

The effect of an artificial destratification system on the water quality of Chichester Reservoir - the role of organic carbon

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The Effect of an Artificial Destratification System on the Water Quality of Chichester Reservoir –The Role of Organic Carbon

By

Wang Wei

A thesis in fulfilment of the requirements for the degree of

Master by Research



School of Civil and Environmental Engineering

Faculty of Engineering

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Decreased dissolved oxygen, increased soluble iron and manganese concentrations are common effects of hypolimnetic anoxia in stratified reservoirs. Artificial destratification systems are applied to break stratification and create consistent temperature and dissolved oxygen levels throughout the reservoir. However, destratifiers can also cause unwanted changes in physical, chemical and biological processes that occur in the water column, which could deteriorate the water quality. Organic carbon, a major energy source for biological decomposition reactions, plays a vital role for reservoir water quality. However, uncertainty exists about how organic carbon degradation processes interact with the operation of destratifiers. Understanding the role of organic carbon during the operation of destratifier is important to manage and optimise the performance of destratifier. In this thesis, water quality data from a one-year monitoring program in Chichester dam is analysed. This is done by analysing: 1) water quality data trends and; 2) how the operation of destratifier affects water quality parameters at different sampling location under different scenarios. A fieldwork investigation was then applied to determine organic carbon content, reactivity and degradation processes in the water column.

The results show that: 1) compared to the middle area which is not affected by the destratifier, the destratifier at the near dam wall area can effectively: a.) break stratification and achieve a well-mixed water column which; b.) reduces temperature and dissolved oxygen level differences between surface and bottom, and increases dissolved oxygen levels near the bottom; 2) two fluorescence dissolved organic matter components were found in the water column: processed and unprocessed humic/fulvic substances. These include a mixture of autochthonous and allochthonous humic/fulvic substances. Ratios of processed to unprocessed humic/fulvic substances range from 0.59 to 0.62. 5-day biological oxygen demand measurements show low organic matter decomposition in the water column. It is concluded that poor water quality at the near dam wall area is associated with: 1) deteriorated water being brought to the near dam wall area from sediments; 2) resuspension of iron, manganese from sediment due to the operation of destratifier in the near dam wall area. Soluble iron, manganese and ammonium in the water column originate from the anaerobic decomposition in sediments.

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Abstract

The adverse water quality effects related to stratification in large enclosed waterbodies, like reservoirs, has long been recognised. Decreased dissolved oxygen levels and increased soluble iron and manganese concentrations are the most common effects caused by hypolimnetic anoxia when stratification occurs. Artificial destratification systems are widely applied to mitigate such effects by achieving mixing and consistent temperature and dissolved oxygen concentrations throughout the reservoir. However, the operation of artificial destratification systems can cause unwanted changes in the physical, chemical and biological processes and reactions that occur in the water column, and could deteriorate rather than improve the water quality.

Organic carbon, a major source of energy for most biological decomposition reactions, plays a vital role in determining reservoir water quality. However, uncertainty still exists about how organic carbon degradation processes interact with the operation of artificial destratification systems. Understanding the role of organic carbon during the operation of artificial destratification systems is important to manage and optimise the performance of artificial destratifiers.

Located in a largely undisturbed catchment in the Hunter Region, Chichester Dam is an ideal study location because it has a recognized annual stratification and detailed historical water quality data records. In this thesis, water quality data obtained from a one-year monitoring program carried out in the middle and near the dam wall area of Chichester Reservoir is analyzed. This is done by analysing: 1) the water quality data trends and; 2) how the operation of the artificial destratifier affects water quality parameters at different sampling locations under different scenarios. A fieldwork investigation was then carried out during the early onset of stratification, to determine organic carbon content/reactivity and the organic carbon degradation processes in the middle of the dam versus near the dam wall area of Chichester Reservoir.

The results of this study show that: 1) compared to the middle area, which is not affected by the destratifier, the artificial destratification system near dam wall area can

effectively break thermal stratification and achieve a well-mixed water column which reduces temperature and dissolved oxygen concentration differences between the surface and the bottom, and increases dissolved oxygen concentrations near the bottom; 2) near the dam wall area affected by the artificial destratification system, dissolved oxygen concentrations are lower than 100% of saturation all the time during the thermal stratification period; 3) the artificial destratification system in Chichester Reservoir has a limited influence on controlling the release of iron, manganese and nutrients from bottom sediments near the dam wall area; and, 4) based on fieldwork data, two dominant fluorescence dissolved organic matter components were found in water column: unprocessed humic/fulvic substances and processed humic/fulvic substance. These include a mixture of both autochthonous and allochthonous humic/fulvic substances. The ratio of unprocessed humic/fulvic substances to processed humic/fulvic substances ranges from 0.587 to 0.620. Measurements of BOD₅ (biological oxygen demand) show low organic matter decomposition in the water column of Chichester Reservoir.

Overall, it is concluded that poor water quality near the dam wall area is associated with:

- 1) Deteriorated water being transported to the dam wall area from bottom sediments in the middle of the dam and near the dam wall area and the hypolimnion in the middle of dam; and,
- 2) Resuspension of iron, manganese and nutrients from sediments due to the operation of the destratification system near the dam wall area. Soluble iron, manganese and ammonium in the water column originate from anaerobic decomposition reaction processes in the bottom sediments, which are located in the middle of the dam and near the dam wall area.

The findings of this study add to a growing body of literature investigating the impact of artificial destratification systems on water quality in temperate reservoirs.

Key words: drinking water quality, stratification, artificial destratification, organic carbon degradation, fluorescence organic matter, biological oxygen demand.

Acknowledgement

“Confucius said, ‘To know that we know what we know, and that we do not know what we do not know, that is true knowledge.’”

–Henry David Thoreau, Walden

“孔子曰：‘知之为知之，不知为不知，是知也。’”

– 亨利·戴维·梭罗《瓦尔登湖》

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List of Abbreviations

Abbreviation	Full name/definition/explanation
DOC	Dissolved Organic Carbon
POC	Particulate Organic Carbon
TOC	Total Organic Carbon
DOM	Dissolved Organic Matter
SUVA	Specific Ultraviolet Absorbance
Abs	Absorbance under certain wavelength
PW	Peak Wavelength
ex	Excitation wavelength
em	Emission wavelength
FI	Fluorescence Index
DO	Dissolved Oxygen
EC	Electrical Conductivity
Chl a	Chlorophyll a
TP	Total Phosphorus
BOM	Bureau of Meteorology
fDOM	fluorescence dissolved organic matter
s-w test	Shapiro-Wilk normality test
k-s test	Kolmogorov-Smirnov test
m-w test	Mann-Whitney test
BOD5	Five-day Biological Oxygen Dema
M-2m	The sampling location 2m depth, in the middle of Chichester Reservoir.
M-bottom	The sampling location 1m from the bottom, in the middle of Chichester Reservoir.
M-differential	The water quality parameter difference between 2m depth and 1m from the bottom, in the middle of Chichester Reservoir.
DW-SVH	The sampling location Surface Valve House, in near the dam wall area.
DW-bottom	The sampling location 1m from the bottom, in near the dam wall area.
DW-differential	The water quality parameter difference between Surface Valve House and 1m from the bottom, in near the dam wall area.

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Chapter 1: Introduction

This Chapter provides an introduction to Chichester Reservoir and the objectives and hypotheses in this study. A brief introduction to Chichester Reservoir is presented in section 1.1. A summary of the historical destratification systems and water quality records are provided in section 1.2. Section 1.3 introduces our study objectives and hypotheses.

1.1 Introduction to Chichester Reservoir

Chichester Reservoir, located in the Hunter Region, northeast of New South Wales, is one of the oldest gravity reservoirs in Australia (Miller, 2013). As the most important freshwater storage and supply system in the Hunter region, it has been supplying drinking water in the Lower Hunter area for more than 80 years (Cole, 1997, Miller, 2013). It is currently operated by Hunter Water Corporation (HWC).

The current maximum capacity of Chichester Reservoir is 18,356 megalitres (ML) with a maximum water storage level 156.2 m (Australian Height Datum, updated October 2016). It has a surface area of 180 hectares and a maximum depth of 37 m (Figure 1.1). Chichester Reservoir is continuously being drawn, with the discharge rate typically around 75-90 ML/day when the water storage is above 60% full. The reservoir is approximately 32.5 m deep at the dam offtake.

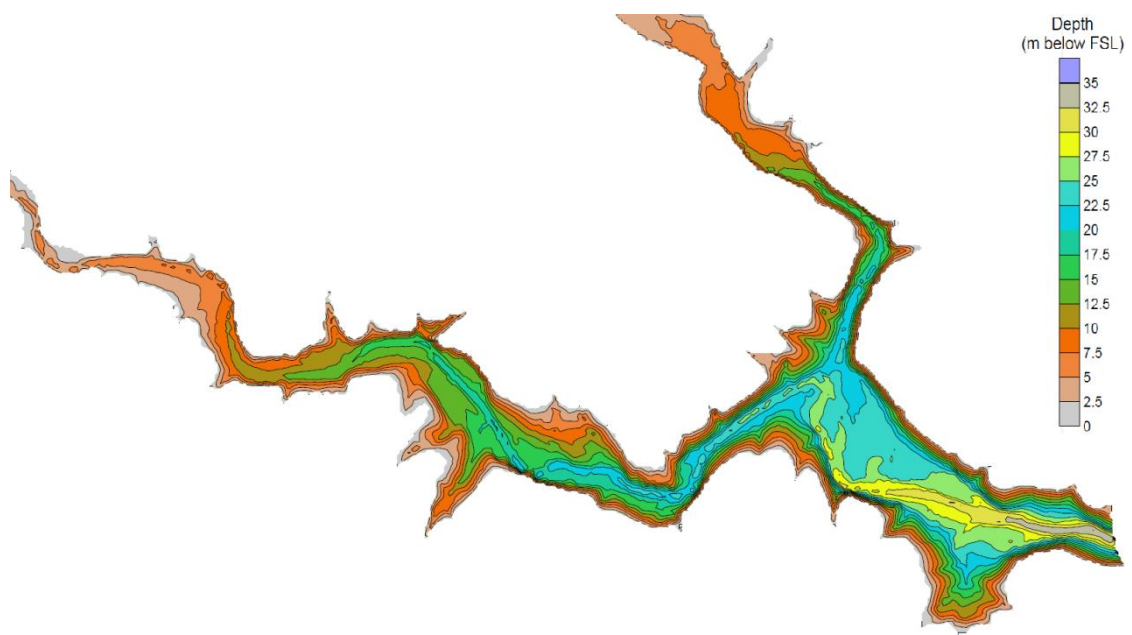


Figure 1.1 Bathymetry of Chichester Reservoir (2013 Bathymetric Survey)

Detailed geological and vegetation surveys of Chichester catchment area are available from Cole (1997). The reservoir is supplied by two major tributaries: Chichester River and Wangat River. The Wangat River catchment is largely undisturbed, while the Chichester River catchment is currently affected by limited agricultural activities. This conclusion is supported by a sediment investigation study in the Chichester Reservoir catchment area (Pointon et al., 2016). In this report, two sediment mixing models and water quality data from the two rivers reveal that, on average, the Chichester River catchment contributes only 6% more sediment per unit area, compared to the Wangat River catchment (Pointon et al., 2016).

1.2 Historical destratification systems and water quality records

A water quality monitoring program in Chichester Reservoir, near the dam wall area, started from the middle of last century. Computer archived water quality data is available since 1987 (Cole, 1997). For a detailed description of Chichester Reservoir near the dam wall area, please see section 3.1.

With a maximum depth of 37 m, and located in a temperate climatic zone, Chichester Reservoir is impacted by thermal stratification for more than six months per annum. The stratification typically occurs from September until the reservoir overturns the following year around April, and reaches its most stable stratified condition in January (Miller, 2013). To solve the deteriorated water quality problems caused by thermal stratification, several artificial destratification systems had been installed since 1992 (Glamore, 2004). A brief description of these systems is detailed below:

- 1) From 1923 to 1988, drinking water supplied from Chichester Reservoir only received limited chemical treatment (Cole, 1997);
- 2) An aeration system was installed in Chichester Reservoir in 1987. The aeration system was operated only during the onset of summer during 1987-1992. During that time, at the near dam wall area, uniform temperature and dissolved oxygen (DO) values were difficult to achieve. Substantial temperature differentials between surface and bottom were recorded, with maxima higher than 10°C. At this time, the maximum DO concentration differential was 8 mg/L (Cole, 1997).

3) In 1992, a new aeration system was installed and operated all year around. The new aeration system effectively maintains uniform iron and manganese concentrations as well as temperature values at the near dam wall area. Typical temperature differentials were recorded between 0-3°C, and maximum temperature differentials decreased to less than 5°C. However, it was difficult to maintain the uniform and elevated DO levels. Typical DO differentials were recorded as 1-2 mg/L, with maxima values of 3-4 mg/L (Cole, 1997).

Water quality data from August 1987 to June 1997 are summarized in Table 1, Appendix 1.

4) Between 27th June 2002 and 27th January 2014, a mechanical destratification system with a flexible draft tube (WEARS) was installed in the Chichester Reservoir to reduce power consumption. It was concluded by Glamore (2004) that WEARS was not able to maintain a completely uniform water column, high DO levels and low soluble iron (<0.2mg/L) and manganese (<0.03mg/L) concentrations at the near dam wall area. Maximum temperature differentials were recorded of 5.4°C and DO levels decreased with depth (Glamore, 2004).

Water quality data from March 2001 to January 2004 are summarized in Table 2 and Table 3, Appendix 1.

5) Since 2004, the operation of the WEARS units ceased. Hunter Water Corporation then restarted the operation of the previous aeration system. The aeration system installed in 1992 is a bubble plume destratifier with a dual perforated pipe system, supplying atmospheric pressure air. It is suspended 2-3m above the reservoir bed (Clausen and Fanning, 2012, Miller, 2013). This system is operating with one compressor in winter, two compressors in summer and is still in use today (Cater et al., 2010, HWC, 2013).

The water quality sampling area was extended into the middle of Chichester Reservoir in 2012 (Clausen and Fanning, 2012, Miller, 2013). Results suggest that the air bubble destratification system has a limited effectiveness at a distance of 150 metres away from the dam wall. In the destratified area, the water quality in regards to the dissolved oxygen, iron and manganese level declined compared to the unaffected area

(Clausen and Fanning, 2012, Miller, 2013). Water quality data from July 2007 to June 2012 are summarized in Table 4-7, Appendix 1.

In addition to the routine water quality monitoring program, which was carried out at Chichester Reservoir near the dam wall area, Hunter Water Corporation started an additional water quality sampling program in the middle of Chichester Reservoir since 25th May 2015. Our analysis of the reservoir in this thesis is based on this sampling program.

1.3 Thesis objectives and hypotheses

Previous technical reports conclude the following reasons for the poor water quality in Chichester Reservoir (Glamore, 2004, Clausen and Fanning, 2012, Miller, 2013):

- 1) The configuration of the bubble diffuser plumes is highly inefficient and cannot effectively destratify the whole waterbody in Chichester Reservoir (Miller, 2013);
- 2) The current location of the destratification system, 2m off the bed, allows low oxygenated water to accumulated on the reservoir bed (Miller, 2013);
- 3) Low oxygenated water in the hypolimnion is brought to the epilimnion at the near dam wall area by the bubble diffuser plume (Miller, 2013);
- 4) Due to the age of Chichester Reservoir, there is a high sediment oxygen demand in the reservoir bed (Glamore, 2004, Miller, 2013);
- 5) The resuspension of sediment increases iron and manganese concentrations in the water column (Glamore, 2004, Clausen and Fanning, 2012, Miller, 2013).

This study aims to understand the role of organic carbon in the degradation processes, during the operation of artificial destratification system in the Chichester Reservoir. Organic carbon is a major source of energy for most microbial aerobic and anaerobic decomposition reactions in large enclosed waterbodies. The degradation processes of organic carbon interact with the operation of artificial destratification systems. However, the role of organic carbon in determining reservoir water quality remains unclear and has not been studied in Chichester Reservoir until now.

To achieve this objective, water quality data monitored between 25th May 2015 and 30th May 2016, in the middle and near dam wall area of Chichester Reservoir was

analysed. To address key processes, a two-day fieldwork campaign was carried out on the 5th, 6th December 2016 to determine the organic carbon content, reactivity and organic carbon degradation processes in the water column at both the middle and near the dam wall area.

The study hypotheses are:

- 1) The artificial destratification system in Chichester Reservoir has an impact on water quality, including organic carbon, near the dam wall area;
- 2) Thermal stratification, heavy rainfall events and high inflow events influence water quality, including organic carbon, in Chichester Reservoir;
- 3) Organic carbon degradation processes are accelerated during the thermal stratification period, due to the impact of the artificial destratification system near the dam wall area.

Chapter 2: Literature Review

This chapter provides a detailed literature review on the following aspects: 1) the theory and mechanism of thermal stratification (section 2.1); 2) physical transport process of a catchment inflow event (section 2.2); 3) organic carbon in natural aquatic systems (section 2.3), and; 4) introduction to artificial destratification system (section 2.4).

2.1 The theory and mechanism of thermal stratification

The purpose of this section is to introduce the formation of thermal stratification and to review its relative impacts on water quality in lakes and reservoirs. Thermal stratification is a common problem often encountered in deep enclosed waterbodies, like lakes and reservoirs, during summer seasons (Wetzel, 2001). Waterbodies, especially eutrophic waterbodies, which suffer from severe thermal stratifications are usually associated with hypolimnetic anoxia and various water quality problems, such as low dissolved oxygen level and increased soluble metal concentrations (Beutel and Horne, 1999, Liboriussen et al., 2009, Bryant et al., 2011).

2.1.1 Formation of thermal stratification

In a large enclosed waterbody, surface water accepts more solar radiation compared to benthic water during warm seasons, especially in summer (Clausen and Fanning, 2012). The rate of thermal heating in surface water can exceed the heating dispersion rate from the surface to the lower layer (Clausen and Fanning, 2012). Thermal stratification occurs under this circumstance as water in the cooler benthic water has a higher density than the warmer surface water, resulting in three layers: epilimnion (surface layer), metalimnion (also known as thermocline) and hypolimnion (bottom layer) (Clausen and Fanning, 2012). In winter, the epilimnion cools down and sinks to the bottom, until the whole waterbody is mixed well (Clausen and Fanning, 2012). This process is called 'overturn'.

2.1.2 Impacts of thermal stratification on water quality in lakes and reservoirs

Due to the water density differential, vertical water mixing and oxygen transport is unable to completely proceed between the surface water and bottom water. This will

potentially lead to an isolated hypolimnion (Sherman et al., 2001). Anoxic conditions occur below the thermocline, after aerobic microbial transformation of organic matter consumes all dissolved oxygen. Hypolimnetic anoxia is one of the most common problems arising in an organic matter rich, isolated hypolimnion (Liboriussen et al., 2009). The impact of an anoxic environment is described below:

Firstly, in an anoxic environment, microbes start to use nitrate, manganese oxides, iron oxides and sulfate as their decomposition reaction's ultimate electron acceptors, resulting in the accumulation of ammonia, soluble manganese, soluble iron and sulphide in the water column (Hartland et al., 2015, Bryant et al., 2011). The elevated levels of ammonia, sulphide, soluble manganese and iron can: 1) be harmful to benthic biota; 2) intensify the phenomenon of eutrophication; 3) reduce the aesthetic quality of distributed drinking water and result in widely complained soluble iron and manganese problems (Holmer and Storkholm, 2001, Höhener and Gächter, 1994). A detailed literature review of aerobic and anaerobic decomposition processes in lakes and reservoirs can be found in section 2.3.2.1.

Secondly, the anoxic condition in the hypolimnion can also increase internal nutrient loading from sediment (Liboriussen et al., 2009). For instance, in an aerobic environment, phosphorus is bonded with iron complexes. When the waterbody or sediment becomes anoxic, phosphorus can be released into the water column via two pathways: 1) being released from iron complexes, or; 2) being directly released from bacteria (Sherman et al., 2001). The release of phosphorus from sediment may further enhance algal productivity once the phosphorus enters into the epilimnion or thermocline, where algae can receive suitable solar radiation (Liboriussen et al., 2009).

Finally, several studies reported that depleted oxygen concentrations and reduced temperatures in the hypolimnion have direct adverse impact on benthic biota (Dinsmore and Prepas, 1997, Aku and Tonn, 1999, Müller and Stadelmann, 2004).

2.2 Physical transport processes of a catchment inflow event

Catchment inflow events are essential in every large enclosed waterbody as they introduce terrestrial sediments and nutrients from the watershed to the waterbody (Sherman et al., 2001). In a reservoir, inflows from the tributaries laden with

organic/inorganic sediments and nutrients first mix with reservoir water in the shallow area (Sherman et al., 2001). If the inflow is not large enough, it will not break the established thermal stratification. The inflow will then sink to the level of neutral buoyancy in the deep main basin, where the density of reservoir water matches the density of the tributary inflow (Yu et al., 2010). After the tributary inflow reaches the dam wall, it decelerates and spreads out laterally (Sherman et al., 2001). The larger particles in the tributary inflow sink to the bottom of reservoir subsequently (Sherman et al., 2001).

A detailed literature review describes the role of the tributary inflow as an important source of allochthonous organic carbon can be found in section 2.3.1.3.2 and section 2.3.1.4.

2.3 Organic carbon in natural aquatic systems

Organic carbon plays a pivotal role in various natural water systems, including groundwater, interstitial soil and sediment water, snow and glacial water, rainfall, seawater, estuarine water, rivers, lake and reservoirs and wetlands (Thurman, 2012, Wetzel, 2001). In this thesis, we include the following systems:

- 1) Interstitial sediment water: The organic carbon participates in aerobic and anaerobic microbial processes in the interstitial sediment water. These microbiological organic carbon decomposition processes have a direct impact on overlying water, and may further affect the water quality in lakes and reservoirs;
- 2) Rivers: Rivers transport terrestrial organic carbon and other materials to lakes and reservoirs. As such, rivers are important allochthonous organic carbon sources;
- 3) Lake and reservoirs: In lake and reservoirs, organic carbon is involved in biological respiration and decomposition as a major 'food', and might be further transferred to biomass or higher levels of the food web (Bade et al., 2007).

2.3.1 Organic carbon character

2.3.1.1 Differences between organic carbon and organic matter

Compared to organic carbon, organic matter is a broader definition of the entire organic molecule. It contains not only carbon, but also other elements, like hydrogen

and oxygen. The measurement of organic carbon is usually applied as a proxy of the organic matter measurement. In general, the ratio between organic carbon content and organic matter content is approximately 2:1 (Thurman, 2012).

2.3.1.2 Introduction to DOC, POC and TOC

2.3.1.2.1 Dissolved organic carbon (DOC)

DOC refers to organic carbon that can pass through a 0.45-micrometre filter (Findlay, 2003). Compared to particulate organic carbon (POC), DOC is more chemically reactive because it is composed of individual dissolved organic compounds (Thurman, 2012). DOC further contains the following categories:

1) Humic substances:

Aquatic humic substances account for 40% to 60% of the DOC in natural waters (Frimmel, 2005). They are also the major fraction of dissolved organic matter in natural water. The sources of humic substances are similar to that of organic carbon (see section 2.3.1.4), and can be classified into two categories: a.) terrestrial sources from soils and plants (also known as allochthonous humic substances), and; b.) internal sources from algal and microbiological activities (also known as autochthonous humic substances) (Thurman, 2012, Thurman, 1985b, Frimmel, 2005). Aquatic humic substances, such as polyelectrolytes of carboxylic hydroxyl and phenolic functional groups, have a molecular weight of 500-5000 and yellow colour. They are refractory to microbial decompositions because of their chemical properties (Thurman, 2012, Bastviken et al., 2003).

Humic substances can be subdivided into humic acid and fulvic acid. Humic acids precipitate when pH values are less than 2.0, while fulvic acids remain dissolved. Fulvic acids have diameters of approximately 2 nanometres and contain more carboxylic and hydroxyl functional groups amount than humic acids (Thurman, 2012, Thurman, 1985b);

2) Colloidal organic matters: Colloidal organic matters account for 10% of DOC in natural water systems. They are humic acids aggregates with diameters between 2 and

50 nanometres (Frimmel, 2005). These aggregates are usually absorbed and chemically bonded to clays, silts, iron oxides and aluminium oxides (Thurman, 2012);

3) Simple organic compounds: Simple organic compounds are individual molecules that exist in natural water systems (Findlay, 2003). Major compounds include simple sugars, amino acids, fatty acids and hydroxyl acids. These simple organic compounds origin from the decomposition processes of organic materials (Thurman, 2012);

4) Hydrophilic acids: Hydrophilic acids, also known as hydrophilic humic substances, are polymeric molecules that have similar molecular weights to humic substances (Findlay, 2003). Compared to humic substances, these polymeric molecules contain more carboxylic, hydroxyl and carbohydrate functional groups (Thurman, 2012).

2.3.1.2.2 Particulate organic carbon (POC)

POC refers to organic carbon that cannot pass through a 0.45-micrometre glass-fibre filter (Findlay, 2003). POC is composed of zooplankton, algae, bacteria, detrital organic matter from soil and plants, and organic coating on silts and clays (Neilson and Allard, 2007). POC can be subdivided into fine organic carbon (FPOC) and coarse organic carbon (CPOC). The diameter of FPOC ranges from 0.45 to 1.0 millimetre, while the diameter of CPOC is greater than 1.0 millimetre (Thurman, 2012).

2.3.1.2.3 Total organic carbon (TOC)

Total organic carbon (TOC) is calculated as the sum of DOC and POC (Findlay, 2003, Neilson and Allard, 2007).

2.3.1.3 Organic carbon concentration

2.3.1.3.1 Interstitial sediment water

The concentration of DOC in interstitial pore water depends on the oxygen condition of the system (Littke, 2006). Under aerobic conditions, organic matter is oxidized to CO₂ via aerobic microbial decomposition processes. DOC concentration ranges from 4 to 20 mg/L in oxic interstitial pore waters (Thurman, 2012, Thurman, 1985a, Littke, 2006). During anaerobic microbiological processes, DOC levels are elevated due to the accumulation of simple and complex organic acids and range from 10 to 390 mg/L (Thurman, 2012, Thurman, 1985a).

Many studies show that, in interstitial pore water, DOC concentrations increase with depth (Krom and Sholkovitz, 1977, Nissenbaum et al., 1972, Ben - Yaakov, 1973). However, other studies point out that DOC concentrations increase with the anaerobic decomposition stage, instead of depth (Lyons et al., 1979). It is generally concluded that interstitial sediment water has higher DOC concentrations (2-390 mg/L) compared to surface waters (Thurman, 2012).

A detailed literature review relating to aerobic and anaerobic decomposition processes can be found in section 2.3.2.1.

2.3.1.3.2 River water

POC concentrations in rivers vary with the size of the river and increase with high sediment loads (Wetzel, 2001). The ratio between POC and DOC concentration in a small stream (discharge rate less than 100 m³/s) is approximately 0.1, while this ratio increases to 0.5 in large rivers (Wetzel, 2001, Meybeck, 1981). Distributions, concentrations and compositions of DOC and POC in rivers are largely influenced by wet and dry seasons (Meybeck, 1981). For instance, in a wet season, when high discharge rates occur, the POC concentration to DOC concentration ratio may increase to 1 (or even higher in a large river) (Thurman, 2012, Thurman, 1985a, Meybeck, 1981). Depending on different discharge rates, DOC concentrations in rivers vary from 1 to 10 mg/L (Findlay, 2003). Unlike POC, DOC concentrations do not remarkably vary with the changing discharge. Therefore, it is POC, instead of DOC, that largely contributes to the increasing of TOC during wet seasons (Thurman, 2012, Thurman, 1985a).

2.3.1.3.3 Lake and reservoir water

In a large enclosed waterbody, like a lake or reservoir, total organic carbon is dominated by DOC, whereas POC accounts for only 10% (Wetzel, 2001, Birge and Juday, 1934). Both DOC and POC concentrations in a lake or reservoir increase with the trophic state of the waterbody (Wetzel, 2001, Hama and Handa, 1983). For instance, DOC concentrations in oligotrophic lakes and reservoirs range from 1 to 3 mg/L, while DOC concentrations in eutrophic waterbodies range from 3 to 34 mg/L (Thurman, 2012, Birge and Juday, 1934, Wetzel, 2001).

Thermal stratification also has an important control on DOC and POC concentrations in lakes and reservoirs (Birge and Juday, 1934). When a lake or reservoir is thermally stratified, concentrations of DOC and POC in the epilimnion depend on the trophic state of the waterbody (Wetzel, 2001). DOC concentrations in the epilimnion can be kept in a steady state because of the relatively rapid aerobic decomposition processes and algal activities (Holm - Hamen et al., 1976). However, in the thermocline and hypolimnion, aerobic decomposition reactions are slowed down due to dissolved oxygen limitation. Meanwhile, algal amounts and production are reduced due to light limitation. Anaerobic decomposition processes may occur after dissolved oxygen being depleted (Wetzel, 2001). These anaerobic reactions in the hypolimnion are not as efficient as aerobic reactions in the epilimnion (Thurman, 1985a). Therefore, POC and DOC concentrations may slightly decrease with depth in a thermal stratified lake or reservoir (Thurman, 1985a, Thurman, 2012, Wetzel, 2001).

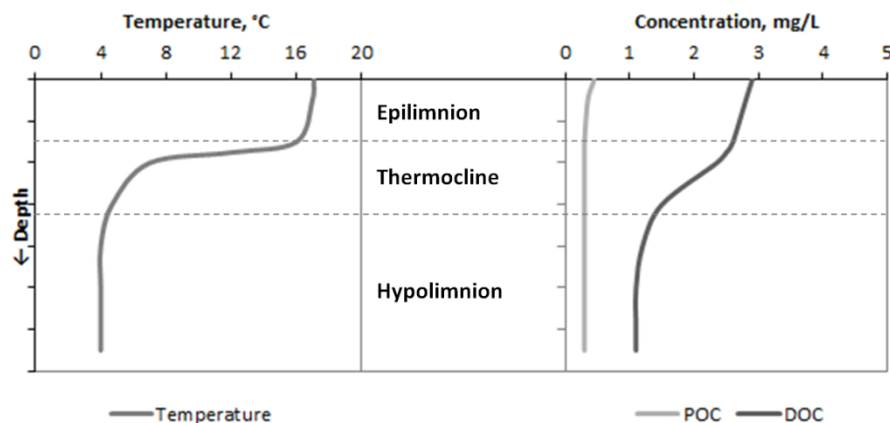


Figure 2.1 Decrease of DOC with depth in a stratified oligotrophic lake (Thurman, 1985a)

2.3.1.4 Origin of organic carbon in lakes and reservoirs

This section describes two types of organic carbon origin: terrestrial sources (also known as allochthonous organic carbon) and internal sources (also known as autochthonous organic carbon) (Wetzel, 2001). Other anthropogenic organic carbon sources, such as wastewater treatment effluent, urban runoff and agriculture land drainage, are not discussed as Chichester Reservoir is largely not affected by anthropogenic activities (Rosario-Ortiz et al., 2007).

In limnology literature, allochthonous organic carbon refers to organic carbon that originates from outside the aquatic system (Mash et al., 2004, Wetzel, 2001). The

ultimate origin of allochthonous organic carbon includes: 1) organic carbon from soils, and; 2) organic carbon from plants. Organic carbon concentrations and distributions in soil and plants depend on the region of the aquatic system (Schoeneberger et al., 2012). For instance, prairie soils contain the largest amount of organic matter, while arid soils contain the least amount of organic matter (Brady and Weil, 2000). Temperate forest and tropical forest have more organic matter in plants, while arid regions have the least amount of organic matter in plants (Brady and Weil, 2000). In a temperate forest, the amount of organic matter in the soil is approximately 15-20 kg/m², whereas the amount of organic matter in plants is around 10 kg/m² (Thurman, 2012, Schoeneberger et al., 2012). Dissolved allochthonous organic carbon carried by surface runoff during heavy rainfalls is the major source of organic carbon in aquatic systems, such as streams, rivers, lakes and reservoirs (Mash et al., 2004, Thurman, 2012).

In limnology literature, autochthonous organic carbon refers to organic carbon that originates from the internal aquatic systems (Wetzel, 2001). This type of organic carbon is typically derived from algal and microbiological activities, like primary production and organic carbon decomposition processes in lakes and reservoirs (Thurman, 2012, Rosario-Ortiz et al., 2007, Gudas et al., 2015). They are relatively more recently produced and liable to microbial decomposition, compared to allochthonous organic carbon (Coble et al., 2014, Thurman, 2012). Autochthonous organic carbon derived from primary productions and other types of autotrophic productions can also be found in river systems (Hadwen et al., 2010). A study from Hadwen et al. (2000) proposed that under severe drought conditions, autochthonous organic carbon might dominate the organic carbon pool in the river systems under such conditions due to the reduced allochthonous organic carbon inputs.

In large enclosed waterbodies with tributaries inflows, organic carbon is usually a mixture of both allochthonous and autochthonous organic carbon (Cole et al., 1984). Under this circumstance, terrestrial and internal inputs are both important organic carbon sources (Jordan and Likens, 1980). The relative dominance of allochthonous and autochthonous organic carbon relates to the following factors:

- 1) The size of the waterbody:

A small lake receives relatively significant allochthonous organic carbon input, and allochthonous organic carbon is the dominant source in an organic carbon balance (Wetzel, 2001). Conversely, in a large lake, the amount of allochthonous organic carbon decreases while autochthonous organic carbon amount increases, especially in a temperate climate region (Mash et al., 2004). That is, the larger the waterbody, the more important autochthonous sources become (Thurman, 2012);

2) Allochthonous organic carbon productivity in watershed:

Allochthonous organic carbon produced in the littoral zone is essential to small lakes, especially in wet seasons (Thurman, 2012, Yu et al., 2010). The amount of allochthonous organic carbon input largely depends on the development of the littoral zone and allochthonous organic carbon productivity in watersheds (Parks and Baker, 1997, Kim et al., 2000);

3) Primary productivity in aquatic system:

The amount of autochthonous organic carbon derived from primary productivities usually depends on the trophic state and the climate zone of the aquatic system. For instance, eutrophic lakes and reservoirs usually have higher autochthonous organic carbon loading records, due to abundant nutrient supplies (Mendonça et al., 2014). Long warm seasons and sufficient sunlight in temperate and tropical regions allows for more intensive primary production, hence higher autochthonous organic carbon inputs (Mash et al., 2004);

4) Hydrologic residence time (HRT):

A sufficient hydrologic residence time (HRT) will allow complete geochemical and biochemical processing in aquatic systems (Mash et al., 2004). Therefore, allochthonous organic carbon is able to be transformed to autochthonous organic carbon, and the autochthonous organic carbon concentration is subsequently increased (Rosario-Ortiz et al., 2007). Conversely, short HRTs could result in a lower autochthonous organic carbon loading, as autochthonous organic carbon does not have sufficient time to accumulate in the waterbody, especially during a heavy rainfall period (Kim et al., 2000).

2.3.1.5 Characterization of organic carbon origin and chemical properties

2.3.1.5.1 Total carbon to total nitrogen ratio (C/N)

The ratio between total carbon and total nitrogen (C/N) is widely adopted as a proxy of organic carbon origin in many aquatic systems and sediments studies (López et al., 2016, Maerki et al., 2009, Sobek et al., 2009, Urban et al., 2005, Mendonça et al., 2014).

As the relative importance of allochthonous organic carbon increases, the amount of nutrients (nitrogen and phosphorus) inclusion decreases (Mash et al., 2004). That is, allochthonous organic carbon contains a lower percentage of nitrogen, while autochthonous organic carbon contains a higher percentage of nitrogen (Wetzel, 2001). A C/N ratio greater than 20, is usually identified as an indicator of higher allochthonous organic carbon proportion; while a C/N ratio lower than 10 indicates the dominance of autochthonous organic carbon (Gudasz et al., 2012, Meyers and Ishiwatari, 1993). However, different definitions were proposed by Wetzel (2001): Wetzel defined the dominance of allochthonous organic carbon as a C/N ratio around 50, while the dominance of autochthonous organic carbon was defined as a C/N ratio around 12.

A weakness of using C/N ratios as a proxy of organic carbon origin, however, is that it could be unreliable under certain circumstances, especially when organic content is relatively low (Gudasz et al., 2015). C/N ratios could be altered by: 1) specific degradation pathways, like preferential degradation of carbon and nitrogen; 2) significant input of low C/N ratio biomass, and; 3) ammonium adsorption on inorganic silt and clay (Gudasz et al., 2012, Sobek et al., 2009).

2.3.1.5.2 Spectroscopic indices

Spectroscopic indices, including absorbance indices and fluorescence indices, have been adopted as proxies of organic matter origins, chemical properties and distributions for more than 50 years (Coble et al., 2014, Hudson et al., 2007). Fluorescence, compared to absorbance, were considered as a more robust and reliable proxy because it receives relatively fewer interferences from inorganic and organic light absorbing compounds (Coble et al., 2014). Some commonly and frequently used spectroscopic indices are listed below.

Specific ultraviolet absorbance (SUVA) is calculated as dividing the value of absorbance under 254 nm (Abs254) by the DOC concentration (Weishaar et al., 2003). Abs254 can also be replaced by Abs250 or Abs253 in the aforementioned calculation method (Aberg et al., 2004, Gudas et al., 2015). SUVA is commonly used as a surrogate of fluorescence organic matter aromaticity and aromatic content (Mash et al., 2004, Gudas et al., 2012, Rosario-Ortiz et al., 2007). A higher SUVA value usually represents higher allochthonous organic matter proportions, because allochthonous organic carbon usually has higher aromaticity and aromatic content (Mash et al., 2004).

Westerhoff and Anning (2000) also used peak wavelength (PW) as a surrogate of organic carbon origin. Peak wavelength (PW) is defined as the emission wavelength where the highest intensity can be observed, under an excitation wavelength of 370 nm (ex370nm). A PW value larger than 450 nm (em450nm) indicates an allochthonous organic carbon origin, while PW values smaller than em450nm represents a higher autochthonous organic carbon input (Westerhoff and Anning, 2000).

Another index, fluorescence ratio (also known as fluorescence index, FI), was also adopted by Westerhoff and Anning (2000) to identify organic carbon origin. The FI value is calculated as the ratio between em450nm and em500nm, under ex370nm. A FI value smaller than 1.5 indicates an allochthonous organic carbon origin, while FI values larger than 1.8 represents a higher autochthonous organic carbon input (Westerhoff and Anning, 2000). This index was then modified for instrument-corrected spectra: the corrected FI value is calculated as the ratio between em470nm and em520nm, under ex370nm (Coble et al., 2014). Corrected FI values smaller than 1.2 indicates more terrestrially derived organic matter, while corrected-FI values larger than 1.8 represent a higher microbial organic matter input (Cory and McKnight, 2005, McKnight et al., 2001).

For humic substances characterization, Gudas et al. (2012) adopted the ratio between Abs250 and Abs365 (A250/A365). This ratio is demonstrated having a strong correlation with aromaticity and molecular weight (Peuravuori and Pihlaja, 1997). Lower A250/A365 ratios usually represent higher allochthonous humic substances proportions, while higher A250/A365 ratios represent higher autochthonous humic substances proportions (Gudas et al., 2012).

Freshness Index (β/α), also known as BIX, is a proxy of organic matter age (Coble et al., 2014). It is calculated as the ratio of em_{380n} to the maximum intensity between em_{420nm} and em_{435nm} , under ex_{310nm} (Coble et al., 2014). Higher BIX values indicate more recently created organic matter input, while lower BIX values indicate more decomposed and aged organic matter input (Wilson and Xenopoulos, 2009).

The Peak T/Peak C ratio, calculated as the ratio between maximum intensity at Peak T and maximum intensity in the Peak C region (Coble et al., 2014). Peak T is defined as em_{350nm} , under ex_{274nm} ; while the Peak C region is defined as em_{410nm} - em_{430nm} , ex_{320nm} - ex_{340nm} (Baker, 2001). This index indicates the relationship between BOD and DOC (Baker, 2001).

2.3.2 Biochemical processes in lakes and reservoirs

2.3.2.1 Carbon cycle

Organic carbon degradation processes are major biochemical pathways in all natural aquatic systems (Wetzel, 2001). The size of the organic matter determines the organism that degrades that organic carbon. For instance: both animals and microbes degrade POC, while DOC is largely only degraded by microbes (Thurman, 2012). In lake and reservoirs, DOC dominates in waterbodies and is highly correlated with certain water quality concerns, like soluble iron and manganese (Findlay, 2003). For this reason, in this section, we focus on the microbial decomposition of organic carbon and organic carbon cycle in lakes and lake sediments.

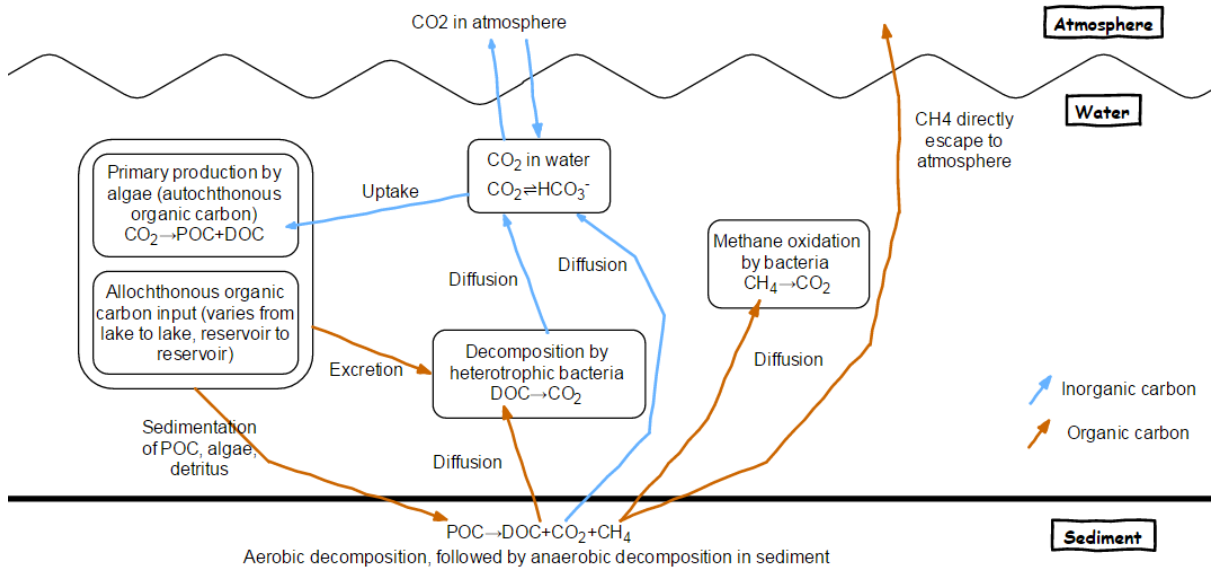


Figure 2.2 Carbon cycle conceptual model in a lake (Thurman, 1985c)

The above figure (Figure 2.2) shows the carbon cycle in a lake via microbial actions. This cycle starts with organic carbon inputs, including: 1) autochthonous POC and DOC produced by primary production, and; 2) allochthonous POC and DOC originating from tributaries inflow and surface runoff. These POC, algae and detritus will then be decomposed in the lake water column via initial DOC leaching processes. This DOC will be subsequently decomposed to simple organic compounds via microbial degradation processes. The length of time complex organic carbon takes for complete degradation is usually longer than that for simple organic compounds. In this circumstance, complete degradation refers to the conversion of complex organic carbon to carbon dioxide or methane, depending on the oxygen conditions in the water column (Thurman, 1985c, Thurman, 2012, Wetzel, 2001).

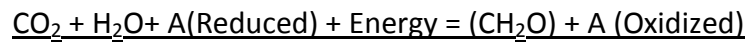
Apart from being decomposed, POC, algae (usually dead algae) and detritus can also settle to the lake bottom via sedimentation processes (Wetzel, 2001). Depending on the oxygen condition and microbial community in the sediment, these organic matters will be degraded via either aerobic or anaerobic decomposition reactions (Neilson and Allard, 2007). Usually, aerobic decomposition reactions first occur. After dissolved oxygen is depleted in the interstitial water, anaerobic decomposition reactions start. Organic matters in sediments will be transformed to carbon dioxide and methane as final products (Thurman, 1985c, Thurman, 2012, Wetzel, 2001). DOC, carbon dioxide and methane then diffuse into the water column from the sediment. A portion of

methane escapes into the atmosphere directly; the remaining methane is oxidized by methane oxidizing bacteria in the water column (Thurman, 1985c).

Carbon dioxide in the water column has three sources: 1) products of aerobic and anaerobic decomposition reaction in sediment; 2) products of aerobic and anaerobic decomposition reactions in the water column, and; 3) the exchange of carbon dioxides between the water surface and atmosphere. Carbon dioxide serves as a source for inorganic carbon assimilation in lake water and may be converted to different types of organic carbon afterwards (Thurman, 1985c, Neilson and Allard, 2007).

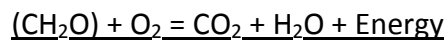
Three types of aforementioned carbon transformations are listed as follows (Appelo and Postma, 2005, Thurman, 2012, Thurman, 1985c, Tratnyek et al., 2011):

1) Inorganic carbon assimilations from photosynthesis and chemosynthesis:



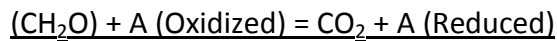
Where, A: electron donor (electron donor is a group of reduced species, like oxygen, sulfur and iron). This reaction becomes an autotrophic reaction when A is an inorganic electron donor.

2) Aerobic decomposition:



This is the dominant reaction in aerobic waterbodies (Tratnyek et al., 2011).

3) Anaerobic decomposition:



Where, A: electron acceptor, it could be nitrate, manganese oxides, iron oxides, sulfate, carbon dioxide or other organic compound. When the system is depleted of dissolved oxygen, the anaerobic microbial community will first use nitrate as the ultimate electron acceptor in this anaerobic decomposition reaction, followed by manganese oxides, iron oxides, sulfate in sequence. In the final stage, carbon dioxide will be reduced to methane after sulfate is used up (Appelo and Postma, 2005).

Anaerobic decomposition is actually a series of reactions instead of an independent reaction, because the product of one reaction can be utilized by another. Anaerobic

decomposition reactions are not as efficient as aerobic decomposition reactions and are relatively slower. Final products of anaerobic decomposition are always carbon dioxide and methane (Thurman, 1985c, Wetzel, 2001).

2.3.2.2 Organic carbon mineralization

Organic carbon in a large enclosed waterbody can be either mineralized or buried once it settles to the reservoir bed (Fortino et al., 2014, Sobek et al., 2009). The relative importance of organic carbon mineralization and organic carbon burial determines the ultimate role of these large enclosed waterbodies: a carbon sink or a carbon source. As such, the role of large enclosed waterbodies plays a vital role in the global carbon cycle (Mendonça et al., 2014, Fortino et al., 2014).

Organic carbon mineralization refers to the amount of carbon dioxide and methane emission in a defined water or sediment surface area and within a specific measuring duration; unit in mg C/m²/day or g C/m²/year (Jonsson et al., 2001, Guérin et al., 2008). There are two microbial carbon transformations involved in organic carbon mineralization: 1) aerobic decomposition, which is the dominated major reaction in aerobic water (final carbon form: carbon dioxide), and; 2) anaerobic decomposition, which is a series of much slower reactions undertaken under anaerobic conditions (final carbon forms include carbon dioxide and methane) (Gale et al., 1992, Thurman, 2012).

Organic carbon mineralization rates are a useful index for measuring the extent of organic carbon degradation, as it can effectively avoid interferences from organic carbon uptaking, ingestion and coarse organic carbon breakdown by certain microbe species (Guérin et al., 2008, Thurman, 2012).

A published journal article from Gudas et al. (2010) is the first study that demonstrated the direct correlation between temperature and sediment organic carbon mineralization in boreal and temperate areas. They revealed that sediment organic carbon mineralization is primarily controlled by temperature, while other factors, like total phosphorus concentration, trophic state and organic carbon source, has relatively minor effects (Gudas et al., 2010). The model between temperature and

sediment organic carbon mineralization was then extended to tropical areas and confirmed (Cardoso et al., 2014).

Apart from temperature, other factors, like the quality and origin of organic carbon (Gudas et al., 2012, Sobek et al., 2009), trophic state and lake morphometry (den Heyer and Kalff, 1998), thermocline depth (Fortino et al., 2014), differences between lakes and reservoirs (Aberg et al., 2004), and the availability and accessibility of oxygen (Fortino et al., 2014, Sobek et al., 2009, Maerki et al., 2009, Bastviken et al., 2003), were also reported to have correlations with sediment organic carbon mineralization rate.

2.4 Introduction to artificial destratification system

The installation and experiment of artificial destratification systems were first reported in a small Michigan lake in 1953 (Hooper et al., 1953). Artificial destratification is now widely used to reduce temperature and dissolved oxygen differentials between the surface and bottom water by enhancing internal water circulation (Sherman et al., 2001).

The technique aims to: 1) break down existing thermal stratification (Antenucci et al., 2005); 2) prevent and inhibit the onset of thermal stratification (Beutel and Horne, 1999, Zaw and Chiswell, 1999); 3) alleviate hypolimnion anoxia and its related side effects (Fast et al., 1973, Heo and Kim, 2004); 4) mitigate the symptoms of eutrophication (Heo and Kim, 2004, Brosnan and Cooke, 1987), and; 5) increase the diversity of organisms in oligotrophic lakes (Cover and Wilhm, 1982).

2.4.1 Theory and mechanism of artificial destratification system

There are two types of commonly used artificial destratification systems: 1) bubble plume aeration systems, and; 2) mechanical mixing systems (Newcombe, 2009).

In a bubble plume aeration system, compressed air is usually pumped into the water via perforated pipes installed at the bottom of a waterbody (Beutel and Horne, 1999). The location of perforated pipes should be at least 1m above the sediment to prevent sediment disturbance and entrainment (Brosnan and Cooke, 1987). Injected air bubbles that rise to the water surface also entrain surrounded fluid, and together they

develop a cone-shaped rising plume (Sherman et al., 2001, Newcombe, 2009). At the water surface, the plume spreads out and then plunges into a level of neutral buoyancy (Sherman et al., 2001, Newcombe, 2009). The plume intrusion further spreads out into the whole water column at the depth of neutral buoyancy (Sherman et al., 2001). After that, as shown in Figure 2.3, two circulations formed by two return flows appear: one above the intrusion and another below the intrusion (Newcombe, 2009). If the aeration system is designed appropriately (regarding the number of plumes, the air flow rate and the configuration of pipes), the whole waterbody can be well mixed and achieve isothermal equilibrium after long-term aeration (Newcombe, 2009, Sherman et al., 2001).

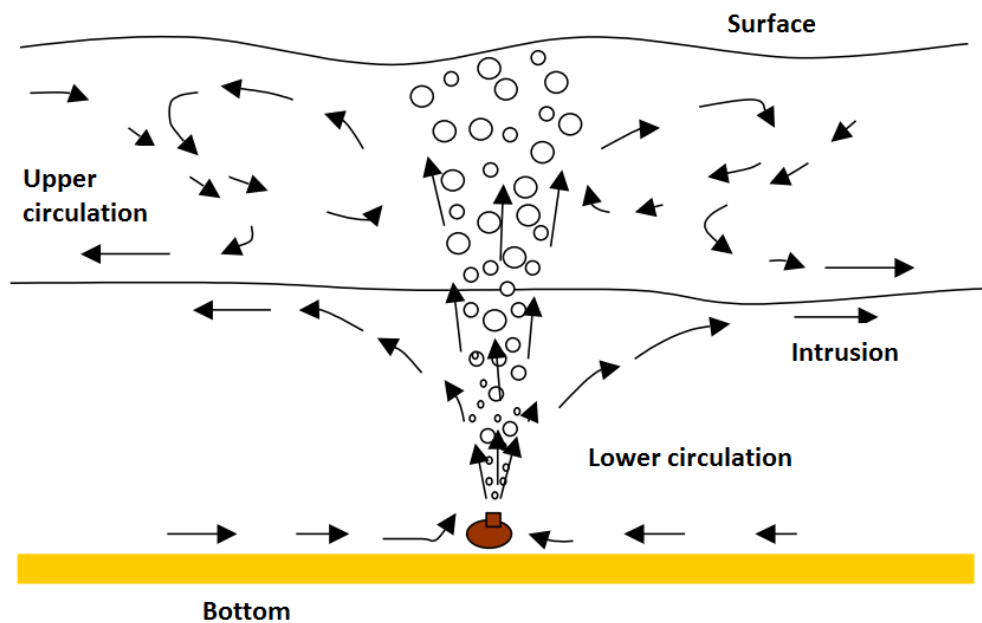


Figure 2.3 Upper and lower circulations created by a bubble plume aeration system
(Newcombe, 2009)

Different from bubble plume aeration systems, mechanical mixing systems are usually installed at the water surface and simply mix water from the epilimnion to the hypolimnion (Newcombe, 2009). Figure 2.4 shows the circulation created by a mechanical mixing system:

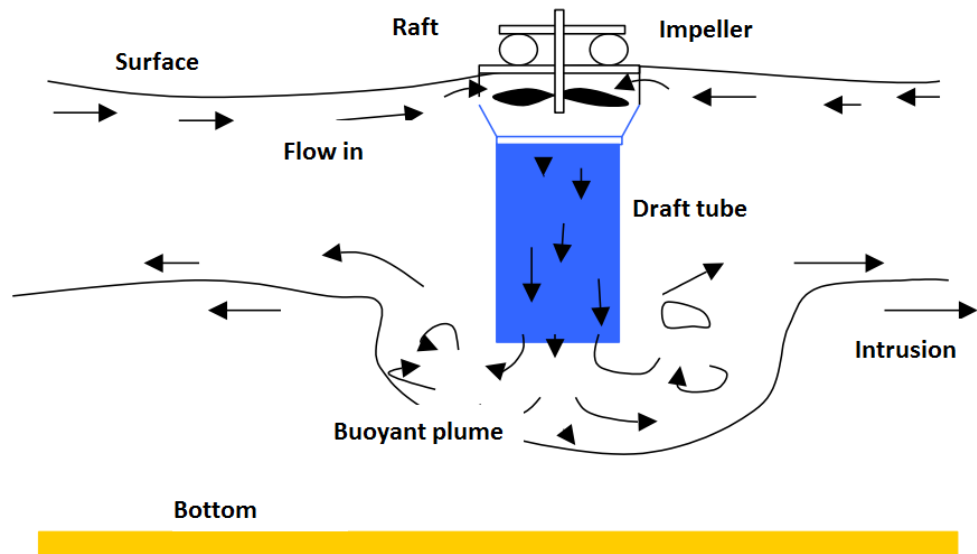


Figure 2.4 Circulation created by a surface mechanical mixing system (Newcombe, 2009)

2.4.2 Impacts from artificial destratification system

To date, many studies have investigated the effectiveness and impacts of artificial destratification systems on the following aspects:

1) Breaking down thermal stratification, increasing hypolimnion temperature and DO levels:

Destroying existing thermal stratification, achieving uniformed physical and chemical parameters in the water column, increased hypolimnion temperature and DO levels are the most common impacts from an artificial destratification system (Brosnan and Cooke, 1987).

Gupta and Gupta (2012) reported that a half year operation of a destratifier in Lake Nainital (a high altitude eutrophic lake in India) could effectively destroy thermal stratification within ten days of aeration and increased water temperature at the bottom of the lake. In the initial phase of aeration, the whole water column of Lake Nainital became anoxic due to: a). the anoxic hypolimnion water being mixed with oxic epilimnion water, and; b). DO consumption during microbial decomposition processes. After two days of aeration, DO levels increased dramatically in the whole water column (Gupta and Gupta, 2012).

Fast et al. (1973) reported that four months operation of a destratifier in Section Four Lake (an oligotrophic lake in Michigan, USA) could effectively achieve homogeneous

physical and chemical parameters in the whole water column. The majority of Section Four Lake achieved isothermal equilibrium after four days of aeration. Average temperature and DO levels increased and were evenly distributed at all depths (Fast et al., 1973).

Heo and Kim (2004) reported that four years of regular destratifier operation in Lake Dalbang (a eutrophic lake in South Korea) effectively destratified the thermal stratification and achieve homogeneous physical and chemical parameters in the whole water column. The water temperature was significantly reduced in the epilimnion and increased in hypolimnion (Heo and Kim, 2004).

Ismail et al. (2002) reported that a two month trial of a destratifier in the Upper Layang Reservoir (a tropical reservoir in Malaysia) effectively eliminated thermal stratification within one-week of continuous aeration. DO concentrations were homogenized at all depths after two weeks of continuous aeration (Ismail et al., 2002). However, the elevated water temperature in the hypolimnion may increase the reaction rate of microbial decomposition processes and further result in an increased oxygen demand (also known as induced oxygen demand) (Beutel and Horne, 1999). If the increased amount of DO concentration cannot offset the induced oxygen demand in the hypolimnion, the overall DO concentrations in the waterbody would decrease rather than increase (Sherman et al., 2001).

2) Reducing soluble iron and manganese concentrations:

Artificial destratification system may also reduce soluble iron and manganese concentrations in the water column by increasing DO levels.

Zaw and Chiswell (1999) reported that the long-term operation of a destratifier in Hinze Dam (Queensland, Australia) significantly reduced soluble iron and manganese levels in the whole water column during the initial phase of aeration. Nevertheless, soluble iron and manganese levels experienced a steady increase in the following years. This study suggested that under naturally stratified conditions (usually from early September to the following May), soluble iron and manganese levels were relatively high in the whole waterbody, whereas insoluble iron and manganese levels were low. In other seasons, when the dam was not stratified, insoluble iron and manganese

dominated the whole waterbody, while soluble iron and manganese levels were relatively low. It is summarized that the operation of the destratifier during the warm seasons can effectively: a.) reduce the temperature difference between surface and bottom water, and; b.) increase DO levels in the hypolimnion; c.) reduce soluble iron levels. However, soluble manganese received relatively low impacts from the destratifier in the whole waterbody during the warm seasons. The operation of the destratifier during the winter seasons showed limited influence on controlling soluble iron and manganese levels. It is suggested that the destratifier in Hinze Dam's failure to remove soluble manganese is due to the pH requirement of soluble manganese oxidation process. The oxidation of soluble iron requires a pH value between 6.5 and 7, while the oxidation of soluble manganese requires a pH value larger than 9. Soluble manganese can only be removed via: a.) adsorption on particulates, and; b.) autocatalytic reactions with manganese dioxides when the pH value is lower than 9. It is also suggested that soluble and insoluble iron levels were affected by heavy rainfall events, whereas soluble and insoluble manganese levels were not affected by heavy rainfall (Zaw and Chiswell, 1999).

Similar observation was also reported by Ismail et al. (2002), whereby soluble iron concentrations in the hypolimnion of Upper Layang Reservoir significantly reduced during the two month aeration period, whilst soluble manganese concentrations only reduced slightly in the hypolimnion. In contrast, no significant chemical changes were observed in the whole waterbody of Section Four Lake after four months of aeration, as reported by Fast et al. (1973);

3) Reducing internal nutrients loading:

Artificial destratification systems may impact internal nutrients loading from sediments by increasing DO levels in the waterbody, but no conclusive observations have been made so far. To date, previous studies have reported that: a.) Nitrogen and phosphorus levels did not change during the aeration period (Jungo et al., 2001, Gächter and Wehrli, 1998, Balangoda, 2016); b.) Internal phosphorus loading was reduced under aeration condition (Harris et al., 2015, Sherman et al., 2001); c.) Increased nutrients levels were observed during the aeration period (Gupta and Gupta, 2012), and; d.) The concentrations of nutrients in the water column were largely

affected by external nutrient loading, like tributaries inflows (Osgood and Stiegler, 1990, Gerling et al., 2014, Gupta and Gupta, 2012).

Balangoda et al. (2016) reported that no significant changes in total nitrogen, total phosphorus and reactive phosphorus concentrations were observed in the Heinrich-Martin Dam Impoundment (a small eutrophic reservoir in North Dakota, USA), during three summers of destratifier operation. The authors suggested that this is because of nutrient resuspension from dam sediments. The destratification system then evenly distributed resuspended nutrients throughout the whole waterbody. In this study, occasionally observed total phosphorus level reduction might be the result of reduced external phosphorus loading, instead of the impact from the artificial destratification system (Balangoda, 2016).

The resuspension of nutrients from the sediment and the subsequent mixing of the nutrient-rich hypolimnion water with epilimnion water were also reported as a reason for increased nutrients levels (Gupta and Gupta, 2012, Brosnan and Cooke, 1987);

4) Mitigating the symptoms of eutrophication:

Artificial destratification systems can mitigate the symptoms of eutrophication without changing dominant algae species in two ways: a.) by increasing DO levels in the hypolimnion and reducing internal nutrient loading, and; b.) by mixing the whole waterbody, transporting algae to deeper water levels and hence, reducing light availability for algae (Heo and Kim, 2004, Brosnan and Cooke, 1987, Sherman et al., 2001).

Artificial destratification systems can also mitigate the symptoms of eutrophication by changing the dominant algae species from cyanobacteria to green algae and diatoms, and hence, reduce the amounts of toxin production from cyanobacteria (Balangoda, 2016, Hawkins and Griffiths, 1993, Heo and Kim, 2004). Vertical mixing created by the destratifier could: a.) deprive cyanobacteria's preference in its adjustable buoyancy in the stilled water column, and; b.) increase the sedimentation losses of cyanobacteria (Visser et al., 2016, Sherman et al., 2001). Conversely, green algae and diatoms can benefit from the vertical mixing, and they are well distributed throughout the whole water column under aeration condition (Sherman et al., 2001, Visser et al., 2016).

However, the management of eutrophication cannot be achieved without an effective control of external nutrients loading (Brosnan and Cooke, 1987);

5) Others:

In addition, artificial destratification systems also have impacts on: a.) changing the dominant species, diversity and density of phytoplankton and benthic macroinvertebrates, bottom fauna and microcrustaceans (Antenucci et al., 2005, Cover and Wilhm, 1982, Brosnan and Cooke, 1987), and; b.) reducing evaporation rate at the water surface (Lackey, 1973, Fernandez et al., 2012).

2.5 Summary of literature review

In this chapter, previous literature has been reviewed on the following aspects:

1) The theory and mechanism of thermal stratification: This section contains details on the formation of thermal stratification, and the impacts from thermal stratification on water quality in lakes and reservoirs.

2) Physical transport processes of a catchment inflow event;

3) Organic carbon in natural aquatic systems: This section includes literature regarding organic carbon character and biochemical processes in lakes and reservoirs. The organic carbon character section further contains details on organic carbon concentration, organic carbon origin in lakes and reservoirs, and characterization of organic carbon origin and chemical properties. The biochemical processes section contains details on carbon cycle in lakes and reservoirs, and organic carbon mineralization in lakes and reservoirs;

4) Introduction to artificial destratification system: This section describes the theory and mechanism of artificial destratification system, and impacts from the artificial destratification system.

Together these studies provide important insights into the impacts from thermal stratification and artificial destratification system in lakes and reservoirs, and the role of organic carbon in lakes and reservoirs. However, most studies have only focused on either impacts from artificial destratification system or the role of organic carbon in

lakes and reservoirs. The interaction between the operation of artificial destratification system and the role of organic carbon remains unclear.

Our study aims, as mentioned in section 1.3, to understand the role of organic carbon in the degradation processes, during the operation of artificial destratification system in Chichester Reservoir. Based on what has been reviewed in this chapter, the impacts from the operation of artificial destratifier on the water quality (section 2.4.2), the organic carbon content/reactivity (section 2.3.1), the organic carbon degradation processes (section 2.3.2) and impacts from a catchment inflow event (section 2.2) in Chichester Reservoir are analysed and discussed in the following chapters. Chapter 3 introduces the materials and methodology applied in this thesis, and Chapter 4 summarizes the results of the data analyses.

Chapter 3: Materials and methods

This chapter presents the materials and methodology utilized in this study. The materials in this study include the current study site (section [3.1](#)) and data collection (section [3.2](#)). Data collection further contains: 1) water quality data obtained from Hunter Water Corporation (section [3.2.1](#)); 2) rainfall and watercourse discharge data for Chichester Reservoir (section [3.2.2](#)), and; 3) organic carbon data obtained from fieldwork (section [3.2.3](#)). These data are then analysed by using various statistical methods (section [3.3](#)), such as two-sampled student's t-test, Kolmogorov-Smirnov test, Mann-Whitney test and regression analyses.

3.1 Current study site

For the purpose of comparison, two groups of water quality data were monitored during the whole study period (25th May 2015 to 30th May 2016, Figure 3.1):

- 1) Group one: Water quality data monitored from the middle of Chichester Reservoir (not influenced by the artificial destratification system).

Table 3.1 Detailed information for the monitoring site in the middle of Chichester Reservoir

Site Name	Site Location	GPS Coordinate	Site Code
Middle of Chichester Reservoir	Around 500m away from dam offtake/ dam wall	32°14'11.63"S, 151°41'3.83"E	35C0000- 35C0007

Note that water column profiles were collected in the middle of Chichester Reservoir at depths of 2m, 4m, 6m, 12m, 15m, 20m and 1m from the bottom.

- 2) Group two: Water quality data monitored from near the dam wall area (influenced by artificial destratification system).

Table 3.2 Detailed information for three monitoring sites near the Chichester Dam wall area

Site Name	Site Description	Site Location	GPS Coordinate	Site Code
Surface valve house	Chichester dam surface water quality measured at the valve house	Near dam offtake/ dam wall	32°14'16.26"S, 151°41'22.88"E	15B0000
Screens	Measured at Chichester dam intake screens	Near dam offtake/ dam wall	32°14'15.45"S, 151°41'23.85"E	1610000
1m from the bottom	Measured at 1m from the bottom of valve house	Near dam offtake/ dam wall	32°14'15.72"S, 151°41'22.64"E	-

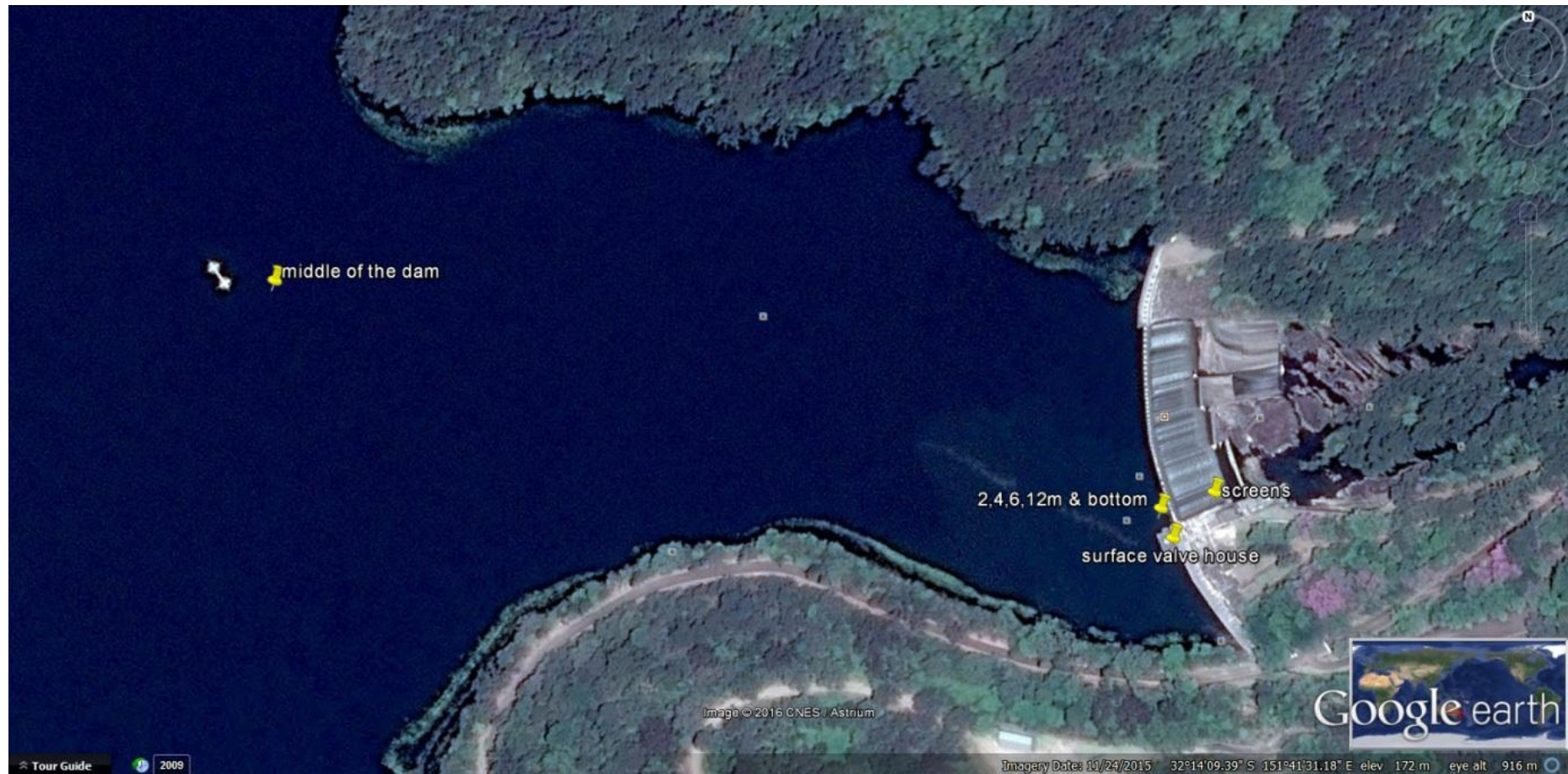


Figure 3.1 Plotted Hunter Water Corporation monitoring sites in Chichester Reservoir (Google Earth 2016)

To supplement these long-term datasets, two groups of water quality data were collected onsite on the 5th and 6th of December, 2016. Group one was collected near the dam wall area, while group two was collected in the middle of Chichester Reservoir. Detailed sampling site information for group one was consistent with the 'Surface valve house' in Table 3.2. Detailed sampling site information for group two was in line with the 'Middle of Chichester Reservoir' in Table 3.1.

3.2 Data Collection

3.2.1 Water quality data obtained from Hunter Water Corporation

Water quality data included in this section is provided by Hunter Water Corporation from:

- 1) The routine monitoring program near the dam wall area;
- 2) The additional water quality sampling program in the middle of Chichester Reservoir during the whole study period.

The full list of water quality parameters is shown in Table 3.3. Temporal distribution graphs for different water quality parameters can be found in Figure 1-18, Appendix 3.

The entire study period is from 25th May 2015 to 30th May 2016.

Table 3.3 Water quality parameters descriptions and units

Parameter	Description	Unit
Temperature	-	°C
DO	Dissolved Oxygen	mg/L
DO%	Dissolved Oxygen Saturation	%
Turbidity	-	NTU
EC	Specific Electrical Conductivity at 25°C	µS/cm at 25°C
pH	pH at 25°C	-
Fe	Total Iron	µg/L
Mn	Total Manganese	µg/L
Chl a	Chlorophyll a	µg/L
TOC	Total Organic Carbon	mg/L C
TP	Total Phosphorus	mg/L
NH₄-N	Ammonium	mg/L N

Sampling location, sampling depth and sampling frequency for each water quality parameter are summarized in Table 3.4. Methodology, quality assurance (QA) and quality control (QC) information for each water quality parameter can be found in

Table 1, Appendix 3. Note that the program of water quality sampling and field measurements in the middle of Chichester Reservoir was undertaken by the Australian Laboratory Services Pty Ltd (ALS).

3.2.2 Climate and Water data for Chichester Reservoir

Chichester Reservoir has a temperate climate. No local air temperature record is available on site, as there is no local weather station. Lostock Dam (32.33° S, 151.46° E, 21.0 km away Chichester Reservoir) is the nearest weather station (weather station number 061288, green pin on the left bottom of Figure 3.2) that provides available air temperature data (BOM 2016).

Table 3.4 Sampling location, sampling depth, sampling frequency and data availability for each water quality parameter

Parameter	Sampling locations and depths		Sampling frequency	Notes	
	Middle of Chichester Reservoir	Near Chichester Dam wall area		Data availability	Sampling frequency
Temperature	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, 1m from the bottom	About-weekly	-	-
DO	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, 1m from the bottom	About-weekly	-	-
DO%	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, 1m from the bottom	About-weekly	No available DO% data at 1m from the bottom, near dam wall area before 28-Mar-2016.	-
Turbidity	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, Screens, 1m from the bottom	About-weekly	No available Turbidity data at Screens, near dam wall area before 09-Nov-2015.	-
EC	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, Screens	About-fortnightly	EC data at Screens, near dam wall area is only available from 01-Dec-2015 to 05-Apr-2016.	-
pH	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, Screens, 1m from the bottom	About-weekly	No available pH data at Screens, near dam wall area before 09-Nov-2015.	-
Total Fe	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, Screens, 1m from the bottom	About-weekly	Fe data at Screens, near dam wall area is only available from 09-Nov-2015 to 04-Apr-2016.	-
Total Mn	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, Screens, 1m from the bottom	About-weekly	Mn data at Screens, near dam wall area is only available from 09-Nov-2015 to 04-Apr-2016.	-
Chl a	2m	Surface Valve House	About-weekly	-	-
TOC	2m, 4m, 6m, 12m, 15m,	Surface Valve House	About-	-	-

	20m, 1m from bottom		fortnightly		
TP	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House	About- fortnightly	-	-
NH3-N	2m, 4m, 6m, 12m, 15m, 20m, 1m from bottom	Surface Valve House, Screens	About- fortnightly and monthly	-	Sampling frequency for NH3-N in the middle of reservoir and Surface Valve House near dam wall area is about fortnightly; Sampling frequency for NH3-N at Screens, near dam wall area is about monthly.



Rainfall and watercourse discharge data were acquired from BOM's official website. Temporal distribution graphs for rainfall and watercourse discharge data can be accessed from Figure 19-21, Appendix 3. Detailed information of BOM weather stations is available in Table 3.5, Figure 3.3 and Figure 3.4. Increased runoff was often reported in late summer and autumn in previous technical reports, due to the high monthly rainfall and intense thunderstorms (Cole, 1997, Carter et al., 2010, HWC, 2013).

Table 3.5 BOM weather stations and detailed sample information (BOM 2016)

	Station Name	Station Number	GPS Coordinate	Monitoring Start Date	Unit
Rainfall	Chichester Dam	061151	32°14'24.00"S, 151°40'48.00"E	1 st January 1942	Millimetres (mm)
Watercourse Discharge	Chichester River at Chichester	210136	32°12'4.32"S, 151°37'59.16"E	1 st August 1997	m ³ /s
	Wangat River at Wangat	210137	32°12'31.68"S, 151°39'51.12"E	16 th September 1997	m ³ /s
	Chichester River at Cipolletti Weir	210150	32°14'20.82"S, 151°41'43.88"E	27 th March 2015	m ³ /s



Figure 3.3 Hunter Water Corporation monitoring sites, BOM station number 061151 and BOM station number 210150 (Google Earth 2016)

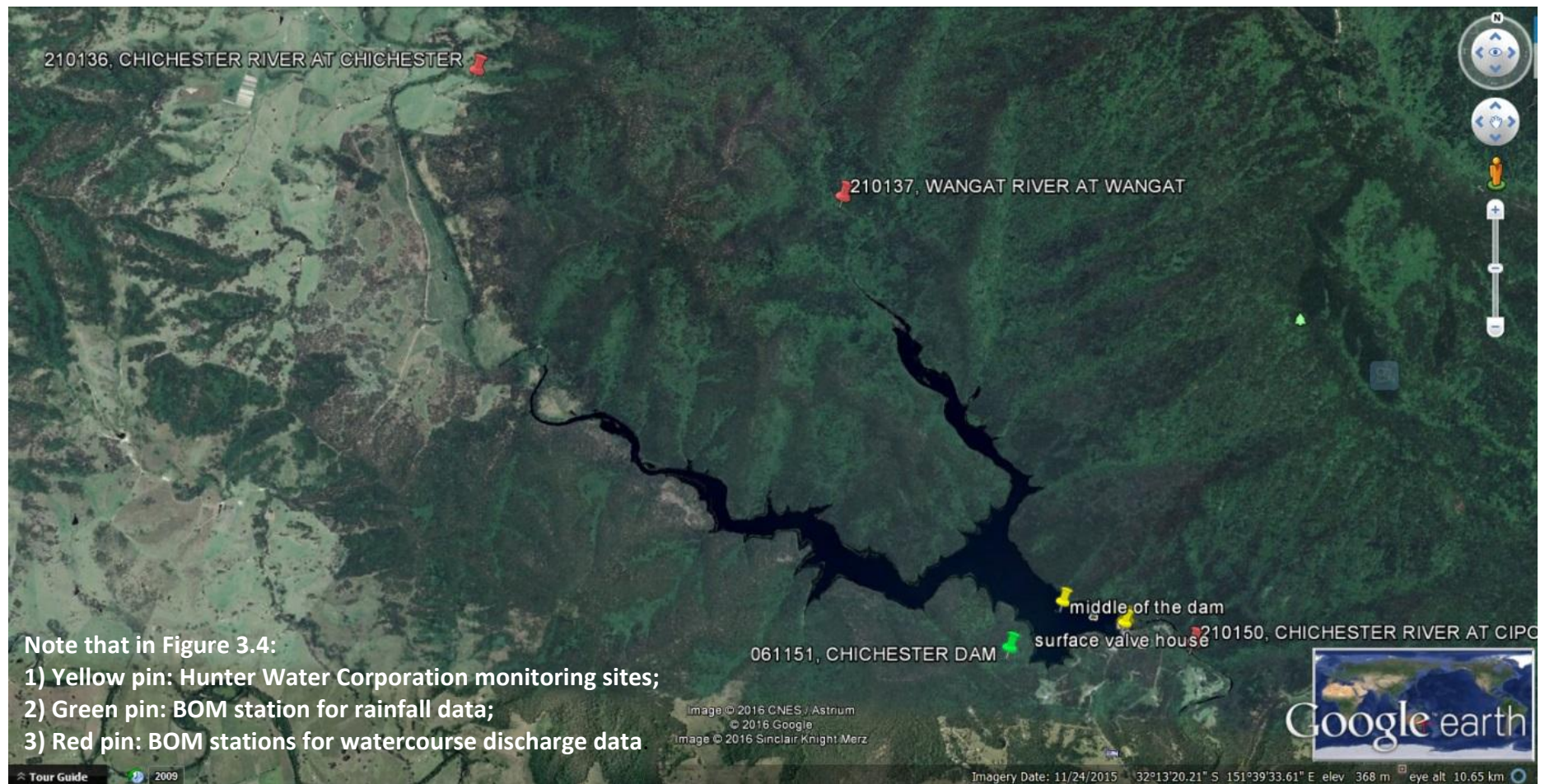


Figure 3.4 Hunter Water Corporation monitoring sites, BOM station number 061151, 210150, 210137 and 210136 (Google Earth 2016)

3.2.3 Organic carbon data obtained from the fieldwork campaign

Studies of organic carbon content, reactivity and organic carbon degradation processes in the middle and near the dam wall area of Chichester Reservoir were undertaken as part of a fieldwork campaign on the 5th and 6th of December, 2016. The fieldwork was divided into two components:

1) Water column profiles in the middle and near the dam wall area of Chichester Reservoir:

Water column profiles were collected using an EXO2 multiparameter sonde (7 sensors, YSI, USA) in the middle and near the dam wall area of Chichester Reservoir. An in-situ water level data logger (Level TROLL 700 Data Logger, In-Situ, USA) was attached to the EXO2 probe to record real-time water pressure (depth) data. The EXO2 probe and in-situ logger were both set to log every second and lowered at a slow and constant rate into the water to get a detailed, continuous water profile. Water column profiles were downloaded and plotted on-site to determine the depth of the thermocline and the exact sampling depths for further sampling work described below. Water quality parameters recorded by the EXO2 probe include: Chlorophyll a, Blue Green Algae-Phycocyanin, DO%, DO, fluorescence DOM, Temperature, Specific Conductivity, Total Dissolved Solids, pH, Oxidation-Reduction Potential and Turbidity.

2) Detailed water quality data at each sampling location and sampling depth:

Detailed sampling depths are summarized in Table 3.6. Note that replicate samples were taken at 9m depth, near the dam wall area. For each sampling depth, 9 samples were collected for further analysis, resulting in 207 samples in total.

Table 3.6 Fieldwork sampling depths

Sampling site location	Sampling date	Sampling depths (meters from water surface)
Near dam wall	5 th December 2016	0.5, 1, 5, 9, 9, 13, 17, 21, 23, 24, 24.5, 24.25.
Middle of dam	6 th December 2016	0.5, 1, 3, 4, 5, 10, 15, 20, 25, 26, 27.

Water samples were collected using a peristaltic pump to avoid air entrapment. A flow cell in-line with the pump provided temperature, DO, EC, Eh and pH for each sampling depth to match with each sample.

Water samples were delivered to the UNSW Kensington campus (Mark Wainwright Analytical Centre) and analysed onsite. Iron, manganese, phosphorus, nitrogen and carbon levels were analysed to provide a better understanding of the dynamics of each parameter. Major cations and anions were analysed to verify the sample electroneutrality. BOD5 samples were sent to the ALS Laboratory for further analysis. BOD5 data were analysed as indices of aerobic organic matter decomposition rates. Detailed information for water quality parameters measured in each sample are summarized in Table 3.7:

Table 3.7 Water quality parameters measured in each sample

Parameter	Sample description	Instrumentation/ methodology	Notes
Fe soluble (II) and Fe total (II+III)	One filtered and one unfiltered, stored in 2 acid-washed 20ml vials, stored on ice.	ICP-MS	Use 10% HNO ₃ to pre-acid wash vials. Use 0.45µm filter to filter samples. Digest unfiltered samples in the lab.
Mn soluble (II) and Mn total (IV)		ICP-MS	
P soluble and TP		ICP-MS	
Major cations (Ca, Mg, Na and K)		ICP-OES	
Major anions (Cl⁻, SO₄²⁻ and PO₄³⁻)	Filtered, stored in one 50ml Falcon tube, stored on ice.	IC	Use 0.45µm filter to filter sample.
Nitrogen (NH₄⁺, NO₂⁻ and NO₃⁻)	Filtered, stored in one 50ml Falcon tube, stored on ice.	FIA	Use 0.45µm filter to filter sample.
DOC and total N	One filtered and one unfiltered, stored in 2 50ml Falcon tubes, stored on ice.	Multi N/C	Use 0.45µm filter to filter sample.
Organic matter fluorescence (OMF)	Filtered, stored in one 50ml Falcon tube, stored on ice.	Horiba Aqualog (BEES)	Use 0.45µm filter to filter sample.
BOD5	Unfiltered, stored in one 500ml BOD5 bottle, stored on ice in dark esky	APHA (2012) 5210 B with LOR 2 mg/L	Analysed by ALS.

Dissolved organic matter fluorescence (fDOM) data exported from a Horiba Aqualog were characterized by using parallel factor analysis (PARAFAC analysis) in MATLAB (Stedmon and Bro, 2008). For all 23 organic matter fluorescence (OMF) samples, the

following fluorescence indices were calculated based on PARAFAC analysis results including:

- 1) Ratio between absorbance at 253nm and DOC concentration (SUVA);
- 2) Ratio between absorbance at 250nm and absorbance at 365nm (A250/A365);
- 3) Freshness Index (BIX);
- 4) Fluorescence index (FI), and;
- 5) Peak T/Peak C ratio.

These fluorescence indices were conducted to provide a better understanding of the origins of fDOM and the chemical properties of fDOM. Total carbon to total nitrogen ratios (TC/TN) were also calculated for all 23 samples as indices of organic carbon origins.

3.3 Data analyses

All data management and statistical analyses were performed using Microsoft Excel (Professional Plus 2010 edition) and XLSTAT 2016 for Microsoft Excel. Statistical significant levels were set at the 5% level in all analyses. A description of the statistical analyses and justification is provided below.

3.3.1 Water quality data obtained from Hunter Water Corporation

3.3.1.1 Two-sampled student's t-tests and Kolmogorov-Smirnov tests in the entire study period

Statistically significant differences between two sets of water quality data (from the middle of Chichester Reservoir and near the dam wall area, in whole study period) were analysed using two-sampled Student t-tests (t-test) and the Kolmogorov-Smirnov tests (k-s test) as appropriate, to evaluate the destratifier impacts on water quality parameters at various sampling locations during the whole study period.

T-test examined the difference between the means of two sets of data. T-tests were undertaken by first running the Shapiro-Wilk normality tests (s-w test) to identify the normality of each data series. Data series that did not follow normal distributions were normalised using box-cox transformations. F-tests were applied to determine the type

of t-tests (two-sampled equal variance t-test or two-sampled unequal variance t-test), subsequently. The following t-tests were then analysed in two-tailed distributions.

K-s test, as a non-parametric test, does not require a normal distribution of dataset and has less effect from outliers. K-s test analysed the difference between the distributions of two sets of data. Distributions of data sets may differ in variability, median and the shape of distribution. For those two data sets that have no statistically significant differences in their distributions, Mann-Whitney tests (m-w test) were then carried out to identify the difference between data medians.

Detailed information for t-test, k-s test and m-w test applications was summarized in Table 2, Appendix 3.

3.3.1.2 K-s tests at different sampling locations, under different scenarios

For different sampling locations non-parametric k-s tests were undertaken to evaluate different scenario impacts on water quality parameters at various sampling locations.

K-s tests were used instead of t-tests because some water quality parameter groups have small sample sizes ($n < 15$) at certain locations and scenarios (Frost, 2015). Detailed information for k-s test applications is summarized in Table 3, Appendix 3.

3.3.1.3 Regression analyses

By using regression analysis, it was possible to identify potential correlations between different water quality parameters. Regression analyses were carried out under four different scenarios:

- 1) Scenario 1: Regression analyses for the entire study period;
- 2) Scenario 2: Regression analyses for the 'Stratification period' and the 'No stratification period';
- 3) Scenario 3: Regression analyses for the 'Wet period' and the 'Normal and dry period';
- 4) Scenario 4: Regression analyses for the 'High inflow period' and the 'Normal and low inflow period'.

Detailed information for the regression analyses applications can be found in Table 4, Appendix 3. Note that regression analyses applications vary at different site locations under different scenarios due to the different data availability.

3.3.2 Water quality data obtained from the fieldwork campaign

3.3.2.1 K-s tests

For each water quality parameter, 11 samples were collected from the middle of Chichester Reservoir and 12 samples were collected from near the dam wall area. Therefore, each data group has a data amount less than 15. As such, non-parametric k-s tests were adopted instead of t-tests, because it has no requirements regarding data amount.

For each water quality parameter, a k-s test was applied to identify the statistically significant difference between the distribution of water quality data sampled from the middle of Chichester Reservoir and the distribution of water quality data sampled from near the dam wall area.

3.3.2.2 Simple regression analyses

Initially, regression analyses were carried out for each water quality parameter to analyse the correlation between sampling depth and water quality parameters. These regression analyses were applied: 1) in the middle of Chichester Reservoir and; 2) near the dam wall area.

Simple regression analyses were then undertaken between two groups of data: 1) Absorbance at 253nm and; 2) DOC concentrations. Each group contains all 23 samples collected from both the middle of Chichester Reservoir and near the dam wall area. This simple regression analysis was adopted to identify whether SUVA can be used as a predictor of DOC in Chichester Reservoir water column.

Simple regression analyses between fluorescence data and BOD5 data were carried out to identify if fluorescence data is a good proxy for BOD5 data in the water column of Chichester Reservoir. However, more than half (17/27) of BOD5 results were recorded as 'smaller than 2mg/L' (below limit of detection). As a consequence, regression analyses were not applied between fluorescence data and BOD5 data.

3.3.3 Determining different scenarios

3.3.3.1 Determining the ‘Stratification period’ and the ‘No stratification periods’

The onset of thermal stratification in an enclosed waterbody can be determined using different methods (Demers and Kalff, 1993, Robertson and Ragotzkie, 1990, Branco and Torgersen, 2009). In this study, we use the z-score of water temperature differential between M-2m and M-bottom (as defined in List of Abbreviations) to calculate the onset date of stratification in Chichester Reservoir.

$$Z = \frac{X_i - \bar{X}}{\sigma}$$

Where, X_i is the temperature differential during the whole study period;

$\bar{X}$ is the average temperature differential;

σ is the temperature differential standard deviation.

The date of thermal stratification onset was defined as the first day when $z > 0.5$, while the date of overturn was defined as the last day when $z > 0.5$.

Based on above method, the stratification period was determined as:

7th October 2015 to 14th March 2016

Therefore, no stratification was evident from:

25th May 2015 to 6th October 2015, and 15th March 2016 to 30th May 2016

This result is consistent with other published papers in that temperature differentials between the epilimnion and hypolimnion as small as 1-2°C were considered as criteria for determining the onset date of lake thermal stratification (Woolway et al., 2014, Magee and Wu, 2016).

3.3.3.2 Determining the ‘Wet period’ and the ‘Baseflow and dry periods’

‘Wet’ and ‘Baseflow and dry periods’ were determined based on monthly total rainfall data (BOM 2016) by using the Z-score equation (Kutiel and Paz, 1998):

$$Z = \frac{X_i - \bar{X}}{\sigma}$$

Where, X_i is monthly total rainfall in the year;

$\bar{X}$ is the average monthly total rainfall;

σ is the monthly total rainfall standard deviation.

The wet, baseflow and dry condition was defined as the following Table 3.8:

Table 3.8 Z-score ranges for determining wet, normal and dry condition

	Z score range
Extraordinarily dry	$Z \leq -2.5$
Extremely dry	$-2.5 < Z \leq -1.5$
Dry	$-1.5 < Z \leq -0.5$
Baseflow	$-0.5 < Z \leq 0.5$
Wet	$0.5 < Z \leq 1.5$
Extremely wet	$1.5 < Z \leq 2.5$
Extraordinarily wet	$2.5 < Z$

For the result of this calculation, see Table 3.9:

Table 3.9 The results of determining wet, normal and dry periods (unit: mm)

Month	Monthly Total, X_i	Z score	Result
May 2015	144.5	0.337	Baseflow
June 2015	42.1	-0.812	Dry
July 2015	22.4	-1.033	Dry
August 2015	55.2	-0.665	Dry
September 2015	85.6	-0.323	Baseflow
October 2015	42.5	-0.807	Dry
November 2015	188.4	0.830	Wet
December 2015	197.4	0.931	Wet
January 2016	316.0	2.262	Extremely Wet
February 2016	205.6	1.023	Wet
March 2016	81.0	-0.375	Baseflow
April 2016	79.2	-0.395	Baseflow
May 2016	27.6	-0.974	Dry
Average	114.42	SD, σ	89.12

3.3.3.3 Determining the ‘High inflow periods’ and the ‘Normal and low inflow periods’

‘High inflow periods’ and ‘Normal and low inflow periods’ were determined based on monthly total watercourse discharge volume data (BOM 2016). Monthly total watercourse discharge volume data from BOM station number 210136 and 210137

were summed to calculate the monthly total inflow from the two tributaries. The same calculation method as per section 3.3.3.2 was then applied to determine high, normal and low inflow periods. For the result of this calculation, see Table 3.10:

Table 3.10 The results of determining high, normal and low inflow periods (unit: ML)

Month	Monthly Total, X_i	Z score	Result
May 2015	16640.9	0.906	High
June 2015	4240.5	-0.414	Normal
July 2015	2367.7	-0.614	Low
August 2015	1992.7	-0.654	Low
September 2015	4598.2	-0.376	Normal
October 2015	2825.7	-0.565	Low
November 2015	9199.0	0.114	Normal
December 2015	4389.9	-0.398	Normal
January 2016	34760.3	2.836	Extremely High
February 2016	15517.2	0.787	High
March 2016	4406.0	-0.397	Normal
April 2016	2711.2	-0.577	Low
May 2016	2043.6	-0.648	Low
Average	8130.23	SD, σ	9390.56

3.4 Summary of materials and methods

This chapter provides a description and justification of the materials and methods utilized in this study. This is done by introducing the current study site and the data collected from Hunter Water Corporation, BOM weather stations, and the fieldwork; and the statistical analyses applied in this thesis. The definitions of different scenarios are also given in this chapter, and is summarized as follows:

- 1) 'Stratification period': 7th October 2015 to 14th March 2016; 'No stratification periods': 25th May 2015 to 6th October 2015, and 15th March 2016 to 30th May 2016;
- 2) 'Wet period': November 2015 to February 2016; 'Baseflow and dry periods': May 2015 to October 2015, and March 2016 to May 2016;
- 3) 'High inflow periods': May 2015, January 2016 and February 2016; 'Normal and low inflow periods': June 2015 to December 2015, and March 2016 to May 2016.

The results of the statistical analyses are summarized in Chapter 4.

Chapter 4: Results

This chapter details the available field data and provides statistical analyses for various climatic conditions. Initially, a description of the long-term water quality parameters obtained from Hunter Water Corporation is provided in section [4.1](#). This data is then statistically analysed to assess potential temporal and spatial patterns (section [4.1.1-4.1.4](#)). The fieldwork dataset specifically obtained for this study is then summarized in section [4.2.1](#), with the statistical analyses of this dataset presented in section [4.2.2](#) and [4.2.3](#). The organic carbon content data is highlighted as it is the first time this data has been collected in Chichester Reservoir.

4.1 Water quality data obtained from Hunter Water Corporation

In this section, the long-term data trends and ranges of the water quality parameters obtained from Hunter Water Corporation are presented, including temperature, dissolved oxygen (DO), total Mn and total organic carbon (TOC). While the full dataset was analysed, only these parameters are provided for brevity.

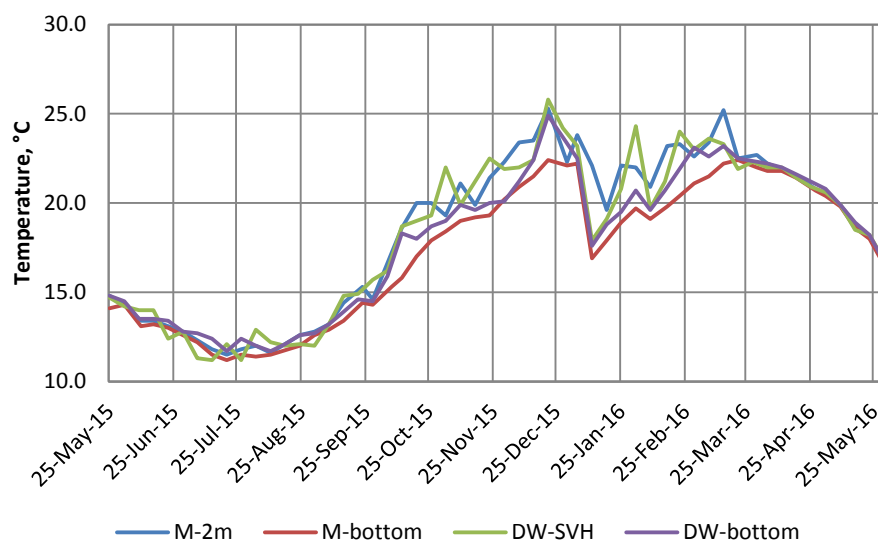


Figure 4.1 Temporal distributions of temperature at M-2m, M-bottom, DW-SVH and DW-bottom

Figure 4.1 provides temperature data at the dam wall and middle of dam over a 12 month period. This data depicts that during the pre-stratification period (from 25th May 2015 to 6th October 2015), the water temperature in Chichester Reservoir ranged from 11.2°C to 16.2°C. The minimum water temperature during the whole study

period was 11.2°C and was recorded twice during the pre-stratification period on: 1) 13th July 2015 at sampling location 'DW-bottom', and; 2) 20th July 2015 at sampling location 'M-bottom', respectively. No significant temperature differentials can be observed between the surface and bottom water, as the whole waterbody was fully mixed during the 'no stratification' period (discussed further in section 5.2).

During the stratification period (from 7th October 2015 to 14th March 2016), the water temperature in Chichester Reservoir ranged from 15.3°C to 25.8°C. The maximum water temperature during the whole study period was 25.8°C on 21st December 2015, at sampling location 'DW-bottom'. Significant temperature differentials between the surface and bottom water can be observed during this period due to thermal stratification (discussed further in section 5.3).

A sharp decrease in the water temperature during the stratification period was recorded from the 4th to 25th January 2016 due to a high inflow event (discussed in section 5.4). The water temperature in Chichester Reservoir ranged from 16.9°C to 23.8°C during the high inflow period. The water temperature then steady increased until the overturn event (water temperature ranged from 22.2°C to 25.2°C on 14th March 2016). After that, the whole waterbody was fully mixed and the water temperature differentials decreased (water temperature ranged from 16.5°C to 22.7°C).

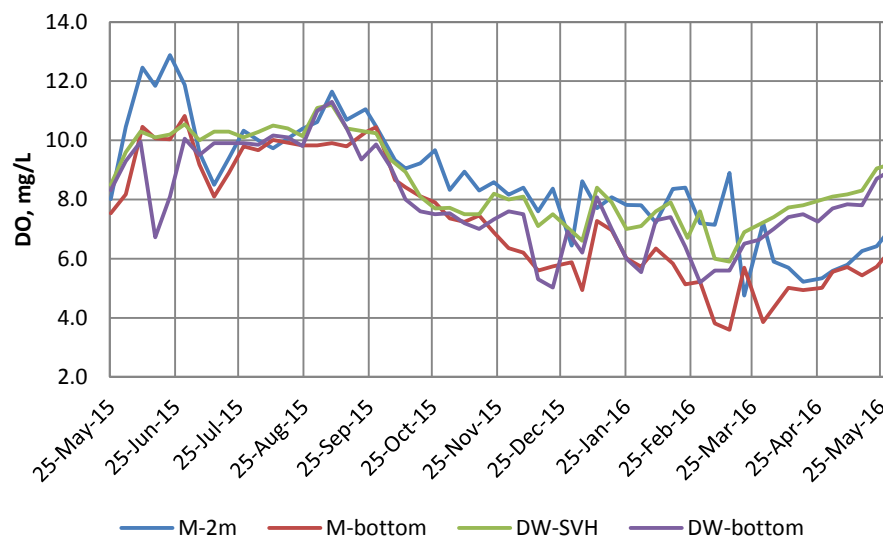


Figure 4.2 Temporal distributions of DO at M-2m, M-bottom, DW-SVH and DW-bottom

Figure 4.2 provides Dissolved Oxygen (DO) data over a corresponding 12 month period. This data reveals that during the pre-stratification period (from 25th May 2015 to 6th October 2015), DO levels in Chichester Reservoir ranged from 6.72 mg/L to 12.88 mg/L. The maximum DO level was 12.88 mg/L on 22nd June 2015 at sampling location 'M-2m'. No significant DO differentials can be observed between the surface and bottom water, as the whole waterbody was fully mixed during the 'no stratification' period.

During the stratification period (from 7th October 2015 to 14th March 2016), DO levels in Chichester Reservoir ranged from 3.59 mg/L to 9.67 mg/L. The minimum DO level during the whole study period was 3.59 mg/L on 14th March 2016 (the date of the overturn event), at sampling location 'M-bottom'. Significant DO levels differentials between the surface and bottom water can be observed during this period due to thermal stratification (discussed further in section 5.3).

An unstable and slight increase in the DO level was observed on 4th January 2016 (DO levels ranged from 4.94 mg/L to 8.62 mg/L) due to the high inflow event discussed previously.

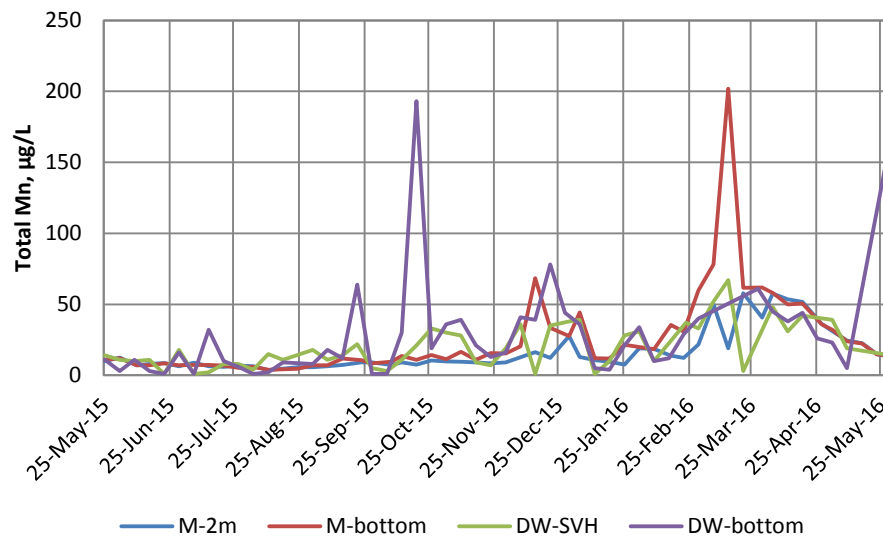


Figure 4.3 Temporal distributions of total Mn at M-2m, M-bottom, DW-SVH and DW-bottom

Figure 4.3 provides Mn levels over the length of the study. This data reveals that during the pre-stratification period (from 25th May 2015 to 6th October 2015), the total Mn levels in Chichester Reservoir ranged from 1 µg/L to 64 µg/L. No significant total Mn differentials were observed between the surface and bottom water, as the whole

waterbody was fully mixed during the ‘no stratification period’ (discussed in section [5.2](#)).

During the stratification period (from 7th October 2015 to 14th March 2016), the total Mn levels in Chichester Reservoir ranged from 1 µg/L to 202 µg/L. Significant differentials between the surface and bottom water can be observed during this period due to thermal stratification.

Three significant Mn outliers were recorded as follows: 1) 193 µg/L on 19th October 2015, at sampling location ‘DW-bottom’; 2) 202 µg/L on 14th March 2016, at sampling location ‘M-bottom’; and, 3) 170 µg/L on 30th May 2016, at sampling location ‘DW-bottom’. The outliers of 193 µg/L and 170 µg/L might be attributed to sampling and measurement errors (as discussed in section [5.1.4](#)). The second outlier of 202 µg/L was due to the overturn event (discussed in section [5.5](#)).

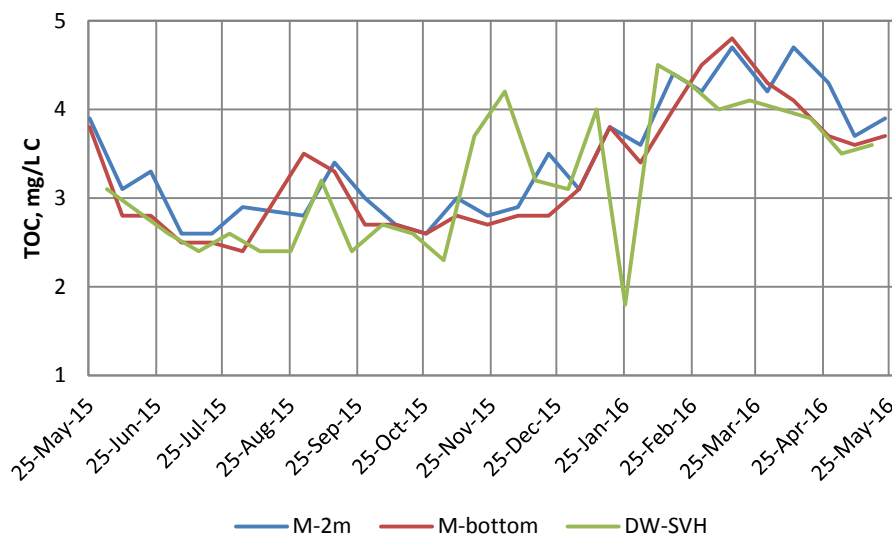


Figure 4.4 Temporal distributions of TOC at M-2m, M-bottom and DW-SVH

Figure 4.4 provides TOC measurements over the 12 month investigation period. This data depicts that during the pre-stratification period (from 25th May 2015 to 6th October 2015), the TOC levels in Chichester Reservoir ranged from 2.4 mg/L to 3.9 mg/L. During the stratification period (from 7th October 2015 to 14th March 2016), the TOC levels in Chichester Reservoir ranged from 1.8 mg/L to 4.8 mg/L. The maximum TOC level during the study period was 4.8 mg/L on 14th March 2016, at sampling

location 'M-bottom'. This maximum value could be explained by the overturn event as discussed in section 5.5.

4.1.1 S-w normality tests and t-tests in the whole study period

S-w normality tests results are summarized in Table 1, Appendix 4. S-w normality tests showed that the null hypothesis (the data are sampled from a Gaussian distribution) could not be rejected in the following datasets ($P > 0.05$): 1) DO levels monitored at 'M-2m'; 2) DO levels monitored at 'DW-bottom'; 3) pH values monitored at 'M-2m'; 4) pH values monitored at 'DW-bottom'; 5) Total Fe monitored at 'DW-SVH'; 6) TOC levels monitored at 'M-2m', and; 7) TOC monitored at 'DW-SVH'. S-w normality tests also indicated that the remaining datasets were not sampled from Gaussian populations ($P < 0.05$).

Detailed results of t-tests between two groups of the water quality data in the whole study period are summarized in Table 2, Appendix 4. The robustness of the t-tests in the whole study period was relatively low in this study: 1) 82.05% (32/39) of the results of t-tests showed statistically significant differences between the means of two data groups ($P < 0.05$); 2) 90.63% (29/32) of these significant t-tests results had a p-value less than 0.0001.

The following reasons may be responsible for the low robustness of t-tests in this study:

- 1) In this study, different λ values for various data groups were applied in box-cox transformations. Therefore, subsequent t-tests could violate prerequisite assumptions and did not compare with arithmetic means (Sakia, 1992);
- 2) Different λ applied in the box-cox transformations were estimated from original data in each data groups. An estimated λ in the transformed model could: a.) severely inflate the data variances; b.) increase the likelihood of obtaining a statistically significant result, and; c.) result in a misleading result subsequently (Doksum and Wong, 1983).

4.1.2 K-s tests and m-w tests in the whole study period

4.1.2.1 K-s tests

Statistically significant differences were found between the distribution of two data groups in 10 comparisons, in the entire study period (10/39, k-s tests, $P < 0.05$). This result indicates that the operation of the destratifier had significant impacts on the distribution of the water quality parameters, including temperature, DO, turbidity, pH, total Fe, total Mn and Chlorophyll a, in these 10 comparisons, during the entire study period. These comparisons are summarized in Table 4.1. In the remaining comparisons (29/39), no significant results were obtained from k-s tests. This indicates that the operation of the destratifier had no significant impacts on the distribution of the water quality parameters in these 29 comparisons during the study period. Detailed results of k-s tests in the whole study period, including significant and not significant results, are summarized in Table 3, Appendix 4.

In summary, the majority of statistically significant distribution differences were found between 'M-differential' and 'DW-differential', including temperature, DO, turbidity, pH, total Fe and total Mn. Statistically significant distribution differences were found between 'M-2m' and 'M-bottom' in DO and Total Mn data. As shown in Figure 4.2, during the whole study period, the DO levels at sampling location 'M-2m' ranged from 4.75 mg/L to 12.88 mg/L, while the DO levels at sampling location 'M-bottom' ranged from 3.59 mg/L to 10.82 mg/L. Total Mn levels during the whole study period, as shown in Figure 4.3, ranged from 3.7 µg/L to 57.7 µg/L at sampling location 'M-2m', and ranged from 4.0 µg/L to 202.0 µg/L at sampling location 'M-bottom'. Statistically significant distribution differences between 'M-bottom' and 'DW-bottom' were found only in DO data. Figure 4.2 shows that, during the whole study period, the DO levels at sampling location 'DW-bottom' ranged from 5.02 mg/L to 11.3 mg/L.

4.1.2.2 M-w tests

For those 29 comparisons that had no statistically significant distribution differences, statistically significant differences were found between the medians of two data groups in 3 comparisons (3/29, m-w tests, $P < 0.05$). This indicates that the operation of the destratifier had significant impacts on the median values of the water quality

parameters in these 3 comparisons: 1) DO: the median value at 'DW-SVH' (8.2 mg/L) was higher than 'DW-bottom' (7.6 mg/L); 2) pH: the median value at 'M-2m' (7.10) was higher than 'M-bottom' (7.00); and 3) Total Fe: the median value at 'DW-SVH' (240 µg/L) was lower than 'DW-bottom' (280 µg/L). These comparisons are summarized in Table 4.2. In the remaining comparisons (26/29), no significant results were obtained from m-w tests across the study period. This indicates that the operation of the destratifier had no significant impacts on the distributions and the median values of the water quality parameters in these 26 comparisons, during the whole study period. Detailed results of m-w tests in the whole study period, including significant and not significant values, are summarized in Table 4, Appendix 4.

In summary, statistically significant median differences were found between 'DW-SVH' and 'DW-bottom' in DO and Total Fe data. The statistically significant median difference between 'M-2m' and 'M-bottom' was found only in pH data.

Table 4.1 Significant results of k-s tests in the whole study period (k-s tests $P < 0.05$)

Parameter	Comparison ('group a' vs 'group b')	P-value	Descriptions of average, median values and data variability	Note that 'differential data' were calculated as 'surface data minus bottom data', therefore negative values may occur:
Temperature	'M-differential' vs 'DW-differential'	<0.0001	Compared to 'DW-differential', 'M-differential' has higher average, median values and higher variability.	Average and median values at DM-differential are negative.
DO	'M-bottom' vs 'DW-bottom'	0.0074	Compared to 'DW-bottom', 'M-bottom' has lower average, median values and higher variability.	All values are positive.
	'M-differential' vs 'DW-differential'	<0.0001	Compared to 'DW-differential', 'M-differential' has higher average, median values and higher variability.	All values are positive.
	'M-2m' vs 'M-bottom'	0.0086	Compared to 'M-2m', 'M-bottom' has lower average, median values and higher variability.	All values are positive.
Turbidity	'M-differential' vs 'DW-differential'	0.0022	Compared to 'DW-differential', 'M-differential' has lower average value, higher median value and higher variability.	Average and median values at both M-differential and DW-differential are negative.
pH	'M-differential' vs 'DW-differential'	0.0251	Compared to 'DW-differential', 'M-differential' has higher average and median values and higher variability.	All values are positive.
Total Fe	'M-differential' vs 'DW-differential'	0.0095	Compared to 'DW-differential', 'M-differential' has higher average, median values and lower variability.	Average and median values at both M-differential and DW-differential are negative.
Total Mn	'M-differential' vs 'DW-differential'	0.0002	Compared to 'DW-differential', 'M-differential' has higher average value, lower median value and lower variability.	Average and median values at both M-differential and DW-differential are negative.
	'M-2m' vs 'M-bottom'	0.0495	Compared to 'M-2m', 'M-bottom' has higher average, median values and higher variability.	All values are positive.
Chl a	'M-2m' vs 'DW-SVH'	0.0001	Compared to 'DW-SVH', 'M-2m' has higher average, median values and higher variability.	All values are positive.

Table 4.2 Significant results of m-w tests in the whole study period (k-s tests $P > 0.05$, m-w tests $P < 0.05$)

Parameter	Comparison (‘group a’ vs ‘group b’)	k-s tests P-value	m-w tests P- value	Description of median value
DO	‘DW-SVH’ vs ‘DW-bottom’	0.0832	0.010	Compared to ‘DW-bottom’, ‘DW-SVH’ has a higher median value.
pH	‘M-2m’ vs ‘M-bottom’	0.1321	0.012	Compared to ‘M-bottom’, ‘M-2m’ has a higher median value.
Total Fe	‘DW-SVH’ vs ‘DW-bottom’	0.1447	0.038	Compared to ‘DW-SVH’, ‘DW-bottom’ has a higher median value.

4.1.3 K-s tests at different sampling locations, under different scenarios

Statistically significant differences were found between the distributions of two data groups in 39 comparisons (39/93, k-s tests, $P < 0.05$). This indicates that different scenarios had significant impacts on the distribution of the water quality parameters in these 39 comparisons, at various sampling locations (discussed later in this section). Significant results at different sampling locations are summarized in Table 4.3-4.6 respectively. In the rest of the comparisons (54/93), no significant results were obtained from k-s tests. This indicates that different scenarios had no significant impacts on the distribution of the water quality parameters in these 54 comparisons, at various sampling locations.

Detailed results of k-s tests at different sampling locations under different scenarios are summarized in Table 5-16, Appendix 4. Overall, results of k-s tests at various sampling locations under different scenarios indicate that:

- 1) Temperature data are affected by thermal stratification and heavy rainfall at ‘M-2m’, ‘M-bottom’, ‘DW-SVH’ and ‘DW-bottom’;
- 2) DO data are affected by thermal stratification, heavy rainfall and high inflow from tributaries at ‘M-2m’, ‘M-bottom’, ‘DW-SVH’ and ‘DW-bottom’;
- 3) Turbidity data are: a.) affected by heavy rainfall and high inflow from tributaries at ‘M-2m’; b.) affected by thermal stratification and high tributaries inflow at ‘M-bottom’ and ‘DW-bottom’; and c.) affected by thermal stratification, heavy rainfall and high tributaries inflow at ‘DW-SVH’;

- 4) Total Fe data are affected by high tributaries inflow at 'M-2m', 'M-bottom';
- 5) Total Mn data are: a.) affected by thermal stratification and heavy rainfall at 'M-bottom'; and b.) by thermal stratification at 'DW-SVH' and 'DW-bottom';
- 6) TP data are affected by high tributaries inflow at 'M-2m', 'M-bottom' and 'DW-SVH' (no available TP data at 'DW-bottom');
- 7) Chl a data is affected by thermal stratification at 'DW-SVH';
- 8) TOC and ammonium data are not affected by thermal stratification, heavy rainfall and high tributaries inflow at 'M-2m', 'M-bottom', 'DW-SVH' and 'DW-bottom'.

4.1.4 Regression analyses

Significant correlations ($n > 5$, $R^2 > 0.7$) were found in 54 simple regression analyses at different sampling locations under different scenarios. These significant results (R^2 , negative/positive) and their corresponding sample amounts (n) are summarized in Table 4.7. Detailed results of simple regression analyses and a sample size summary can be found in Table 17-30, Appendix 4.

Results of the regression analyses show that:

- 1) 90.74% (49/54) of significant correlations were found in the middle of Chichester Reservoir. Figure 4.5 shows the significant correlation (negative) between Total Mn and DO at sampling location 'M-2m' during the no stratification period (discussed in section 5.2.1):

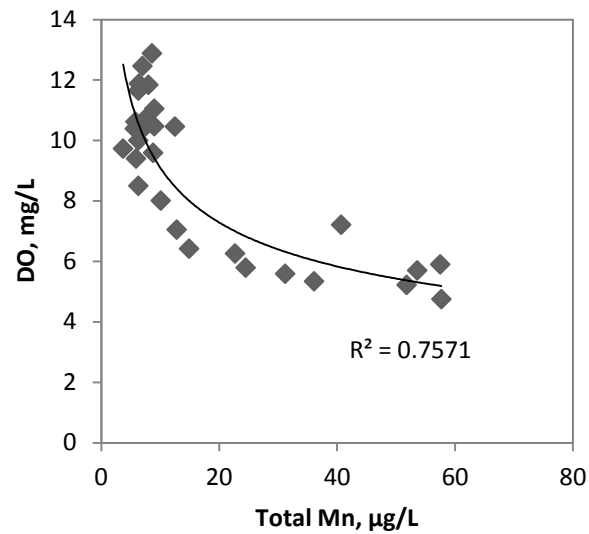


Figure 4.5 Total Mn and DO at 'M-2m' during the no stratification period (n=29, $R^2=0.7571$)

- 2) More than half (33/54) of the significant correlations were found at 'M-bottom', compared to other sampling locations;
- 3) Only 5 significant correlations were found near the dam wall area. The limited data availability may also contribute to this result;
- 4) Significant results are evenly distributed in different study periods. Except for the whole study period which contains only 3 significant results (Table 4.7). Figure 4.6 shows the significant correlation (positive) between Total Mn and Temperature at sampling location 'M-bottom' during the study period:

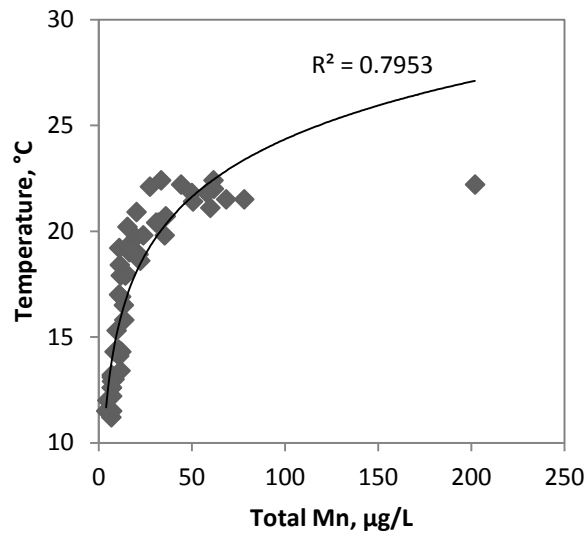


Figure 4.6 Total Mn and Temperature at 'M-bottom' during the whole study period (n=53, $R^2=0.7953$)

5) 22.22% (12/54) of significant correlations were found between Total Mn and DO (negative), followed by 12.96% (7/54) between Total Mn and Temperature (positive), and 11.11% (6/54) between Total Fe and TP (positive). Figure 4.7 shows the significant correlation (positive) between Total Fe and TP at sampling location 'M-2m' during the stratification period (discussed in section [5.3.2](#)):

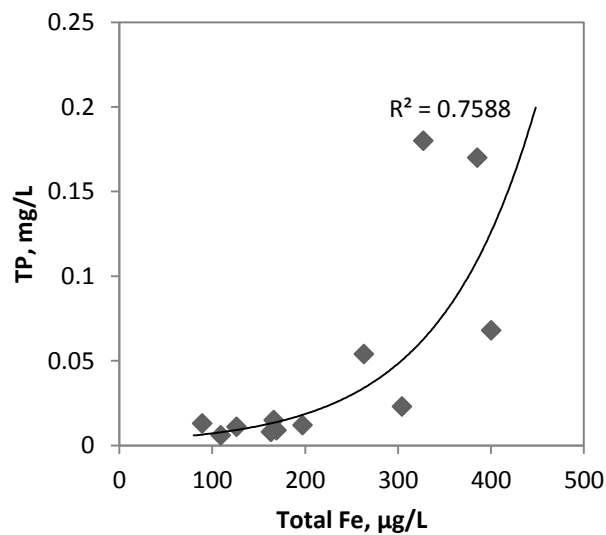


Figure 4.7 Total Fe and TP at 'M-bottom' during the whole study period (n=12, $R^2=0.7588$, positive)

Table 4.3 Significant results of k-s tests at M-2m, under different scenarios (k-s tests $P < 0.05$)

Parameter	Comparison ('group a' vs 'group b')	P-value	Descriptions of average, median values and data variability
Temperature	'Stratification period' vs 'No stratification period'	<0.0001	Compared to 'No stratification period', 'Stratification period' has higher average, median values and lower variability.
DO		0.0022	Compared to 'No stratification period', 'Stratification period' has lower average, median values and lower variability.
Temperature	'Wet period' vs 'Normal and dry period'	<0.0001	Compared to 'Normal and dry period', 'Wet period' has higher average, median values and lower variability.
DO		0.0009	Compared to 'Normal and dry period', 'Wet period' has lower average, median values and lower variability.
Turbidity		0.0183	Compared to 'Normal and dry period', 'Wet period' has higher average, median values and higher variability.
DO	'High inflow period' vs 'Normal and low inflow period'	0.0286	Compared to 'Normal and low inflow period', 'High inflow period' has lower average, median values and lower variability.
Turbidity		<0.0001	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and higher variability.
Total Fe		0.0321	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and lower variability.
TP		0.0140	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and higher variability.

Table 4.4 Significant results of k-s tests at M-bottom, under different scenarios (k-s tests $P < 0.05$)

Parameter	Comparison ('group a' vs 'group b')	P-value	Descriptions of average, median values and data variability
Temperature	'Stratification period' vs 'No stratification period'	<0.0001	Compared to 'No stratification period', 'Stratification period' has higher average, median values and lower variability.
DO		0.0018	Compared to 'No stratification period', 'Stratification period' has lower average, median values and lower variability.
Turbidity		0.0209	Compared to 'No stratification period', 'Stratification period' has higher average value, lower median value and higher variability.

Total Mn		0.0044	Compared to 'No stratification period', 'Stratification period' has higher average, median values and higher variability.
Temperature	'Wet period' vs 'Normal and dry period'	0.0004	Compared to 'Normal and dry period', 'Wet period' has higher average, median values and lower variability.
DO		0.0002	Compared to 'Normal and dry period', 'Wet period' has lower average, median values and lower variability.
Total Mn		0.0073	Compared to 'Normal and dry period', 'Wet period' has higher average, median values and lower variability.
DO	'High inflow period' vs 'Normal and low inflow period'	0.0147	Compared to 'Normal and low inflow period', 'High inflow period' has lower average, median values and lower variability.
Turbidity		<0.0001	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and lower variability.
Total Fe		0.0015	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and lower variability.
TP		0.0013	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and higher variability.

Table 4.5 Significant results of k-s tests at DW-SVH, under different scenarios (k-s tests P<0.05)

Parameter	Comparison ('group a' vs 'group b')	P-value	Average, median and variability
Temperature	'Stratification period' vs 'No stratification period'	<0.0001	Compared to 'No stratification period', 'Stratification period' has higher average, median values and lower variability.
DO		<0.0001	Compared to 'No stratification period', 'Stratification period' has lower average, median values and lower variability.
Turbidity		0.0272	Compared to 'No stratification period', 'Stratification period' has higher average, median values and higher variability.
Total Mn		0.0157	Compared to 'No stratification period', 'Stratification period' has higher average, median values and higher variability.
Chl a		0.0326	Compared to 'No stratification period', 'Stratification period' has lower average, median values and lower variability.
Temperature	'Wet period' vs 'Normal and dry period'	0.0001	Compared to 'Normal and dry period', 'Wet period' has higher

			average, median values and lower variability.
DO		<0.0001	Compared to 'Normal and dry period', 'Wet period' has lower average, median values and lower variability.
Turbidity		0.0370	Compared to 'Normal and dry period', 'Wet period' has higher average, median values and higher variability.
DO	'High inflow period' vs 'Normal and low inflow period'	0.0195	Compared to 'Normal and low inflow period', 'High inflow period' has lower average, median values and lower variability.
Turbidity		<0.0001	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and higher variability.
TP		0.0108	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and higher variability.

Table 4.6 Significant results of k-s tests at DW-bottom, under different scenarios (k-s tests $P < 0.05$)

Parameter	Comparison ('group a' vs 'group b')	P-value	Average, median and variability
Temperature	'Stratification period' vs 'No stratification period'	<0.0001	Compared to 'No stratification period', 'Stratification period' has higher average, median values and lower variability.
DO		<0.0001	Compared to 'No stratification period', 'Stratification period' has lower average, median values and lower variability.
Turbidity		0.0080	Compared to 'No stratification period', 'Stratification period' has higher average, median values and higher variability.
Total Mn		0.0358	Compared to 'No stratification period', 'Stratification period' has higher average, median values and higher variability.
Temperature	'Wet period' vs 'Normal and dry period'	0.0002	Compared to 'Normal and dry period', 'Wet period' has higher average, median values and lower variability.
DO		0.0001	Compared to 'Normal and dry period', 'Wet period' has lower average, median values and lower variability.
DO	'High inflow period' vs 'Normal and low inflow period'	0.0455	Compared to 'Normal and low inflow period', 'High inflow period' has lower average, median values and lower variability.
Turbidity		<0.0001	Compared to 'Normal and low inflow period', 'High inflow period' has higher average, median values and higher variability.

Table 4.7 Significant correlations obtained from simple regression analyses ($R^2 > 0.7$)

Scenario	Study period	Site location	Significant correlations		Sample size (n)	R ²	Positive or negative correlation	Amount of significant results	
			x	y					
Scenario 1	Whole study period	M-bottom	Total Fe	Turbidity	53	0.7492	P	3	3
			Total Mn	Temperature	53	0.7953	P		
			Total Mn	DO	53	0.8503	N		
Scenario 2	Stratification period	M-2m	Total Fe	TP	12	0.7588	P	2	8
			TOC	Total Fe	12	0.7934	P		
		M-bottom	Total Fe	DO	24	0.7532	N	6	
			Total Fe	Turbidity	24	0.7722	P		
			Total Mn	DO	24	0.8462	N		
			TOC	Turbidity	12	0.845	P		
			TOC	TP	11	0.7476	P		
			TOC	Total Fe	12	0.8665	P		
	No stratification period	M-2m	Total Mn	Temperature	29	0.9474	P	4	10
			Total Mn	DO	29	0.7571	N		
			TOC	Temperature	14	0.8345	P		
			TOC	Total Mn	14	0.7949	P		
		M-bottom	Total Mn	Temperature	29	0.9516	P	4	
			Total Mn	DO	29	0.8423	N		
			TOC	Temperature	14	0.7079	P		
			TOC	Total Mn	14	0.7109	P		
		DW-SVH	TOC	Temperature	14	0.8479	P	2	
			TOC	DO	14	0.7752	N		
Scenario 3	Wet period	M-2m	Total Fe	TP	9	0.8207	P	3	8
			TOC	TP	9	0.9067	P		
			TOC	Total Fe	9	0.7813	P		
		M-bottom	Total Fe	TP	9	0.7274	P	5	
			Total Mn	DO	18	0.7553	N		

			TOC	Turbidity	18	0.7292	P		
			TOC	TP	9	0.7664	P		
			TOC	Total Fe	9	0.9383	P		
	Normal and dry period	M-2m	Total Fe	Turbidity	35	0.7001	P	3	10
			Total Mn	Temperature	35	0.7383	P		
			Total Mn	DO	35	0.7226	N		
		M-bottom	Total Fe	Turbidity	35	0.9061	P	6	
			Total Fe	TP	16	0.9788	P		
			Total Mn	Temperature	35	0.8913	P		
			Total Mn	DO	35	0.8697	N		
			Total Mn	Turbidity	35	0.7645	P		
			Total Mn	TP	16	0.8989	P		
		DW-SVH	TOC	Temperature	16	0.7967	P	1	
Scenario 4	High inflow period	M-2m	Total Fe	TP	6	0.7207	P	3	7
			TOC	TP	6	0.9852	P		
		M-bottom	Total Mn	Temperature	10	0.8185	P	3	
			Total Mn	DO	10	0.7991	N		
			TOC	Total Fe	6	0.9707	P		
		DW-SVH	Total Mn	DO	9	0.7303	N	1	
		DW-bottom	Total Mn	DO	10	0.7498	N	1	
	Normal and low inflow period	M-2m	Total Mn	DO	43	0.7168	N	2	8
			TOC	DO	20	0.7110	P		
		M-bottom	Total Fe	Turbidity	43	0.8999	P	6	
			Total Fe	TP	19	0.9797	P		
			Total Mn	Temperature	43	0.7953	P		
Total Mn			DO	43	0.8552	N			
Total Mn			Turbidity	43	0.7275	P			
Total Mn	TP	19	0.8869	P					

4.2 Water quality data obtained from the fieldwork campaign

4.2.1 Data summarization

Depth profiles for each water quality parameters that obtained from the fieldwork can be accessed from Figure 1-25, Appendix 4.

In summary, water quality data obtained from fieldwork indicated that:

- 1) Stratification: The water column near the dam wall area was well-mixed, while thermal stratification was recognized in the middle of Chichester Reservoir.
- 2) Temperature: A steep temperature gradient (thermocline) was detected in the middle of Chichester Reservoir between 1m depth and 3m depth. Temperature differentials between the water surface and the bottom near the dam wall area (0.5m depth: 23.5°C, 24.5m depth: 22.7°C, differential: 0.8°C) is lower than that in the middle (0.5m depth: 25.1°C, 27m depth: 22.9°C, differential: 2.2°C).
- 2) Dissolved Oxygen: DO differentials between the water surface and the bottom near the dam wall area (0.5m depth: 6.87mg/L, 24.5m depth: 6.64mg/L, differential: 0.23mg/L) is lower than that in the middle (0.5m depth: 8.94mg/L, 27m depth: 5.69mg/L, differential: 3.25mg/L). DO% values near the dam wall area ranged from 69.1% (23m depth) to 80.8% (0.5m depth). DO% values in the middle of Chichester Reservoir ranged from 66.2% (27m depth) to 109.0% (0.5m depth).
- 3) Water Quality Parameter: Concentrations of other water quality parameters, including soluble Fe, soluble P, TP, ammonium, TC, TN and DOC, were evenly distributed in the water column both near the dam wall area and the middle area. However, some parameters have significant outliers at the following sampling locations: 1) at 24.24m depth near the dam wall, and; 2) at 27m depth in the middle of Chichester Reservoir. These outliers may be due to the surface of the bottom sediments being disturbed and stirred during the sampling processes.
- 4) BOD5: BOD5 data in Chichester Reservoir ranged from less than 2 mg/L (the detection limit) to 5 mg/L. More than half (17/27) of BOD5 results were recorded as 'less than 2mg/L'.

5) Chlorophyll a: Based on the Chlorophyll a data recorded by the EXO2 probe during the fieldwork period, a significant Chlorophyll a concentration increase was observed near the thermocline, in the middle of Chichester Reservoir. The maximum Chlorophyll a concentration was recorded as 31.4µg/L at 0.992m depth, in the middle of Chichester Reservoir.

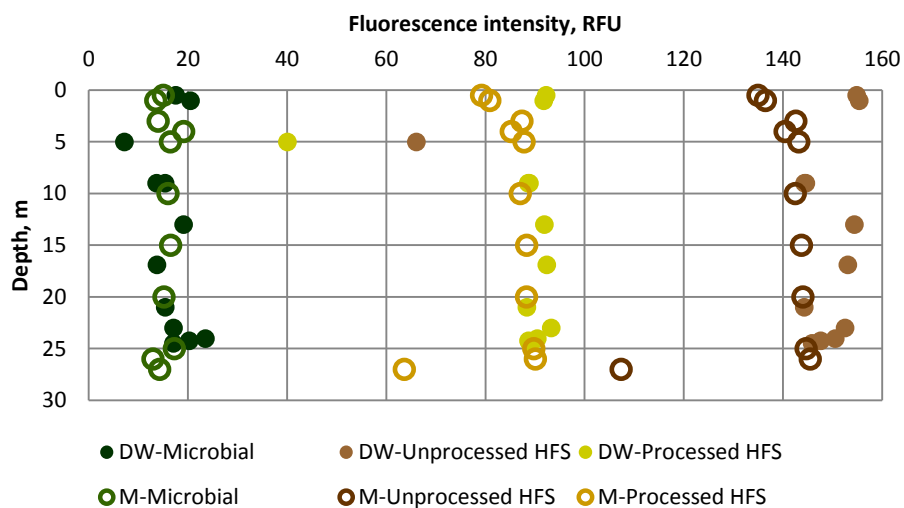


Figure 4.8 Profiles of organic matter fluorescence in Chichester Reservoir during the fieldwork period

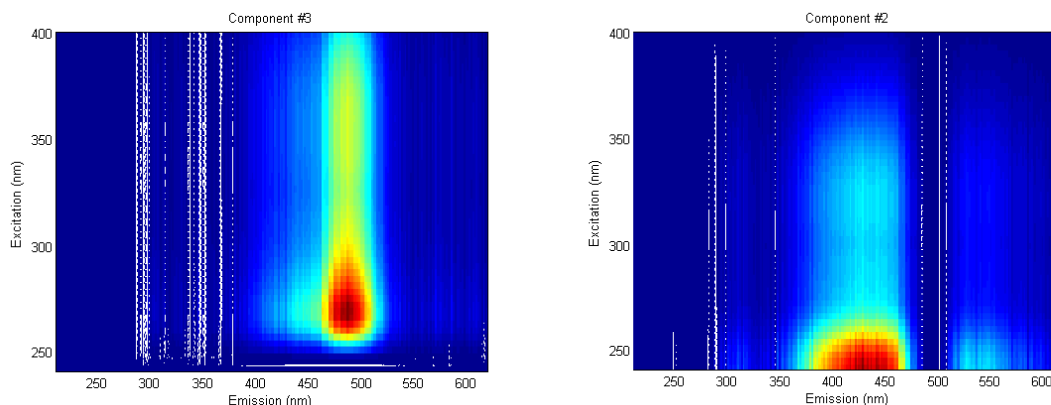


Figure 4.9 EEMs of Component #3 (left, processed humic/fulvic substances) and Component #2 (right, unprocessed humic/fulvic substances)

6) Based on the PARAFAC analysis, two dominant fluorescence organic matters were found in the Chichester Reservoir water column (Figure 4.8). They are: a). processed humic/fulvic substances (Component #3, Figure 4.9, fluorescence intensity: 40.1-93.3 RFU) and; b). unprocessed humic/fulvic substances (Component #2, Figure 4.9, fluorescence intensity: 66.1-15.4 RFU).

7) Fluorescing microbially derived OM: Only low fluorescing activity of tryptophan-like fDOM were observed in the water samples (Component #1, Figure 4.10, fluorescence intensity: 7.2-23.5 RFU) compared to the fluorescence intensity of processed and unprocessed humic/fulvic substances (Figure 4.8).

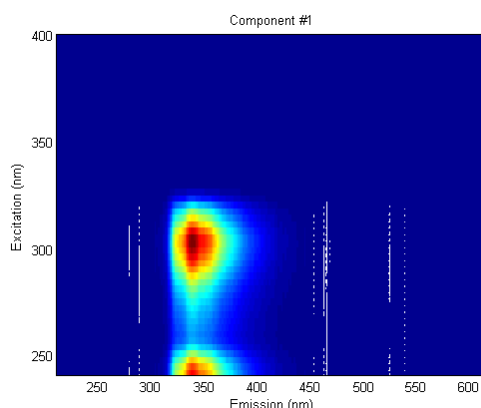


Figure 4.10 EEM of Component #1 (microbial content)

8) Ratios of 'processed humic/fulvic substances' to 'unprocessed humic/fulvic substances' in all 23 samples were relatively consistent (ratios: 0.587-0.620, Figure 4.11).

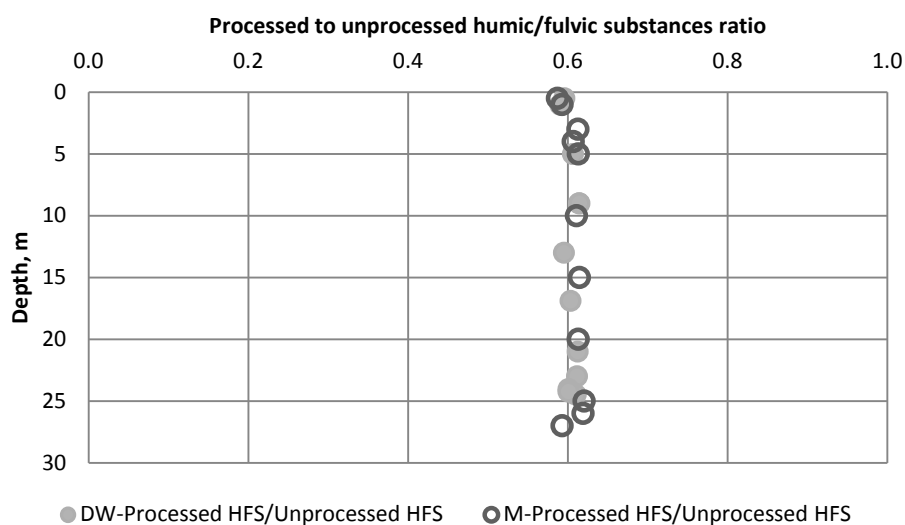


Figure 4.11 Depth profile data of processed to unprocessed humic/fulvic substances ratios in Chichester Reservoir during the fieldwork period

9) TC/TN ratios of 10.8-26.8, A250/A365 ratios of 3.15-4.75 and FI values of 1.45-1.58 show that the organic carbon in Chichester Reservoir is a mixture of both autochthonous and allochthonous organic carbon (Figure 4.12).

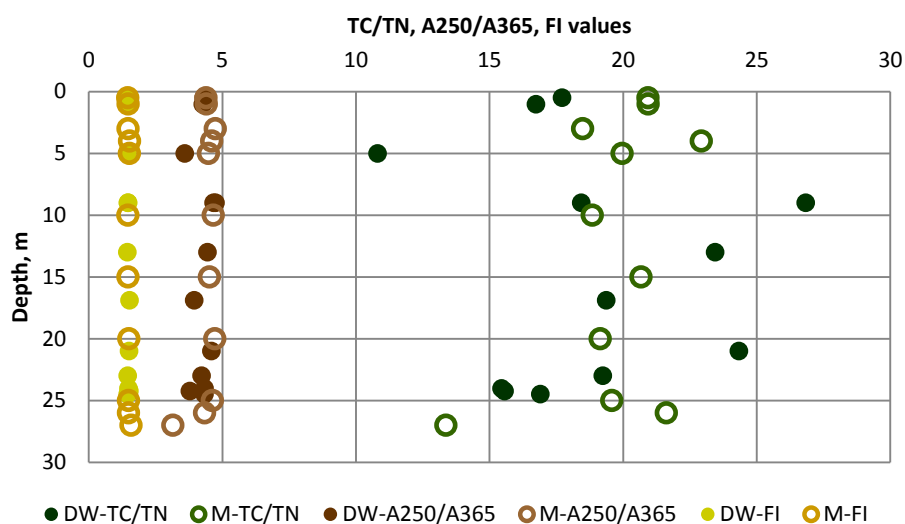


Figure 4.12 Depth profile data of TC/TN, A250/A365 and FI values in Chichester Reservoir during the fieldwork period

10) BIX values provide the ratios between 'recently produced fDOM' and 'older, more decomposed fDOM'. In Chichester Reservoir they range from 0.56 to 0.66 (Figure 4.13).

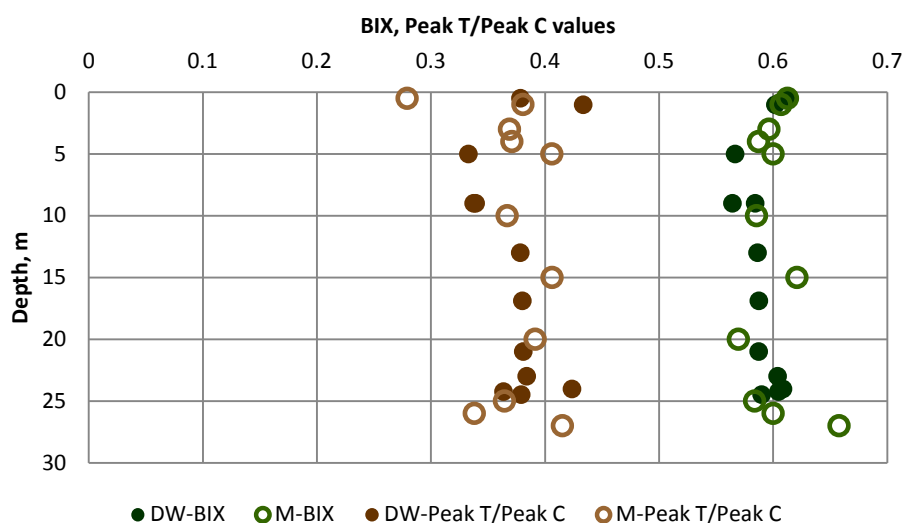


Figure 4.13 Depth profile data of BIX and Peak T/Peak C values in Chichester Reservoir during the fieldwork period

11) Peak T/Peak C ratio indicates the relationship between BOD and DOC. Peak T/Peak C ratios in Chichester Reservoir range from 0.28 to 0.43 (Figure 4.13).

12) SUVA values in Chichester Reservoir range from 6.4% to 24.8%. The lowest value of 6.4%, which is likely an outlier, was from the sample collected from 5m depth, in the near dam wall area. This low value is probably due to the sample being accidentally frozen in the fridge during storage. Without this outlier, SUVA values in Chichester Reservoir range from 9.4% to 24.8% (Figure 4.14).

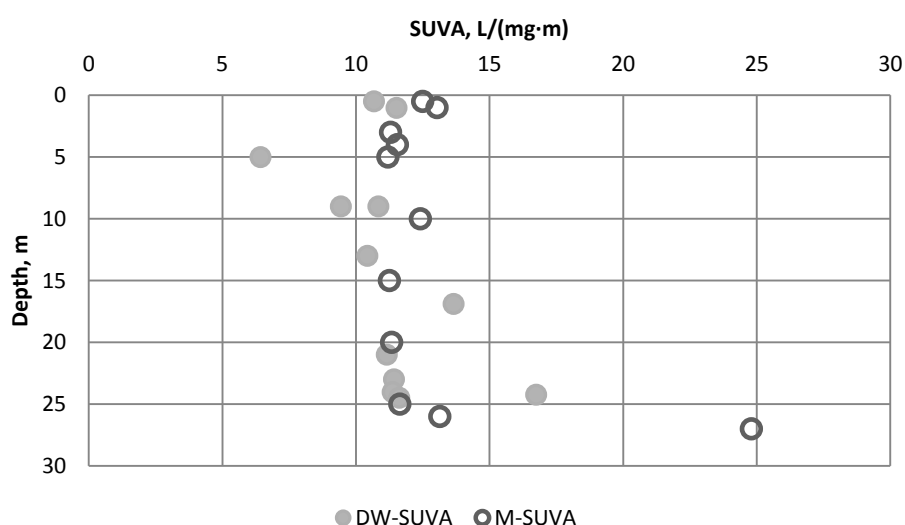


Figure 4.14 Depth profile data of SUVA values in Chichester Reservoir during the fieldwork period

4.2.2 K-s tests

Statistically significant distribution differences were found in 8 comparisons (k-s tests, $P < 0.05$). This result indicates that the operation of the destratifier had significant impacts on the distribution of water quality parameters in these 8 comparisons, during the fieldwork period. These significant results are summarized in Table 4.8. No statistically significant distribution differences were found in the rest of the comparisons. Detailed results of k-s tests in this part can be found in Table 31, Appendix 4.

Table 4.8 Significant results of k-s tests for water quality data collected in fieldwork ($P < 0.05$)

Parameter	Comparison ('group a' vs 'group b')	P-value	Descriptions of average, median values and data variability
EC	'Dam Wall' vs 'Middle'	0.001	Compared to 'Dam Wall', 'Middle' has lower average, median values and lower variability.
Eh		0.006	Compared to 'Dam Wall', 'Middle' has lower average, median values and lower variability.
pH		0.023	Compared to 'Dam Wall', 'Middle' has higher average, median values and higher variability.
Total Fe		0.005	Compared to 'Dam Wall', 'Middle' has higher average value, lower median value and higher variability.
Soluble Mn		0.001	Compared to 'Dam Wall', 'Middle' has higher average value, lower median value and higher variability.
Total Mn		0.005	Compared to 'Dam Wall', 'Middle' has higher average median values and higher variability.
Unprocessed HFS		0.004	Compared to 'Dam Wall', 'Middle' has lower average, median values and lower variability.
Processed HFS		0.004	Compared to 'Dam Wall', 'Middle' has lower average, median values and lower variability.

4.2.3 Regression analyses

Significant correlations ($R^2 > 0.7$) were only found in the following situations:

- 1) Temperature vs Sampling depth, at near the dam wall area ($n=11$, $R^2=0.923$);
- 2) DO vs Sampling depth, in the middle of Chichester Reservoir ($n=11$, $R^2=0.762$).

No significant correlations were found between Absorbance at 253nm and DOC concentrations ($n=23$, $R^2=0.0437$, negative correlation).

Detailed results of the regression analyses in this part can be accessed in Table 32, Appendix 4.

4.3 Summary of results

In this chapter, the following results of the statistical analyses and the fieldwork are presented:

- 1) Due to the limited robustness of t-tests in this study, the results of k-s tests and m-w tests are adopted in the statistical analyses regarding the water quality data obtained from Hunter Water Corporation (section [4.1.1](#));
- 2) The operation of the destratifier had significant impacts on the distribution of the water quality parameters in 10 comparisons, during the study period (section [4.1.2.1](#), discussed in section [5.1](#));
- 3) Different scenarios had significant impacts on the distribution of water quality parameters in 39 comparisons, at various sampling locations (section [4.1.3](#), discussed in section [5.3](#) and [5.4](#));
- 4) 54 significant correlations were found at different sampling locations under different scenarios, based on the water quality data obtained from Hunter Water Corporation (section [4.1.4](#), discussed later in section [5.2.1](#), [5.3.2](#) and [5.4.2](#));
- 5) During the fieldwork period: a.) the water column near the dam wall area was well-mixed, while thermal stratification was noted in the middle of Chichester Reservoir; b.) measurements of BOD5 show low organic matter decomposition in the water column of Chichester Reservoir; and c.) two dominant fluorescence dissolved organic matter components were found in the water column: unprocessed humic/fulvic substances and processed humic/fulvic substance. These include a mixture of both autochthonous and allochthonous humic/fulvic substances. The ratio of unprocessed humic/fulvic substances to processed humic/fulvic substances ranged from 0.587 to 0.620 (section [4.2.1](#), discussed in section [5.6](#));

6) During the fieldwork period, the operation of the destratifier had significant impacts on the distribution of the water quality parameters in 8 comparisons, including EC, Eh, pH, total Fe, soluble Mn, total Mn, unprocessed and processed humic/fulvic substances (section 4.2.2, discussed later in section 5.6.1).

The results, as mentioned above, of the statistical analyses and the fieldwork will be explained and discussed in Section 5.

Chapter 5: Discussion

The initial objective of this project was to understand the role of organic carbon in the degradation processes, during the operation of an artificial destratification system, in Chichester Reservoir. It was hypothesized that: 1) the artificial destratification system has an impact on water quality data, including organic carbon, near the dam wall area; 2) thermal stratification, heavy rainfall events and high inflow events influence water quality, including organic carbon; and 3) organic carbon degradation processes are accelerated during the thermal stratification period, due to the impact of the artificial destratification system near the dam wall area (section [1.3](#)).

In this chapter, the impacts from the artificial destratification system on the water quality parameters in Chichester Reservoir during the study period will be discussed based on the results of the data analyses in Chapter 4 (section [4.1.2](#)). Five conceptual models are then presented for different climatic periods including: 1) a no stratification period; 2) a stratification period; 3) high inflow periods; 4) overturn periods, and; 5) during the fieldwork campaign. Each conceptual model will be discussed, supported by the results of the data analyses in section [5.2-5.6](#). As no organic carbon content/reactivity and organic carbon degradation data is available from the long-term data (as per Hunter Water Corporation), the organic carbon dynamics for the first four conceptual models (section [5.2-5.5](#)) will be discussed and validated based on the organic carbon data collected from the fieldwork campaign (section [4.2](#) and [5.6](#)).

5.1 Impacts from artificial destratification system

Impacts from the artificial destratification system in the Chichester Reservoir are discussed in this subsection. The discussion is based on results of the k-s tests across the entire period, as shown in section [4.1.2](#) (Table 4.1).

5.1.1 Effects on temperature

As shown in Table 4.1, statistically significant differences were found between the distributions of: 1). the temperature differential in the middle of Chichester Reservoir, and; 2). the temperature differential near the dam wall area ($P < 0.0001$). The

temperature differential data in the middle of Chichester Reservoir has higher average and median values and higher variability, compared to near the dam wall area. These results indicate that the destratifier in Chichester Reservoir can effectively reduce the temperature differential between the water surface and the bottom near the dam wall area (Table 4.1) (Heo and Kim, 2004, Brosnan and Cooke, 1987, Gupta and Gupta, 2012).

5.1.2 Effects on DO

As shown in Table 4.1, statistically significant differences were found in the following comparisons:

- 1) 'M-bottom' vs 'DW-bottom': DO data at 1m from the bottom, in the middle of Chichester Reservoir, has lower average and median values and higher variability, compared to 1m from the bottom near the dam wall. This result indicates that, under the assumption of equal biological and chemical oxygen demands, the destratifier in Chichester Reservoir can effectively increase DO concentrations at the bottom near the dam wall (Table 4.1, section 2.4.2) (Brosnan and Cooke, 1987, Fast et al., 1973, Ismail et al., 2002);
- 2) 'M-differential' vs 'DW-differential': DO differential data in the middle of Chichester Reservoir, has higher average and median values and higher variability, compared to near the dam wall area. This further supports the above conclusion that the destratifier in Chichester Reservoir can effectively reduce the DO differential between the water surface and the bottom near the dam wall area (Table 4.1, section 2.4.2);
- 3) 'M-2m' vs 'M-bottom': DO data at 1m from the bottom, in the middle of Chichester Reservoir, has lower average and median values and higher variability, compared to 2m depth in the middle of Chichester Reservoir. This result can be explained by the inhibited oxygen transport between the epilimnion and the hypolimnion in the middle of Chichester Reservoir during the stratification period (Table 4.1, section 2.1.2) (Sherman et al., 2001, Liboriussen et al., 2009).

5.1.3 Effects on Total Fe

As shown in Table 4.1, statistically significant differences were found between the distributions of: 1). the total Fe differential in the middle of the Chichester Reservoir, and; 2). the total Fe differentials near the dam wall ($P < 0.0001$). The Total Fe differential data in the middle of Chichester Reservoir has higher average and median values (both average and median values are negative) and lower variability, compared to near the dam wall. This result is likely to be related to:

- 1) Three significant Total Fe outliers at 1m from the bottom near the dam wall area. They are: 870 $\mu\text{g/L}$ (13th July 2015), 910 $\mu\text{g/L}$ (21st September 2015), and 2440 $\mu\text{g/L}$ (19th October 2015). The reason for these outliers is not clear, but it may be related to sampling and measurement errors, as noted by Glamore (2004);
- 2) A significant Total Fe outlier (2130 $\mu\text{g/L}$) at 1m from the bottom, in the middle of Chichester Reservoir, was observed on 14th March 2016. The reason for this outlier is related to an overturn event as discussed in section 5.5.

5.1.4 Effects on Total Mn

As shown in Table 4.1, statistically significant differences were found in the following comparisons:

- 1) 'M-differential' vs 'DW-differential': Total Mn differential data in the middle of Chichester Reservoir has higher average values, lower median values (both average and median values are negative) and lower variability compared to near the dam wall area. This result is likely to be related to: 1) two significant Total Mn outliers at 1m from the bottom near the dam wall area. They are: 193 $\mu\text{g/L}$ (19th October 2015) and 170 $\mu\text{g/L}$ (30th May 2015). The reason for these outliers is unclear, but it may be related to sampling and measurement errors, as noted by Glamore (2004); 2) a significant Total Mn outlier (202 $\mu\text{g/L}$) at 1m from the bottom, in the middle of Chichester Reservoir, was observed on 14th March 2016, and is related to the previous mentioned overturn event (section 5.5);
- 2) 'M-2m' vs 'M-bottom': Total Mn data at 1m from the bottom in the middle of Chichester Reservoir has higher average values, median values and higher variability

compared to 2m depth in the middle of Chichester Reservoir. This result can be explained by: 1) the diffusion and resuspension of total manganese from the sediment into the bottom water, and; 2) the inhibited oxygen transport between the epilimnion and hypolimnion in the middle of Chichester Reservoir during the stratification period (Section [5.3](#), Figure 5.3) (Sherman et al., 2001, Thurman, 2012, Liboriussen et al., 2009).

5.1.5 Effects on Total Organic Carbon

No significant results were found for TOC concentrations from k-s tests in the study period. This might indicate that the concentrations of TOC received limited impacts from the artificial destratification system in Chichester Reservoir. However, the lack of statistical significance could be due to limited TOC data available (Table 3.4). The role of organic carbon in different study periods and the related conceptual models are discussed in the following sections.

5.2 No stratification period

The conceptual model in Chichester Reservoir during the no stratification period is introduced and discussed in this section (Figure 5.1). The no stratification period consists of two time periods: 1) from the first day of the study period (25th May 2015) until the onset of thermal stratification (6th October 2015); 2) the second time period is from the second day of overturn (15th March 2016), until the last day of the study period (30th May 2016). The two time periods are shown in the yellow dashed boxes in Figure 5.2.

July 20th 2015 (the yellow arrow in Figure 5.2) is selected to represent typical water quality conditions during the no stratification period. DO, TOC, total Mn, and ammonium profiles on 20th July 2015 are presented in Figure 5.2. Significant correlations during the no stratification period (as discussed in section [5.2.1](#)) formed the basis for constructing the 'no stratification' conceptual model (section [5.2.2](#)).

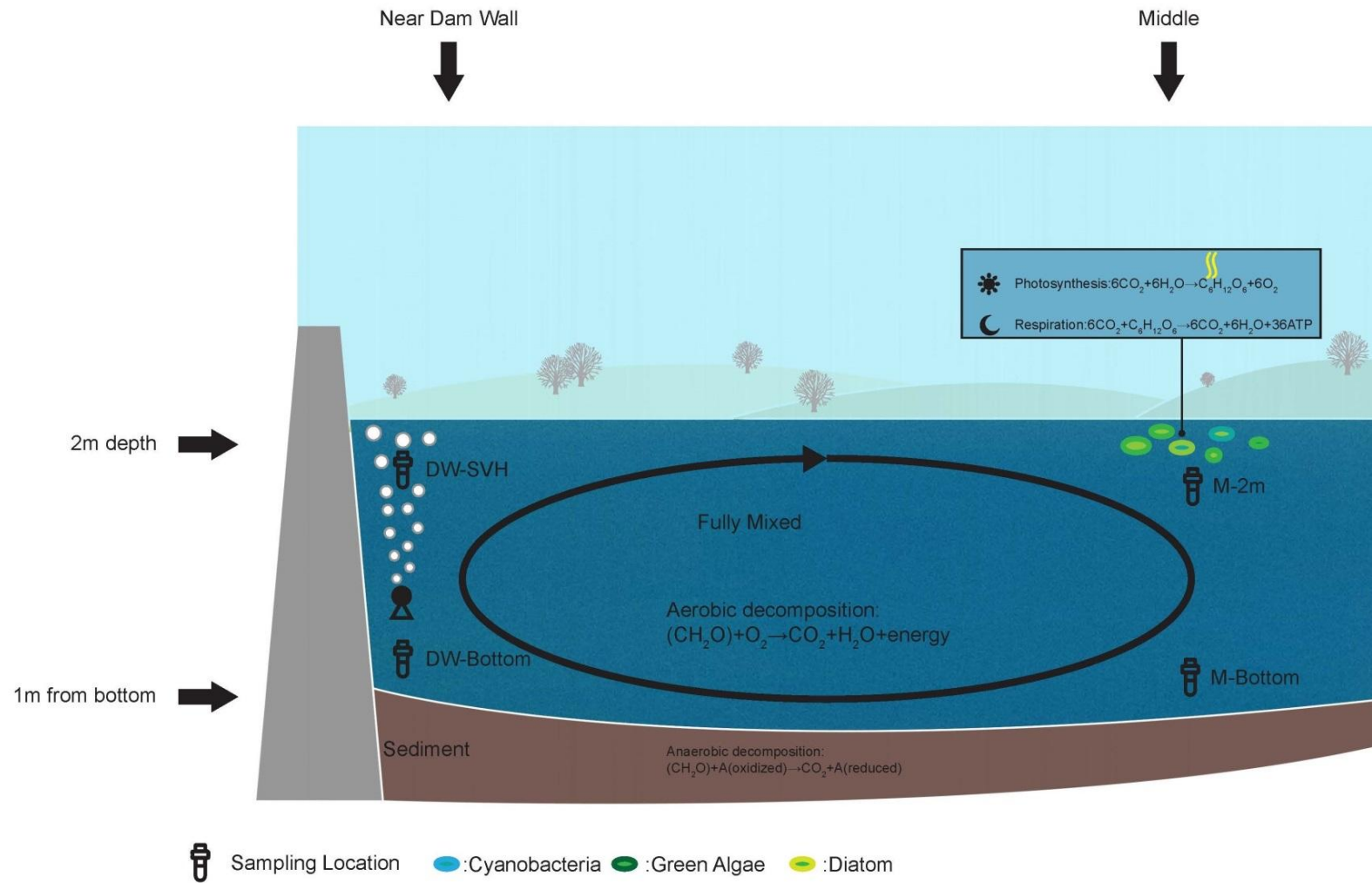


Figure 5.1 Chichester Reservoir conceptual model during the no stratification period

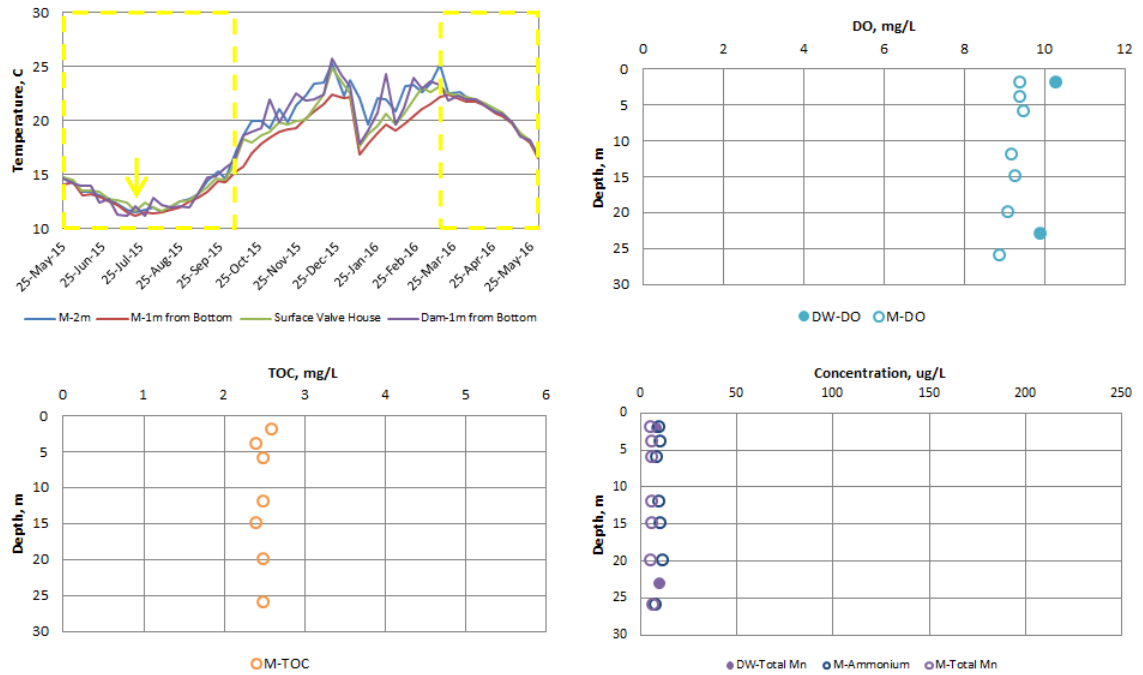


Figure 5.2 Temporal distributions of temperature at all sampling locations, and DO, TOC, Total Mn, Ammonium profiles on 20th July 2015 (no stratification period)

As shown in Figure 5.1, during the no stratification period, the entire waterbody in Chichester Reservoir was fully mixed. Physical and chemical parameters were homogeneously distributed throughout the waterbody (Figure 5.2). Microbial aerobic decomposition processes, instead of anaerobic decomposition processes, occurred in the waterbody, as DO concentrations never dropped below 0 mg/L at all sampling locations. Minimum DO concentration during the no stratification period was 3.86 mg/L, observed on 30th March 2016 at sampling location 'M-bottom'. Algal photosynthesis occurred during the daytime, while respiration reactions proceeded both day and night. It is reasonable to assume that microbial anaerobic decomposition processes occurred within interstitial sediment water due to the depletion of dissolved oxygen within the sediment (discussed in section 5.2.2).

5.2.1 Significant correlations during the no stratification period

As summarized in section 4.1.4 (Table 4.7), results of the regression analyses during the no stratification period indicate that:

- 1) Significant correlations were found between Total Mn and Temperature (positive), Total Mn and DO (negative) at 'M-2m' and 'M-bottom'. These can be explained by

microbial anaerobic decomposition processes in the interstitial sediment water. No significant correlations were found between Total Fe and Temperature, Total Fe and DO, at 'M-2m' and 'M-bottom'. A possible explanation for this might be that the redox potential in the sediment during the no stratification period rarely decreases below manganese-oxide reduction and hence allows for limited iron-oxide reduction and limited iron mobilisation (Table 4.7, section [2.3.2.1](#)) (Appelo and Postma, 2005, Wetzel, 2001, Thurman, 1985c);

2) Significant positive correlations were found between TOC and Total Mn at 'M-2m' and 'M-bottom'. These relationships may partly be explained by organic matter coating and manganese coating on inorganic silts and clays (Table 4.7, section [2.3.1.2](#)) (Sherman et al., 2001);

3) No significant correlations were found between Total Mn and other parameters near the dam wall. This result indicates that, during the no stratification period, the concentration of Total Mn near the dam wall area was not influenced by Temperature and DO level near the dam wall. One possible explanation is that Total Mn levels near the dam wall are a result of Mn transported from the middle of Chichester Reservoir as a result of the convection caused by the destratifier (discussed in more detail in section [5.6.2](#)). This explanation is supported by the TOC and Total Mn data available near the dam wall (Table 3.4).

5.2.2 Organic carbon dynamics during the no stratification period

Based on the above discussion, a hypothesis about the organic carbon dynamics in Chichester Reservoir during the no stratification period can be proposed as follows:

When algal blooms and high inflow events are not occurring, dissolved and suspended particulate organic carbon concentrations could be relatively low and homogeneously distributed in the entire waterbody during the no stratification period (section [5.2](#), [5.6.1.2](#) and [5.6.2](#)). Organic matter in the Chichester Reservoir could be a mixture of both autochthonous and allochthonous organic matter and was homogeneously distributed in the whole waterbody with regards to its composition and origin (section [5.6.1.4](#) and [5.6.2](#)). Given the high DO levels throughout the reservoir microbial organic matter (OM) degradation in the water column is likely to be via an aerobic

decomposition process (section [5.2](#) and [5.6.2](#)). At some depth into the sediment it is reasonable to expect that microbial OM degradation is via anaerobic processes. However, the redox potential in the sediment during the no stratification period allows mainly the reduction of manganese to proceed with limited iron-oxide reduction and Fe mobilisation (section [5.2.1](#)) (Appelo and Postma, 2005). Dissolved manganese and iron (to a lesser degree), together with organic carbon, could diffuse from the sediment to the overlying water. As the reservoir is fully mixed they may distribute to the whole waterbody. However, the Mn and Fe would probably be reoxidised, due to the high DO, to form suspended metal solids or exist as organic complexes (section [2.3.1.2](#) and [5.2.1](#)) (Neilson and Allard, 2007, Tratnyek et al., 2011).

Under the hypothesis that significant algal blooms occurs during the no stratification period, due to the intense primary production in the waterbody: 1) the origin of organic carbon in Chichester Reservoir could be dominated by autochthonous organic carbon (section [2.3.1.4](#)) (Mendonça et al., 2014, Mash et al., 2004); 2) both the DOC and POC concentrations in the whole waterbody could increase (section [2.3.1.3.3](#) and [5.6.1.2](#)) (Wetzel, 2001, Birge and Juday, 1934, Hama and Handa, 1983), and; 3) subsequently the sediment organic carbon mineralization rate could also increase (section [2.3.2.2](#)) (Gudas et al., 2010, den Heyer and Kalff, 1998).

Under the hypothesis that high inflow events occurs during the no stratification period, Chichester Reservoir could receive a higher influx of allochthonous organic carbon (section [2.3.1.4](#)) (Mash et al., 2004) and the POC concentrations could remarkably increase with the increasing discharge at the depth of neutral buoyancy in the waterbody (section [2.2](#), [2.3.1.3.2](#) and [5.6.1.2](#)) (Meybeck, 1981, Thurman, 1985a).

5.3 Stratification period

The conceptual model in Chichester Reservoir during the stratification period is introduced and discussed in this section (Figure 5.3). The stratification period starts 7th October 2015, ends 14th March 2016 and is shown in the yellow dashed box in Figure 5.4.

December 7th 2015 (the yellow arrow in Figure 5.4) is selected as a representative date during the stratification period. DO, TOC, total Mn, ammonium profiles on 7th

December 2015 are presented in Figure 5.4. Impacts from thermal stratification and significant correlations during the stratification period are discussed in section 5.3.1 and 5.3.2 respectively to support and explain the conceptual model (section 5.3.3). A hypothesis proposed about the organic carbon dynamics during the stratification period in Chichester Reservoir is proposed in section 5.3.3

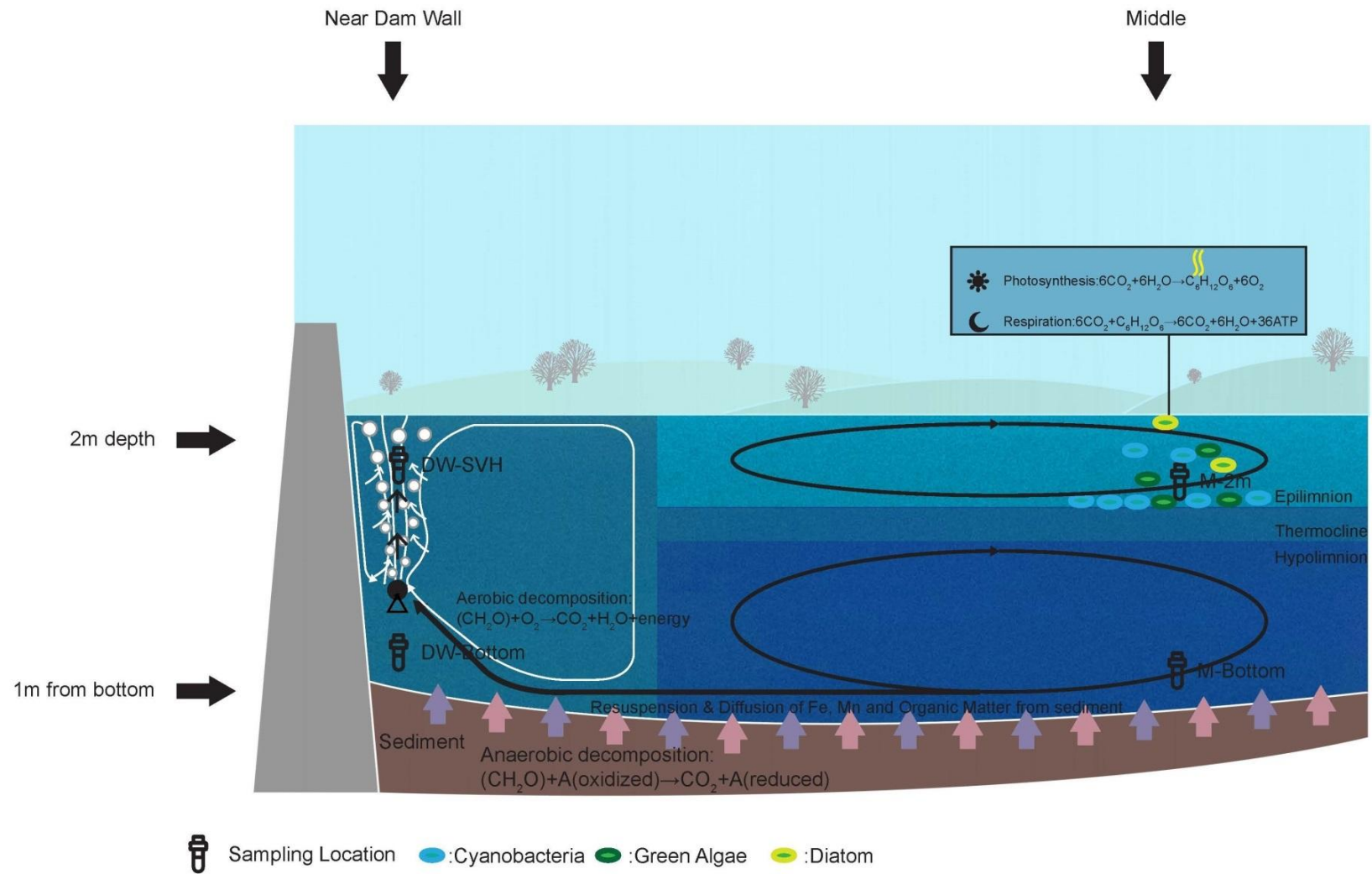


Figure 5.3 Chichester Reservoir conceptual model during the stratification period

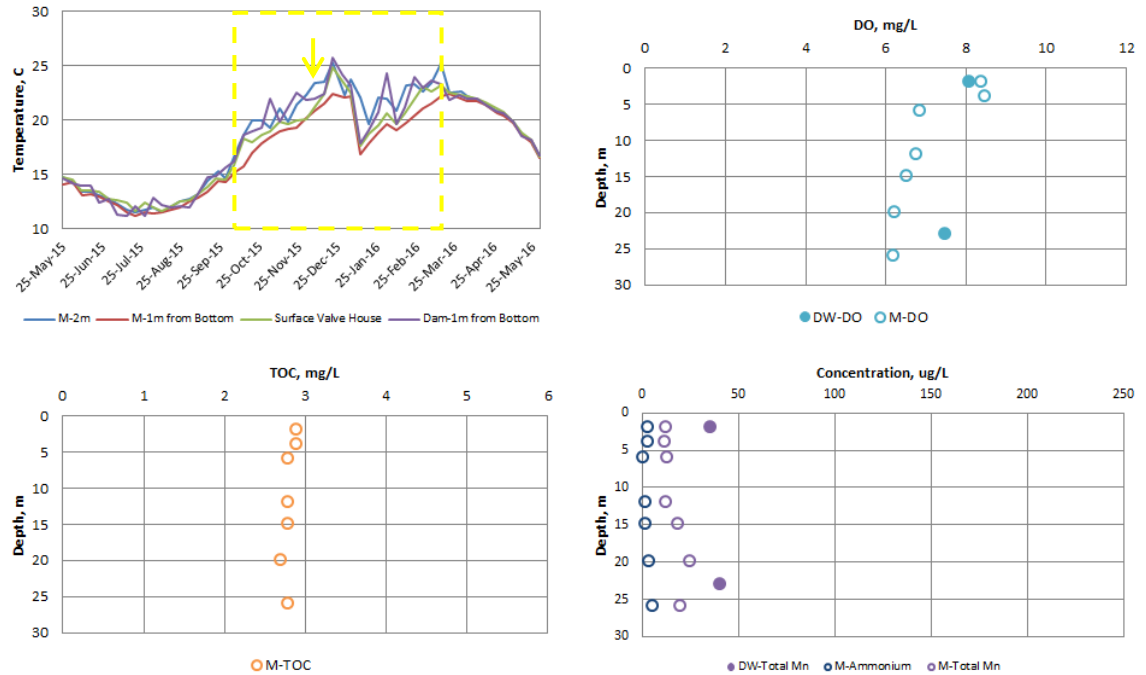


Figure 5.4 Temporal distributions of temperature at all sampling locations, and DO, TOC, Total Mn, Ammonium profiles on 7th December 2015 (stratification period)

As shown in Figure 5.3, during the stratification period, the water column near the dam wall was fully mixed because of the operation of the destratifier. White arrows in Figure 5.3 show the circulation cell created by the air bubble destratification system near the dam wall. While in the middle of Chichester Reservoir, the water column was stratified into three layers: epilimnion, thermocline and hypolimnion. Black arrows in Figure 5.3 show isolated circulations in the epilimnion and hypolimnion. Due to thermal stratification, intensive algal growth was observed near the thermocline, where algae could receive suitable solar radiation and sufficient nutrients released from the sediment via the hypolimnion at the same time (section [4.2.1](#)). Microbial aerobic OM decomposition still occurred in the whole waterbody as DO concentrations never dropped below 0 mg/L at any sampling location (and consequently hypolimnetic anoxia never occurred).

The lowest DO concentration during the stratification period was 3.59 mg/L, observed 14th March 2016 at sampling location 'M-bottom'. Compared to the no stratification period, more intensive microbial anaerobic decomposition processes occurred in interstitial sediment water due to higher overlying water temperature, lower DO levels

in hypolimnion and dissolved oxygen depletion likely occurring in the shallow sediments (Figure 5.4, discussed in section [5.3.3](#)).

5.3.1 Impacts from thermal stratification

The impacts of the thermal stratification period in Chichester Reservoir are discussed in this subsection. The discussion is based on results of k-s tests at different sampling locations, between the 'stratification period' and the 'no stratification period', as discussed in section [4.1.3](#) (Table 4.3 - 4.6).

5.3.1.1 Effects on temperature

As summarized in section [4.1.3](#), the distribution of temperature data is affected by thermal stratification at 'M-2m', 'M-bottom', 'DW-SVH' and 'DW-bottom'. At these sampling locations, the average and median values of temperature during the 'stratification period' are higher than that during the 'no stratification period' (Figure 5.4). This is because thermal stratification usually occurs in warm seasons. Thus, it is not surprising that the water temperature in the whole water column was higher during the 'stratification period' (section [2.1.1](#)).

5.3.1.2 Effects on Dissolved Oxygen

As summarized in section [4.1.3](#), the distribution of DO data is affected by thermal stratification at 'M-2m', 'M-bottom', 'DW-SVH' and 'DW-bottom'. At all these sampling locations, average and median values of DO during the 'stratification period' are lower than that during the 'no stratification period'. In the middle of Chichester Reservoir, these results can be explained by the inhibited oxygen transport between the epilimnion and hypolimnion (Sherman et al., 2001, Liboriussen et al., 2009). Near the dam wall the water column was fully mixed due to the operation of the destratifier (Brosnan and Cooke, 1987, Fast et al., 1973). Ideally, DO concentrations would be spatially consistent and approximately equal to 100% saturation near the dam wall, presuming that the oxygen transfer from the atmosphere is the dominant process controlling the DO concentrations, during the stratification period. However, DO% values ranged from 60.47% to 95.30% (60.47% equals to 5.2 mg/L, observed on 29th February 2016; 95.30% equals to 8.93 mg/L, observed on 12th October 2015) during

the stratification period and never achieved 100%. The reason for this phenomenon is either that DO consumption by OM degradation in the water column is causing lower DO concentrations or that the water column near the dam wall was mixed with deteriorated water being brought in from the hypolimnion and bottom sediments in the middle of Chichester Reservoir (as shown in Figure 5.3) (Beutel and Horne, 1999). Considering the low BOD₅ results from the fieldwork (section 5.6.2) the later explanation is more likely.

5.3.1.3 Effects on Total Fe, Total Mn and TOC

As summarized in section 4.1.3, the distribution of Total Mn data is affected by thermal stratification at 'M-bottom', 'DW-SVH' and 'DW-bottom'. At these sampling locations, average and median values of Total Mn during 'stratification period' are higher than that during the 'no stratification period'. Possible explanations for these results are:

- 1) During the stratification period, more total manganese was diffused from the sediment to the overlying water due to more intensive anaerobic microbial decomposition processes in the bottom sediment (as shown in Figure 5.3: pink and purple arrows; discussed in section 2.3.2.2) (Appelo and Postma, 2005);
- 2) During the stratification period, Total Mn levels near the dam wall was homogeneously distributed, and hence increased, due to the operation of the destratifier. It is possible that the action of the destratifier is also resuspending material from the bottom sediment near the dam wall (Sherman et al., 2001).

No significant results were found for Total Fe and TOC in section 4.1.3, indicating that the thermal stratification has limited effect on the concentrations of Total Fe and TOC in Chichester Reservoir.

5.3.2 Significant correlations during the stratification period

As summarized in section 4.1.4 (Table 4.7), results of regression analyses during the stratification period show that:

- 1) Significant negative correlations were found between Total Mn and DO ($R^2=0.8462$, negative), Total Fe and DO ($R^2=0.7532$, negative) at 'M-bottom'. These significant

correlations may be explained as follows: lower redox potentials in the sediment during the stratification period allowed increased microbial anaerobic reduction of iron-oxides (section 2.3.2.1) (Thurman, 1985c).

No significant negative correlations were found between Total Mn and DO, Total Fe and DO at 'M-2m'. This can be explained by the minimal transport of Total Fe, Total Mn and oxygen across the thermocline, in the middle of Chichester Reservoir, during the stratification period (section 2.1.2) (Liboriussen et al., 2009);

2) Significant positive correlations were found between Total Fe and TP, TOC and Total Fe at 'M-2m'. These significant correlations may be explained by the high inflow event in January 2016. Substantial amounts of terrestrial Total Fe, TP and turbidity were transported to Chichester Reservoir during the high inflow event (section 5.4). Iron oxides, together with organic matter, might be chemically bonded to inorganic clay and silt via organic coating (section 2.3.1.2) (Sherman et al., 2001). This high inflow event will be discussed further in section 5.4;

3) Significant positive correlations were found between Total Fe and turbidity at 'M-bottom'. An overturn event, occurred on 14th March 2016, largely contributed to this significant correlation. This overturn event will be discussed in section 5.5;

4) Significant positive correlations were found between TOC and turbidity, TOC and TP, TOC and Total Fe at 'M-bottom'. These significant correlations might be a consequence of the combined effect of two aforementioned events.

5) Significant correlations were only found in the middle of Chichester Reservoir. No significant correlations were found near the dam wall. Possible explanations are: a). during the stratification period, the concentration of Total Fe and Total Mn near the dam wall was not determined by DO levels near the dam wall (as discussed in section 5.2.1); b). during the stratification period, DO levels near the dam wall were mainly caused by deteriorated water from hypolimnion and bottom sediment in the middle of Chichester Reservoir (as discussed in section 5.3.1.2); c). high inflow and overturn events had relatively limited impacts near the dam wall, this will be discussed in section 5.4 and 5.5 in detail.

5.3.3 Organic carbon dynamics during the stratification period

Based on the above discussion, a hypothesis about the organic carbon dynamics in Chichester Reservoir during the stratification period can be proposed as follows:

During the stratification period (excluding periods of algal blooms and high inflow events), organic carbon concentrations may decrease with depth in the middle of Chichester Reservoir (Thurman, 1985a, Wetzel, 2001, Birge and Juday, 1934), while organic carbon levels are homogeneously distributed near the dam wall area due to the operation of the destratifier (section [2.3.1.3.3](#), [5.3](#), [5.6.1.2](#) and [5.6.2](#)) (Brosnan and Cooke, 1987). Microbial aerobic decomposition occurred in the waterbody (section [5.3](#) and [5.6.2](#)). More intensive microbial anaerobic decomposition occurred within interstitial sediment water and a lower redox potential in the sediment allows the microbial anaerobic reduction of insoluble iron to proceed more completely during the stratification period (section [2.3.2.2](#), [5.3.1.3](#) and [5.3.2](#)) (Appelo and Postma, 2005). Resuspended and diffused organic carbon from the bottom sediment in the dam wall and potentially also from the middle of Chichester Reservoir were mixed into the water column near the dam wall due to the action of the destratifier (section [5.3.1.2](#), [5.3.2](#) and [5.6.2](#)).

Under the hypothesis that significant algal blooms occurred during the stratification period, due to the intense primary production in the epilimnion: 1) the origin of organic carbon in Chichester Reservoir is likely dominated by autochthonous organic carbon (section [2.3.1.4](#)) (Mendonça et al., 2014), and; 2) both the DOC and POC concentrations in epilimnion could increase and become higher than in the hypolimnion, in the middle of Chichester Reservoir (section [2.3.1.3.3](#) and [5.6.1.2](#)) (Yoshioka et al., 2002, Hama and Handa, 1983, Wetzel, 2001). However, the organic carbon levels near the dam wall were homogeneously distributed due to the operation of the destratifier (section [5.3](#)).

5.4 High inflow event

The conceptual model of Chichester Reservoir during the high inflow event is discussed in this section (Figure 5.5).

A three day extreme flood event was observed from 5th January 2016 to 7th January 2016 in the Wangat River and the Chichester River. This conclusion was derived based on the flow rates between Q0 (the largest flow rate) and Q1 (the flow rate equalled or exceeded for 1% of the time) from flow duration curves of two tributaries. Recorded high flow rates (Q0-Q10, Q10 represents the flow rate equalled or exceeded for 10% of the time) in two tributaries continued until 25th January 2016. Flow duration curves can be found in Figure 1, Appendix 5.

In this section, the high inflow event is defined as the three days of the extreme flood event succeeding a high flow rate event. High inflow periods in this study refer to the following months: May 2015; January 2016 and; February 2016 (see section 3.3.3.3). The high inflow periods are shown in the yellow dashed box in Figure 5.6.

January 18th 2016 (the yellow arrow in Figure 5.6) is selected as a representative date during the high inflow event. DO, TOC, total Mn, ammonium profiles on 18th January 2016 are presented in Figure 5.6. Impacts from the high inflow event and significant correlations during the corresponding 'no stratification' period are discussed in section 5.4.1 and 5.4.2.

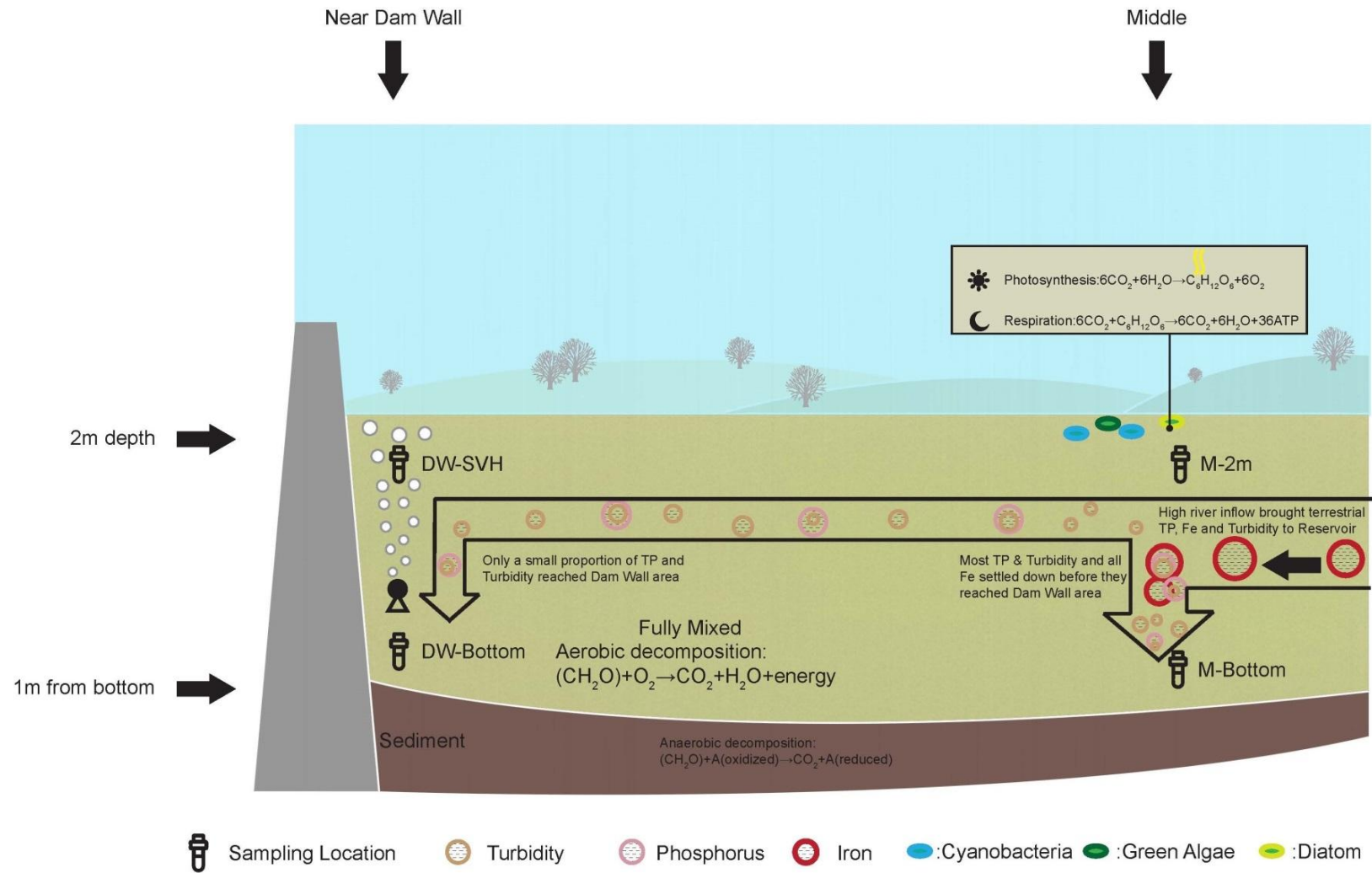


Figure 5.5 Chichester Reservoir conceptual model: high inflow event

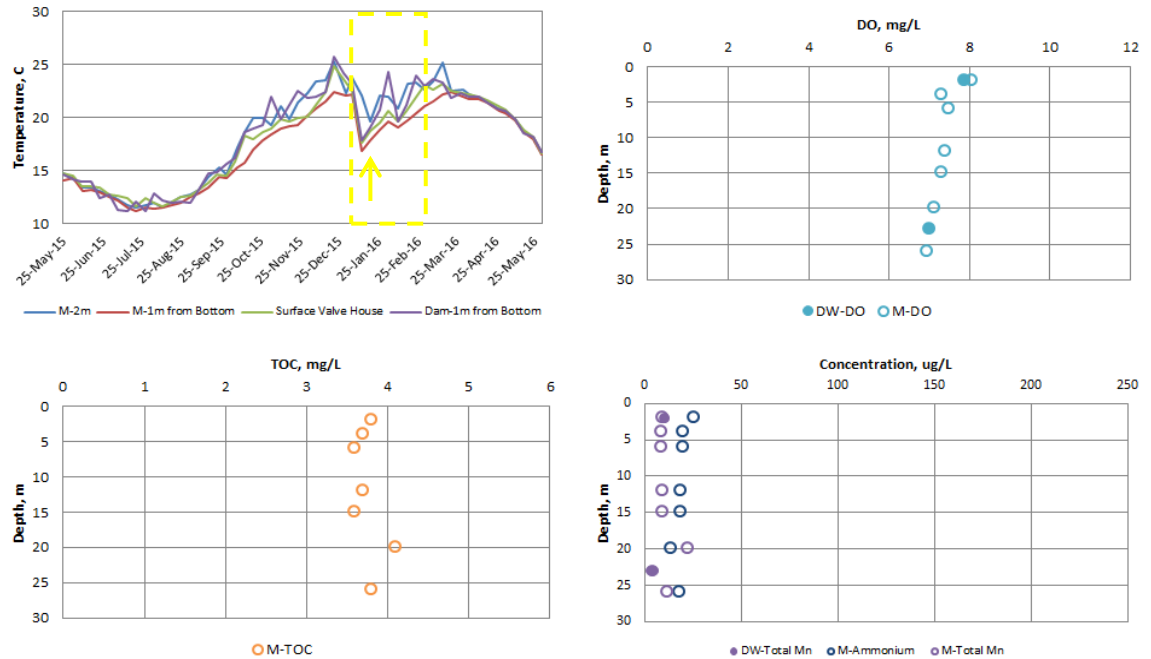


Figure 5.6 Temporal distributions of temperature at all sampling locations, and DO, TOC, Total Mn, Ammonium profiles on 18th January 2016 (extreme flood event)

According to water temperature data, the whole waterbody in Chichester Reservoir was fully mixed soon after the three day flood event (Figure 5.5 and 5.6). This indicates that large tributary inflows during the flood event intruded into the whole waterbody in Chichester Reservoir and was strong enough to break down the existing thermal stratification. Microbial aerobic decomposition processes occurred in the water column as DO concentrations never declined below 0 mg/L at all sampling locations. DO concentrations during the high inflow event range from 6 mg/L to 8.4 mg/L. Microbial anaerobic decomposition is probably reduced in the interstitial sediment water because the whole waterbody was fully mixed and DO levels significantly elevated at all sampling locations (Figure 5.6, discussed in section 5.4.3).

5.4.1 Impacts from the high inflow event

Impacts from the high inflow events are discussed in this subsection. Discussions are based on results of the k-s tests at different sampling locations, between the 'high inflow period' and the 'normal and low inflow period', as shown in section 4.1.3 (Table 4.3-4.6).

5.4.1.1 Effects on DO

As summarized in section [4.1.3](#), the distribution of DO data is affected by high inflow at 'M-2m', 'M-bottom', 'DW-SVH' and 'DW-bottom'. At all these sampling locations, average and median values of DO during 'high inflow period' are lower than during 'normal and low inflow periods'. A possible explanation for these results is that a majority of the 'high inflow period' was in January and February 2016, and consequently DO levels were relatively low in the hypolimnion of Chichester Reservoir due to thermal stratification during these summer months. Even if DO levels were slightly increased because of the high inflow event, DO levels during January and February were still lower than during the no stratification period (section [2.1.2](#) and [5.3.1.2](#)).

5.4.1.2 Effects on Turbidity

As summarized in section [4.1.3](#), the distribution of turbidity data is affected by high inflow at 'M-2m', 'M-bottom', 'DW-SVH' and 'DW-bottom'. At all these sampling locations, average and median values of turbidity during the 'high inflow period' are higher than during 'normal and low inflow periods'. In addition, turbidity levels in the middle of Chichester Reservoir were generally higher than near the dam wall during the high inflow event. For instance, turbidity data on 11th January 2016 recorded 26 NTU at 'M-2m', 25 NTU at 'M-bottom', 12.3 NTU at 'DW-SVH', and 13.1 NTU at 'DW-bottom'. Possible explanations for these results are: 1) during the high inflow event, surface water with high turbidity levels were discharged from the tributaries into the Chichester Reservoir; and 2) a large proportion of this terrestrial turbidity input had settled to the bed before they reached the dam wall area as indicated by the halving of the turbidity values from the middle of the dam to dam wall (as shown in Figure 5.5 and section [2.2](#)) (Sherman et al., 2001).

5.4.1.3 Effects on Total Fe

As summarized in section [4.1.3](#), the distribution of Total Fe data is affected by high inflows at 'M-2m' and 'M-bottom'. At all these sampling locations, average and median values of Total Fe during the 'high inflow period' is higher than during the 'normal and low inflow period'. Meanwhile, the distributions of Total Fe data are not affected by

the high inflow near the dam wall. Possible explanations are: 1) during the high inflow event, surface water with high Total Fe was delivered from the tributaries to Chichester Reservoir; and 2) almost all of this Total Fe then settled out of the water column before it reached the dam wall area (as shown in Figure 5.5 and section [2.2](#)) (Yu et al., 2010, Sherman et al., 2001).

5.4.1.4 Effects on TP

As summarized in section [4.1.3](#), the distributions of TP data are affected by high inflow at 'M-2m', 'M-bottom' and 'DW-SVH'. At all these sampling locations, average and median values of TP during the 'high inflow period' is higher than during the 'normal and low inflow period'. In addition, TP levels in the middle of Chichester Reservoir were generally higher than near the dam wall during the high inflow event. Possible explanations for these results are that during the high inflow event, surface water with high TP levels was brought from the tributaries into Chichester Reservoir; and some parts of the terrestrial TP inputs had settled out of the water column before they reached the dam wall area, while the remaining terrestrial TP reached the dam wall area. However, the second explanation is limited by the limited TP data available near the dam wall (as shown in Figure 5.5 and section [2.2](#)). The correspondence of TP with Total Fe could indicate that the TP is largely associated with phosphate adsorption on to solid iron-oxide particles (Hartland et al., 2015).

5.4.1.5 Effects on Total Mn and TOC

No significant results were found for Total Mn and TOC in section [4.1.3](#), indicating that the concentrations of Total Mn and TOC in Chichester Reservoir might have a limited influence from the high tributary inflow. However, this speculation can be limited by the limited TOC data available in Chichester Reservoir (Table 3.4).

5.4.2 Significant correlations during the high inflow period

As summarized in section [4.1.4](#) (Table 4.7), results of the regression analyses during the high inflow period show that:

- 1) Significant positive correlations were found between: a). Total Fe and TP, TOC and TP at 'M-2m', and; b). TOC and Total Fe at 'M-bottom'. These significant correlations

may be explained by the terrestrially derived turbidity, Total Fe and TP inputs, and the sedimentation of this suspended matter and Total Fe in the middle of Chichester Reservoir, during the high inflow event. It is also possible that terrestrially derived TOC contributed to some proportion of turbidity measurements during the high inflow period (section [2.3.1.2](#)) (Wetzel, 2001, Meybeck, 1981). No significant correlations were found between Total Fe, TP and TOC near the dam wall because of the limited data available (Table 3.4);

2) Significant correlations were found between Total Mn and Temperature (positive), and Total Mn and DO (negative) at 'M-bottom'. These can be explained by microbial anaerobic OM decomposition processes in the interstitial sediment water (section [2.3.2.1](#)) (Thurman, 1985c). No significant correlations were found between Total Fe and Temperature, Total Fe and DO at 'M-bottom'. A possible explanation for this might be that DO levels in Chichester Reservoir were too high to allow Fe-oxide reduction to occur due to DO being supplied by the high inflow event (section [5.4.1.1](#)) (Appelo and Postma, 2005);

5.4.3 Dynamic of organic carbon during the high inflow event

Based on the above discussion, a hypothesis about the organic carbon dynamics in Chichester Reservoir during the high inflow event (from 5th January 2016 to 7th January 2016) can be proposed as follows:

When the high inflow event occurred in Chichester Reservoir, the tributary inflows were sufficient to break the existing thermal stratification and the whole waterbody was fully mixed as a consequence (section [5.4](#)). Terrestrially derived organic carbon was then transported to Chichester Reservoir from the tributaries (Mash et al., 2004). POC concentrations in Chichester Reservoir can increase due to the substantial terrestrial input from the tributaries (section [2.3.1.3.2](#)), and the DOC concentrations can be homogeneously distributed in the whole waterbody (section [5.6](#)) (Meybeck, 1981, Wetzel, 2001). The origin of organic carbon during this event is likely to be dominated by allochthonous organic carbon (section [2.3.1.4](#)). Measured DO levels indicated that microbial aerobic OM decomposition is likely to be occurring in the waterbody (section [5.4](#) and [5.6.2](#)). Microbial anaerobic decomposition probably

prevailed within the interstitial sediment water, but the redox potential in the sediment during the high inflow event only allows the reduction of manganese-oxides and limited Fe reduced from iron-oxide reduction can proceed completely (section [5.4.2](#)) (Tratnyek et al., 2011). The water from the tributaries also contained increased levels of turbidity, total Fe and TP (section [5.4.1](#) and [5.4.2](#)).

5.5 Overturn event

The conceptual model of Chichester Reservoir during the autumn overturn event is introduced and discussed in this section (Figure 5.7). The autumn overturn occurred on 14th March 2016 (as per the yellow arrow in Figure 5.8). DO, TOC, total Mn, and ammonium profiles on 14th March 2016 are presented in Figure 5.8. A hypothesis about the organic carbon dynamics during the overturn event in Chichester Reservoir is proposed in section [5.5.1](#) and validated in section [5.6](#).

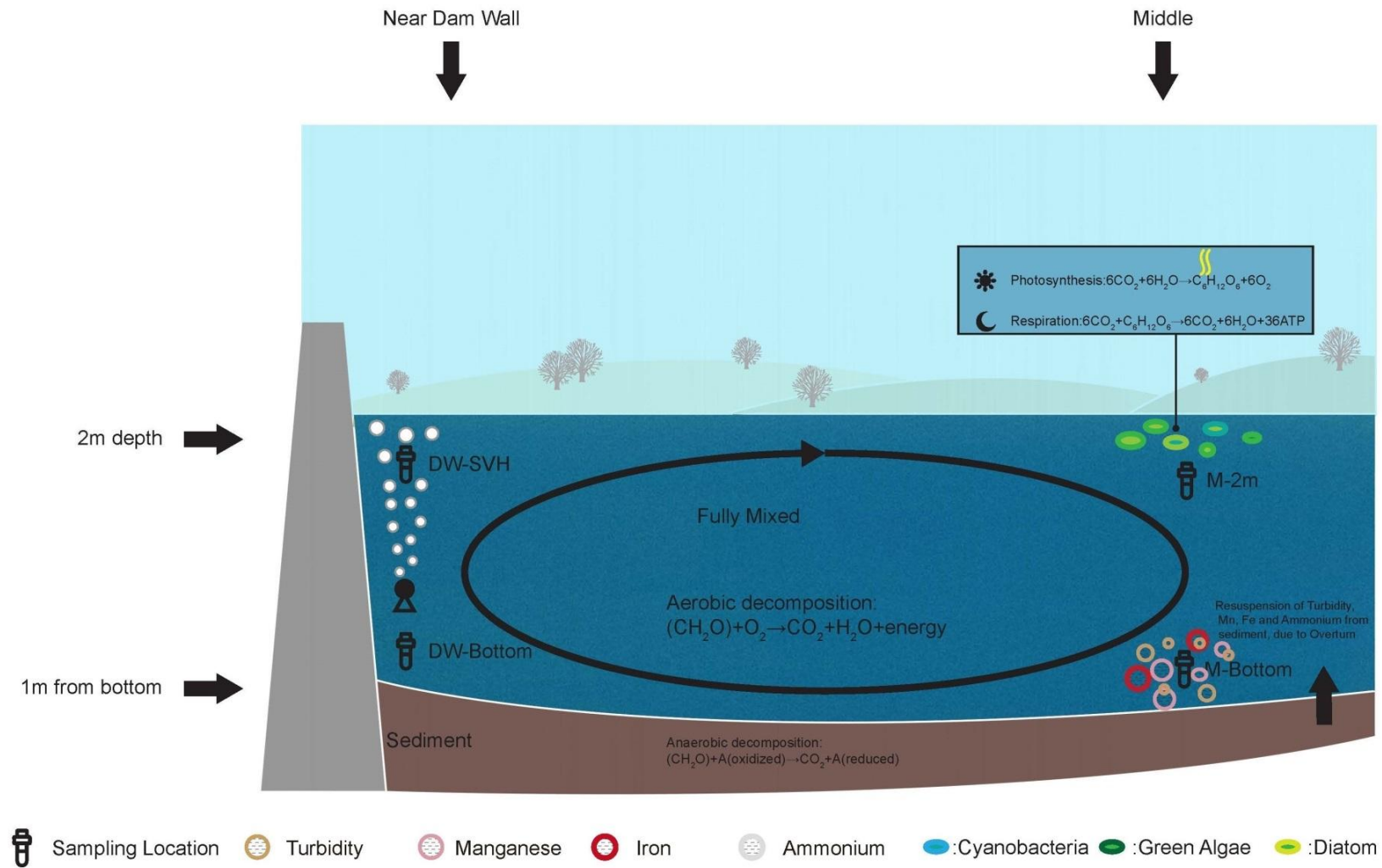


Figure 5.7 Chichester Reservoir conceptual model: overturn event

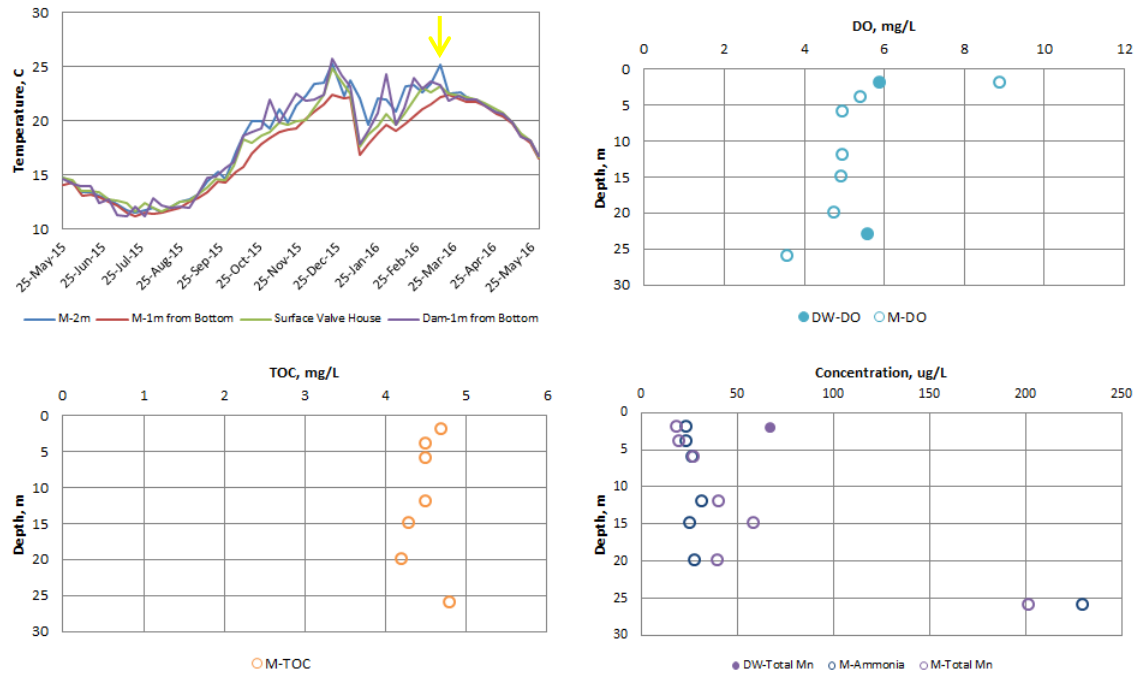


Figure 5.8 Temporal distributions of temperature at all sampling locations, and DO, TOC, Total Mn, Ammonium profiles on 14th March 2016 (overturn event)

As shown in Figure 5.7, Figure 5.8 and Table 5.4, on 14th March 2016, Turbidity, Total Mn, Total Fe and Ammonium levels at ‘M-bottom’ were significantly elevated due to the overturn. One week after the overturn, on 21st March 2016: 1) the whole waterbody was fully mixed (Figure 5.7 and 5.8); 2) temperature differentials in both the middle of Chichester Reservoir and near the dam wall were diminished (Figure 5.8), and; 3) in the middle of Chichester Reservoir, upwelling low DO concentrations water from hypolimnion entered the epilimnion and reduced the DO concentration at ‘M-2m’ (Table 5.4).

5.5.1 Organic carbon dynamics during the overturn event

During the overturn event, the organic carbon concentrations in the middle of Chichester Reservoir increased at the bottom layer, due to the overturn as it may cause resuspension of material from the bottom. Microbial aerobic OM decomposition prevailed in the waterbody as the DO concentrations never fell below 0 mg/L at all sampling locations. Microbial anaerobic decomposition occurred within interstitial sediment water (section [5.3.2](#) and [5.6.2](#)).

5.6 Fieldwork

The conceptual model for Chichester Reservoir during the fieldwork period is introduced and discussed in this section (Figure 5.9). Fieldwork was carried out at an early stage of the thermal stratification period (5th December 2016 and 6th December 2016). Temperature, DO, fDOM and BOD5 profiles on 5th and 6th December 2016 are presented in Figure 5.10. Discussions based on statistical analyses are summarized in section 5.6.1 to support the conceptual model (section 5.6.2). The organic carbon dynamics during fieldwork period is proposed in section 5.6.2.

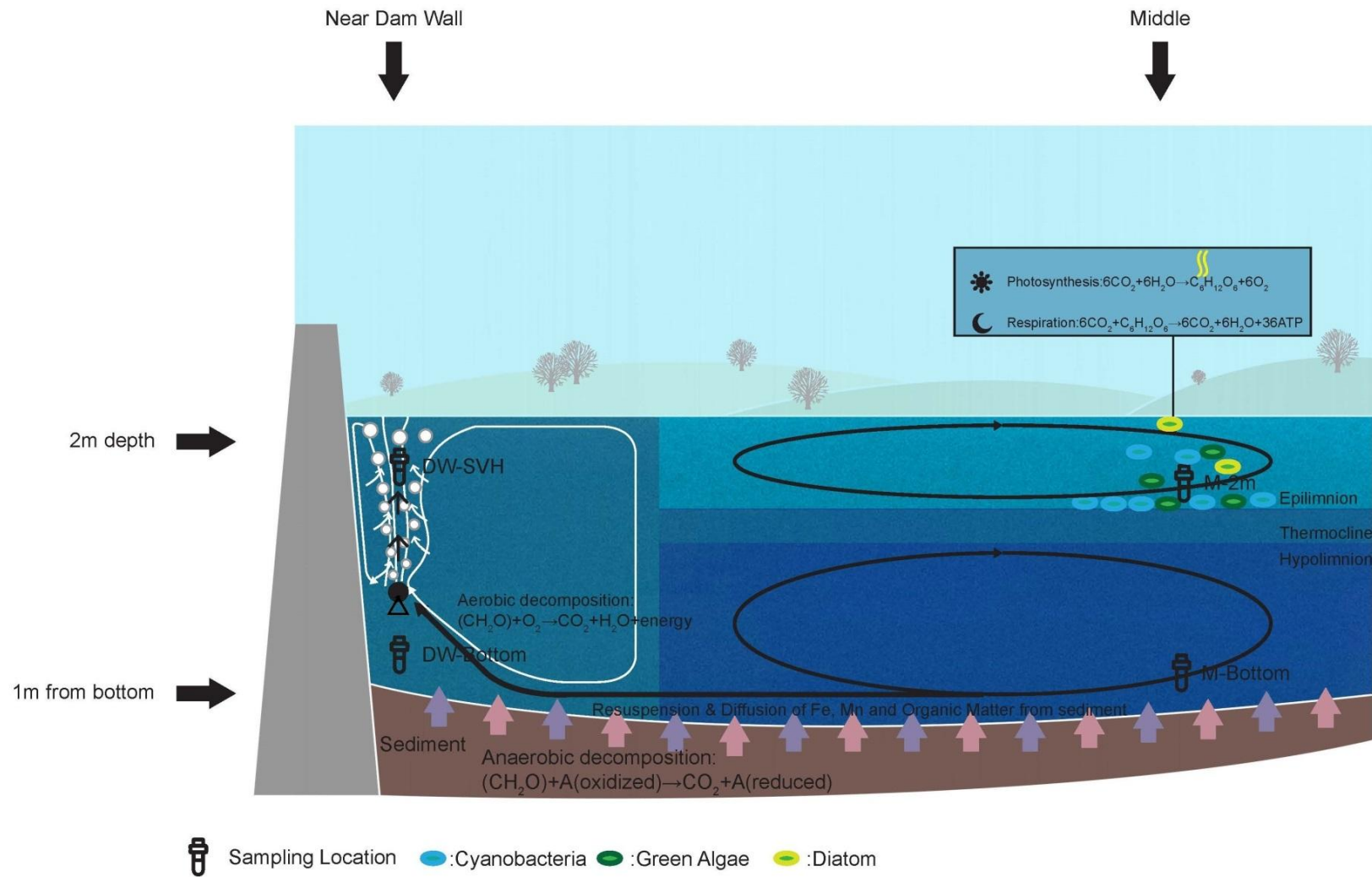


Figure 5.9 Chichester Reservoir conceptual model: fieldwork

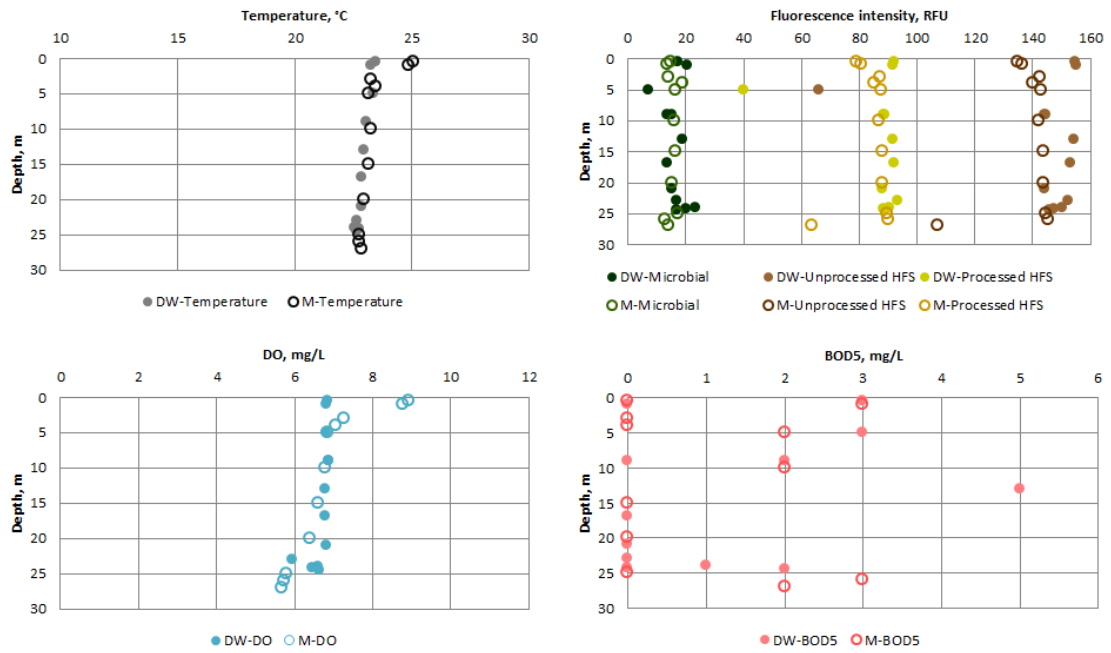


Figure 5.10 Temperature, DO, fDOM and BOD5 profiles on 5th December 2106 and 6th December 2016 (fieldwork)

As summarized in section [4.2.1](#) and [5.2](#), during the fieldwork, temperature and DO differentials near the dam wall were lower than in the middle of the dam. While a shallow thermocline was observed in the middle of the reservoir, no thermocline or DO gradient was detected near the dam wall. This indicates that the water column near the dam wall was fully mixed, while the water column was stratified in the middle of the Chichester Reservoir (Figure 5.10).

Microbial aerobic OM decomposition occurred in the whole waterbody as the DO concentrations during fieldwork ranged from 5.69 mg/L to 8.94 mg/L (Figure 5.10). The lowest DO concentration (5.69 mg/L) during the fieldwork was observed at 27m depth, in the middle of Chichester Reservoir (Figure 5.10). Compared to the no stratification period, it is likely that higher rates of microbial anaerobic OM decomposition occurred in the interstitial sediment water due to higher overlying water temperature, lower DO levels in hypolimnion and DO depletion in the sediment.

5.6.1 Discussion based on statistical analyses

5.6.1.1 Iron and manganese

As summarized in section [4.2.2](#) and Table 4.8, statistically significant distribution differences were found in the following comparisons: 1) 'Total Fe-Middle' and 'Total Fe-Dam Wall' ($P=0.005$); 2) 'Soluble Mn-Middle' and 'Soluble Mn-Dam Wall' ($P=0.001$), and; 3) 'Total Mn-Middle' and 'Total Mn-Dam Wall' ($P=0.005$). No statistically significant differences were found between the distributions of soluble Fe in the middle of Chichester Reservoir and near the dam wall ($P=0.668$). Total Fe and soluble Mn data in the middle of Chichester Reservoir have higher average values, lower median values and higher variability, compared to near the dam wall area. Total Mn data in the middle of Chichester Reservoir has higher average and median values and higher variability.

Possible explanations for these results are: 1. Total Mn levels were generally higher in the middle of Chichester Reservoir due to: a). a lower redox potential in the sediment (section [2.3.2.1](#)) (Appelo and Postma, 2005, Wetzel, 2001), and; b). a higher diffusive flux of Total Mn from sediment to the overlying water, in the middle of Chichester Reservoir (section [5.3.3](#)) (Sherman et al., 2001), and; 2. Iron and manganese values for the deepest sampling point were probably elevated due to disturbance of the surface sediments during the sampling process (section [4.2.1](#)).

5.6.1.2 Phosphorus, nitrogen and carbon

No statistically significant distribution differences were found for soluble and total P, ammonium, TC, TN and DOC, between 'the middle of Chichester Reservoir' and 'near the dam wall area'. In addition, no significant correlations were found between sampling depth and aforementioned parameters. These results might indicate that the whole waterbody in Chichester Reservoir was well mixed in terms of these chemical parameters during the fieldwork period and hence, more closely resembled the water quality of the 'no-stratification' periods (Figure 6-16, Appendix 4).

The homogeneously distributed DOC concentration observed in Chichester Reservoir during the fieldwork agrees with the overall conclusions of a global DOC study from Sobek et al. (2007). This study analysed the relationships between DOC and other

parameters based on over 7500 lakes from 6 continents. The authors summarized that no correlation was found between DOC and lake depth based on their global data (Sobek et al., 2007).

DOC concentrations in Chichester Reservoir ranged from 1.5 to 2.5 mg/L during the fieldwork period. Based on DOC concentration ranges given by Thurman (2012), Chichester Reservoir could be characterised as oligotrophic during the fieldwork period (see section 2.3.1.3.3). In addition, the homogenous distribution of DOC concentration in large enclosed water bodies was also discussed by Thurman (2012). As mentioned in section 2.3.1.3.3, Thurman (2012) summarized that the concentration of DOC largely depends on the trophic state of the waterbody; and the DOC concentration may decrease with depth in a stratified waterbody.

Another study from Kim et al. (2000) studied the distribution of DOC in Lake Soyang (a deep reservoir in South Korea). They found that DOC concentrations were homogeneously distributed in the reservoir in spring and early summer. During the monsoon season, DOC levels in the middle layer increased. After the monsoon season, DOC levels in the upper and middle layers were elevated. However, DO level in the bottom layer only increased after the summer season (Kim et al., 2000). The results from this study further support the organic carbon dynamics proposed for the Chichester Reservoir during periods of high tributary inflows (section 5.2.2, 5.3.3 and 5.4.3).

A different result was reported by Yoshioka et al. (2002) in Lake Baikal (a Russian oligotrophic lake, also the largest lake in the world). Yoshioka et al. (2002) summarized that the DOC concentrations in the surface layer were generally higher than in deeper layers, due to intensive primary production and increased autochthonous organic carbon concentration in epilimnion (Yoshioka et al., 2002). The results from this study agree with the observations in Chichester Reservoir during the stratification period (section 5.3.3).

In Chichester Reservoir, the homogeneously distributed DOC levels measured during the fieldwork may partly be attributed to the relatively less intensive primary

production in the surface layer, relatively low tributaries inflow and rainfall. The sampling was also conducted at the early stage of summer stratification.

5.6.1.3 Processed and unprocessed humic/fulvic substances

As summarized in section [4.2.2](#) and Table 4.8, statistically significant distribution differences were found in the following comparisons: 1) 'Unprocessed HFS-Middle' and 'Unprocessed HFS-Dam Wall' ($P=0.004$), and; 2) 'Processed HFS-Middle' and 'Processed HFS-Dam Wall' ($P=0.004$). Unprocessed and processed humic/fulvic substances in the middle of Chichester Reservoir have lower average and median values and lower variability, compared to near the dam wall area. Possible explanations for these results are: 1) differences between vertical distributions of humic/fulvic substances in the middle and near the dam wall area (discussed later in this section), and; 2) more humic/fulvic substances were diffused and resuspended from sediment to overlying water near the dam wall, due to the destratifier (section [5.6.2](#)).

No significant correlations were found between sampling depth and the fluorescence intensities of processed and unprocessed humic/fulvic substances at all sampling sites. These results indicate that the humic/fulvic concentrations were not affected by depth in the entire waterbody of Chichester Reservoir. However, slight decreases were observed for both processed and unprocessed humic/fulvic substances at the surface layer in the middle of Chichester Reservoir (Figure 5.10).

Borisover et al. (2009) studied the vertical distribution of fluorescence organic matter in Lake Kinneret (a freshwater lake in Israel). They concluded that stratification in humic substances was formed during the thermal stratification period in Lake Kinneret. The humic substance concentrations were higher in the bottom layer due to: 1) the microbial anaerobic OM decomposition processes in sediments; 2) the resuspension and releasing of humic substances from the sediment, and; 3) the biological decomposition processes of sinking POM in the water column. It is also suggested that lower concentrations of humic substances in upper layer might be affected by the photochemical degradation of the humic substances (Borisover et al., 2009). Similar results have previously been reported by (Hayase et al., 1987, Jørgensen et al., 2011, Yao et al., 2016).

In the middle of Chichester Reservoir, the low humic/fulvic substance levels at the surface layer might be attributed to photochemical degradation, while the vertically homogeneously distributed humic/fulvic substances at the middle and bottom layers may partly be attributed to: 1) the relatively low biological decomposition processes in the water column (see section [5.6.2](#)), and; 2) the fact that the reservoir had been fully mixed during the time of sampling (see section [5.6.2](#)). Near the dam wall, the vertical distribution of humic/fulvic substances was homogenous. These results indicate that the artificial destratification system could uniformly mix the water column and eliminate humic/fulvic substances stratification near the dam wall area.

5.6.1.4 Other fDOM data, fluorescence indices and TC/TN ratio

No statistically significant distribution differences were found between ‘the middle of Chichester Reservoir’ and ‘near the dam wall’, for the following parameters: TC/TN, microbial content, processed to unprocessed humic/fulvic substances ratio, A250/A365, BIX, FI and Peak T/Peak C. In addition, no significant correlations were found between sampling depth and the aforementioned parameters.

The homogenous distribution of aforementioned parameters in Chichester Reservoir may indicate that: 1) the origin of organic matter was uniform in the whole waterbody, and; 2) the fluorescence aromaticity, aromatic content and molecular weight of organic matter were evenly distributed in the waterbody. Therefore, we speculate that the chemical composition of fluorescence organic matter was homogeneously distributed and no significant preferential degradation was visible from the data during the fieldwork campaign.

No significant correlation was found between Abs254 and DOC concentration in Chichester Reservoir, during the fieldwork period. A possible reason for this result may be that the relationship between absorbance indices and DOC largely depends on basin morphology, and therefore could only be applied in large-scale studies among basins (Toming et al., 2016). The watershed size and structure largely affects the hydrologic residence time (HRT) and organic carbon degradation processes in the waterbody. However, in a specific lake or reservoir, these factors are generally fixed and cannot be altered. Thus, DOC concentrations in a large enclosed waterbody may

correlate well with other factors, such as external loading and primary production, instead of absorbance indices.

5.6.2 Organic carbon dynamics in Chichester Reservoir

As mentioned in section 5.3.1.2, DO concentrations near the dam wall never achieved 100% saturation, and this phenomenon was also observed during the fieldwork. Our initial hypothesis was that, during the thermal stratification period (generally the summer period), the increased water temperatures in the lower part of the reservoir caused by the artificial destratification system accelerates organic carbon decomposition processes and further results in an induced oxygen demand near the dam wall. Consequently, the overall DO concentrations near the dam wall never achieve 100% saturation as the increased DO concentrations caused by the destratifier cannot sustain the oxygen demand.

However, results of the fieldwork show that: BOD₅ values (<2-5 mg/L) and microbial contents (7.2-23.5 RFU) were relatively low in the Chichester Reservoir during the fieldwork period and may be the cause of the observed decreased DO saturations. In addition: 1) DOC concentrations in Chichester Reservoir indicate an oligotrophic system (Thurman, 1985a, Wetzel, 2001); 2) the fluorescing intensities indicate dominance by humic/fulvic substances which are relatively resistant to microbial decomposition (Bastviken et al., 2003), and; 3) the chemical composition and origin of DOM in Chichester Reservoir were evenly distributed in the whole waterbody. Thus, it is speculated that the intensity of microbial aerobic OM decomposition processes in the water column of Chichester Reservoir was relatively low, during the fieldwork period, and the aforementioned hypothesis have to be rejected. Since the DO levels near the dam wall never achieved 100% saturation, another possible explanation is proposed; namely that water with low DO saturation was brought into the dam wall area from bottom sediments in the middle of the dam and near the dam wall, and the hypolimnion in the middle of Chichester Reservoir.

Based on the above discussion, the organic carbon dynamics in Chichester Reservoir during the fieldwork period can be summarized as follows:

In Chichester Reservoir, primary production is low in the surface layer, and no significant inflow events were observed. Because of this and the fact that the reservoir was sampled shortly after the onset of stratification DOC concentrations were relatively low and homogeneously distributed in the whole waterbody. Two dominant dissolved fluorescence organic matter components were found in the water column: processed and unprocessed humic/fulvic substances. Humic/fulvic substances levels were slightly decreased due to photochemical degradation at the surface layer, in the middle of Chichester Reservoir. Near the dam wall, the humic/fulvic substances stratification was eliminated due to the operation of the destratifier. Organic matter in the Chichester Reservoir is a mixture of both autochthonous and allochthonous organic matter and was homogeneously distributed in the whole waterbody with regards to its chemical composition and origin. Fluorescing microbially derived organic matter was also found, but with a relatively low amount. The rate of aerobic microbial OM decomposition processes in the whole water column was also fairly low, as indicated by BOD5 measurements and shown in Figure 5.10. Based on observations of other water quality parameters (including DO, Total Mn and Total Fe), the rate of anaerobic microbial decomposition processes in the bottom sediment could be higher during the stratification period than during the no stratification period. Resuspended and diffused humic/fulvic substances from the bottom sediment in the dam wall area and the middle of Chichester Reservoir were transported to the water column near the dam wall as a result of the destratifier.

Chapter 6: Conclusion and recommendations

The following overall conclusions can be derived from the research presented in Chapter 5:

- 1) The fieldwork was carried out at the early stage of summer stratification and no significant high inflow events or intensive primary productions occurred. The DOC concentrations during the fieldwork period in Chichester Reservoir indicate an oligotrophic system and were homogeneously distributed in the whole waterbody.
- 2) During the fieldwork period, two dominant fluorescence DOM components were found in the water column: an unprocessed humic/fulvic component and a processed humic/fulvic component. These components are a mixture of both autochthonous and allochthonous humic/fulvic material. Humic/fulvic substances stratification was observed in the middle of Chichester Reservoir, while no humic/fulvic substances stratification was observed near the dam wall, indicating that the artificial destratification system could uniformly mix the water column and eliminate humic/fulvic substances stratification near the dam wall area. This conclusion support one of our initial hypotheses that the artificial destratification system in Chichester Reservoir has an impact on water quality, including organic carbon, near the dam wall area.
- 3) During the fieldwork period, the origin, fluorescence aromaticity, aromatic content and molecular weight of organic matter were evenly distributed in the waterbody, which might indicate that no significant preferential degradation was visible from the data during the fieldwork campaign.
- 4) Near the Dam Wall area, the destratification system can effectively:
 - a. Break thermal stratification and achieve a well-mixed water column;
 - b. Reduce Temperature and DO differentials between the surface and bottom, while increasing the DO concentrations near the bottom.

Our initial hypothesis that the artificial destratification system has an impact on water quality data, including organic carbon, near the dam wall area is validated based on these conclusions.

However, Temperature and DO differentials still exist. DO concentrations remain unsaturated (lower than 100% saturation) all the time during periods of stratification. This might be the result of low-DO water being brought to the Dam Wall area from: a.) bottom sediments in the middle of the dam and near the dam wall area; b.) the hypolimnion in the middle of Chichester Reservoir, where the waterbody maintains the stratification condition. It is unlikely that the lower DO saturation is due to in-situ degradation in the water column at the dam wall area, because microbial contents and the intensity of microbial aerobic decomposition reactions were relatively low. Therefore, our initial hypothesis that organic carbon degradation processes are accelerated during the thermal stratification period, due to the impact of the artificial destratification system near the dam wall area, cannot be validated.

5) The destratification system has a limited influence on controlling the release of Fe, Mn and nutrients from the bottom sediment. A possible explanation is that more iron, manganese and nutrients were mobilised from the bottom due to the operation of artificial destratification system. Soluble iron, manganese and ammonium in the water column originate from the anaerobic decomposition reaction processes in the bottom sediments.

6) High river inflows are able to destabilise thermal stratification. Total Fe, TP and turbidity levels are related to high river inflows: high concentrations of total Fe, TP and turbidity load from the tributaries into Chichester Reservoir during the high inflow event. However, one of our initial hypotheses that high inflow events can influence water quality data, including organic carbon, in Chichester Reservoir cannot be validated because: a.) statistical analyses show that the concentrations of TOC in Chichester Reservoir might have a limited influence from the high tributaries inflow due to the limited long-term TOC data available (as per Hunter Water Corporation); b.) no significant high inflow events were observed during the fieldwork period.

This study has some limitations that have not been investigated. Following suggestions and recommendations are given based on these limitations:

1) Further Chichester Reservoir sediment research is suggested to understand the chemical properties and dynamics of the sediment content;

2) A 3-Dimensional hydrodynamic model is suggested to understand water movements in Chichester Reservoir during the different conceptual periods detailed in this study;

3) This study is limited by data availability near the dam wall area. Therefore, we recommend an increased sampling frequency at the bottom, near the Dam Wall area. The following parameters are suggested namely: TOC, TP, Ammonia and Chl a;

4) The organic carbon dynamics we suggested in section 5.6.2 might be altered when significant algal blooms and high tributaries inflows occurs. When significant algal blooms occur, organic carbon in the waterbody may be dominated by autochthonous organic carbon due to the higher primary production intensities. Autochthonous organic carbon is more available for microbial decomposition and the intensity of microbial decomposition processes in the water column may increase. Conversely, when high inflow events occur, organic carbon in the waterbody may be dominated by allochthonous organic carbon due to substantial external loadings. The variations of organic carbon origins may affect microbe decomposition of the organic carbon processes and further alter the dissolved oxygen demand in the water column. Therefore, event-based monitoring is highly recommended;

5) Organic matter fluorescence data is a useful indicator of organic carbon origin and chemical properties, which can help to understand organic carbon degradation processes. When there is an event (e.g. algae bloom or high inflow), organic matter content may change. Fluorescence monitoring is recommended when these events occur to understand the variation of organic carbon content and reactivity.

However, fluorescence data might not be a good indicator of DOC concentration and BOD5 data, because:

a. As discussed in section 5.6.1.4, absorbance indices may not be a good indicator of DOC concentration in the study of a specific lake or reservoir;

b. As discussed in section 5.6.2, the majority of fluorescence DOM in Chichester Reservoir were humic/fulvic substances, which are more resistant to microbe degradation in 5 days.

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Appendix 1

Table 1 Water quality records from August 1987 to June 1997

	EC, uS/cm at 25°C		Turbidity, NTU		TP, mg/L		Total Fe, mg/L		Total Mn, ug/L	
	Max	Median	Max	Median	Max	Median	Max	Median	Max	Median
Chichester River	193	67	66	1.9	0.097	0.013	1.3	0.12	70.1	5
Wangat River	110	82	16	1.7	0.04	0.015	2.26	0.1	170.2	3
Dam Wall-Surface	-	-	45	3	-	-	1.46	0.32	150	20
Dam Wall-Screen	120	75	46	3.3	0.08	0.01	1.79	0.34	150	20

Table 2 DO% data from March 2001 to January 2004

Location	DO%, %		
	Max	Min	Average
Dam Wall-surface to bottom	130	6.4	82.9
Dam Wall-2m	-	-	89
Dam Wall-4m above bottom	-	-	77

Table 3 Total and soluble Iron and Manganese data from June 2002 to January 2004

Location	Total Mn, mg/L			Soluble Mn, mg/L			Total Fe, mg/L	Soluble Fe, mg/L
	Max	Min	Average	Max	Min	Average	Max	Max
Dam Wall-surface to bottom	0.442	undetectable	0.041	0.198	0.001	0.026	3.47mg/L	0.71

Table 4 Temperature and DO% data from July 2007 to June 2009

Location	Temperature, °C			DO%, %		
	Max	Min	Average	Max	Min	Average
Dam Wall-Surface	26	12	18	100	69	88
Dam Wall-Screen	14	10	12.6	-	-	-

Table 5 Other water quality records from July 2007 to June 2009

Location	EC, uS/cm at 25°C		Turbidity, NTU		TP, mg/L		Total Fe, mg/L		Total Mn, ug/L	
	Max	Median	Max	Median	Max	Median	Max	Median	Max	Median
Chichester River	95	74	25	1.3	0.025	0.005	0.65	0.08	20	5
Wangat River	93	89	13	2.2	0.12	0.01	1.05	0.13	77	9.5
Dam Wall-Surface	87	73	42	6.9	0.15	0.013	1.01	0.34	0.119	0.014
Dam Wall-Screen	82	54	40.5	6.9	0.022	0.012	1.09	0.36	0.083	0.014

Table 6 Temperature and DO% data from July 2009 to June 2012

Location	Temperature, °C			DO%, %		
	Max	Min	Average	Max	Min	Average
Dam Wall-Surface	24.5	10.7	17.4	113	64	88
Dam Wall-Screen	-	-	-	-	-	-

Table 7 Other water quality records from July 2009 to June 2012

Location	EC, uS/cm at 25°C		Turbidity, NTU		TP, mg/L		Total Fe, mg/L		Total Mn, ug/L	
	Max	Median	Max	Median	Max	Median	Max	Median	Max	Median
Chichester River	90	71	18	2.3	0.024	0.01	0.425	0.141	29	7.5
Wangat River	93	81	19	2.9	0.068	0.018	1.32	0.277	21	10
Dam Wall-Surface	349	74	52.1	3.8	0.12	0.015	11	0.28	82	16
Dam Wall-Screen	-	-	55.1	3.8	0.032	0.017	1.07	0.3	170	15

Appendix 3

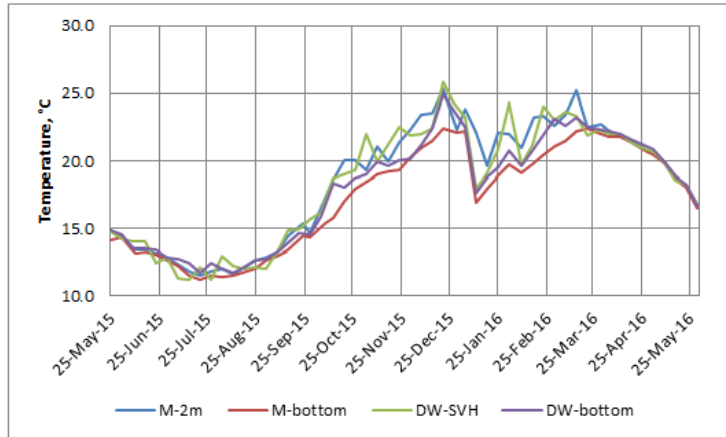


Figure 1 Temporal distributions of Temperature at M-2m, M-bottom, DW-SVH and DW-bottom

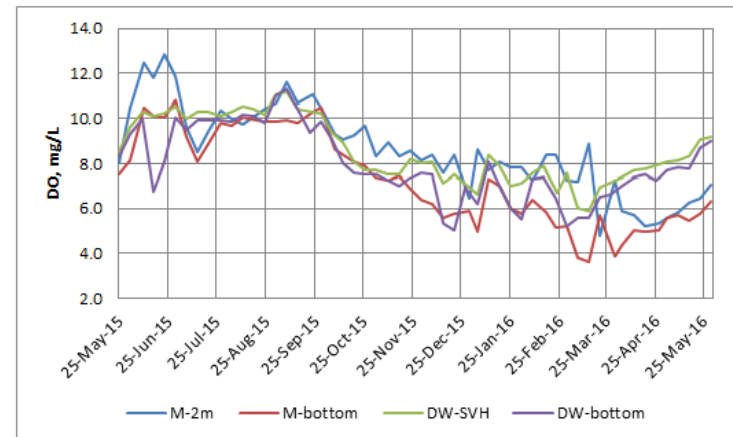


Figure 2 Temporal distributions of DO at M-2m, M-bottom, DW-SVH and DW-bottom

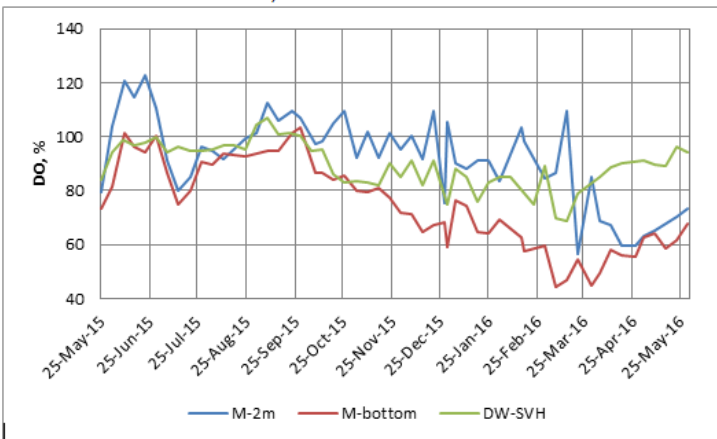


Figure 3 Temporal distributions of DO% at M-2m, M-bottom and DW-SVH

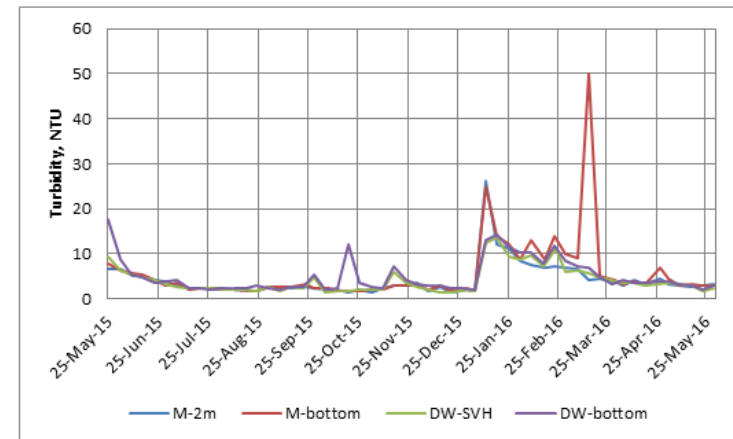


Figure 4 Temporal distributions of Turbidity at M-2m, M-bottom, DW-SVH and DW-bottom

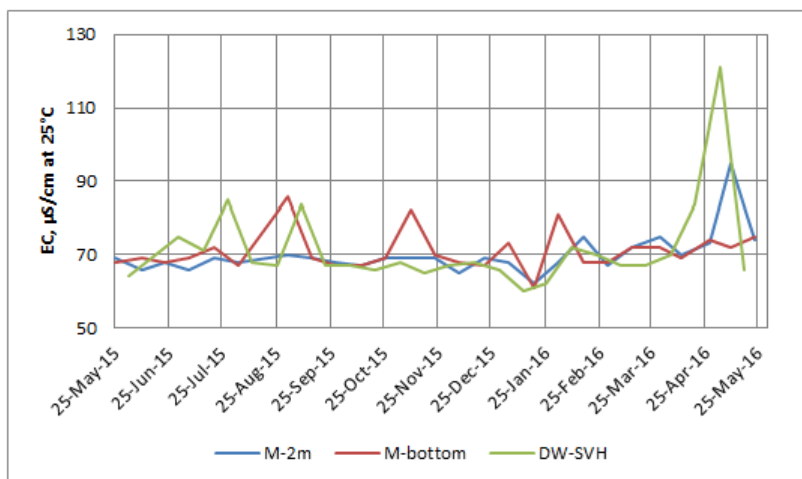


Figure 5 Temporal distributions of EC at M-2m, M-bottom and DW-SVH

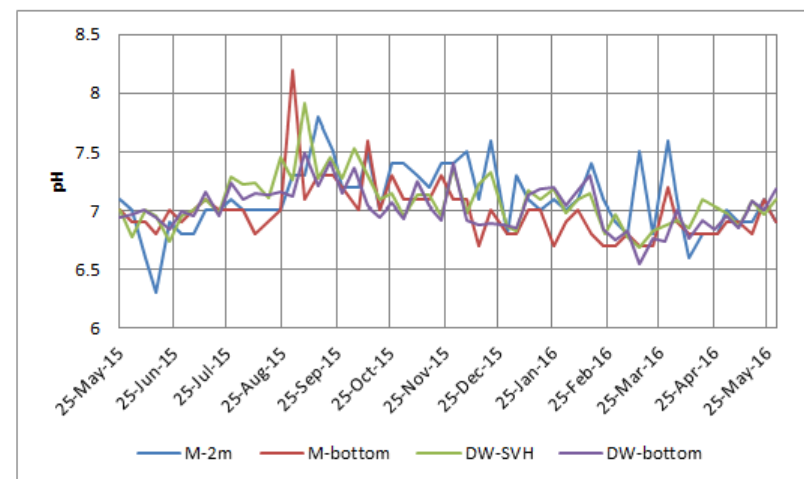


Figure 6 Temporal distributions of pH at M-2m, M-bottom, DW-SVH and DW-bottom

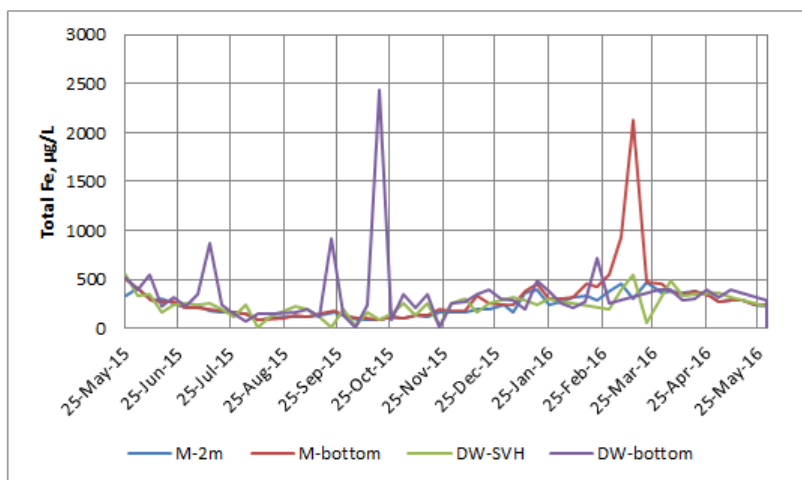


Figure 7 Temporal distributions of Total Fe at M-2m, M-bottom, DW-SVH and DW-bottom

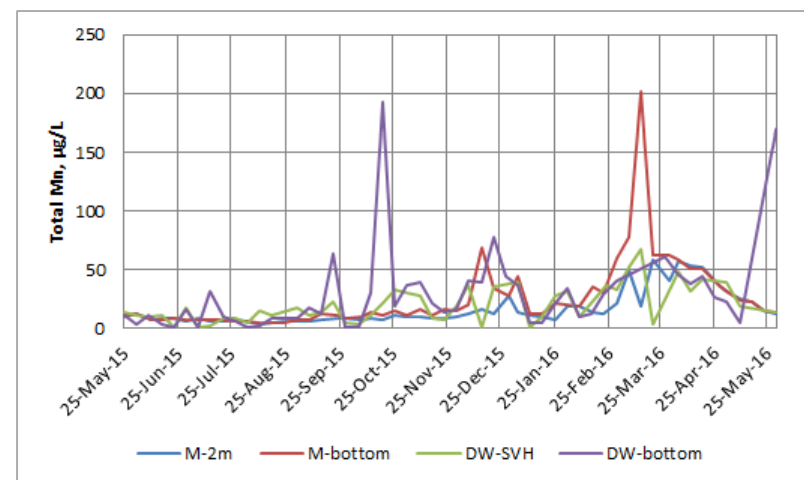


Figure 8 Temporal distributions of Total Mn at M-2m, M-bottom, DW-SVH and DW-bottom

Appendix 3

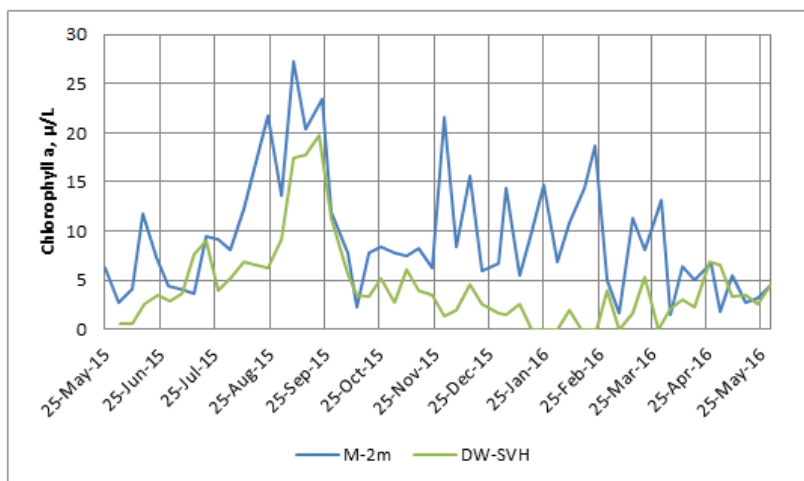


Figure 9 Temporal distributions of Chlorophyll a at M-2m and DW-SVH

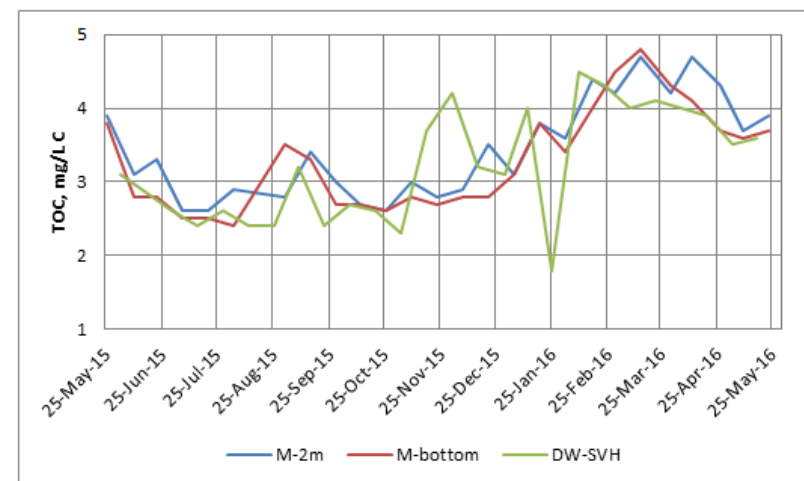


Figure 10 Temporal distributions of TOC at M-2m, M-bottom and DW-SVH

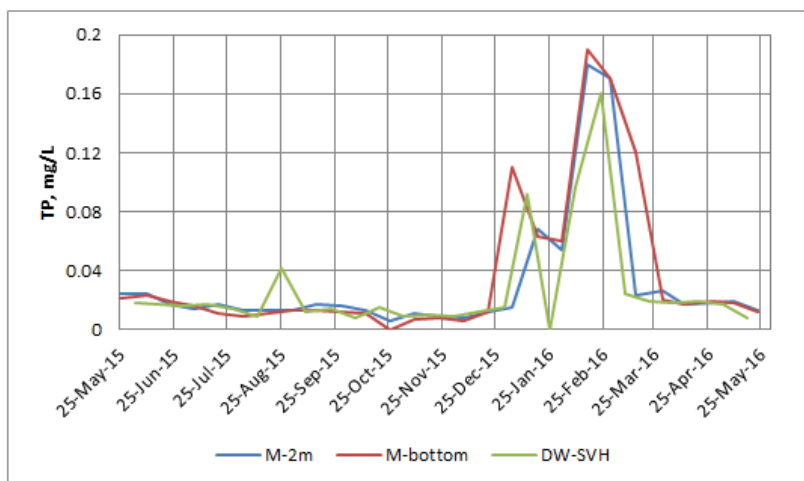


Figure 11 Temporal distributions of TP at M-2m, M-bottom and DW-SVH

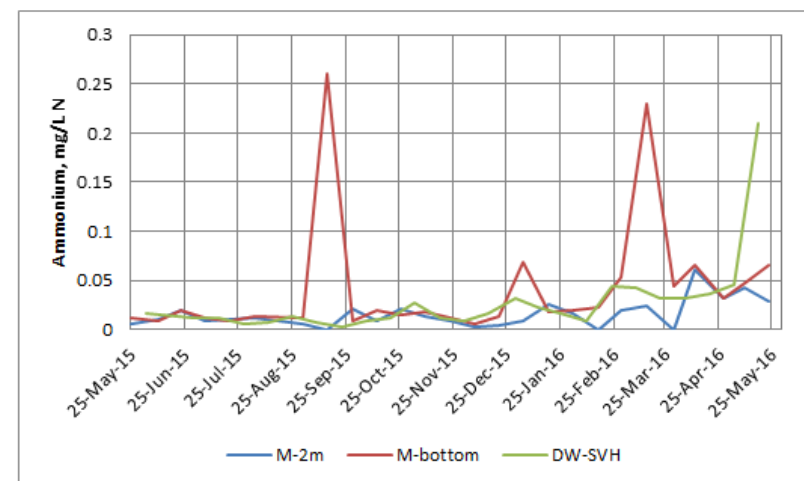


Figure 12 Temporal distributions of Ammonium at M-2m, M-bottom and DW-SVH

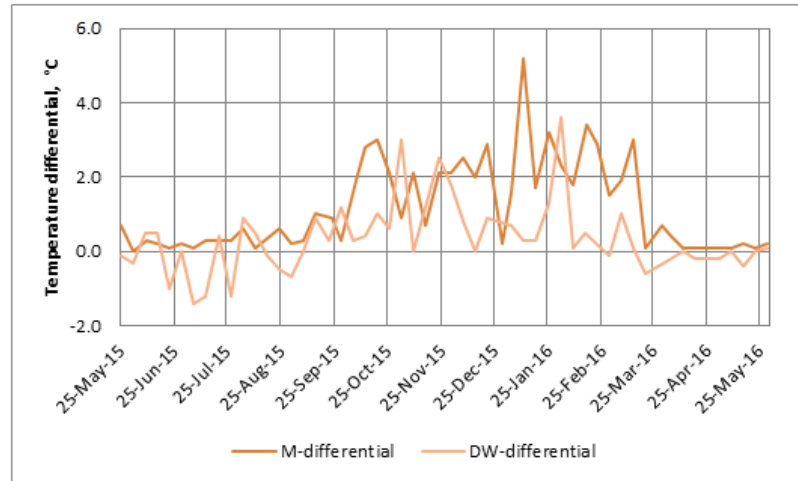


Figure 13 Temporal distributions of Temperature differential in the middle and near the dam wall area

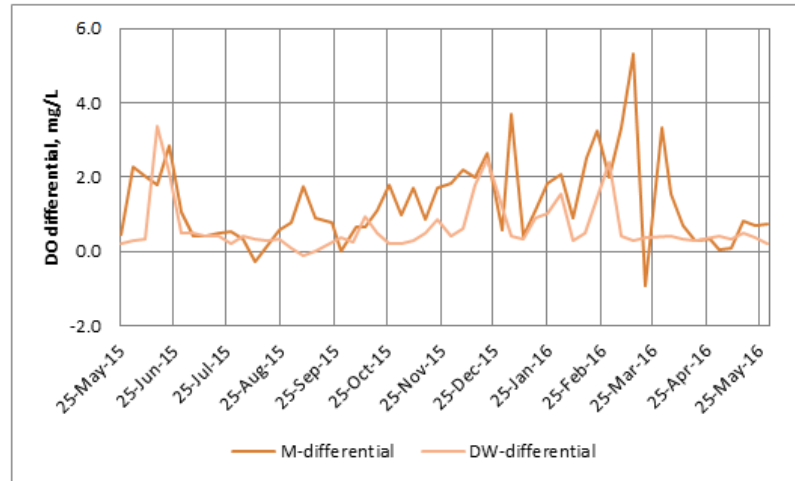


Figure 14 Temporal distributions of DO differential in the middle and near the dam wall area

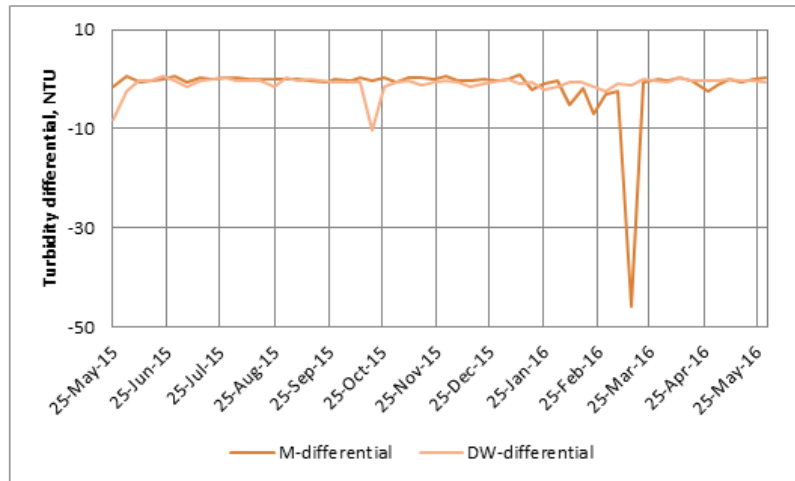


Figure 15 Temporal distributions of Turbidity differential in the middle and near the dam wall area

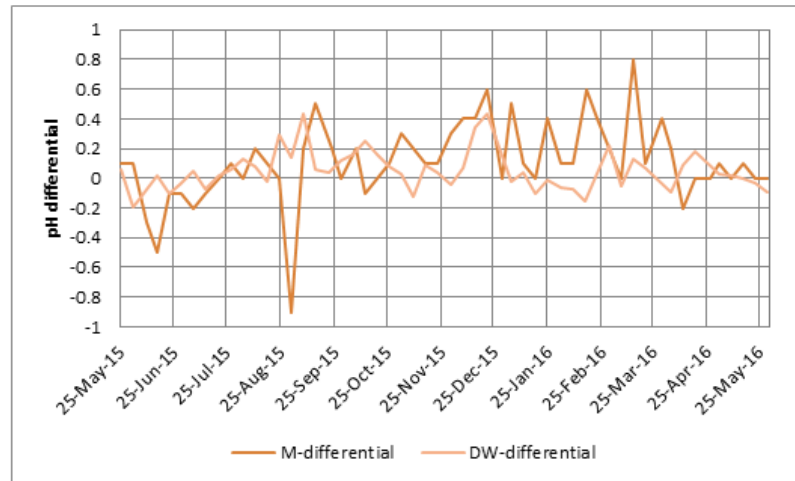


Figure 16 Temporal distributions of pH differential in the middle and near the dam wall area

Appendix 3

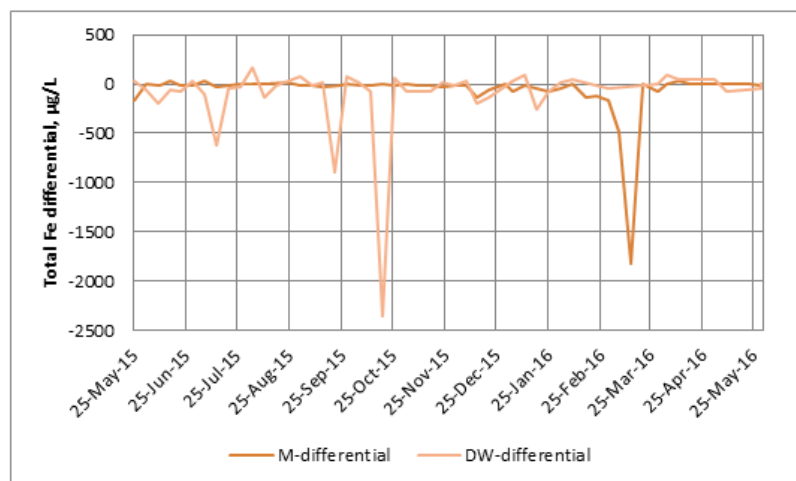


Figure 17 Temporal distributions of Total Fe differential in the middle and near the dam wall area

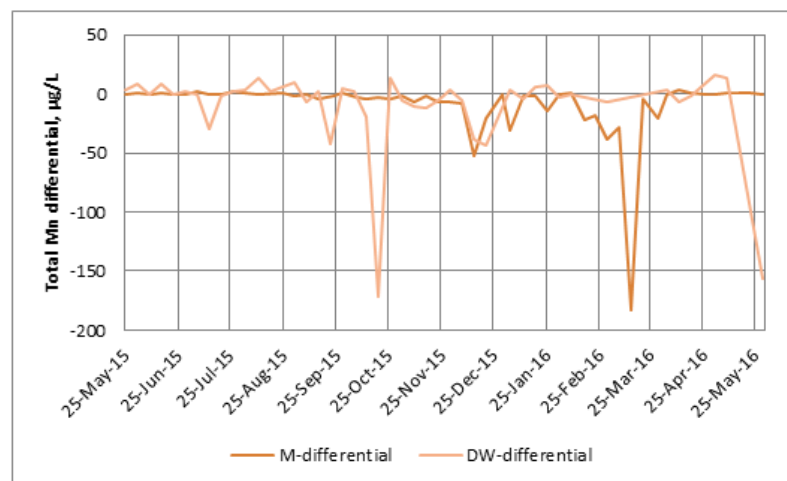


Figure 18 Temporal distributions of Total Mn differential in the middle and near the dam wall area

Table 1 Methodology, QC criteria for each water quality parameter

	Method applied	LOR	NATA	TAT	QC criteria				
					Std	RPD	Recovery	Blk	Other criteria
Turbidity	APHA (2012) 2130 B	0.1 NTU	Yes	3 days	No failure for Std 2NTU and Std 20NTU	No failure for RPD>0.3 NTU	-	-	-(No information or not provided)
EC	APHA (2012) 2510 B	1 µS/cm	Yes	2 days	No failure for Std 1015 µS/cm	No failure for RPD>10 µS/cm	-	-	-
pH	APHA (2012) 4500-H ⁺ B	0.1	Yes	2 days	No failure for Std 10.0 and Std 7.6	No failure	-	-	Buffer acceptance: Yes

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Total Fe	APHA (2012) 3125 B	5.0 ug/L	Yes	3 days	-	-	-	-	-
Total Mn	APHA (2012) 3125 B	0.2 ug/L	Yes	3 days	-	-	-	-	-
Chl a	APHA (2012) 10200 H	1 ug/L	Yes	4 days	-	No failure for RPD>5 MDL	-	No failure	MDL=2 ug/L
TOC, middle of Chichester Reservoir	Measured as T-NPOC, APHA (2012) 5310 C	0.2 mg/L	Yes	5 days	No failure for Std 10 mg/L	No failure	No failure	-	-
TOC, near dam wall area	Measured as TOC, APHA (2012) 5310 B	0.1 mg/L	Yes	5 days	No failure for Std 10 mg/L	No failure	No failure	-	-
TP	Measured as TP LOW, APHA (2012) 4500-PH	0.005 mg/L	Yes	5 days	No failure for Std 0.10 mg/L	No failure for RPD >10MDL	No failure	No failure	MDL=0.005 mg/L
NH3-N	Measured as Ammonia LOW, APHA (2012) 4500-NH ₃ H	0.005 mg/L	Yes	5 days	No failure for Std 0.2 mg/L	No failure for RPD > 5MDL and RPD <5MDL	No failure	No failure	MDL=0.005 mg/L

LOR: Limit of reporting

NATA: National Association of Testing Authorities accreditation

TAT: Turnaround time (the amount of time taken to fulfil the request)

Std: Standard solution for equipment calibration

RPD: Relative Percent Difference for duplicates

Recovery: Spike recovery

Blk: Method blank

MDL: Method detect limit

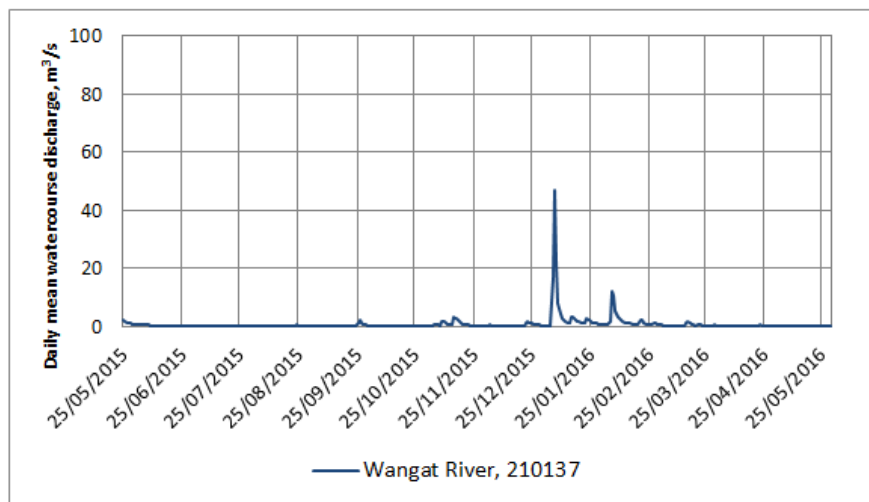


Figure 19 Temporal distribution of daily mean watercourse discharge from Wangat River

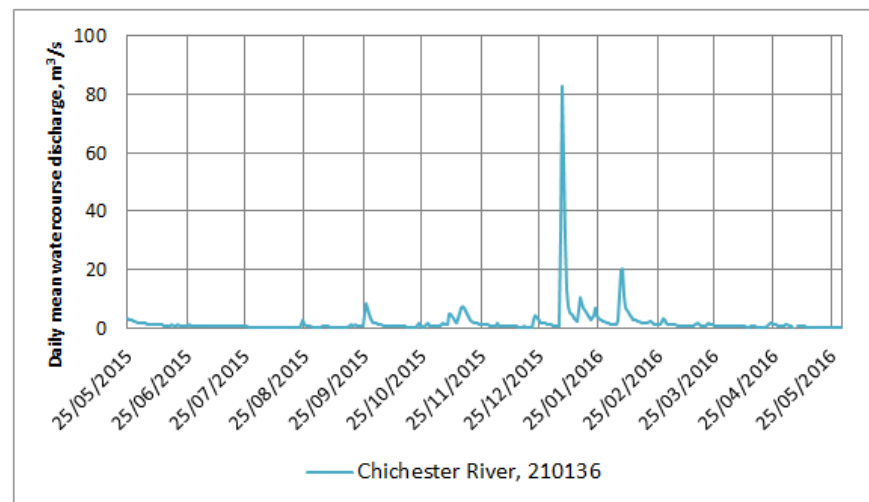


Figure 20 Temporal distribution of daily mean watercourse discharge from Chichester River

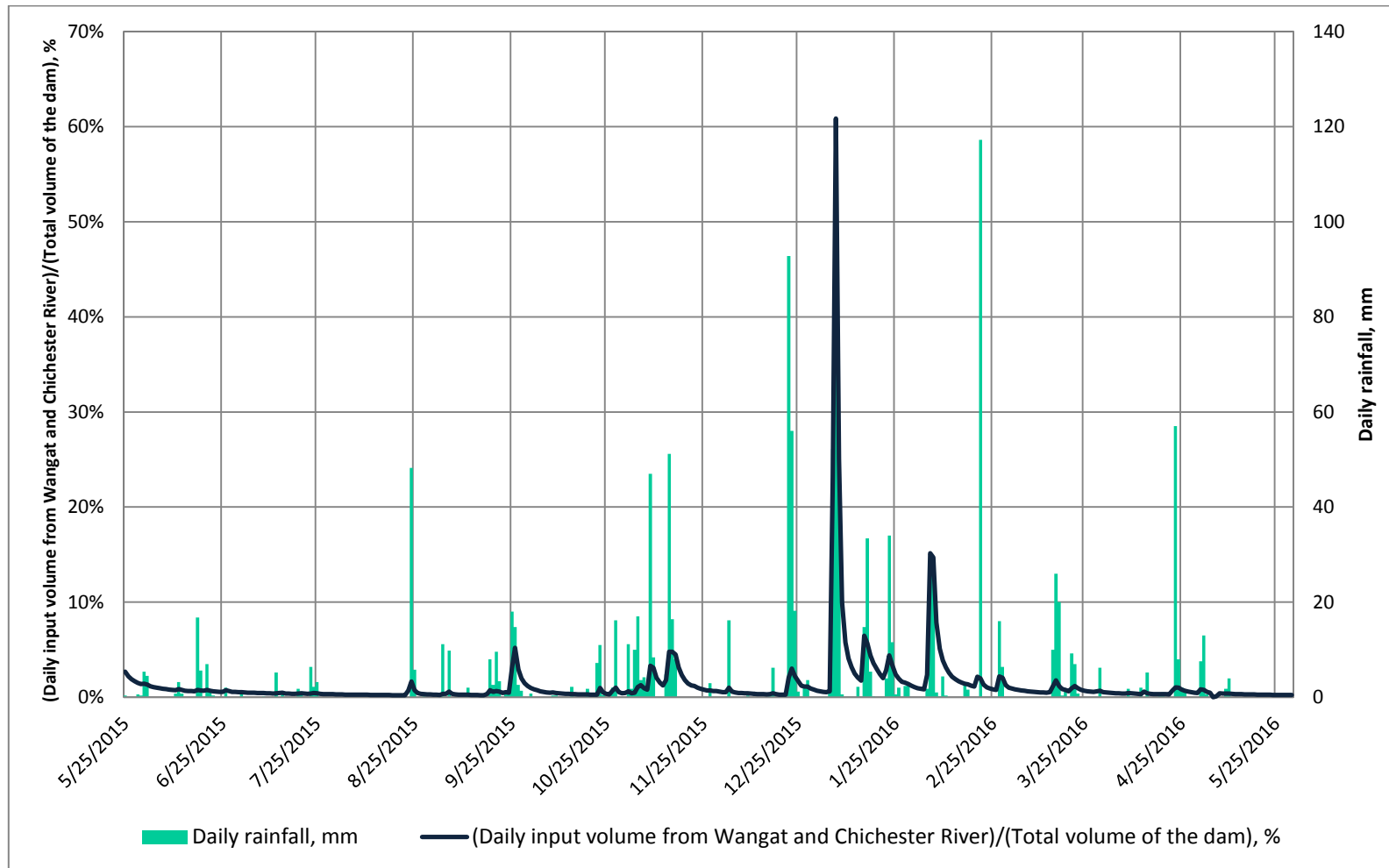


Figure 21 Temporal distributions of rainfall data and the ratio between 'daily input volume from Wangat and Chichester River' and 'total volume of the dam'

Table 2 Detailed information for where s-w tests, t-tests, k-s tests and m-w tests were applied in whole study period

Parameter	S-w normality test	Parametric t-test	Non- parametric k-s test	Notes
Temperature	1) M-2m; 2) M-bottom; 3) DW-SVH; 4) DW-bottom; 5) M-differential; 6) DW-differential.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	-
DO	1) M-2m; 2) M-bottom; 3) DW-SVH; 4) DW-bottom; 5) M-differential; 6) DW-differential.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	-
Turbidity	1) M-2m; 2) M-bottom; 3) DW-SVH; 4) DW-bottom; 5) M-differential; 6) DW-differential.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	-
EC	1) M-2m; 2) M-bottom; 3) DW-SVH.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	No available EC data at DW-bottom.
pH	1) M-2m; 2) M-bottom; 3) DW-SVH; 4) DW-bottom; 5) M-differential; 6) DW-differential.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	-
Total Fe	1) M-2m; 2) M-bottom; 3) DW-SVH; 4) DW-bottom; 5) M-differential; 6) DW-differential.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom; 3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	-
Total Mn	1) M-2m; 2) M-bottom;	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom;	1) M-2m vs DW-SVH; 2) M-bottom vs DW-bottom;	-

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	3) DW-SVH; 4) DW-bottom; 5) M-differential; 6) DW-differential.	3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	3) M-differential vs DW-differential; 4) M-2m vs M-bottom; 5) DW-SVH vs DW-bottom.	
Chl a	1) M-2m; 2) DW-SVH.	1) M-2m vs DW-SVH.	1) M-2m vs DW-SVH.	No available Chl a data at M-bottom and DW-bottom.
TOC	1) M-2m; 2) M-bottom; 3) DW-SVH.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	No available TOC data at DW-bottom.
TP	1) M-2m; 2) M-bottom; 3) DW-SVH.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	No available TP data at DW-bottom.
NH₃-N	1) M-2m; 2) M-bottom; 3) DW-SVH.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	1) M-2m vs DW-SVH; 2) M-2m vs M-bottom.	No available NH ₃ -N data at DW-bottom.

Table 3 Detailed information for where k-s tests were applied at different sampling locations under different scenarios

Location	Parameter	Stratification period' vs 'No stratification period'	Wet period' vs 'Normal and dry period'	High inflow period' vs 'Normal and low inflow period'
M-2m	Temperature	k-s test applied	k-s test applied	k-s test applied
	DO	k-s test applied	k-s test applied	k-s test applied
	Turbidity	k-s test applied	k-s test applied	k-s test applied
	Fe	k-s test applied	k-s test applied	k-s test applied
	Mn	k-s test applied	k-s test applied	k-s test applied
	TOC	k-s test applied	k-s test applied	k-s test applied
	TP	k-s test applied	k-s test applied	k-s test applied
	NH₃-N	k-s test applied	k-s test applied	k-s test applied
	Chl a	k-s test applied	k-s test applied	k-s test applied
M-bottom	Temperature	k-s test applied	k-s test applied	k-s test applied

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	DO	k-s test applied	k-s test applied	k-s test applied
	Turbidity	k-s test applied	k-s test applied	k-s test applied
	Fe	k-s test applied	k-s test applied	k-s test applied
	Mn	k-s test applied	k-s test applied	k-s test applied
	TOC	k-s test applied	k-s test applied	k-s test applied
	TP	k-s test applied	k-s test applied	k-s test applied
	NH3-N	k-s test applied	k-s test applied	k-s test applied
	Chl a	No available Chl a data at M-bottom		
DW-SVH	Temperature	k-s test applied	k-s test applied	k-s test applied
	DO	k-s test applied	k-s test applied	k-s test applied
	Turbidity	k-s test applied	k-s test applied	k-s test applied
	Fe	k-s test applied	k-s test applied	k-s test applied
	Mn	k-s test applied	k-s test applied	k-s test applied
	TOC	k-s test applied	k-s test applied	k-s test applied
	TP	k-s test applied	k-s test applied	k-s test applied
	NH3-N	k-s test applied	k-s test applied	k-s test applied
DW-bottom	Chl a	k-s test applied	k-s test applied	k-s test applied
	Temperature	k-s test applied	k-s test applied	k-s test applied
	DO	k-s test applied	k-s test applied	k-s test applied
	Turbidity	k-s test applied	k-s test applied	k-s test applied
	Fe	k-s test applied	k-s test applied	k-s test applied
	Mn	k-s test applied	k-s test applied	k-s test applied
	TOC	No available TOC data at DW-bottom		
	TP	No available TP data at DW-bottom		
	NH3-N	No available NH3-N data at DW-bottom		
	Chl a	No available Chl a data at DW-bottom		

Table 4 Detailed information for where simple regression analyses were applied

	Detailed study period	Site location	Regression analyses application
Scenario 1	Whole study period	Middle of reservoir	1) Fe vs Temp, DO, DO%, Turb, pH, Chl a, TP, NH ₃ -N, NO ₂ -N, NO ₃ -N, TKN, TON, TN; 2) Mn vs Temp, DO, DO%, Turb, pH, Chl a, TP, NH ₃ -N, NO ₂ -N, NO ₃ -N, TKN, TON, TN; 3) TOC vs Temp, DO, DO%, Turb, Chla, TP, NH ₃ -N, NO ₂ -N, NO ₃ -N, TKN, TON, TN; 4) TOC vs Fe, Mn; Chl a vs TP.
		Near dam wall area	1) Fe vs Temp, DO, DO%, Turb, pH, Chl a; 2) Mn vs Temp, DO, DO%, Turb, pH, Chl a; 3) TOC vs TP, NH ₃ -N, TKN, TON, TN.
Scenario 2	Stratification period	Middle of reservoir	1) Fe vs Temp, DO, DO%, Turb, Chla, TP; 2) Mn vs Temp, DO, DO%, Turb, Chla, TP; 3) TOC vs Temp, DO, DO%, Turb, Chla, TP; 4) TOC vs Fe, Mn; Chla vs TP.
		Near dam wall area	1) Fe vs Temp, DO, DO%, Turb, Chla; 2) TOC vs TP.
	No stratification period	Middle of reservoir	1) Fe vs Temp, DO, DO%, Turb, Chla, TP; 2) Mn vs Temp, DO, DO%, Turb, Chla, TP; 3) TOC vs Temp, DO, DO%, Turb, Chla, TP; 4) TOC vs Fe, Mn; Chla vs TP.
		Near dam wall area	1) Fe vs Temp, DO, DO%, Turb, Chla; 2) TOC vs TP.
Scenario 3	Wet period	Middle of reservoir	1) Fe vs Temp, DO, DO%, Turb, Chla, TP; 2) Mn vs Temp, DO, DO%, Turb, Chla, TP; 3) TOC vs Temp, DO, DO%, Turb, Chla, TP; 4) TOC vs Fe, Mn; Chla vs TP.
		Near dam wall area	1) Fe vs Temp, DO, DO%, Turb, Chla; 2) TOC vs TP.
	Normal and dry period	Middle of reservoir	1) Fe vs Temp, DO, DO%, Turb, Chla, TP; 2) Mn vs Temp, DO, DO%, Turb, Chla, TP; 3) TOC vs Temp, DO, DO%, Turb, Chla, TP; 4) TOC vs Fe, Mn; Chla vs TP.
		Near dam wall area	1) Fe vs Temp, DO, DO%, Turb, Chla; 2) TOC vs TP.
Scenario 4	High inflow period	Middle of reservoir	1) Fe vs Temp, DO, DO%, Turb, Chla, TP; 2) Mn vs Temp, DO, DO%, Turb, Chla, TP; 3) TOC vs Temp, DO, DO%, Turb, Chla, TP; 4) TOC vs Fe, Mn; Chla vs TP.
		Near dam wall area	1) Fe vs Temp, DO, DO%, Turb, Chla; 2) TOC vs TP.
	Normal and low inflow period	Middle of reservoir	1) Fe vs Temp, DO, DO%, Turb, Chla, TP; 2) Mn vs Temp, DO, DO%, Turb, Chla, TP; 3) TOC vs Temp, DO, DO%, Turb, Chla, TP; 4) TOC vs Fe, Mn; Chla vs TP.
		Near dam wall area	1) Fe vs Temp, DO, DO%, Turb, Chla; 2) TOC vs TP.

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Table 1 S-w normality tests results in whole study period

	Temperature	DO	Turbidity	EC	pH	Total Fe	Total Mn	Chl a	TOC	TP	Ammonium
M-2m	0.0003	0.7165	< 0.0001	< 0.0001	0.2897	0.0259	< 0.0001	0.0003	0.0583	< 0.0001	0.0044
M-bottom	0.0004	0.0083	< 0.0001	0.0014	< 0.0001	< 0.0001	< 0.0001	No data	0.0465	< 0.0001	< 0.0001
DW-SVH	0.0023	0.0075	< 0.0001	< 0.0001	0.0179	0.1363	0.0026	< 0.0001	0.1209	< 0.0001	< 0.0001
DW-bottom	0.0016	0.0729	< 0.0001	No data	0.6924	< 0.0001	< 0.0001	No data	No data	No data	No data
M-differential	< 0.0001	0.0031	< 0.0001	-	0.0020	< 0.0001	< 0.0001	-	-	-	-
DW-differential	0.0006	< 0.0001	< 0.0001	-	0.0180	< 0.0001	< 0.0001	-	-	-	-

* Font colour green: The variable from which the sample was extracted follows a Normal distribution ($P > 0.05$);

* Font colour red: The variable from which the sample was extracted does not follow a Normal distribution ($P < 0.05$). Box-Cox transformations were applied subsequently to transform data into normal distributions.

Table 2 T-tests results in whole study period

	Group a	Group b	Temperature	DO	Turbidity	EC	pH	Total Fe	Total Mn	Chl a	TOC	TP	Ammonium
Middle vs Dam Wall	M-2m	DW-SVH	<0.0001	<0.0001	0.6658	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.2700	0.2700	<0.0001
	M-bottom	DW-bottom	<0.0001	<0.0001	0.9900	-	<0.0001	<0.0001	<0.0001	-	-	-	-
	M-differential	DW-differential	<0.0001	<0.0001	0.0055	-	0.0431	<0.0001	<0.0001	-	-	-	-
Surface vs bottom	M-2m	M-bottom	<0.0001	<0.0001	0.4027	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	0.0752	<0.0001
	DW-SVH	DW-bottom	<0.0001	<0.0001	0.7066	-	<0.0001	<0.0001	0.0039	-	-	-	-

* Font colour green: The difference between the means is different from 0 ($P < 0.05$);

* Font colour red: The difference between the means is equal to 0 ($P > 0.05$).

Table 3 K-s tests results in whole study period

	Group a	Group b	Temperature	DO	Turbidity	EC	pH	Total Fe	Total Mn	Chl a	TOC	TP	Ammonium
Middle vs Dam Wall	M-2m	DW-SVH	0.2813	0.6070	0.3779	0.2367	0.4548	0.7577	0.1053	0.0001	0.4227	0.9651	0.5146
	M-bottom	DW-bottom	0.2037	0.0074	0.5551	-	0.1918	0.4831	0.3145	-	-	-	-
	M-differential	DW-differential	< 0.0001	< 0.0001	0.0022	-	0.0251	0.0095	0.0002	-	-	-	-
Surface vs bottom	M-2m	M-bottom	0.1321	0.0086	0.7444	0.9180	0.1321	0.7444	0.0495	-	0.4930	0.8660	0.1975
	DW-SVH	DW-bottom	0.5471	0.0832	0.0638	-	0.3753	0.1447	0.8475	-	-	-	-

* Font colour green: The distributions of the two samples are different ($P < 0.05$);

* Font colour red: The two samples follow the same distribution ($P > 0.05$). Mann-Whitney tests were applied subsequently to identify the differences between medians.

Table 4 M-w tests results in whole study period

	Group a	Group b	Temperature	DO	Turbidity	EC	pH	Total Fe	Total Mn	Chl a	TOC	TP	Ammonium
Middle vs Dam Wall	M-2m	DW-SVH	0.167	0.899	0.675	0.311	0.619	0.955	0.196	-	0.278	0.593	0.293
	M-bottom	DW-bottom	0.224	-	0.347	-	0.143	0.272	1.000	-	-	-	-
	M-differential	DW-differential	-	-	-	-	-	-	-	-	-	-	-
Surface vs bottom	M-2m	M-bottom	0.058	-	0.611	0.454	0.012	0.324	-	-	0.331	0.873	0.065
	DW-SVH	DW-bottom	0.393	0.010	0.053	-	0.184	0.038	0.495	-	-	-	-

* Font colour green: The difference between the medians is different from 0 ($P < 0.05$);

* Font colour red: The difference between the medians is equal to 0 ($P > 0.05$).

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Note that in following tables (Table 5-16), font colour green represents $P < 0.05$, font colour red represents $P > 0.05$.

Table 5 K-s tests at sampling location M-2m, under Scenario 2

Location: Middle, 2m depth	Unit	Scenario 2: Based on thermal stratification condition											
		Group a: Stratification Period					Group b: No Stratification Period					K-S test, P value	Interpreting P value
		Min	Media n	Max	Average	SD	Min	Media n	Max	Average	SD		
Temperatur e	°C	17.2	22.1	25.3	21.7708	2.0367	11.5	14.4	22.7	15.9069	3.9522	< 0.0001	The distributions of the two samples are different.
DO	mg/L	6.44	8.345	9.67	8.2358	0.7744	4.75	9.59	12.88	8.7997	2.5325	0.0022	The distributions of the two samples are different.
Turbidity	NTU	1.3	2.95	26	5.2583	5.4400	1.6	3	6.6	3.3517	1.2377	0.0951	The two samples follow the same distribution.
Fe	ug/L	80	192	448	222.083 3	110.170 2	80	238	467	244.137 9	105.328 3	0.8222	The two samples follow the same distribution.
Mn	ug/L	7.2	11.4	49.9	14.3333	9.1524	3.7	9	57.7	18.5207	17.6667	0.1104	The two samples follow the same distribution.
TOC	mg/L C	2.6	3.3	4.7	3.4417	0.7077	2.6	3.35	4.7	3.4571	0.6699	1.0000	The two samples follow the same distribution.
TP	mg/L	0.006	0.014	0.18	0.0474	0.0627	0.013	0.017	0.026	0.0177	0.0043	0.2119	The two samples follow the same distribution.
Ammonia	mg/L N	0	0.011	0.026	0.0128	0.0087	0.005	0.016	0.061	0.0213	0.0171	0.5176	The two samples follow the same distribution.
Chl a	ug/L	1.634 0	7.9820	21.627 0	9.4658	4.9158	1.457 8	6.7033	27.234 0	8.9619	6.7907	0.2234	The two samples follow the same distribution.

Table 6 K-s tests at sampling location M-2m, under Scenario 3

Location: Middle, 2m depth	Unit	Scenario 3: Based on monthly total rainfall data											
		Group a: Wet Period					Group b: Normal and Dry Period					K-S test, P value	Interpreting P value
		Min	Media n	Max	Average	SD	Min	Media n	Max	Average	SD		
Temperatur e	°C	19.3	22.2	25.3	22.1167	1.5648	11.5	15.3	25.2	16.7343	4.1950	< 0.0001	The distributions of the two samples are different.
DO	mg/L	6.44	8.23	8.94	8.0194	0.6146	4.75	9.33	12.88	8.8143	2.3239	0.0009	The distributions of the two samples are

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													different.
Turbidity	NTU	1.3	3.25	26	6.0167	6.0361	1.3	3	6.6	3.2886	1.3659	0.0183	The distributions of the two samples are different.
Fe	ug/L	105	215.5	400	234.3333	93.4320	80	225	467	234.0571	114.7606	0.7013	The two samples follow the same distribution.
Mn	ug/L	7.6	12.25	27.5	13.3722	5.3299	3.7	9	57.7	18.2971	17.2565	0.0692	The two samples follow the same distribution.
TOC	mg/L C	2.8	3.5	4.4	3.4778	0.5761	2.6	3.3	4.7	3.4353	0.7365	0.9004	The two samples follow the same distribution.
TP	mg/L	0.008	0.015	0.18	0.0586	0.0695	0.006	0.017	0.026	0.0171	0.0051	0.1954	The two samples follow the same distribution.
Ammonia	mg/L N	0	0.008	0.026	0.0110	0.0086	0.005	0.02	0.061	0.0207	0.0155	0.4756	The two samples follow the same distribution.
Chl a	ug/L	4.9662	8.3264	21.6270	10.4459	4.9407	1.4578	7.3425	27.2340	8.5442	6.3993	0.1191	The two samples follow the same distribution.

Table 7 K-s tests at sampling location M-2m, under Scenario 4

Location: Middle, 2m depth	Unit	Scenario 4: Based on monthly total watercourse discharge data from tributaries											
		Group a: High Inflow Period					Group b: Normal and Low Inflow Period					K-S test, P value	Interpreting P value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD		
Temperature	°C	14.8	22.1	23.8	21.4400	2.6336	11.5	18.8	25.3	17.8930	4.4181	0.0519	The two samples follow the same distribution.
DO	mg/L	7.2	7.915	8.62	7.9230	0.4740	4.75	8.9	12.88	8.6888	2.1312	0.0286	The distributions of the two samples are different.
Turbidity	NTU	1.6	7.35	26	9.4000	6.4658	1.3	2.7	6.6	3.0093	1.2313	< 0.0001	The distributions of the two samples are different.
Fe	ug/L	166	324.5	400	308.0000	71.6318	80	187	467	216.9767	107.2140	0.0321	The distributions of the two samples are different.
Mn	ug/L	7.6	12.6	21.7	13.6100	4.6458	3.7	9.1	57.7	17.3256	15.8788	0.1279	The two samples follow the same distribution.
TOC	mg/L C	3.1	3.85	4.4	3.8333	0.4590	3.1	3.85	4.4	3.8333	0.4590	0.1447	The two samples follow the same distribution.
TP	mg/L	0.015	0.061	0.18	0.0852	0.0723	0.006	0.015	0.026	0.0153	0.0052	0.0140	The distributions of the two samples are different.

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Ammonia	mg/L N	0	0.017	0.026	0.0142	0.0103	0.003	0.012	0.061	0.0178	0.0150	0.9947	The two samples follow the same distribution.
Chl a	ug/L	4.9662	10.3649	18.7087	10.6410	4.7525	1.4578	7.7430	27.2340	8.8526	6.2126	0.3735	The two samples follow the same distribution.

Table 8 K-s tests at sampling location M-bottom, under Scenario 2

Location: Middle, 1m from bottom	Unit	Scenario 2: Based on thermal stratification condition											
		Group a: Stratification Period					Group b: No Stratification Period					K-S test, P value	Interpreting P value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD		
Temperature	°C	15.3	19.5	22.4	19.5292	2.0350	11.2	14.1	22.4	15.6069	3.9995	< 0.0001	The distributions of the two samples are different.
DO	mg/L	3.59	6.27	8.66	6.3596	1.3255	3.86	8.9	10.82	7.9459	2.3031	0.0018	The distributions of the two samples are different.
Turbidity	NTU	1.6	2.85	50	8.1083	10.7416	1.6	3.1	7.8	3.5690	1.5400	0.0209	The distributions of the two samples are different.
Fe	ug/L	80	249.5	2130	359.5000	422.1543	86	244	500	254.5517	114.9247	0.7744	The two samples follow the same distribution.
Mn	ug/L	9.6	19.15	202	33.4125	40.5953	4	10.7	61.8	19.4241	18.9523	0.0044	The distributions of the two samples are different.
TOC	mg/L C	2.6	2.95	4.8	3.3333	0.7644	2.4	3.4	4.3	3.2643	0.6368	0.9280	The two samples follow the same distribution.
TP	mg/L	0.006	0.06	0.19	0.0688	0.0688	0.009	0.0165	0.023	0.0159	0.0043	0.0677	The two samples follow the same distribution.
Ammonia	mg/L N	0.006	0.0185	0.23	0.0411	0.0622	0.008	0.016	0.26	0.0434	0.0658	0.7672	The two samples follow the same distribution.
Chl a	ug/L	No data											

Table 9 K-s tests at sampling location M-bottom, under Scenario 3

Location: Middle,	Unit	Scenario 3: Based on monthly total rainfall data			
		Group a: Wet Period		Group b: Normal and Dry Period	
				K-S	Interpreting P value

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1m from bottom		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD	test, P value	
Temperature	°C	16.9	19.75	22.4	19.9444	1.5394	11.2	14.4	22.4	16.0657	3.9335	0.0004	The distributions of the two samples are different.
DO	mg/L	4.94	6.105	7.46	6.2306	0.8047	3.59	8.17	10.82	7.7403	2.3255	0.0002	The distributions of the two samples are different.
Turbidity	NTU	1.6	2.95	25	7.1389	6.5095	1.6	3	50	4.8457	8.0585	0.0565	The two samples follow the same distribution.
Fe	ug/L	103	277	548	286.6111	125.8412	80	237	2130	310.0286	357.1806	0.6460	The two samples follow the same distribution.
Mn	ug/L	11	20.15	68.4	26.2944	16.7068	4	11	202	25.4829	36.6933	0.0073	The distributions of the two samples are different.
TOC	mg/L C	2.7	3.1	4.5	3.3222	0.6457	2.4	3.3	4.8	3.2824	0.7239	0.8815	The two samples follow the same distribution.
TP	mg/L	0.006	0.06	0.19	0.0696	0.0720	0.009	0.0165	0.12	0.0221	0.0264	0.1215	The two samples follow the same distribution.
Ammonia	mg/L N	0.006	0.018	0.068	0.0254	0.0208	0.008	0.019	0.26	0.0512	0.0756	0.9841	The two samples follow the same distribution.
Chl a	ug/L	No data											

Table 10 K-s tests at sampling location M-bottom, under Scenario 4

Location: Middle, 1m from bottom	Unit	Scenario 4: Based on monthly total watercourse discharge data from tributaries											
		Group a: High Inflow Period					Group b: Normal and Low Inflow Period					K-S test, P value	Interpreting P value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD		
Temperature	°C	14.1	19.4	22.2	19.0100	2.2947	11.2	17.9	22.4	17.0047	3.9796	0.2296	The two samples follow the same distribution.
DO	mg/L	4.94	5.92	7.54	6.0980	0.9154	3.59	7.46	10.82	7.4902	2.1751	0.0417	The distributions of the two samples are different.
Turbidity	NTU	1.7	11	25	11.5000	5.9956	1.6	2.9	50	4.2581	7.3058	< 0.0001	The distributions of the two samples are different.
Fe	ug/L	241	394.5	548	391.3000	99.4921	80	201	2130	281.3256	324.6305	0.0015	The distributions of the two samples are different.
Mn	ug/L	11	20.7	59.9	26.4800	16.0853	4	13.5	202	25.5907	33.8749	0.1583	The two samples follow the same distribution.

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TOC	mg/L C	3.1	3.8	4.5	3.7667	0.4844	2.4	2.8	4.8	3.1550	0.6817	0.0721	The two samples follow the same distribution.
TP	mg/L	0.021	0.0865	0.19	0.1023	0.0667	0.006	0.013	0.12	0.0193	0.0248	0.0013	The distributions of the two samples are different.
Ammonia	mg/L N	0.018	0.023	0.068	0.0362	0.0229	0.006	0.015	0.26	0.0438	0.0695	0.2178	The two samples follow the same distribution.
Chl a	ug/L	No data											

Table 11 K-s tests at sampling location DW-SVH, under Scenario 2

Location: Dam Wall, SVH	Unit	Scenario 2: Based on thermal stratification condition											
		Group a: Stratification Period					Group b: No Stratification Period					K-S test, P value	Interpreting P value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD		
Temperature	°C	17.6	20	24.9	20.4952	1.9656	11.7	13.9	22.5	15.4379	3.6253	< 0.0001	The distributions of the two samples are different.
DO	mg/L	5.9	7.6	8.93	7.5023	0.7424	6.9	10.1	11.2	9.5338	1.1707	< 0.0001	The distributions of the two samples are different.
Turbidity	NTU	1.3	3.5	13.5	5.2013	3.8782	1.4	2.7	9.4	3.2138	1.6866	0.0272	The distributions of the two samples are different.
Fe	ug/L	20	250	2130	330.9524	426.3555	10	235	540	228.0769	133.3872	0.5457	The two samples follow the same distribution.
Mn	ug/L	1	29	67	26.1818	16.6609	1	11	48	14.7308	12.6351	0.0157	The distributions of the two samples are different.
TOC	mg/L C	1.8	3.7	4.5	3.4273	0.8945	2.4	2.9	4.1	3.0643	0.6488	0.5089	The two samples follow the same distribution.
TP	mg/L	0.009	0.015	0.16	0.0482	0.0547	0.008	0.0165	0.042	0.0165	0.0083	0.4310	The two samples follow the same distribution.
Ammonia	mg/L N	0.008	0.016	0.044	0.0218	0.0131	0.006	0.011	0.017	0.0104	0.0040	0.6254	The two samples follow the same distribution.
Chl a	ug/L	1.3	2.7	6.1	3.0412	1.3734	0.5	4.8	19.7	6.1821	5.0063	0.0326	The distributions of the two samples are different.

Table 12 K-s tests at sampling location DW-SVH, under Scenario 3

Location: Dam Wall, SVH	Unit	Scenario 3: Based on monthly total rainfall data											
		Group a: Wet Period					Group b: Normal and Dry Period					K-S test, P value	Interpreting P value
		Min	Media n	Max	Average	SD	Min	Media n	Max	Average	SD		
Temperatur e	°C	17.6	20.05	24.9	20.6000	1.8454	11.7	14.55	23.2	16.1324	3.8476	0.0001	The distributions of the two samples are different.
DO	mg/L	6.6	7.6	8.4	7.5541	0.5165	5.9	9.8	11.2	9.2091	1.4171	< 0.0001	The distributions of the two samples are different.
Turbidity	NTU	1.3	4.7	13.5	5.6794	4.1401	1.4	2.695	9.4	3.2529	1.7453	0.0370	The distributions of the two samples are different.
Fe	ug/L	20	250	310	232.0000	77.1085	10	230	540	234.5161	141.4882	0.2435	The two samples follow the same distribution.
Mn	ug/L	1	28	39	23.0588	13.7544	1	14	67	18.2903	16.4382	0.1118	The two samples follow the same distribution.
TOC	mg/L C	1.8	3.7	4.5	3.4556	0.9342	2.4	2.9	4.1	3.0938	0.6608	0.5441	The two samples follow the same distribution.
TP	mg/L	0.009	0.015	0.16	0.0564	0.0602	0.008	0.0165	0.042	0.0169	0.0080	0.3328	The two samples follow the same distribution.
Ammonia	mg/L N	0.008	0.016	0.044	0.0198	0.0125	0.0025	0.009	0.017	0.0094	0.0043	0.8928	The two samples follow the same distribution.
Chl a	ug/L	1.3	2.6	6.1	2.9385	1.4086	0.5	4.2	19.7	5.8313	4.7860	0.1091	The two samples follow the same distribution.

Table 13 K-s tests at sampling location DW-SVH, under Scenario 4

Location: Dam Wall, SVH	Unit	Scenario 4: Based on monthly total watercourse discharge data from tributaries											
		Group a: High Inflow Period					Group b: Normal and Low Inflow Period					K-S test, P value	Interpreting P value
		Min	Media n	Max	Average	SD	Min	Media n	Max	Average	SD		
Temperatur e	°C	14.8	19.6	23.1	19.7000	2.5169	11.7	18	24.9	17.0927	4.0495	0.1163	The two samples follow the same distribution.
DO	mg/L	6.6	7.6	8.5	7.5300	0.6667	5.9	9.05	11.2	8.9324	1.4297	0.0195	The distributions of the two samples are different.

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Turbidity	NTU	1.8	9.4	13.5	8.8530	3.3448	1.3	2.3	6.2	2.8780	1.3091	< 0.0001	The distributions of the two samples are different.
Fe	ug/L	200	275	540	298.7500	103.5702	10	235	540	220.0000	123.8788	0.1919	The two samples follow the same distribution.
Mn	ug/L	1	28	39	22.5556	13.8844	1	14	67	19.3846	16.0322	0.7600	The two samples follow the same distribution.
TOC	mg/L C	1.8	4.15	4.5	3.6500	1.2503	2.3	3.1	4.2	3.1429	0.6607	0.2435	The two samples follow the same distribution.
TP	mg/L	0.092	0.097	0.16	0.1163	0.0379	0.008	0.015	0.042	0.0158	0.0075	0.0108	The distributions of the two samples are different.
Ammonia	mg/L N	0.008	0.019	0.044	0.0225	0.0154	0.0025	0.011	0.027	0.0112	0.0066	0.9251	The two samples follow the same distribution.
Chl a	ug/L	1.5	2.25	3.9	2.4750	1.0532	0.5	3.6	19.7	5.2415	4.4159	0.3511	The two samples follow the same distribution.

Table 14 K-s tests at sampling location DW-bottom, under Scenario 2

Location: Dam Wall, 1m from bottom	Unit	Scenario 2: Based on thermal stratification condition											
		Group a: Stratification Period					Group b: No Stratification Period					K-S test, P value	Interpreting P value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD		
Temperature	°C	17.9	22	25.8	21.7182	2.1615	11.2	14.7	22.3	15.75483871	3.8613	< 0.0001	The distributions of the two samples are different.
DO	mg/L	5.02	7	8.08	6.7313	0.9656	6.51	9.3	11.3	8.9	1.3571	< 0.0001	The distributions of the two samples are different.
Turbidity	NTU	1.9	6.9	14.2	6.5261	4.1709	1.9	3.2	17.6	3.815483871	2.9054	0.0080	The distributions of the two samples are different.
Fe	ug/L	10	270	2440	393.3333	489.4827	10	290	910	311.8518519	211.2060	0.7261	The two samples follow the same distribution.
Mn	ug/L	4	30	193	36.1905	39.7047	1	11	170	23.03703704	34.7081	0.0358	The distributions of the two samples are different.
TOC	mg/L C	No Data											
TP	mg/L	No Data											
Ammonia	mg/L N	No Data											

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Chl a	ug/L	No Data
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Table 15 K-s tests at sampling location DW-bottom, under Scenario 3

Location: Dam Wall, 1m from bottom	Unit	Scenario 3: Based on monthly total rainfall data											
		Group a: Wet Period					Group b: Normal and Dry Period					K-S test, P value	Interpreting P value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD		
Temperature	°C	17.9	22	25.8	21.9941	2.0681	11.2	15.3	23.6	16.4528	4.0708	0.0002	The distributions of the two samples are different.
DO	mg/L	5.02	7	8.08	6.6956	0.9386	5.6	8.85	11.3	8.6167	1.4986	0.0001	The distributions of the two samples are different.
Turbidity	NTU	1.9	5.55	14.2	6.5722	4.3608	1.9	3.35	17.6	4.1689	3.1186	0.0531	The two samples follow the same distribution.
Fe	ug/L	10	275	710	305.5556	141.9703	10	285	2440	372.6667	440.8763	0.5121	The two samples follow the same distribution.
Mn	ug/L	4	31.5	78	28.7778	18.1774	1	11.5	193	28.8000	45.2109	0.1641	The two samples follow the same distribution.
TOC	mg/L C	No Data											
TP	mg/L	No Data											
Ammonia	mg/L N	No Data											
Chl a	ug/L	No Data											

Table 16 K-s tests at sampling location DW-bottom, under Scenario 4

Location: Dam Wall, 1m from bottom	Unit	Scenario 4: Based on monthly total watercourse discharge data from tributaries											
		Group a: High Inflow Period					Group b: Normal and Low Inflow Period					K-S test, P value	Interpreting P value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD		
Temperature	°C	14.7	21	24.3	20.7900	3.0362	11.2	18.5	25.8	17.6349	4.4702	0.2296	The two samples follow the same distribution.
DO	mg/L	5.2	6.7	8.31	6.7430	1.0458	5.02	7.82	11.3	8.2566	1.5947	0.0455	The distributions of the two samples are different.
Turbidity	NTU	1.9	10.8	17.6	10.6600	4.2133	1.9	3.06	12.1	3.6768	2.0224	< 0.0001	The distributions of the two samples are different.

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Fe	ug/L	190	275	710	354.0000	166.5466	10	285	2440	345.7895	395.2395	0.6433	The two samples follow the same distribution.
Mn	ug/L	4	16.5	40	20.2000	13.5794	1	18.5	193	31.0526	41.0346	0.7662	The two samples follow the same distribution.
TOC	mg/L C	No Data											
TP	mg/L	No Data											
Ammonia	mg/L N	No Data											
Chl a	ug/L	No Data											

Note that: 1) In following tables (Table 17-23), 'N' represents 'Negative correlation', while 'P' represents 'Positive correlation';2) In following tables (Table 17-30), 'x' represents 'predictor variable', 'y' represents 'criterion variable'.

Table 17 Simple regression analyses results (R^2) in whole study period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	0.1455, P	0.2945, N	0.4956, P	0.1375, N	0.4675, P	-	-
	Total Mn	0.4311, P	0.6904, N	0.0473, P	0.1653, N	0.0675, P	-	-
	TOC	0.2682, P	0.3812, N	0.3672, P	0.0122, P	0.3458, P	0.6839, P	0.5983, P
M-bottom	Total Fe	0.2644, P	0.4828, N	0.7492, P	No data	0.5006, P	-	-
	Total Mn	0.7953, P	0.8503, N	0.4792, P		0.3180, P	-	-
	TOC	0.2985, P	0.5224, N	0.5507, P		0.4153, P	0.6565, P	0.5435, P
DW-SVH	Total Fe	0.0951, P	0.1524, N	0.1969, P	0.2896, N	0.1334, P	-	-
	Total Mn	0.3986, P	0.4190, N	0.0026, P	0.0656, N	0.0096, P	-	-
	TOC	0.3982, P	0.3033, N	0.2185, P	0.1551, N	0.2374, P	0.1602, P	0.0324, P
DW-bottom	Total Fe	0.0040, P	0.0408, N	0.1239, P	No data		-	-
	Total Mn	0.3342, P	0.2002, N	0.0008, P			-	-
	TOC	No data						

Table 18 Simple regression analyses results (R^2) in stratification period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	0.3454, P	0.4751, N	0.6315, P	0.0164, N	0.7588, P	-	-
	Total Mn	0.2788, P	0.2023, N	0.0437, P	0.2373, N	0.3438, P	-	-
	TOC	0.2748, P	0.3084, N	0.4504, P	0.1531, P	0.6317, P	0.7934, P	0.5134, P
M-bottom	Total Fe	0.3259, P	0.7532, N	0.7722, P	No data	0.5302, P	-	-
	Total Mn	0.5951, P	0.8462, N	0.5534, P		0.3826, P	-	-
	TOC	0.1375, P	0.5309, N	0.8450, P		0.7476, P	0.8665, P	0.5499, P
DW-SVH	Total Fe	0.1715, P	0.4851, N	0.1337, P	0.3982, N	0.0818, P	-	-
	Total Mn	0.3297, P	0.5253, N	0.0458, N	0.0832, N	0.0074, N	-	-
	TOC	0.0459, P	0.0056, N	0.1342, P	0.4304, N	0.3968, P	0.0798, P	0.0434, N
DW-bottom	Total Fe	0.0327, N	0.0241, N	0.1461, P	No data		-	-
	Total Mn	0.1718, P	0.1179, N	0.1379, N			-	-
	TOC	No data						

Table 19 Simple regression analyses results (R^2) in no stratification period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	0.5475, P	0.3858, N	0.5871, P	0.3785, N	0.4274, P	-	-
	Total Mn	0.9474, P	0.7571, N	0.181, P	0.1921, N	0.1182, P	-	-
	TOC	0.8345, P	0.5921, N	0.3571, P	0.0169, N	0.1825, P	0.6337, P	0.7949, P
M-bottom	Total Fe	0.4867, P	0.4773, N	0.6447, P	No data	0.6658, P	-	-
	Total Mn	0.9516, P	0.8423, N	0.2002, P		0.1904, P	-	-
	TOC	0.7079, P	0.6790, N	0.2034, P		0.2137, P	0.453, P	0.7109, P
DW-SVH	Total Fe	0.1278, P	0.1705, N	0.3577, P	0.3161, N	0.4382, P	-	-

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	Total Mn	0.4408, P	0.2934, N	0.0041, P	0.0164, N	0.1588, P	-	-
	TOC	0.8479, P	0.7752, N	0.3289, P	0.1255, N	0.0086, N	0.2834, P	0.2719, P
DW-bottom	Total Fe	0.0242, P	0.0747, N	0.1749, P	No data		-	-
	Total Mn	0.2457, P	0.0742, N	0.0149, N			-	-
	TOC	No data						

Table 20 Simple regression analyses results (R^2) in wet period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	0.0274, P	0.2578, N	0.6473, P	0.0099, N	0.8207, P	-	-
	Total Mn	0.0994, P	0.6565, N	0.0127, N	0.0647, N	0.381, P	-	-
	TOC	0.0007, P	0.4424, N	0.5104, P	0.0305, P	0.9067, P	0.7813, P	0.3411, P
M-bottom	Total Fe	0.0026, P	0.3015, N	0.5656, P	No data	0.7274, P	-	-
	Total Mn	0.5865, P	0.7553, N	0.033, N		0.5153, P	-	-
	TOC	0.0253, N	0.1389, N	0.7292, P		0.7664, P	0.9383, P	0.3051, P
DW-SVH	Total Fe	0.0009, P	0.0948, N	0.0660, P	0.3673, N	0.1387, P	-	-
	Total Mn	0.2664, P	0.2269, N	0.1064, N	0.1046, N	0.0187, P	-	-
	TOC	0.0043, N	0.0727, P	0.0772, P	0.1108, N	0.4218, P	0.0706, N	0.1212, N
DW-bottom	Total Fe	0.0529, P	0.0884, N	0.1052, P	No data		-	-
	Total Mn	0.6277, P	0.4020, N	0.4502, N			-	-
		TOC	No data					

Table 21 Simple regression analyses results (R^2) in normal and dry period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn

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M-2m	Total Fe	0.3123, P	0.3487, N	0.7001, P	0.2081, N	0.5261, P	-	-
	Total Mn	0.7383, P	0.7226, N	0.2091, P	0.1976, N	0.1162, P	-	-
	TOC	0.5419, P	0.4300, N	0.4683, P	0.0123, P	0.3562, P	0.674, P	0.6834, P
M-bottom	Total Fe	0.3812, P	0.5402, N	0.9061, P	No data	0.9788, P	-	-
	Total Mn	0.8913, P	0.8697, N	0.7645, P		0.8989, P	-	-
	TOC	0.6088, P	0.6864, N	0.4885, P		0.4518, P	0.6179, P	0.7265, P
DW-SVH	Total Fe	0.1774, P	0.2311, N	0.4600, P	0.3028, N	0.4822, P	-	-
	Total Mn	0.5504, P	0.5734, N	0.0809, P	0.0461, N	0.3288, P	-	-
	TOC	0.7967, P	0.6705, N	0.4323, P	0.1082, N	0.0199, P	0.3708, P	0.353, P
DW-bottom	Total Fe	0.0266, P	0.0703, N	0.2685, P	No data		-	-
	Total Mn	0.2808, P	0.1127, N	0.0575, P			-	-
		TOC	No data					

Table 22 Simple regression analyses results (R^2) in high inflow period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	0.3141, N	0.2669, N	0.4896, P	0.2784, N	0.7207, P	-	-
	Total Mn	0.0237, P	0.3046, N	0.1526, N	0.2379, N	0.1447, P	-	-
	TOC	0.0205, N	0.2258, N	0.4549, P	0.0798, N	0.9852, P	0.6928, P	0.0699, P
M-bottom	Total Fe	0.0286, N	0.0156, P	0.2719, P	No data	0.2861, P	-	-
	Total Mn	0.8185, P	0.7991, N	0.4611, N		0.6798, P	-	-
	TOC	0.0583, N	0.0382, P	0.5011, P		0.3782, P	0.9707, P	0.1667, P
DW-SVH	Total Fe	0.5998, N	0.1477, N	0.0005, N	0.7467, N	n=2	-	-
	Total Mn	0.5388, P	0.7303, N	0.4512, N	0.0126, N	0.9759, P	-	-
	TOC	0.1261, N	0.0993, P	0.2239, P	n=2	0.0466, P	0.8, N	0.1145, N
DW-bottom	Total Fe	0.0953, P	0.0442, N	0.1159, P	No data		-	-

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	Total Mn	0.6261, P	0.7498, N	0.3595, N		-	-
	TOC	No data					

Table 23 Simple regression analyses results (R^2) in normal and low inflow period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	0.1341, P	0.3080, N	0.6035, P	0.2122, N	0.4872, P	-	-
	Total Mn	0.5040, P	0.7168, N	0.1782, P	0.1800, N	0.1755, P	-	-
	TOC	0.2922, P	0.3911, N	0.3634, P	0.0131, P	0.3495, P	0.6728, P	0.7110, P
M-bottom	Total Fe	0.2774, P	0.5124, N	0.8999, P	No data	0.9797, P	-	-
	Total Mn	0.7953, P	0.8552, N	0.7275, P		0.8869, P	-	-
	TOC	0.3465, P	0.6123, N	0.4922, P		0.4814, P	0.4568, P	0.6505, P
DW-SVH	Total Fe	0.1364, P	0.1574, N	0.2349, P	0.2760, N	0.3065, P	-	-
	Total Mn	0.3967, P	0.4253, N	0.0257, P	0.0712, N	0.2511, P	-	-
	TOC	0.6077, P	0.4832, N	0.2972, P	0.1178, N	0.0035, N	0.2726, P	0.1320, P
DW-bottom	Total Fe	0.0052, P	0.0296, N	0.4508, P	No data		-	-
	Total Mn	0.3458, P	0.2035, N	0.1332, P			-	-
		TOC	No data					

Note that in following tables (Table 24-30), font colour red represents $n \leq 5$.

Table 24 Sample sizes (n) for single regression analyses in whole study period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	53	53	53	53	26	-	-
	Total Mn	53	53	53	53	26	-	-
	TOC	26	26	26	26	26	26	26
M-bottom	Total Fe	53	53	53	No data	25	-	-
	Total Mn	53	53	53		25	-	-
	TOC	26	26	26		25	26	26
DW-SVH	Total Fe	46	46	46	40	19	-	-
	Total Mn	46	47	48	41	21	-	-
	TOC	23	24	25	22	24	21	23
DW-bottom	Total Fe	47	48	48	No data	-	-	
	Total Mn	47	48	48		-	-	
		TOC	No data					

Table 25 Sample sizes (n) for single regression analyses in stratification period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	24	24	24	24	12	-	-
	Total Mn	24	24	24	24	12	-	-
	TOC	12	12	12	12	12	12	12
M-bottom	Total Fe	24	24	24	No data	11	-	-
	Total Mn	24	24	24		11	-	-
	TOC	12	12	12		11	12	12
DW-SVH	Total Fe	20	20	20	16	7	-	-
	Total Mn	20	21	22	17	9	-	-
	TOC	9	10	11	8	10	9	11
DW-bottom	Total Fe	20	21	21	No data		-	-
	Total Mn	20	21	21			-	-
		TOC	No data					

Table 26 Sample sizes (n) for single regression analyses in no stratification period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	29	29	29	29	14	-	-
	Total Mn	29	29	29	29	14	-	-
	TOC	14	14	14	14	14	14	14
M-bottom	Total Fe	29	29	29	No	14	-	-

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	Total Mn	29	29	29	data	14	-	-
	TOC	14	14	14		14	14	14
DW-SVH	Total Fe	26	26	26	24	12	-	-
	Total Mn	26	26	26	24	12	-	-
	TOC	14	14	14	14	14	12	12
DW-bottom	Total Fe	27	27	27	No data	-	-	
	Total Mn	27	27	27		-	-	
		TOC	No data					

Table 27 Sample sizes (n) for single regression analyses in wet period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	18	18	18	18	9	-	-
	Total Mn	18	18	18	18	9	-	-
	TOC	9	9	9	9	9	9	9
M-bottom	Total Fe	18	18	18	No data	9	-	-
	Total Mn	18	18	18		9	-	-
	TOC	9	9	9		9	9	9
DW-SVH	Total Fe	15	15	15	12	5	-	-
	Total Mn	15	16	17	13	7	-	-
	TOC	7	8	9	7	8	7	9
DW-bottom	Total Fe	17	18	18	No data	-	-	
	Total Mn	17	18	18		-	-	
		TOC	No data					

Table 28 Sample sizes (n) for single regression analyses in normal and dry period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	35	35	35	35	17	-	-
	Total Mn	35	35	35	35	17	-	-
	TOC	17	17	17	17	17	17	17
M-bottom	Total Fe	35	35	35	No data	16	-	-
	Total Mn	35	35	35		16	-	-
	TOC	17	17	17		16	17	17
DW-SVH	Total Fe	31	31	31	28	14	-	-
	Total Mn	31	31	31	28	14	-	-
	TOC	16	16	16	15	16	14	14
DW-bottom	Total Fe	30	30	30	No data	-		-
	Total Mn	30	30	30		-		-
	TOC	No data						

Table 29 Sample sizes (n) for single regression analyses in high inflow period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	10	10	10	10	6	-	-
	Total Mn	10	10	10	10	6	-	-
	TOC	6	6	6	6	6	6	6
M-bottom	Total Fe	10	10	10	No data	6	-	-
	Total Mn	10	10	10		6	-	-
	TOC	6	6	6		6	6	6
DW-SVH	Total Fe	8	8	8	4	2	-	-
	Total Mn	8	9	9	4	3	-	-
	TOC	3	4	4	2	3	3	4
DW-bottom	Total Fe	10	10	10	No data		-	-
	Total Mn	10	10	10			-	-
		TOC	No data					

Table 30 Sample sizes (n) for single regression analyses in normal and low inflow period

Site location	x	y						
		Temperature	DO	Turbidity	Chl a	TP	Total Fe	Total Mn
M-2m	Total Fe	43	43	43	43	20	-	-
	Total Mn	43	43	43	43	20	-	-
	TOC	20	20	20	20	20	20	20
M-bottom	Total Fe	43	43	43	No data	19	-	-
	Total Mn	43	43	43		19	-	-
	TOC	20	20	20		19	20	20
DW-SVH	Total Fe	38	38	38	36	17	-	-
	Total Mn	38	38	39	37	18	-	-
	TOC	20	20	21	20	20	18	19
DW-bottom	Total Fe	37	38	38	No data		-	-
	Total Mn	37	38	38			-	-
		TOC	No data					

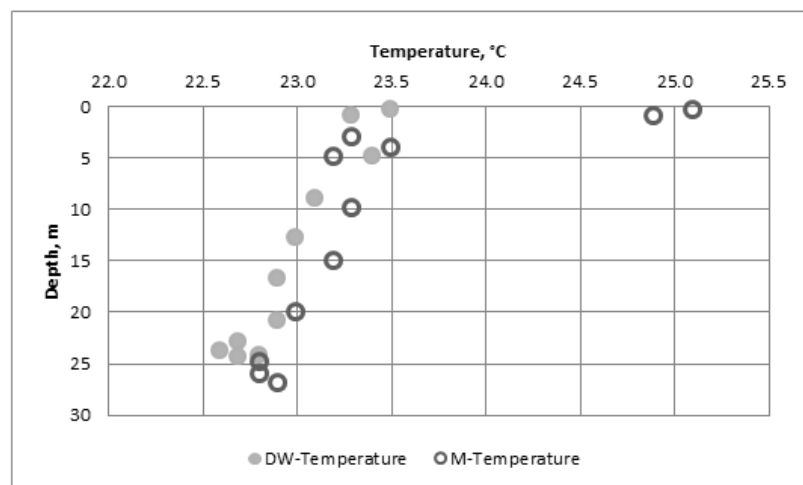


Figure 1 Temperature profiles in the middle of Chichester reservoir and near the dam wall area

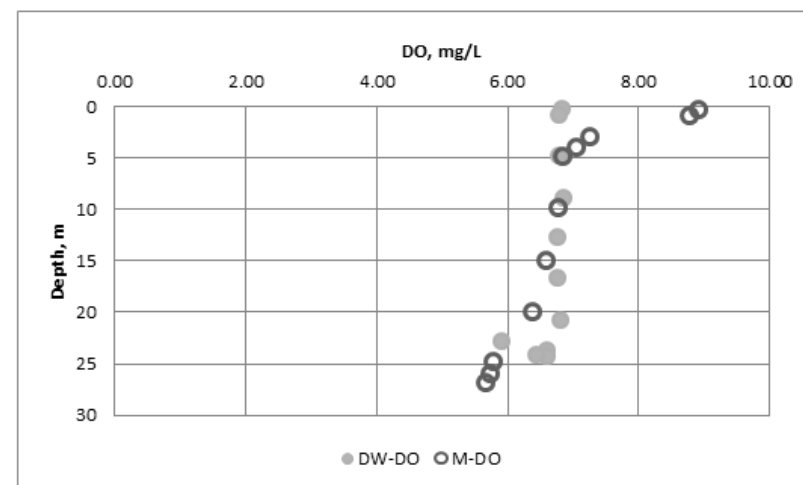


Figure 2 DO profiles in the middle of Chichester reservoir and near the dam wall area

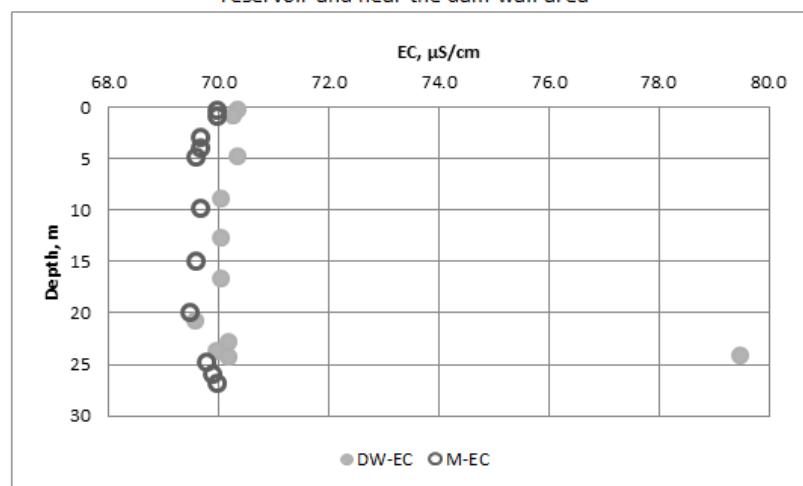


Figure 3 EC profiles in the middle of Chichester reservoir and near the dam wall area

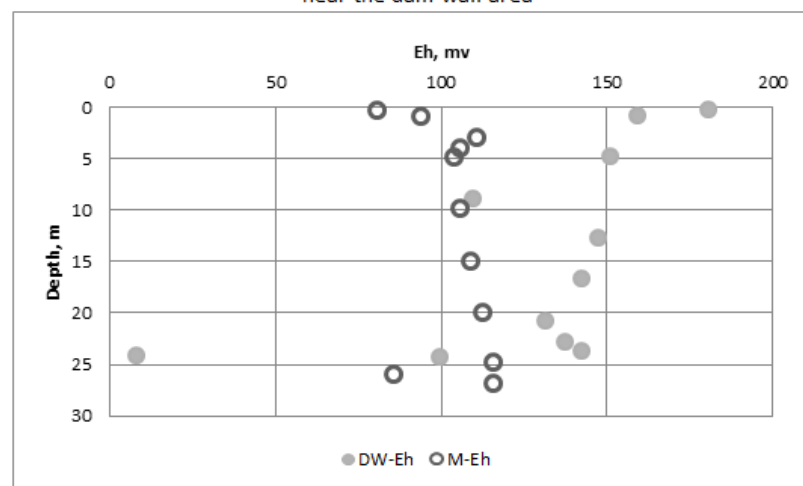


Figure 4 Eh profiles in the middle of Chichester reservoir and near the dam wall area

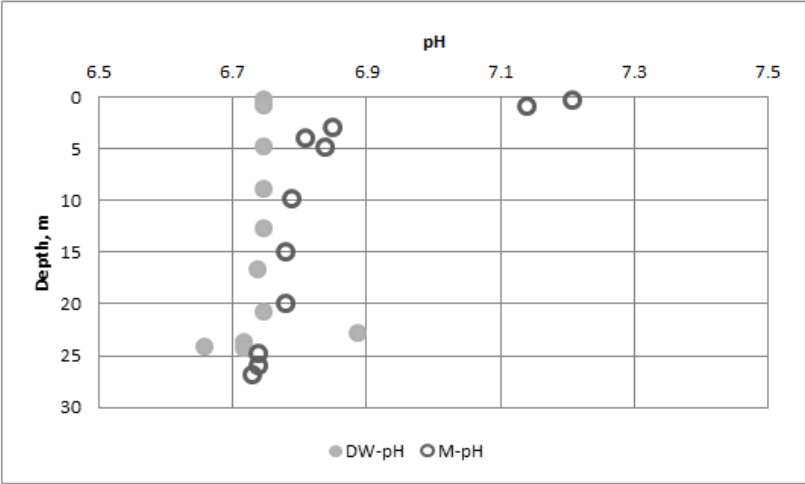


Figure 5 pH profiles in the middle of Chichester reservoir and near the dam wall area

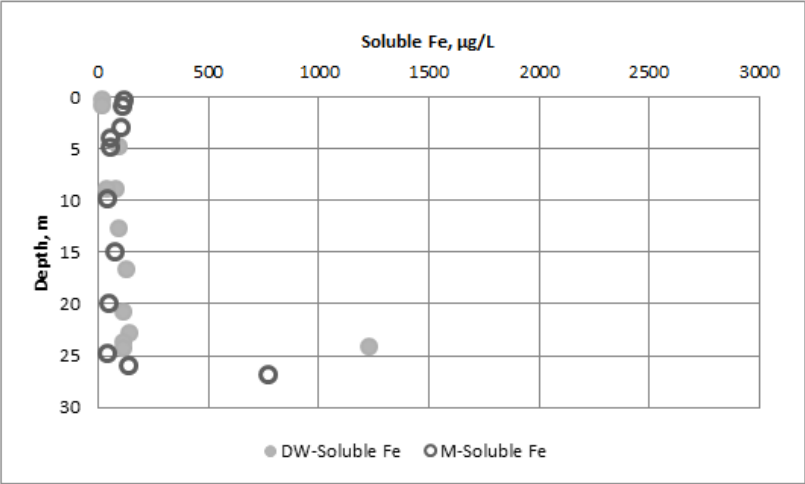


Figure 6 Soluble Fe profiles in the middle of Chichester reservoir and near the dam wall area

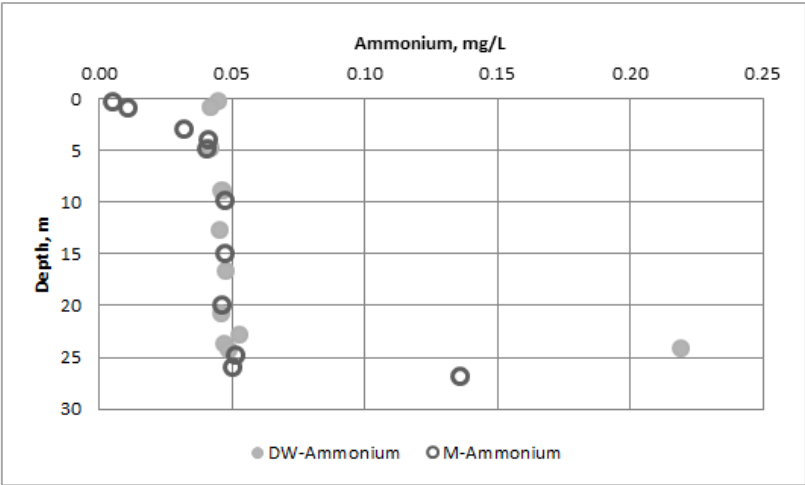


Figure 7 Ammonium profiles in the middle of Chichester reservoir and near the dam wall area

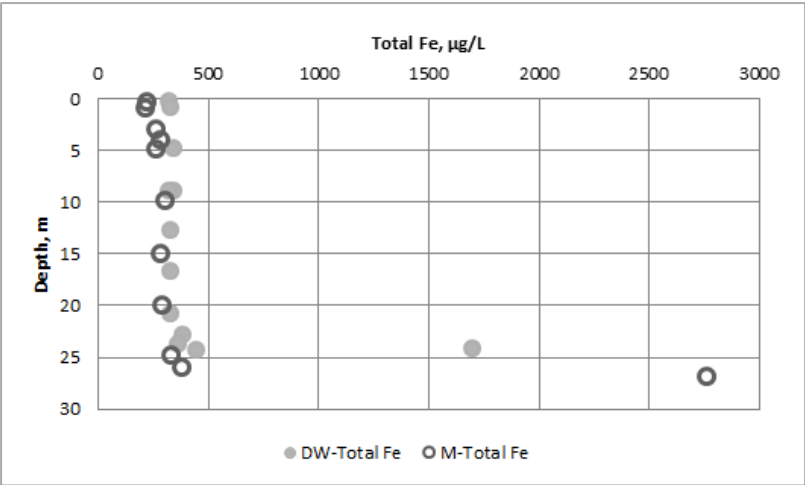


Figure 8 Total Fe profiles in the middle of Chichester reservoir and near the dam wall area

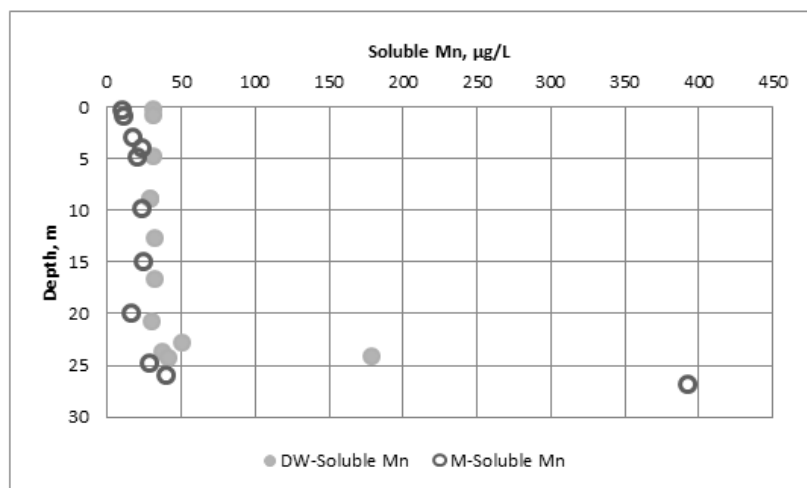


Figure 9 Soluble Mn profiles in the middle of Chichester reservoir and near the dam wall area

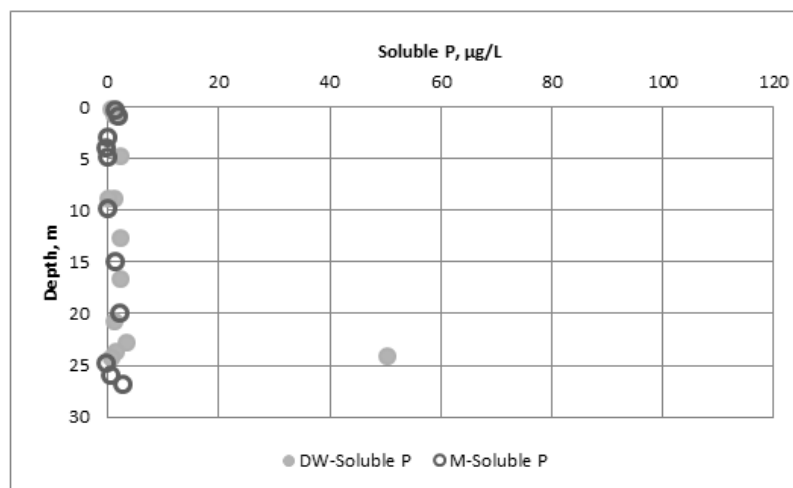


Figure 10 Soluble P profiles in the middle of Chichester reservoir and near the dam wall area

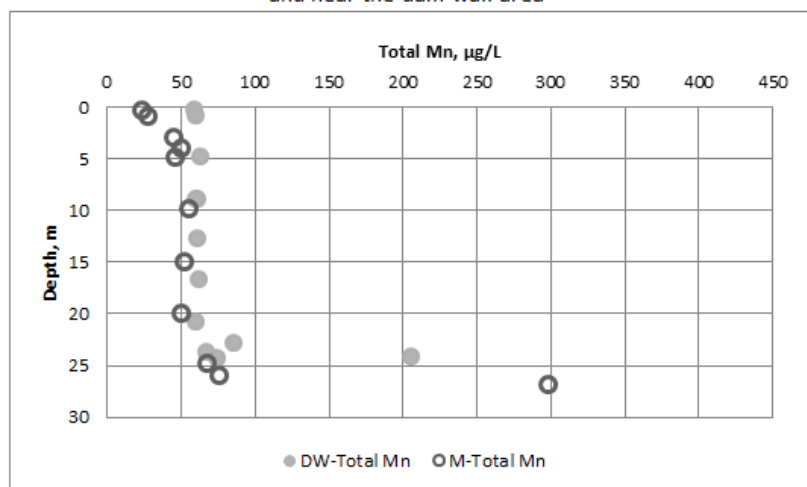


Figure 11 Total Mn profiles in the middle of Chichester reservoir and near the dam wall area

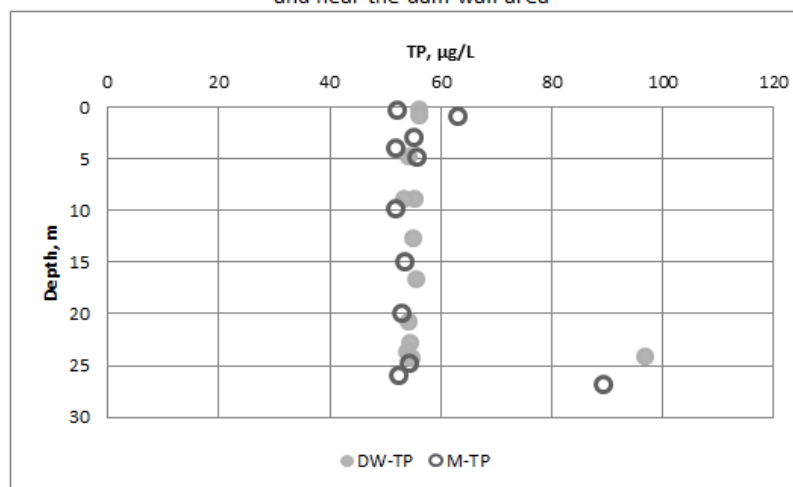


Figure 12 TP profiles in the middle of Chichester reservoir and near the dam wall area

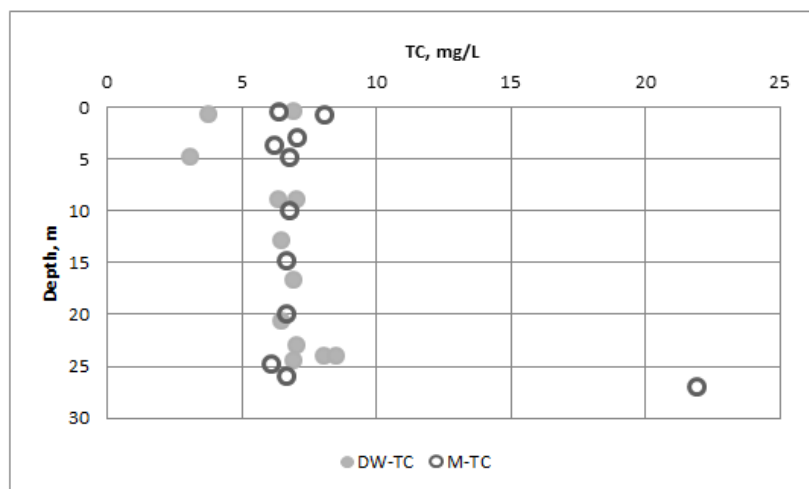


Figure 13 TC profiles in the middle of Chichester reservoir and near the dam wall area

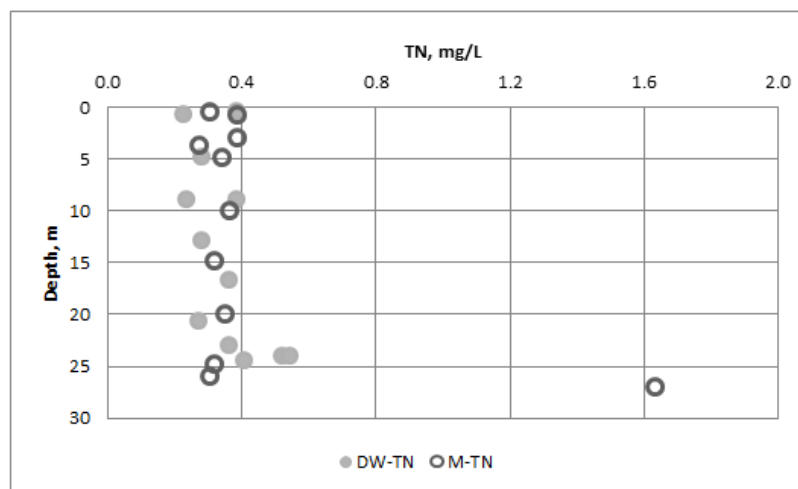


Figure 14 TN profiles in the middle of Chichester reservoir and near the dam wall area

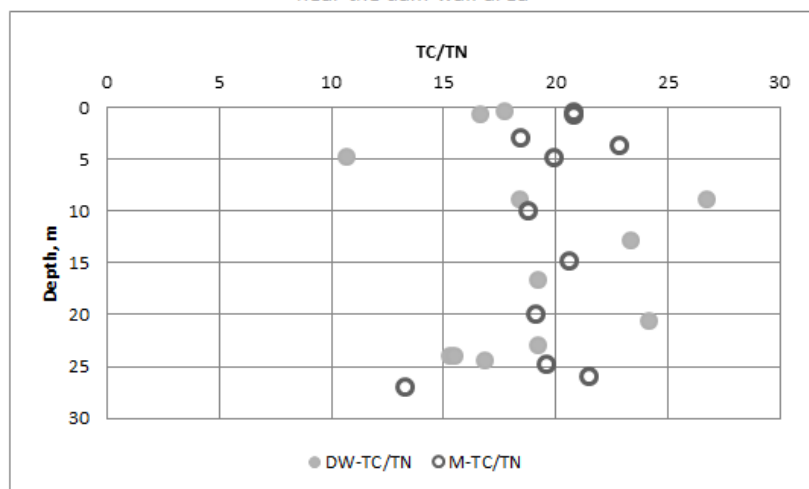


Figure 15 TC/TN profiles in the middle of Chichester reservoir and near the dam wall area

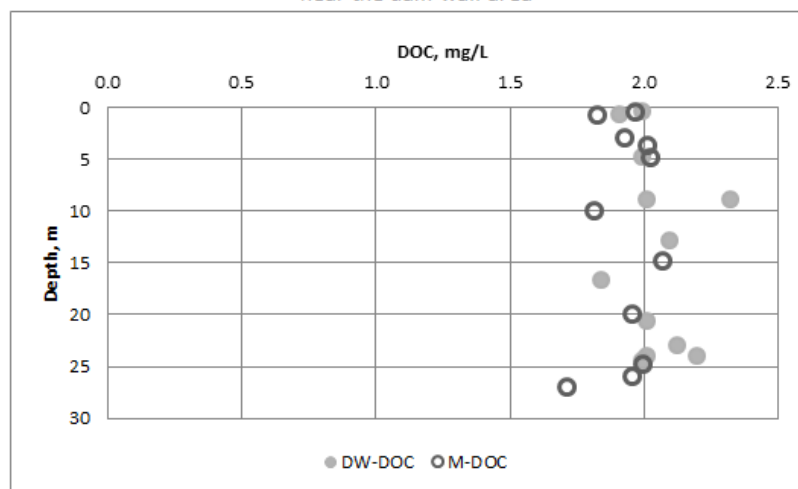


Figure 16 DOC profiles in the middle of Chichester reservoir and near the dam wall area

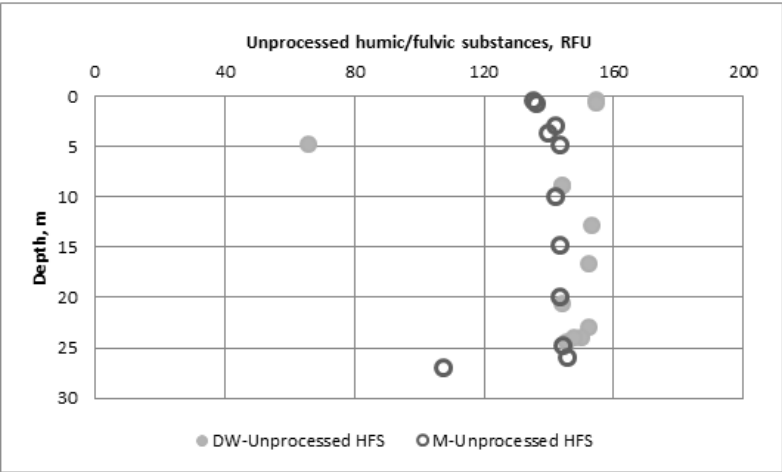


Figure 17 Unprocessed humic/fulvic substances profiles in the middle of Chichester reservoir and near the dam wall area

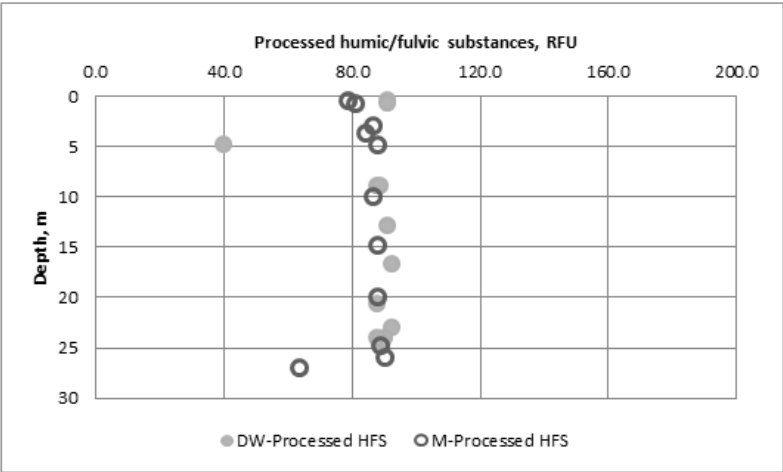


Figure 18 Processed humic/fulvic substances profiles in the middle of Chichester reservoir and near the dam wall area

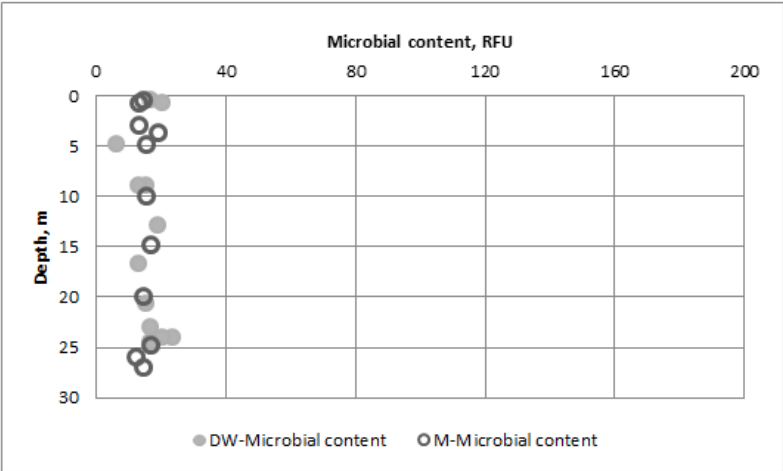


Figure 19 Microbial content substances profiles in the middle of Chichester reservoir and near the dam wall area

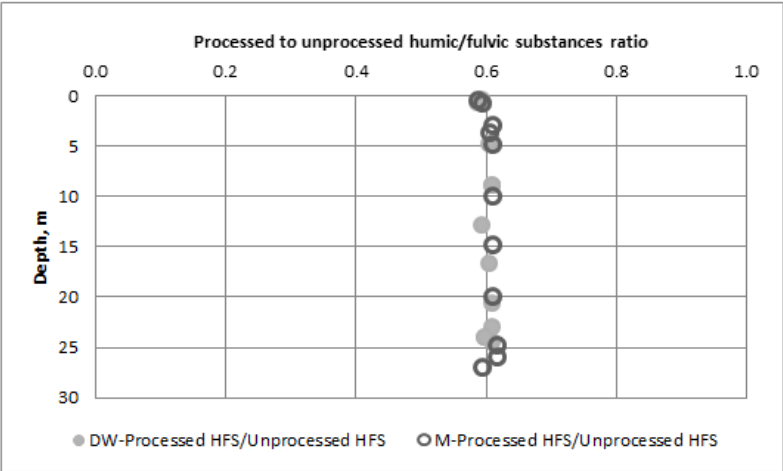


Figure 20 Processed to unprocessed humic/fulvic substances ratio profiles in the middle of Chichester reservoir and near the dam wall area

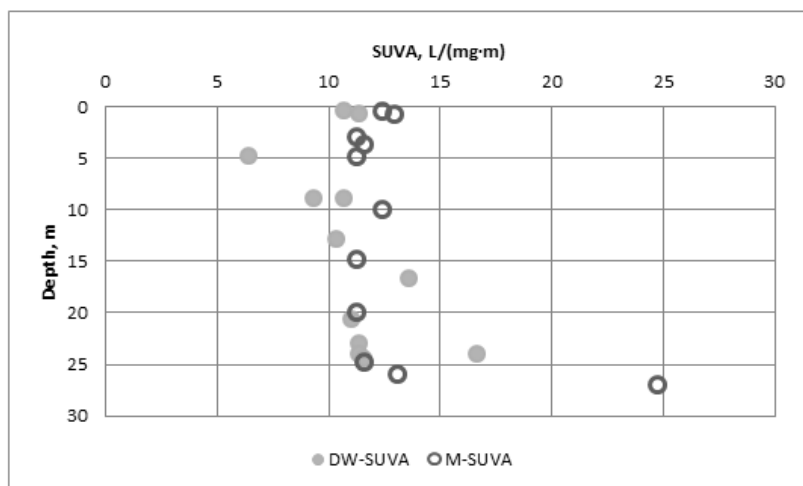


Figure 21 SUVA profiles in the middle of Chichester reservoir and near the dam wall area

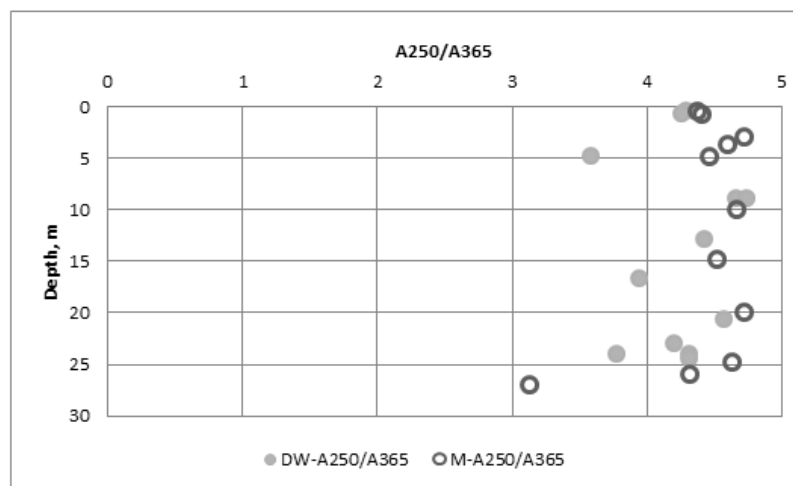


Figure 22 A250/A365 profiles in the middle of Chichester reservoir and near the dam wall area

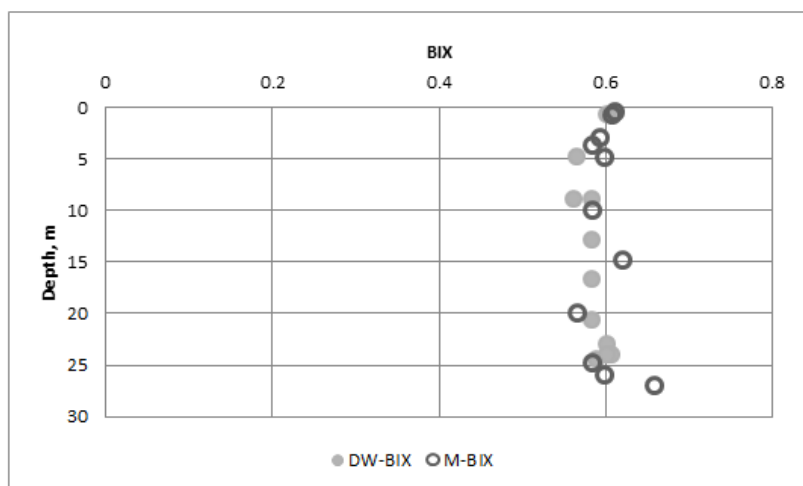


Figure 23 BIX profiles in the middle of Chichester reservoir and near the dam wall area

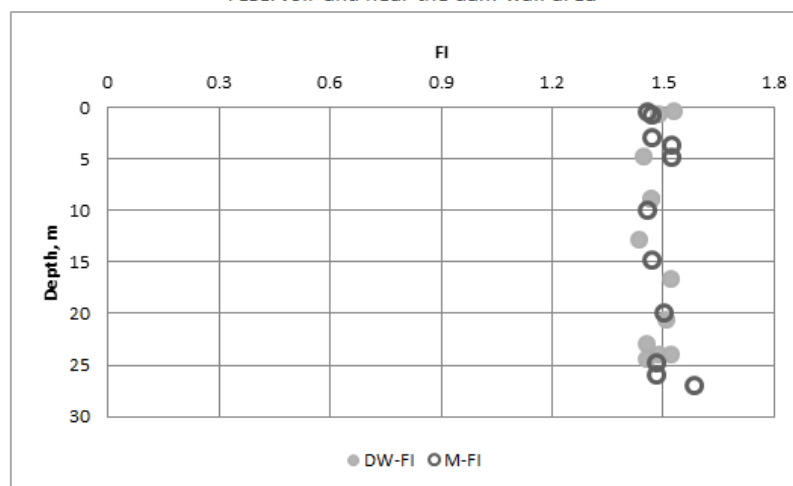


Figure 24 FI profiles in the middle of Chichester reservoir and near the dam wall area

Appendix 4

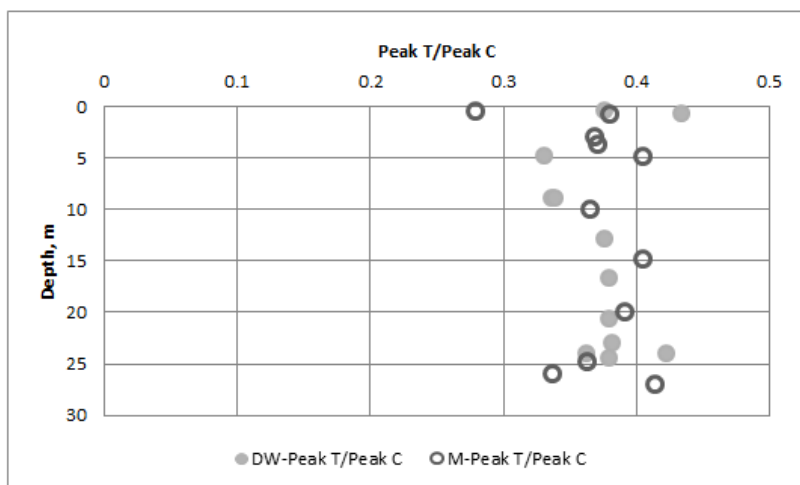


Figure 25 Peak T/Peak C profiles in the middle of Chichester reservoir and near the dam wall area

Table 31 Results of k-s tests based on fieldwork data

Parameter	Unit	Group a: Dam Wall					Group b: Middle					P-value
		Min	Median	Max	Average	SD	Min	Median	Max	Average	SD	
Temperature	°C	22.60	22.90	23.50	22.99	0.30	22.80	23.20	25.10	23.45	0.80	0.4611
DO	mg/L	5.94	6.79	6.90	6.68	0.28	5.69	6.80	8.94	6.91	1.11	0.4611
EC	µS/cm	69.60	70.20	79.50	70.99	2.83	69.50	69.70	70.00	69.77	0.18	0.0013
Eh	mv	8.30	143.00	181.00	128.66	45.61	81.00	106.00	116.00	103.81	11.86	0.0059
pH	-	6.66	6.75	6.89	6.75	0.05	6.73	6.79	7.21	6.86	0.16	0.0233
Soluble Fe	µg/L	27.66	113.34	1240.40	190.62	333.07	44.63	80.26	771.85	145.09	210.57	0.6677
Total Fe	µg/L	327.56	341.91	1710.99	468.55	393.04	221.46	288.62	2763.81	513.87	747.71	0.0046
Soluble Mn	µg/L	30.21	33.15	179.58	47.51	42.07	10.93	25.07	393.55	56.22	112.19	0.0009
Total Mn	µg/L	59.65	62.76	206.78	77.78	41.40	24.87	50.89	298.78	72.89	76.41	0.0046

Appendix 4

Soluble P	µg/L	0.46	1.72	50.55	5.96	14.07	0.00	0.94	3.00	1.10	1.03	0.1723
TP	µg/L	53.81	55.31	97.21	58.72	12.15	52.08	53.59	89.73	57.83	11.04	0.0657
Ammonium	mg/L	0.04	0.05	0.22	0.06	0.05	0.01	0.05	0.14	0.05	0.03	0.1865
TC	mg/L	3.07	6.95	8.58	6.51	1.57	6.17	6.69	21.89	8.14	4.59	0.6371
TN	mg/L	0.23	0.37	0.55	0.36	0.10	0.27	0.34	1.64	0.45	0.39	0.5763
DOC	mg/L	1.84	2.01	2.34	2.05	0.13	1.71	1.97	2.08	1.94	0.11	0.1589
TC/TN	-	10.81	18.08	26.84	18.74	4.39	13.37	19.96	22.93	19.68	2.47	0.1236
Unprocessed humic/fulvic substances	RFU	66.07	149.08	155.39	142.80	24.54	107.37	142.60	145.50	138.68	10.90	0.0041
Processed humic/fulvic substances	RFU	40.07	89.72	93.27	86.30	14.67	63.65	87.36	90.07	84.33	7.67	0.0041
Microbial content	RFU	7.20	17.10	23.54	16.73	4.18	12.96	15.18	19.15	15.49	1.82	0.3131
Processed to unprocessed humic/fulvic substances	-	0.591	0.605	0.615	0.605	0.008	0.587	0.613	0.620	0.608	0.011	0.3825
A250/A365	-	3.59	4.32	4.75	4.27	0.35	3.15	4.52	4.74	4.42	0.44	0.1236
BIX	-	0.56	0.59	0.61	0.59	0.02	0.57	0.60	0.66	0.60	0.02	0.7868
FI	-	1.45	1.48	1.54	1.49	0.03	1.46	1.49	1.58	1.50	0.04	0.8887
Peak T/Peak C	-	0.33	0.38	0.43	0.38	0.03	0.28	0.37	0.42	0.37	0.04	0.9585

* Font colour green: The distributions of the two samples are different ($P < 0.05$);

* Font colour red: The two samples follow the same distribution ($P > 0.05$).

Table 32 Results of simple regression analyses based on fieldwork data

Site location	y	R ² (x: depth)	Positive (P)/negative (N)	Sample size (n)	Site location	y	R ² (x: depth)	Positive (P)/negative (N)	Sample size (n)
Dam Wall	Temperature	0.9230	N	11	Middle	Temperature	0.5461	N	11
	DO	0.3347	N	11		DO	0.7623	N	11
	EC	0.0819	P	11		EC	0.0003	P	11
	Eh	0.3291	N	11		Eh	0.1363	P	11

Appendix 4

pH	0.0032	N	11
Soluble Fe	0.1866	P	12
Total Fe	0.1593	P	12
Soluble Mn	0.1809	P	12
Total Mn	0.2050	P	12
Soluble P	0.1295	P	12
TP	0.0942	P	12
Ammonium	0.1453	P	12
TC	0.4478	P	12
TN	0.3329	P	12
DOC	0.0249	P	12
TC/TN	0.0040	P	12
Unprocessed humic/fulvic substances	0.0625	P	12
Processed humic/fulvic substances	0.0810	P	12
Microbial content	0.1067	P	12
Processed to unprocessed humic/fulvic substances	0.1260	P	12
SUVA	0.2771	P	12
A250/A365	0.0022	N	12
BIX	0.0543	P	12
FI	0.0009	N	12
Peak T/Peak C	0.0238	P	12

pH	0.5163	N	11
Soluble Fe	0.1880	P	11
Total Fe	0.2564	P	11
Soluble Mn	0.2556	P	11
Total Mn	0.3593	P	11
Soluble P	0.0978	P	11
TP	0.1222	P	11
Ammonium	0.5129	P	11
TC	0.1726	P	11
TN	0.1913	P	11
DOC	0.0307	N	11
TC/TN	0.1921	N	11
Unprocessed humic/fulvic substances	0.051	N	11
Processed humic/fulvic substances	0.0105	N	11
Microbial content	0.0191	N	11
Processed to unprocessed humic/fulvic substances	0.1629	P	11
SUVA	0.2050	P	11
A250/A365	0.1747	N	11
BIX	0.0274	P	11
FI	0.1622	P	11
Peak T/Peak C	0.0771	P	11

Appendix 5

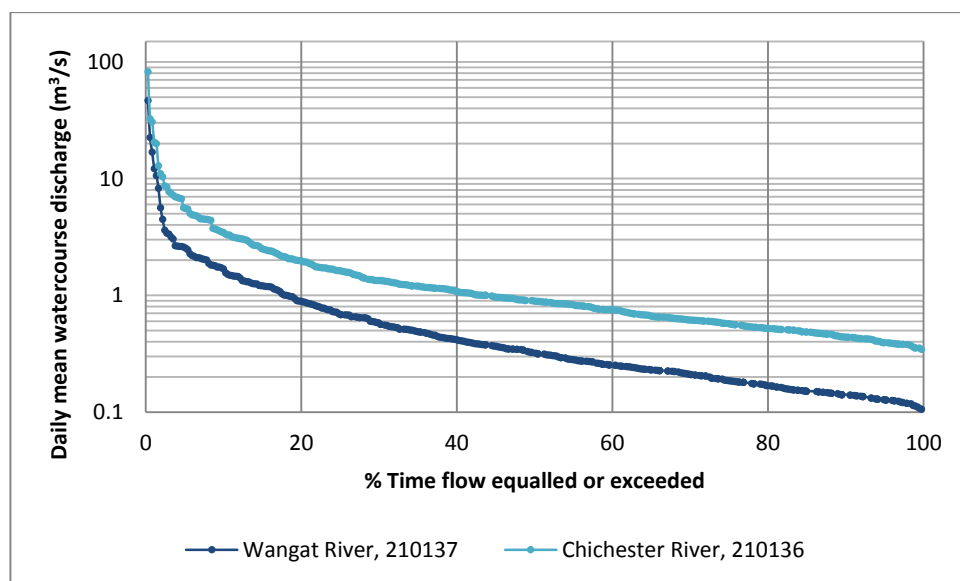


Figure 1 Flow duration curves for Wangat River and Chichester River (Log intervals)