FINAL REPORT

Poole Park Lakes: Research and monitoring

DATE:	March 2016
VERSION:	Final v1.0
BUG REFERENCE:	BUG2710
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TITLE: **Poole Park Lakes: Research and monitoring**
CLIENT: **Borough of Poole**
BUG REF: **BUG2710**

This document has been issued and amended as follows:

VERSION	DATE	DESCRIPTION	CHECKED BY LEAD AUTHOR	APPROVED BY
Draft v0.1	19/02/2016	Draft for client review	A. Harrison	
Final v1.0	03/03/2016	Final version	A. Harrison	

This report should be cited as:

Harrison A., Pinder A., Herbert R., O'Brien W., Pegg J. and Franklin D. (2016) Poole Park Lakes: Research and monitoring. BU Global Environmental Solutions (BUG) report to Borough of Poole. 96 pp.

EXECUTIVE SUMMARY

Poole Park was officially opened in 1890 and celebrated its 125 year anniversary in 2015; it is regarded as a focal point for recreational activity and outdoor space within the Borough of Poole (BoP) and is widely enjoyed by a variety of stakeholders. Central to the amenity and recreational value of Poole Park are the three water bodies; two small freshwater lakes and the larger 'boating lake' (referred to throughout this report as the Lagoon). All three lakes represent highly degraded ecosystems, characterised by poor water quality, algal blooms and problem swarms of non-biting chironomid midges.

Previous monitoring of the water bodies has been restricted to a limited number of small scale 'snapshot' investigations, mainly focussing on the Lagoon. As a result, previous management regimes have been severely constrained by a lack of robust evidence.

The findings of the current study corroborate previous short-term investigations and anecdotal information; albeit, providing a much more robust and holistic dataset. Results from the water quality and sediment quality, ecology and hydrology investigations are provided in Sections 4, 5 and 6, respectively.

The impounded nature of the Lagoon, along with limited opportunity for tidal exchange with Poole Harbour, have been identified as key factors constraining the ecological function of the Lagoon. The two main effects of prolonged impoundment are that a) salinity is gradually reduced due to rainfall and surface water inputs, and b) due to elevated nutrient loadings, phytoplankton and algae can capitalise on extended residence times and proliferate to nuisance levels. These are considered to be two of the most important contributory factors to the ecological issues affecting the Lagoon.

Sections 8 and 9 provide a detailed interpretative discussion of the environmental and hydrological monitoring results, and highlight the key management issues that need to be addressed. In particular, the sustainable management of these water bodies must rely on addressing the root causes of problems rather than the reactive application of 'sticky plaster' solutions.

Based on the data and interpretation presented within this report, it is important for BoP managers to accept and work within the limits of ecological potential the lakes offer. The current study reinforces the need for a fundamental shift in thinking with regard to the amenity value of the lakes and the management of on-going ecological issues. Specifically, it would be unrealistic to believe that the Lagoon could be maintained as a low nutrient, weed free water body. Rather, recognising and promoting the water body as a saline lagoon with the potential to attract unique wildlife, including invertebrates, fish and birds will be key to managing public expectations and allow BoP to set realistic and sustainable management targets with tangible outcomes for stakeholders.

Achieving these goals whilst balancing the sensitivities associated with 'change', however, will require a coherent management strategy, incorporating a maintained range of synergistic management actions.

With regard to the Lagoon; to realise the ecological potential offered by this unique system, such management actions include, but are not limited to:

- Increase and maintain the flushing frequency between the Lagoon and Poole Harbour.

- Divert the large drain input on the north-eastern shore (referred to as ‘L2’ in this report) directly to Poole Harbour.
- Increased water depth and re-profiling of bed sediment; facilitated by creation of submerged reedbed islands, accessible via boardwalks.
- Remove barley straw bales.

For the freshwater lakes, the following should be considered:

- Carp removal from the large freshwater lake (referred to as ‘FW1’ in this report).
- Dredging of nutrient rich, anoxic sediment from both freshwater lakes.
- Reduction in wildfowl numbers, particularly geese, through a humane management plan.
- Investigate drainage issues; potential to divert drains into ‘L2’ and straight to Poole Harbour.

A future vision for Poole Park?

Given the long-standing and on-going ecological issues surrounding the Poole Park Lakes, in particular the Lagoon, a concerted effort will be required to realise the full potential of the ecosystem services offered by the water bodies and the surrounding area. Recognising, enhancing and managing the water body as a saline lagoon with unique habitats and species, whilst maintaining (and enhancing) the opportunity for water sports activities, would provide a whole range of ecological and societal benefits.

Section 9.3 discusses a potential ‘future vision for Poole Park’, including a schematic representation of one possible plan for the Lagoon, utilising the unique features of the water body to provide a shared resource offering both enhanced ecological benefits and high amenity value. This includes re-profiling the bed by the creation of new ‘submerged’ reed islands from dredged sediment. It is anticipated that these islands would be accessible via boardwalks to allow the public to engage more with the main lake and, combined with interpretation boards, highlight the unique lagoonal ecosystem, habitats and species present.

Reed beds (on the islands and shoreline), gravel shoals and varying depths in inaccessible areas would all provide habitat for invertebrates and wading birds, which could be observed from a bird watching hide.

Currently, water sports are mainly focussed on the western end of the lake; increased depths, better water quality and removal of the barley straw bales would all provide enhanced opportunities for a variety of activities on the lake in this watersports area.

Enhancing the accessibility of the Lagoon through the creation of submerged islands and boardwalks may also shift the focus from bird feeding in the freshwater lakes, which contributes to the degraded water quality and nuisance geese in these areas. For example, creation of a deeper ‘crabbing’ zone on one of the islands / boardwalks would provide additional activities for young families to enjoy.

Enhancing the overall ecological and amenity value of the Lagoon would provide significant tangible benefits. In addition to helping alleviate the on-going ecological issues; physical activity, mental health and societal benefits would be realised through promoting public engagement with green outdoor spaces.

CONTENTS

1. INTRODUCTION

Officially opened in 1890, Poole Park incorporates three separate water features which were designed to aesthetically enrich the park and be enjoyed by a range of recreational stakeholders. Originally an intertidal bay of Poole Harbour, the main 'boating lake' (hereafter referred to as the 'Lagoon') represents the largest of these water bodies (approximately 21 hectares) and was formed when the intertidal zone was separated from the main harbour by the construction of the Weymouth to London Waterloo railway embankment.

With hydraulic connectivity with the harbour since controlled by a single sluice gate, impounded water levels have typically been maintained at a level consistent with high spring tides. This fundamental change to the hydrology of the site has created a dramatic shift from a natural saline intertidal bay to a man-made brackish lagoon, resulting in an unusual aquatic system which has for many years presented managers of the Lagoon with a range of complex management challenges.

Figure 1.1 The southwest corner of the impounded Lagoon during the early 1900's. Note the lack of hard bank engineering and presence of natural sloping beach habitat.

The chemical and ecological processes which interact to drive water and ecological quality are typically complex; however, the considerable temporal range of salinities evident in the Lagoon adds to the instability of the system. This, combined with other stressors, such as the Lagoon acting as a sump for diffuse pollutants, has manifested to create a highly degraded ecosystem characterised by poor water quality, algal blooms and episodic occurrence of problem swarms of non-biting chironomid midges.

Several small, independent investigations of the Lagoon have been conducted over the years, with a view to managing the variety of problems to the best advantage for a range of park users. These studies have been reviewed in Pinder (2014) and shall not, therefore, be discussed in detail within the current report. However, the key issues associated with management of the Lagoon are briefly highlighted below.

1.1 Historic and recent flushing regime

The water levels in the Lagoon are controlled by the manual operation of a sluice gate connecting the water body to Poole Harbour. Historically (based mainly on anecdotal information), the Lagoon was 'flushed' with saline water from the harbour on a regular basis, maintaining relatively high salinities within the Lagoon and, consequently, a relatively stable ecological community.

In recent years, however, largely due to the expansion of recreational water sport activities and budgetary constraints, the flushing regime has been modified to the extent that the Lagoon water is impounded for prolonged periods, with limited tidal exchange.

The two main effects of prolonged impoundment are that a) salinity is gradually reduced due to rainfall and surface water inputs, and b) due to elevated nutrient loadings, phytoplankton and algae can capitalise on extended residence times and proliferate to nuisance levels. These are considered to be two of the most important contributory factors to the ecological issues discussed below.

1.2 Lagoon drain inputs

There are in excess of 50 drain inputs entering the Lagoon from a variety of sources, including surface water drains and licensed combined sewer overflows (CSO). The total catchment area for surface water drain inputs is approximately 2 km^2.

The combined effect of multiple drain inputs is to gradually decrease the salinity of the Lagoon by the addition of fresh water to the system between tidal flushing events. In addition, the inputs contribute to increased nutrient and contaminant loading within both the water body and bed sediment.

1.3 Proliferation of tasselweed and filamentous algae

The shallow nature of the Lagoon, along with its hypereutrophic nutrient status, result in regular blooms of problematic filamentous algae (blanket weed), such as spirogyra and cladophora. In addition, proliferations of tasselweed (*Ruppia maritima*) are common during the summer months, often completely covering large areas of the water body.

This has significant implications for recreational use of the Lagoon, with both water sports and model boating being seriously affected. For example, it is not uncommon for the model boating enclosure to be completely choked with tasselweed, to the extent that the area cannot be used.

In addition to the direct impact on water users; subsequent dieback and decay of large quantities of tasselweed and filamentous algae can result in unpleasant odours that have been the source of complaints by park users and local residents. In an attempt to alleviate some of these problems, weed harvesting boats have been used in recent years to remove large quantities of weed during the summer months; however, the underlying causal factors remain.

1.4 Swarming chironomids

The Chironomidae represent a family of non-biting midges, with individual species spending the majority of their life cycle under water. Larvae are typically associated with bottom sediments where they develop into pupae before emerging ‘on the wing’. Because the adults don’t feed, this life stage is short, typically spanning from just hours to a couple of days, allowing sufficient time to mate and deposit eggs on the water surface to complete the life cycle.

Due to their elevated tolerance of poor water quality (e.g. high nutrients and anoxic conditions), chironomids can often dominate the macroinvertebrate communities of degraded water bodies and, in doing so, build up extremely high population densities. With generation turnover being achieved in just two to three weeks during the summer months, problematic swarms of adults are not uncommon.

Over recent years the highly variable salinity regime within the Lagoon has limited the establishment of less tolerant species, allowing *Chironomus salinarius* to establish without the presence of predators. Swarms experienced during the summers of 2011 to 2014 (Figure 1.2) have been the cause of residential complaints to the Borough of Poole (BoP), with additional socio-economic implications associated with the temporal avoidance of the park and its facilities by the general public.

Figure 1.2 Swarming chironomids at the Lagoon.

1.5 Freshwater lakes

Located immediately to the north of the Lagoon are two much smaller freshwater lakes, referred to in the current report as FW1 and FW2 (respective surface areas approximately 1.2 and 0.2 hectares).

This area of the park provides a major focal point for visitors; amenities include a children's playground and a miniature railway which encircles the larger of the two lakes (FW1). Accordingly, the lakes represent important and well utilised features of the park, with the feeding of ducks and numerous large carp constituting popular activities with young families in particular.

The lakes themselves have been subject to high levels of nutrient enrichment over an extended time period. This has been the cause of ongoing water quality issues, such as algal blooms and low dissolved oxygen, which dramatically limit the ecological potential of these water bodies.

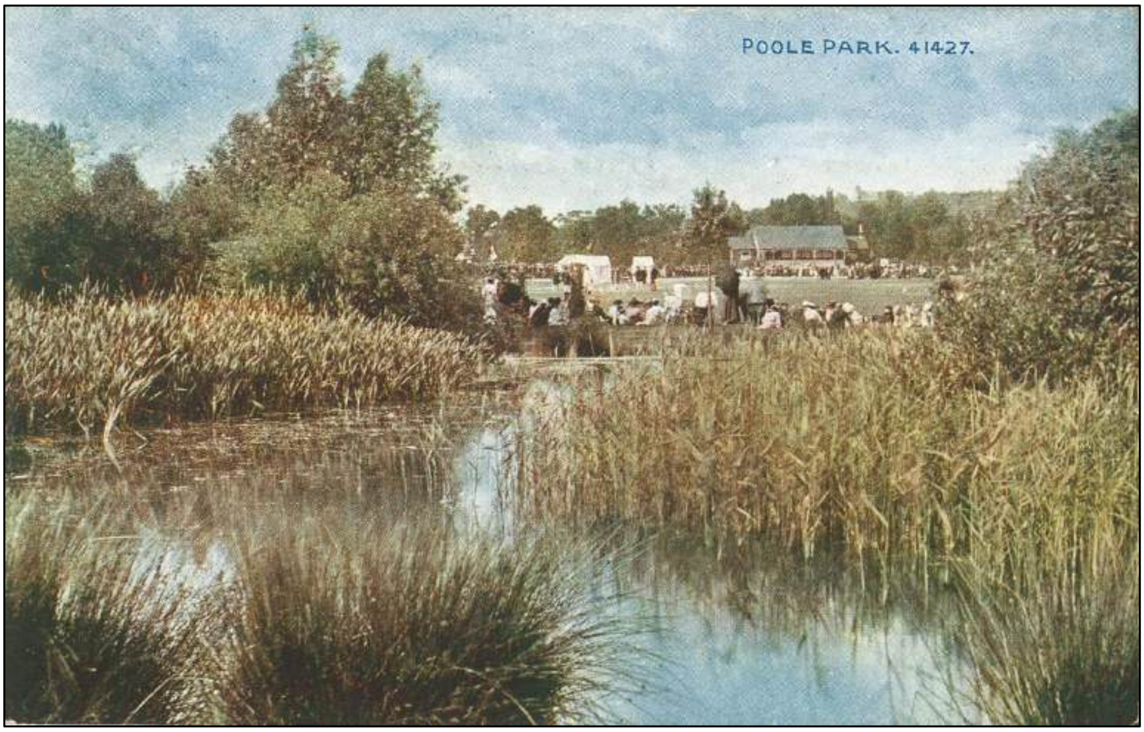


Figure 1.3 View across the smaller lake (FW2) towards the cricket pavilion (circa 1920).

1.6 Project objectives

The overarching objective of this project was to establish the scientific evidence base required to inform and appraise future management options for the Poole Park water features. The key components of the project are outlined below:

- Conduct a 12 month monitoring programme to establish a baseline of water quality within the two freshwater lakes, the Lagoon and Poole Harbour.
- Conduct a 12 month monitoring programme to establish the quality of water entering the Lagoon from four major drain inputs.

- Collect ecological data to determine current biodiversity of the two freshwater lakes and the Lagoon, focusing on macroinvertebrates and fish.
- Establish stage versus volume relationship of the Lagoon using hydroacoustic bathymetry.
- Quantify sediment chemistry, volume and distribution within the Lagoon.
- Quantify water volume exchange rates through the Lagoon sluice gate and identify temporal opportunity and capacity for potential water exchange with Poole Harbour.
- Identify recommended management to optimise the future amenity value and sustainable management of the three water bodies.

2. CHARACTERISTICS OF COASTAL LAGOONS

Coastal lagoons have been defined as ‘shallow bodies of enclosed brackish or salt water separated from an adjacent coastal sea by either an anthropogenically engineered structure (i.e. sluice) or a natural barrier of sedimentary material’ (Barnes 1980, 1989). Invertebrate, plant and algal assemblages within these habitats differ from estuarine species in their adaptation to the stresses associated with reduced tidal exchange. A tolerance to spatially and temporally variable salinity, temperature and pH ensures their survival in these habitats, where competition and predation from marine and estuarine species is reduced (Bamber *et al*. 1992).

There are both natural lagoon features e.g. the Fleet in Dorset, and man-made lagoons. However although they are distinguishable in many respects, both types can result in similar communities and accommodate rare and protected species.

Globally, lagoons comprise 13% of the coastline; however only 5% of the European coast is lagoonal, the smallest proportion of any continent (Barnes 1980, 1995; Cromwell 1971), and they are particularly scarce in the north-east Atlantic. Coastal lagoon habitats are especially threatened by developments and pollution (Beer and Joyce 2013), are prone to successional change and can have a transient existence (Barnes 1994). In Europe, coastal lagoons are a ‘priority’ habitat for conservation under the EU Habitats Directive (92/43/EEC). Five main sub-types of lagoon have been determined in the UK; these have been used in identifying statutory sites including SSSIs and Special Areas of Conservation (Brown *et al*. 1997).

2.1 Lagoon ecological communities

Lagoons can contain a mixture of freshwater, brackish water and marine species, with the composition being mainly determined by salinity. This will ultimately be dependent on water exchange and the connection with the sea, with highest species richness generally found the closer the lagoon is to the sea.

The biological assemblages present in UK lagoons have been classified as biotopes (Bamber *et al*. 2001), although this is still regarded as fairly provisional and under development; further work still needs to be done to determine the rarity of these assemblages. However, the ‘best’ lagoons are those with a good number of ‘specialist’ species. Salinity is often tolerated over a large range 5 – 40 ppt; however, the salinity preference of species of highest conservation importance are typically 20 – 35 ppt (Bamber *et al*. 2001). Table 2.1 shows a selection of these species that are found in UK lagoons, including local protected lagoon sites in Dorset (Fleet and Brownsea Island Lagoon) and the Solent.

Table 2.1. Selection of lagoonal specialist species found in UK lagoons, including nationally and internationally protected species found in Dorset (Fleet and Brownsea Island Lagoon) and the Solent. Species highlighted bold have been recorded in the Lagoon during this study.

Group	Order	Species	Common name	IUCN Status	BAP	W&C 1981	SPI (NERC 2006)	FOCI
PLANTS & ALGAE		*Lamprothamnium papulosum*	Foxtail stonewort	Vuln^R	Y	Sch 8	Y	
		Ruppia maritima	**Beaked Tassleweed**	LC^R				
		Ruppia cirrosa	Spiral Tassleweed	LC^R				
CNIDARIA		***Nematostella vectensis***	**Starlet sea anemone**	Vuln^R	Y	Sch 5	Y	Y
CRUSTACEA	Amphipoda	*Gammarus insensibilis*	Lagoon sand shrimp		Y	Sch 5	Y	Y
		Monocorophium insidiosum	**Amphipod**					
	Isopoda	*Idotea chelipes*	Lagoon slater					
	Decapoda	***Palaemonetes varians***	**Lagoon prawn**					
INSECTS		*Paracymus aeneus*	Bembridge water beetle	Endgd^R		Sch 5		
MOLLUSCS		***Cerastoderma glaucum***	**Lagoon cockle**					
	Gastropoda	***Ecrobia ventrosa***	**Lagoon mud snail**					
		Haminoea navicula	Sea slug					
BRYOZOA		*Conopeum seurati*	Lagoon sea-mat					
FISH		***Pomatoschistus microps***	**Sand goby**	BC				

Endgd^R = IUCN Red List of Threatened Species (Endangered); Vuln^R = IUCN Red List of Threatened Species (Vulnerable); LC^R = IUCN Red List of Threatened Species (Least Concern); BC = protected under Appendix III of Bern Convention on Conservation of European Wildlife and Natural Habitats; BAP = Biodiversity Action Plan Priority Species; W&C = protected under Wildlife and Countryside Act (1981); SPI = Species of Principle Importance in England (Section 41, NERC Act, 2006); FOCI = Feature of Conservation Importance (England &Wales).

2.2 Is Poole Park Lake (the Lagoon) a coastal lagoon?

Yes, it is. It is an example of a 'sluiced lagoon'; the most common type of lagoon in the UK (Bamber *et al*. 2001). The Lagoon is relatively tide-less, of 'low hydrodynamics' and the salinity is much more variable than in Poole Harbour (Figure 4.4), as is the pH (Figure 4.5); all of which are physical and physico-chemical lagoonal characteristics.

The invertebrate fauna and flora of the Lagoon is also indicative of coastal lagoons. These are not freshwater organisms, but those found in brackish (partially saline) and marine environments. Species found include tassleweed (*Ruppia* spp.) and specialised invertebrates that are tolerant of this range of salinity and other parameters indicative of lagoons.

Importantly, the fauna includes some scarce species that are protected under national and international designations (Table 2.1 above). These include the species of tassleweed (*Ruppia* spp.) and the starlet sea anemone *Nematostella vectensis*. It is unknown how these species colonise lagoons, which are naturally isolated habitats. Some will arrive in water as eggs, larvae or seeds; however there is evidence that birds might be responsible for some species dispersal.

N.vectensis used to be present in Blue Lagoon in Poole (Sheader and Sheader 1985); however, it was lost from this site when it ceased to be a lagoon and became intertidal (Sheader and Sheader 1992).

It was subsequently discovered in Brownsea Island Lagoon in 2008 and 2009, where there is currently a large population (Seasearch 2008; Herbert *et al*. 2010).

3. SAMPLE LOCATIONS

Sample locations for the 2015 environmental monitoring programme are shown below in Figure 3.1 and Table 3.1. The main water quality monitoring programme comprised locations L1 to L6, FW1, FW2 and PH. In addition, L8 and L9 were added to the survey programme in August to investigate coliform and *E. coli* concentrations at these locations.

Fish surveys were conducted at six marginal locations, identified in Figure 3.1. Sediment samples were collected from L1 to L6, FW1 and FW2, and benthic invertebrate samples were collected from L5, L6, FW1 and FW2.

Figure 3.1 Sampling locations for the 2015 environmental monitoring programme. Blue circles = water quality, sediment quality and invertebrate samples. Green circles = fish samples.

Table 3.1. Sampling locations for the 2015 environmental monitoring programme.

Sampling location	OS Grid Reference	Description
L1	SZ0239691183	Lagoon – Small drain input
L2	SZ0252990998	Lagoon – Large drain input
L3	SZ0205190673	Lagoon – Medium drain input
L4	SZ0245291178	Lagoon – Medium drain input
L5	SZ0239090799	Lagoon – centre
L6	SZ0238091004	Lagoon – centre
L8	SZ0220391074	Lagoon – Adjacent to Rockley Watersports
L9	SZ0247990924	Lagoon – Corner of model yacht enclosure
PH	SZ0246990627	Poole Harbour at sluice gate channel exit
FW1	SZ0258291037	Large freshwater lake
FW2	SZ0265891196	Small freshwater lake
FISH SAMPLE 1	SZ0208690869	Lagoon margin
FISH SAMPLE 2	SZ0212990657	Lagoon margin
FISH SAMPLE 3	SZ0243190705	Lagoon margin
FISH SAMPLE 4	SZ0252290728	Lagoon margin
FISH SAMPLE 5	SZ0256491052	Lagoon margin
FISH SAMPLE 6	SZ0232391146	Lagoon margin

4. WATER QUALITY AND SEDIMENT QUALITY

This section outlines the sampling methodologies and presents the results from the water quality and sediment quality monitoring programme. The following elements are included:

- Water quality – weekly samples (Section 4.1)
- Water quality – continuous monitoring (Section 4.2)
- Sediment quality (Section 4.3)

Each section is restricted to a factual presentation of the key data, with limited commentary, other than to draw attention to the main trends. Full interpretation and discussion of the key findings are presented in Section 8.

4.1 Water quality – weekly samples

Weekly water quality samples were collected over a period of 49 weeks, from 14th January 2015 to 16th December 2015. On each occasion, physico-chemical parameters were collected in-situ at each location using a YSI Pro Plus handheld multi-parameter probe. In-situ physico-chemical parameters recorded on each sampling occasion included:

- Temperature
- Salinity
- pH
- Dissolved Oxygen

For the Lagoon drain input locations L1 to L4, and Poole Harbour location PH, in-situ measurements were taken by collecting a sample of water in a 5 litre bucket (either directly from the input flow – where the pipe was above water level, or from as close to the input as was practicable – where the pipe was submerged) and immediately holding the probe in this sample until the readings stabilised. For Lagoon locations L5 and L6, and freshwater lake locations FW1 and FW2, in-situ measurements were taken by holding the probe approximately 0.25 m under the water surface until readings stabilised.

Ammonium (NH_4^+) was also recorded in-situ using a HANNA instruments HI96733C portable ammonia meter. A sample of water from each location was placed into the reader in-situ and a reading of ammonium (NH_4^+) concentration recorded.

In addition to in-situ monitoring of physico-chemical parameters and ammonium, water samples were also collected for laboratory analysis of the following determinands:

- Biochemical Oxygen Demand (BOD)
- Total Nitrogen (TN)
- Total Phosphorus (TP)
- Chlorophyll
- Total Suspended Solids (TSS)
- Faecal Coliforms
- Escherichia coli

Note: Detergents were included in the original water quality suite; however, due to very low levels recorded during initial sampling, the decision was taken to remove these from the weekly water quality monitoring programme and replace with increased frequency of coliform sampling.

Water samples were collected at Lagoon locations L5 and L6, and freshwater lake locations FW1 and FW2, by immersing pre-labelled sample bottles approximately 0.3 m below the water surface until a full sample was achieved. At Lagoon drain input locations L1 to L4, and Poole Harbour location PH, water samples were collected by collecting a sample of inflowing water in a 5 litre bucket (either directly from the input flow – where the pipe was above water level, or from as close to the input as was practicable – where the pipe was submerged) before immediately filling pre-labelled sample bottles from the collected water.

All water samples were collected and stored in appropriate sample bottles, depending on the determinands to be analysed (e.g. sterile sample bottles used for bacterial analyses, green bottles used for chlorophyll analyses). All pre-labelled samples were securely packaged and delivered to the UKAS accredited National Laboratory Service (NLS) for analysis.

4.1.1 Temperature

Temperature varied among locations in the Lagoon and Poole Harbour, with temperatures in the harbour (PH) typically being 2 - 3°C lower than the Lagoon during the spring and summer months (Figure 4.1).

Temperatures of the Lagoon drain input locations L1 to L4 varied more widely than in the main lagoon locations L5 and L6. Most notable was the significantly higher temperatures recorded at drain input location L3 during January and February (12 - 14°C) compared with the main lake (Figure 4.1); during this period, steam could be seen rising from the open water surface in the vicinity of the L3 input, at a time when the majority of the remainder of the water surface was frozen (Figure 4.2).

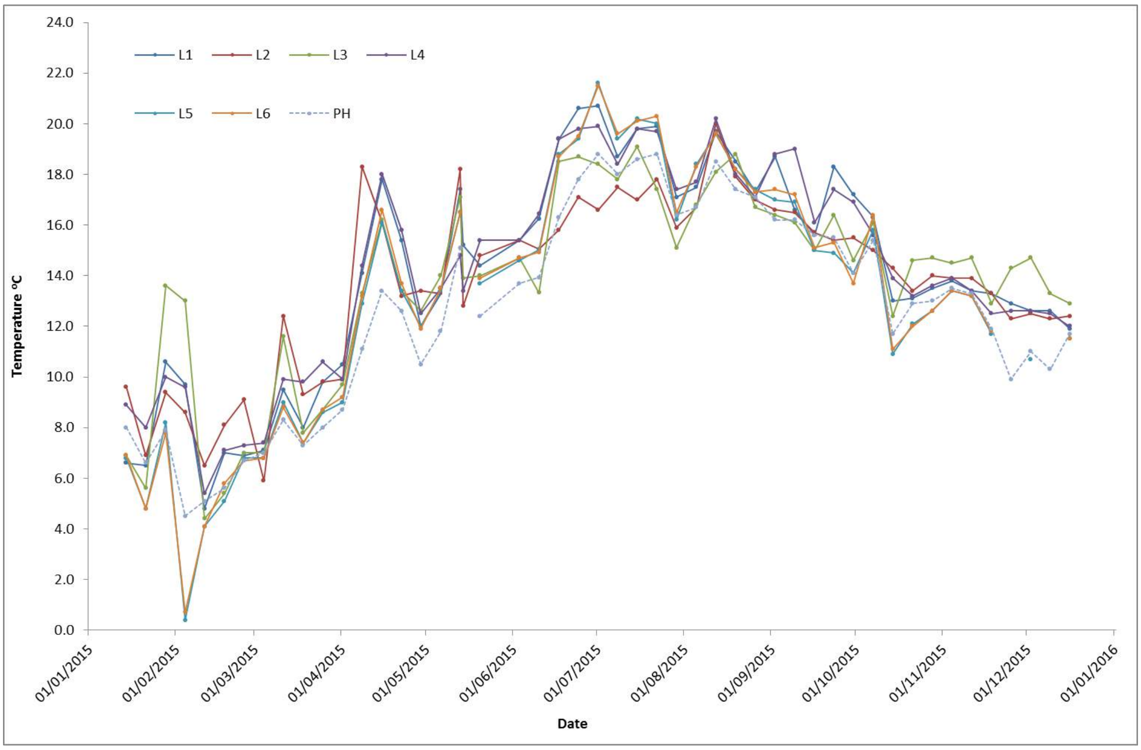


Figure 4.1 Temperature at Lagoon locations L1 to L6 and Poole Harbour location PH.

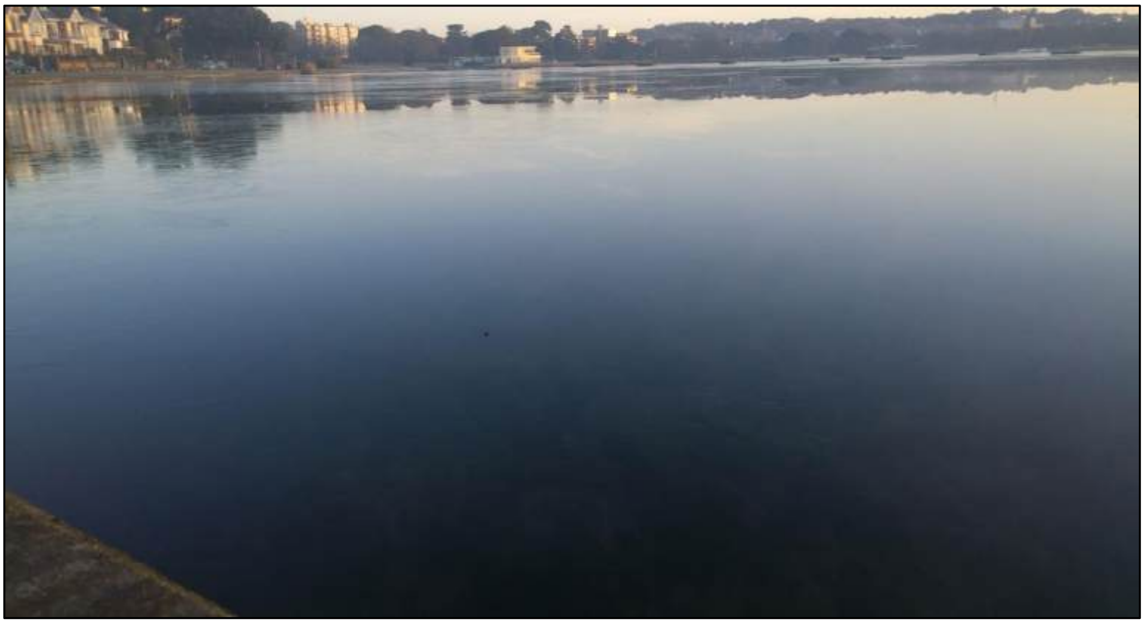


Figure 4.2 Steam rising from open water in the vicinity of Lagoon drain input L3, with the majority of the surrounding lake surface area frozen.

The larger freshwater lake (FW1) was typically 2 - 3°C higher than the smaller freshwater lake (FW2) during the summer months (Figure 4.3). This could potentially be explained by the much higher degree of shading by overhanging trees at FW2 compared with FW1.

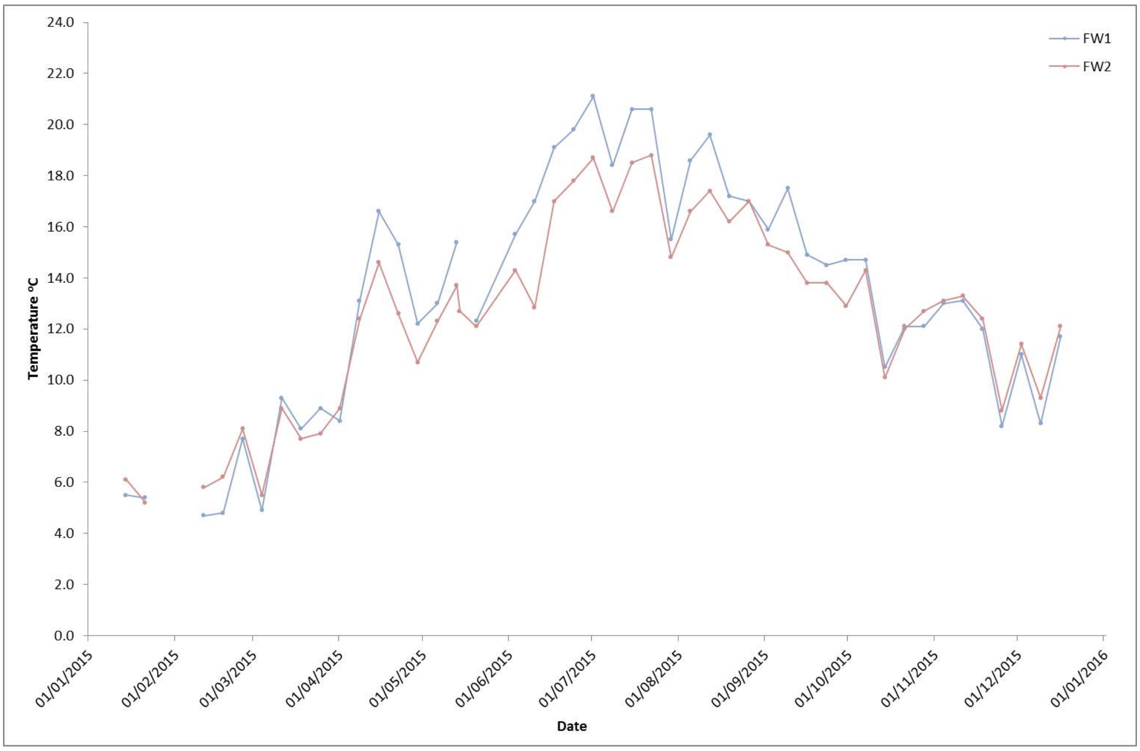


Figure 4.3 Temperature at freshwater lake locations FW1 and FW2.

4.1.2 Salinity

Salinity at Lagoon locations L5 and L6, along with Poole Harbour location PH, are shown in Figure 4.4). Salinity in Poole Harbour generally ranged between 25 and 33 ppt, with notable declines in salinity values being associated with fresh water overtopping the sluice during high rainfall events.

As expected, flushing (hashed grey boxes) has a considerable influence on salinity within the lake; salinities at L5 and L6 typically increased by 10 – 15 ppt after flushing events.

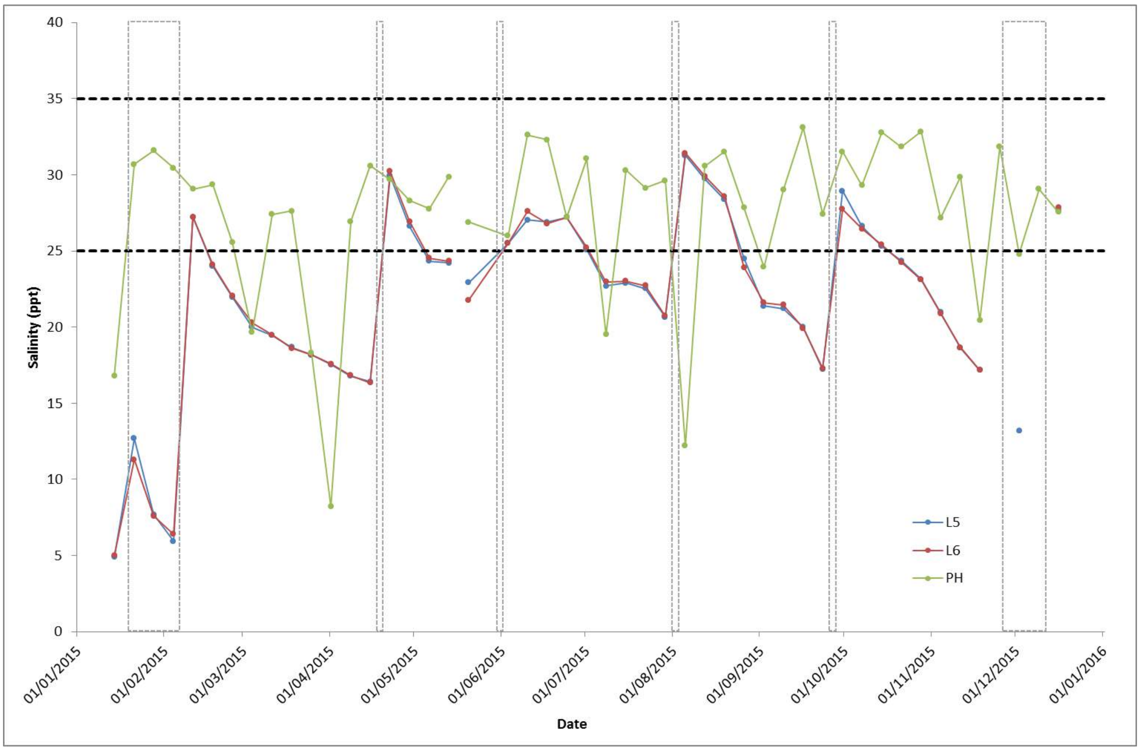


Figure 4.4 Salinity at Lagoon locations L5 and L6, and Poole Harbour location PH. Hashed grey boxes indicate flushing events. Hashed horizontal black lines indicate the target salinity range for maintaining a healthy lagoon ecosystem.

4.1.3 pH

Poole Harbour at location PH generally exhibited pH values within the typical range for sea water (7.5 – 8.4). In contrast, the Lagoon locations L5 and L6 had relatively high pH values; particularly during the summer months when pH peaked at 9.4 (Figure 4.5).

The pH of Lagoon drain inputs L1 to L4 varied throughout the year. Broadly speaking, L1 and L2 had relatively higher pH values than L3 and L4, where a minimum pH of 6.3 was recorded (Figure 4.6).

Freshwater lake locations FW1 and FW2 exhibited broadly similar pH ranges, generally ranging from 6.5 to 9 (Figure 4.7).

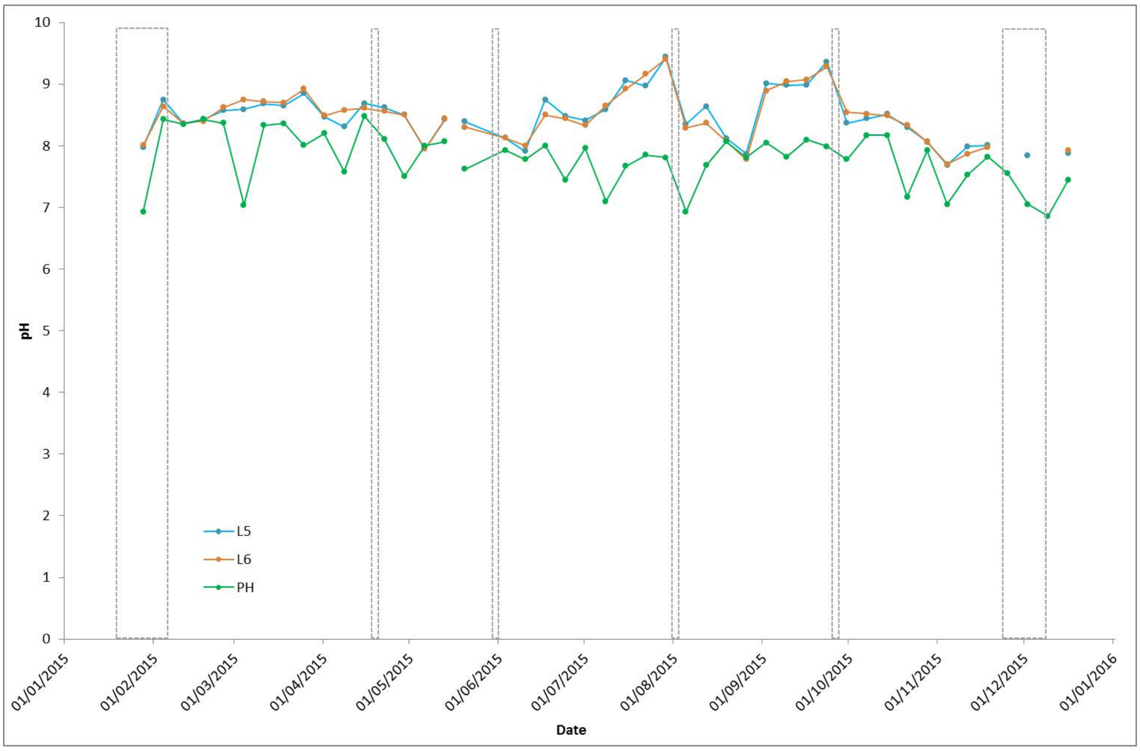


Figure 4.5 pH at Lagoon locations L5 and L6, and Poole Harbour location PH. Hashed grey boxes indicate flushing events.

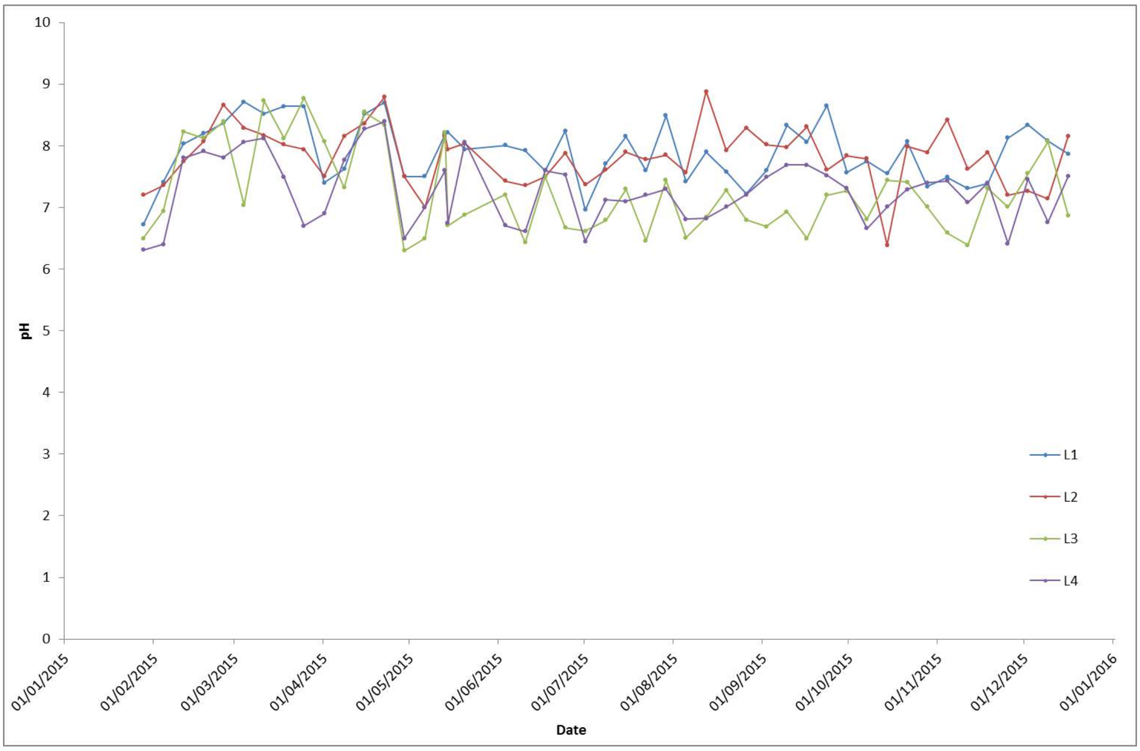


Figure 4.6 pH at Lagoon drain input locations L1 to L4.

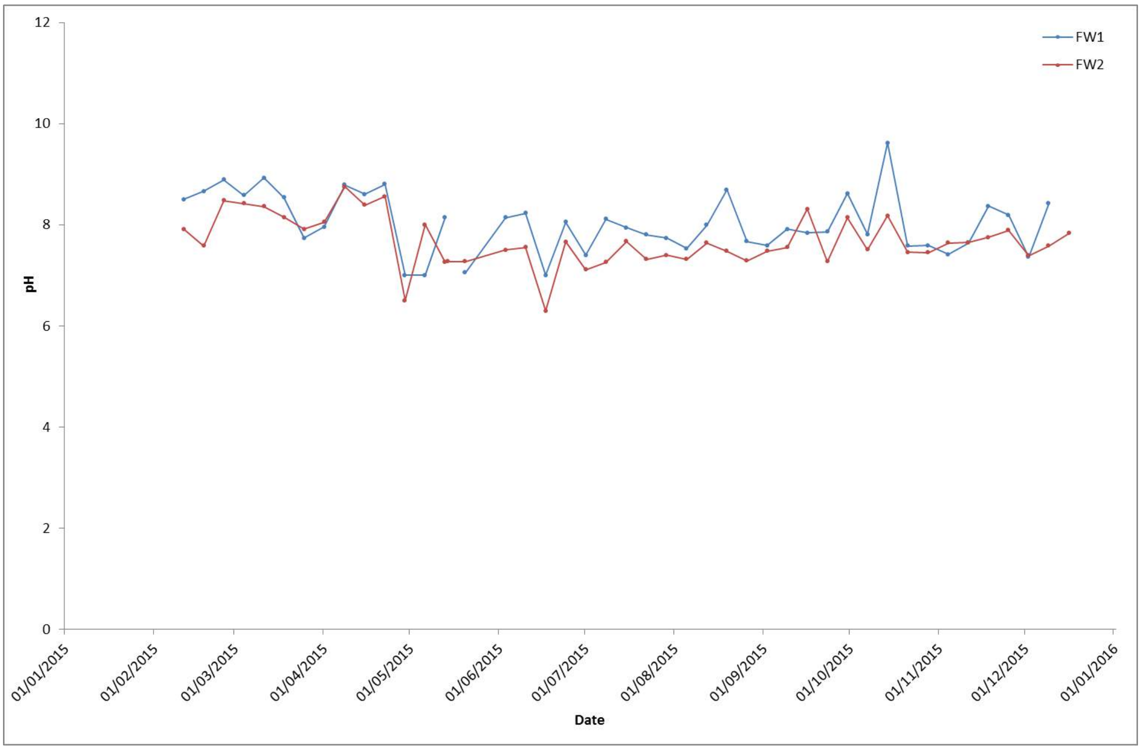


Figure 4.7 pH at freshwater lake locations FW1 and FW2.

4.1.4 Dissolved oxygen

Dissolved oxygen (DO) at Lagoon locations L5 and L6 remained relatively high throughout the year (Figure 4.8). Although not a WFD water body, the 5th-percentile value for L5 and L6 combined would classify the lake as ‘Good’ with regard to dissolved oxygen (based on these weekly data). Large peaks were observed during July and September, with a maximum value of 13.0 mgl^{-1} recorded on 2nd September 2015.

Dissolved oxygen in Poole Harbour was generally lower than observed in the main Lagoon.

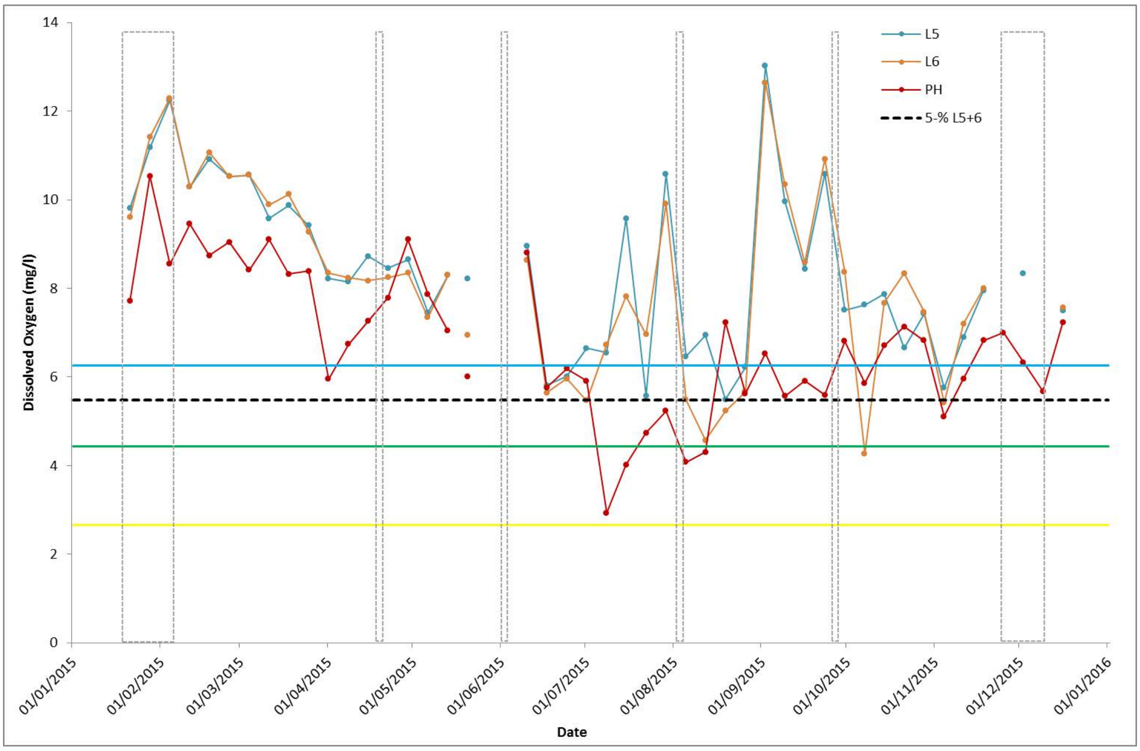


Figure 4.8 Dissolved oxygen at Lagoon locations L5 and L6, and Poole Harbour location PH. Hashed grey boxes indicate flushing events. Blue, green and yellow lines indicate 5th percentile values for WFD status of High, Good and Moderate, respectively. Hashed horizontal black line indicates 5th percentile for L 5 and 6.

Dissolved oxygen at the Lagoon drain input locations L1 to L4 fluctuated considerably (Figure 4.9). The largest drain input by volume (L2) maintained relatively high DO levels throughout the year (minimum recorded = 5.6 mgl^{-1}); indicating that, although BOD and coliforms were relatively high at this location, sufficient dilution was present to maintain favourable DO levels.

The lowest DO levels were recorded at L4, with a minimum value of 1.4 mgl^{-1} recorded during August 2015.

Both freshwater lakes exhibited large fluctuations in dissolved oxygen, with values regularly falling to very low levels (Figure 4.10). Although not categorised as WFD water bodies, mean July-August values for FW1 and FW2 (based on these weekly data) would classify the lakes as ‘Good’ and ‘Poor’, respectively.

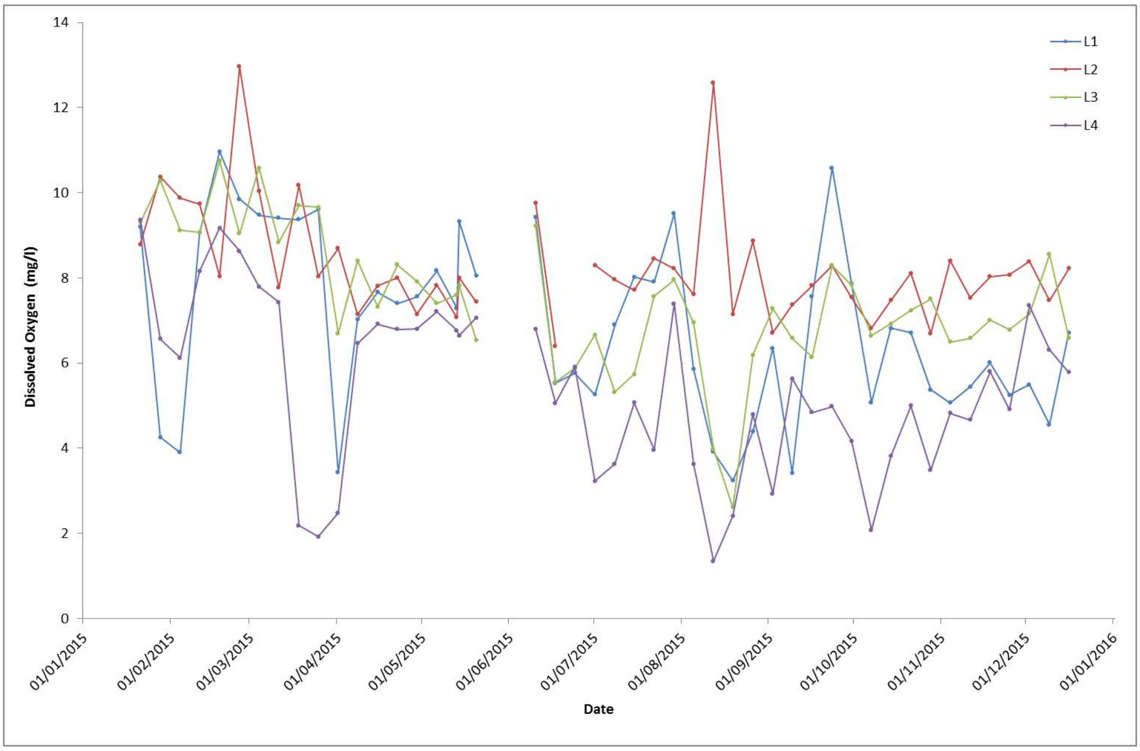


Figure 4.9 Dissolved oxygen at Lagoon drain input locations L1 to L4.

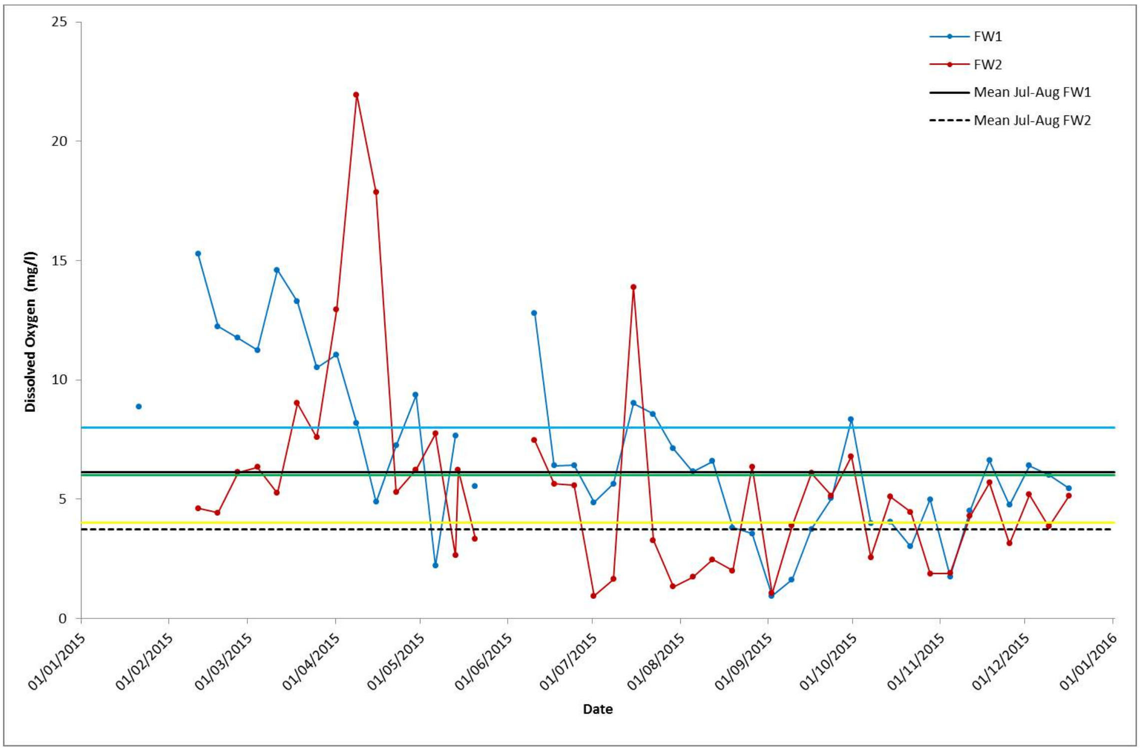


Figure 4.10 Dissolved oxygen at freshwater lake locations FW1 and FW2. Blue, green and yellow lines indicate mean July-Aug values for WFD status of High, Good and Moderate, respectively. Solid and hashed black lines indicate mean July-Aug values for FW1 and FW2, respectively.

4.1.5 Ammonium (NH_4^+)

Ammonium concentrations varied considerably at Lagoon locations L5 and L6 (Figure 4.11), regularly exceeding the ‘Mandatory’ threshold values contained within the Freshwater Fish Directive (1 mgl^{-1}).

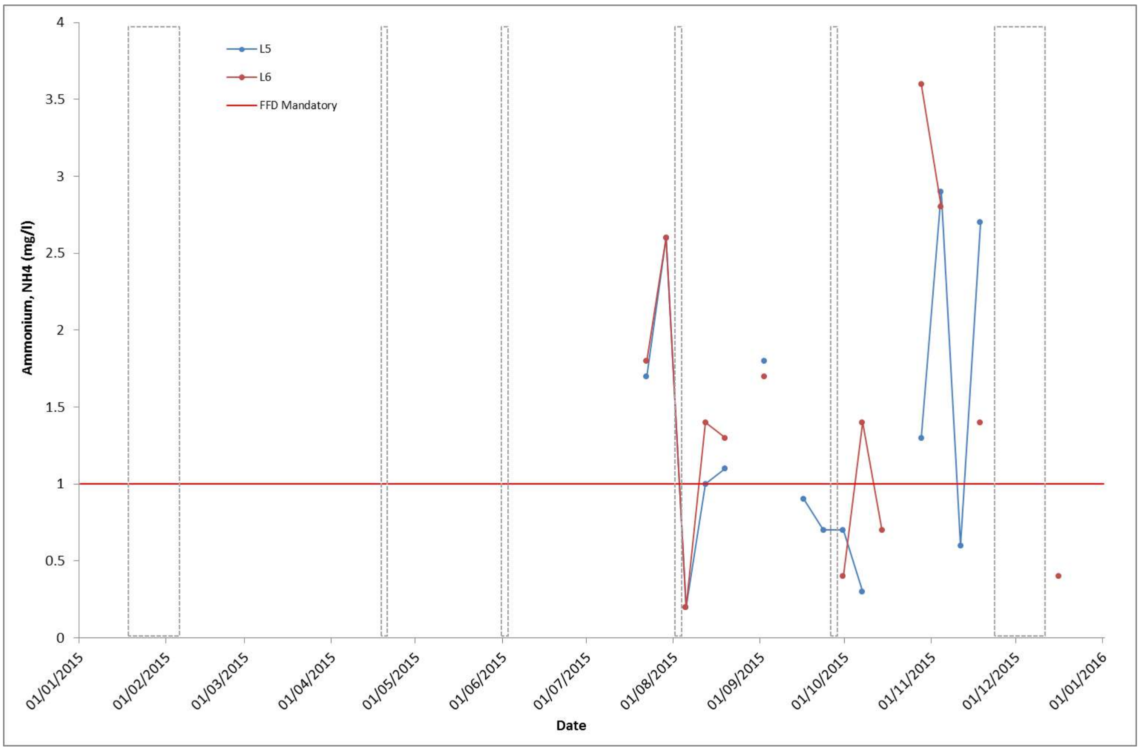


Figure 4.11 Ammonium (NH_4^+) at Lagoon locations L5 and L6. Hashed grey boxes indicate flushing events. Horizontal red line indicates Mandatory exceedance value for Freshwater Fish Directive.

Ammonium concentrations varied amongst the four Lagoon drain input locations L1 to L4 (Figure 4.12). All drain inputs exceeded Freshwater Fish Directive Mandatory threshold values to some extent – most notable was a very high spike at L1 on 9th September 2015. Although records indicate this reading was recorded correctly; such a high single value should be afforded due caution, especially given that concurrent water quality parameters did not indicate any particular unique event.

Ammonium concentrations varied throughout the year at the freshwater lake locations FW1 and FW2 (Figure 4.13), generally exceeding Freshwater Fish Directive Mandatory threshold values – most notable was a very high spike at FW1 on 5th August 2015. Again; although records indicate this reading was recorded correctly; such a high single value should be afforded due caution, especially given that concurrent water quality parameters did not indicate any particular unique event.

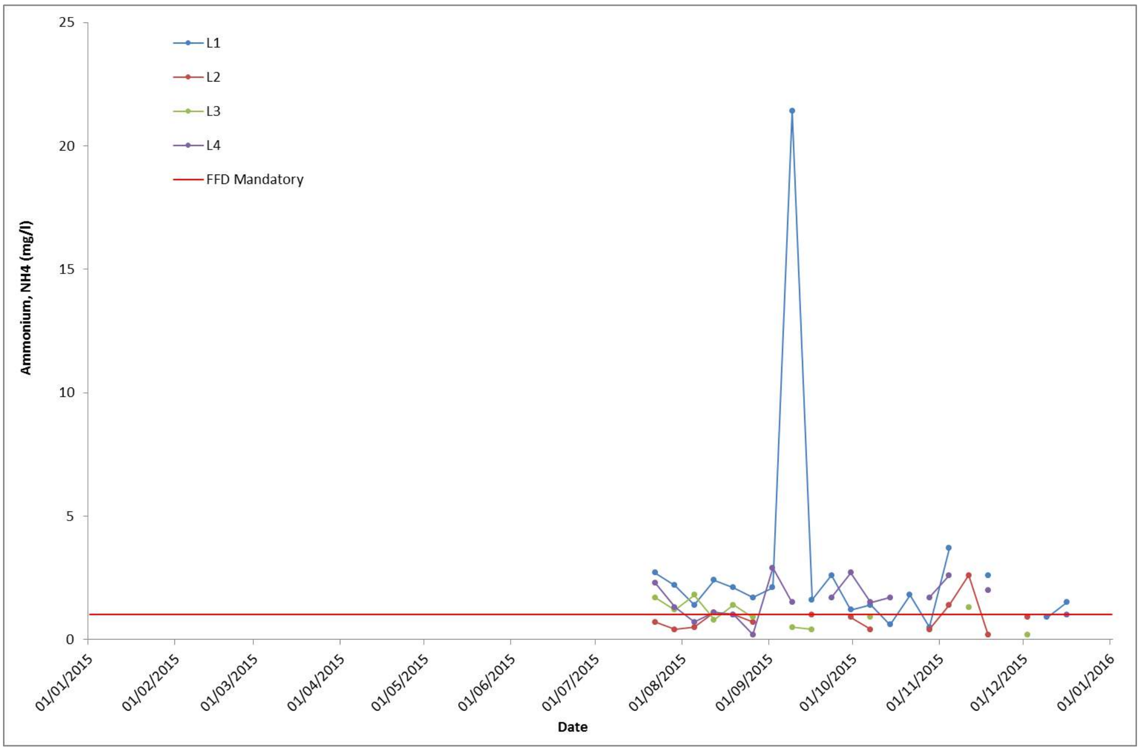


Figure 4.12 Ammonium (NH_4^+) at Lagoon drain input locations L1 to L4. Horizontal red line indicates Mandatory exceedance value for Freshwater Fish Directive.

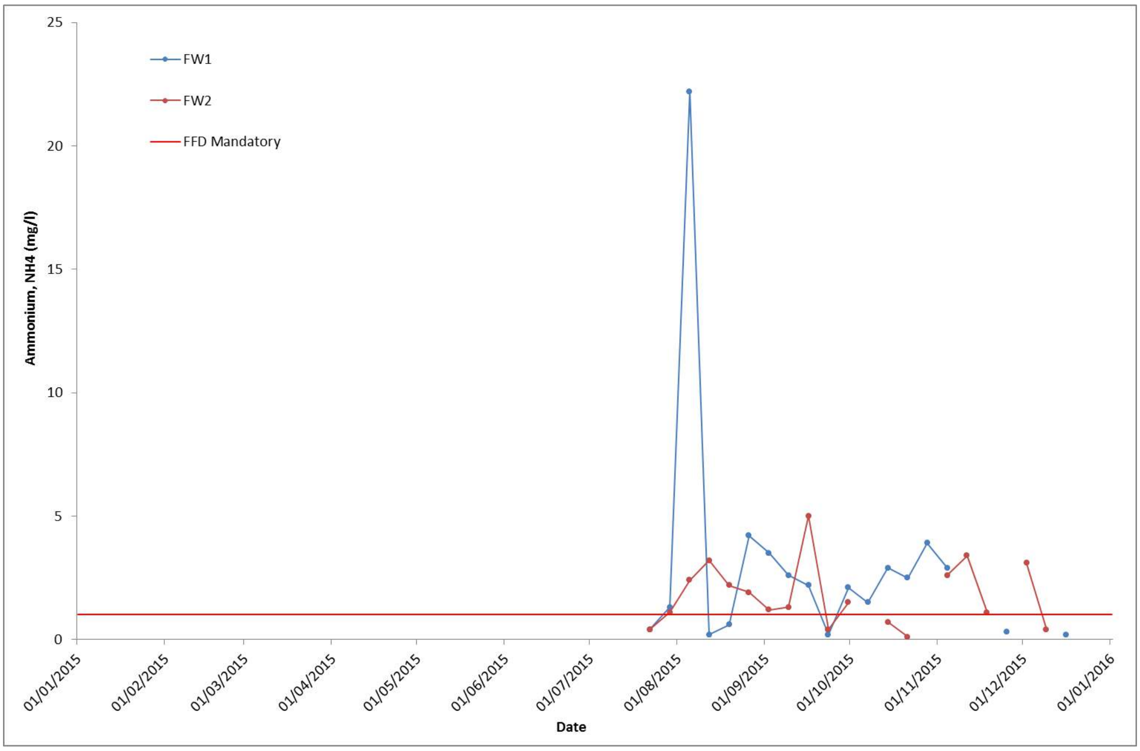


Figure 4.13 Ammonium (NH_4^+) at freshwater lake locations FW1 and FW2. Horizontal red line indicates Mandatory exceedance value for Freshwater Fish Directive.

4.1.6 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) recorded at Lagoon locations L5 and L6 is shown in Figure 4.14. Flushing events (shown as hashed grey boxes) appear to dramatically reduce BOD in the Lagoon. Maximum BOD throughout the year remained lower than the 6 mgl^{-1} Mandatory exceedance threshold stipulated in the Freshwater Fish Directive for cyprinid (e.g. carp) waters.

Although peak drain inputs at L1 and L2 exceeded 6 mgl^{-1} on two occasions, BOD was generally lower than this value throughout the year (Figure 4.15).

In contrast, BOD in freshwater lake FW1 regularly exceeded the 6 mgl^{-1} freshwater Fish Directive Mandatory threshold (Figure 4.16).

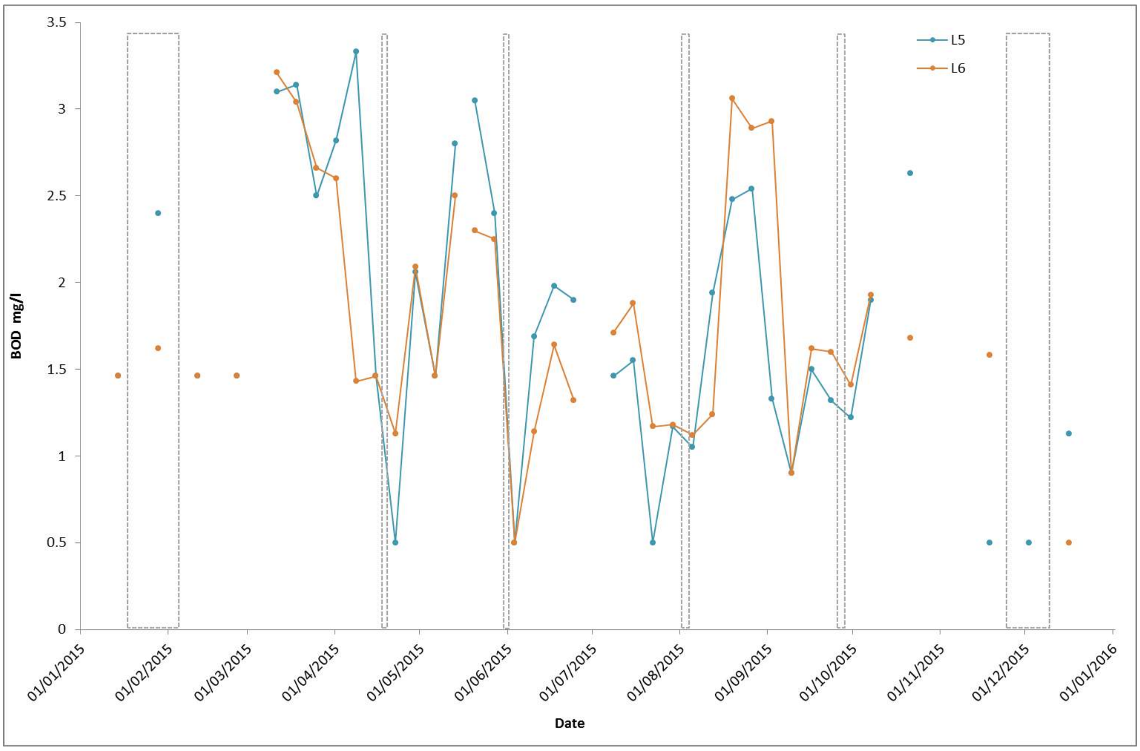


Figure 4.14 BOD at Lagoon locations L5 and L6. Hashed grey boxes indicate flushing events.

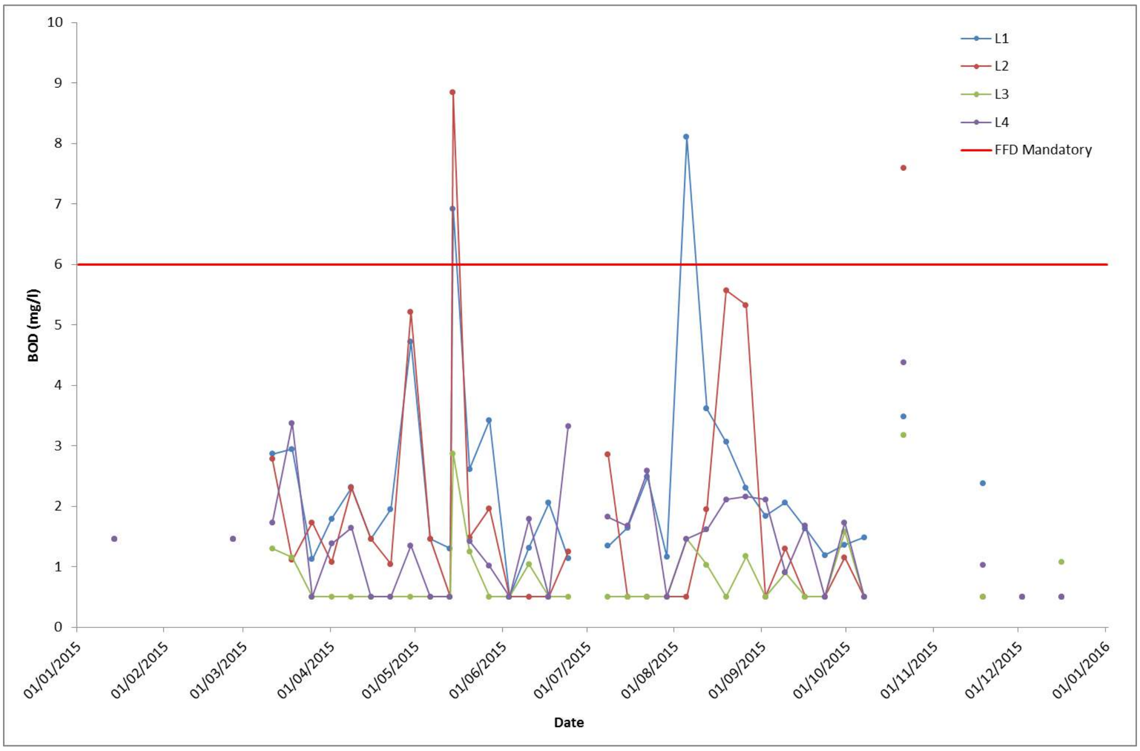


Figure 4.15 BOD at Lagoon drain input locations L1 to L4. Horizontal red line indicates Freshwater Fish Directive Mandatory exceedance value.

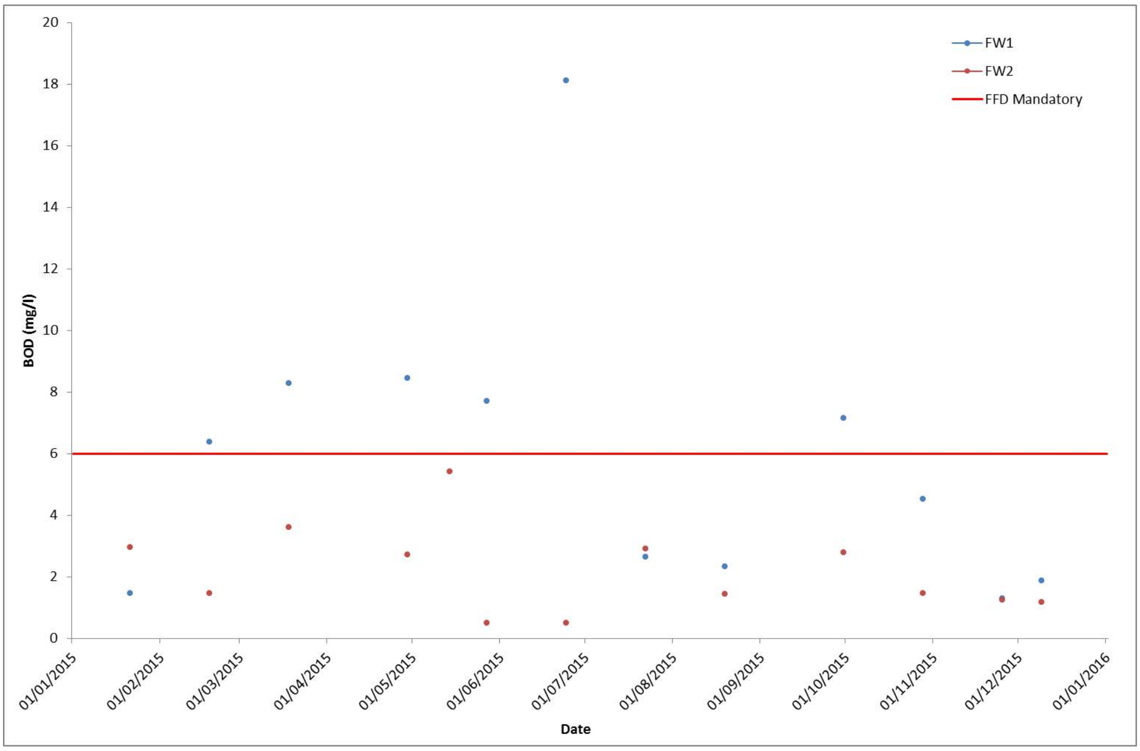


Figure 4.16 BOD at freshwater lake locations FW1 and FW2. Horizontal red line indicates Freshwater Fish Directive Mandatory exceedance value.

4.1.7 Total Nitrogen (TN)

Total nitrogen in the Lagoon was relatively low throughout the majority of the year, generally remaining below 1 mgl^{-1}. However, during the early months until the end of April, total nitrogen in both the Lagoon and Poole Harbour was comparatively high (Figure 4.17). Although total nitrogen in Poole Harbour was generally similar or higher than the Lagoon, concentrations in the Lagoon appeared to reduce post-flush.

Total nitrogen concentrations at Lagoon drain input locations L1 to L3 were high. L4 was the only drain input with relatively lower concentrations, generally below 1 mgl^{-1} (Figure 4.18).

Total nitrogen in both freshwater lakes FW1 and FW2 were elevated throughout the year (Figure 4.19).

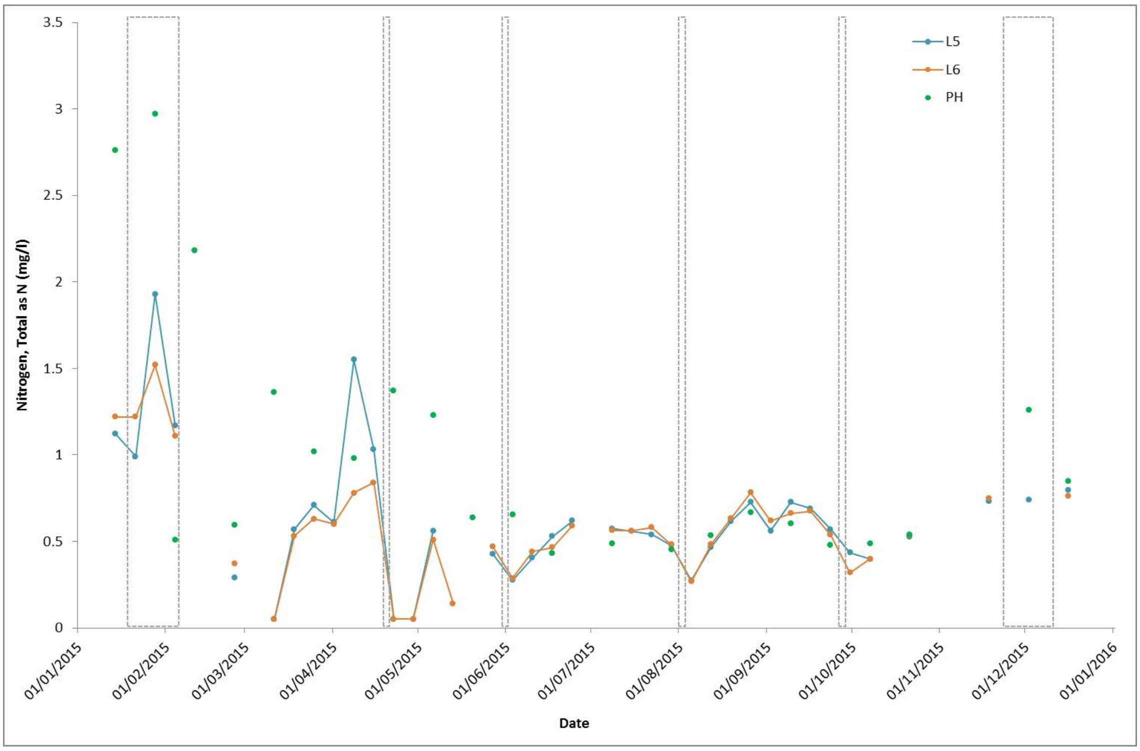


Figure 4.17 Total Nitrogen at Lagoon locations L5 and L6, and Poole Harbour location PH. Hashed grey boxes indicate flushing events.

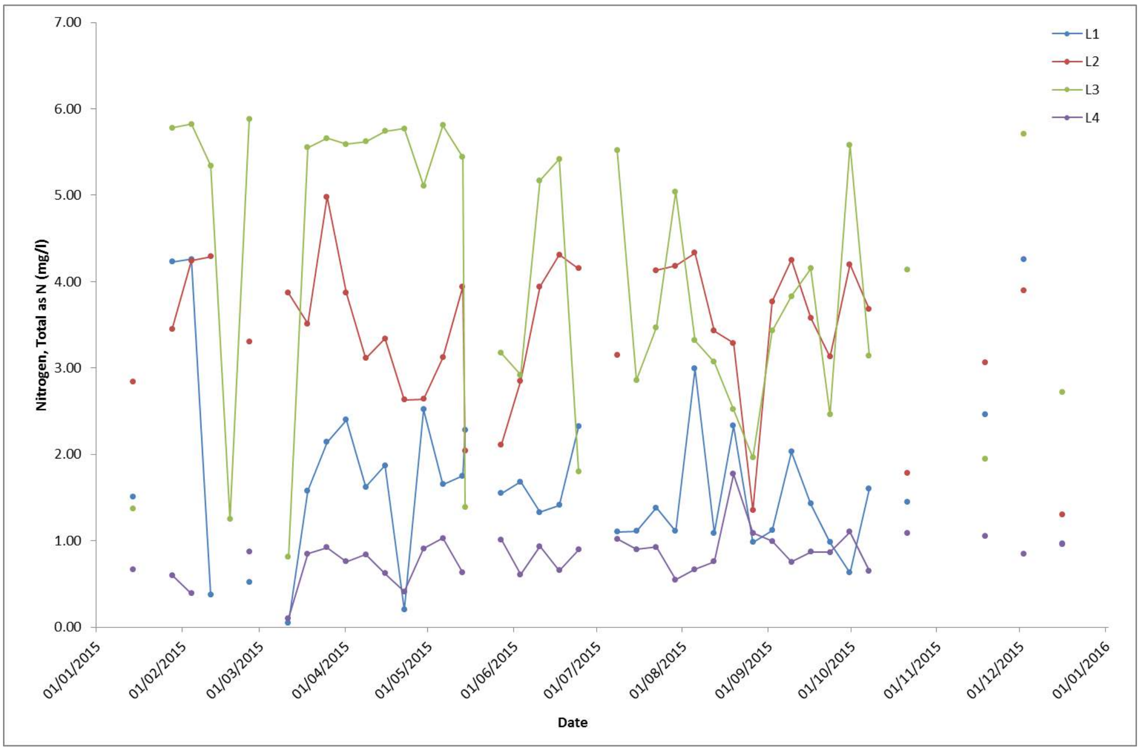


Figure 4.18 Total Nitrogen concentrations at Lagoon drain input locations L1 to L4.

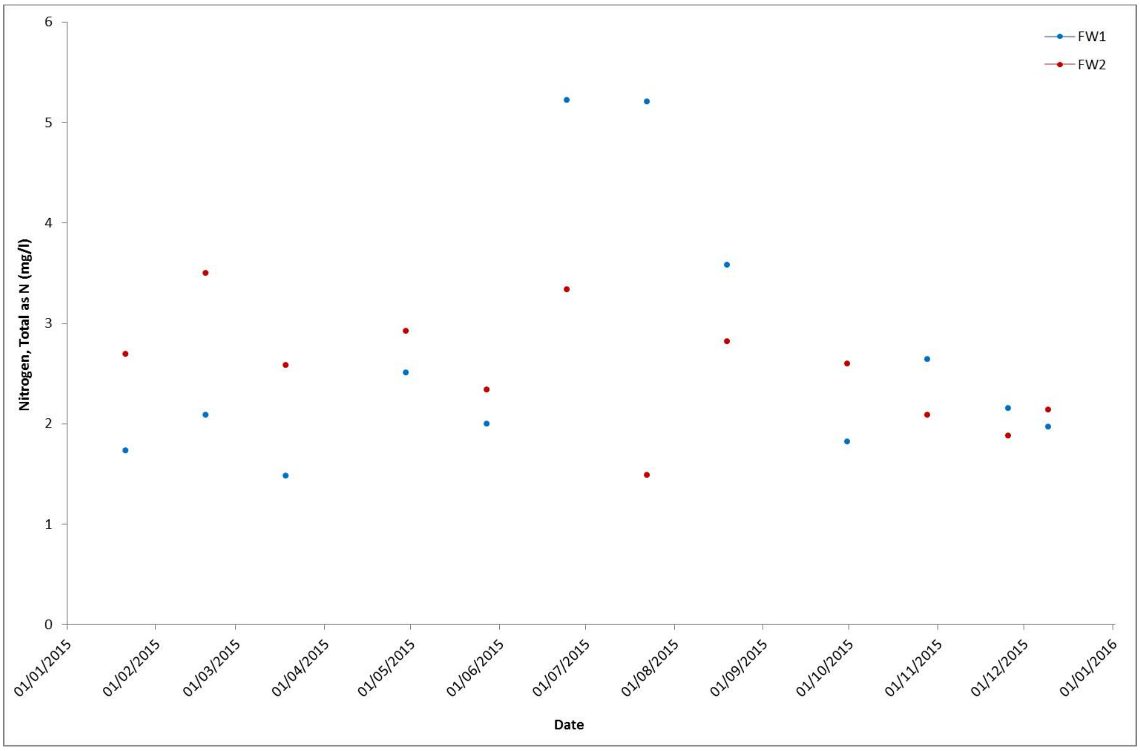


Figure 4.19 Total Nitrogen concentrations at freshwater lake locations FW1 and FW2.

4.1.8 Total Phosphorus (TP)

Total phosphorus was relatively low throughout the year, with the exception of a large peak during August and September (Figure 4.20). Although not categorised as a WFD water body; the annual mean value for L5 and L6 combined (0.058 mgl^{-1}) would classify the lake as ‘Moderate’ status with regard to TP.

Total phosphorus in Lagoon drain inputs L1 to L4 varied considerably throughout the year (Figure 4.21); most notable are three very large spikes in TP in L1, the first of which coincided with very high levels of faecal coliforms (Figure 4.30). The second two spikes do not have associated coliform data (from bi-weekly sampling).

Both freshwater lakes FW1 and FW2 exhibited elevated TP levels throughout the year (Figure 4.22). Although not categorised as a WFD water bodies; the annual mean values for FW1 and FW2 would classify both lakes as Bad status with regard to TP.

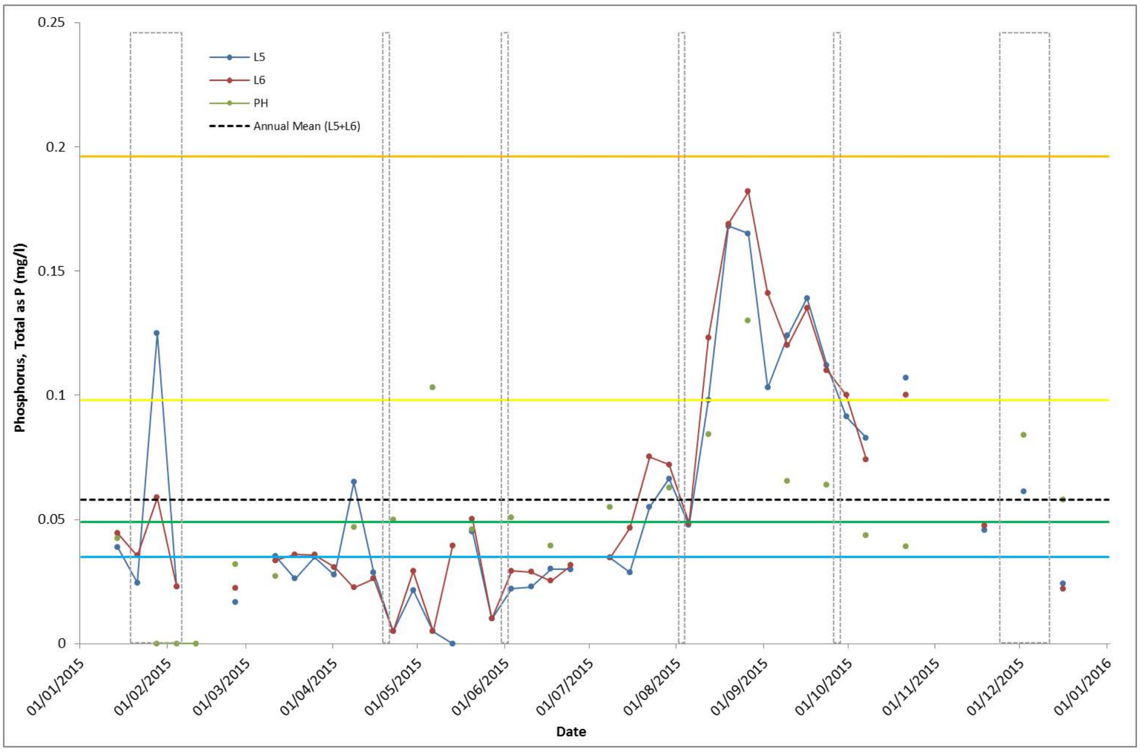


Figure 4.20 Total Phosphorus at Lagoon locations L5 and L6, and Poole Harbour location PH. Hashed grey boxes indicate flushing events. Blue, green, yellow and orange lines indicate annual mean values for WFD status of High, Good, Moderate and Poor, respectively. Hashed horizontal black line indicates annual mean for L 5 and 6.

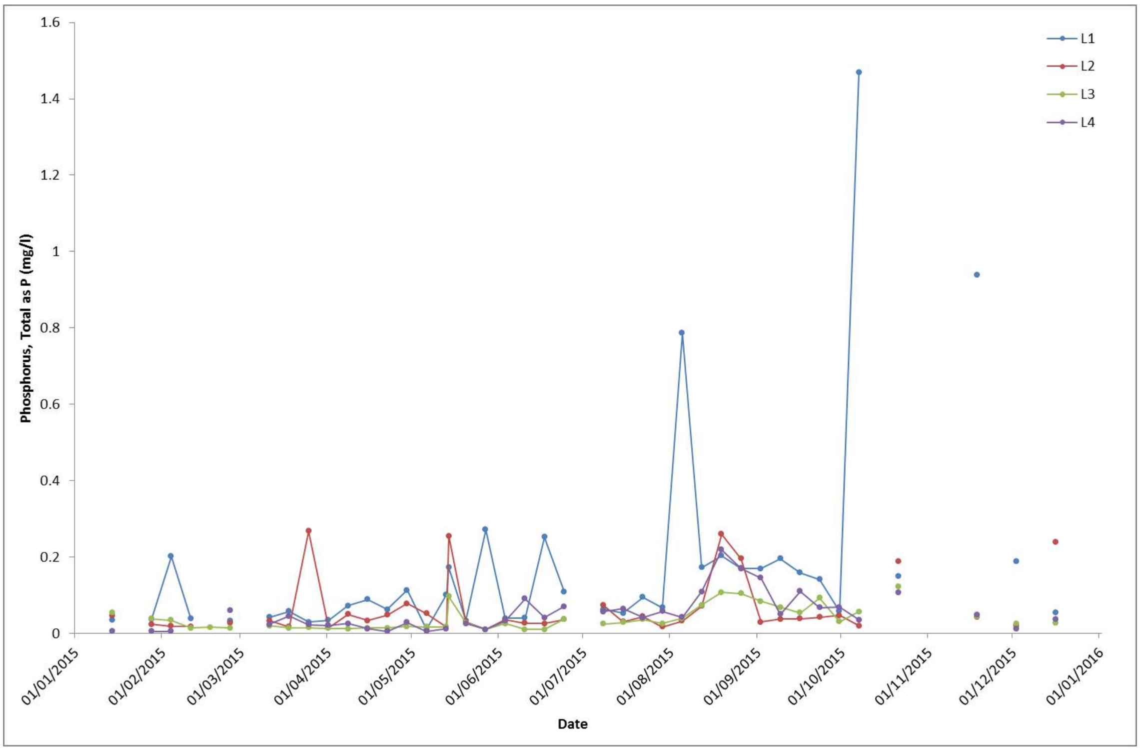


Figure 4.21 Total Phosphorus at Lagoon drain input locations L1 to L4.

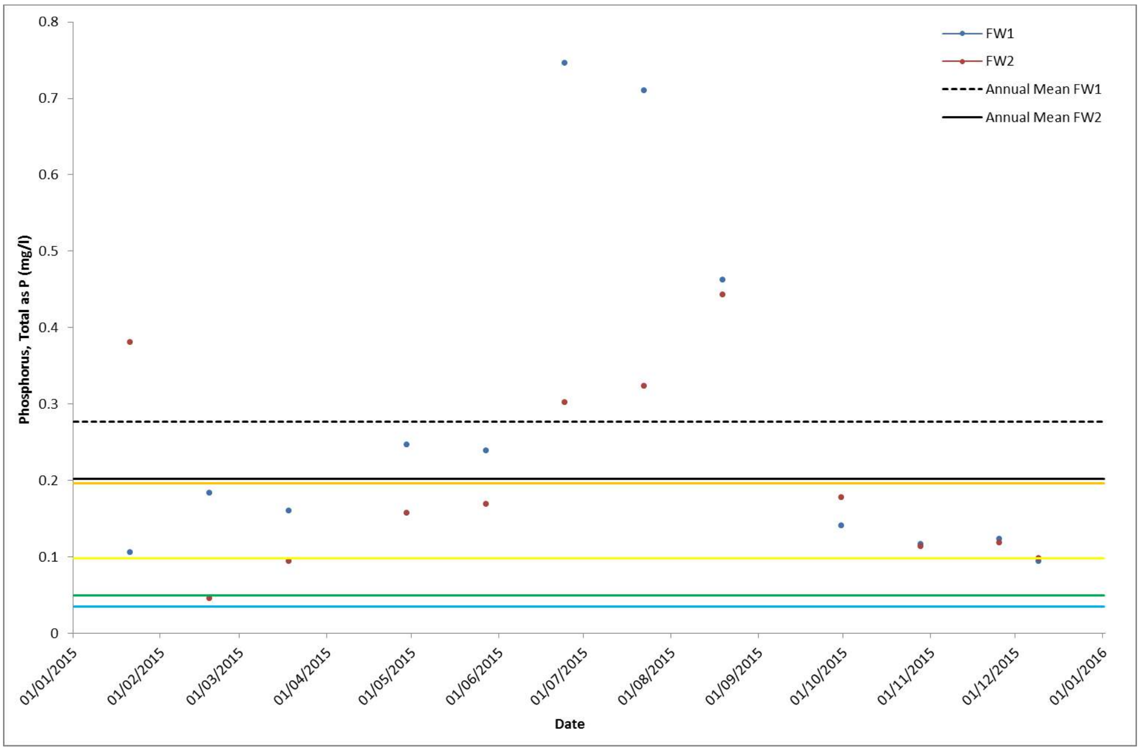


Figure 4.22 Total Phosphorus at freshwater lake locations FW1 and FW2. Blue, green, yellow and orange lines indicate annual mean values for WFD status of High, Good, Moderate and Poor, respectively. Hashed and solid horizontal black lines indicate annual mean values for FW1 and FW2, respectively.

4.1.9 Chlorophyll

Chlorophyll concentration in Poole Harbour was generally higher than in the Lagoon; however, flushing events did not appear to increase chlorophyll concentrations within the lake (Figure 4.23).

The larger freshwater lake FW1 had highly elevated chlorophyll concentrations throughout the year, whilst concentrations in FW2 were relatively low (Figure 4.24).

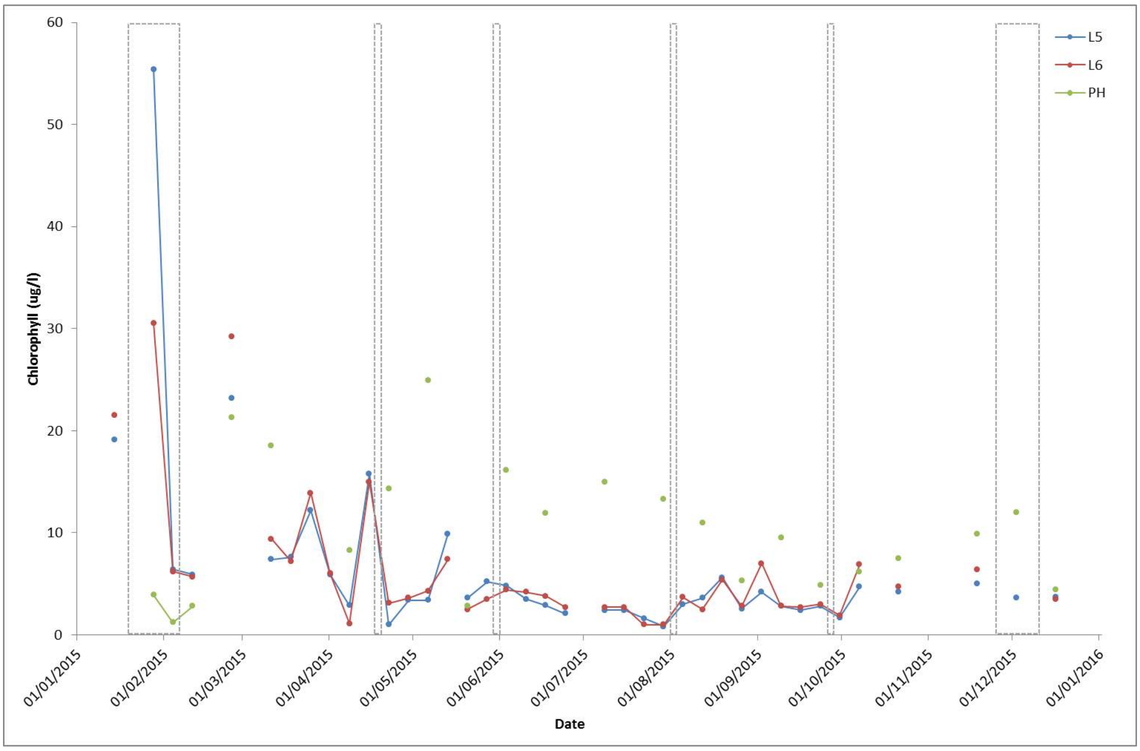


Figure 4.23 Chlorophyll at Lagoon locations L5 and L6, and Poole Harbour location PH. Hashed grey boxes indicate flushing events.

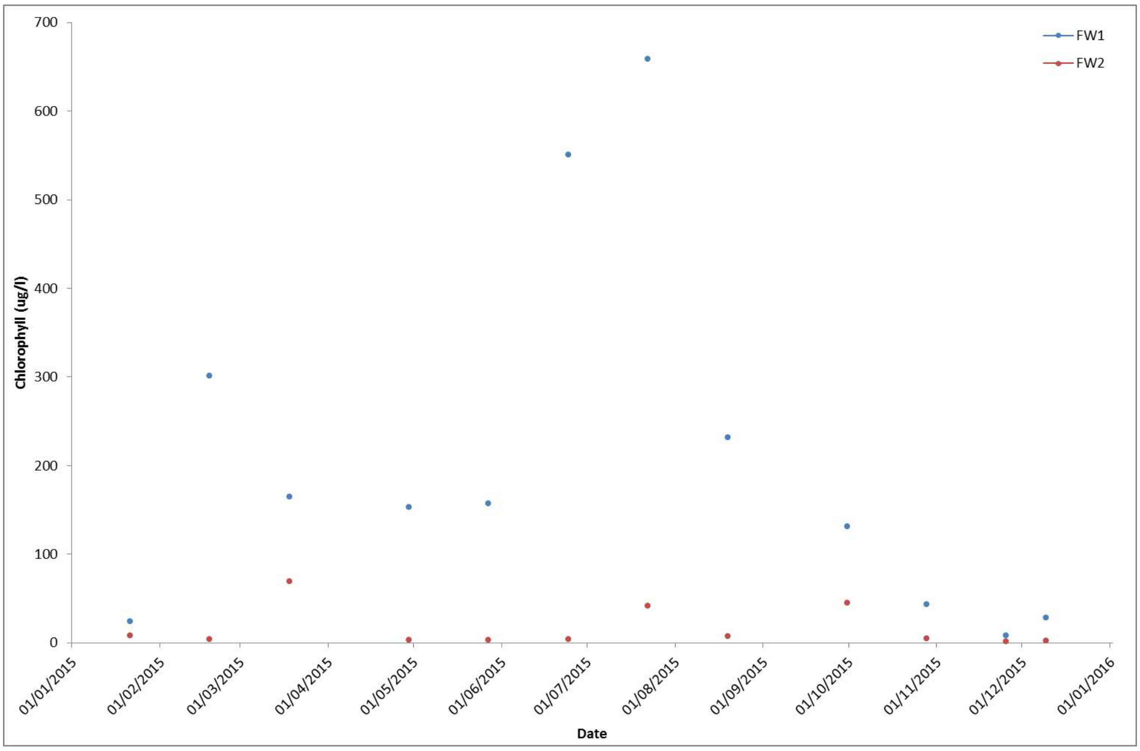


Figure 4.24 Chlorophyll at freshwater lake locations FW1 and FW2.

4.1.10 Total Suspended Solids (TSS)

The mean TSS value for L5 and L6 combined was below the Freshwater Fish Directive Guideline value. However, elevated levels of TSS are seen early in the year and during peak events associated with increased rainfall (Figure 4.25).

Lagoon drain input TSS loads varied considerably, in response to rainfall events, surface run-off and sewage treatment works discharges (Figure 4.26). Evidence of TSS inputs and lake bed scouring at Lagoon drain input L2 (the largest input by volume) can be seen in Figure 4.27.

Total Suspended Solids in freshwater lake FW1 were elevated throughout the year, with the mean value exceeding the Freshwater Fish Directive Guideline value of 25 mgl^{-1}. In contrast, fresh water lake FW2 fell within Freshwater Fish Directive Guidelines, with only a few larger peaks (Figure 4.28).

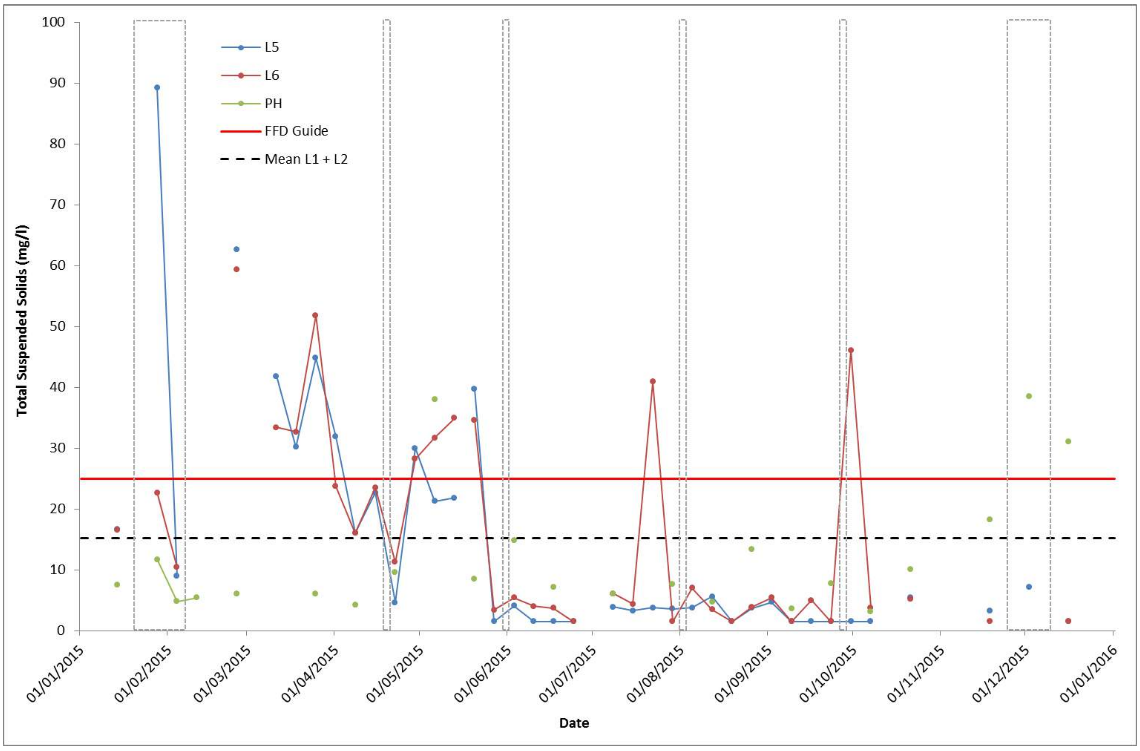


Figure 4.25 Total Suspended Solids at Lagoon locations L5 and L6, and Poole Harbour location PH. Hashed grey boxes indicate flushing events. Horizontal red line indicates Guideline mean value for Freshwater Fish Directive. Hashed black line indicates mean L5 + L6.

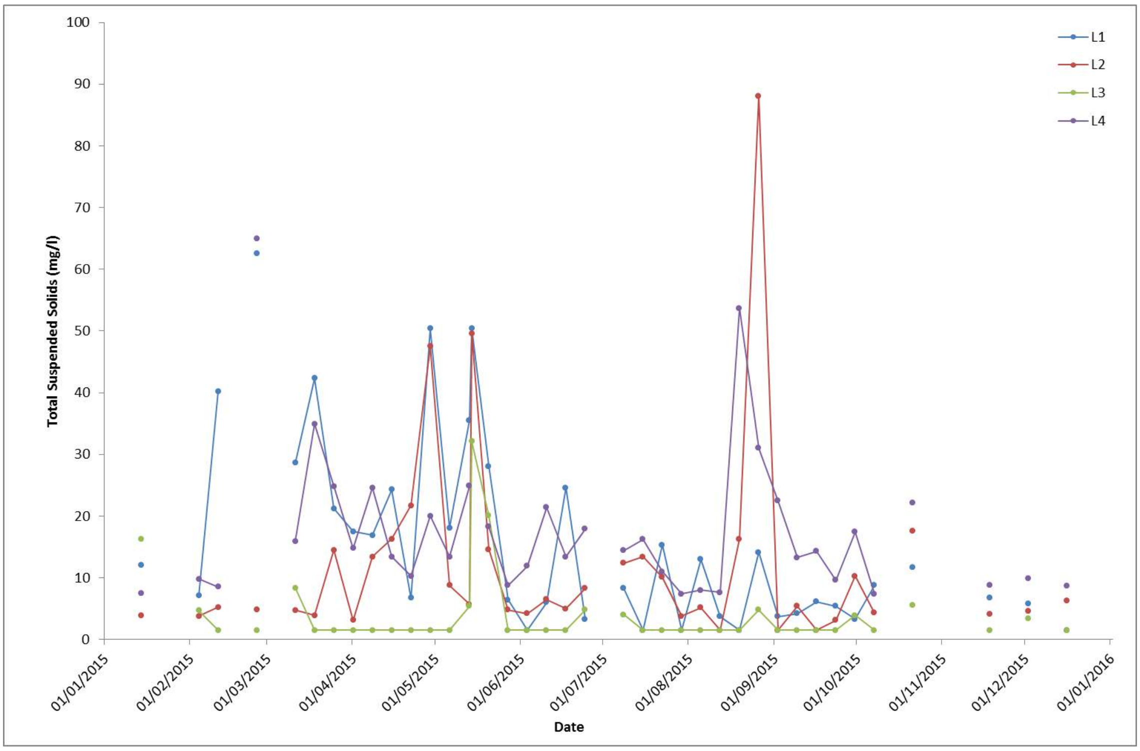


Figure 4.26 Total Suspended Solids at Lagoon drain input locations L1 to L4.

Figure 4.27 Evidence of suspended solid input and lake bed scouring at L2 during a drain down.

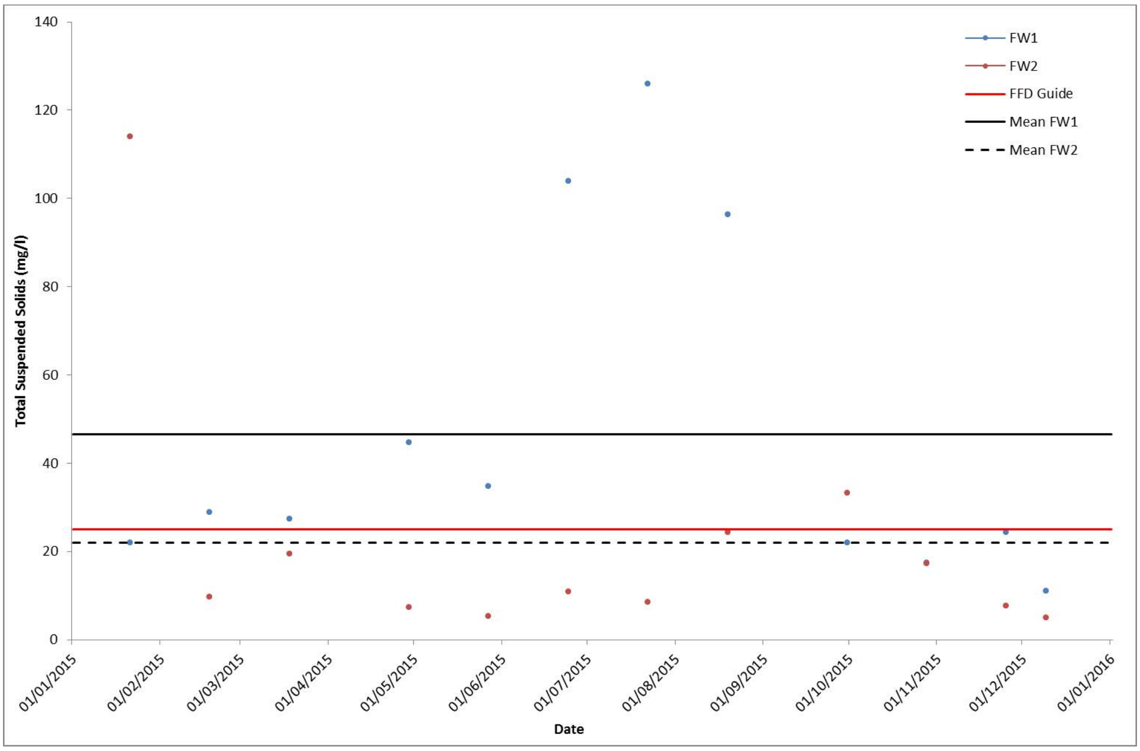


Figure 4.28 Total Suspended Solids at freshwater lake locations FW1 and FW2. Horizontal red line indicates Guideline mean value for Freshwater Fish Directive. Solid and hashed black lines indicate mean values for FW1 and FW2 respectively.

4.1.11 Coliforms, Faecal

Faecal coliform concentrations were relatively low in the main Lagoon at locations L5 and L6, falling below the 90th-percentile exceedance thresholds outlined in the EC Bathing Waters Directive (Figure 4.34).

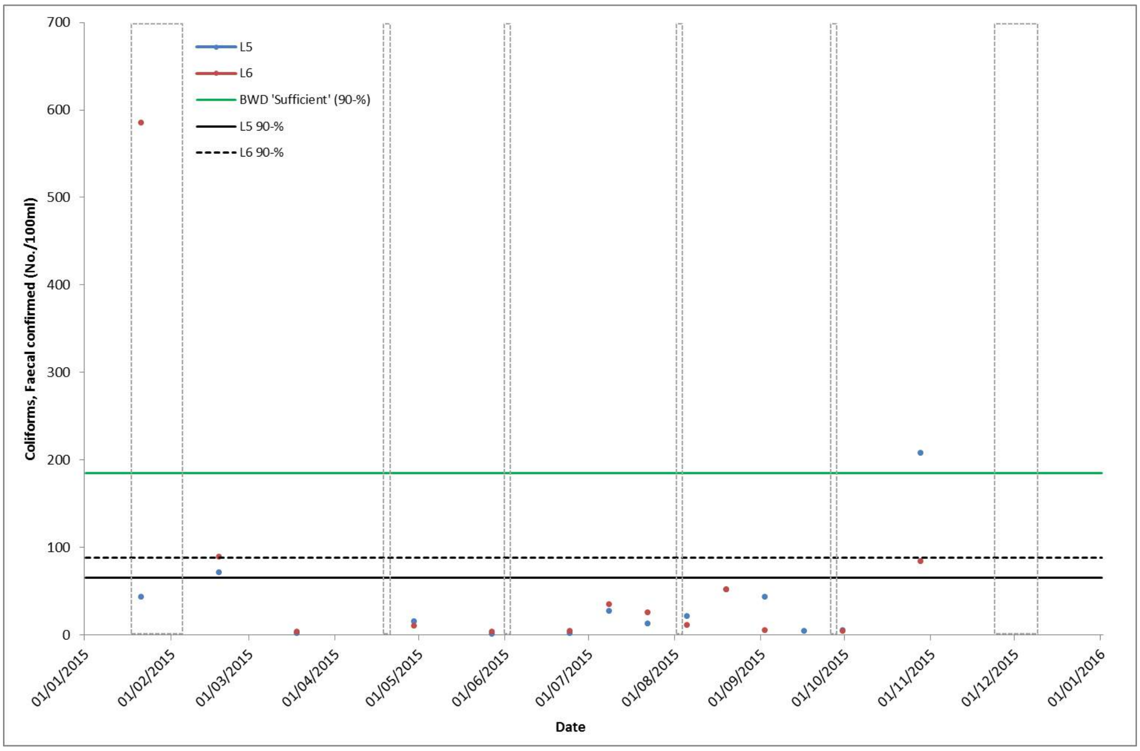


Figure 4.29 Faecal Coliforms at Lagoon locations L5 and L6. Hashed grey boxes indicate flushing events. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid and hashed black lines indicate 90th percentiles for L5 and L6, respectively.

All Lagoon drain inputs sampled exhibited faecal coliform concentrations in excess of the exceedance thresholds outlined in the Bathing Water Directive (Figure 4.30 to Figure 4.35). In particular, considerably high levels were recorded at L1, L2 and L4.

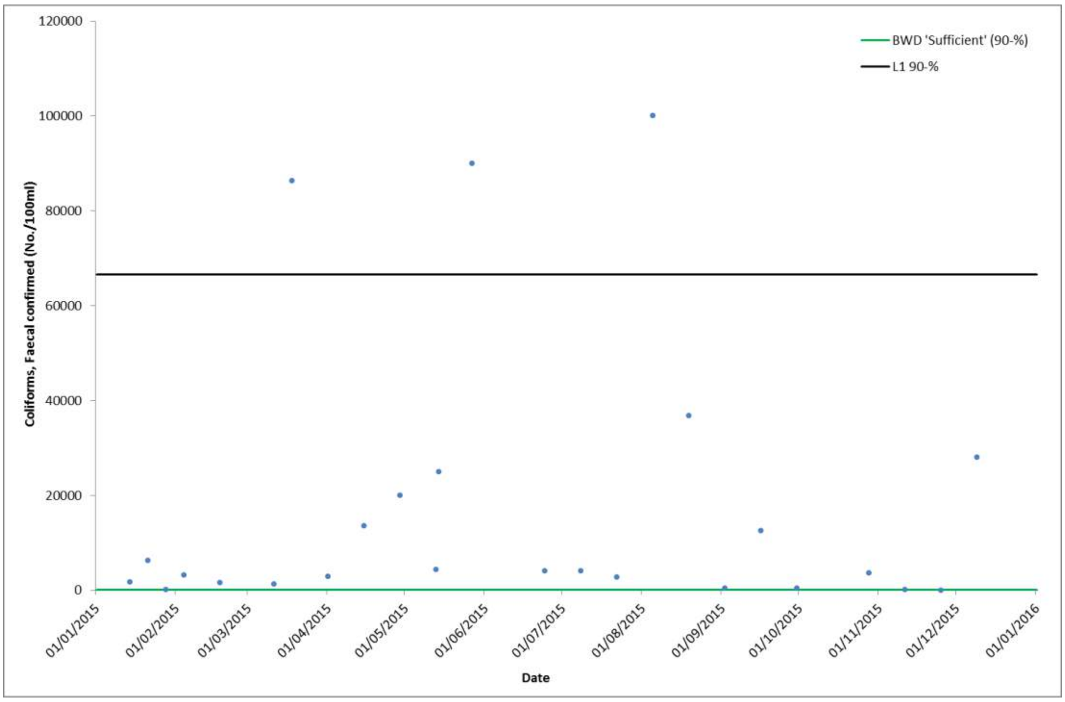


Figure 4.30 Faecal Coliforms at Lagoon drain input location L1. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L1.

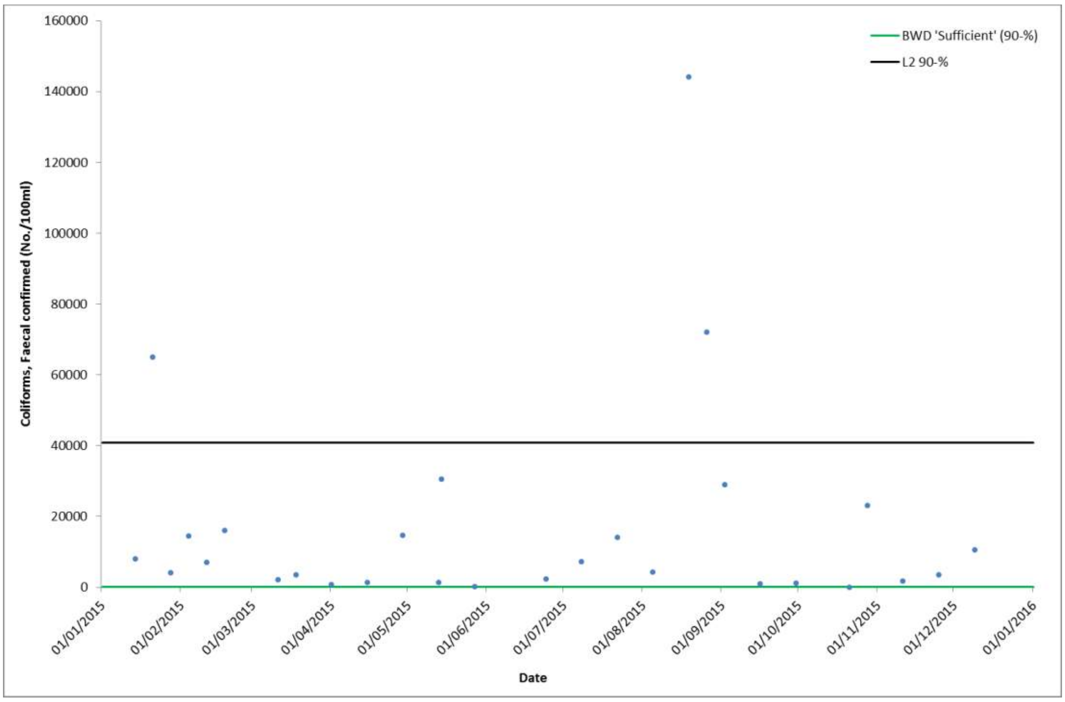


Figure 4.31 Faecal Coliforms at Lagoon drain input location L2. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L2.

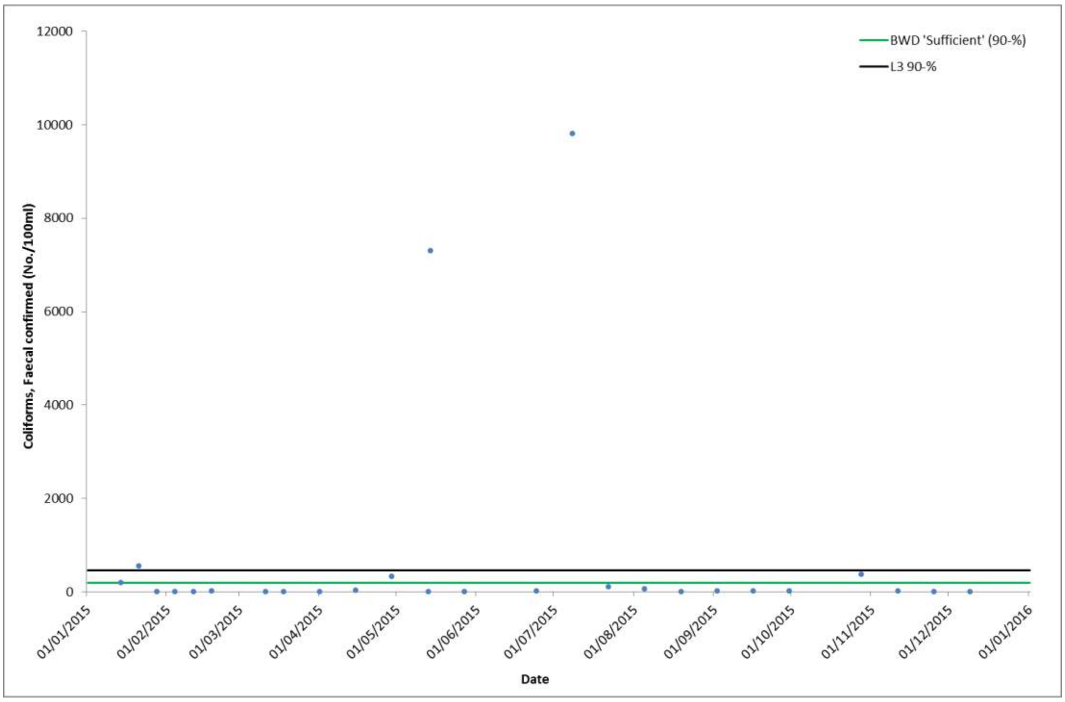


Figure 4.32 Faecal Coliforms at Lagoon drain input location L3. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L3.

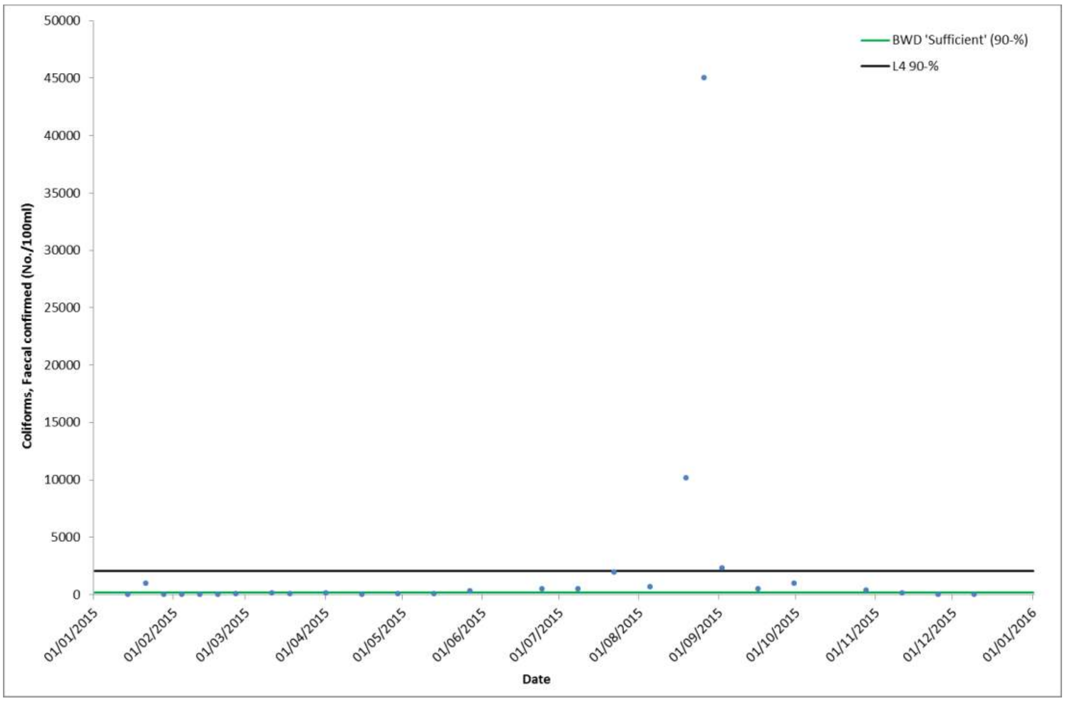


Figure 4.33 Faecal Coliforms at Lagoon drain input location L4. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L4.

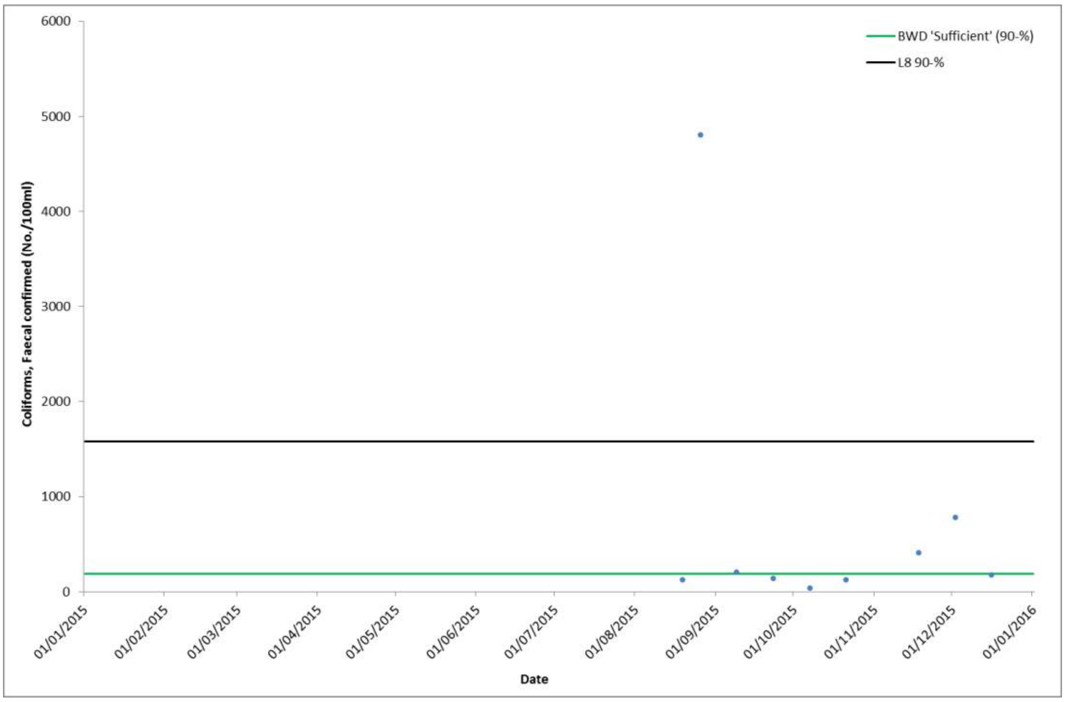


Figure 4.34 Faecal Coliforms at Lagoon drain input location L8. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L8.

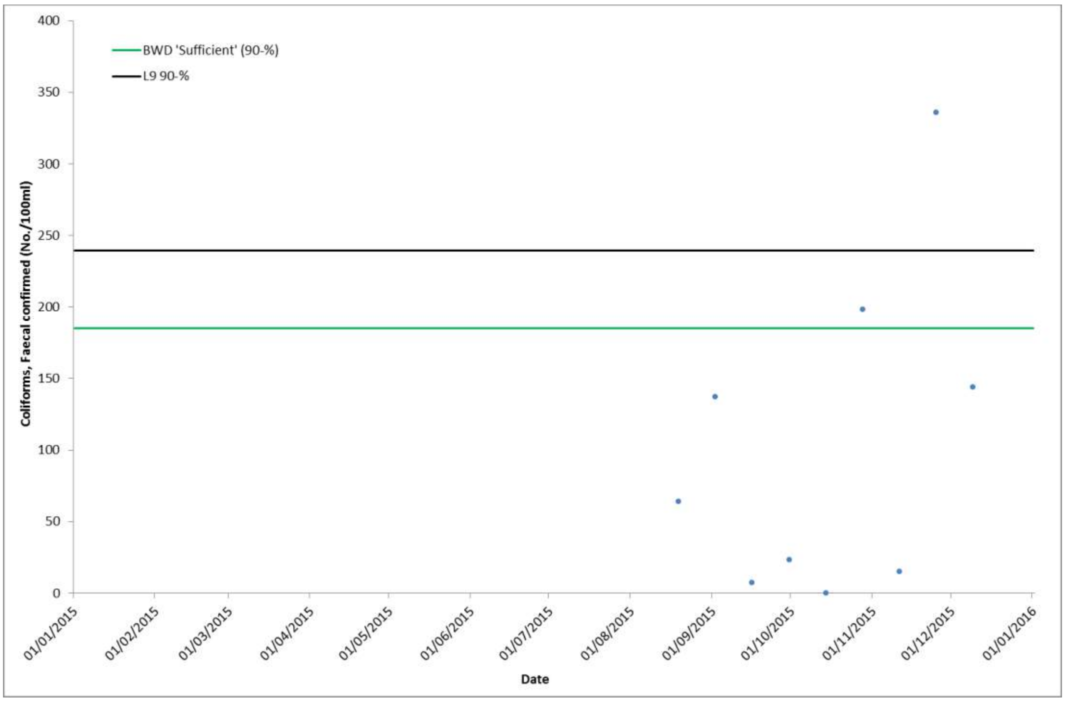


Figure 4.35 Faecal Coliforms at Lagoon location L9. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L9.

4.1.12 Escherichia coli (*E. coli*)

All Lagoon drain inputs sampled exhibited *E. coli* concentrations in excess of the exceedance thresholds outlined in the Bathing Water Directive (Figure 4.36 to Figure 4.41). In particular, considerably high levels were recorded at L1, L2 and L4. In contrast, *E.coli* levels at L9 were relatively low.

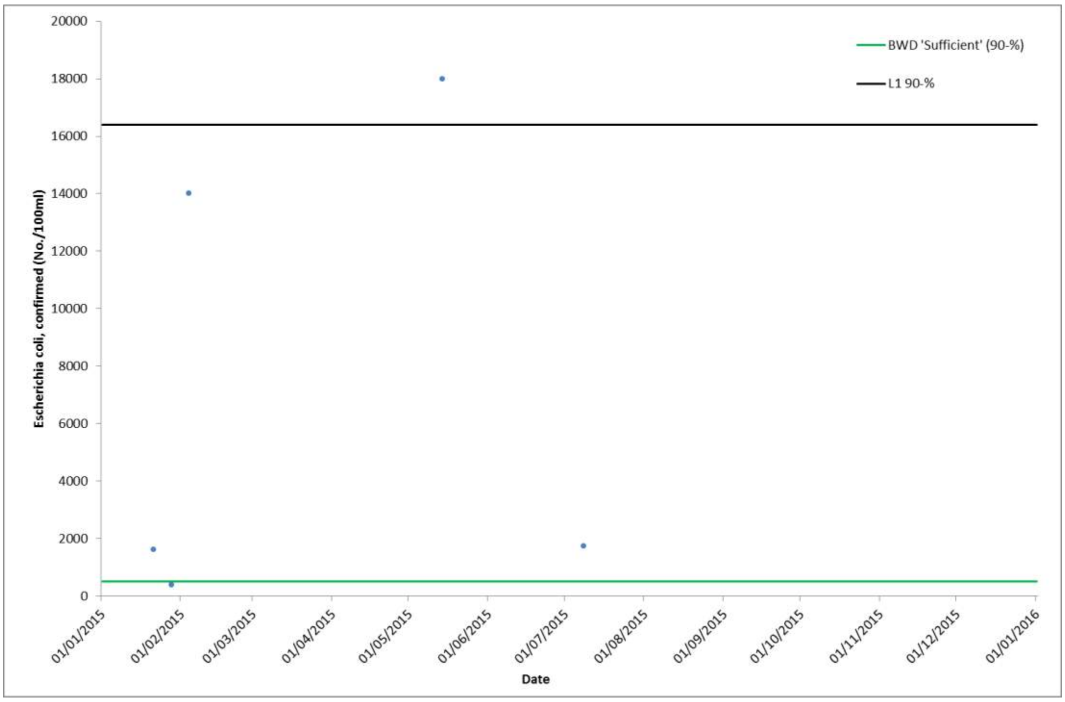


Figure 4.36 *Escherichia coli* at Lagoon drain input location L1. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L1.

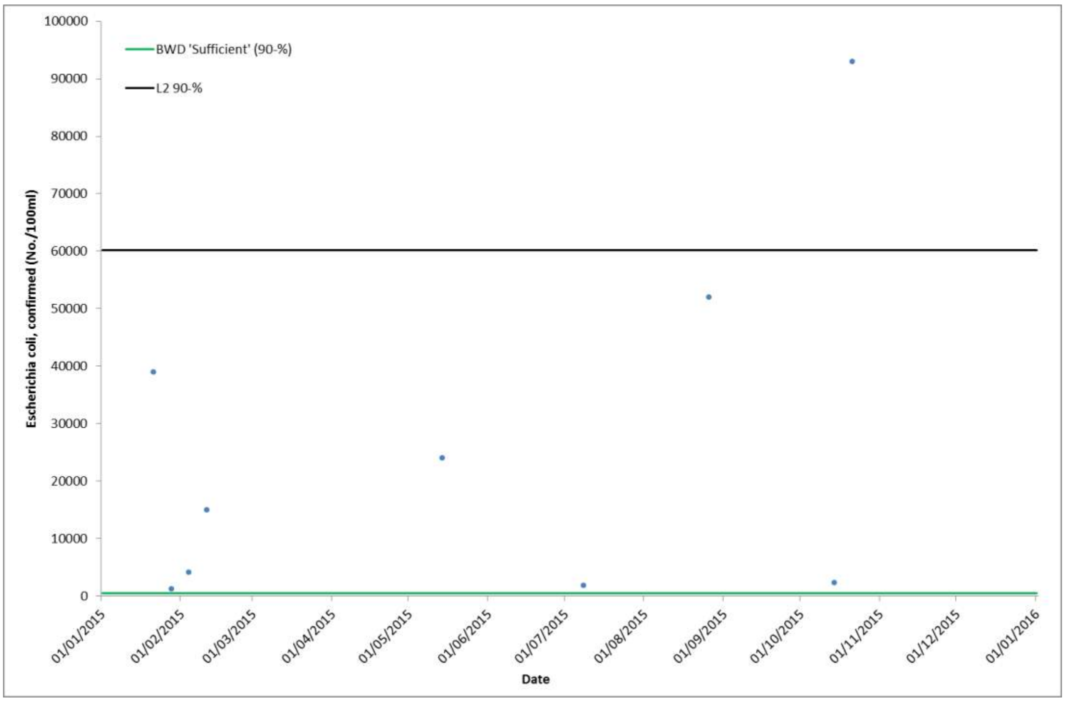


Figure 4.37 ***Escherichia coli*** **at Lagoon drain input location L2. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L2.**

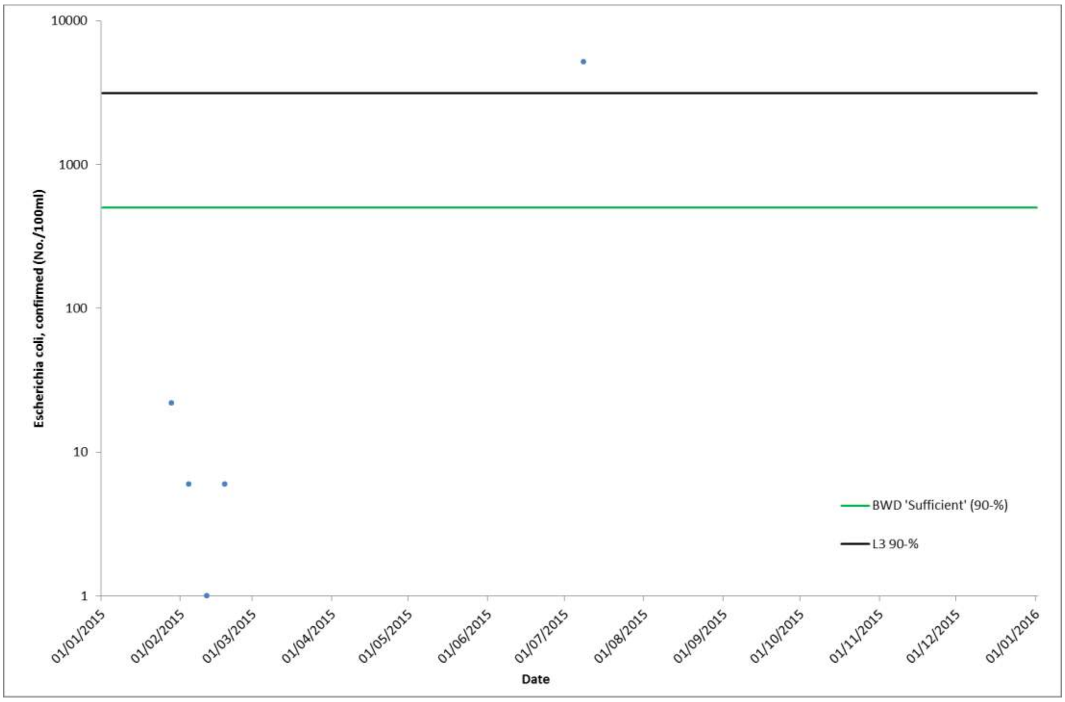


Figure 4.38 ***Escherichia coli*** **at Lagoon drain input location L3. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L3.**

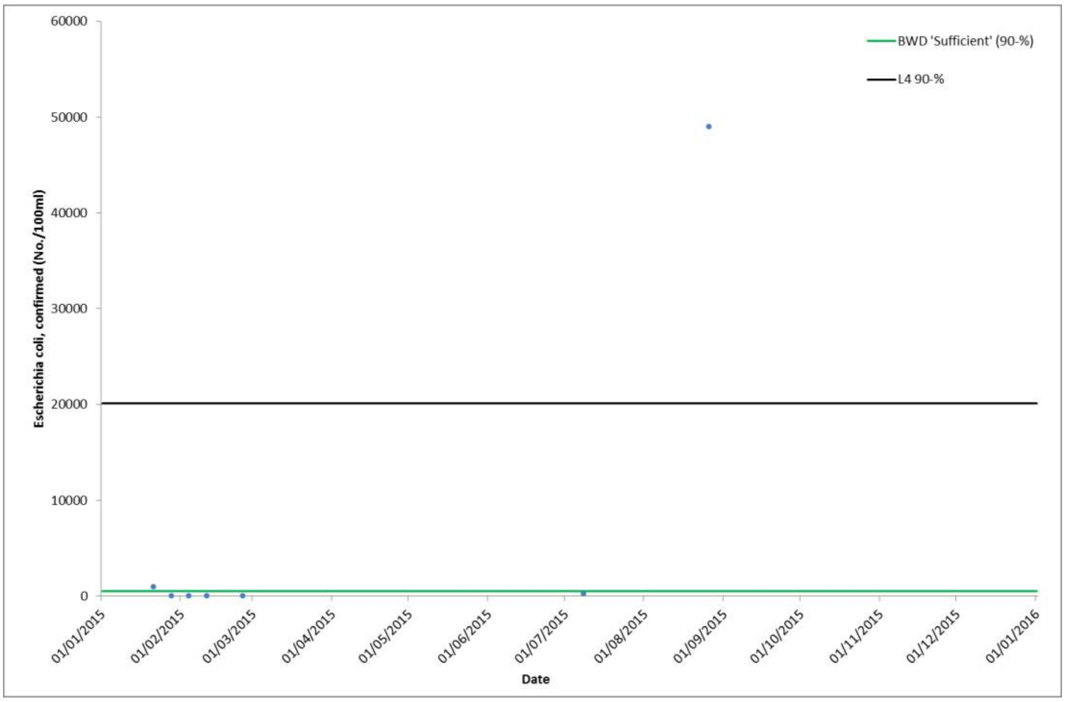


Figure 4.39 ***Escherichia coli*** **at Lagoon drain input location L4. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L4.**

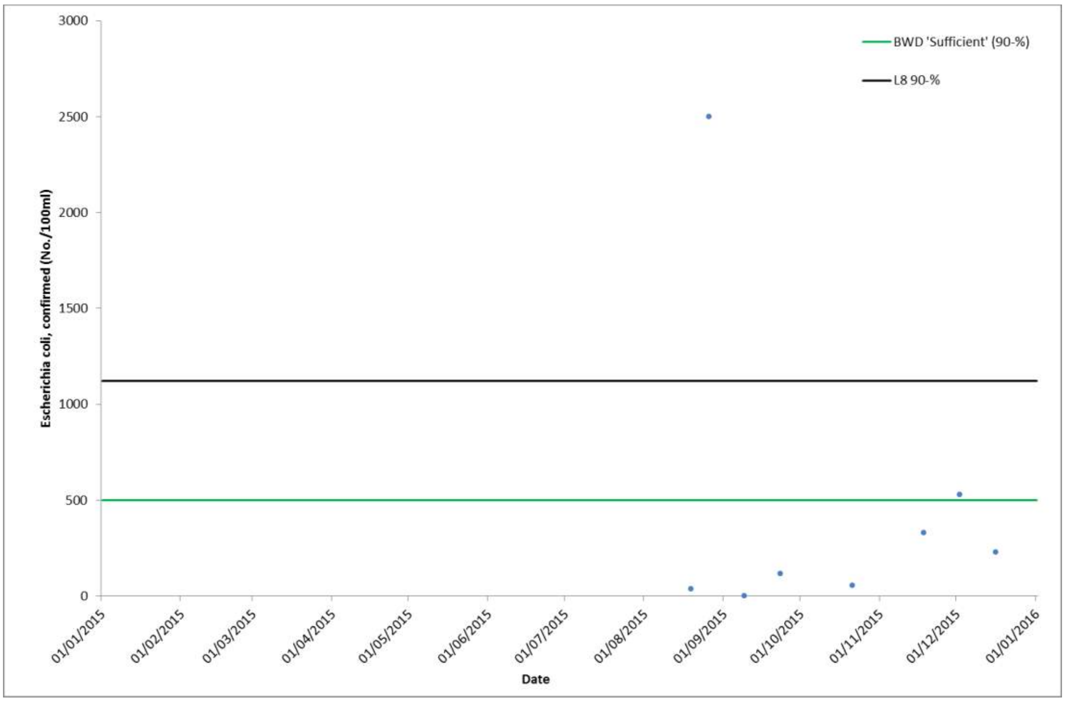


Figure 4.40 ***Escherichia coli*** **at Lagoon drain input location L8. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L8.**

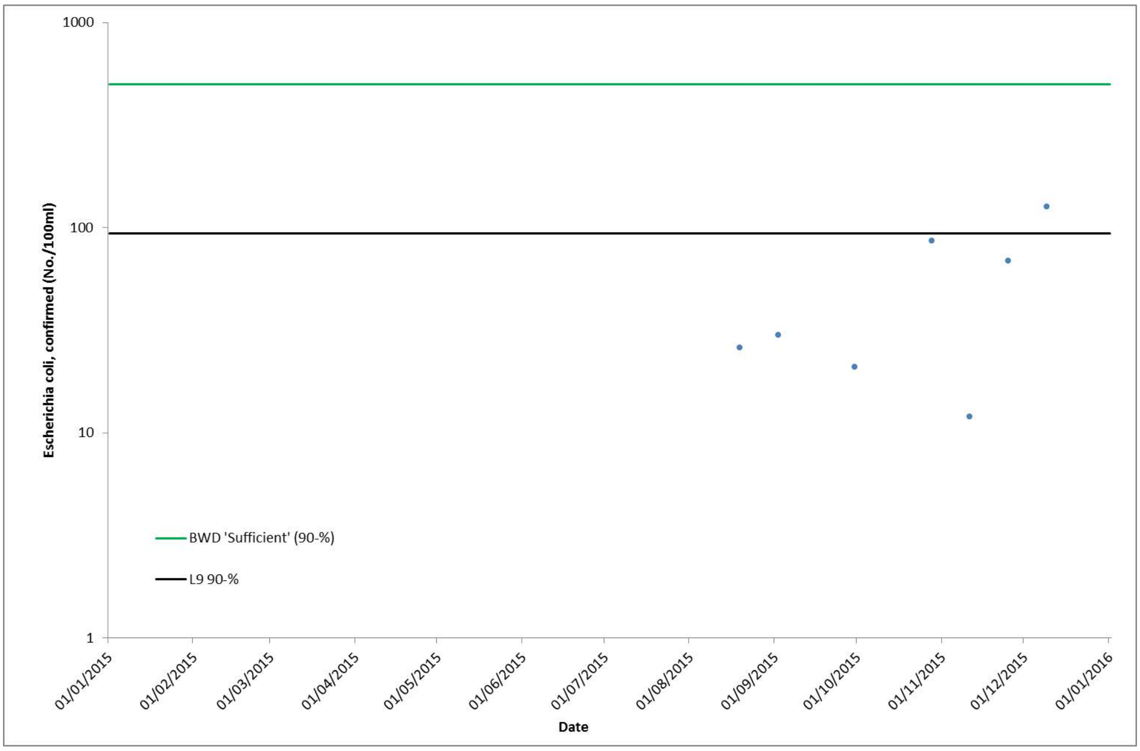


Figure 4.41 *Escherichia coli* at Lagoon location L9. Horizontal green line indicates 90th percentile for 'Sufficient' quality for the Bathing Water Directive. Solid black line indicates 90th percentile for L9.

4.2 Water quality – continuous monitoring

In addition to weekly water quality sampling, data were collected in-situ every 10 minutes from 23rd September 2015 to 14th October 2015 using a YSI 6600 V2 Multi-Parameter Water Quality Sonde placed in the centre of the Lagoon. Sections 4.2.1 to 4.2.3 show the continuous monitoring data for salinity, dissolved oxygen and pH.

4.2.1 Salinity

Salinity data collected using the in-situ sonde exhibited the same patterns as those recorded during weekly monitoring; however, the increased resolution of data collection provides a more detailed picture of salinity patterns between flushing events (Figure 4.42). For example, a three-day rainfall event from 4th to 6th October is reflected in a corresponding drop in salinity within the Lagoon.

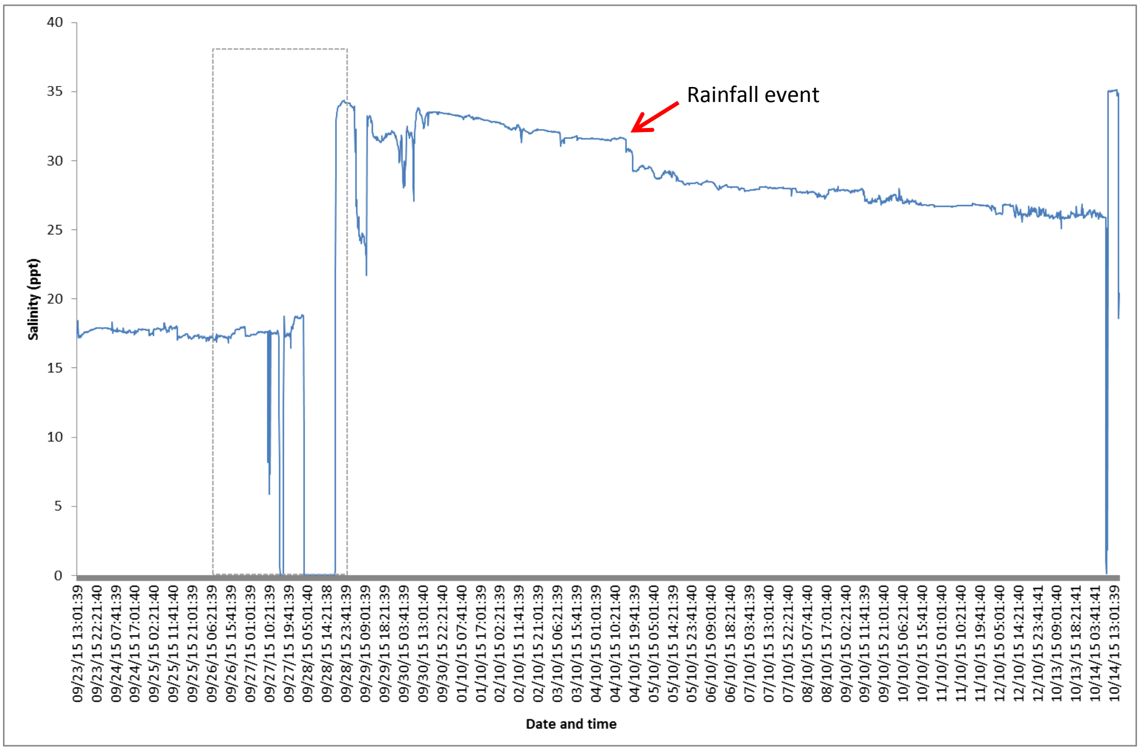


Figure 4.42 Salinity in the Lagoon measured in-situ using a multi-parameter water quality sonde. Hashed grey box indicates flushing event.

4.2.2 Dissolved oxygen

Although Figure 4.8 shows dissolved oxygen to remain relatively high throughout the year; these weekly data (taken during the day) do not show the diurnal variation that occurs as a result of algal and plant production.

Figure 4.43 below highlights the considerable diurnal variation in dissolved oxygen levels recorded by the in-situ sonde. On several occasions, dissolved oxygen fell to critical levels during the night.

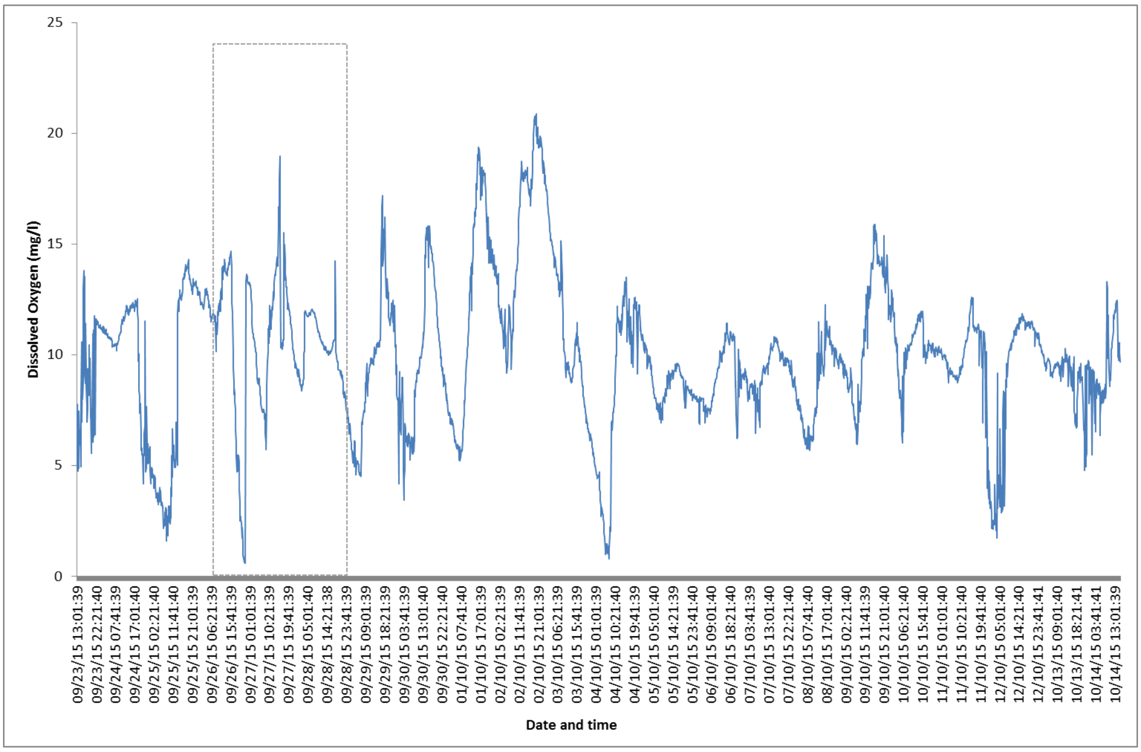


Figure 4.43 Dissolved oxygen in the Lagoon measured in-situ using a multi-parameter water quality sonde. Hashed grey box indicates flushing event.

4.2.3 pH

Figure 4.44 below shows the pH data collected in-situ using the multi-parameter sonde. Pre-flush values reflect those high values recorded during weekly water quality sampling, with a post-flush reduction in pH evident.

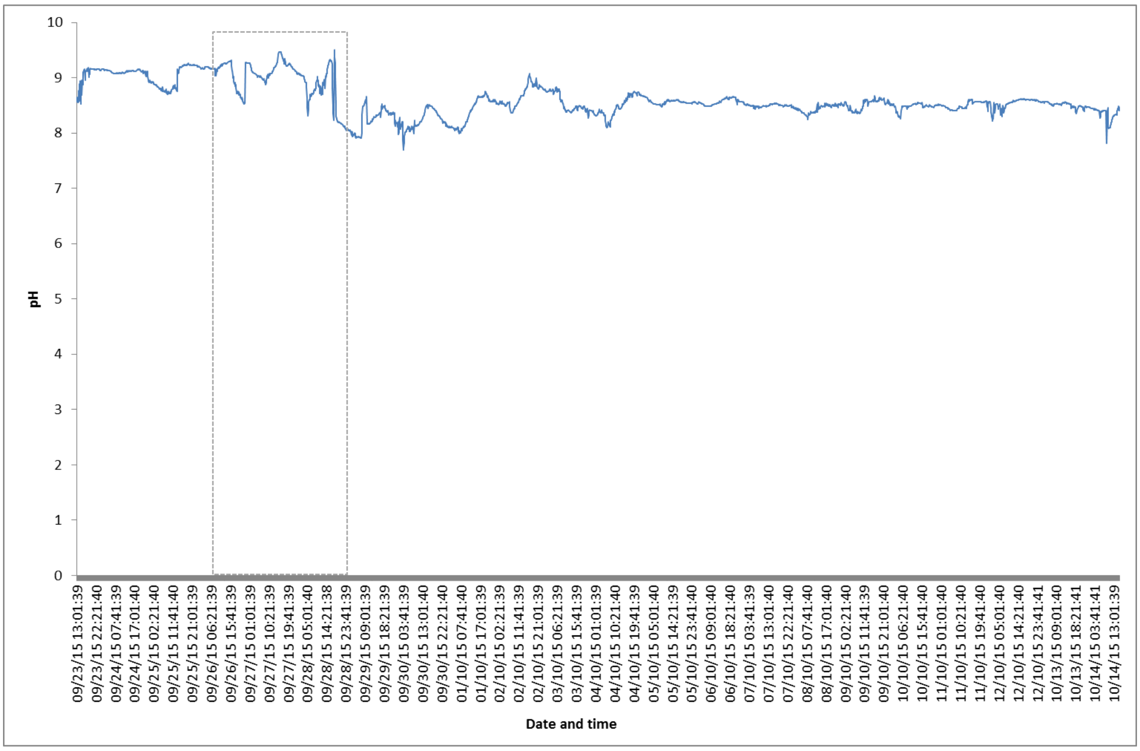


Figure 4.44 pH in the Lagoon measured in-situ using a multi-parameter water quality sonde. Hashed grey box indicates flushing event.

4.3 Sediment quality

Using a 10cm^2 corer, sediment samples were collected from the non-drain input sites of the Lagoon and the freshwater lakes on the following two dates:

- 10th June 2015 (Nutrients only) – L5, L6, FW1, FW2
- 14th October 2015 (Nutrients and metals) – L5, L6, FW1, FW2

With particular reference to the high metal loadings recorded from the middle of the Lagoon (L5 & L6), further strategic sampling was conducted in the vicinity of the four main drain inputs (L1 –L4) to investigate potential spatial sources of these contaminants. This targeted survey was conducted on a single occasion as detailed below:

- 18th November 2015 (Nutrients and metals) – L1, L2, L3, L4

The nutrient suite included laboratory analysis of the following determinands:

- Soil Organic Matter (SOM)
- Orthophosphate
- Phosphorus
- Nitrogen
- Dry solids
- Organic carbon

The metals suite included laboratory analysis of the following key determinands:

- Arsenic
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Zinc
- Iron

All sediment samples were collected and stored in appropriate pre-labelled containers, before being securely packaged and delivered to the UKAS accredited National Laboratory Service (NLS) for analysis.

4.3.1 Sediment Soil Organic Matter (SOM)

Soil organic matter levels in the Lagoon and freshwater lakes are shown in Figure 4.45 and Figure 4.46, respectively. Organic matter constituted a higher proportion of sediment in the middle of the lake (L5 and L6) than in the vicinity of the drain inputs.

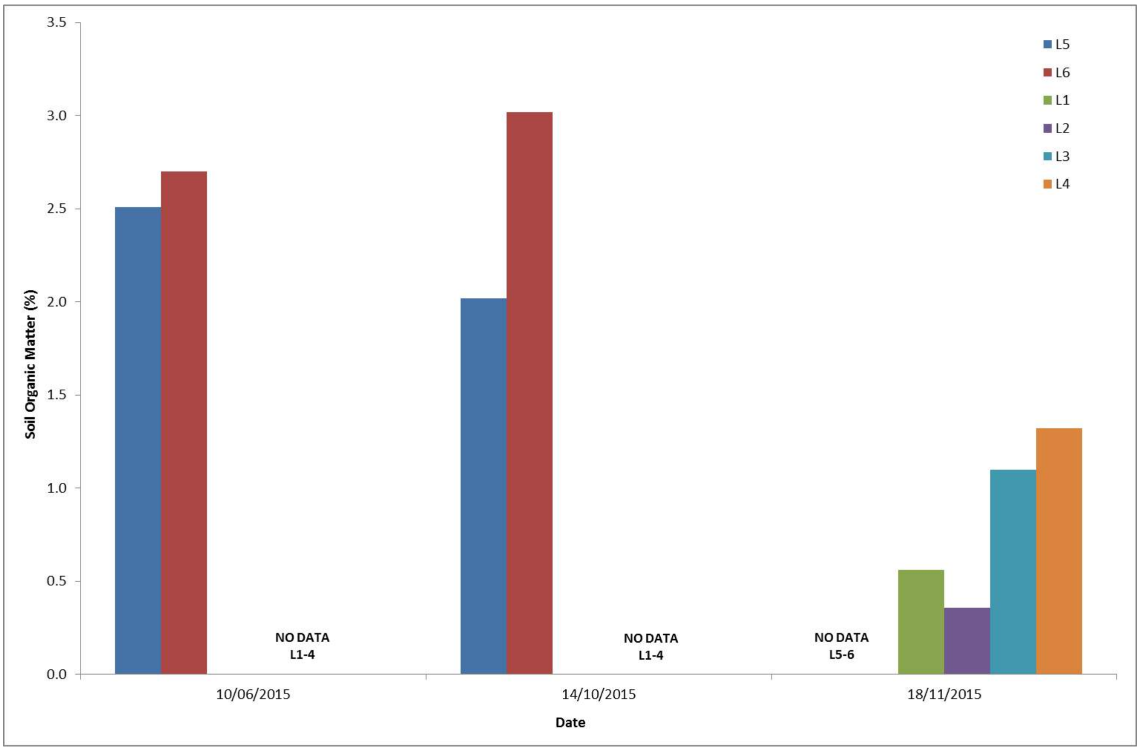


Figure 4.45 Sediment Soil Organic Matter at Lagoon locations L1 to L6.

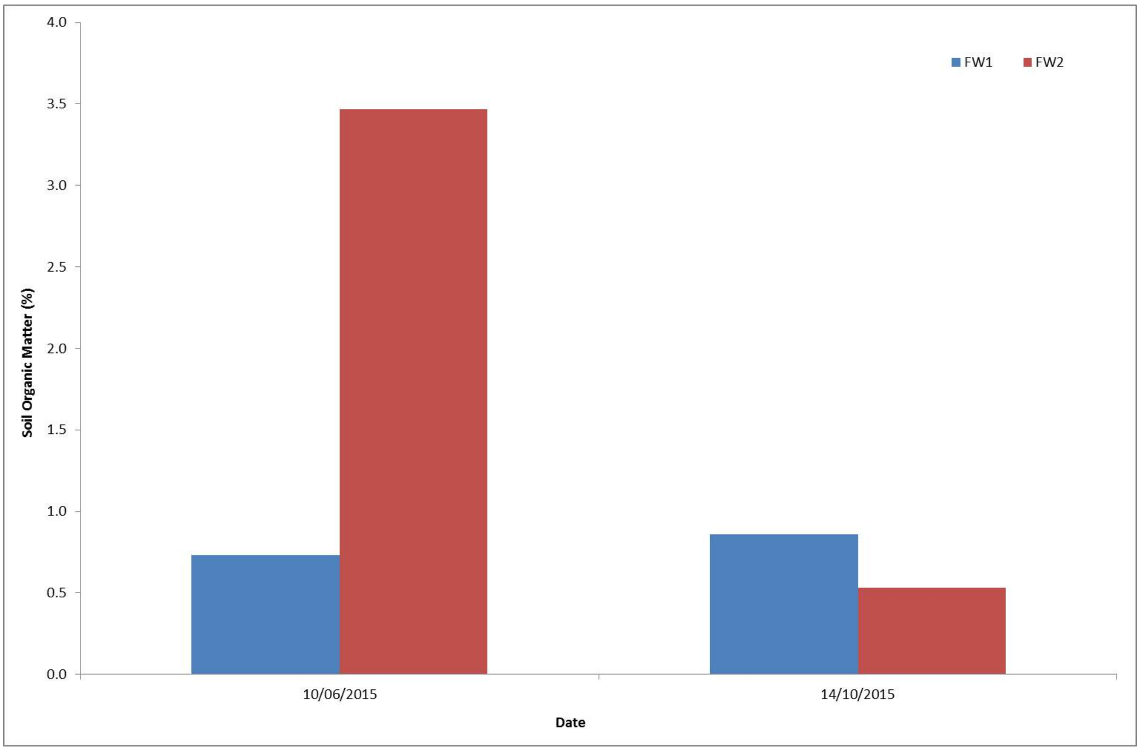


Figure 4.46 Sediment Soil Organic Matter at freshwater lake locations FW1 and FW2.

4.3.2 Sediment Orthophosphate

Orthophosphate levels in the Lagoon and freshwater lakes are shown in Figure 4.47 and Figure 4.48, respectively. In the Lagoon, the highest levels were recorded at drain input L4 – located within the reed bed adjacent to the car park, where extensive feeding of wildfowl is evident.

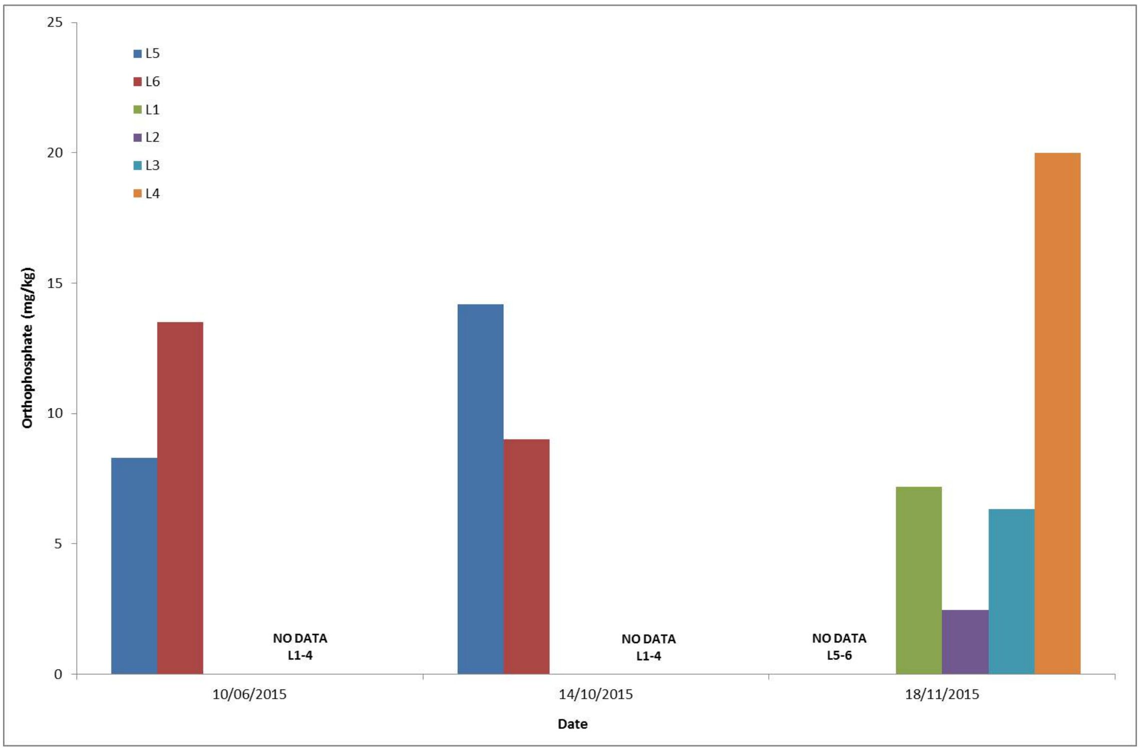


Figure 4.47 Sediment orthophosphate at Lagoon locations L1 to L6.

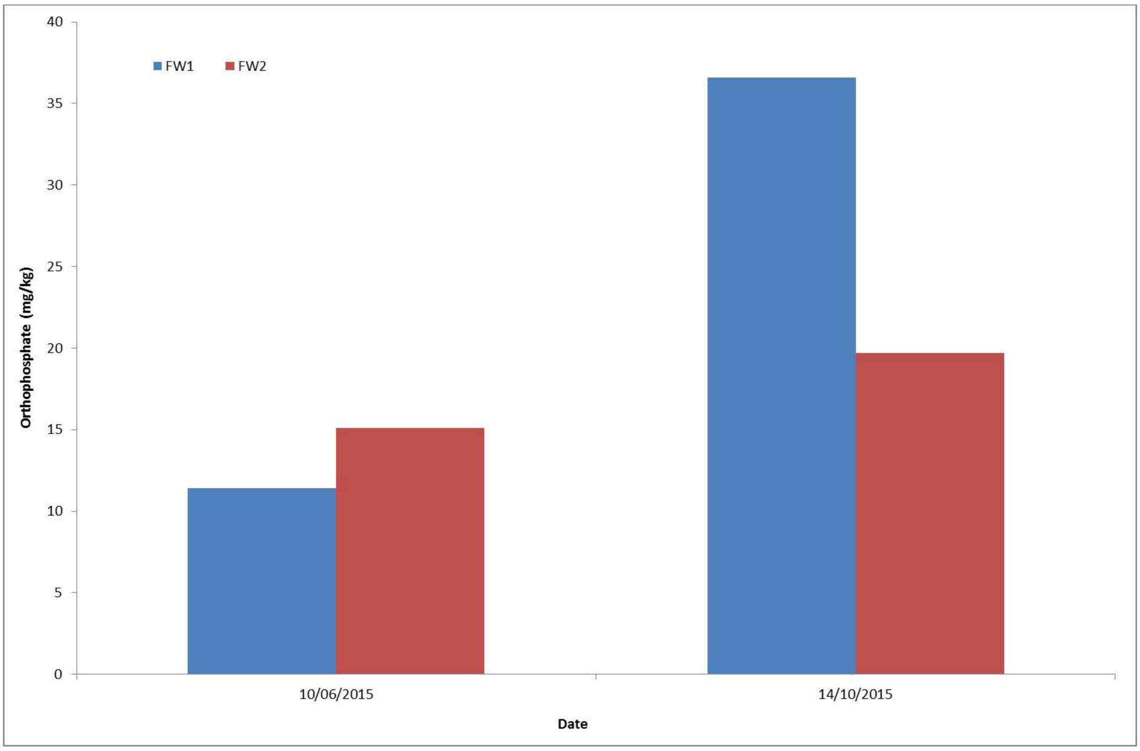


Figure 4.48 Sediment orthophosphate at freshwater lake locations FW1 and FW2.

4.3.3 Sediment Phosphorus

Total phosphorus levels in the Lagoon and freshwater lakes are shown in Figure 4.49 and Figure 4.50, respectively. Similar to orthophosphate; around the Lagoon margins, the highest levels of phosphorus were recorded at L4.

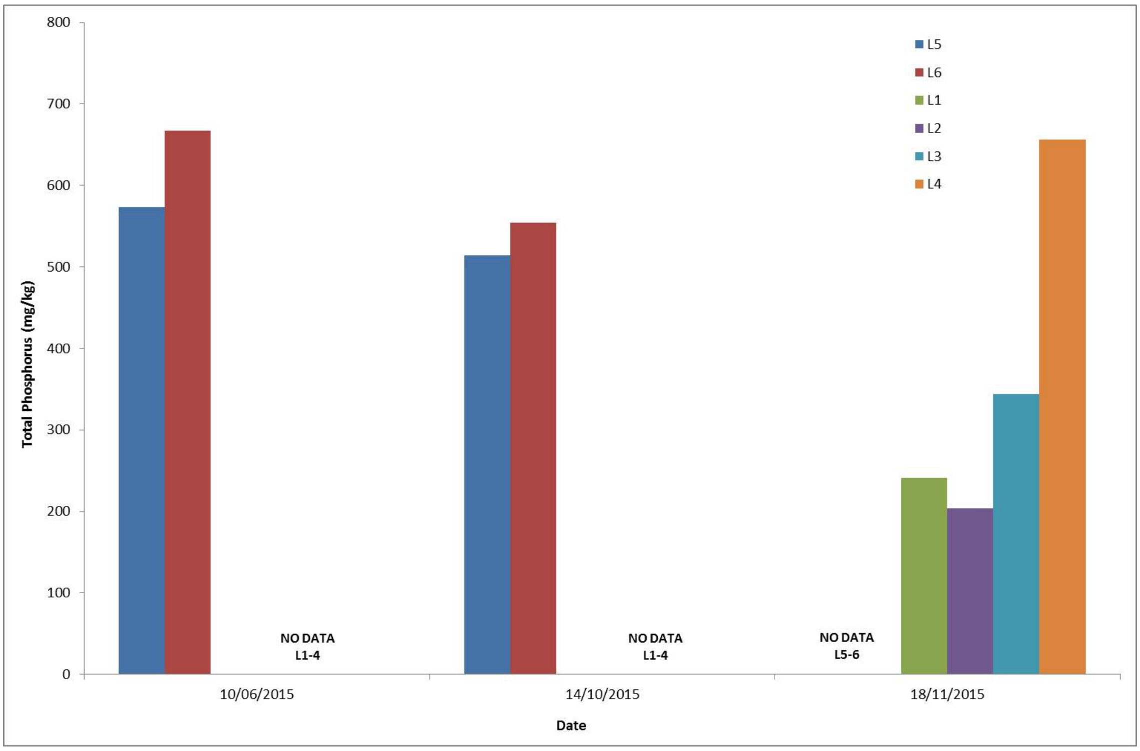


Figure 4.49 Sediment total phosphorus at Lagoon locations L1 to L6.

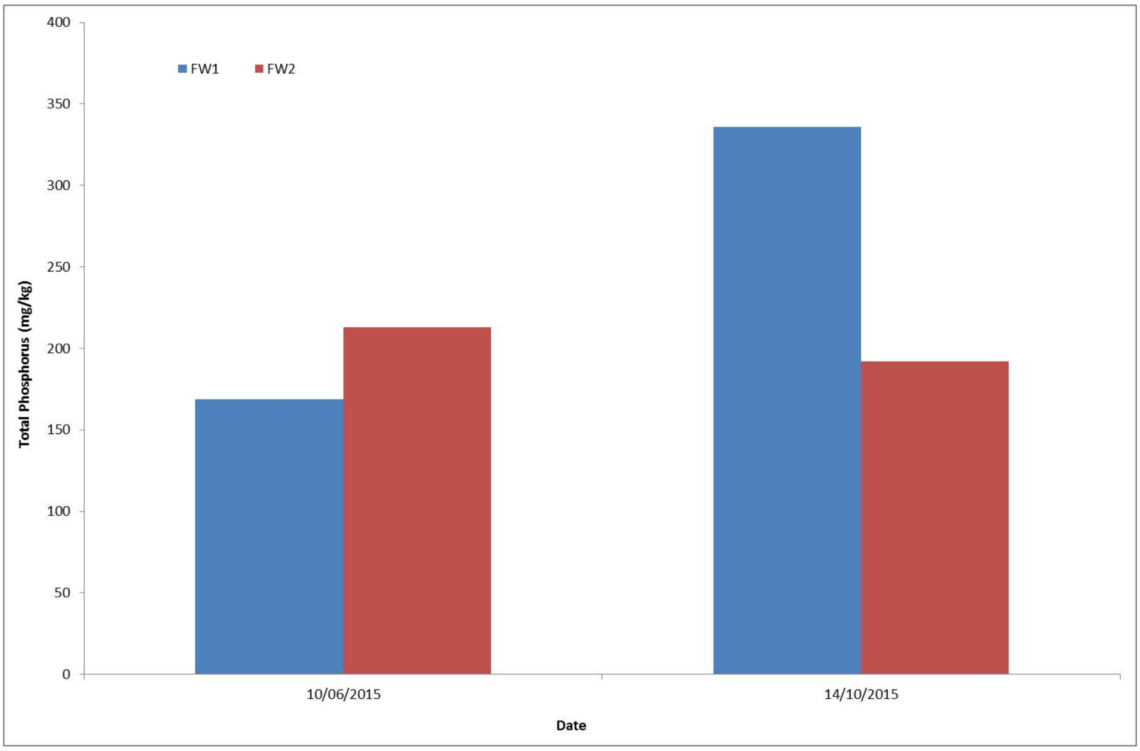


Figure 4.50 Sediment total phosphorus at freshwater lake locations FW1 and FW2.

4.3.4 Sediment Nitrogen

Sediment nitrogen levels were elevated in the centre of the main Lagoon at locations L5 and L6 (Figure 4.51). With regard to Lagoon drain inputs, only L4 showed elevated levels of nitrogen, most likely associated with excessive wildfowl feeding at this location. Sediment nitrogen was also relatively high in both freshwater lakes (Figure 4.52).

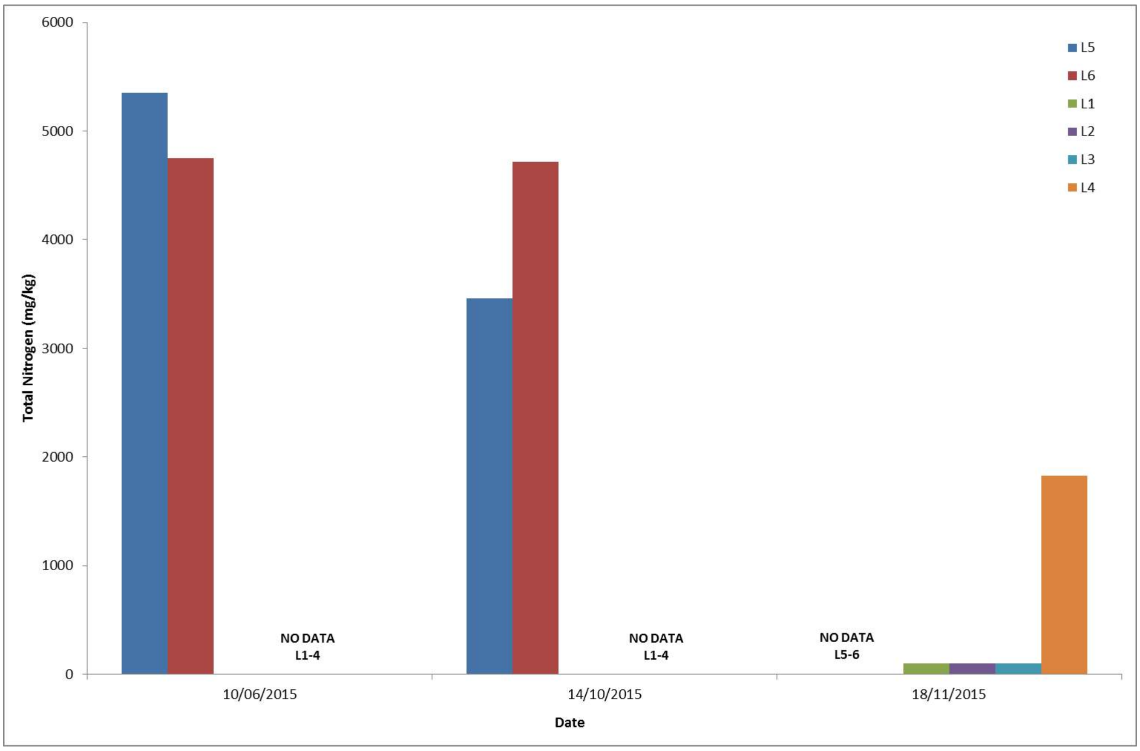


Figure 4.51 Sediment total nitrogen at Lagoon locations L1 to L6.

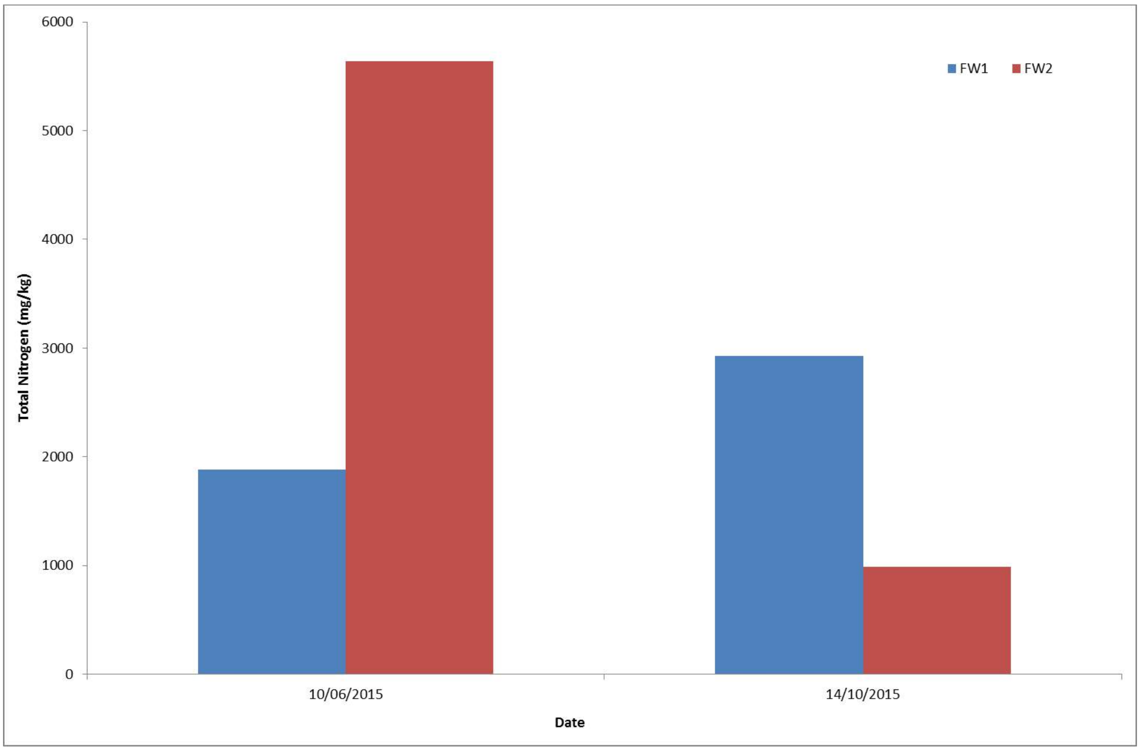


Figure 4.52 Sediment total nitrogen at freshwater lake locations FW1 and FW2.

4.3.5 Dry solids

Dry solids in the Lagoon constituted a higher proportion of sediment at drain inputs L1 to L3 than in the main lake or at drain input L4 (Figure 4.53). Dry solids in the freshwater lakes were broadly similar, and comparable with levels in the centre of the main Lagoon (Figure 4.54).

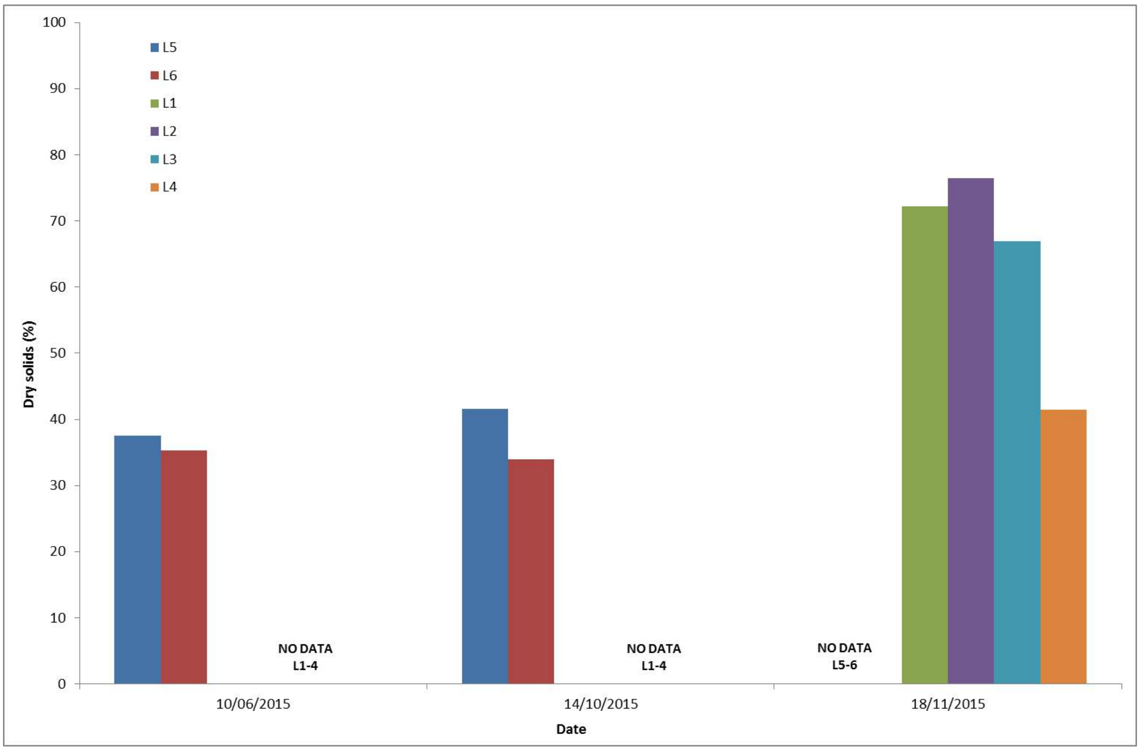


Figure 4.53 Sediment dry solids at Lagoon locations L1 to L6.

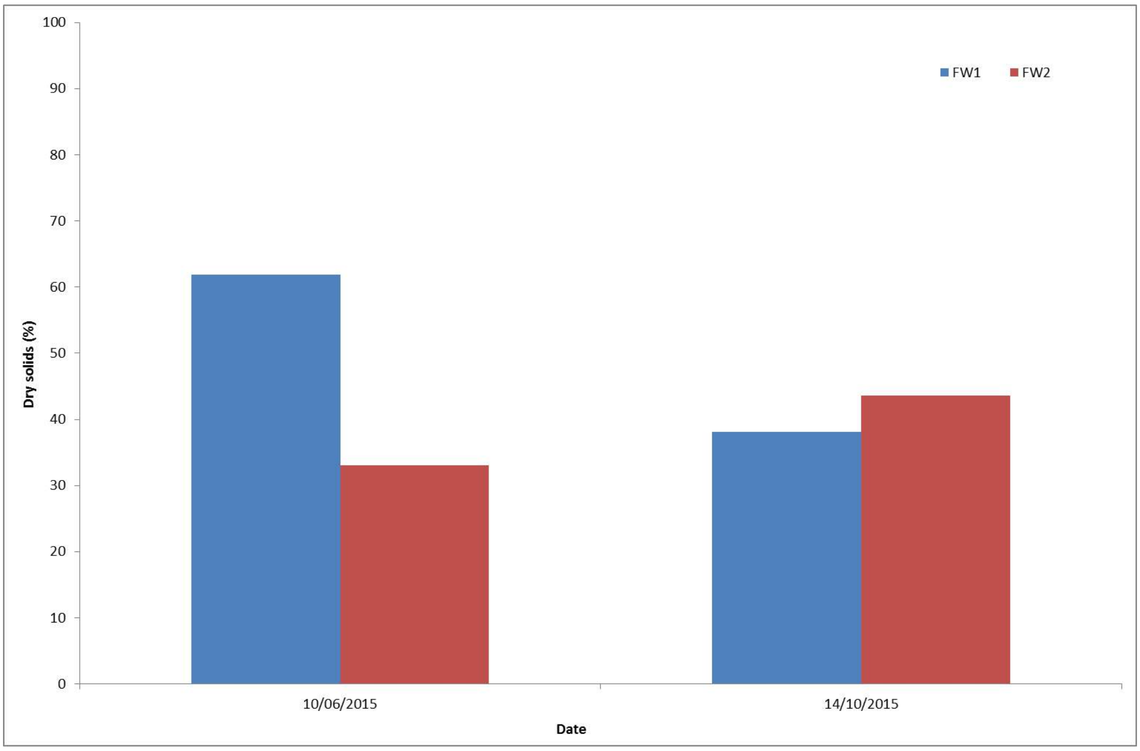


Figure 4.54 Sediment dry solids at freshwater lake locations FW1 and FW2.

4.3.6 Organic carbon

Organic carbon was higher in the centre of the Lagoon than in the vicinity of the drain inputs, although was generally relatively low throughout (Figure 4.55).

Similarly, organic carbon was relatively low in both freshwater lakes (Figure 4.56).

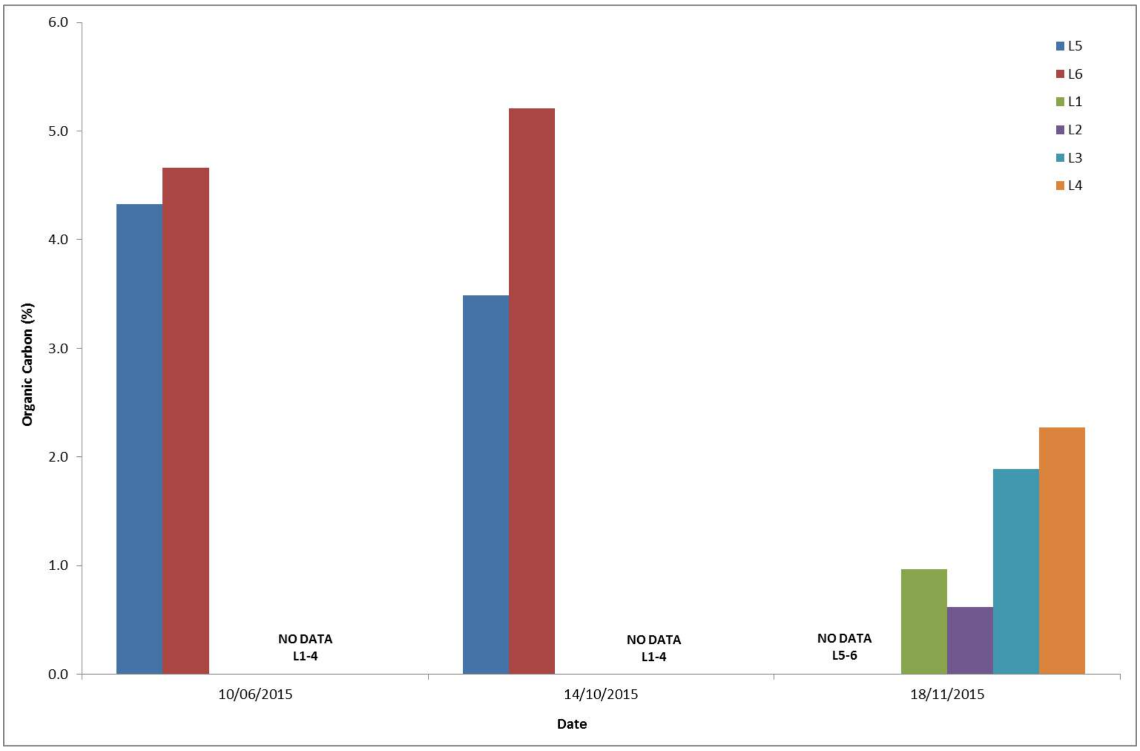


Figure 4.55 Sediment organic carbon at Lagoon locations L1 to L6.

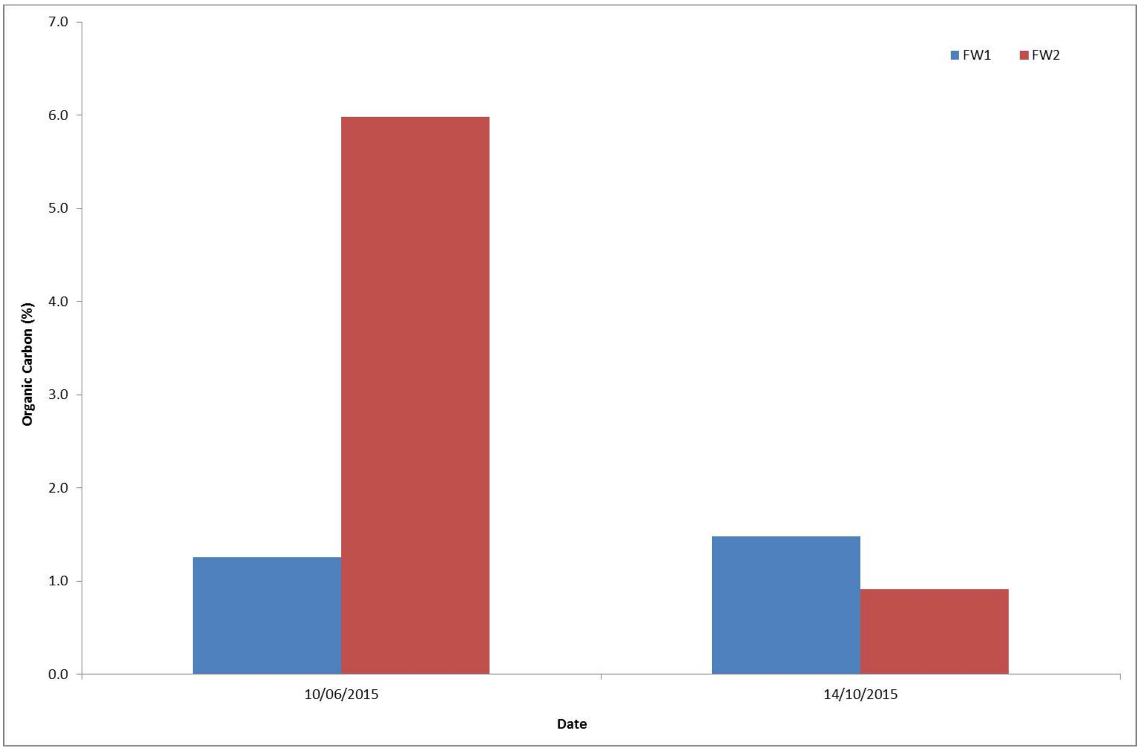


Figure 4.56 Sediment organic carbon at freshwater lake locations FW1 and FW2.

4.3.7 Metals

In the absence of any current formal sediment quality guidelines (SQGs) in England and Wales, the sediment chemistry results have been contextualised against other existing guidelines to provide a basic appreciation of the magnitude of contamination within each lake. One such example, frequently used to evaluate risks in the UK, is the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. This guidance has also been adopted by various UK authorities and provides the following two important reference levels:

- The 'Threshold Effects Level' (TEL) represents the lower concentration level, below which sediment associated chemicals are not considered to represent significant hazards to aquatic organisms.
- The 'Predicted Effects Level' (PEL) represents the upper level and indicates the lower limit of the range of chemical concentrations that have been associated with adverse biological effects.

Both limits are useful in determining the environmental significance of the concentrations detected. By using both the TEL and PEL, levels of contamination can be allocated into the three colour-coded categories highlighted below:

<TEL

Between TEL and PEL

>PEL

Rather than definitive standards which must be achieved, these guidelines and categories are widely recognised as indicators of whether concentrations detected may cause environmental stress. The main constraint with the Canadian system is that guidance is limited to a relatively small number of determinands. Table 4.1 highlights the TEL and PEL for selected key sediment metal determinands.

Table 4.1. Threshold Effect Level (TEL) and Predicted Effects Level (PEL) for key sediment metal determinands. From the Canadian Sediment Quality Guidelines.

Determinand	Canadian sediment guidelines (mg/kg)	
	TEL	PEL
Arsenic	5.9	17
Cadmium	0.596	3.53
Chromium	37.3	90
Copper	36.7	197
Lead	35	91.3
Mercury	0.174	0.486
Nickel	18	35.9
Zinc	123	315

Values for the key sediment metal determinands recorded at each site within Poole Park are provided in Table 4.2 below. Where available, cells have been highlighted according to the Canadian Sediment Quality Guideline criteria outlined above.

Table 4.2. Concentration (mg/kg) of metals in sediment samples. Green cells = <TEL, Yellow cells = between TEL and PEL, Red cells = >PEL.

Date	Site	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Iron
18/10/2015	L1	1.86	0.162	6.37	16.9	14.8	<1	5.63	40.7	4,820
18/10/2015	L2	2.59	0.205	9.5	12	43.3	<1	5.56	65.6	8,830
18/10/2015	L3	3.69	0.549	9.05	21.1	40.2	<1	5.49	83.9	6,120
18/10/2015	L4	3.98	0.52	11	40.5	52.4	<1	10.2	154	9,640
14/10/2015	L5	20.1	2.28	36.8	52.7	121	<1	24.5	194	33,400
14/10/2015	L6	20.6	2.48	39.3	80.8	146	<1	28.9	250	38,800
14/10/2015	FW1	2.7	0.166	7.08	14.6	51.3	<1	11.3	106	12,500
14/10/2015	FW2	1.07	<0.1	3.69	9.64	17	<1	2.8	38.5	2,700

5. ECOLOGY

This section outlines the sampling methodologies and presents the results from the ecological monitoring programme. The following elements are included:

- Invertebrate community (Section 5.1)
- Fish community (Section 5.2)

Each section is restricted to a factual presentation of the key data, with limited commentary, other than to draw attention to the main trends. Full interpretation and discussion of the key findings are presented in Section 8.

5.1 Invertebrate community

Aquatic invertebrates play a vital role in aquatic food chains. Not only do they represent the main diet of many fish species, they also assist in the cycling of nutrients from algae and plants to higher trophic levels (e.g. fish and birds). Due to the broad range of sensitivities of individual taxa to water quality, the species composition of invertebrate communities can also provide a powerful indicator of pollution and environmental stress (specifically nutrient enrichment).

5.1.1 Freshwater lakes

Samples were collected in accordance with the standard Environment Agency (EA) three-minute ‘sweep’ procedure using a 1mm mesh long-handled pond net (set out in “*Procedures For Collecting and Analysing Macroinvertebrate Samples”*. BT001 3.0, Third Issue; 1991), and by the procedure for collecting and analysing macroinvertebrate samples for RIVPACS (Murray-Bligh *et al,* 1997). This ensured that a representative range of mesohabitats were sampled in proportion to their occurrence to facilitate spatial and temporal comparisons.

Macroinvertebrate samples were fixed immediately after collection using 70% Industrial Methylated Spirits (IMS). Sample pots were clearly labelled both internally, using pencil and waterproof paper labels, and externally using a waterproof marker, and returned to the laboratory for processing.

Laboratory Sample Processing

Macroinvertebrate samples were sorted, identified and enumerated following the procedures set out in ‘*Procedures For Collecting and Analysing Macroinvertebrate Samples”*. BT001 3.0, Third Issue; 1991) and by the procedure for collecting and analysing macroinvertebrate samples for RIVPACS (Murray-Bligh *et al.* 1992). Samples were processed to family-level, and numerical abundances of all taxa were estimated and recorded on laboratory sample data sheets.

Examination of picked invertebrates was made using a binocular/compound microscope with appropriate taxonomic keys used to aid identification. All samples were reconstituted (put back into their original sample pots and re-preserved) and retained for subsequent quality assurance purposes.

Calculation of Biotic Indices

Using the freely available River Invertebrates Classification Tool (RICT) as hosted by SEPA http://www.sepa.org.uk/environment/water/classification/river-invertebrates-classification-tool/, family level data were imported and queried to output the following biotic indices:

- BMWP (Biological Monitoring Working Party)
- NTAXA (number of taxa)
- ASPT (Average Score Per Taxon)

Two surveys were conducted on the freshwater lakes to reflect invertebrate community structure between spring and late summer. Results for FW1 are presented in Table 5.1 and Figure 5.1. Results for FW2 are presented in Table 5.2 and Figure 5.2.

Table 5.1. Total number of invertebrates recorded during each survey period in FW1.

Common name	Taxa	BMWP Score	06/05/2015	26/08/2015
Water flea	*Daphniidae*	N/A	152	24
Chironomid larva / pupa	*Chironomidae*	2	65	29
Greater water boatman	*Notonectidae*	5	32	6
Unknown	*Unknown*	N/A	1	9
Lesser water boatman	*Corixidae*	5	0	9
Diving beetle	*Dytiscidae*	5	4	0
Water mite	*Hydrachnidiae*	N/A	2	0
Freshwater shrimp	*Gammaridae*	6	0	1
Combined BMWP score			**12**	**18**
Qualifying NTAXA			**3**	**4**
Qualifying ASPT score			**4**	**4.5**

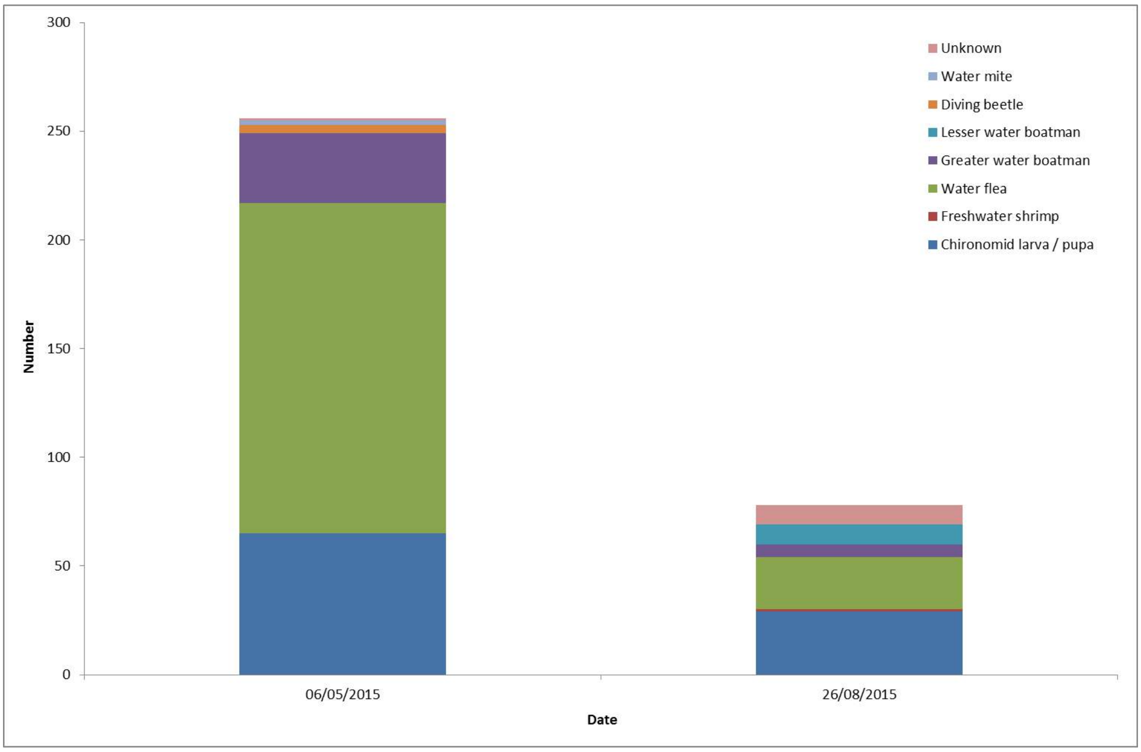


Figure 5.1 Total number of invertebrates recorded during each survey period in FW1.

Table 5.2. Total number of invertebrates recorded during each survey period in FW2.

Common name	Taxa	BMWP Score	06/05/2015	26/08/2015
Water flea	*Daphniidae*	N/A	1,100	1,300
Chironomid larva / pupa	*Chironomidae*	2	16	12
Freshwater shrimp	*Gammaridae*	5	8	2
Pond snail	*Unknown*	N/A	0	4
Greater water boatman	*Notonectidae*	5	3	0
Water mite	*Hydrachnidiae*	N/A	1	0
Unknown	*Unknown*	N/A	0	1
Total BMWP score			**12**	**7**
Qualifying NTAXA			**3**	**2**
Qualifying ASPT score			**4**	**3.5**

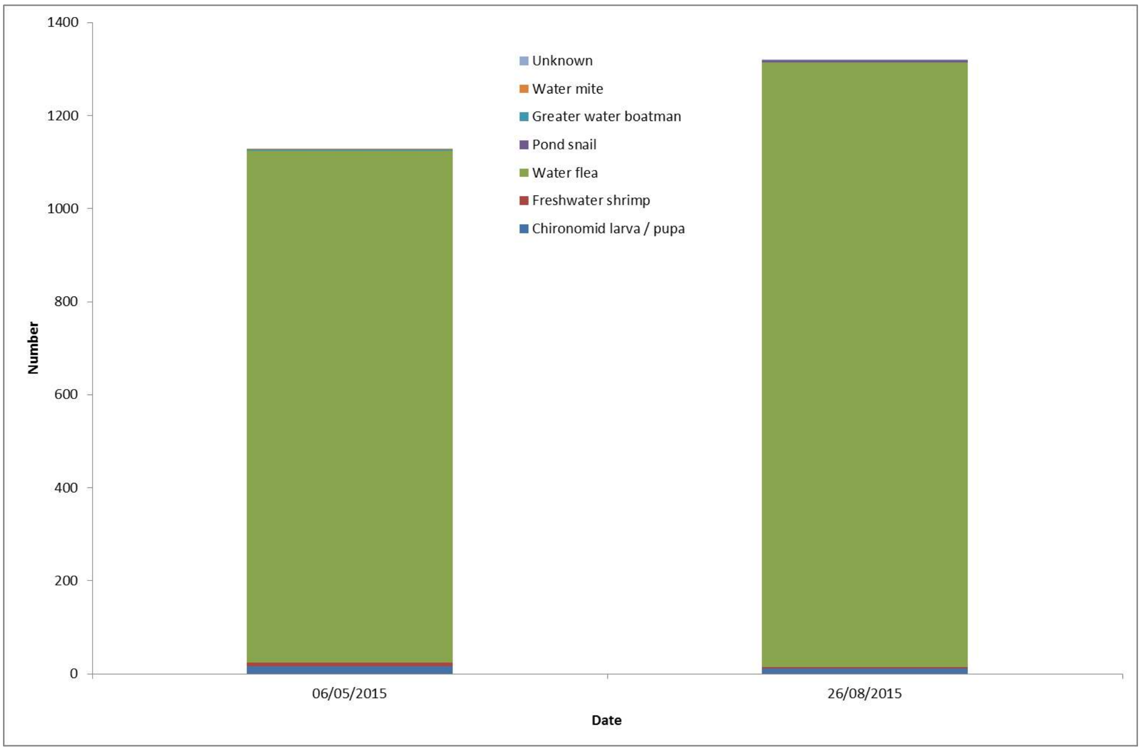


Figure 5.2 Total number of invertebrates recorded during each survey period in FW2.

5.1.2 Lagoon

Benthic samples were collected in accordance with the JNCC Marine Monitoring Handbook (Davies *et al*. 2001) using a suction corer of 10 cm diameter to a depth of 15 cm.

Samples were fixed immediately after collection using 70% Industrial Methylated Spirits (IMS). Sample pots were clearly labelled both internally, using pencil and waterproof paper labels, and externally using a waterproof marker, and returned to the laboratory for processing.

Laboratory Sample Processing

Samples were sorted, identified to species level where possible, and numerical abundances of all taxa were recorded.

Examination of picked invertebrates was made using a binocular/compound microscope with appropriate taxonomic keys used to aid identification. All samples were reconstituted (put back into their original sample pots and re-preserved) and retained for subsequent quality assurance purposes.

Samples were collected from L5 and L6 at fortnightly intervals between the 1st April and 22nd July. Lacking biotic indices for marine invertebrate communities the abundance of individual taxa and total species diversity are presented for each site and date surveyed in Table 5.3 and Figure 5.3.

Table 5.3. Total number of invertebrates recorded (L5 + L6 combined) during each survey period in the Lagoon.

Common name	Scientific name	01/04/2015	15/04/2015	29/04/2015	13/05/2015	27/05/2015	10/06/2015	24/06/2015	08/07/2015	27/07/2015	05/08/2015	TOTAL
Amphipoda	*Monocorophium insidiosum*	0	0	0	0	0	0	272	0	8	16	**354**
Ragworm	*Hediste diversicolor*	10	13	5	12	6	12	22	13	14	18	**232**
Chironomid larvae	*Chironomus salinarius*	40	28	28	4	8	4	28	4	0	4	**181**
Amphipoda	*Microdeutopus gryllotalpa*	0	0	4	0	0	0	76	36	12	40	**170**
Oligochaete	Tubificoides spp.	0	0	0	0	0	0	100	4	0	0	**130**
Starlet sea anemone	*Nematostella vectensis*	0	0	8	0	4	0	52	12	8	20	**110**
Lagoon spire snail	*Ecrobia ventrosa*	0	0	4	0	0	0	28	12	0	0	**55**
Polychaete	*Polydora* sp.	0	0	0	4	0	0	12	4	8	12	**38**
Spire snail	*Peringia ulvae*	0	0	0	0	0	8	0	0	0	0	**10**
Bivalvia spat	Bivalvia	0	4	0	0	0	0	4	0	0	0	**10**
Lagoon Cockle	*Cerastoderma glaucum*	0	0	0	0	0	0	0	4	0	0	**5**
Mysid Shrimp	Mysida sp.	0	0	0	0	0	0	0	4	0	0	**5**
Sand Gaper	*Mya arenaria*	0	2	0	0	0	0	0	0	0	0	**4**
TOTAL SPECIES DIVERSITY		**2**	**4**	**5**	**3**	**3**	**3**	**9**	**9**	**5**	**6**	**13**

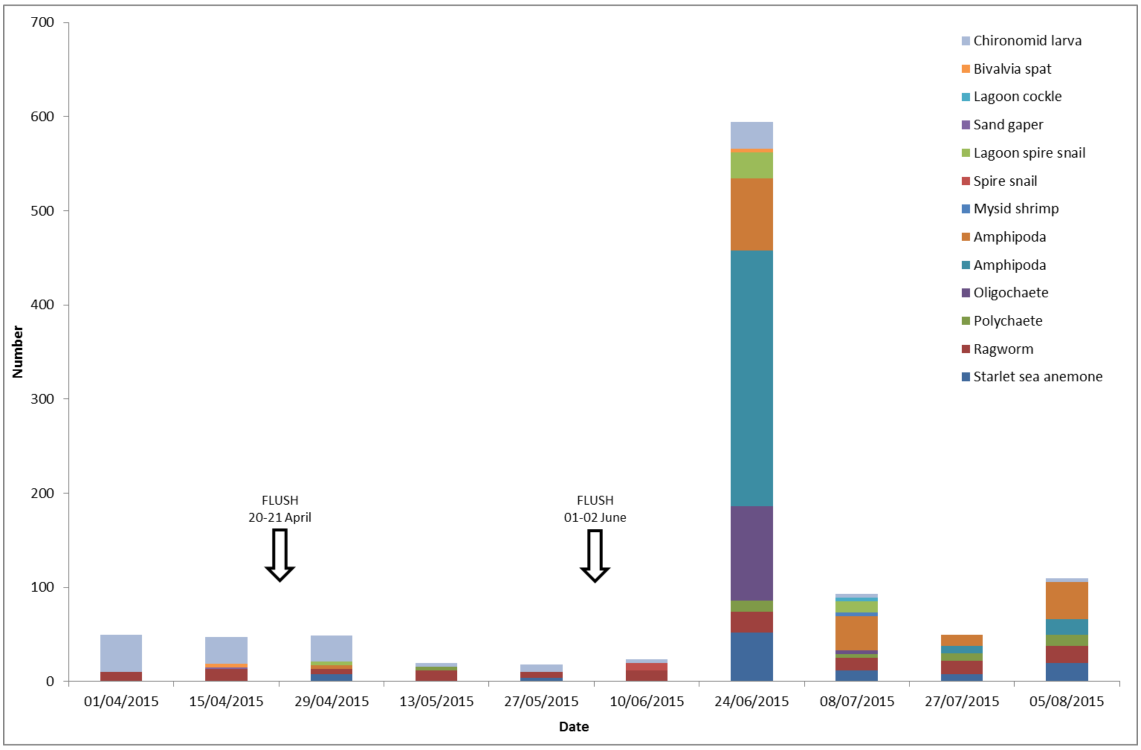


Figure 5.3 Total number of invertebrates recorded (L5 + L6 combined) during each survey period in the Lagoon.

5.2 Fish community

Through their role as both predators and prey, fish perform a fundamental role in trophic food-chains and can thus impact on a range of trophic levels, from primary production through to bird populations.

Despite their own potential to influence water quality (e.g. through depletion of zooplankton and/or mechanical re-suspension of particulate matter), fish depend on adequate water chemistry, appropriate food resources and habitat availability in order to maintain diverse and sustainable populations.

To assess the resident fish populations present within the freshwater lakes and form an understanding of the transient fish utilisation of the Lagoon, the following suite of surveys was conducted.

5.2.1 Freshwater lakes

Prior to the initiation of the current study, a survey of the fish populations of the two freshwater lakes was conducted by Anderson (2014). Using angling to target a range of fish species, this study concluded that fish were absent from the smaller of the two freshwater lakes (FW2). Conversely, the larger lake (FW1) was found to support a high density of fish, with the biomass dominated by large carp, *Cyprinus carpio*, with smaller numbers of rudd, *Scardinius erythrophthalmus* and eel, *Anguilla anguilla* also present. While the numbers of rudd and eel captured did not exceed six individuals of either species, a total of 51 carp, ranging between 40 cm and 75cm in length (1.81 kg – 7.71 kg) were recorded.

Considering this background information, in combination with current visual observations of very large numbers of carp which could be seen feeding and stirring up the sediment on warm days; this provided sufficient evidence to conclude that the biomass of carp was extremely high and likely to be exacerbating poor water quality problems in FW1.

With future management requiring the cropping of carp from the lake, further resources were applied to obtaining a health check of the fish present to establish the presence of disease, general condition, recreational value of the stock and, ultimately, the available options for relocation.

On 28th September 2016, a further nine carp ranging 59 cm to 70cm were captured on rod and line. Of this total, four fish were humanely dispatched for autopsy using the Environment Agency's (EA) Section 30 Health Check procedure. This was conducted by a professional fish health practitioner registered under the EA and the Institute of Fisheries Management (IFM). Inspecting these fish externally (e.g. skin mucus swabs) and internally (intestinal tract, gills and major organs), no notable parasites were recorded, thus indicating the stock not to be infected with any pathogens which would restrict their movement to another fishery (Figure 5.4).

Figure 5.4 Typical condition of carp observed during the fish survey in FW1.

All other fish captured were inspected for external parasites and, with the exception of a single fish louse (*Argulus foliaceus*), all fish were noted to be parasite free and in excellent condition prior to their release.

Figure 5.5 Combining the FW1 fish survey with a public engagement event allowed local children and their parents to get a close up view of some of the lake's fish. Here, a large carp is being measured and inspected for external parasites prior to release.

5.2.2 Lagoon

A total of four fish surveys were conducted in the Lagoon during 2015 using a fine-meshed seine net (15 m x 2 m x 3 mm) to sample marginal areas. Pre- and post-flush surveys were conducted on 14th and 28th April, respectively; with the lake being flushed from Poole Harbour on 20th to 21st April. Similarly, pre- and post-flush surveys were conducted on 24th September and 01st October, respectively; with the lake being flushed (or drained down) on 26th to 28th September. Fish sample locations are shown in Figure 3.1 and Table 3.1. A total of six sites around the perimeter of the lake were sampled on each survey occasion.

The total number of each fish species captured during each survey period (all sites combined) is shown in Table 5.4 and Figure 5.6 below.

Table 5.4. Total number of fish captured (all sites combined) during each survey period in the Lagoon.

Common name	Scientific name	14/04/2015	28/04/2015	24/09/2015	01/10/2015	TOTAL
Three-spined stickleback	*Gasterosteus aculeatus*	1,882	724	234	161	**3,001**
Common goby	*Pomatoschistus microps*	2,277	181	174	190	**2,822**
Sand smelt	*Atherina presbyter*			213	699	**912**
Bass	*Dicentrarchus labrax*			3	26	**29**
Flounder	*Platichthys flesus*			2	1	**3**
Herring	*Clupea harengus*				1	**1**
TOTAL		**4,159**	**905**	**626**	**1,078**	**6,768**

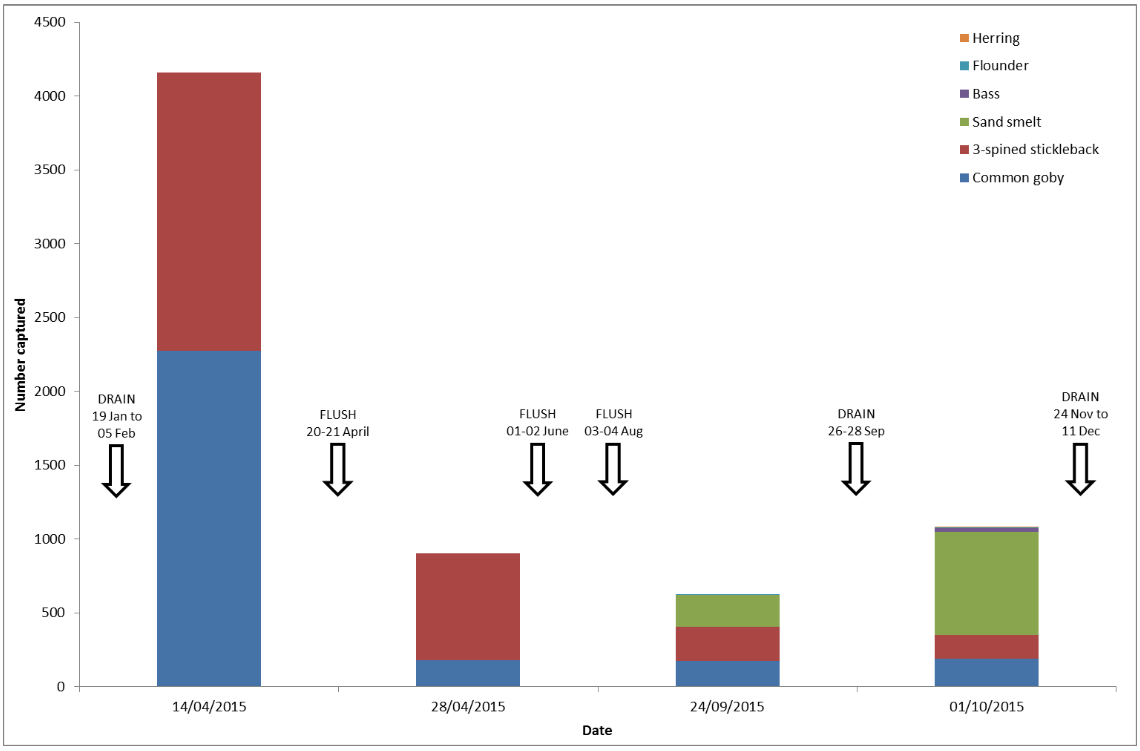


Figure 5.6 Total number of fish captured among all survey sites.

6. HYDROLOGY

This section outlines the sampling methodologies and presents the results from the hydrology investigations in the Lagoon. The following elements are included:

- Gauge board installation and monitoring (Section 6.1)
- Bathymetry (Section 6.2)
- Stage-volume relationship (Section 6.3)
- Sediment depth (Section 6.4)
- Tidal volume exchange (Section 6.5)
- Lagoon drain input volume (Section 6.6)

Each section is restricted to a factual presentation of the key data, with limited commentary, other than to draw attention to the main trends. Full interpretation and discussion of the key findings are presented in Section 8.

6.1 Gauge boards

Two gauge boards were installed in the Lagoon; one adjacent to The Kitchen restaurant (Figure 6.1) and one on the lake side of the sluice gate (Figure 6.2). Both gauge boards were levelled to mAOD. In addition, a metal plate was installed on the Poole Harbour side of the sluice gate, which was also levelled to mAOD.

Gauge boards were read on each survey visit by the BUG field team. In addition, as part of the public engagement strategy, members of the public were encouraged to take photos of the gauge board adjacent to The Kitchen restaurant and post them to a dedicated Facebook group page (Section 7.4).

Figure 6.1 Gauge board installed in the Lagoon adjacent to The Kitchen restaurant. Photo taken at low water level during a drain down (lake full water level ~0.7 mAOD).

Figure 6.2 Gauge board installed in the Lagoon adjacent to the sluice gate. Photo taken at lake full water level.

6.2 Bathymetry

To determine the Lagoon depth profile, total volume and stage-volume relationship, a bathymetric survey was conducted during 26th and 27th March 2015 by BUG field staff in conjunction with Hydro-Logic Services.

Depth was recorded using a Teledyne RDI StreamPro Acoustic Doppler Current Profiler (ADCP). This device has four beams that measure the depth using a pulse of sound. The four beams are averaged to provide a composite depth for each reference point, with depth readings being taken approximately every second. Locations of the depth values were simultaneously collected using a differential Global Positioning System (dGPS). The output comprises a stream of co-ordinates with associated depth data in WinRiver II, the ADCP processing software.

Data were collected from approximately 70 transects, including long transects across the lake and more detailed data collection at the lake margins and around any specific features, such as islands. A minimum depth of approximately 0.015 m is required for ADCP operation, to allow for boat draft and a digital blanking distance. Most of the lake was well within the operational range of the instrument. Although some loss of volume is likely to have occurred at the marginal zones of the islands, this will have a very limited impact on overall volume calculations. A large proportion of the lake edge has a vertical bank, allowing good profiling to the boundary of the lake. The survey was undertaken during a period of limited weed growth, ensuring that the pulses of sound reached the lake bed and provided valid depth readings.

Routine gauge board readings were taken throughout the field monitoring to tie in the level data to ordnance datum. This ensured that the lake level remained stable as the unit referenced depth to the water surface.

Data were exported from WinRiver II in ASCII format and processed using specialist extraction software which outputs the data as a shapefile with the X, Y and Z co-ordinates logged. Point features with depth information were then converted into a bathymetric grid of lake depth using Triangulation with Smoothing to calculate the depth values across the grid. Triangulation determines a network of lines from the original data points to build a mesh of triangular faces, called a Triangular Irregular Network (TIN). Grid values are estimated according to the slope of the TIN surface at the nearest point. In this way, depths for the non-surveyed areas are interpolated between the surrounding known points.

The output elevation grid for the Lagoon is shown in Figure 6.3, with levels displayed as mAOD. Features such as the islands in the middle of the lake have been clipped from the grid, ensuring they are not included in volume calculations.

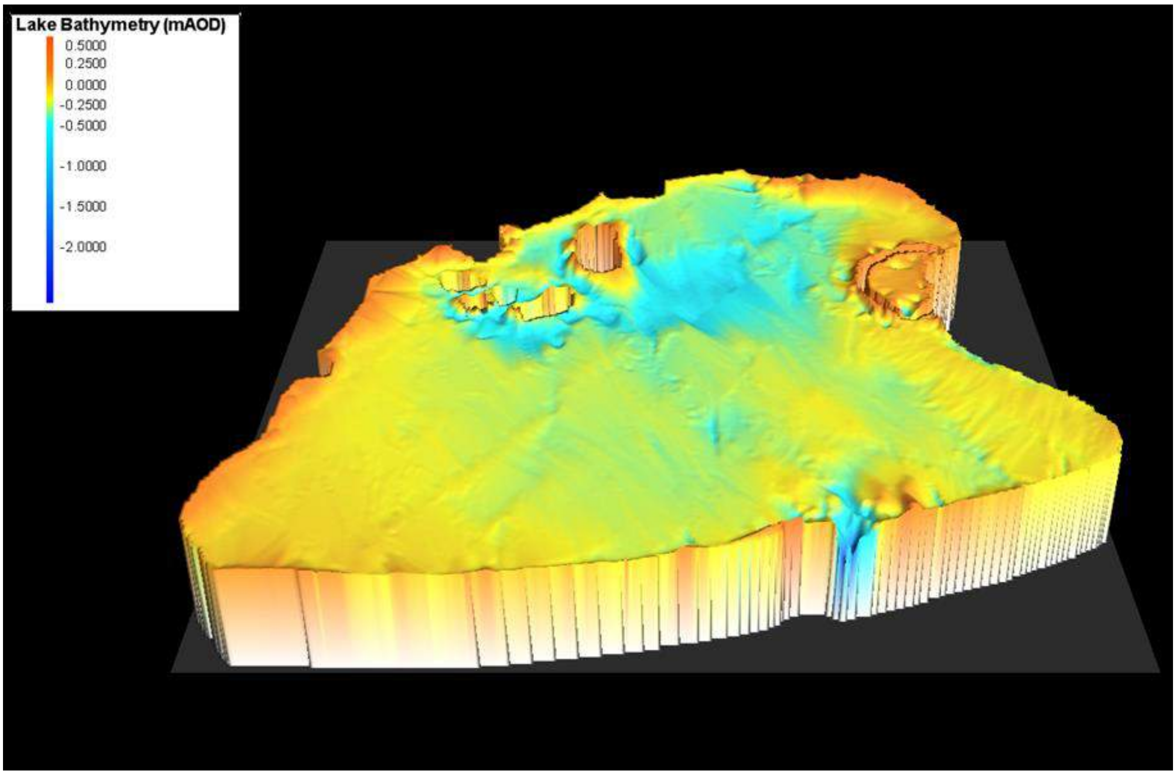


Figure 6.3 3-D elevation grid of the Lagoon, with levels shown as mAOD. Lake-full level is approximately 0.70 mAOD.

The lake-full surface level is approximately 0.70 mAOD. This indicates that the majority of the lake is < 1.0 m deep (approximately -0.25 mAOD) at full level. The deepest sections, adjacent to the islands, are approximately 1.50 m deep (approximately -0.5 to -1.0 mAOD) at full level.

6.3 Stage-volume relationship

A stage-volume relationship for the lake was calculated to allow an estimation of the volume of the lake for any given stage level (mAOD). This relationship, from -0.09 mAOD to 0.9 mAOD, is shown in Figure 6.4 and Table 6.1. The relationship is taken as linear; however this includes some uncertainties, as the sides of the lake have been assumed to be vertical in all cases.

Although this is the case for the majority of the perimeter of the lake, this would not be true for the islands. The sampling of data as close to the island boundary as possible in the field survey has mitigated for this as far as possible.

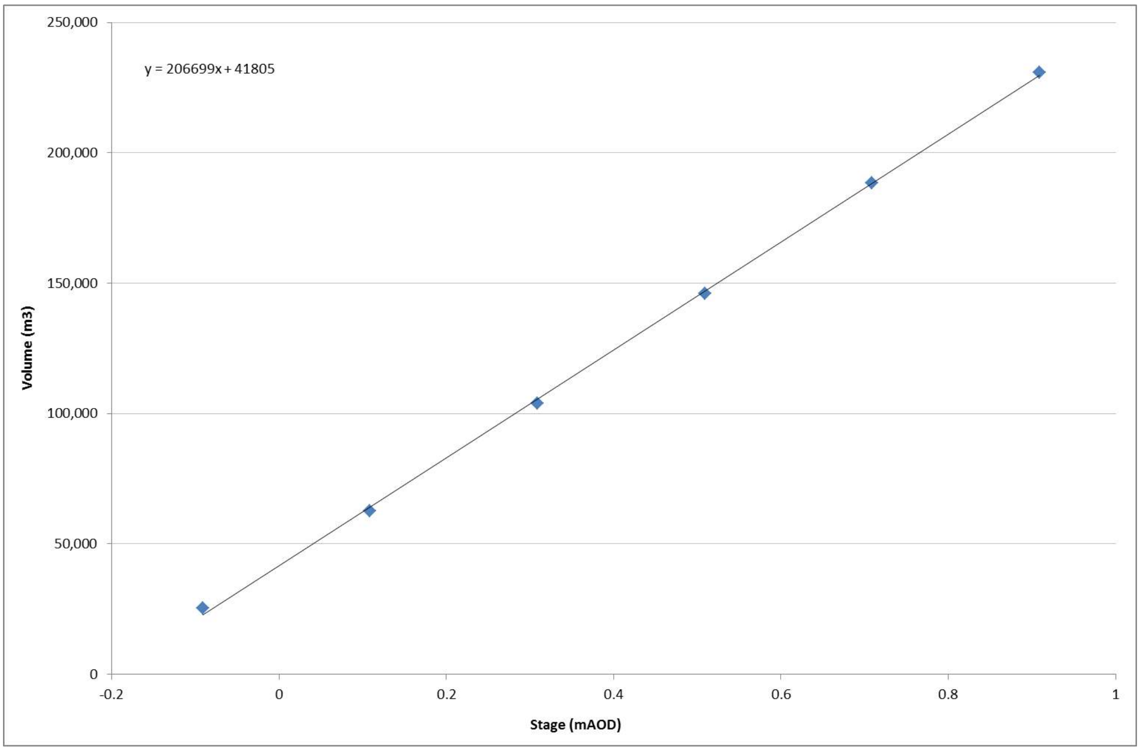


Figure 6.4 Stage-volume relationship for the Lagoon.

Table 6.1. Stage-volume relationship for the Lagoon.

Stage (mAOD)	Volume (m^3)
-0.09	25,506
0.11	62,781
0.31	103,892
0.51	146,161
0.71	188,559
0.91	230,964

6.4 Sediment depth

Sediment depth profiles of the main lake were recorded during a two day survey commencing 3rd January 2015. A total of seven transects across the lake were completed with a total of 136 depth recordings taken (Figure 6.5). At each sampling location, sediment depth was measured using a gauging pole and the location recorded using GPS.

Figure 6.5 Transect locations for sediment depth data collection.

Sediment thickness data from the 136 locations were used to generate a 3-D sediment thickness grid (Figure 6.6). Sediment depths ranged from 0 cm close to the lake edges to up to 200 cm in the lake centre. The total volume of sediment has been estimated at no less than 126,104 m^3.

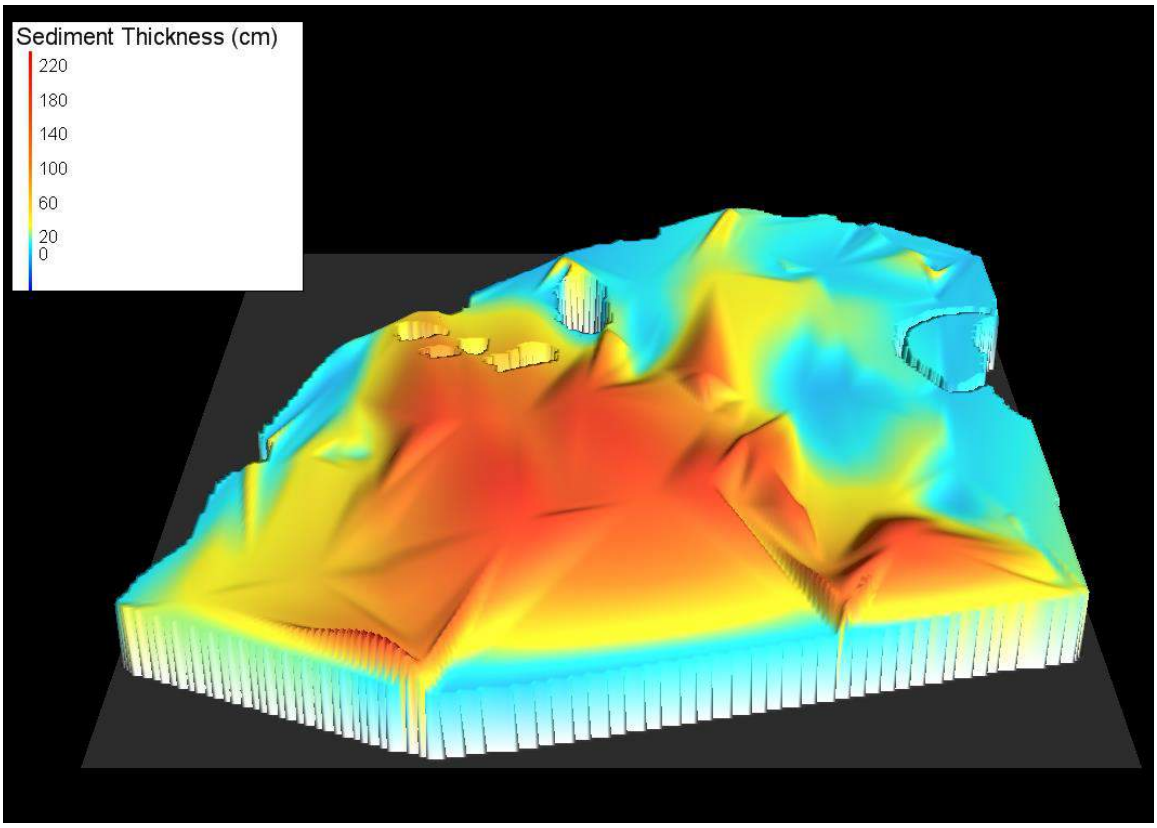


Figure 6.6 Sediment thickness grid of the Lagoon.

6.5 Tidal volume exchange and lake level

To determine the rate of volume exchange during a drain down event of the Lagoon, a Teledyne RDI StreamPro Acoustic Doppler Current Profiler (ADCP) was used to directly measure velocity (ms^{-1}) and discharge (m^3s^{-1}) through the sluice gate (Figure 6.7).

Transect measurements across the channel were recorded every 30 minutes throughout the entire period of lake drain down.

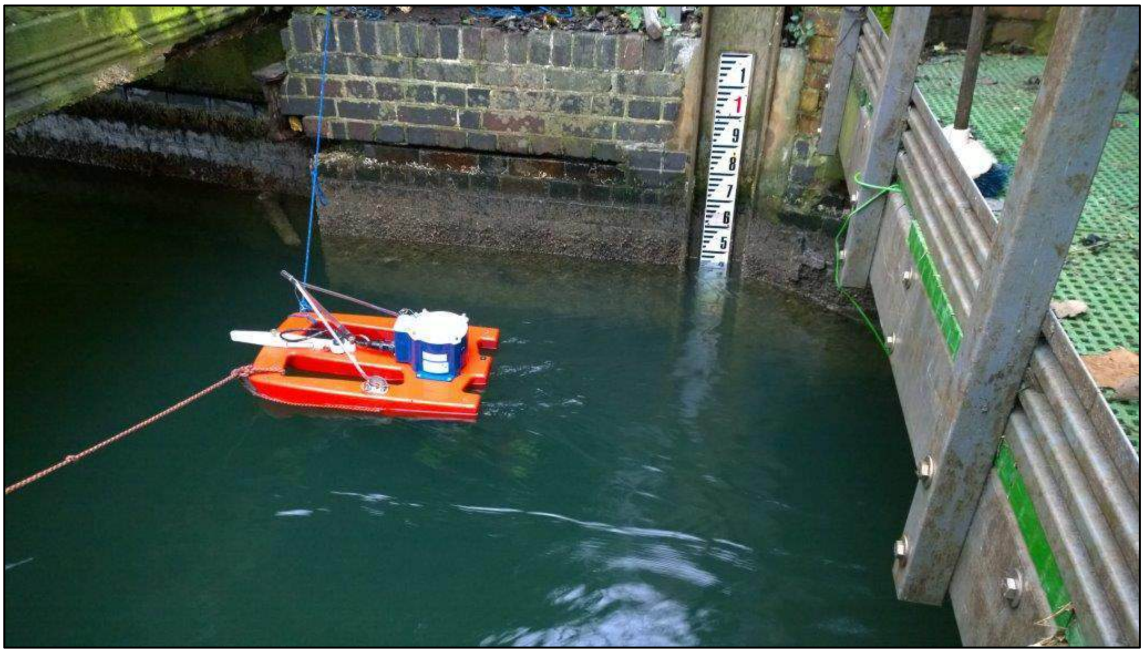


Figure 6.7 Flow gauging at the sluice gate being conducted over the full period of a lake drain down using an Acoustic Doppler Current Profiler (ADCP).

A plot of discharge throughout the duration of drain down is shown in Figure 6.8 below. Discharge ranged from 2 m^3s^{-1} to almost 9 m^3s^{-1} throughout the duration of the flush.

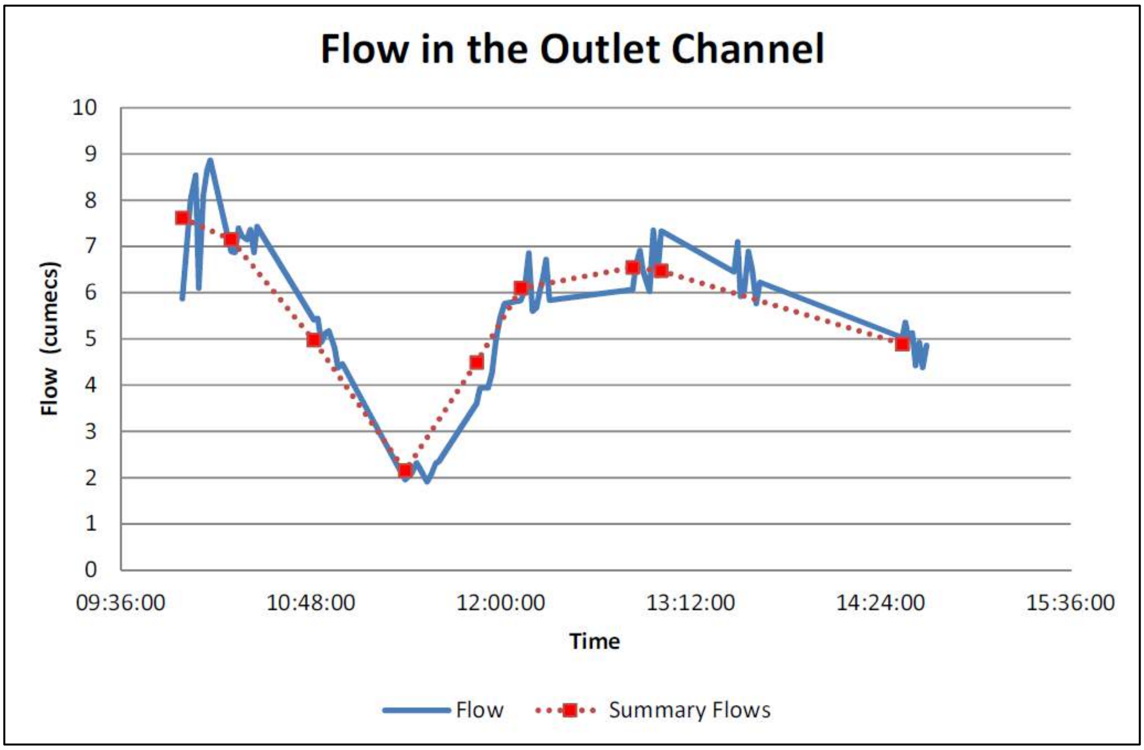


Figure 6.8 Volume discharge (m^3s^{-1}) throughout the duration of lake drain down.

The total lake volume at a target lake level of 0.60 mAOD, calculated from the stage-volume relationship (see Section 6.3), is approximately 165,583 m^3. Assuming the average discharge rate is 5 m^3s^{-1}, the time required to drain 25 % of the lake volume (41,396 m^3) would be approximately 137 minutes (2 hours 17 minutes). Similarly, to drain 50 % of the lake volume (82,792 m^3) would take approximately 276 minutes (4 hours 36 minutes), and to drain 75 % of the lake volume (124,187 m^3) would take approximately 414 minutes (6 hours 54 minutes).

6.5.1 Level data

An important aspect to consider with regard to the flushing regime is the influence of the high tide level on the ability to refill the lake. Figure 6.9 below illustrates level data for both Poole Harbour and the Lagoon, recorded using in-situ rugged data loggers between July and November 2015.

Assuming the target lake level was set at 0.60 mAOD, it would only be possible to achieve this on a refill during periods of the highest spring tides; approximately every month. However, it may be possible to flush more regularly than this during certain times of the year; obtaining accurate tide times, converted to mAOD, would allow for a detailed flushing regime to planned in advance for each year.

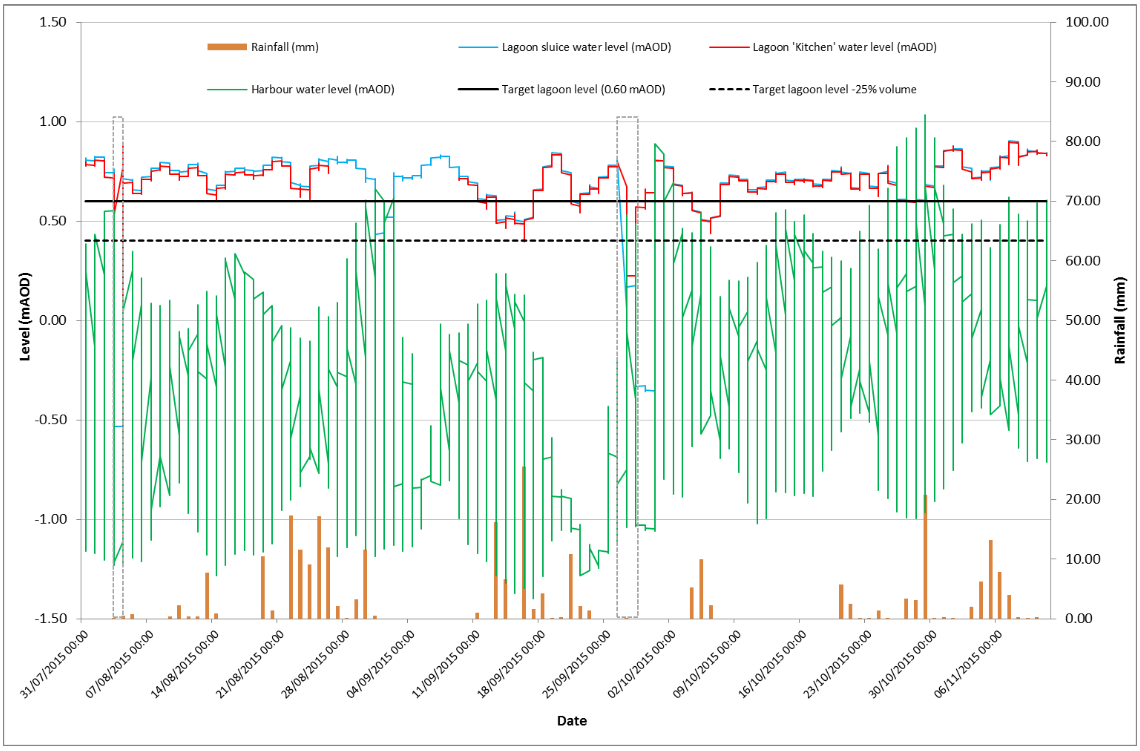


Figure 6.9 Levels (mAOD) in the Lagoon (sluice and 'Kitchen') and Poole Harbour from August to November 2015. Solid black line indicates the target post-flush level. Hashed black line indicates the target level minus 25 % volume.

6.6 Lagoon drain input volume

One aspect of the original environmental monitoring programme was to quantify the volume of water entering the lake via the main drain inputs (L1 to L4). However, considerable variation in drain input flows in response to unpredictable events (e.g. surface water run-off, sewage discharges, municipal discharges and other unknown sources) meant that it was not possible to obtain accurate volume input estimates using weekly spot flow readings at the drain exits.

In addition, drain exits were often submerged (or partially submerged) during weekly survey occasions, depending on lake water levels, causing water to back up inside the pipes.

Accordingly, it is considered that accurate quantification of annual input volumes from each of the key drain inputs can only be achieved by using continuous in-situ flow monitoring within the pipes just upstream of the lake.

7. PUBLIC ENGAGEMENT

An important aspect of the current work was to engage members of the public, with a view to both disseminating information in relation to the project and also obtaining input from the public through social media outlets.

7.1 Poole Park Lake Day

On 8th April 2015, BUG staff contributed to the 'Lake Day Event'. BUG staff manned a 'Lake Research' exhibition stand with images, aquaria and microscope stations. This provided the opportunity to convey issues relating to the ecology and chemistry of the lakes, current water quality problems and what is being done to help towards future management planning.

7.2 Guided walk

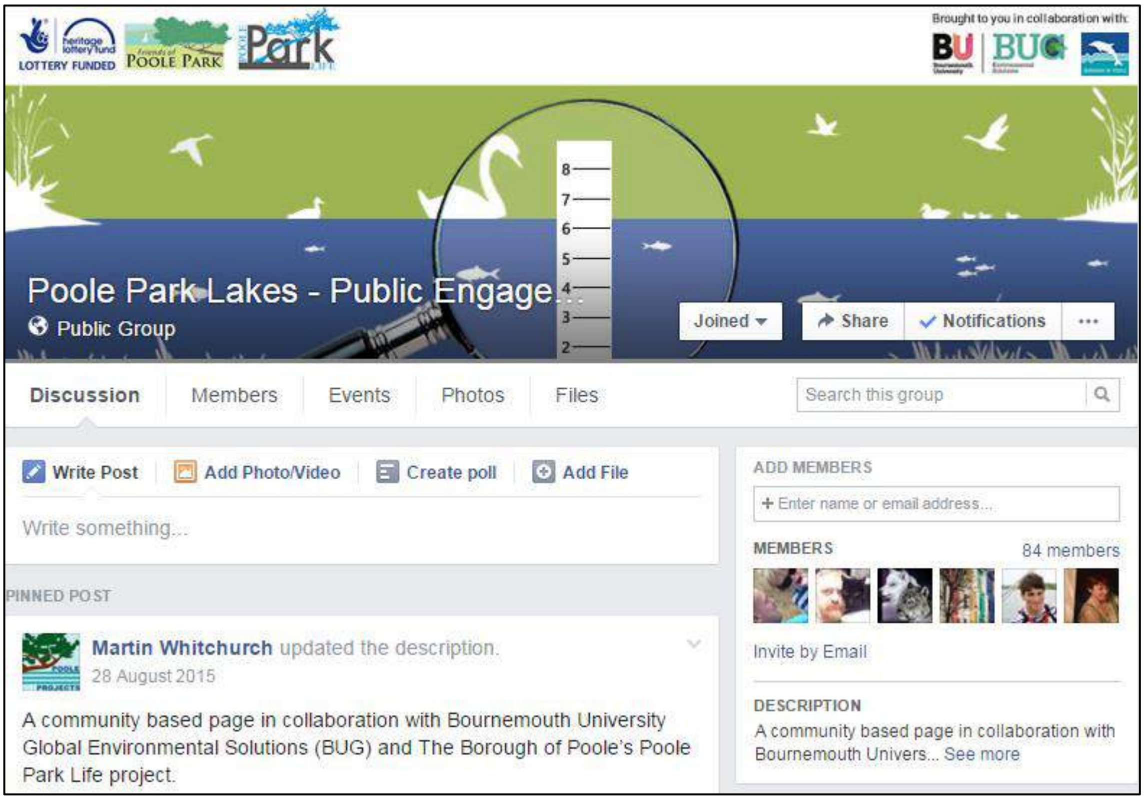
On 18th April 2015, BUG staff delivered a guided walk to allow members of the public to explore some of the challenging environments around the lakes. In addition, members of the public were able to observe water quality monitoring techniques being used in the field.

7.3 Poole Park Lake engagement event

On 28th September 2015, BUG staff contributed to the 'Lake Engagement Event' by conducting a fish survey of the large freshwater lake and engaging members of the public during processing of the catch. Due to the Lagoon being comprehensively drained over this period, BUG staff also assisted in coordinating effort and guiding members of the public (individuals and families) on a litter picking campaign and mapping the location of drain inputs around the perimeter of the lake.

7.4 Social networking: Poole Park Lakes – Public Engagement with Science

A community based project (in collaboration with Borough of Poole and BUG) was initiated by BUG staff in April 2015 via the creation of a dedicated Facebook group "Poole Park Lakes – Public Engagement with Science" (Figure 7.1).



Martin Whitchurch updated the description.
28 August 2015

A community based page in collaboration with Bournemouth University Global Environmental Solutions (BUG) and The Borough of Poole's Poole Park Life project.

DESCRIPTION
A community based page in collaboration with Bournemouth Univers... See more

Figure 7.1 The "Poole Park Lakes – Public Engagement with Science" Facebook group.

This group presently has 84 members who are involved in some of the scientific research carried out at Poole Park Lakes. Invaluable contributions by the public include photographs, observations and general discussion on lake issues; all of which have helped to inform the current project.

In particular, regular photos of the gauge boards have facilitated analyses of the lake level data and informed the discussion on lake levels and flushing regime.

8. INTERPRETATION

This section discusses the results of the various elements of the environmental monitoring programme, and outlines the implications for developing an appropriate lake management regime.

Detailed recommendations for future development and on-going management are provided in Section 9.

8.1 Data limitations

The outputs of the 2015 monitoring programme represent the most comprehensive temporal and spatial dataset available for the Poole Park water bodies to date. However, despite successfully elucidating intra-annual variation during 2015, it is important to acknowledge these data do not account for inter-annual variations.

For example, with rainfall and air temperature known to be key drivers of water quality and biological production, factors such as the relatively low maximum summer temperature recorded in 2015 (see Figure 8.1) may explain the limited production of chlorophyll, which in other years has been observed to proliferate, turning the lake green.

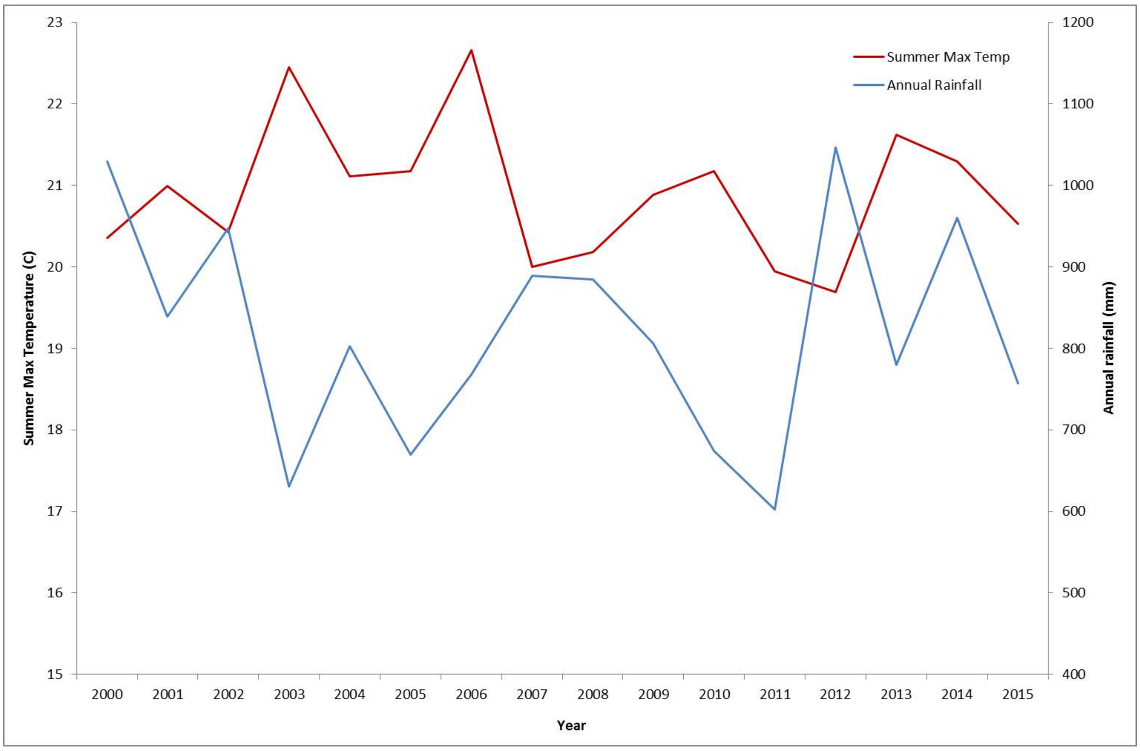


Figure 8.1 Inter-annual variation in total rainfall and maximum summer temperatures for southern England between 2000 and 2015.

8.2 Trophic status

The trophic status of a lake provides an indication of how biologically productive the lake is and is largely indicative of the level of phosphorus and nitrogen in the water body. Lakes with low nutrient levels are classed as oligotrophic and have low biological productivity; whilst lakes with high nutrient concentrations are classed as eutrophic and have high productivity. Eutrophic lakes are generally characterised by a dominance of aquatic plants and/or algal blooms.

Trophic status classification criteria based on TP, chlorophyll, transparency and TN are provided in Table 8.1 below. The trophic status of each lake, based upon the criteria outlined in Table 8.1, is provided in Table 8.2. The Lagoon is classed as eutrophic; whilst both freshwater lakes are classed as hypereutrophic.

Table 8.1. Trophic status classification criteria based on TP, chlorophyll, transparency and TN. From Galvez-Cloutier (2007). TP, chlorophyll and transparency use OECD criteria, whilst TN uses Nürnberg criteria.

Trophic status	TP ($\mu g l^{-1}$)	Chlorophyll a ($\mu g l^{-1}$)		Transparency (m)		TN ($\mu g l^{-1}$)
		Mean	Max	Mean	Max	
Ultra-oligotrophic	< 4	< 1	< 2.5	>12	> 6	
Oligotrophic	< 10	< 2.5	< 8	> 6	> 3	< 350
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5	350-650
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7	651-1,200
Hypereutrophic	> 100	> 25	> 75	<1.5	< 0.7	> 1,200

Table 8.2. Trophic status of each lake in Poole Park based on criteria in Table 8.1.

Lake	TP ($\mu g l^{-1}$)	Chlorophyll a ($\mu g l^{-1}$)		Transparency (m)		TN ($\mu g l^{-1}$)	Trophic status
		Mean	Max	Mean	Max		
Lagoon	58	6.55	55.4	N/A	N/A	606	Eutrophic
FW1	277	205	659	N/A	N/A	2,700	Hypereutrophic
FW2	202	16	70	N/A	N/A	2,533	Hypereutrophic

8.3 TN:TP ratio

The TN:TP (Total Nitrogen:Total Phosphorus) ratio can be used to help inform which of the two nutrients is limiting primary productivity and phytoplankton production within a lake; generally, ratios > 12 are indicative of phosphorus limitation (i.e. algal growth exhausts bioavailable phosphorus supplies before nitrogen), whilst ratios of < 5 are indicative of nitrogen limitation. Values in between suggest there is no clear limitation of either nutrient. However, it is emphasised that using TN:TP ratios as indicators of nutrient limitation is not straightforward due to many other confounding factors (Harris 1995).

Table 8.3. TN:TP ratios of the three lakes within Poole Park.

Water body	Mean TN (mgl^{-1})	Mean TP (mgl^{-1})	TN:TP ratio
Lagoon (L5 + L6)	0.606	0.058	10.4
FW1	2.700	0.277	9.7
FW2	2.533	0.202	12.5

The TN:TP ratios of all three lakes (Table 8.3) suggest that there is no clear nutrient limitation of either TN or TP in any of the water bodies.

8.4 Lagoon water quality

Lagoon communities are sensitive to reduced water quality, including high nutrient levels and industrial and urban run-off, although this is dependent on lagoon size and the amount of seawater exchange. Small, isolated lagoons and those with limited exchange are more sensitive.

Water quality in the Lagoon was generally indicative of a eutrophic water body, with relatively high (but not excessive) nutrient levels.

Temperature in the Lagoon was generally 2 – 3°C higher than that in Poole Harbour (Figure 4.1), most likely as a result of the shallow, sheltered nature of the lake and long residence time of water between flushes. Flushing the lake with water from Poole Harbour, therefore, would help to reduce water temperature; particularly during the summer months.

The pH in the Lagoon was relatively high (peak of 9.4), compared with Poole Harbour, which exhibited a typical seawater pH range from 7.5 to 8.4 (Figure 4.5). High pH ranges are not unusual for lagoons, with pH often being influenced by the time of day. For example, during the summer, early morning photosynthesis of algae (during periods of elevated CO_2) can increase pH up to 8 – 9. Once the CO_2 is used up, the pH then reduces (i.e. becomes more acidic). The pH of water plays an important role in regulating the balance of ionised ammonium versus un-ionised ammonia (toxic for aquatic life, particularly fish), with more un-ionised ammonia being released as pH increases.

Dissolved oxygen was relatively high in the Lagoon, generally remaining above 5 mgl^{-1} during weekly sampling (Figure 4.8). However, these weekly samples were taken during mid-late morning, when dissolved oxygen levels are typically increasing through the photosynthetic action of aquatic plants and algae. Continuous monitoring data from the in-situ multi-parameter water quality sonde during September-October (Figure 4.43) show large diurnal fluctuations (high during day, reduced at night). Critically low dissolved oxygen levels were only observed on a few occasions during this time period; however during periods of algal blooms in the summer months (not seen to any great extent in 2015), dissolved oxygen at night time could fall to critically low levels for prolonged periods, resulting in ecological stress and fish kills.

Ammonium levels were relatively high – regularly exceeding the Freshwater Fish Directive threshold of 1 mgl^{-1} (Figure 4.11). Combined with high pH and periods of low dissolved oxygen, this could result in very high un-ionised ammonia values leading to fish mortalities. Flushing from Poole Harbour appeared to reduce ammonium concentrations.

Biochemical Oxygen Demand (BOD) was relatively low; remaining below the Freshwater Fish Directive exceedance threshold of 6 mgl^{-1} throughout the year (Figure 4.14). In addition, flushing from Poole Harbour appeared to dramatically reduce BOD in the Lagoon.

The two key nutrients driving lake productivity are nitrogen and phosphorus. In particular, total nitrogen can influence the balance between macrophyte and algae communities. Species richness of plants and establishment of submerged macrophytes are reduced by increasing nitrogen concentrations; most likely as a result of nitrogen limitation of phytoplankton being removed, along with high nitrate concentrations favouring filamentous green algae that shades submerged macrophytes. For example, in enclosure experiments, nitrogen concentrations above 1.2-2 mgl^{-1} (along with phosphorus concentrations of 0.1-0.2 mgl^{-1}) increased the risk of turbid conditions (Sondergaard 2007) and decreased species richness of submerged macrophytes (Barker *et al*. (2008).

Total nitrogen was generally low in the Lagoon throughout 2015, with the exception of elevated (although not exceptionally so) levels at the start of the year (Figure 4.17). The mean total nitrogen concentration recorded during 2015 would class the lake as mesotrophic for this nutrient (see Section 8.2). Total nitrogen in Poole Harbour is commonly known to be high due to on-going catchment management issues (see Poole Harbour Catchment Initiative; PHCI 2014), and this was reflected in the data collected during the 2015 environmental monitoring programme (Figure 4.17). Flushing the Lagoon from Poole Harbour, therefore, is unlikely to reduce total nitrogen levels in the Lagoon.

Similar to the situation for total nitrogen, the concentration of total phosphorus in Poole Harbour is comparable with the Lagoon (Figure 4.20), and sometimes exceeds levels in the lake; therefore, tidal flushing is unlikely to reduce the overall total phosphorus concentration in the Lagoon. Although elevated during August and September, total phosphorus levels were generally not excessively high for a water body of this type – lending support to the theory that problems with algal blooms may be more related to lake retention times, rather than nutrient levels *per se* (see Section 8.7).

Chlorophyll concentrations in Poole Harbour were generally higher than in the Lagoon (Figure 4.23); however, flushing events did not appear to increase chlorophyll concentrations within the lake. In general, chlorophyll remained relatively low throughout the year, which supports observations of generally clear conditions during 2015 with no major algal blooms.

8.4.1 Influence of drain inputs on water quality

The four Lagoon drain inputs (L1 to L4) showed varying degrees of freshwater flow and associated input of nutrients and contaminants. Flows varied significantly throughout the year and obtaining accurate measurements of total volume input was not possible (see Section 6.6). However, all inputs contributed to the water quality of the Lagoon to some extent.

Total nitrogen and total phosphorus were elevated in all drain inputs (Figure 4.18 and Figure 4.21); in particular, several very high peaks of total phosphorus were evident at L1. One such peak coincided with very high faecal coliform levels; however, no coliform sampling was undertaken at the time of the subsequent two peaks (coliforms were only sampled bi-weekly).

Faecal coliforms and *Escherichia coli* exhibited very high levels at most drain inputs; particularly L1, L2 and L4. However, levels were diluted in the Lagoon (Figure 4.29 to Figure 4.41). Nevertheless, this has serious implications for water users in the immediate vicinity of drain inputs, where faecal coliform values are often orders of magnitude higher than Bathing Water Directive standards. For example, high levels of faecal coliforms were recorded at L8 (Figure 4.34), adjacent to Rockley Watersports, where children are entering and leaving the water.

Total suspended solids were generally low throughout the year in the Lagoon at L5 and L6 (Figure 4.25). However, high loadings were evident at all of the drain inputs, particularly at L2 which delivers high volumes of surface water run-off and also receives water from a Combined Sewer Overflow (Figure 4.26 and Figure 4.27).

Perhaps the biggest influence on water chemistry from drain inputs is the volume of fresh water entering the lake (particularly through L2), which reduces the salinity between flushes. This is discussed in more detail in Section 8.8.

8.5 Freshwater lake water quality

Water quality in both freshwater lakes was generally indicative of a hypereutrophic water body, with very high levels of both total nitrogen and total phosphorus (Figure 4.19 and Figure 4.22). High nutrients could be partly due to the large amount of wildfowl present. However, the high density of carp in FW1 may also be contributing to the nutrient load by releasing sediment-bound phosphorus through mechanical mobilisation of the lake bed.

Dissolved oxygen exhibited very high levels during spring; however, concentrations reached very low levels during the remainder of the year (Figure 4.10). Furthermore, night time dissolved oxygen levels are likely to be critically low; particularly during periods of algal blooms.

Ammonium levels were relatively high – regularly exceeding the Freshwater Fish Directive threshold of 1 mgl^{-1} (Figure 4.13). Combined with high pH and periods of low dissolved oxygen, this could result in very high un-ionised ammonia values leading to fish toxicity issues in FW1.

Biochemical Oxygen Demand (BOD) was high; particularly in FW1, which regularly exceeded the Mandatory value for Freshwater Fish Directive of 6 mgl^{-1} (Figure 4.16).

Chlorophyll concentrations were high in FW1, probably due to a lack of shading and higher nutrient loading. Conversely, FW2 is very shaded and generally exhibited low chlorophyll levels throughout the year (Figure 4.24).

8.6 Sediment quality

8.6.1 Nutrients

Lake sediments have the potential to store nutrients (particularly phosphorus) which can subsequently be released to the water column under certain conditions. Sediment phosphorus inputs (internal phosphorus loading) can be a significant term in the annual phosphorus budgets of many lakes. Environmental variables that regulate dissolved phosphorus release from sediment (mainly as phosphate, PO_4^{3-}) include temperature, dissolved oxygen, pH and redox potential.

Reduced dissolved oxygen and pH (e.g. as a result of stratification or high Biochemical Oxygen Demand) can lower the redox potential at the sediment-water interface. At low redox potential, Fe (III) in the sediment is reduced to Fe (II), leading to the release of PO_4^{3-} (Nowlin *et al*. 2005).

However, other biotic processes may confound sediment iron-bound phosphorus release; for example high concentrations of nitrate (NO_3^-) in waters overlying sediment can raise the redox potential by providing denitrifying bacteria with an alternative electron receptor – enhancing Fe oxidation and sediment sorption of PO_4^{3-}. Conversely, high NO_3^- concentrations can stimulate the growth of Fe-reducing bacteria resulting in further PO_4^{3-} release from sediments (Nowlin *et al*. 2005). Release of PO_4^{3-} from sediments into the water column is, thus, a complex combination of abiotic and biotic processes.

Notwithstanding the above, sediment phosphorus in the Lagoon (and freshwater lakes) was relatively low at the time of surveying; therefore, in keeping with the findings of previous surveys in 2012 (APEM 2012), sediment phosphorus release probably isn't significant.

In contrast, sediment nitrogen was relatively high at L5 and L6, possibly reflecting the generally high total nitrogen concentrations in the Poole Harbour catchment.

Both phosphorus and, particularly, nitrogen levels were elevated at Lagoon drain input L4. This is most likely a direct result of extremely high numbers of birds being fed at this location beside the car park (see Figure 8.2).

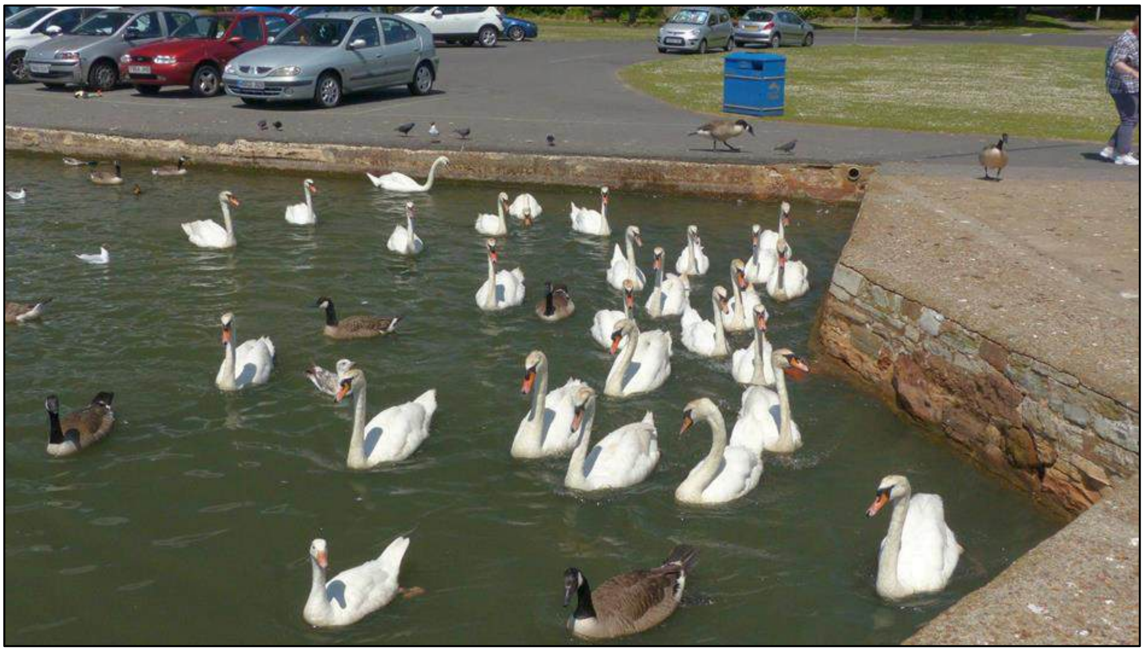


Figure 8.2 High numbers of birds (due to feeding by the public) in the vicinity of L4.

8.6.2 Metals

Relatively high concentrations of metals were recorded in the centre of the Lagoon, particularly arsenic and lead (see Section 4.3.7). Interestingly, levels of metals in the vicinity of the four Lagoon drain inputs were relatively low, suggesting that the source of sediment metal input is either a) from Poole Harbour, or b) a legacy of past industrial pollution to the lake which is no longer present in the inputs currently draining to the lake.

8.7 Retention time and algal proliferation

As discussed in Section 8.4, nutrient levels (TN and TP) in the Lagoon are similar to those in Poole Harbour. Therefore, increasing the frequency of flushing is unlikely to have an effect on the overall nutrient loading to the lake.

However, although nutrient availability is one of the key limiting factors of algal production, another fundamental aspect affecting the proliferation of algal blooms is the retention time of the lake, i.e. the length of time that the water remains impounded.

In natural systems, the retention time is affected by the volume and rate of the inflow and outflow (normally a river/rivers), and is defined as the time taken to circulate the entire volume of the lake. However with respect to the Lagoon in Poole Park, water transfer between the lake and Poole Harbour is artificially controlled by the sluice gate. Accordingly, the retention time is directly associated with the period of time between flushes.

Phytoplankton species composition and abundance are known to be influenced by the retention time of small lakes, with shorter retention times resulting in reduced phytoplankton abundance and increased flushing reducing the standing stock (Jones and Elliott 2007). Accordingly, even though nutrient concentrations may not be significantly reduced by maintaining an increased flushing regime, the shorter retention time is likely to be beneficial by limiting the potential for problem algal blooms to develop.

8.8 Flushing regime, fresh water input and salinity

To investigate the influence of various different flushing regimes on salinity within the Lagoon, data from 2015 were used to calculate an average Daily Decreasing Rate (DDR) of salinity between flushing events.

This salinity DDR was then applied to six different scenarios; monthly flushing of 25 %, 50 % and 75 % lake volume, and bi-monthly flushing of 25 %, 50 % and 75 % lake volume. For all scenarios, both Poole Harbour and the starting lake salinity were taken as 30 ppt.

Figure 8.3 shows the modelled influence of monthly flushing at the three volume exchange scenarios and Figure 8.4 shows the modelled influence of bi-monthly flushing at the three volume exchange scenarios. Actual salinity values from weekly monitoring during 2015 are also shown as hashed grey lines.

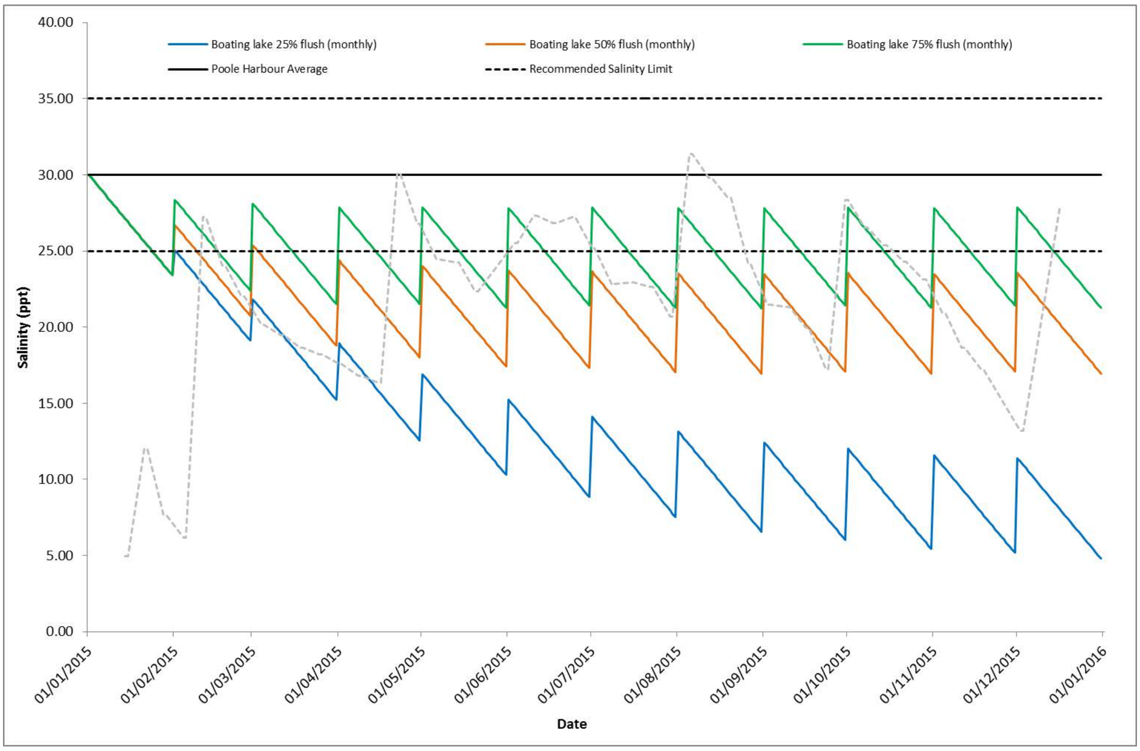


Figure 8.3 Modelled salinity in the Lagoon based on three different monthly lake volume exchange scenarios; 25 %, 50 % and 75 % volume exchange. Hashed grey line represents actual 2015 salinity.

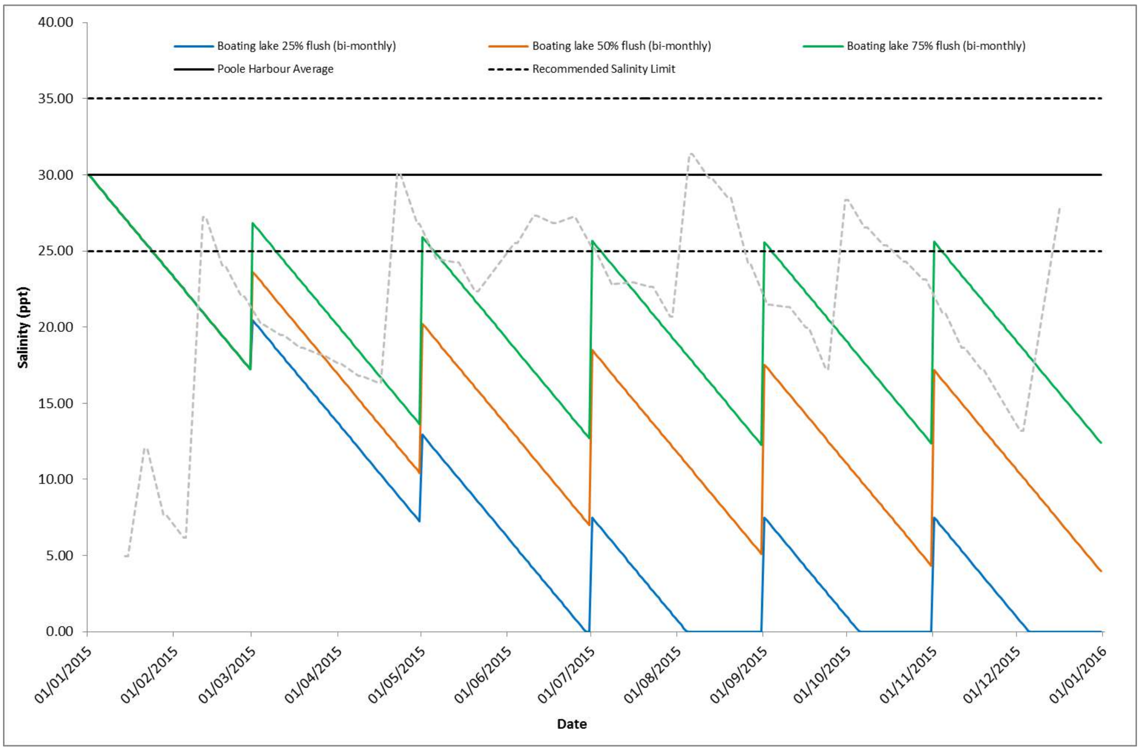


Figure 8.4 Modelled salinity in the Lagoon based on three different bi-monthly lake volume exchange scenarios; 25 %, 50 % and 75 % volume exchange. Hashed grey line represents actual 2015 salinity.

There was a relatively high salinity DDR of 0.22 ppt/day, which is reflective of the significant freshwater inputs to the lake; most notably via the large surface water drain (also a licenced Combined Sewer Overflow) at L2.

Given these relatively high freshwater inputs, monthly flushing of 25 % lake volume would be insufficient to maintain adequate salinity, which would stabilise at around 10 ppt. Under the current freshwater input scenario, even a monthly flush of 50 % lake volume would only be able to maintain a salinity of around 23 ppt (Figure 8.3). The actual flushing regime during 2015 was most closely associated with the 75 % bi-monthly flushing scenario shown in Figure 8.4.

8.9 Invertebrate and fish communities

8.9.1 Lagoon

Fish community

The potential value of the Lagoon to fish populations is considerable. With the exception of gobies and stickleback, which are likely to represent resident components of the community, other species are transient and move between the harbour and the lake during periods of water exchange through the sluice.

On this basis, under a more frequent flushing regime, the fish community within the lake would be expected to reflect the seasonal utilisation of the harbour by different species and life stages. Whilst the Lagoon currently offers some (albeit limited) value as a juvenile nursery zone, as evidenced by the presence of large numbers of juvenile sand smelt and mullet; these fish are currently temporarily trapped within the lake for prolonged periods between flushing events and, therefore, are sensitive to changes in water quality and predation by birds.

Increasing the frequency of flushing events would maintain higher salinity levels and allow greater potential for the passage of fish between the lake and the harbour. With many marine species spawning off-shore, the young-of-the-year arrive at different times of year and at different stages of early development. That said, the diversity and general abundance of juvenile life stages typically peaks around late summer and early autumn. Despite juvenile bass being recorded in previous surveys, it is considered that a more regular flushing regime would dramatically increase the number of young bass (and other species of commercial and conservation importance) utilising the lake, thus providing an important extension of the bass nursery zone already regulated within much of Poole Harbour.

Maintaining a higher diversity of fish species within the Lagoon would help to enhance the overall ecological functioning of the lagoon system by providing a more balanced community of predator and prey interactions. This could, for example, contribute to maintaining lower numbers of swarming chironomids through direct predation of the larval and emerging life stages.

Invertebrate community

The low species diversity of the invertebrate fauna of the Lagoon is typical of water bodies of this type. Specialist lagoonal indicator species found were the crustaceans *Monocorophium insidiosum*, the lagoon snail *Ecrobia ventrosa* and the starlet anemone *Nematostella vectensis,* which is of international importance.

In addition to those species recorded in survey samples; around the edges of the lake the lagoon prawn *Palaeomonetes varians* could be seen swimming and the non-native tube worm *Ficopomatus enigmaticus* colonised parts of the structure. Shore crabs (*Carcinus maenas*) were also captured in traps placed near the sluice.

Bamber *et al* (2001) list three levels of priority for the conservation of biological and structural features within UK lagoons. The Lagoon meets the criteria for Priority 1, the highest priority, owing to the presence of internationally important and nationally important specialist species and BAP species (see Section 2.1).

A high level of temporal (including seasonal) variability in the abundance of invertebrates is another typical characteristic of lagoons and this is exemplified in the Lagoon data for 2015. It is possible that the relatively more diverse fauna observed compared to previous years is due to the more frequent flushing regime and higher salinities. For example, during the spring of 2015 (after a prolonged drain down) only a few species were recorded, with the community being dominated by chironomid larvae. In contrast, later in the season (after two tidal flushes), the species richness and abundance had increased considerably (Figure 5.3). This lends support to the beneficial effects of increasing and maintaining a regular flushing frequency.

8.9.2 Freshwater lakes

The results from the invertebrate surveys conducted on FW1 and FW2 are indicative of impoverished communities, reflecting the highly eutrophic nature of both water bodies. With the BMWP scale ranging between 0 and 10 (10 being the most pollution sensitive species), *Gammarus* sp. was the highest scoring taxon (BMWP = 6), with benthic dwelling species almost exclusively limited to chironomids (BMWP = 2).

With invertebrates representing the main natural food source of cyprinid fishes, the high abundance (and biomass) of carp in FW1 will be highly dependent on an artificial diet of bread and grain fed to the waterfowl on a daily basis. High protein fish pellets are also sold to the public from the miniature railway station and large numbers of carp can be observed throughout the year, competing with the ducks and geese for these food items around the railway bridge.

Figure 8.5 Large carp feeding on bread and fish pellets beneath the railway bridge. Photo courtesy of Jamie Anderson.

Due to the poor water quality recorded in FW1, the fish population within this waterbody is considered to be subject to a high level of risk. With dissolved oxygen and ammonium frequently reaching critical limits, a prolonged period of hot still weather could result in a comprehensive fish kill, with a high biomass of carcasses requiring rapid disposal.

Despite intense visual assessment of FW2, no fish (including pollution tolerant sticklebacks) have been observed to be present. This is likely due to poor water quality; specifically low dissolved oxygen and elevated levels of ammonium.

9. THE FUTURE OF POOLE PARK

With specific reference to the Lagoon, the water bodies of Poole Park constitute key focal features of the park; aquatic-based problems (e.g. chironomid swarms and algal decay), therefore, have the potential to directly impact on the amenity value, business potential and wellbeing of local residents.

Enjoyed across the full demographic of society (local and tourists), the Lagoon has enormous potential to provide a range of currently untapped ecosystem services, which would benefit the public by facilitating and encouraging their engagement with outdoor space and nature.

For the three water bodies to achieve or move towards their functional potential, the 2015 monitoring programme has identified a range of issues which require remedial management action.

9.1 Managing the Lagoon – past, present and future

With previous monitoring of the lakes being restricted to a limited number of small scale ‘snapshot’ investigations, past management of the lakes has been severely constrained by a lack of robust evidence. Despite previous attempts to control algal production with the annual application of blue dye, rafts of barley straw bales and drying of the lake bed during winter, the efficacy of these measures has never been qualified (although appears to be negligible).

Moving forwards, the sustainable management of these water bodies must rely on addressing the root causes of problems rather than the reactive application of ‘sticky plaster’ solutions.

Based on the data and interpretation presented within this report, it is important for BoP managers to accept and work within the limits of ecological potential the lakes offer. Specifically, it would be unrealistic to believe that the Lagoon could be maintained as a low nutrient, weed free water body. Recognising and promoting the water body as a saline lagoon with the potential to attract unique wildlife, including invertebrates, fish and birds will be key to managing public expectations and allow BoP to set realistic and sustainable management targets with tangible outcomes for stakeholders.

Achieving these goals whilst balancing the sensitivities associated with ‘change’, however, will require a coherent management strategy, incorporating a maintained range of synergistic management actions, as outlined in the following sections.

9.1.1 Increase and maintain flushing frequency

Based on the evidence collected, increasing the frequency of flushing with Poole Harbour has been predicted to maintain higher water quality, assist in limiting the proliferation of phytoplankton blooms, limit the risk of chironomid swarms and enhance aquatic biodiversity within the Lagoon.

To increase the diversity and number of specialist lagoonal species present, the management of salinity is priority. Most specialist lagoonal species are closely related to marine species; therefore, most have a preference for salinities approaching that of the open sea i.e. 35 ppt. Although many are tolerant of periodic reductions in salinity, the input of freshwater is not necessary for saline lagoons; however, a freshwater gradient or patchiness in salinity can increase the diversity of habitats. Variation in salinity outside the range 15-40 ppt is likely to be tolerable to these specialist species for a few days; however, without remedial action, when levels fall below 10 ppt, the invertebrate community is likely to become rapidly dominated by high densities of nuisance pest species (e.g. chironomids).

Using a combination of hydrology data (Section 6) and modelled salinity response (Section 8.8), maintaining salinity within the optimal range would require the monthly exchange of 75 percent of the lake total volume. Based on tides and flow exchange rates, opportunities for water exchange would be limited to the largest tidal ranges in the harbour, with both drain down and recharge taking approximately 7 hours. In terms of visualising disruption to current recreational activities and aquatic wildlife, under this management scenario, minimum water levels would be temporarily reduced by approximately 60 cm (to a reading of 0 mAOD) on the gauge board adjacent to The Kitchen restaurant. Given the length of time required to exchange 75 percent of the lake volume, it is likely that this scenario would require two tidal cycles to complete

Whilst the above management strategy would be expected to realise benefits across both water quality and ecology, reducing the volume of freshwater input to the Lagoon has the potential to dramatically reduce salinity dilution rates and thus reduce monthly tidal exchange requirements to 50 percent (or less) of the lake volume. A 50 percent volume exchange has been modelled to take approximately 4.5 hours for both the drain-down and recharge, with water levels on The Kitchen gauge board not dropping below 20 cm. With the continuous and highest proportional volume of freshwater to the lake being delivered from L2, the benefits of rerouting this drain are presented in Section 9.1.2.

It is important to note that leaving the lake drained for more than a single tide (e.g. as previously actioned to facilitate maintenance works) would have a deleterious impact on the ecological community of the lake. To promote the establishment and stability of a functional ecological community, such management practice should be avoided in future.

9.1.2 Divert L2 freshwater drain input

Despite the difficulties associated with gauging the highly variable flow of water entering the Lagoon from marginal drain inputs, observations of flow rates throughout the monitoring programme have confirmed L2 as the most significant source of freshwater to the Lagoon.

Not only does this have implications for diluting the salinity of the Lagoon, L2 periodically delivers licensed Combined Sewer Overflow discharge to the lake, along with a continuous delivery of high coliform and nutrient loadings.

Accordingly, the diversion of L2 to Poole Harbour would provide considerable benefits for the Lagoon and its management. Not only would this reduce the volume of monthly water exchange required to maintain desired salinity levels; removing the input of high nutrient, bacterial and ammonium loadings would also reduce localised health risks to the public (and pets) and translate to general improvements in water quality across the lake.

9.1.3 Island creation and increased water depth

The Lagoon is extremely shallow and, combined with prolonged periods of hot, calm weather, this can exacerbate the problems associated with algal blooms, filamentous algae and tasselweed. Although creation of an excessively deep lake is not considered desirable, increasing the water depth by strategic removal of accumulated silt would provide multiple benefits to both water quality and ecological function.

The majority of UK lagoons are less than 2m deep and it is possible that depths exceeding this value may result in insufficient photosynthetic activity from benthic algae and macrophytes to maintain sufficient oxygen levels. In addition, plants also provide habitats for invertebrates.

Currently, there are five small islands in the Lagoon, created from dredged material from the lake bed. However, these islands are limited in terms of ecological function or amenity value. Increasing the lake depth by the creation of new 'submerged' islands from dredged lake bed sediments would provide multiple benefits to the lake ecology, as well as enhancing the amenity value of the lake to the public by making the islands accessible from the shore via boardwalks (see Section 9.3).

To promote the establishment of reed beds to cover the islands, the new islands should be submerged approximately 30 cm below the lake full water level (depending on reed species); this would also help to discourage wildfowl roosting on the islands. The margins of the islands should comprise a shallow shelving depth profile, providing varying habitats for a range of species.

Creation of sufficiently large islands would enable the lagoon bed to be re-profiled, with a view to providing an increased diversity and quality of habitat. Depths should range between 0 and 2 m, with shallow shelving areas, beaches and gravel shoals to provide habitat for a range of key lagoonal invertebrate and bird species. NOTE: An investigation of groundwater levels should be conducted in advance of any excavation to determine any potential issues with groundwater intrusion.

In addition, creation of new islands in the north-eastern area of the Lagoon would also help to reduce the impact of wave action on the northern banks during periods of high winds from the prevailing south-westerly direction (Figure 9.1).

Figure 9.1 High south-westerly winds creation wave action on the north-east shore due to the large reach across the main body of the Lagoon.

9.1.4 Remove barley straw bales

The efficacy of barley straw in controlling algal blooms in water bodies is largely untested from an independent scientific perspective, with much of the literature relating to its effectiveness being anecdotal in nature and in relation to smaller water bodies.

From a UK perspective, the most comprehensive assessment of the use of barley straw for algae control was produced by CEH (2004). In a recent literature review of aquatic and riparian plant management (EA 2014), this CEH report is still cited as the most up to date literature on the use of barley straw for algal control, with no more recent scientific assessments of its efficacy being presented.

With regard to the Lagoon; the highly variable nature of the nutrient status and water chemistry (particularly salinity), largely augmented through flushing events with Poole Harbour, would likely have a confounding effect on the efficacy of barley straw in limiting algal production. Furthermore, given the often highly turbid nature of the water column, the amount of barley straw required for effective treatment may need to be increased beyond the normal recommended dose by at least a factor of two (CEH 2004). In addition, the current spatial distribution of bales within the lake is not considered sufficient to provide any effective algal control.

Given the continued recent problems with dense algal blooms in the lake, the efficacy of the existing barley straw bales could, and indeed should, be questioned. However, regardless of their effectiveness, attempting to control algal production by continued maintenance of barley straw bales within the lake is regarded as a ‘sticky plaster’ approach that does not address the fundamental underlying causes of the various lake management issues.

In addition, it could be argued that the floating structures used to contain the straw exist as an eyesore, a public health risk due to excessive bird faeces and obstructions to recreational water sports activities.

Given the high profile nature of the site, where recreational activities and aesthetic value are of paramount importance, the continued use of barley straw bales is not considered a viable long-term solution.

9.2 Managing the freshwater lakes

Water quality within the freshwater lakes has become severely degraded over time, which is mirrored by depauperate biodiversity and ecological function. While neither of the freshwater ponds present tangible problems to park users (chironomid swarms and decaying weed), the data presented within this report support consideration of the following management suggestions.

9.2.1 Carp removal in FW1

Due to high nutrient loadings, FW1 is prone to elevated levels of chlorophyll and periodic blooms of blue-green algae. In addition to a high density of wildfowl, high densities of large carp currently exacerbate water quality issues by disturbing bottom sediments, mobilising nutrients and preventing the establishment of a more balanced community of macrophytes.

With water quality frequently reaching threshold conditions to support fish, it is strongly advised that the carp population is severely cropped and translocated to an alternative waterbody. Due to the size and condition of individual fish, the stock is likely to be of commercial interest to fish dealers and it is suggested that a single contractor is identified that can catch and relocate the fish in a single operation.

Not addressing this issue carries a risk for BoP, in that a comprehensive fish kill is not unlikely at some point in the future. Not only would this highlight the poor water quality in the lake, it would also cause distress to park users and require the recovery and disposal of a high biomass of decomposing carcasses.

9.2.2 Dredging

Both lakes have been subject to a high degree of silt accumulation, with water depths in FW2 not exceeding 30cm. Largely due to guano input from the high density of wildfowl, the sediment in both lakes provides a reservoir of nutrients to fuel algal production, is anoxic and would benefit from removal.

9.2.3 Aesthetics

In addition to providing an attractive feature, the installation of one or more decorative fountains on FW1 would assist in maintaining DO levels at a level more conducive to supporting aquatic fauna.

9.2.4 Reduction in wildfowl numbers

The main cause of poor water quality in both freshwater ponds is due to bird numbers. While a humane management programme (e.g. egg pricking) offers the most effective measure of managing this stressor, the discouragement of feeding wildfowl could be promoted through a combination of educational interpretation boards and preventing the sale of bird (and fish) food from the railway kiosk.

The success of such a scheme would, however, depend on the provision of alternative activities, and crabbing within the main lake may assist in this respect. At present, the islands in FW2 are utilised as roosting habitat, so the removal of the islands or the installation of deterrents (such as lighting) may be effective in discouraging birds from congregating on FW2 at night.

9.2.5 Drainage issues

The reduced temporal and spatial scale of water quality sampling in the freshwater lakes continues to constrain knowledge of how drain inputs impact on the water quality of FW1 and FW2. However, the physical drainage to the north of FW2 is clearly an issue, with the path often flooded during wet weather events.

Should the option to divert L2 to Poole Harbour be further investigated, it is strongly recommended that the feasibility of rerouting all drains currently entering the freshwater lakes into the L2 discharge is explored.

9.3 A future vision for Poole Park

Poole Park is a focal point for the local community and the opportunity for development of the area for public benefit raises fundamental questions as to how and for what purpose the lakes should be managed in the future.

Given the long-standing and on-going ecological issues surrounding the Poole Park Lakes, in particular the Lagoon, a concerted effort will be required to realise the full potential of the ecosystem services offered by the water bodies and the surrounding area.

As mentioned in Section 9.1, recognising and promoting the lake as a saline lagoon with the potential to attract unique wildlife, including invertebrates, fish and birds will be key to managing public expectations and allow BoP to set realistic and sustainable management targets. The current study, supported by years of previous smaller investigations, anecdotal information and negative public comments, reinforces the need for a fundamental shift in thinking with regard to the amenity value of the lake and the management of on-going ecological issues.

Currently, the Lagoon is a hugely under-utilised resource in Poole Park, largely focussed on recreational water sports for the benefit of a relatively small minority. Recognising, enhancing and managing the water body as a saline lagoon with unique habitats and species, whilst maintaining (and enhancing) the opportunity for water sports activities, would provide a whole range of ecological and societal benefits.

Figure 9.2 shows a schematic representation of one possible plan for the Lagoon, utilising the unique features of the water body to provide a shared resource offering both enhanced ecological benefits and high amenity value.

The creation of new ‘submerged’ reed islands that are accessible via boardwalks would allow the public to engage more with the main lake and, combined with interpretation boards highlighting the unique lagoonal ecosystem, would increase awareness of the unique habitats and species present.

Reed beds (on the islands and shoreline), gravel shoals and varying depths in inaccessible areas would all provide habitat for invertebrates and wading birds, which could be observed from a bird watching hide.

Currently, water sports are mainly focussed on the western end of the lake; increased depths, better water quality and removal of the barley straw bales would all provide enhanced opportunities for a variety of activities on the lake in this watersports area.

Enhancing the accessibility of the Lagoon through the creation of submerged islands and boardwalks may also shift the focus from bird feeding in the freshwater lakes, which contributes to the degraded water quality and nuisance geese in these areas. For example, creation of a deeper ‘crabbing’ zone on one of the islands would provide additional activities for young families to enjoy (Figure 9.3).

Enhancing the overall ecological and amenity value of the Lagoon would provide significant tangible benefits. In addition to helping alleviate the on-going ecological issues; physical activity, mental health and societal benefits would be realised through promoting public engagement with green outdoor spaces.

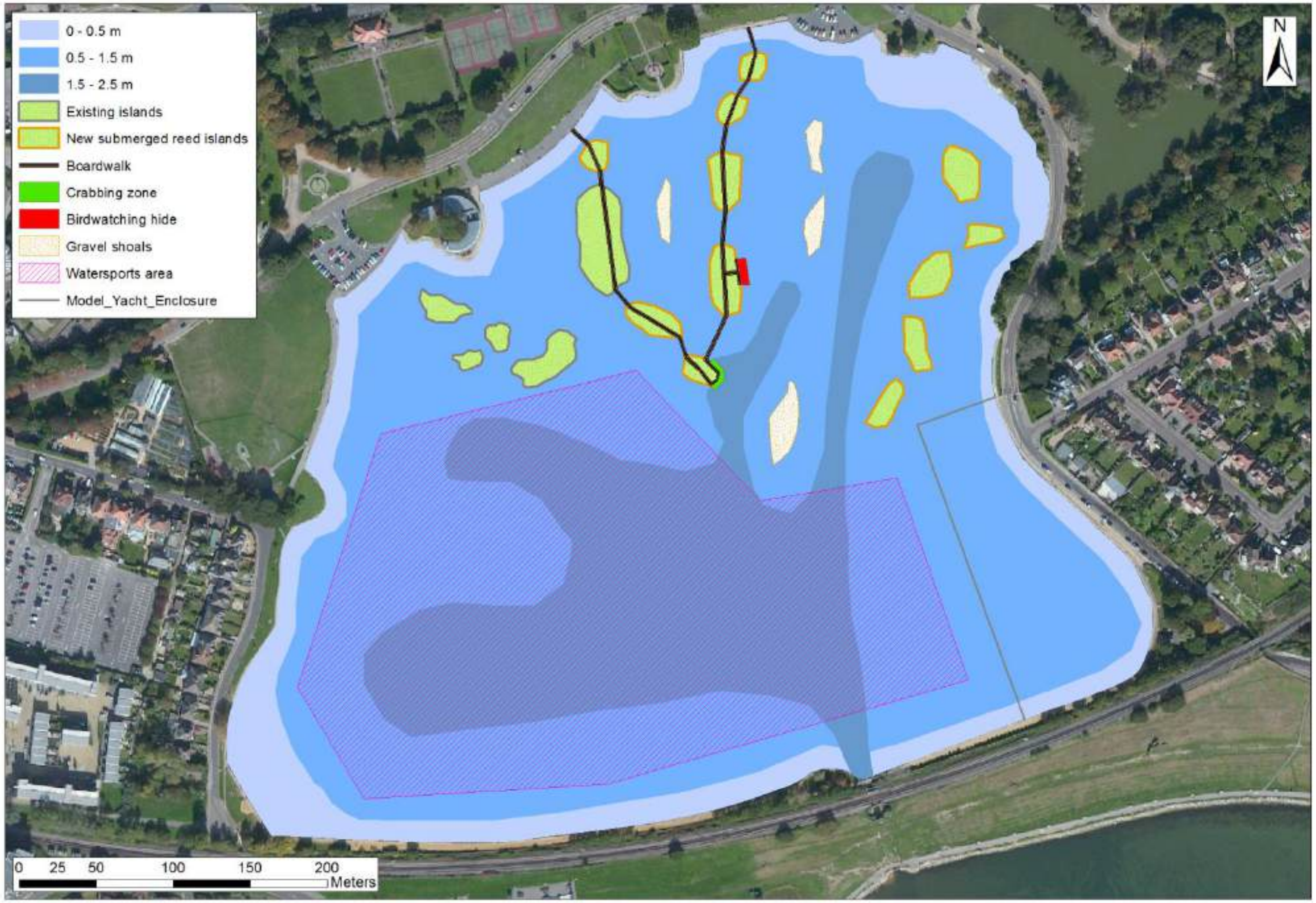


Figure 9.2 Schematic example of the Lagoon with new submerged reed islands, gravel shoals, boardwalk, birdwatching hide, crabbing area, designated water sports zone and model yacht enclosure.

Figure 9.3 Decked boardwalk at Radipole Lake in Weymouth – a children's crabbing area for the Lagoon in Poole Park?

Although considerably larger than the Lagoon and subject to a range of different environmental conditions, Figure 9.4 below shows a photo of Radipole Lake in Weymouth and illustrates the type of habitats that could be created in the Lagoon. In particular, gravel shoals and submerged reedbed islands with shallow depth profiles offer foraging habitat for wading birds, and provide refuge for a range of species.

Figure 9.4 Radipole Lake in Weymouth – an example for the Lagoon in Poole Park?

10. MEASURING IMPROVEMENTS

The current research and monitoring programme has provided a substantial baseline dataset, against which any future environmental monitoring data can be compared (although it should be emphasised that the data are limited to a single year). A key aspect of any ecological improvement works is to incorporate an element of monitoring to assess the effectiveness of the improvement measures implemented.

Assuming large-scale improvement works are conducted in Poole Park, particularly within the Lagoon, future post-works environmental monitoring would be necessary to demonstrate the effectiveness of the measures put in place.

With regard to the existing highly degraded baseline scenario, significant ecological improvements would be expected within a relatively short time frame (1 to 3 years). Along with improvements to water quality, increases in the invertebrate and fish communities are likely to be rapid and readily demonstrable.

Providing a quantitative assessment of ecological improvement will help to demonstrate value for money with regard to public perception, and is also likely to support (or be a requisite of) the Heritage Lottery Fund bid.

The precise scale or nature of future monitoring would depend on the improvement measures implemented; however, it is anticipated that water quality, sediment quality, invertebrate sampling and fish sampling should all be included in any future post-works monitoring programmes.

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