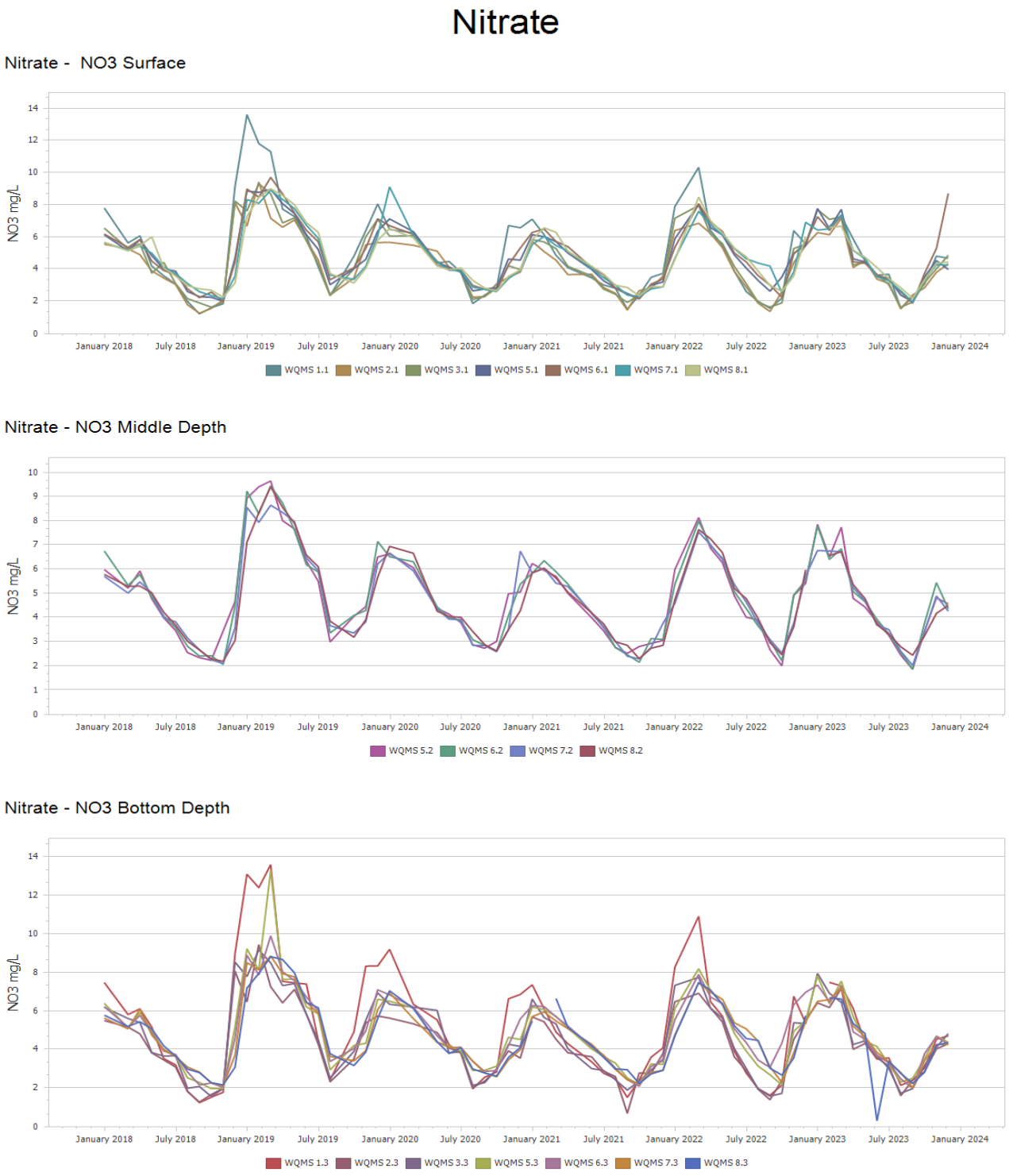


Figure 4: Survey results from all lake water quality sites of nitrate (NO3) from January 2018 – Dec 2023.

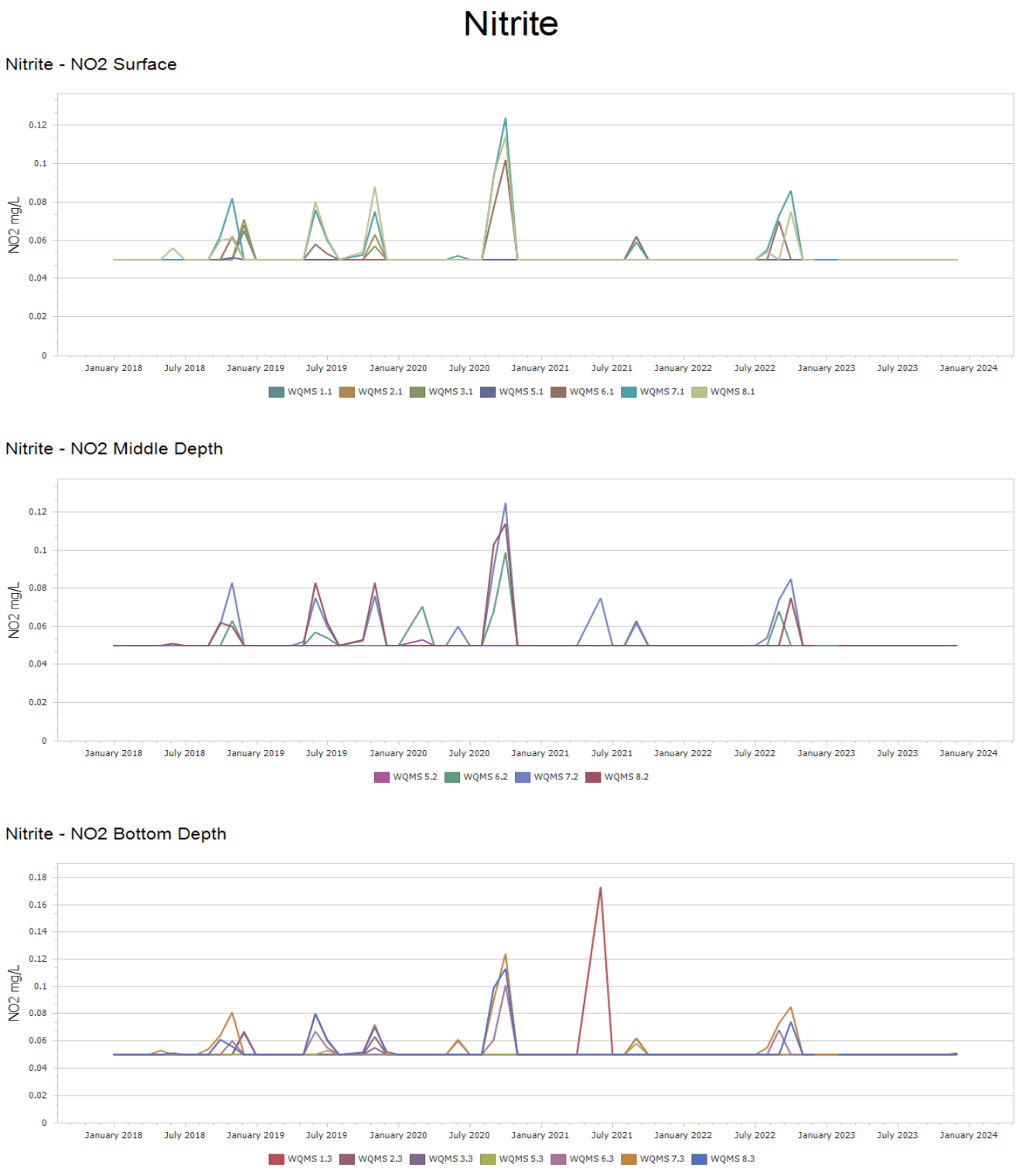
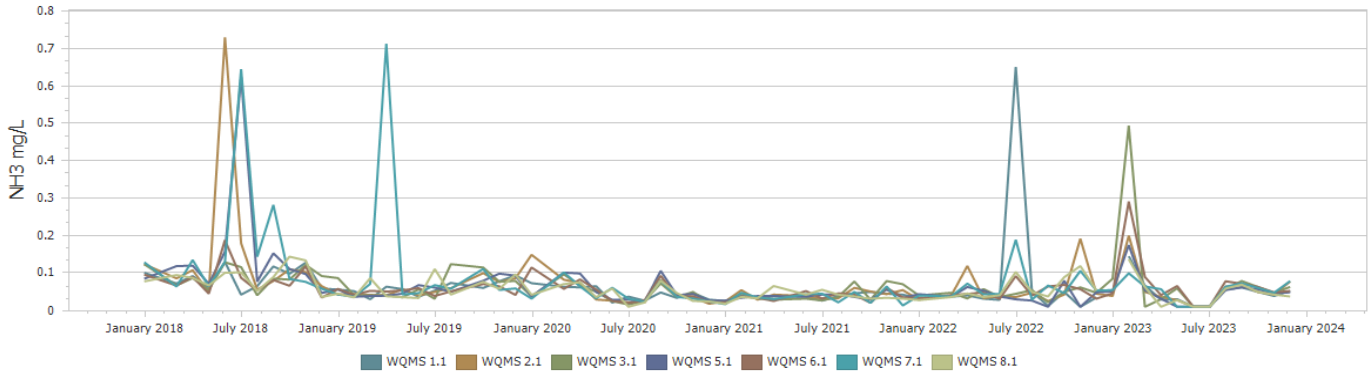


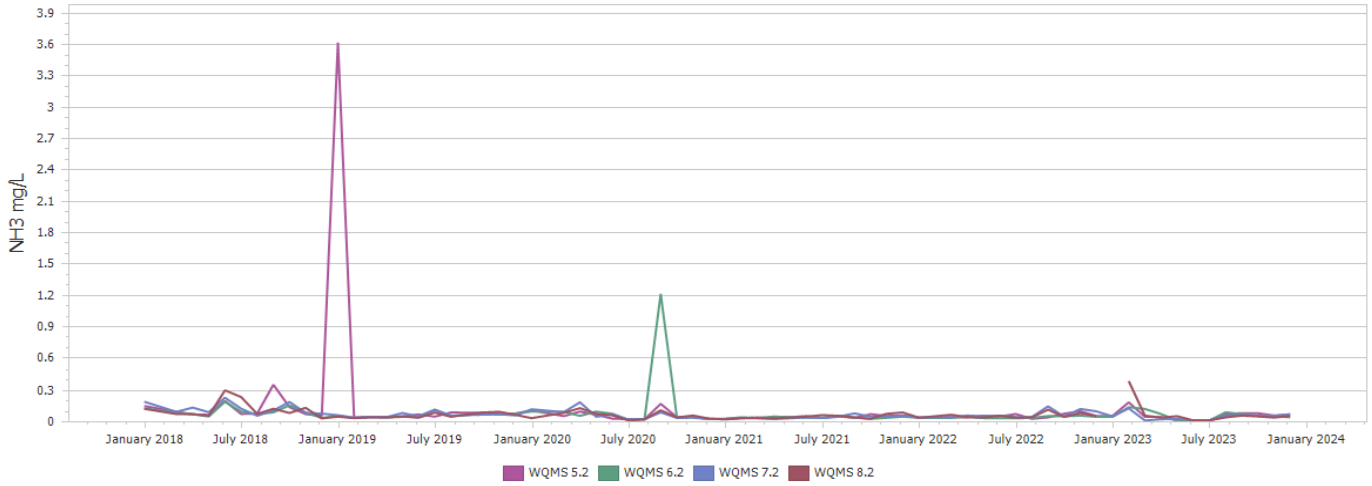
Figure 5: Survey results from all lake water quality sites of nitrite (NO2) from January 2018 – Dec 2023.

Ammonia

Ammonia - NH3 Surface



Ammonia - NH3 Middle Depth



Ammonia - NH3 Bottom Depth

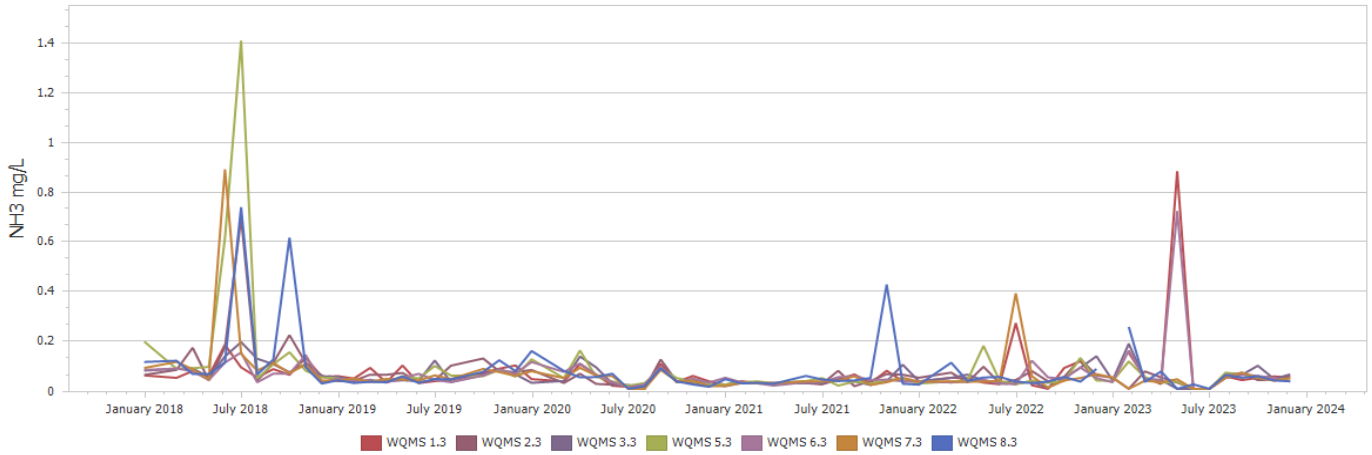


Figure 6: Survey results from all lake water quality sites of ammonia (NH3) from January 2018 – Dec 2023.

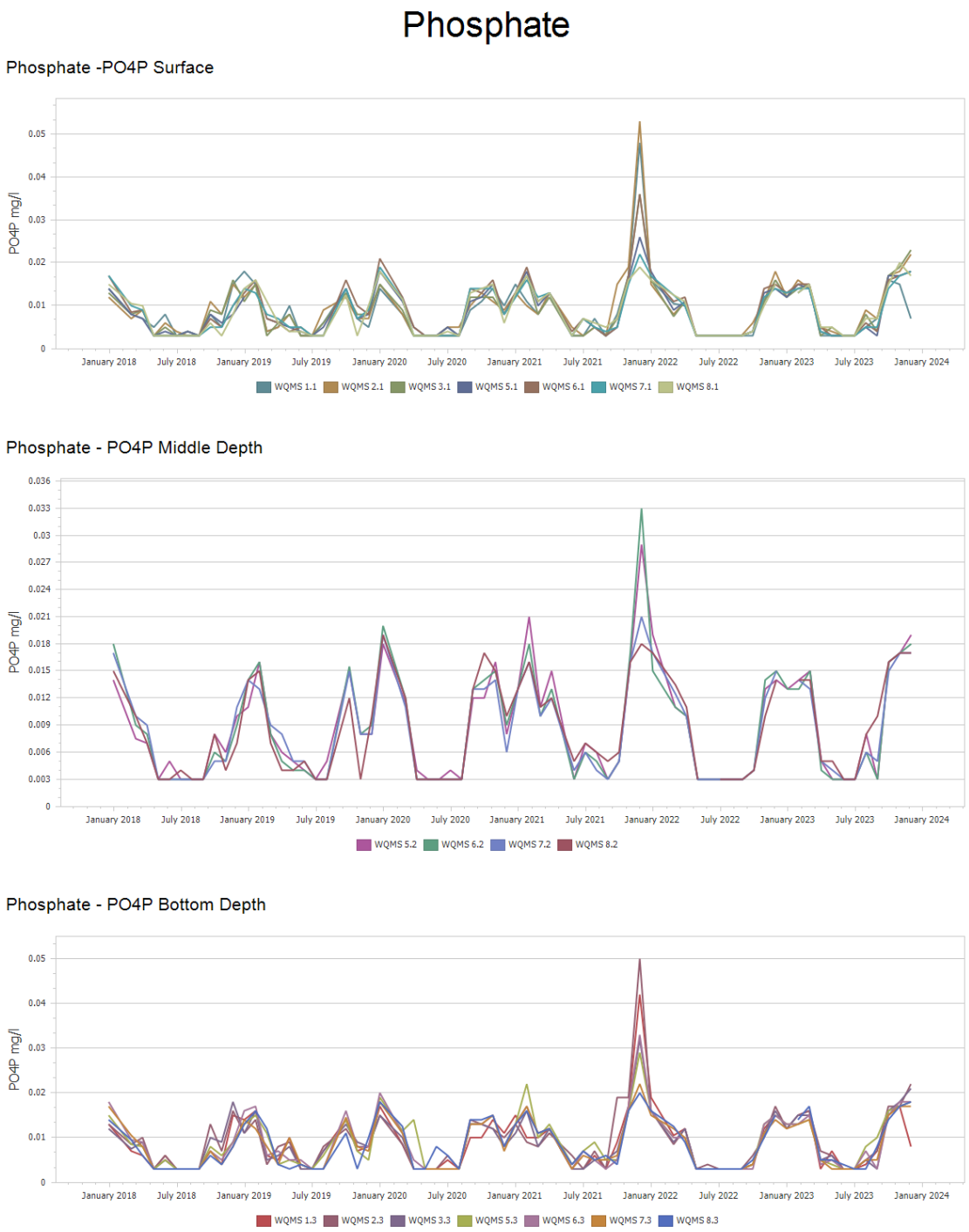


Figure 7: Survey results from all lake water quality sites of Phosphate from January 2018 – Dec 2023.

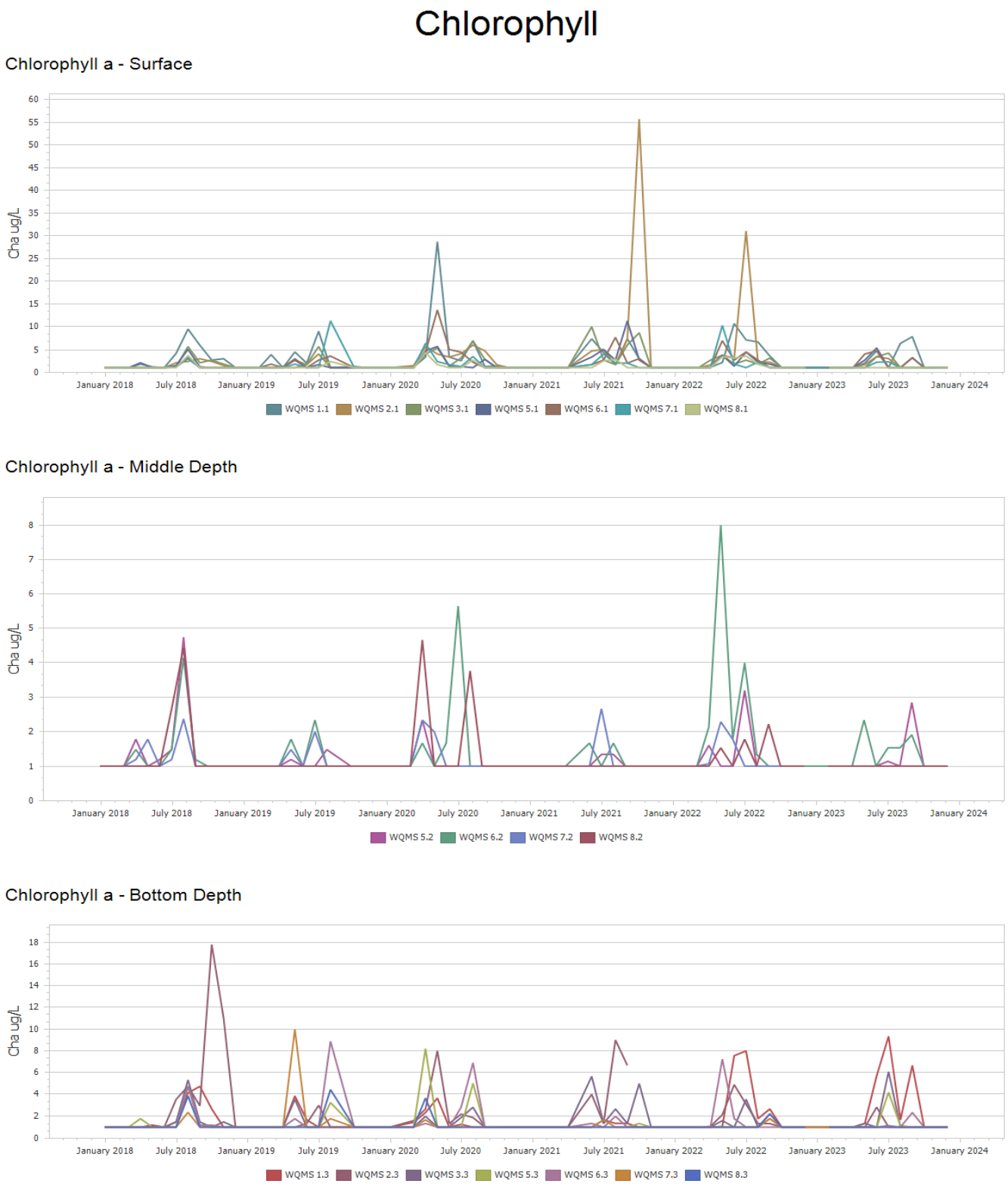
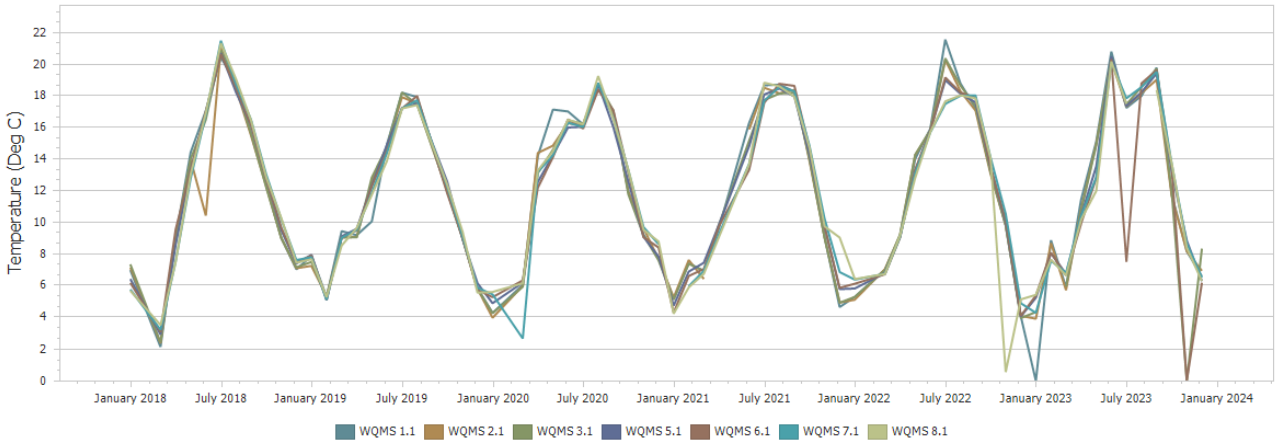


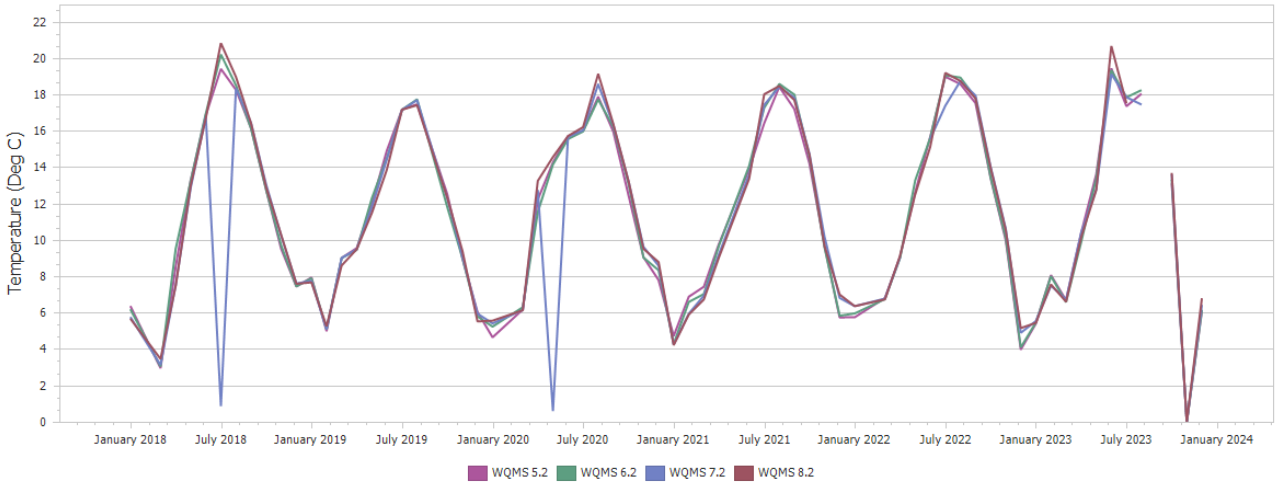
Figure 8: Survey results from all lake water quality sites of Chlorophyll a, from January 2018 – Oct 2023.

Temperature

Temperature - Surface



Temperature - Middle Depth



Temperature - Bottom Depth

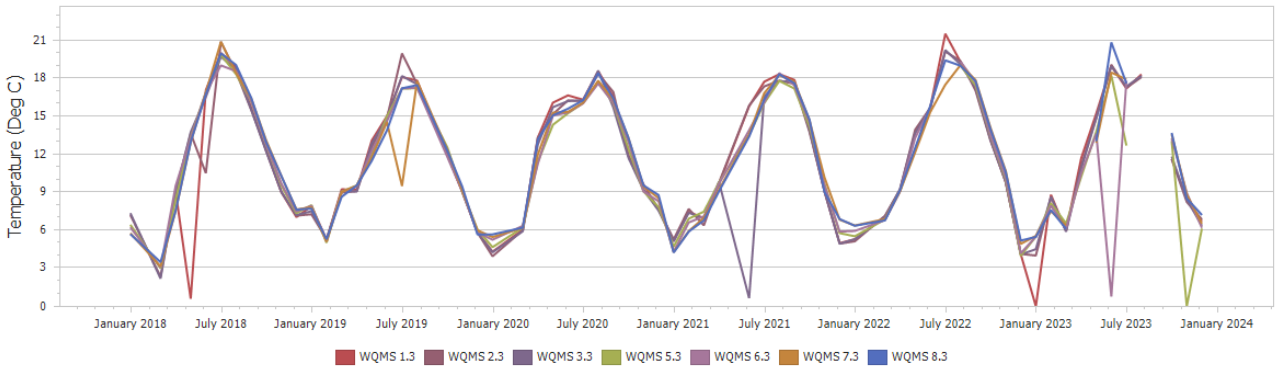


Figure 9: Survey results from all lake water quality sites Temperature from January 2018 – Dec 2023.

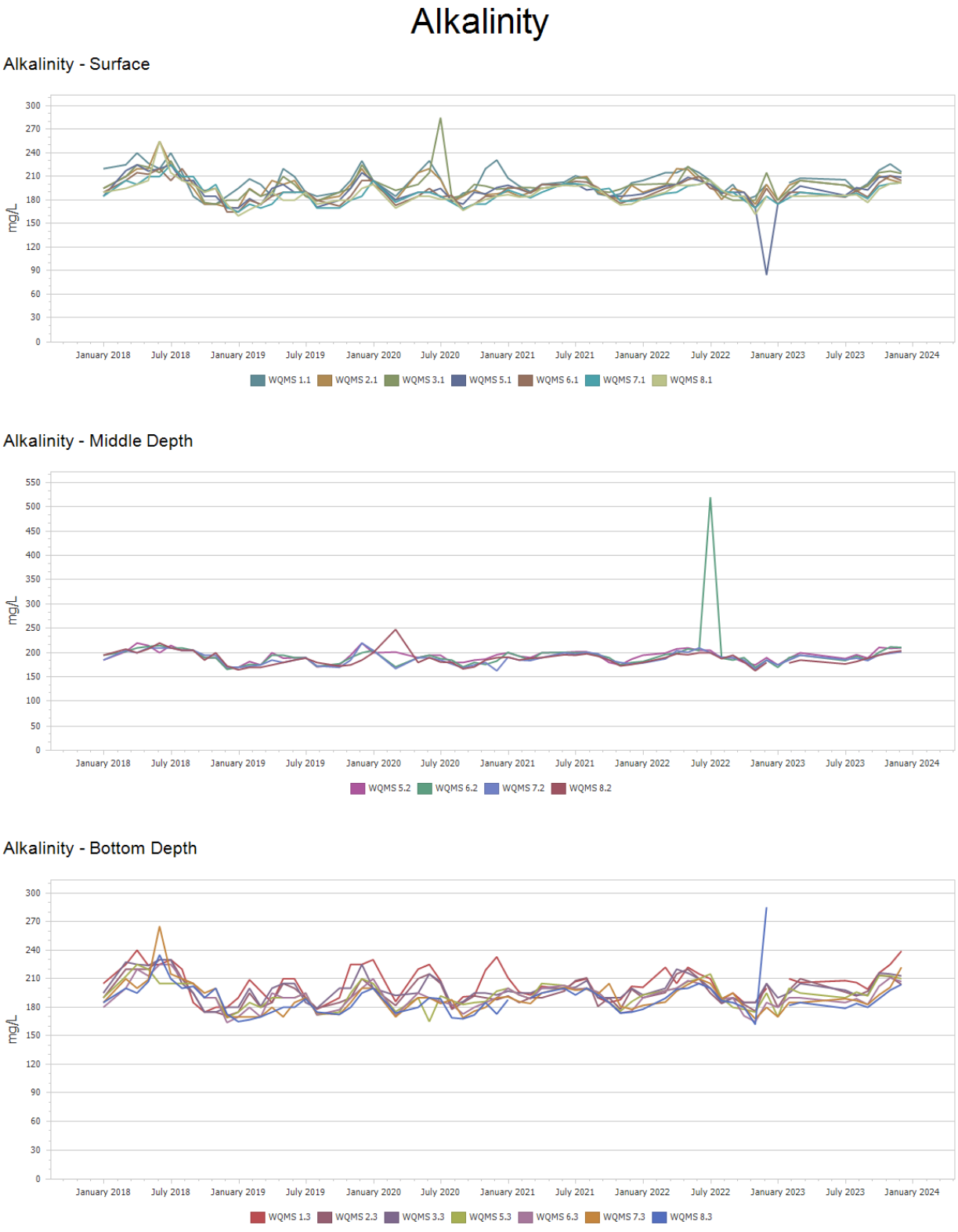
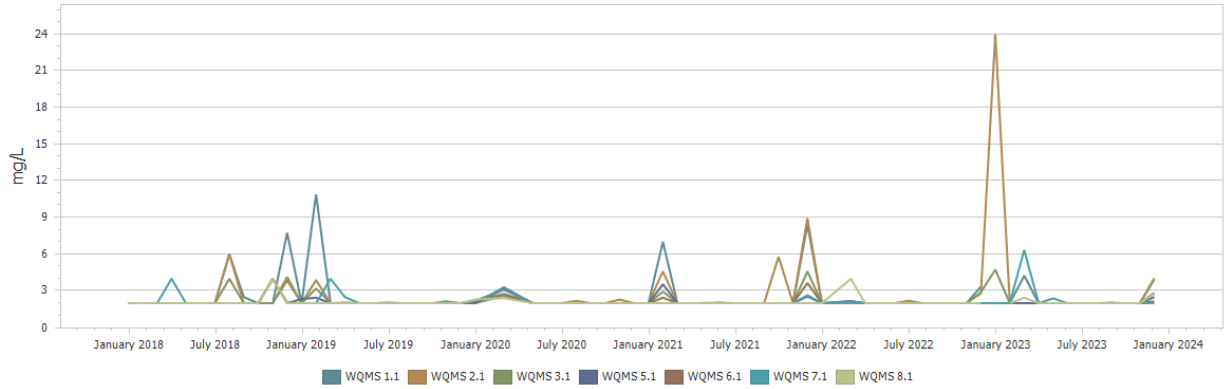


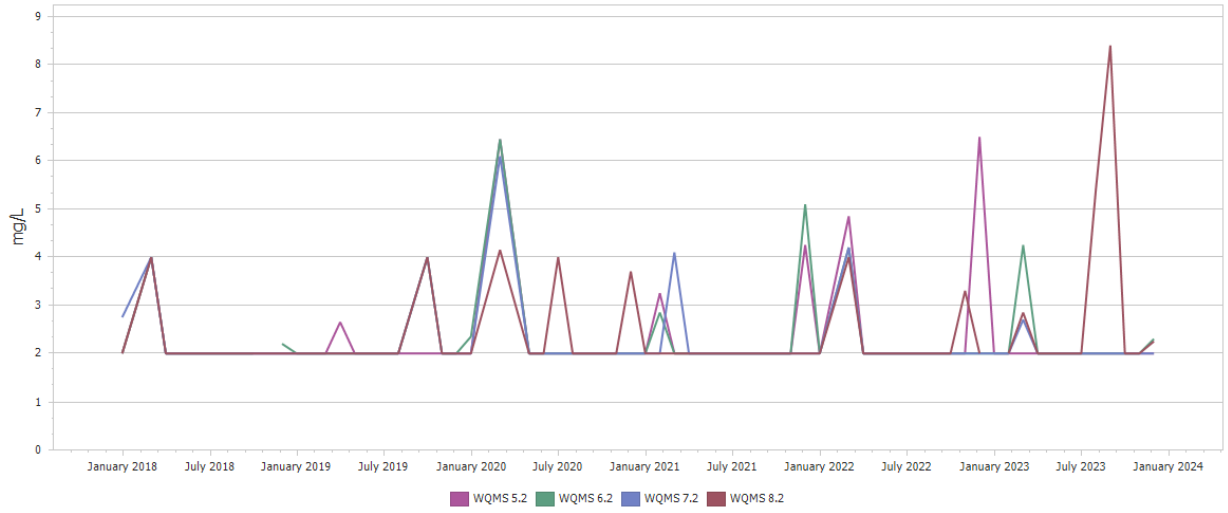
Figure 10: Survey results from all lake water quality sites of Alkalinity from January 2018 – Dec 2023.

TSS

Total Suspended Solids mg/L - Surface



Total Suspended Solids mg/L - Middle Depth



Total Suspended Solids mg/L - Bottom Depth

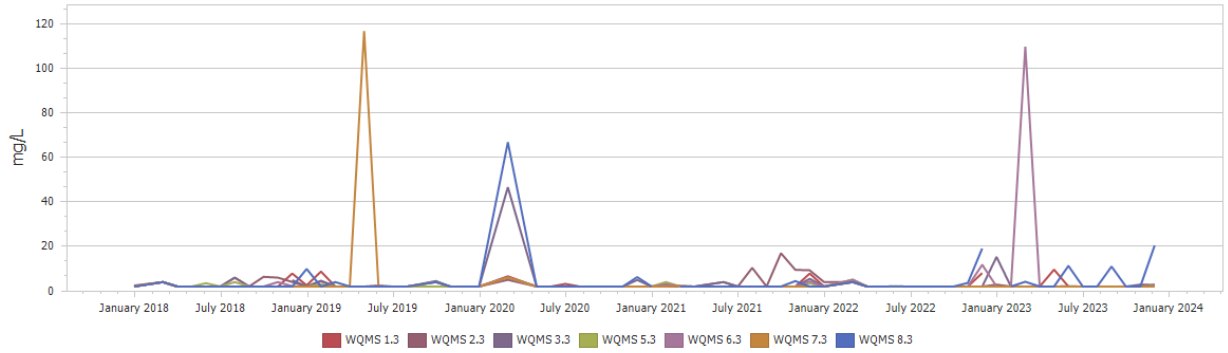
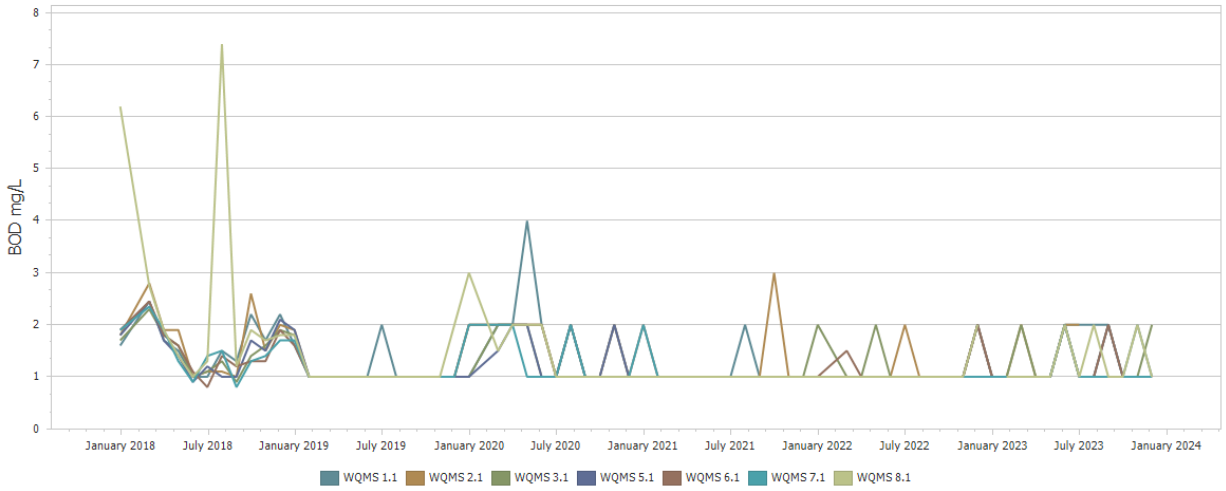


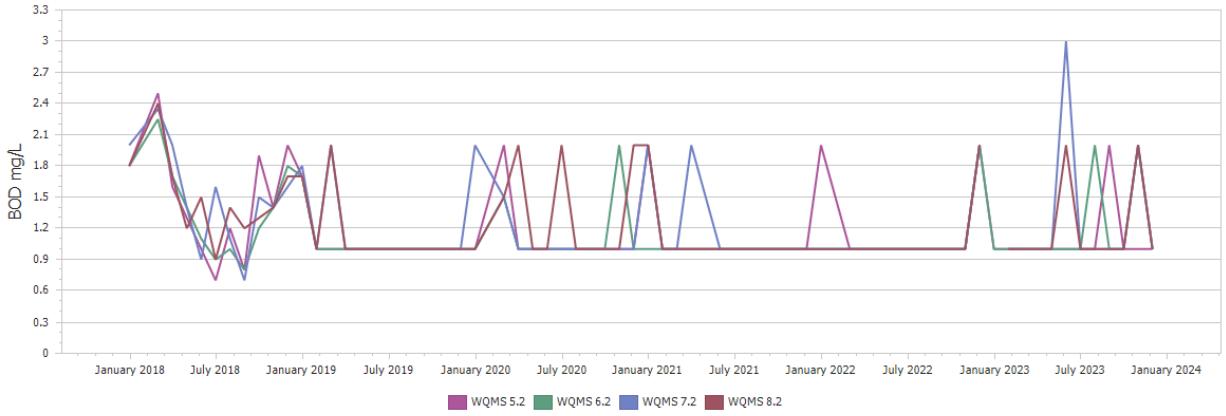
Figure 11: Survey results from all lake water quality sites of Total Suspended Solids from January 2018 – Dec 2023.

BOD

BOD - Surface



BOD - Middle Depth



BOD - Bottom Depth

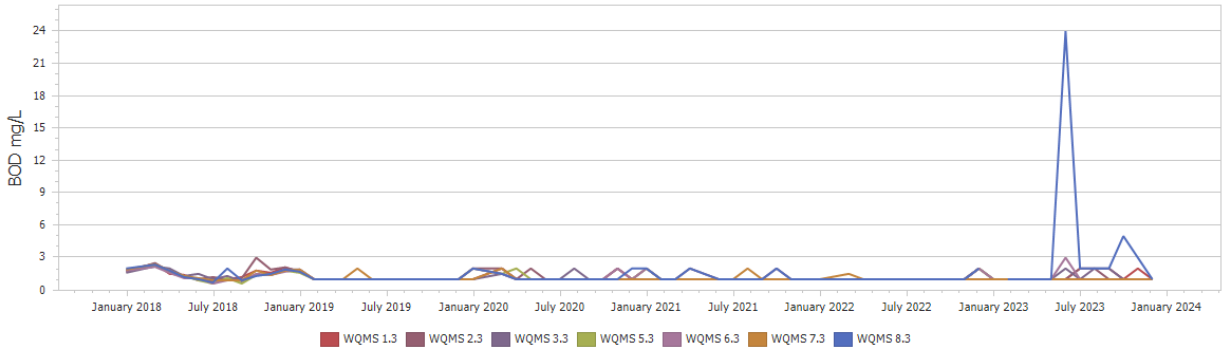


Figure 12:Survey results from all lake water quality sites of BOD from January 2018 – Dec 2023.

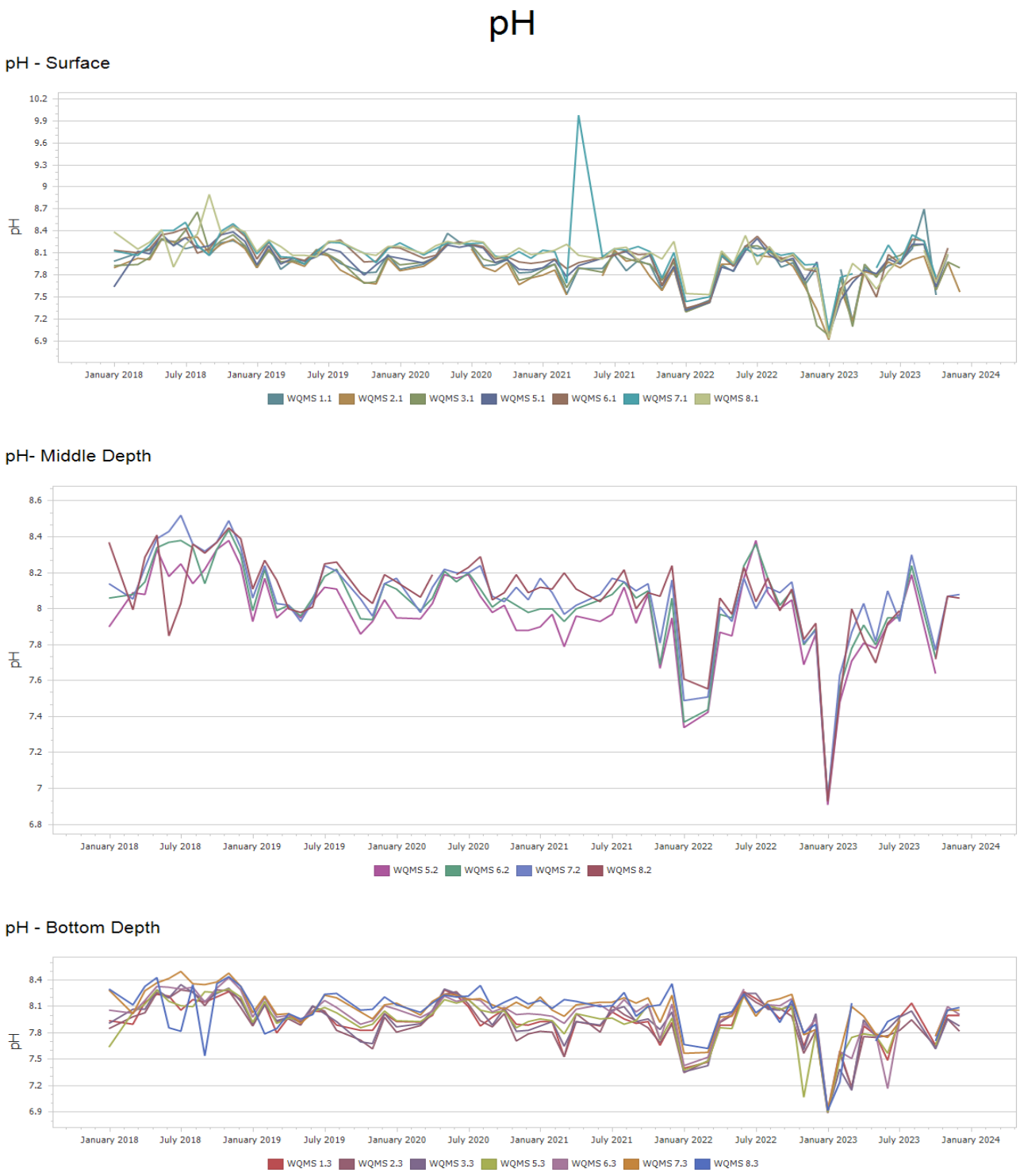
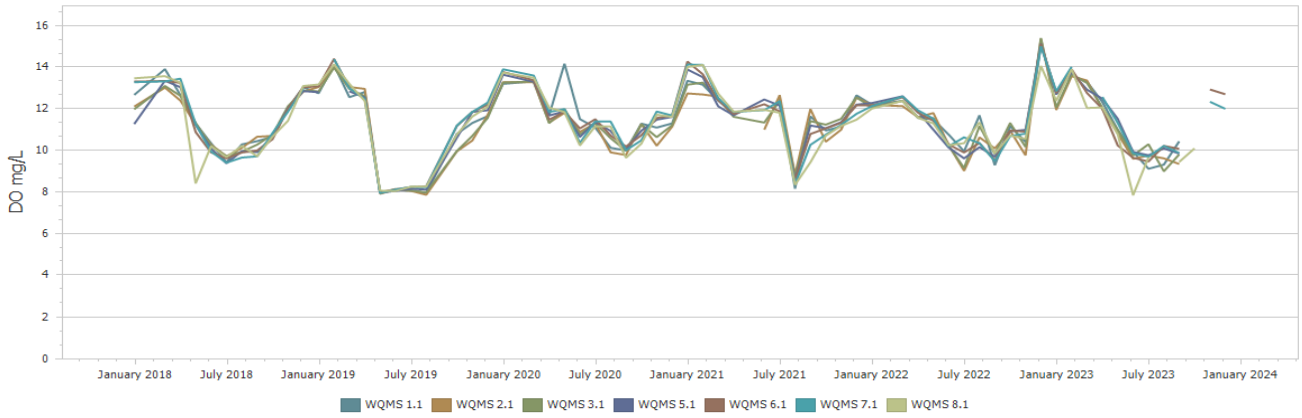


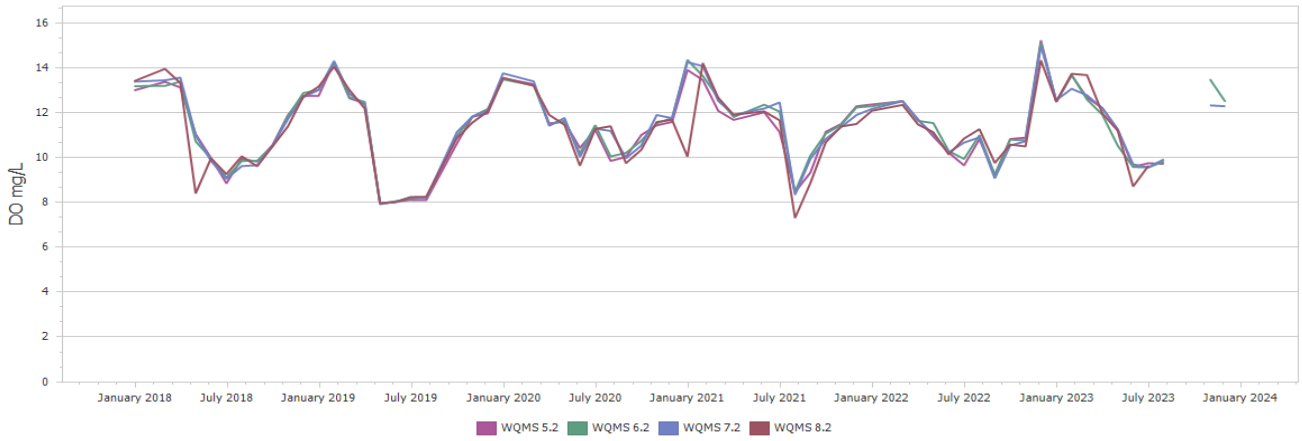
Figure 13: Survey results from all lake water quality sites of pH from January 2018 – Dec 2023.

DO

Dissolved Oxygen mg/L - Surface



Dissolved Oxygen mg/L - Middle Depth



Dissolved Oxygen mg/L - Bottom Depth

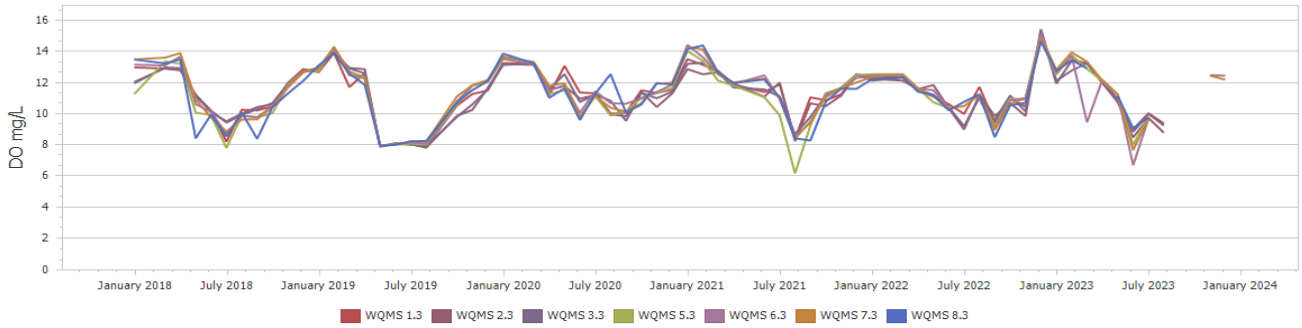


Figure 14: Survey results from all lake water quality sites of Dissolved Oxygen from January 2018 – Dec 2023.

Figure 15: Survey results from all river water quality sites of all Nitrate (NO3), Nitrite (NO2) and Ammonia (NH3) from January 2018 – Dec 2023

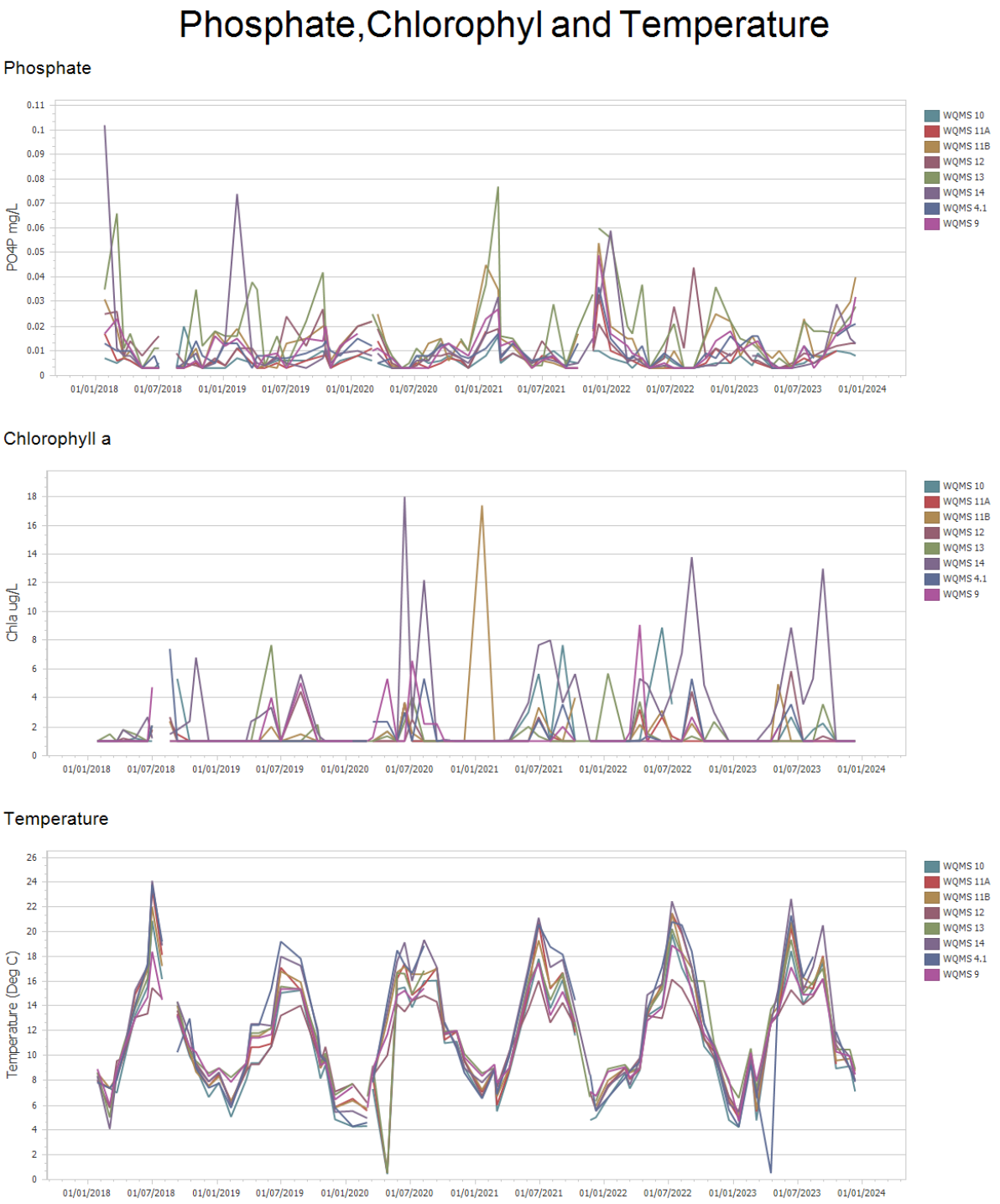


Figure 16: Survey results from all river water quality sites of all Phosphate (POP4), Chlorophyl a and Temperature from January 2018 – Dec 2023

Figure 17: Survey results from all river water quality sites of all Alkalinity, Total Suspended Solids and BOD from January 2018 – Dec 2023

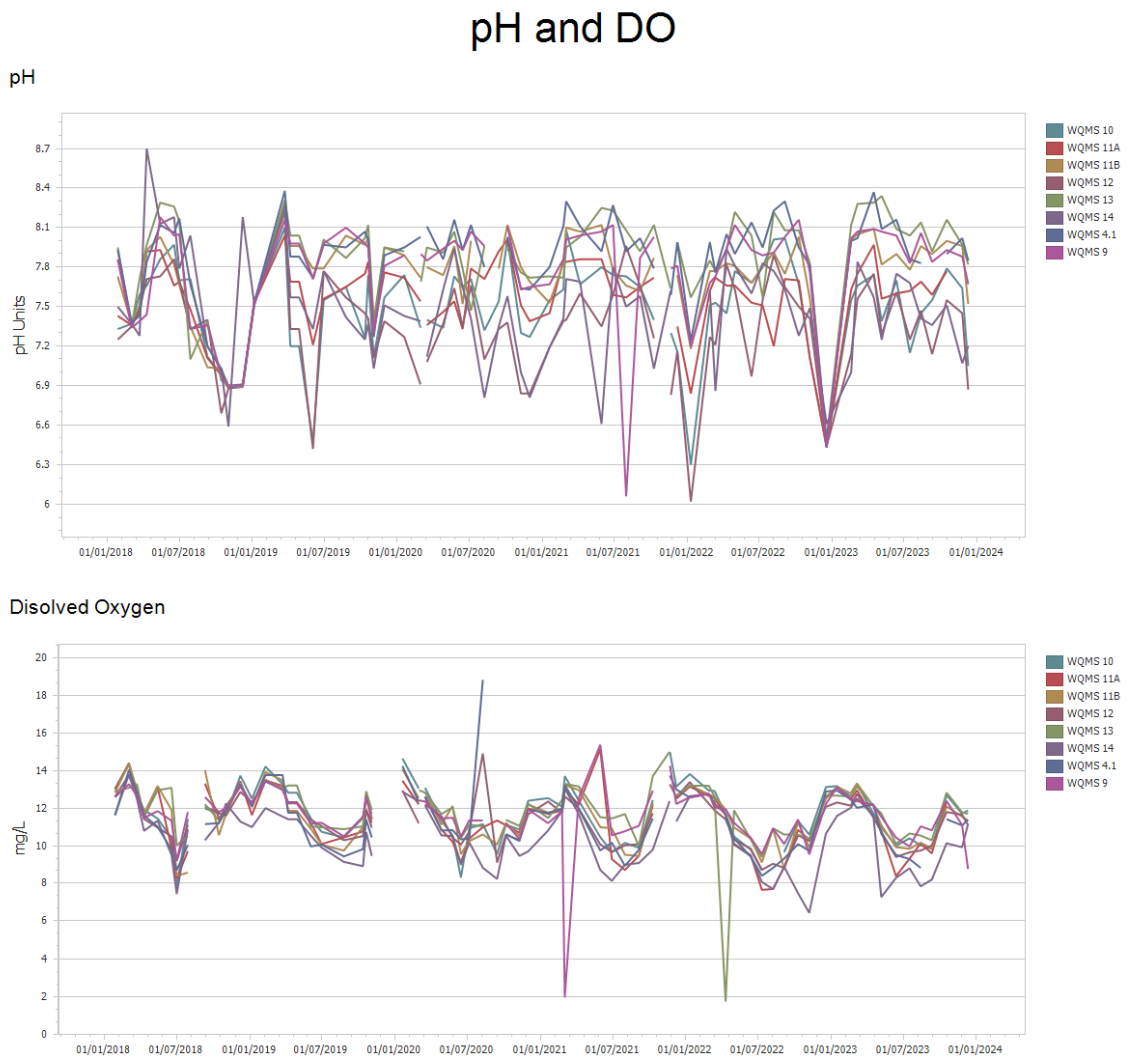


Figure 18: Survey results from all river water quality sites of pH and Dissolved Oxygen from January 2018 – Dec 2023

2.2. T800 Meteorological Survey

Two meteorological stations have been installed on the eastern and western shores of Lough Derg. **Figure 19** and **Figure 20** show meteorological data from both stations at Ballinderry and Whitegate

Whitegate Met Station (MS2)

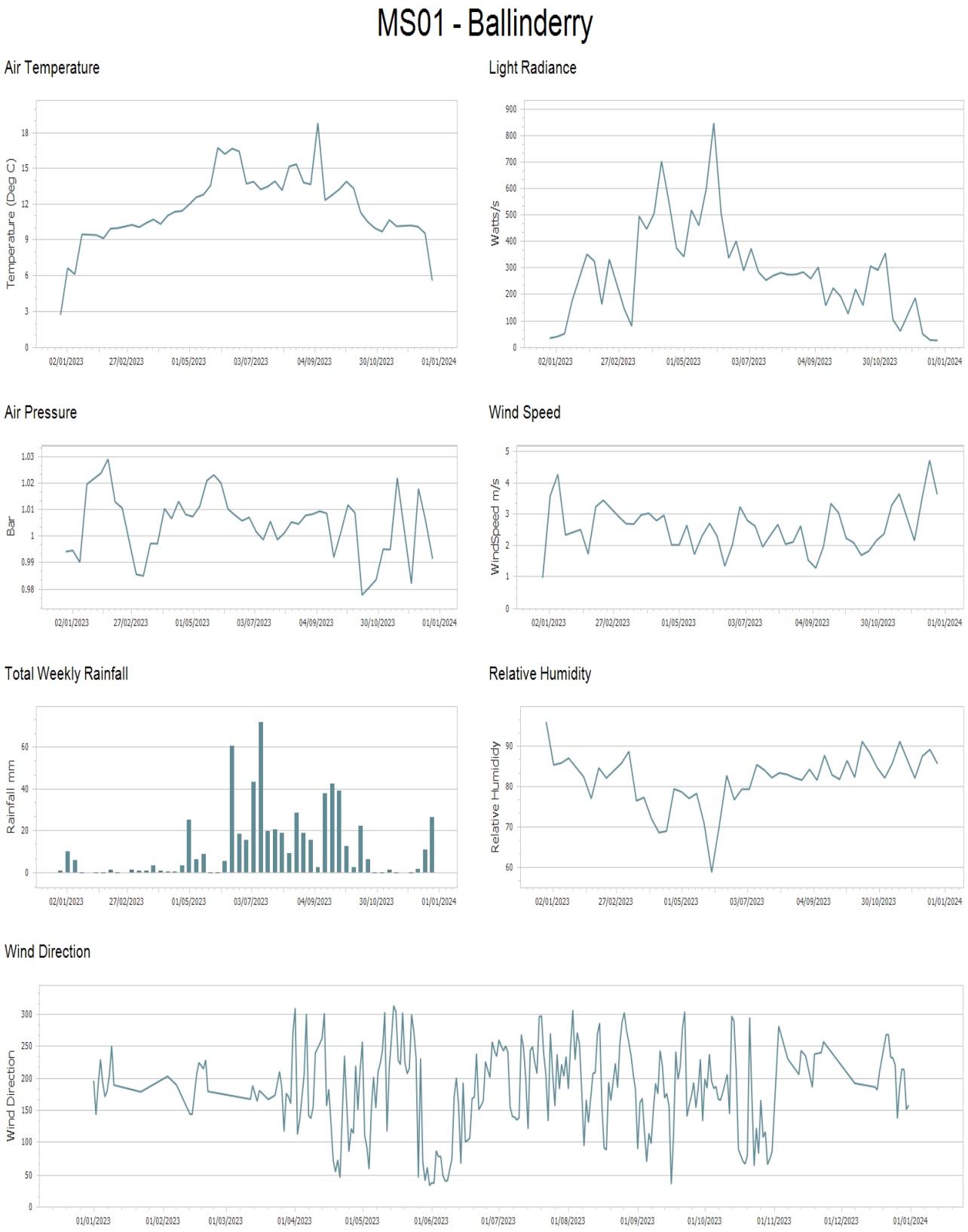


Figure 19: Data from MS01 (Ballinderry) from Jan 2023 – Dec 2023. Air Pressure, Light Radiance, Wind Speed and Relative Humidity show daily averages.

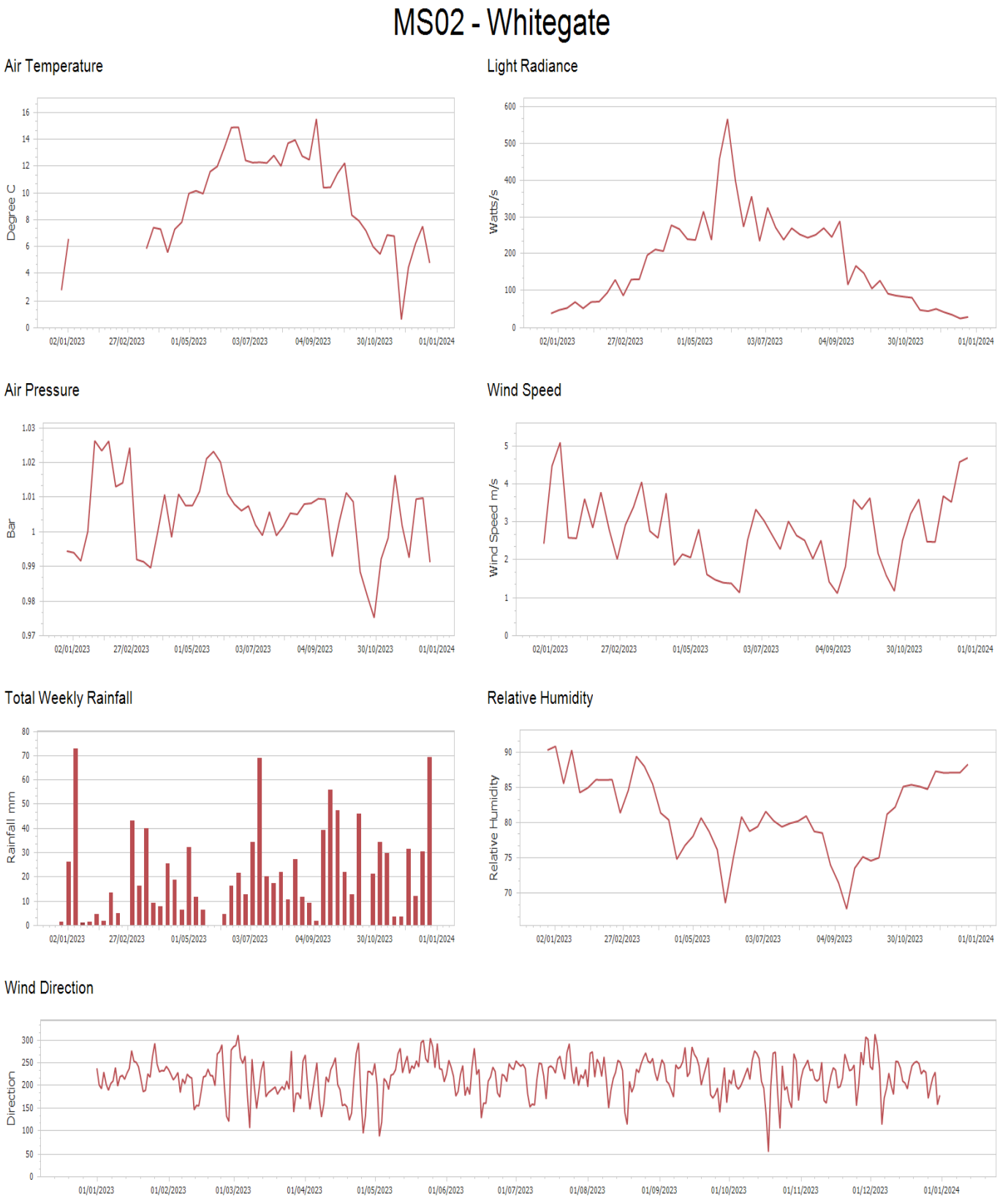


Figure 20: Data from MS02 (Whitegate) from Jan 2023 – Dec 2023. Air Pressure, Wind Speed and Relative Humidity show daily averages.

2.3. Level Monitoring

2.3.1. Lough Derg Lake Levels

In Summer of 2023 Three Level Stations were installed on Lough Derg to record the absolute water levels at three sites. The stations were levelled in using a Real-Time Kinematic instrument.

Station No	Description	Latitude	Longitude	Elevation (M)
101	Portumna Bridge	53.09146	-8.1953	32.45
102	Coondavaun Marina	53.066163	-8.301228	31.038
103	Towmile Gate	52.839831	-8.467437	31.234

During Autumn and Winter of 2023 there was a noticeable increase in lake levels as high rainfall was also recorded during these months.

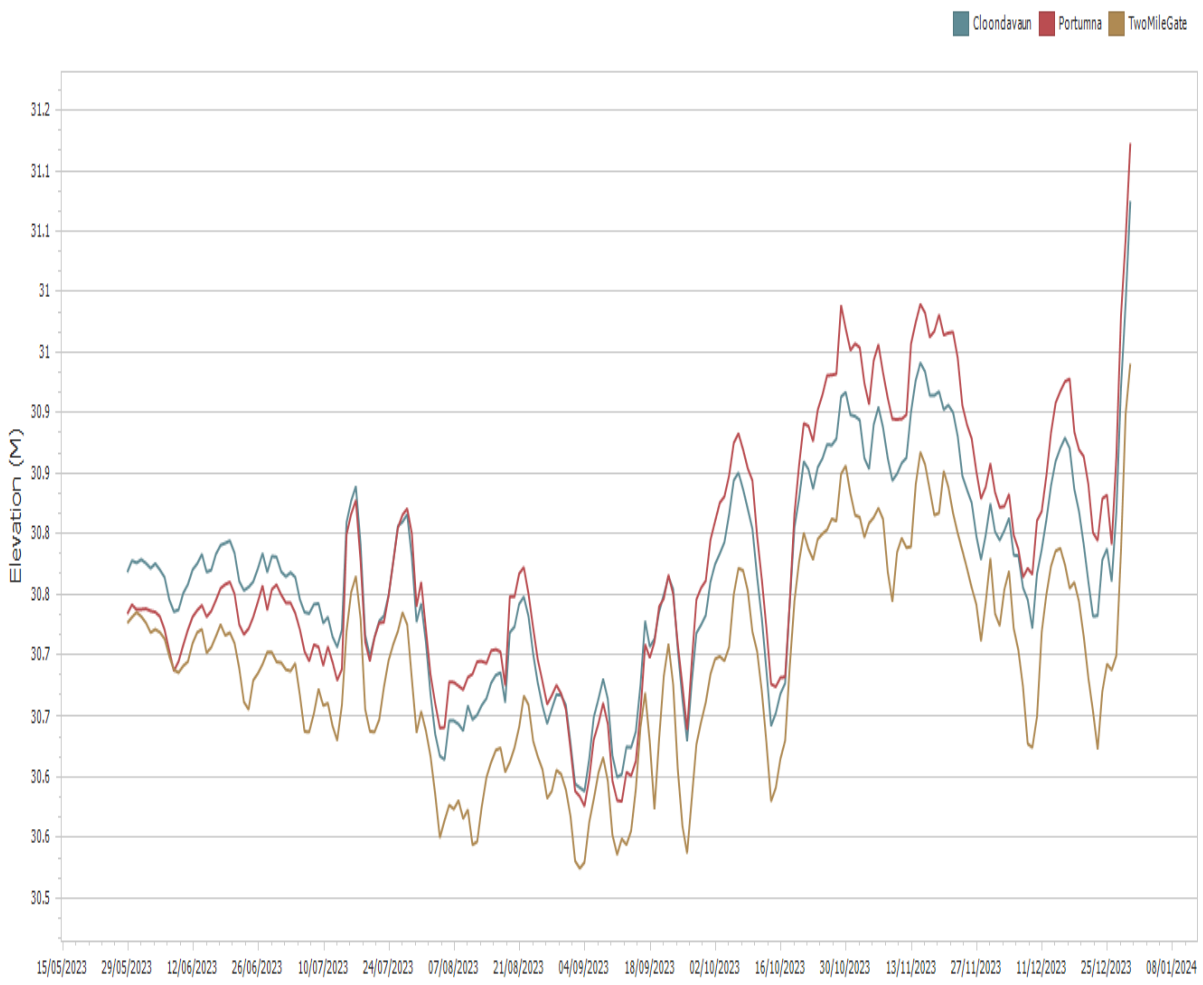


Figure 21: Water elevation at three level stations at Portumna, Cloondavaun and Two mile gate. Levels are related to Ordnance Survey Datum (Malin Head)

2.3.2. Parteen Stream Depths

In June of 2023 Four Level Stations were installed on streams feeding Parteen Basin to record water depth. These stations record water depth at 15 minute itervals.

Station No	Description	Latitude	Longitude
PLS001	Ballina/Killaloe WWTP	52.80293	-8.434541
PLS002	Forthenry	52.789915	-8.433436
PLS003	Upstream Clonfada Killestry	52.792227	-8.450801
PLS005	Upstream Ardclooney	52.773237	-8.481635

A gradual increase in the river levels was recorded during the Autumn and Winter 2023

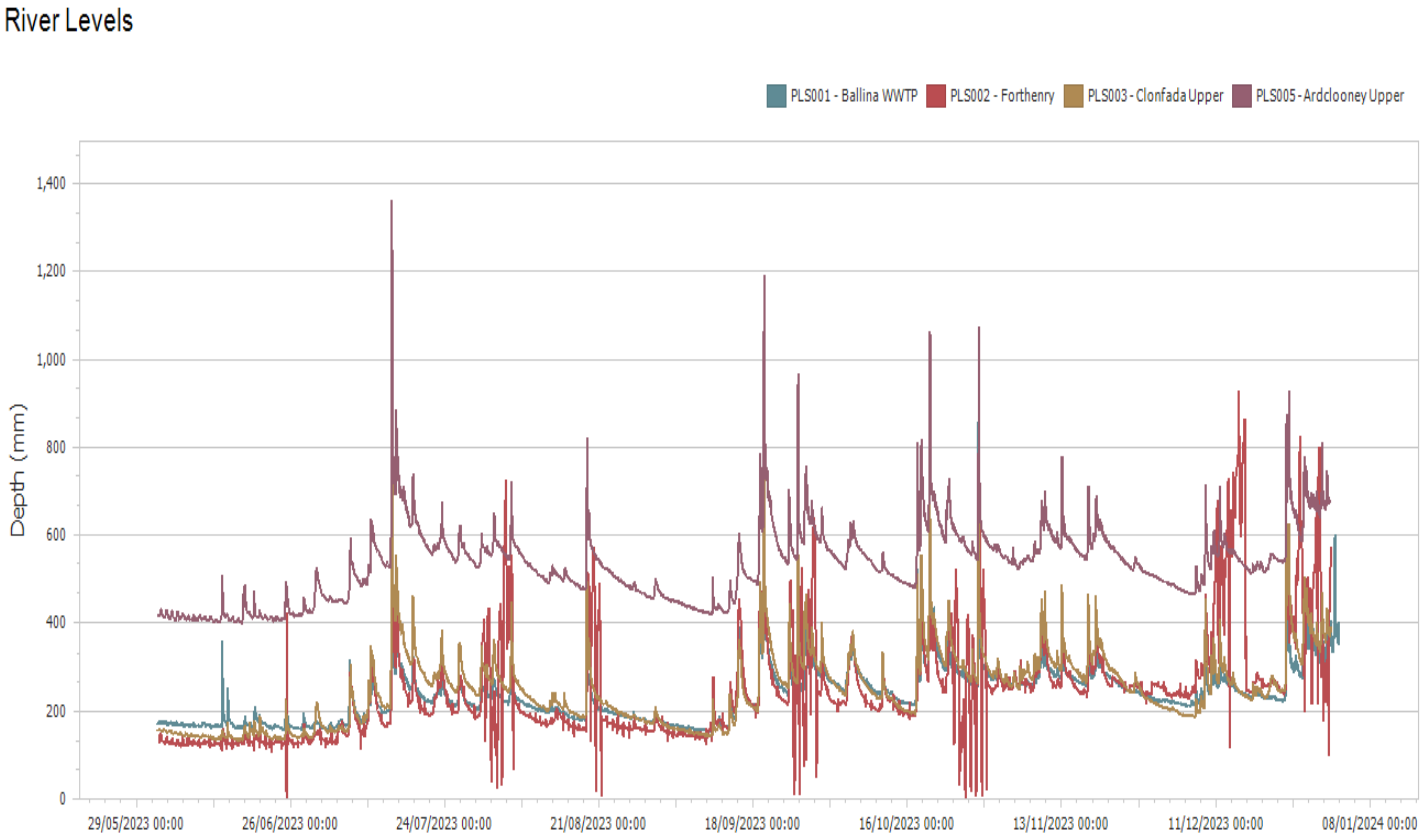
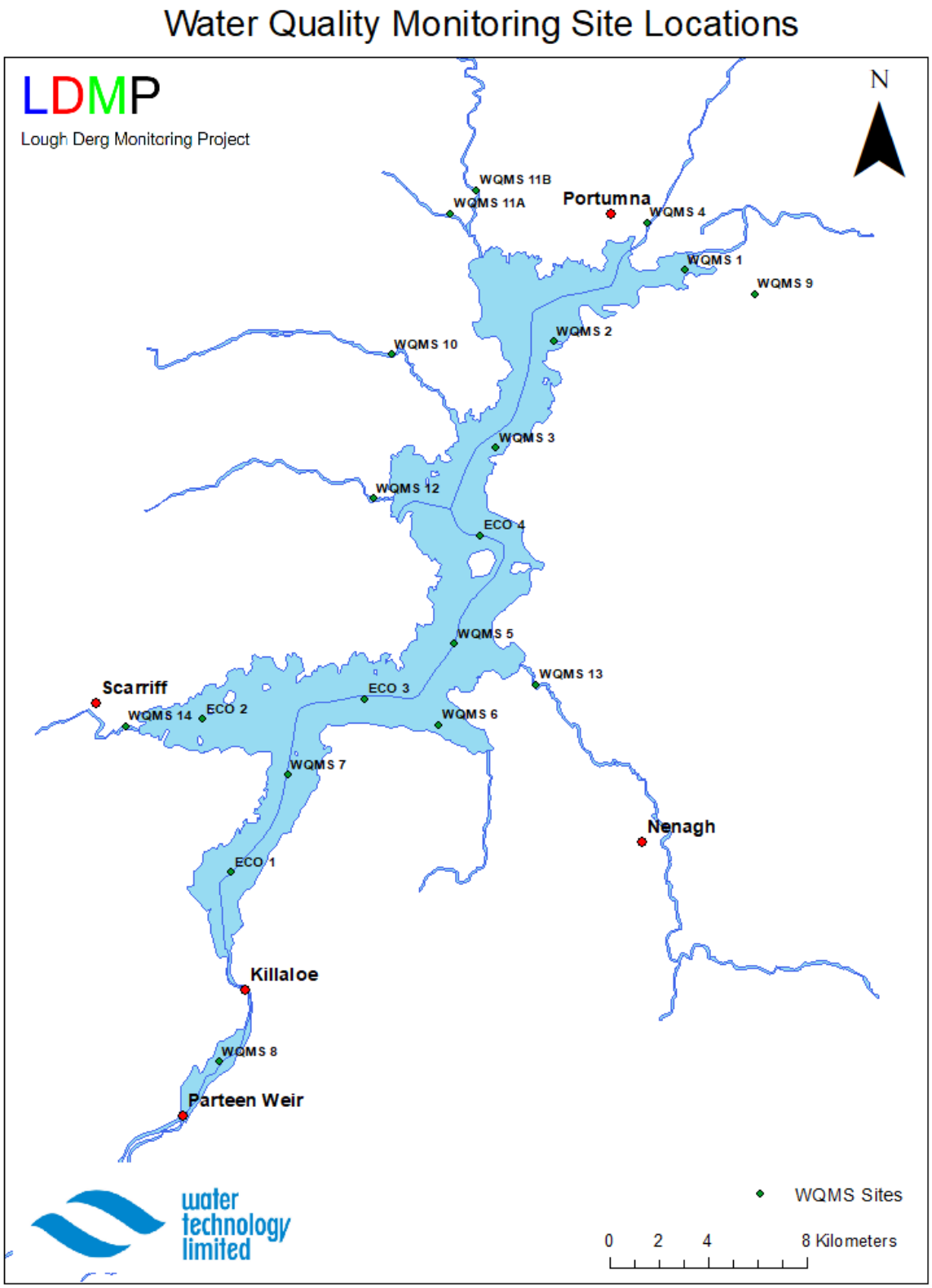


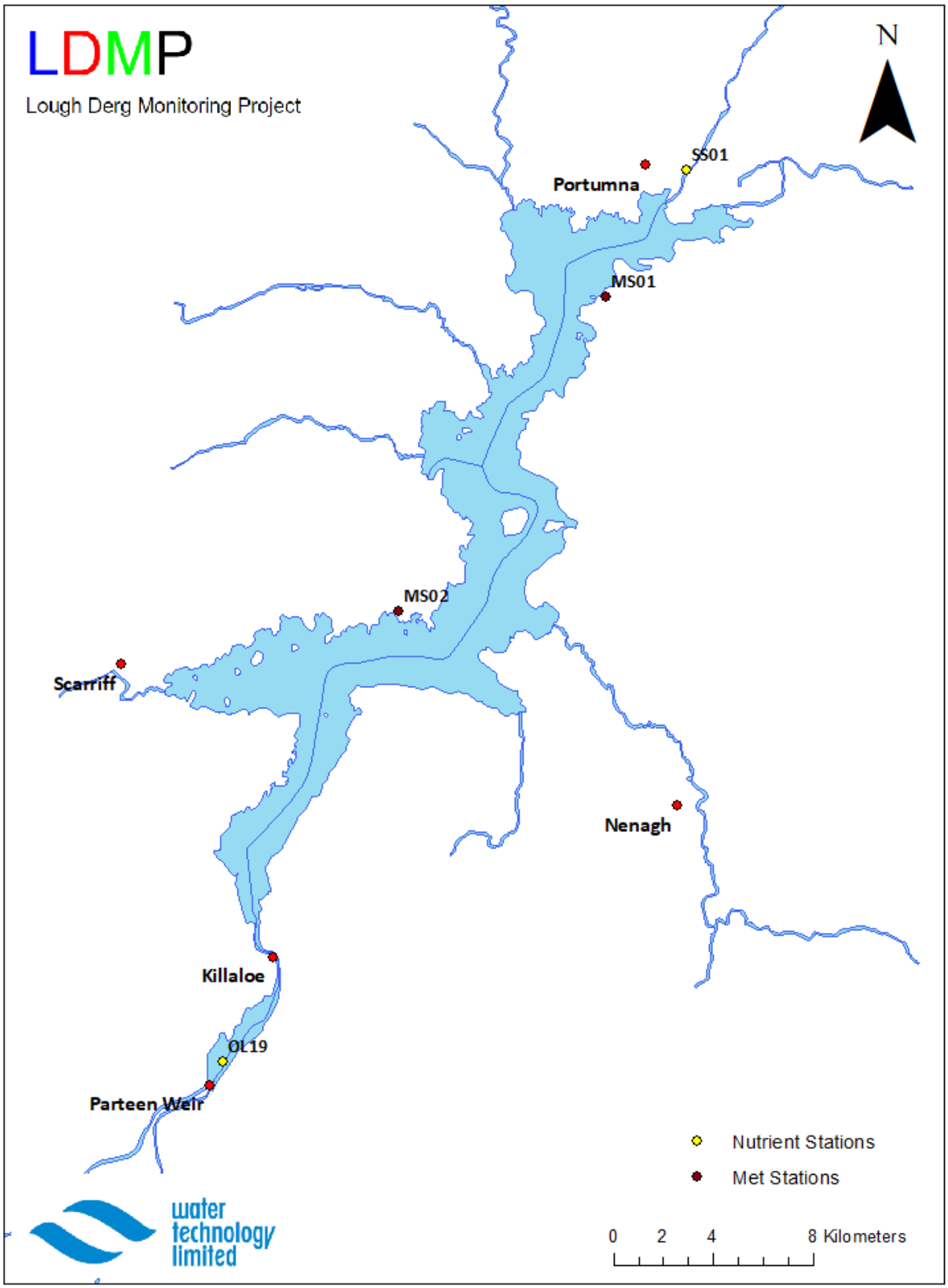
Figure 22: Depth of Streams feeding the Parteen Basin at selected points.

3. Appendices

Appendix 1: Maps showing all site locations.



Monitoring Stations



4. References

MINCHIN, D. & BOELENS, R. 2011. The Distribution and Expansion of Ornamental Plants on the Shannon Navigation. *Biology and Environment-Proceedings of the Royal Irish Academy,* Vol IIIB**,** 1-9.

Tionscadal Soláthair Uisce
Water Supply Project

Environmental Impact Assessment Report (EIAR)

Volume 6 of 6: Appendices

(Appendix A9.1 Annex E) Lough Derg Hydrographic Survey Report

Document no: 32105801/EIARA9.1
Version: Final

December 2025

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Irish Water

Jacobs

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Report of Survey

Lough Derg Hydrographic Survey,

Lough Derg,

Ireland

Prepared by: Kevin Whyte

Edited by: Eoghan Kieran

Date: 28/09/2015

Project No.: G15005

Revision No. 1

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1. Introduction

Geomara was commissioned by Jacobs Engineering/Tobin Environmental on behalf of Irish Water to carry out a hydrographic survey of Lough Derg. The project was undertaken as a component of the Water Supply Project for the Eastern and Midlands Region.

It aims to assess, identify and ultimately deliver a new and sustainable water supply for the future needs of the Eastern and Midlands Region and in particular for the Greater Dublin Area.

As part of this assessment process of examining water abstraction from different sources, Geomara was commissioned to undertake the programme of hydrographic survey of Lough Derg and the Parteen Basin.The data from the survey will aid the development of a comprehensive 3D hydrodynamic and water quality model of this water body.

The survey was carried outfrom 07th April 2015to 10th September 2015 and comprised a multibeamechosounder, single beam echosounder, high resolution side scan sonar anddrop down video survey.

The survey recorded a cumulative total of3934 km of acoustic data. These data sets were divided into 1687 km of side scan sonar, 1687 km multibeamechosounder and 560 km of single beam echosounder data. The survey area covered totals 104.315 km^2.

Figure 1. Survey Location in Red

1.1 Survey Location

The survey area was located within the safe navigable extents of Lough Derg and the Parteen Basin. Listed below are the geographic locations of the survey boundary.

Point	Easting	Northing
A	558036	661467
B	568297	660467
C	593590	705236
D	585133	709582
E	567115	690938

Table 1. Table of survey extent locations

The area surveyed in accordance with the project specifications is defined below:

- The northern extent defined as the main Shannon channel for 1Km upriver (north) of Portumna Bridge.
- The southern extent is defined by Parteen Weir and included a short section of the Ardnacrusha Headrace Canal in the vicinity of the Parteen Weir.

2. Survey design

The survey was required to aid the development of a 3D hydrodynamic model to assess a sustainable abstraction regime for two options (amongst ten being appraised) for the WSP-DR. The primary objective of the lake survey is to determine and provide data on lake bed level profiles and the nature of the lake bed such that the feasibility of abstraction can be determined and its performance predicted for a chosen location. The information/ data produced in carrying out the survey will be used to validate a numerical model which will be developed to predict the performance of proposed abstraction locations and assess the effects of abstraction on the lake water quality and statutory environmental designations.

It was carried out in accordance with the International Hydrographic Organisation (IHO) 1A standards or 1B standards where applicable, as set out in the Standards for Hydrographic Surveys, Special Publication No 44.

The survey comprised of the following elements:

1. A comprehensive multibeam echo sounder (MBES) and sidescan sonar (SSS) of the survey area along with ground truthing of sediment character changes recorded spatially throughout the lake bed.
2. Single beam echo sounder (SBES) of shallow areas where water depths is insufficient to allow for MBES to be safely/efficiently carried out.

2.1 Geodesy and Datum

The project geographic co-ordinate system was: Irish Transverse Mercator (ITM)

Elevation units were Meters.

Lakebed elevationswere referenced to Ordnance Datum Malin Head.

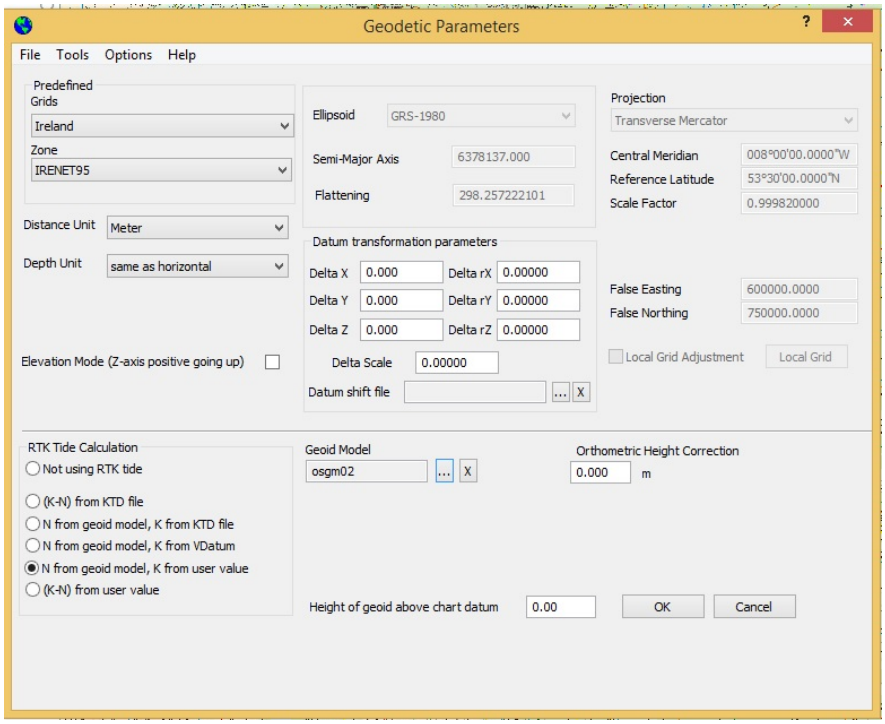

Figure 2. Project Geodetic Parameters

2.2 Survey Vessels

Three survey vessels were utilised during the course of the survey. These were the 7.4m inshore survey vessel 'Dolphin', the 6.5m Rigid Inflatable 'Techtronics' and the 5m lake boat 'Capall Ban'. The choice of vessel was determined by a number of factors including; survey location, equipment requirements and ground conditions.

Vessel	Equipment	Water depths
Dolphin	MBES & SSS	3-35m
Techtronics	SBES & Drop Down Camera	1-35m
Capall Ban	SBES	1-3m

Table 2. Survey vessels used

2.2.1 Dolphin

The survey vessel 'Dolphin'was the main survey vessel used during the survey. This 7m GRP inshore survey vessel was used to acquire both multibeam sonar and side scan sonar data for water depths from 3 – 35m. It was fitted with a multi beam sonar system. The system was pole mounted and

permanently fixed in position via a cantilever bow mounting bracket which is bolted onto deck fittings (Plate 1).

Item	Details
Boat	Bros 23
Year of Build	1993
Dimensions	7.01m long by 2.5m wide
Engine	Yanmar 4LH 170 hp inboard diesel with Hamilton jet drive & auxiliary 9.9 hp Yamaha out board engine
Navigation	Trimble GPS map 750s chart plotter, compass, Koden radar
Electronics	IC-M411 & 2 X Icom IC-M23 , Victron Energy 2Kva inverter, Honda inverter EU20i
Safety Equipment	2 X Life rings, 6 man life raft,3 bilge pumps, 3 fuel shoot offs, gas detector, inshore distress flare kit, throwing rope, navigation lights, radar reflector, search light, first aid kit, fire blanket, 3 fire extinguishers, spill kit,**Spare-** drive belts, fuel filters and separator, spare engine liquids (oil and coolant)

Table 3. Specifications of Survey Vessel Dolphin

Plate 1. Survey Vessel 'Dolphin'

2.2.2 Survey Vessel 'Techtronics'

The survey vessel 'Techtronics' was used as an auxillary survey vessel during the survey (Plate 2). This 6.5m Rigid Inflatable vessel was used to acquire single beam sonar data in the shallow water areas and to acquire the drop down video data. When undertaking single beam sonar survey, the system was pole mounted towards the stern of the vessel, with the positioning antenna located directly over the sonar transducer.

Item	Details
Boat	Delta
Year of Build	2007
Dimensions	6.5m long by 2.8m wide
Engine	2 no. Mariner 115 hp outboard
Navigation	Trimble GPS map 750s chart plotter, compass,
Electronics	IC-M411 & 2 X Icom IC-M23 , Honda inverter EU20i
Safety Equipment	2 X Life rings, 2bilge pumps, 2 fuel shoot offs, inshore distress flare kit, throwing rope, navigation lights, radar reflector, first aid kit, 1 fire extinguishers, spill kit,**Spare-** fuel filters and separator.

Table 4. Specifications of Survey Vessel 'Techtronics'

Plate 2. RIB 'Techtronics'

2.2.3 Survey Vessel 'Capall Ban'

The survey vessel 'Capall Ban' was used as an auxillary survey vessel during the survey. This 5m GRP lake boat was used exclusively to acquire single beam sonar data in the shallow water areas (1-3m). When undertaking single beam sonar survey, the system was pole mounted towards the stern of the vessel, with the positioning antenna located directly over the sonar transducer.

Item	Details
Boat	GRP
Year of Build	2011
Dimensions	5m long by 2m wide
Engine	1 no. Yamaha 15 hp outboard, Auxillary Yamaha 6hp outboard
Navigation	Trimble GPS map 750s chart plotter, compass,
Electronics	Icom IC-M23 , Honda inverter EU20i
Safety Equipment	2 X Life rings, 2bilge pumps, inshore distress flare kit, throwing rope, navigation lights, radar reflector, first aid kit, 1 fire extinguishers, spill kit,**Spare-** fuel filters and separator.

Table 5. Specifications of Survey Vessel 'Capall Ban'

2.3 Single Beam Echosounder

Single beam echo sounding (SBES) was undertaken in water depths of <3m in order to complete the data set. The agreed cut-off for the data set was 1m water depth.This was not always achievable for a number of reasons as some areas were;

- Shallow & difficult to navigate safely; water quality and light conditions have a major bearing on unmarked hazard detection.
- Choked with dense weed/reed growth.
- Deep areas close to shore flanked by rock.
- Restricted due to presence of nesting sea eagles.

There is limited available information outside of the main navigation channels identifying navigation hazards.

2.3.1 Single Beam Echosounder Systems

Two single beam echosounder systems were used during the survey. These were:

- Odom Echotrac – Dual frequency Single Beam Echosounder (12 & 200 kHz)
- Ceescope – High frequency Single Beam Echosounder (200 kHz)

Both systems are designed to be mobile professional hydrographic survey systems that have the ability to log directly to an internal memory or external devices (Plates 3 & 4). Throughout this survey, all data was logged to an external laptop computer. This configuration allowed the surveyor to check the data quality in real time. The Odom Echotrac was used from the survey vessel 'Techtronics' whilst the Ceescope was used exclusively from the 'Capall Ban'.

Plate 3. Ceescope single beam echosounder system

Plate 4. Odom Echotrac single beam echosounder system

2.3.2 Positioning

Trimble SPS 461 Differential Global Positioning systems were used to provide positioning on both single beam echosounder systems (Plate 5). These systems provided very high accuracies and precision. The performance of the DGPS units was such that they were used both for sounding locations but also vessel navigation. Vessel navigation was provided by the Trimble SPS461 receivers through Hypack 2015 software. A helmsman's display monitor provided the vessel skipper with real time navigation and a coverage map. This allowed for the vessel to stay on course throughout the duration of the survey and provided the required level of coverage along with safe navigation.

Plate 5. Trimble SPS 461 DGPS

2.3.3 Sound Velocity Profile

To ensure the accuracy of the acquired data and correction for differing water column densities, sound velocity profiles were taken at various stages throughout the survey .These were then applied to the data at the time of acquisition. At the beginning, middle and end of the survey, sound velocity profiles were taken using a Valeport Mini SVP (Plate 6).This provided the survey with full profile measurements from the surface to the deepest sections of the survey area. These profiles are subsequently imported into Hypack 2015 to assist in the calibration of the single beam sonarsystem.

Plate 6. Valeport Mini SVP

2.4 MultibeamEchosounder

Multibeamechosounder was the hydrographic survey technique used on this survey for all water depths in excess of 3m.

2.4.1 Multi Beam Echosounder

The MBES system used for the survey was the Edgetech 6205.The 6205 system is renowned worldwide for its wide swath coverage in shallow water and co-registered dual frequency side scan and bathymetry with full nadir coverage. The system uses a frequency of 550 kHz and measures over 200 ° swaths across the seafloor. It is highly accurate and delivers a depth resolution of 1 cm, which is within IHO Special Order classification.

The 6205 uses its own processor system and software (Discover) which is interfaced with a high performance desktop computer. Data is streamed to the processor in the sonar head where it is

processed and combined into one data string before being corrected and logged in Hypack 2015 hydrographic survey software.

The MBES sonar head was mounted on a bespoke bow mounting pole and frame that also facilitated the MRU and GPS antenna. All instrumentation was mounted vertically over one common point which eliminated any potential offset errors as all offsets were vertical thereafter, apart from sonar phase centre which is are per manufacturer offsets.

The equipment offsets were derived by setting up the equipment on dry land (boat on trailer) and observing prescribed locations (reference locators as derived by equipment manufactures) using a total station on a local grid system. Once the offsets were calculated the information was input into Hypack equipment setup files. The origin of the boats reference system for all three axis (X, Y & Z) was the measurement centre point of the MRU.

The multi beam was calibrated using industry recognised procedures to determine the systems,

- Latency
- Pitch
- Roll
- Yaw

All of the above procedures were carried out on site prior to the commencement of the survey (See Section 3 for results)

2.4.2 Positioning

Vessel and equipment positioning was provide by a Trimble SPS461 GPS Heading and positioning antennas (Plate 5).The Trimble SPS 461 is a dual frequency receiver which when used in conjunction with VRS RTK provides centimeter accuracy on demand. The positional antenna was placed in order to ensure that it had a clear unobstructed horizon of open sky, directly over the sonar transducer. The vertical offset from the positional antenna to the transducer was measured and inputted in the acquisition software (Hypack 2015) equipment setup configuration.

The SPS461 computes the precise vector between the two antennas to provide a highly accurate heading and positioning values. A second antenna, the heading reference antenna, was placed 4.6m behind the positional antenna. This separation was required to ensure accurate heading referencing throughout the survey. The mounting of the GPS antenna and offset calculations ensured the most accurate heading and position data.

Trimble VRS NOW is a convenient service that provides instant access to real time kinematic (RTK) correction utilizing a network of permanent ground stations to derive centimeter level accuracy anywhere within the network. The network processor performs integrity checks on all observables, while quality checks are carried out on data from each fixed reference station. Upon verification RTK corrections are transmitted to the receiver via a cellular modem.

2.4.3 Sound Velocity Profile

To ensure the accuracy of the acquired data and correction for differing water column densities, sound velocity profiles were taken at various stages throughout the survey. These were then applied to the multibeam data at the time of acquisition.

The Edgetech 6205 sonar head has a flooded section that is used to house an AML Sound Velocity Sensor providing real time SVP at the sonar head with a resolution of 0.001m/s, and a theoretical accuracy of ± 0.025m/s.

Sound velocity profiles were taken using a Valeport Mini SVP (Plate 7).This provided full profile measurements from the surface to the deepest sections of the survey area. These profiles are subsequently imported into Hypack 2015 to assist in the calibration of the MBES system.

2.4.4 Motion Reference System

To ensure accurate bathymetric data heave, pitch and roll values must be integrated into the survey setup. To provide heave, pitch and roll a Teledyne TSS DMS 05 MRU (Motion Reference Unit) and gyro compass were employed (Plate 7).This system provides real time data, which is integrated directly with the multibeam system and Hypack 2015 software .The MRU was located directly above the sonar head and was fully aided by the Trimble SPS461 NMEA output data string with both position and speed, which again improves the accuracy of the system and (particularly during vessel turns), subsequently the bathymetric dataset. The unit was setup specifically for small boat operations with a heave period of 8 seconds as this is the optimum setting for vessels under 8m in length, surveying inshore areas.

Plate 7. Teledyne DMS05 Motion Reference Unit

2.5 Side Scan Sonar

The project specifications required that side scan sonar data be collected throughout the lake.

2.5.1 Side Scan Sonar

All side scan sonar data was acquired using the Edgetech 6205 at a frequency of 550 kHz. The Edgetech 6205 is a combined side scan sonar and multibeamechosounder. It allows for co-registering of side scan sonar data with multibeam data.

2.5.2 Positioning

Positioning for all side scan sonar files was provided by the Trimble SPS 461, as per section 2.4.2 multibeamechosounder positioning.

2.6 Drop down camera

In order to determine the nature of the lakebed, visualinspection of the lakebed was undertaken by drop downvideo to‘ground-truth’ the SSS data.

2.6.1 Drop down camera

The drop down camera system was a bespoke production using a 3.6 mm lens wide angle lens with a 62 deg. opening angle underwater which is ideal to come close to the object in poor visibility water. The video signal output is a standard video signal transmission over twisted pair using a built in video line driver which makes it possible to run the video signal over 600 m of twisted pair cable.

2.6.2 Positioning

Trimble SPS 461 Differential Global Positioning systems were used to provide positioning for the drop down video survey. The system provided very high accuracies and precision. The performance of the DGPS units was such that they were used both for the video locations but also vessel navigation. Vessel navigation was provided by the Trimble SPS461 receivers through Hypack 2015 software. A helmsman's display monitor provided the vessel skipper with real time navigation information.

3. Survey

3.1 MultibeamEchosounder Survey

3.1.1 Acquisition

The multibeam dataset comprises: 1687 linear km; 3286 files; 320 GB, of recorded data.

Multibeam data was acquired and recorded using HYPACK Survey and HYSWEEP Survey. This comprehensive suite of software allows for seamless integration of all systems throughout the survey including MBES, GPS and MRU. HYPACK allows for real time data interrogation which ensures good quality data at all times through the survey.Line plans were created daily by the surveyor, according to the planned area of survey, generally allowing for 15 – 20% overlap. (Fig. 3) Maximum swath width of 8 times water depth was recorded to meet IHO Special order specifications. (Fig. 5) Vessel navigation is also provided through HYPACK with a helmsman display screen located adjacent to the vessel skipper. This gives real time updates on critical data such as line plans, position, speed, heading and data coverage. This helps to ensure that the required area is surveyed efficiently and comprehensively. Multibeam coverage close to shore was restricted by areas of weed / reed growth and in shallow areas where water quality and light conditions influenced navigation hazard detection. There is limited available information outside of the main navigation channels identifying navigation hazards.

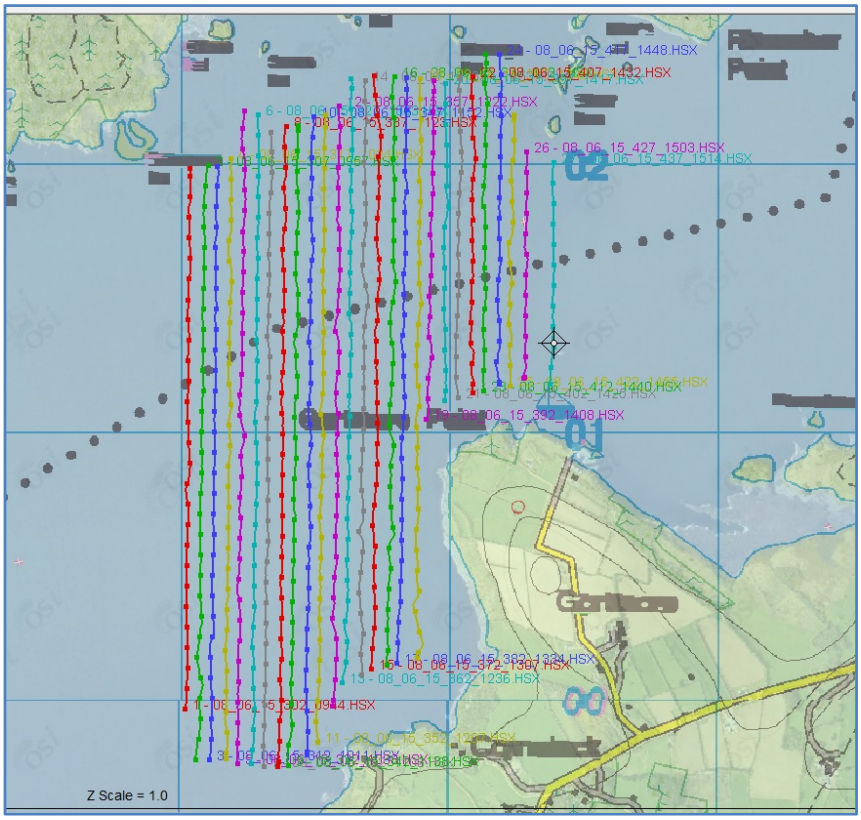

Figure 3. Survey vessel tracklines

After mobilisation and prior to any data acquisition, the MBES system was calibrated. The calibration procedure required the survey vessel to travel across areas of both flat and sloping lakebed, in predetermined lines with appropriate overlap and correlation between lines. This allows the software to calculate the equipment heave, pitch and roll offsets and apply calibration values to correct for these.(Fig. 4)

Figure 4. Calibration results

Error Budget and Uncertainty model

Manufacturer values for positioning and sounding errors were factored into the vessel error budget. Table 6) Vessel offsets were established through an onshore dimension control survey and uncertainty levels over positions of soundings were improved through sound velocity control when surveying. Calibration of the MBES through a standard patch test ensured the vessel error budget

met the IHO specifications. Maximum swath width of 8 times water depth was recorded to meet IHO Special order specifications. (Fig.5)

Position/ Navigation	
Horizontal (X/Y)	0.03m
Vertical (Z)	0.05m
Heading	0.09° RMS
MRU	
Roll/Pitch	+/-0.05° RMS
Heave	0.01m resolution
6205 SVP	+/- 0.025 m/s
Valeport Mini SVP	+/- 0.03m/s
Off Sets X,Y,Z	0.01m

Table 6. Survey Equipment Accuracies

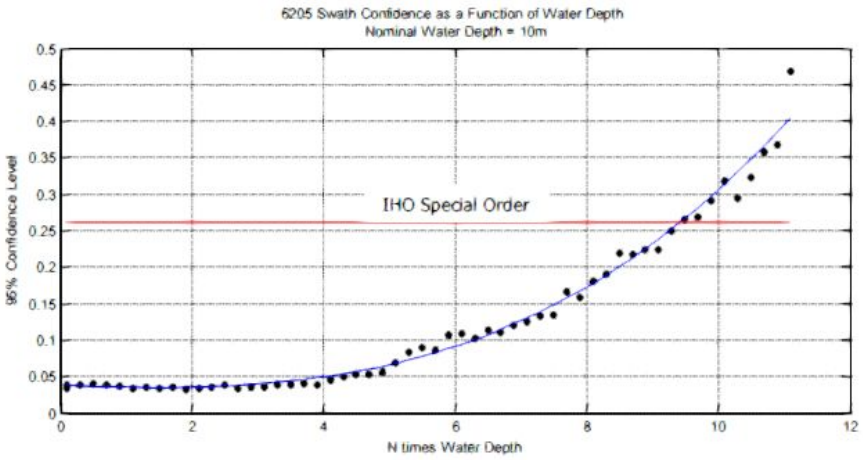

Figure 5. MBES Confidence to IHO Special Order.

3.1.2 Processing

The acquired multibeam data was processed and edited using HYPACK HYSWEEP MBMAX 64 bit multibeam editor (Fig. 6) using a HP Intel i7-3820 processor. Combinations of automated and manual processing procedures were applied to remove systematic errors and obvious outliers. This involved applying a number of factors including equipment offsets (Fig. 8), calibration values etc. SVP data was applied to correct for refraction errors caused by water column heterogeneity. Manual profile sweep editing was used to clean 'noise' spikes from the data (Fig. 7). Once completed, final verification of data consistency and absence of spikes was carried out using subset editing and 3D tin model review. Export of final products from HYSWEEP included Multibeam Bathymetry contour charts and XYZ grids.

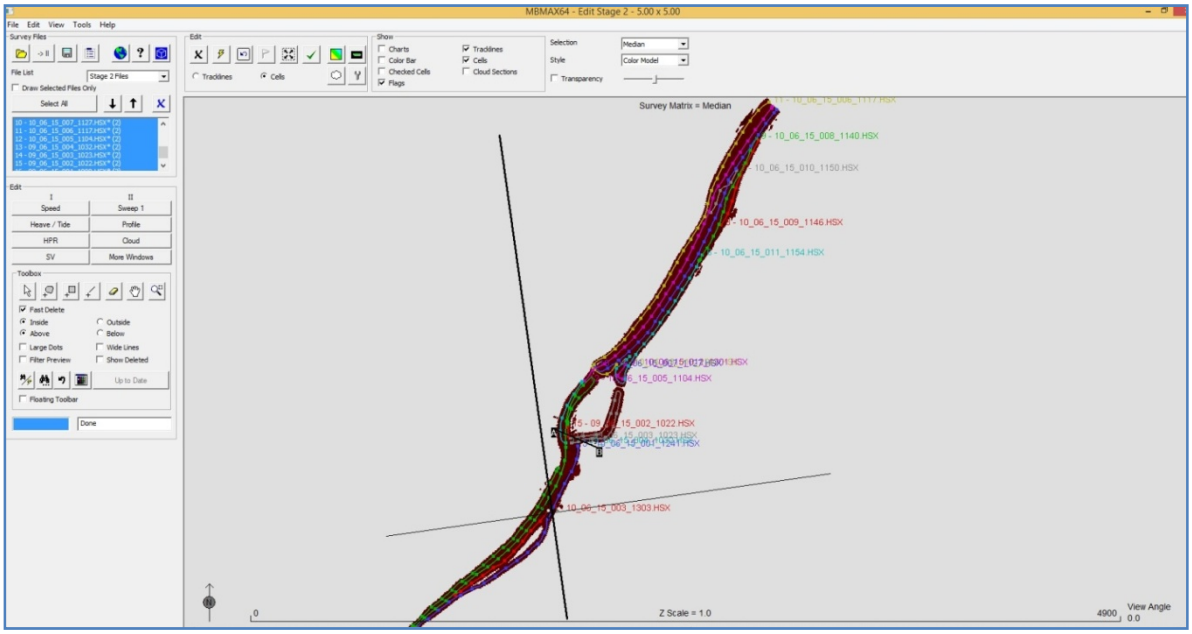

Figure 6. HYSWEEP MBMAX editor

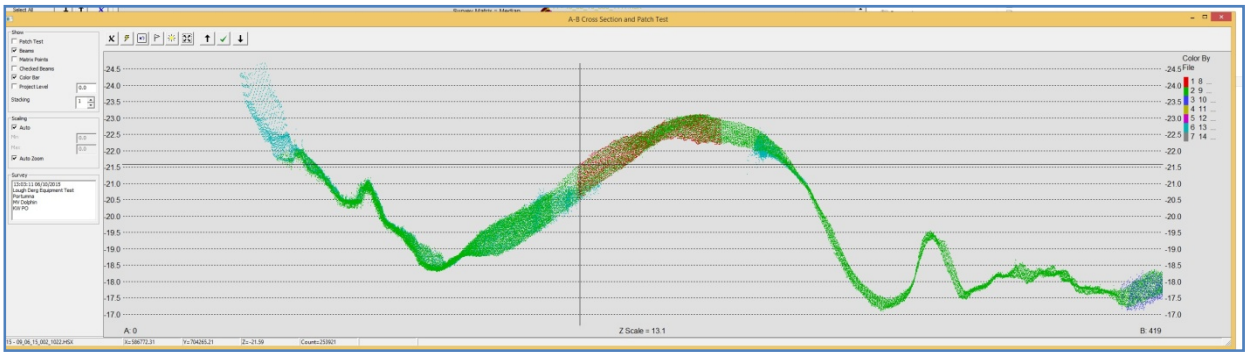

Figure 7. Manual Profile Sweep editor

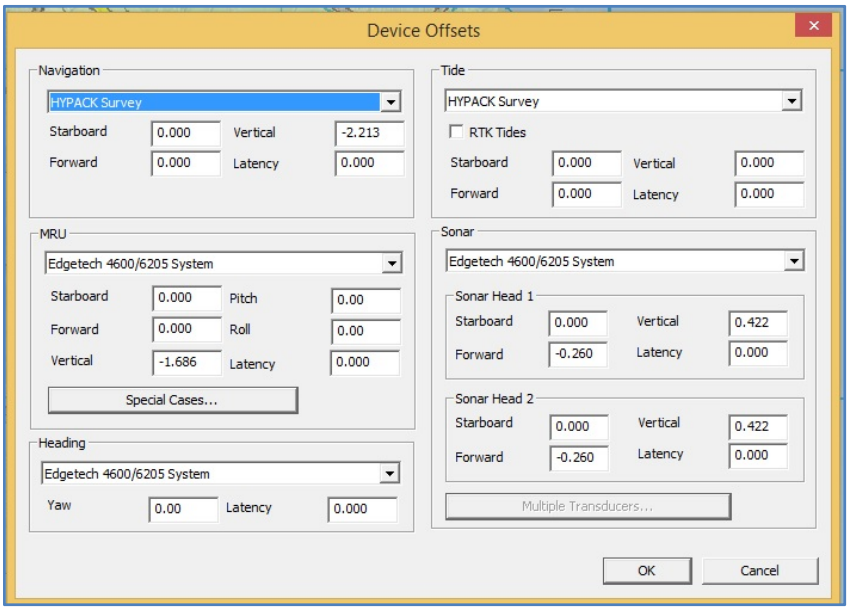

Figure 8. Equipment Offsets

3.2 SinglebeamEchosounder Survey

3.2.1 Acquisition

The singlebeam dataset comprises: 1018 files; 866 MB, of recorded data.

Singlebeam data (depth and position) was recorded using HYPACK Survey. HYPACK allows for real time data interrogation which ensures good quality data at all times through the survey.Line plans were created daily by the surveyor, according to the planned area of survey and required line interval.

3.2.2 Processing

The acquired SBES data was processed and edited using HYPACK single beam editor (Fig.9) using a HP Intel i7-3820 processor. Combinations of automated and manual processing procedures were applied to remove systematic errors and obvious outliers. This involved applying a number of factors including draft, calibration values etc. SVP data was applied to correct for refraction errors caused by water column heterogeneity. Manual profile sweep editing was used to clean 'noise' spikes from the data. Processed single beam data was exported in XYZ grid format which was subsequently merged with the MBES dataset.

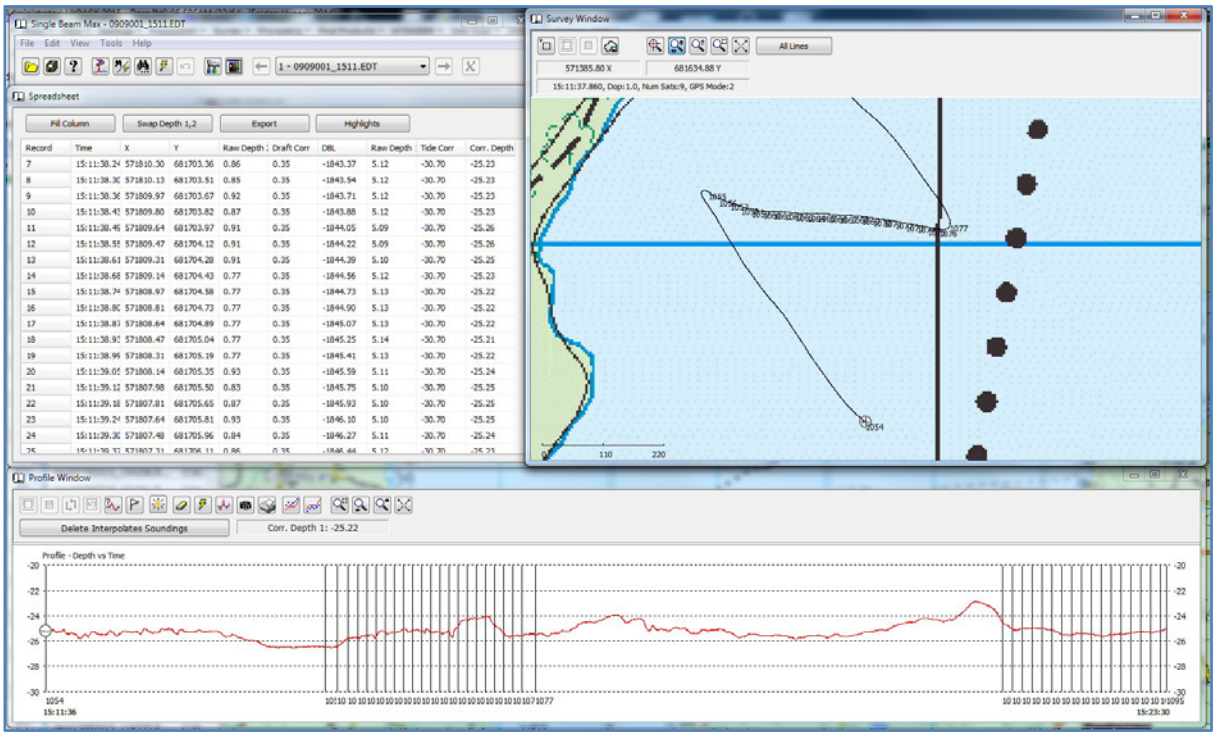

Figure 9. HYPACK Single beam editor

3.3 Side Scan Sonar Survey

3.3.1 Acquisition

A total of 1,428 lines of side scan sonar were acquired during the survey. This equated to 1,687 linear kilometres of 550 kHz side scan sonar data, with an acoustic range of 100m. Side scan sonar lines were acquired in tandem with the multibeam sonar data. As such no separate line plans were

required. Acquisition of the data was carried out using Edgetech Discover software. Discover is a modular acquisition and processing software package compatible with all Edgetech sonar systems. Itserves as the sonar image processing, display, storage and surface control station for the Edgetech family of Sub-Bottom Profilers, Side Scan Sonars, and Combined Systems.

3.3.2 Processing

Processing of the side scan sonar data was carried out suing Sonarwiz software. Below is the data flow chart regarding processing of the raw side scan sonar data (Figure 10).

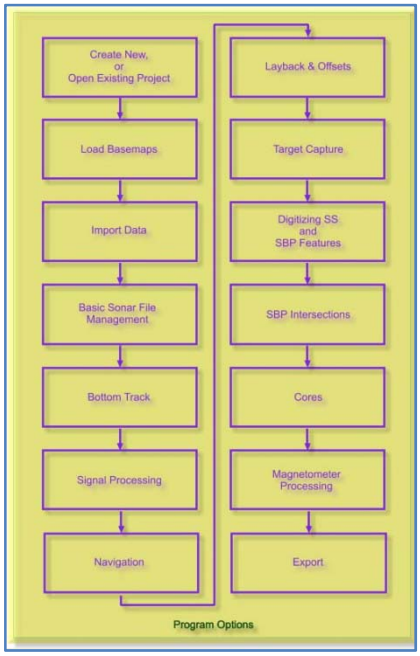

Figure 10. Side scan sonar data processing flow chart

3.4 Drop -down Video Survey

3.4.1 Acquisition

After analysis of the SSS data, a grid of drop down video locationswas created where the data indicates a change in bed sediment(Fig. 11). The camera and light system was controlled via a Seascape surface control box and the video was recorded on a Swann digital video recorder. Video was recorded with the vessel stopped in the water but some drift due to water current and wind resistance occurred at times.

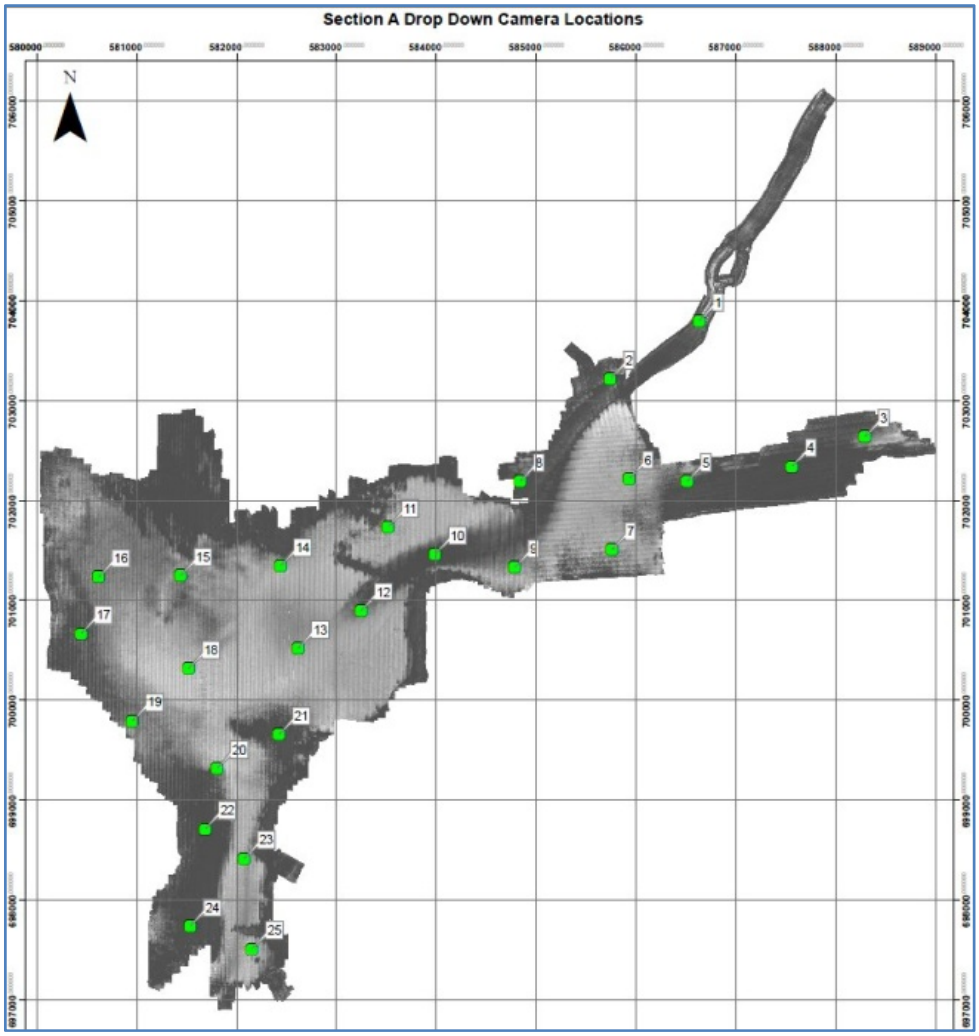

Figure 11. Drop Down Video Locations – Section A

4. Results of Survey

4.1 Bathymetry Grid, Contours and Charts.

The bathymetric data was merged to create a 5x5m Grid of Lakebed elevation, to O.D. Malin. (Fig. 12 – Fig. 13) Bathymetric Charts were created using HYPACK and GIS software (Fig. 14 – Fig. 19). Contours were exported in Autocad DXF format (Fig. 20 – Fig. 21).

Lakebed Elevation ranges from 29.8m O.D. Malin to -6.0m O.D. Malin. Greatest depths were located 2.7 km WNW of Garrykennedy. In general, the northern portion of the lake from Portumna to Mota was shallower and gently sloping. In contrast a deep channel with steeply dipping sides is evident north of Killaloe and continuing to Garrykennedy / Lushag Rocks. The drowned landscape of the Parteen Basin, south of Killaloe is evident, showing the pre 1929 river channel and Killaloe canal. (Fig. 19)

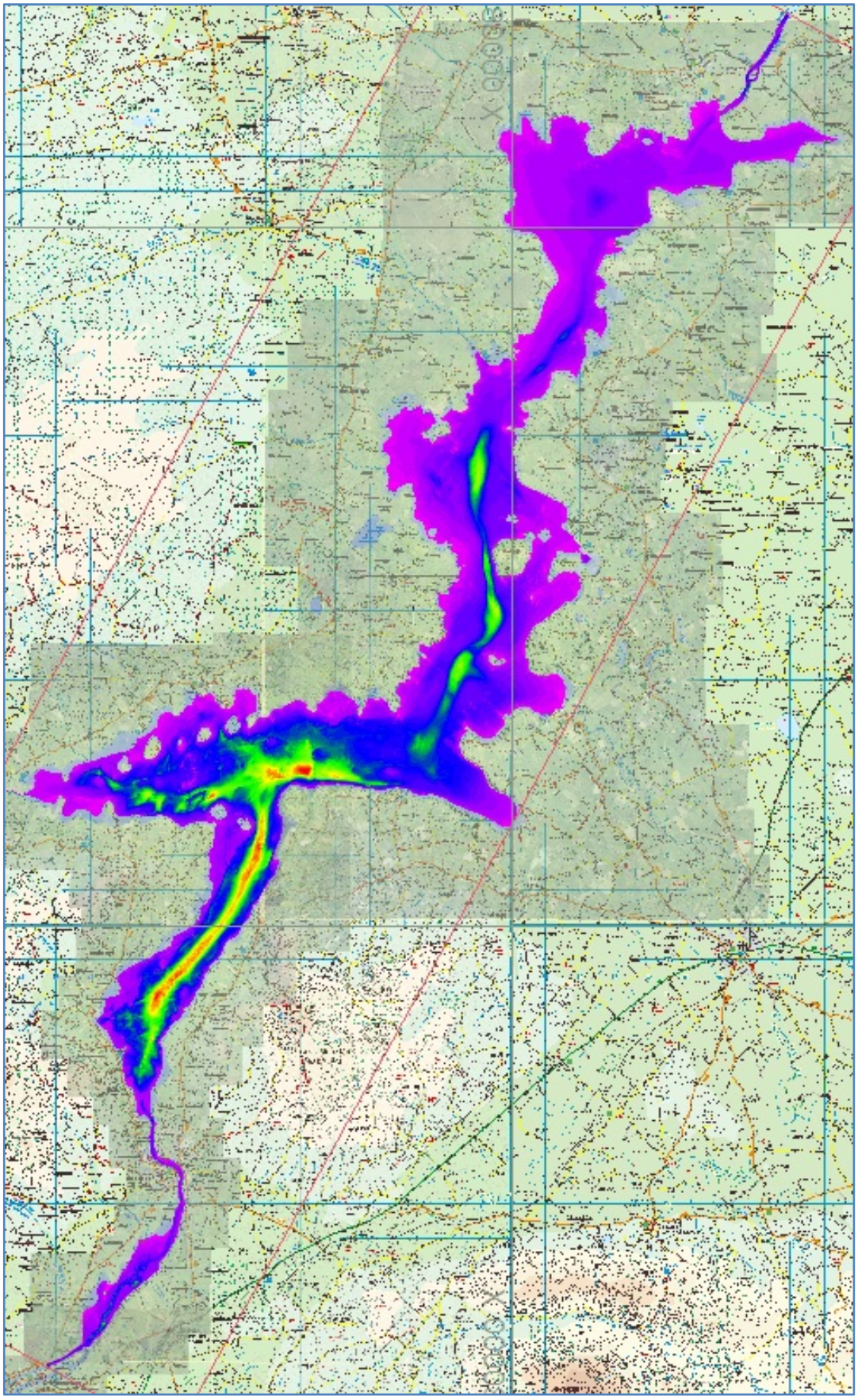

Figure 12. Bathymetry overview

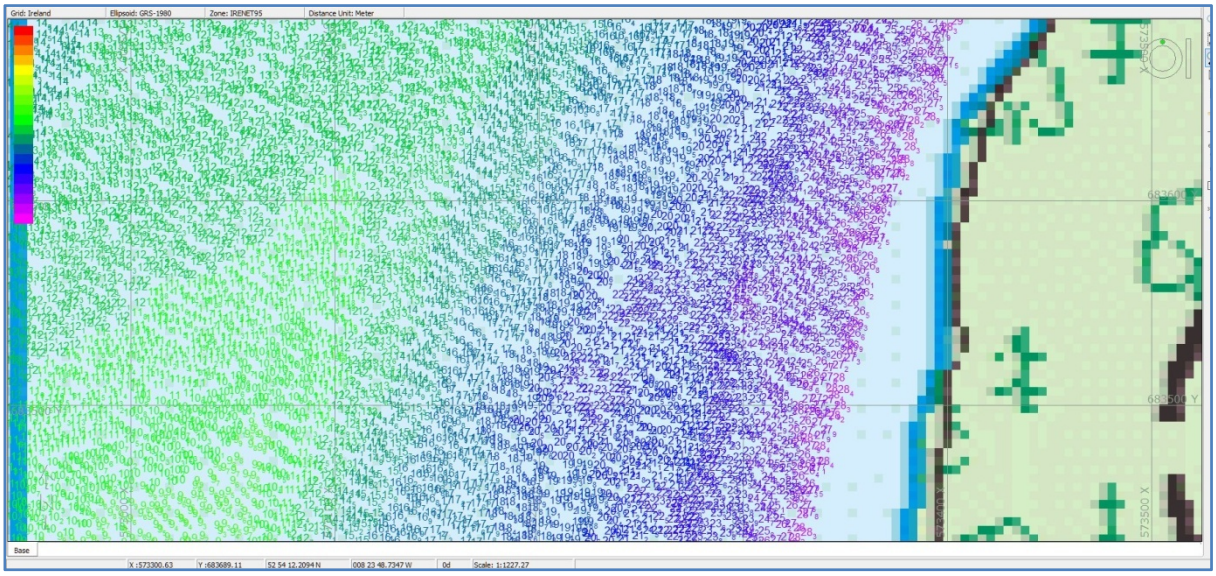

Figure 13. Bathymetric Grid.

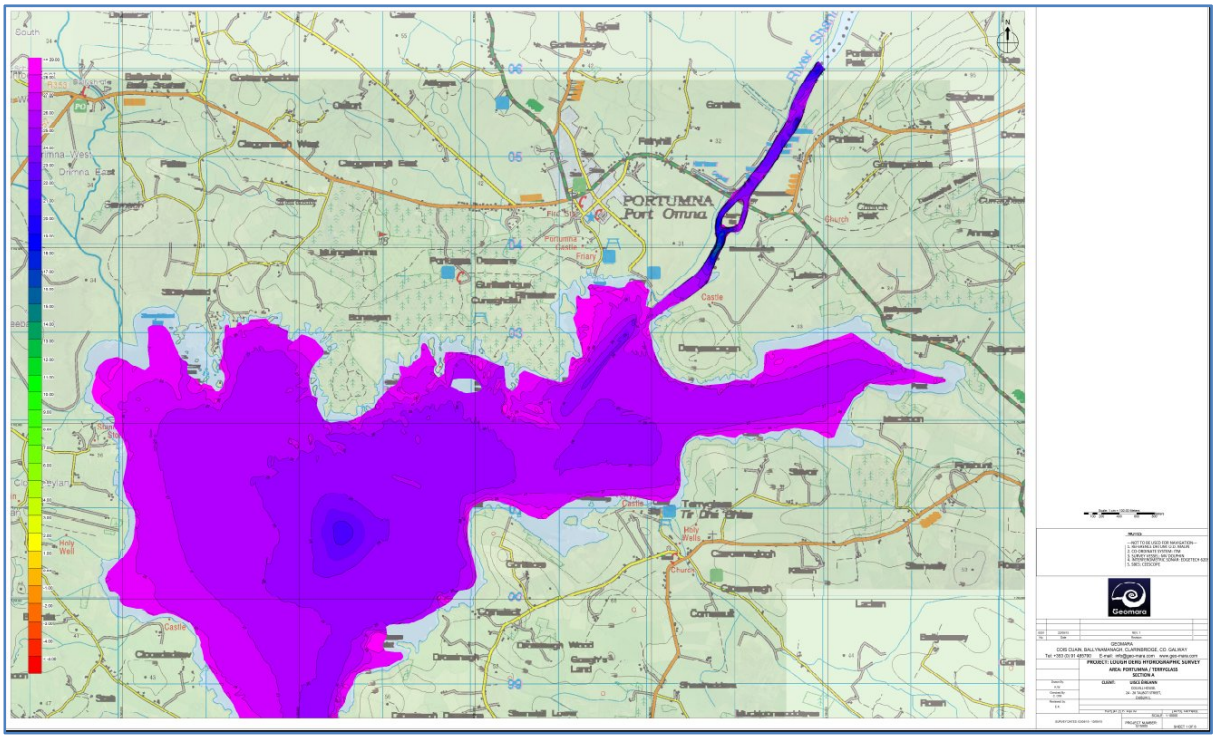

Figure 14. Section A Bathymetric Chart

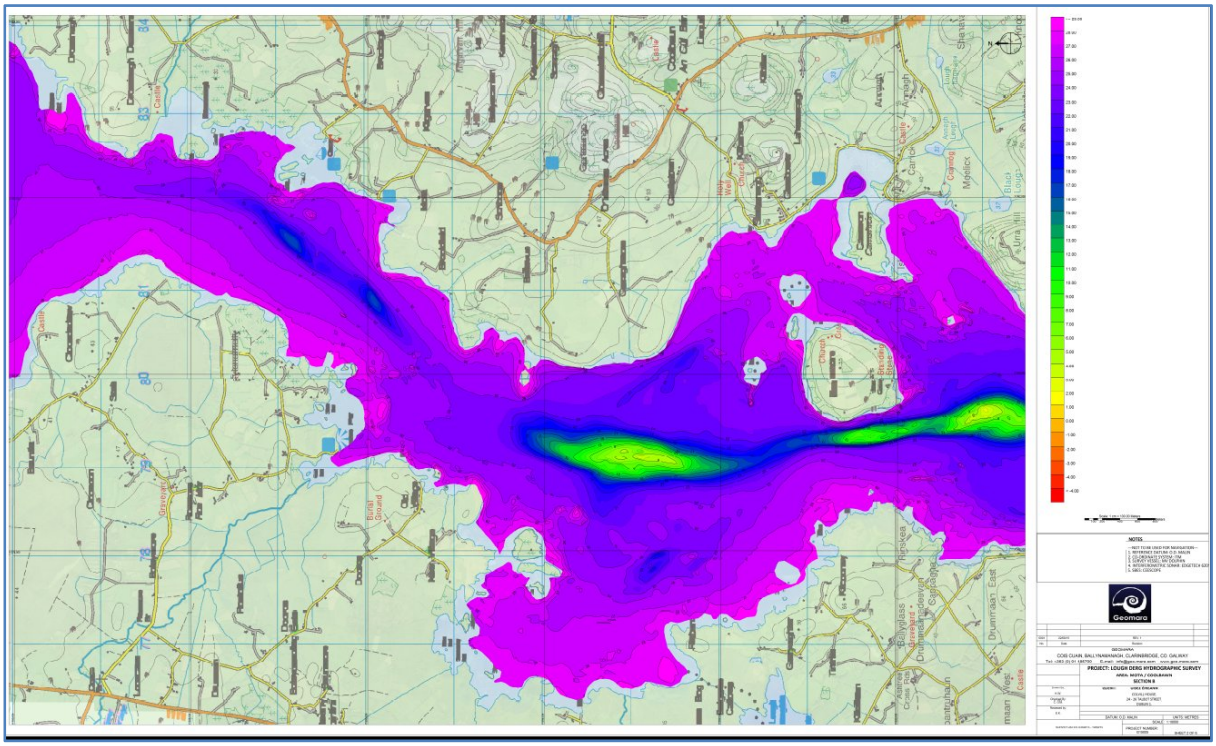

Figure 15. Section B Bathymetric Chart

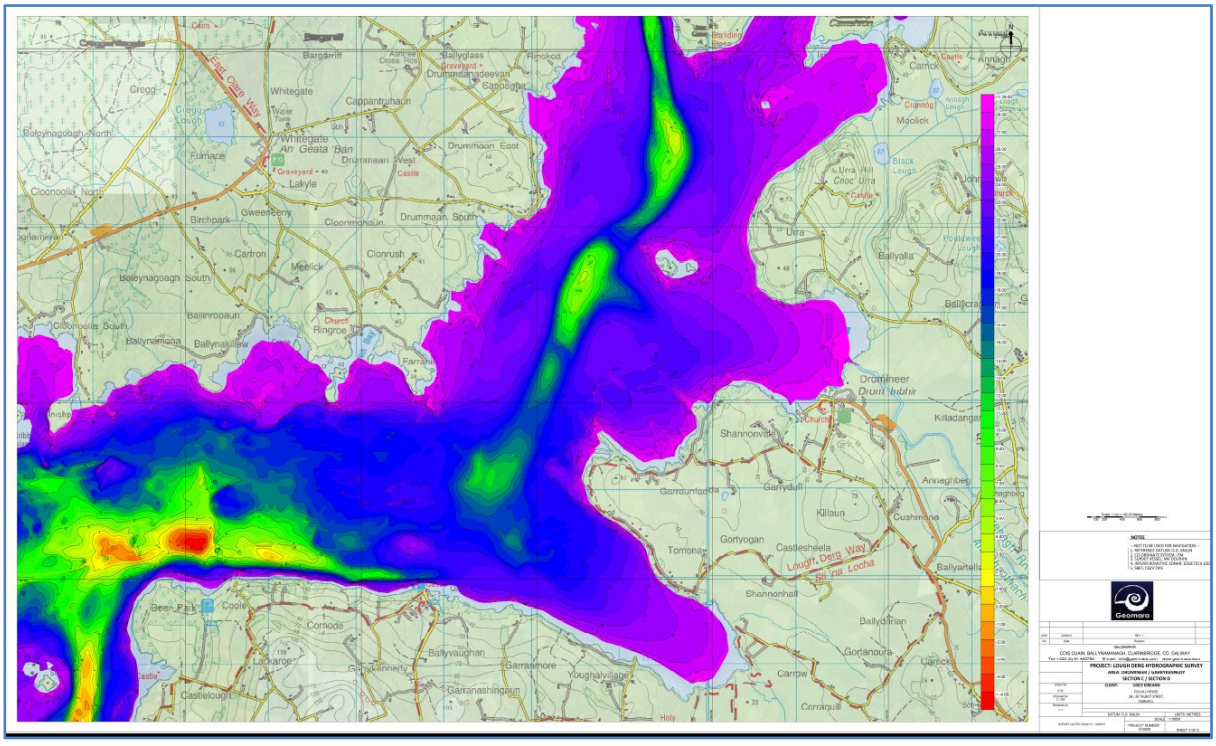

Figure 16. Section C&D Bathymetric Chart

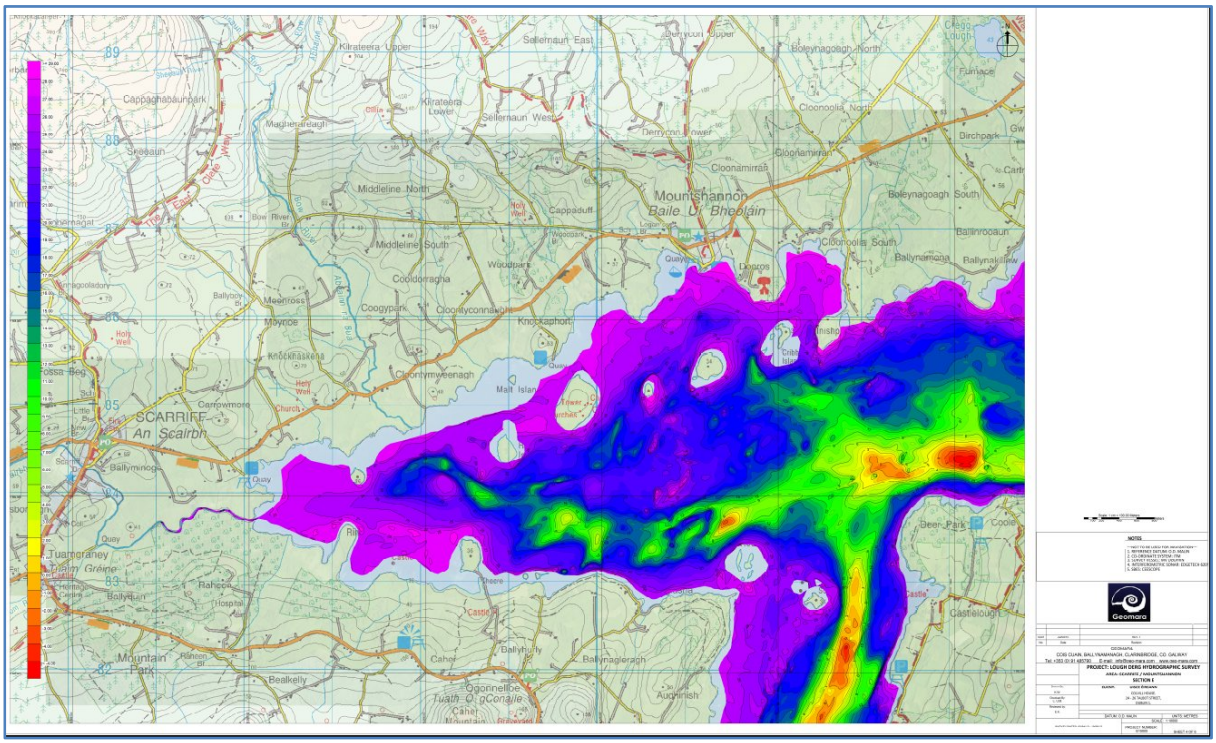

Figure 17. Section E Bathymetric Chart

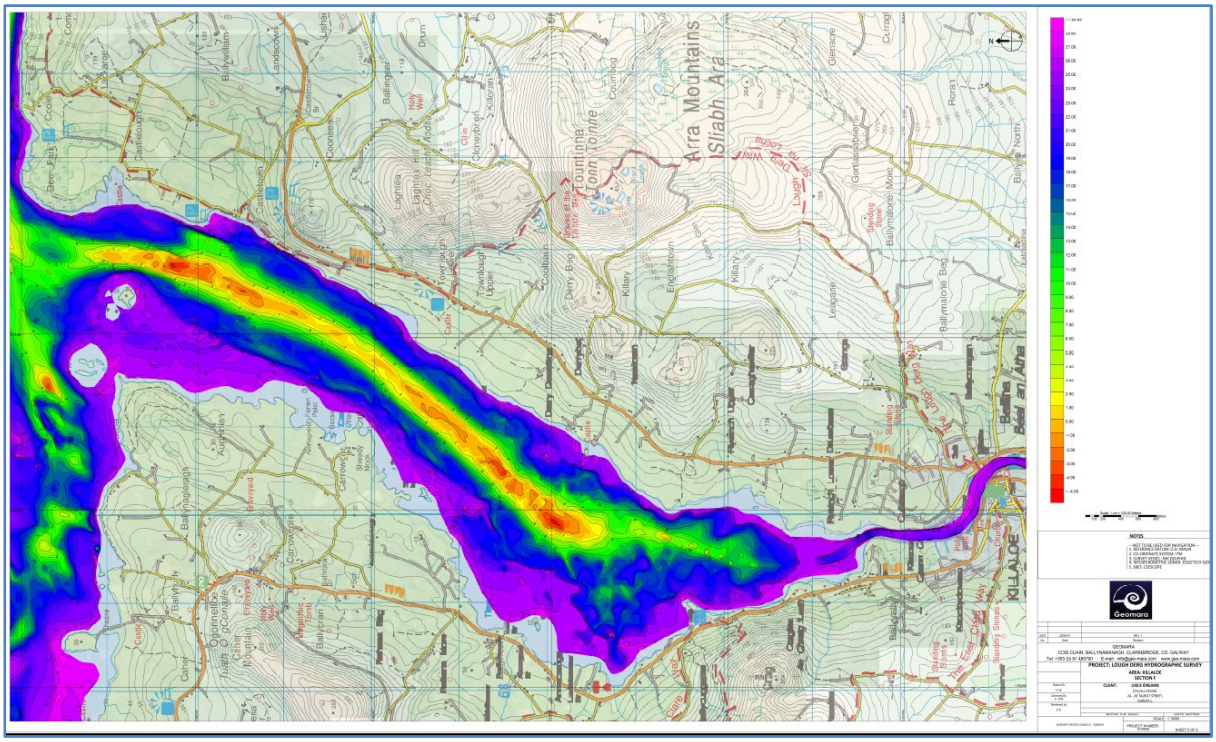

Figure 18. Section F Bathymetric Chart

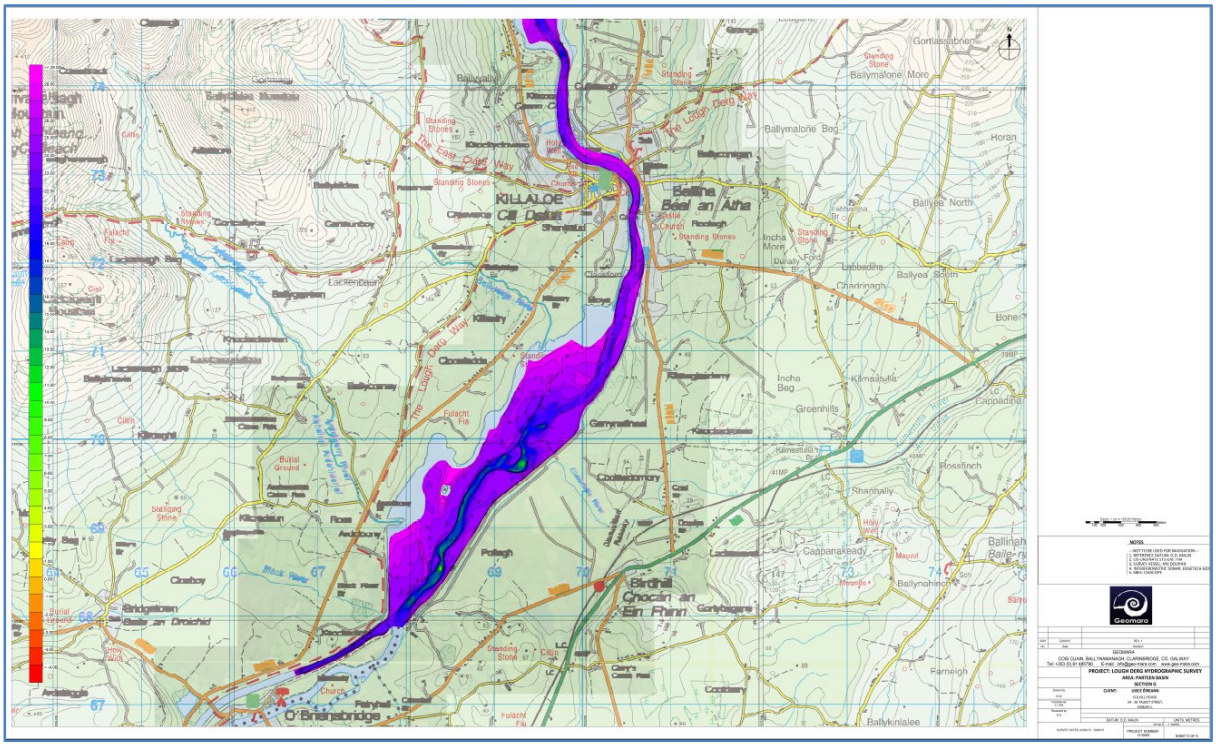

Figure 19. Section G Bathymetric Chart

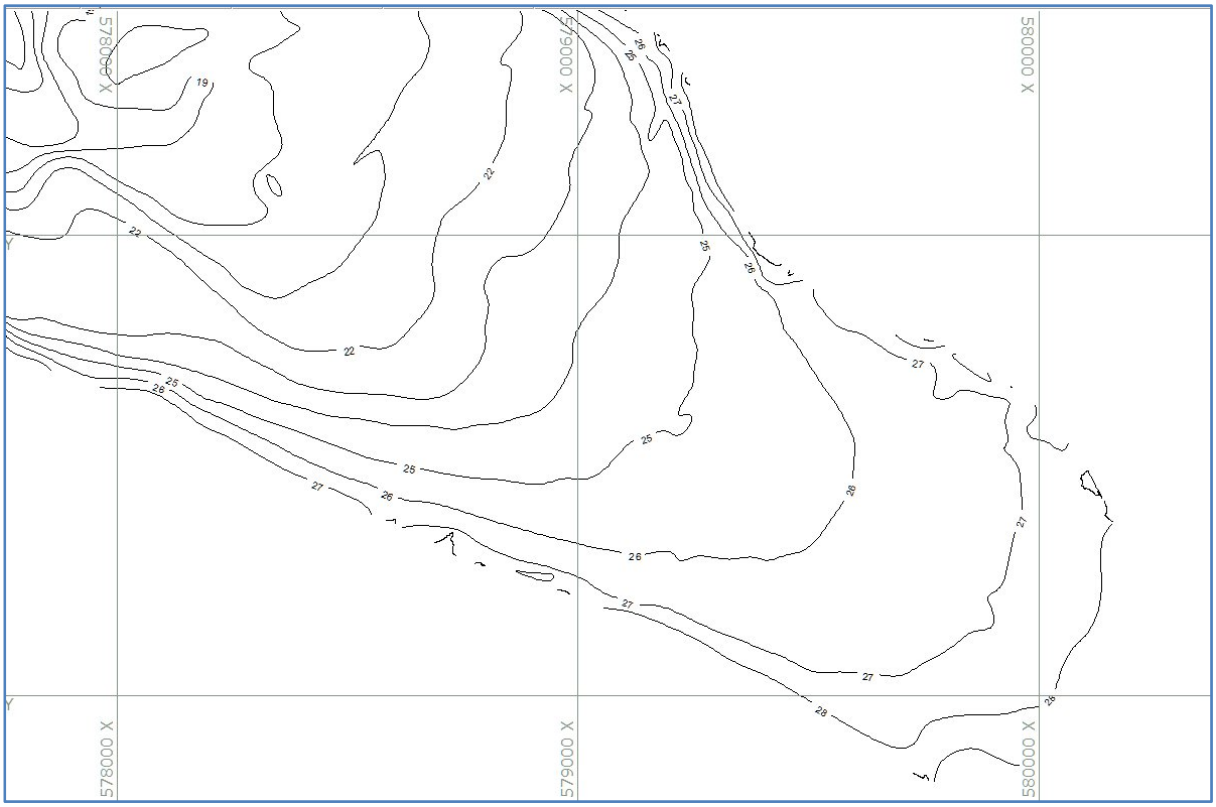

Figure 20. Bathymetric Contour DXF (Youghal Bay)

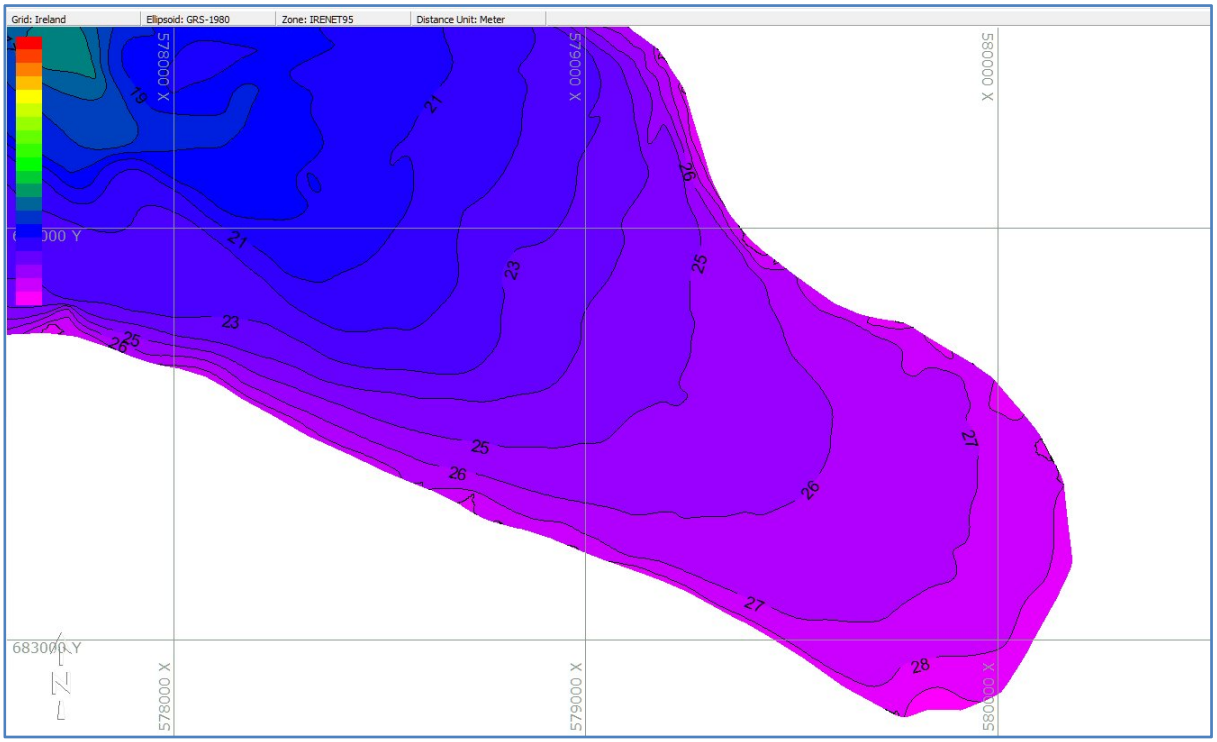

Figure 21. Bathymetric Colour Contour DXF (Youghal Bay)

4.2 Side Scan Sonar

The quality of the side scan sonar data tendered to be good. It indicated discernible sediment variations throughout the lake (Fig. 22). High reflectivity facies were noted in the outer limits of the lake. These appeared to correspond with areas of rock close to shore. Low reflectivity sediments were recorded in the deeper central segments. These again corresponded with soft sediments that were recorded by the drop down camera.

A large number of anomalous features were identified by the side scan sonar, these included 8 wrecks of varying sizes, a large number of anchors and chains, an outfall pipeline and railway track remains which were located close to Garrykennedy. In the area surrounding Parteen, a large number of man-made features were noted; these included fish weirs, former roads and homesteads as well as the former river channel and Killaloe canal(Fig. 23 – Fig. 24).

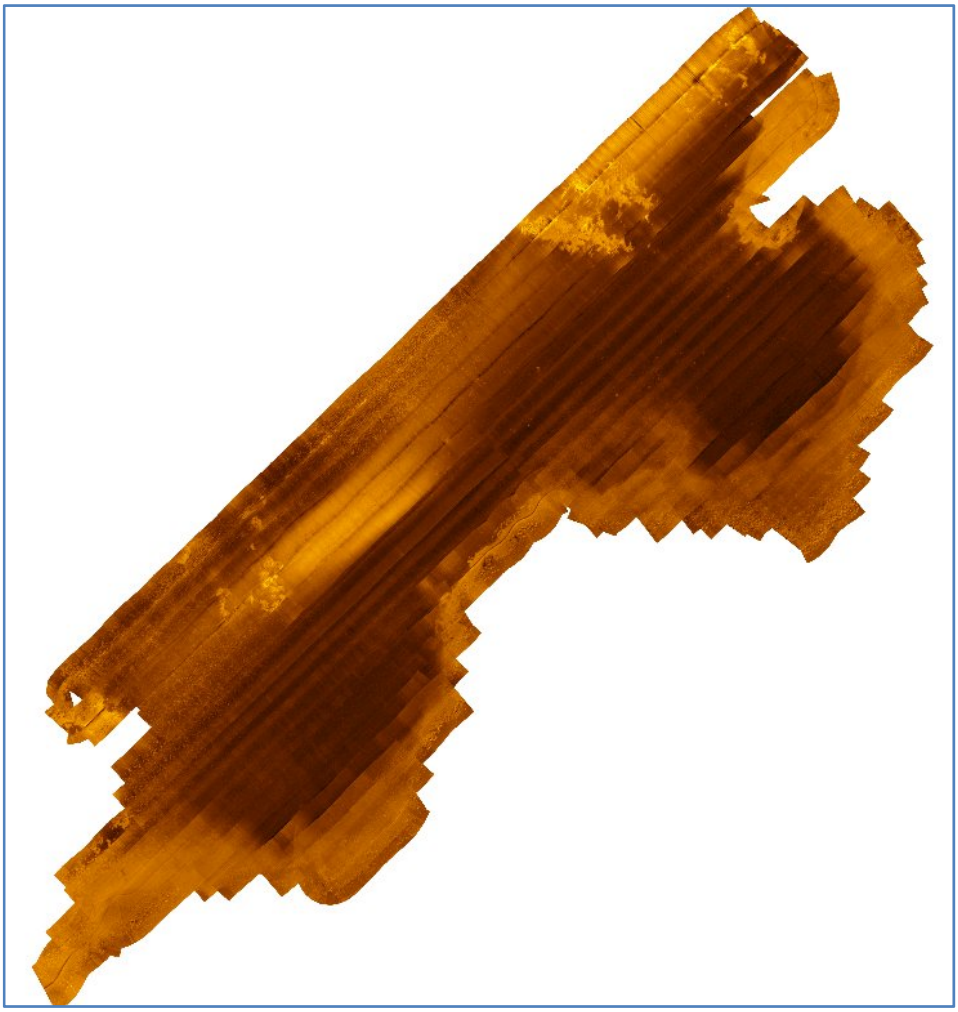

Figure 22. Sidescan Mosaic (Mota)

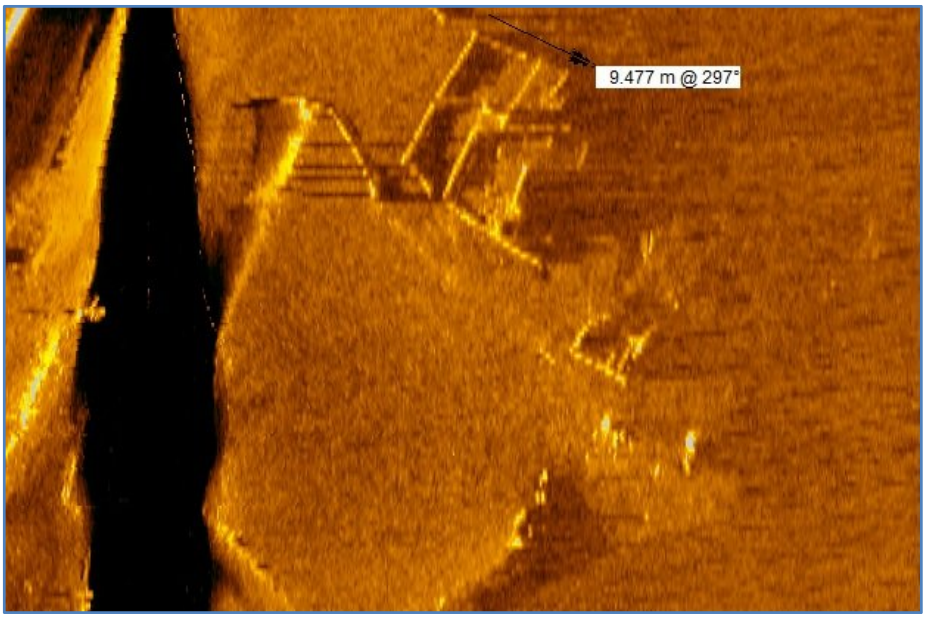

Figure 23. Remains of pre-1929 Homestead (Parteen)

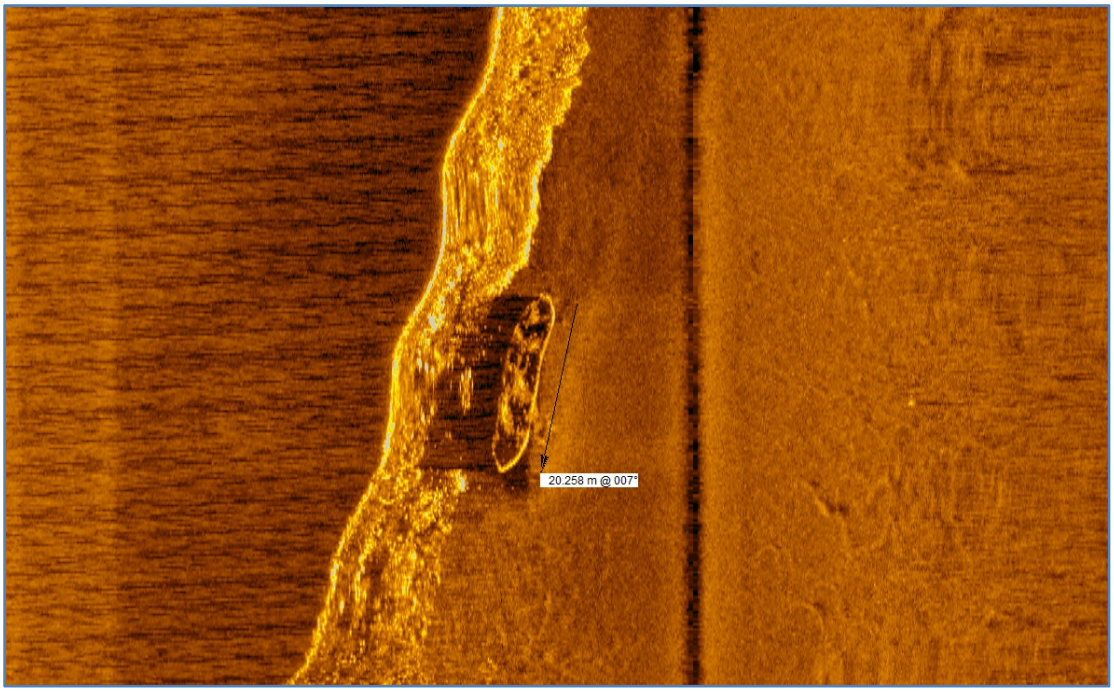

Figure 24. Shipwreck (Parteen)

4.3 Drop down Video

Drop down video shows the lake bed in the area of eachpredetermined sample location, identifying local sediment, anomalous features and lacustrine flora and fauna (Fig. 25).

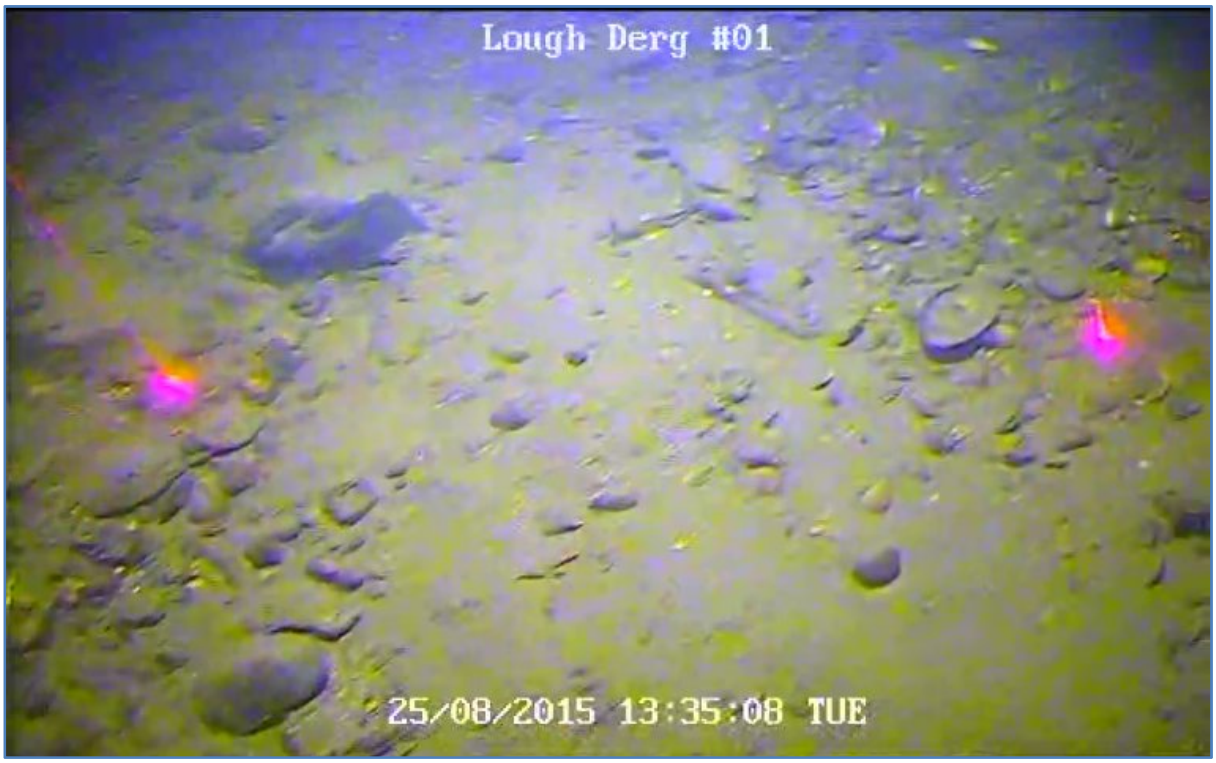

Figure 25. Drop Down Video.