EA-WATER QUALITY BOX 12

ENVIRONMENT AGENCY

BIOLOGICAL STUDY OF UPPER TAMAR LAKE 1997

FINAL REPORT

(REPORT IN RESPONSE TO

THE FRESHWATER TAMAR LEAP ACTION 4.1.3)

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Introduction

Upper Tamar lake is a small water supply reservoir situated in the head waters of the river Tamar near Kilkhampton, on the border between Devon and Cornwall. It is owned and operated by South West Water Services Limited (SWWSL)for the purpose of water supply and recreation. It supports a coarse fishery and a water sports centre used by the public and local adventure schools.

In 1973, before the Upper lake had been built, there was a serious blue-green algal bloom in Lower Tamar Lake, and it was thought by the staff of the then North Devon Water Board that these blooms were fairly regular events. Blue-green algal blooms have been recorded from Upper Tamar Lake every year since the late seventies although the extent of the bloom varies from year to year. Soon after it was built in the mid-seventies, it was considered to be eutrophic and had the potential to cause toxic algal blooms.

During the summer of 1995 there was a severe bloom of the blue-green algae *Aphanizomenon flos-aquae* in the Upper Tamar lake which entered the river system, where it continued to proliferate. Bloom levels (>3000 filaments/ml) reached as far down as the confluence with the Lyd. *A.flos-aquae* was present at warning levels (>600 fils./ml) throughout the rest of the freshwater Tamar downstream of the Lyd.

The Catchment Management Plan for the Freshwater Tamar and Tributaries published in March 1996 states that the Environment Agency will establish the trophic status of Tamar lakes and the levels of input between 1996-2001. During 1997 a study was undertaken on Upper Tamar Lake and the surrounding catchment to try to gain an understanding of the trophic and ecological status of the lake.

Methods

During 1997, chemical and algological analytical methods continued as had been done in previous years. As well as these established methods, two new methods were employed.

i) <u>The Trophic Diatom Index (TDI)</u>

This is a relatively new method for assessing the nutrient status of rivers and streams and detecting polluting inputs. Diatoms are microscopic algae living within the phytoplankton or attached to the substrate of a water body. By identifying the species within the diatom community, the effects of nutrients and pollutants can be determined.

TDI analyses were carried out on sites within the Tamar from as near to the source as possible down to Dexbeer Bridge, downstream of the lower of the two lakes.

Samples were also taken from feeder streams into the lake. This has facilitated an increase in an understanding of the status of the inputs, and the effects of both lakes on the Tamar downstream of the impoundments.

ii) Aquapack

The aquapack is a multi-parameter aquatic monitoring device used for the study of phytoplanktonic communities. It can measure chemical parameters such as dissolved oxygen, pH, redox potential, temperature and conductivity. What separates this from other similar monitoring devices is the inclusion of an accurate photometer for the measurement of levels of chlorophyll A. The Aquapack was originally designed for on-site logging of data at specific intervals. It has been modified by the manufacturers at the request of Agency Biology staff in Bodmin to allow the performing of depth profiles of lakes and estuaries.

The aquapack was first deployed on a test run in June to increase famililiarity with the techniques needed and to use it to its full potential.

Full sample runs were then carried out in August and September. Eight sites were chosen across the reservoir to monitor the extent of algal blooms around the lake (Fig.1). The actual geographical position was recorded by using the boat's GPS (Global Positioning System).

The data recorded from the aquapack was immediately downloaded onto a field PC for processing back at the lab.

Results

The results from the Aquapack surveys reveal that the lake supports a community of algae which are typical of a eutrophic lake. Blue-green algae (Cyanobacteria/ Cyanophyta) are represented by a variety of species including *Anabaena* and *Microcystis*, but throughout the summer of 1997 the community was dominated by *Aphanizomenon flos-aquae* (Table 1 & Fig.2). These are all potentially toxic forming blue-green species and their numbers greatly exceeded the warning thresholds. In August, many of the samples exceeded the levels where scum and toxin formation becomes more likely. A scum was noticed on the shore of the lake along with dead and dying fish in the lake margins.

In June the algae samples that were taken had exceeded warning thresholds for both *A.flos-aquae* and *Anabaena sp.* In July *A.flos-aquae* was the dominant algal species, having succeeded *Anabaena sp.*, and was the only blue-green recorded. It was found at levels greatly exceeding the warning threshold for that particular species.

In July of 1997, as in previous years, *A.flos-aquae* was also found in the main river, although in 1997 it remained below warning levels and consisted of only small short filaments.

Coelospharium sp. was also recorded from the river, again below warning levels. *Coelospharium sp* is another toxin-forming blue-green algae species typical of very eutrophic waters.

A.flos-aquae first appeared in the May samples in very low numbers (150 fils./ml). By June it had reached warning levels (1900 fils./ml) along with *Anabaena* (400 fils./ml). The *A.flos-aquae* continued to increase in numbers, reaching a peak in August where all samples taken were at least one order of magnitude greater than the warning threshold, sometimes considerably more (8500-12400 fils/ml). *Anabaena* was not found from June onwards and had been succeeded by the *A.flos-aquae.* By the beginning of September the numbers of *A.flos-aquae* had reduced to below warning levels (550 fils/ml) and by the middle of the month were still declining (350-450 fils./ml).

In August, the aquapack detected that the lake was stratified with the epilimnial layer being the first two metres. The metalimnion was found between two and three metres deep. Everything below this depth was the hypolimnion. The stratification was clearly seen at sites with sufficient depth to display the various layers (Fig.3-10).

The epilimnion of a eutrophic lake is typified by high chlorophyll A, high pH and super-saturated dissolved oxygen. The metalimnion is the layer in which there is a sudden decline in all these values. The hypolimnion has a neutral pH, low chlorophyll A and a very low DO. In the case of Upper Tamar lake the majority of the hypolimnion is totally deoxygenated resulting in a large anoxic layer eg. Site 3 profile at 4.5m.

In September the extreme values previously recorded by the aquapack had declined and the lake was again fully mixed.

The results from the bloom in the Tamar during the summer of 1995 are included in Table 2. The bloom of *A.flos-aquae* was recorded in the Upper Tamar lake on 14/07/95. Blooms of *A.flos-aquae* were then found within the Tamar throughout the summer down to Polson Bridge upstream of the Lyd confluence. The algae continued at warning levels as far down as Gunnislake. There was a noticeable decline in algal numbers below the confluence with the Lyd (Figure 13). The bloom in the river had dropped below warning levels by the beginning of September. The bloom in the reservoir continued until the end of September.

TDI Results

The results from the analysis of benthic diatom samples are represented by two indices (Figures 11 & 12). The Trophic Diatom Index (TDI) indicates a change in nutrient status of the watercourse. TDI increases in response to an increase in eutrophication. The percentage of pollution tolerant valves (%PTV) responds to an increase in organic pollution. Therefore an increase in %PTV from one site to another reveals that there is a source of organic pollution between these sites.

The TDI increases gradually downstream and this is expected in any river system. The %PTV shows a large increase at Ham Bridge, indicating a significant organic input.

The %PTV decreases through the lakes but increases again at Dexbeer Bridge along with a larger TDI indicating an increase in nutrients.

Discussion

Phytoplankton

The phytoplankton communities provide a useful indication of the trophic status of the lake. The diatom *Melosira sp.*, found in the spring and the chlorococcalian (green) algae *Scenedesmus sp.* are both indicative of eutrophic conditions (Mason, 1996).

The blue-green algae *Anabaena sp.* and *A.flos-aquae* also indicate eutrophic/hypertrophic conditions. These blue green algae are the dominant species throughout the summer with the population dominated by a bloom of *A.flos-aquae* in the summer months. Both of these blue-green species are nitrogen-fixers and therefore the availability of phosphates is the limiting factor. This means that they will dominate the phytoplankton and out-compete other algal species when the nitrogen : phosphorus ratio is low (Wetzel, 1983).

In previous years the blue-green algae have consisted of a mixed community of *Aphanizomenon flos-aquae*, *Anabaena sp.* and *Microcystis sp.*. *Microcystis* was the dominant species in the blooms of the late summer until 1995. *Microcystis* is not able to fix nitrogen and therefore for bloom growth to occur there must be a plentiful supply of Nitrogen entering the system. It will dominate when the nitrogen : phosphorous ratio is high (Wetzel, 1983).

The change in the phytoplankton clearly shows a shift in the limiting factors controlling algal growth within Upper Tamar Lake from an excess of nitrogen to an excess of phosphorous. There may still be a nitrogen problem, but the growth due to the phosphorous inputs masks any effects of elevated nitrogen.

Aphanizomenon flos-aquae.

A.flos-aquae is a potential toxin-forming blue-green algae with a optimum growth temperature between 15-28°C. It ceases growth at 10°C and forms cysts which survive within the sediment over winter until suitable conditions for re-growth are met (Plinski & Jozwiak, 1996). When there is a bloom, toxins, such as Aphanitoxin, can be produced. These can lead to allergic reactions such as violent skin rashes and intestinal problems for people coming into contact with the algal scum. Aphanotoxin is a neurotoxin and has the potential to cause death by paralysis of skeletal and respiratory muscles. The decomposition of these algae can cause taste and odour problems in drinking water (Palmer, 1980).

A.flos-aquae is also able to survive in brackish conditions within estuaries. Therefore, when it was recorded as far down as Gunnislake at warning levels, it is likely that it would have continued to grow within the Tamar estuary. If it blooms within estuaries it can form toxins which can accumulate in shellfish. If these shellfish are eaten it can lead to Paralytic Shellfish Poisoning (Balode & Purina, 1996).

Effects Downstream.

The presence of the algae in the Upper Tamar Lake is due to a deterioration in water quality and the bloom levels exacerbate this problem. This is likely to have an impact on the river downstream of the lakes,. and will be one of many factors contributing to the virtual exclusion of salmonid recruitment and juvenile survival in the upper part of the catchment.

TDI

The analysis of the benthic diatom communities revealed potential sources of nutrients that have not yet been monitored upstream of Buses Bridge. The diatom survey was a preliminary survey to highlight any potential sources of nutrients. A further survey is needed in the spring of 1998 to pin-point the possible sources of enrichment.

Water Chemistry

The phytoplankton community in Upper Tamar Lake indicated that there must be very high levels of phosphorus entering the system.

The River Tamar at Buses Bridge has failed the EC Freshwater Fish Directive and Rivers Ecosystem for the total ammonia. The source of these problems was thought to be traced to a farm upstream. The Investigations Team have indicated that high phosphorus levels have also been recorded in stream immediately downstream of this farm (6-9 mg per litre Orthophosphate). This is a likely source of elevated levels of phosphorus at Buses Bridge on the River Tamar just upstream of the lake (3 mg per litre. Orthophosphate). These levels of phosphorous entering the lake would contribute greatly to the formation of blue-green algal blooms which are limited the levels of phosphorous. The minimum concentration needed to give maximum plant growth is just 0.02-0.03 mg per litre. Therefore levels of orthophosphate at Buses Bridge exceed this minimum concentration by 100-150 times. There are also contaminations of the river due to other agricultural sources upstream.

Aquapack And The Environmental Effects Associated With Eutrophication..

The stratification recorded in the sampling run in August is typical of a eutrophic/hypertrophic lacustrian system. The top of the hypolimnion is the point where complete deoxygenation occurs and therefore the area of water below this level is anaerobic. This prevents most animal and plant life from inhabiting the vast majority of the lake.
The high levels of chlorophyll A recorded from the epilimnion are caused by the large population of algae, in this case blue-greens. During day-light hours the algae photosynthesise, producing large amounts of oxygen. This excess production of oxygen causes super-saturation with dissolved oxygen readings in excess of 120%. A clinograde oxygen profile is present when the lake is stratified in the summer. This matches an idealised curve for a eutrophic lake (Wetzel, 1983).

The process of photosynthesis also causes an increase in the pH. The algae utilise the dissolved CO_2 faster than it can be replaced from the atmosphere. This causes the dissolved inorganic carbon equilibrium to shift, resulting in the water having a higher pH. The anaerobic conditions within the hypolimnion cause an increase in CO_2 and result in a lower pH.

After dark, a large population of algae no longer photosynthesise but still respire. Their respiration causes an oxygen sag in the water and another change in pH. In some cases these changes can be so extreme as to cause complete deoxygenation or a major shift in pH resulting in stress to fish populations and sometimes even fish kills.

The fish in Upper Tamar lake are known to affected by a disease known as Enteric Red

Mouth. The algal filaments are known to cause physical irritation of the fish gills and the environmental changes caused because of the bloom of algae would have resulted in stress to the fish and greater susceptibility to any disease present. This stress may have been exacerbated by angling.

The algae species recorded and their abundances are typical of a lake system suffering from severe eutrophication. The highest concentrations of algae recorded were found at the south of the lake near the dam and in the eastern branch of the lake.

The Mechanism of Eutrophication

Oxidative processes constantly occur within the hypolimnion and this is proportional to the amount of organic matter precipitating from the upper levels of the lake. A high organic loading to the hypolimnion could occur through organic inputs directly to the water body or through high primary production in the epilimnion. With large algae populations there is always a large organic loading to the sediment of the lake from dead and decaying algae (Moss, 1988).

Once stratification has occurred, the hypolimnion continues to stay deoxygenated and increases in size, shrinking the epilimnial layer. In a lake with an obviously large primary production there will be a high load of dead material entering the hypolimnion. This is decomposed by bacteria which utilise large amounts of dissolved oxygen which in turn cause deoxygenation of the waters overlying the sediments. Without mixing, this deoxygenation increases and so the metalimnion moves up the water column.

Whilst there is plenty of oxygen at the sediments, phosphate remains locked within the sediments. When deoxygenation occurs the iron complex binding the phosphate changes from insoluble to soluble. This then dissolves in the water column and rises through the water column carrying the phosphate with it. When the complex reaches the oxygenated epilimnion the iron complex changes back to insoluble releasing the soluble phosphate . This makes the phosphate available for use in primary production. In this way the algae population can be sustained with nutrients for as long as stratification remains intact and the hypolimnion remains deoxygenated (Wetzel, 1983).

When mixing occurs the whole water column becomes oxygenated again, and the phosphate settles out, bound to the iron complexes in the sediment. Mixing also means that the algae are not maintained in the areas of maximum light within the epilimnion, but are moved throughout the water column. This helps to reduce excessive blooms of algae.
Stratification, blooms of blue-green algae, species of algae found within the lake and the deoxygenated hypolimnion are typical of a eutrophic/hypertrophic system.

Since this work was carried out the results for the EC Freshwater Fish Directive monitoring sites for 1997 have been processed. The River Tamar failed at the upper monitoring sites due to high pH . The excessive pH was caused by the algal blooms within the two lakes. As a result of this failure more monitoring work is now being carried out on the Tamar catchment around the two lakes.

Conclusions & Recommendations

1. The extent of the eutrophication within Upper Tamar lake is likely to be having a deleterious effect on the river downstream of the impoundment. Continued monitoring of the lake and its surrounding catchment needs to continue in an attempt to determine the sources of nutrient enrichment to the lake.

2. Consideration should be given to requesting that South West Water Services Limited (SWWSL) employ some method of destratification to minimise the ecological impact within the lake and the downstream habitat.

3. Consideration should be given to discussions with SWWSL over the long term management of Upper Tamar Lake.

4. The relevant Environmental Health Authorities should be made aware of the possible health risks from recreation on Upper Tamar Lake.

References

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Site	24/04/97	21/05/97	10/06/97	09/07/97	10/07/97	15/08/97	09/09/97	17/09/97
Dam - Surface	No b/g *Ankistrodesmus*, *Melosira*, *Tribonema*	150 fils./ml *A.flos-aquae* *Scenedesmus*, *Crucigenia*, *Ankistrodesmus*.	1900 fils./ml *A.flos-aquae* 400 fils./ml *Anabaena*	4050 fils./ml *A.flos-aquae*				350 fils./ml *A.flos-aquae*
Dam - Mid water	No b/g *Ankistrodesmus*, *Crucigenia*, Scenedesmus, *Tribonema*, *Melosira*	1 fils./ml *A.flos-aquae*, *Scenedesmus*, *Pandoria*, *Crucigenia*, *Pediastrum*	150 fils./ml *A.flos-aquae* *Anabaena* 150 fils./ml *Anabaena*	1200 fils./ml *A.flos-aquae*				450 fils./ml *A.flos-aquae*
Dam - Bottom + 1m	No b/g *Ankistrodesmus*, *Scenedesmus*, *Melosira*, *Navicula*	1 fils./ml *A.flos-aquae*, *Pediastrum*, *Scenedesmus*, *Navicula*, *Melosira*, *Pinnularia*.	1000 fils./ml *A.flos-aquae* 150 fils./ml *Anabaena*	1100 fils./ml *A.flos-aquae*				400 fils./ml *A.flos-aquae*
Aquapack - Site 3						8500 fils./ml *A.flos-aquae*	550 fils./ml *A.flos-aquae*	
Aquapack - Site 5						16150 fils./ml *A.flos-aquae*	300 fils./ml *A.flos-aquae*	
Aquapack - Site 7						12400 fils./ml *A.flos-aquae*	550 fils./ml *A.flos-aquae*	
Below spillway - Lower Tamar Lake					500 fils./ml *A.flos-aquae* 50 fils./ml *Anabaena sp.* Small colonies of *Coelosphaerium*			
Tamarstone Bridge					50 fils./ml *A.flos-aquae* + 200 small filaments			
Crowford Bridge					50 very small filaments of *A.flos-aquae*			

Table 1 - Phytoplankton results from the River Tamar and Upper Tamar Lake (1997).

Site	Date					
	02/08/95	04/08/95	30/08/95	06/09/95	12/09/95	28/09/95
Lower Tamar Lake						7600
Below Spillway Lower Tamar Lake	3100	4000	1950	4700	5250	9300
Below Dexbeer Bridge	2950	2500	1700	1200		
Below Moreton Mill Bridge	1900	1300	1300	2700		
Below Tamarstone Bridge	1200	2600	100	1750		
Below Bridgerule Bridge	1118	1500	50	3050		
Below North Tamarton bridge	2769	3400	400	0		
Below Boyton Bridge	5900	6150	150	400	1600	50
Netherbridge	4150	5750	550	0		
Polson	3400	6600	700	50	200	150
Greystone		1000				
Horsebridge		1500				
Gunnislake		1300				

Table 2- *Aphanizomenon flos-aquae* filaments/ml in the River Tamar Summer 1995

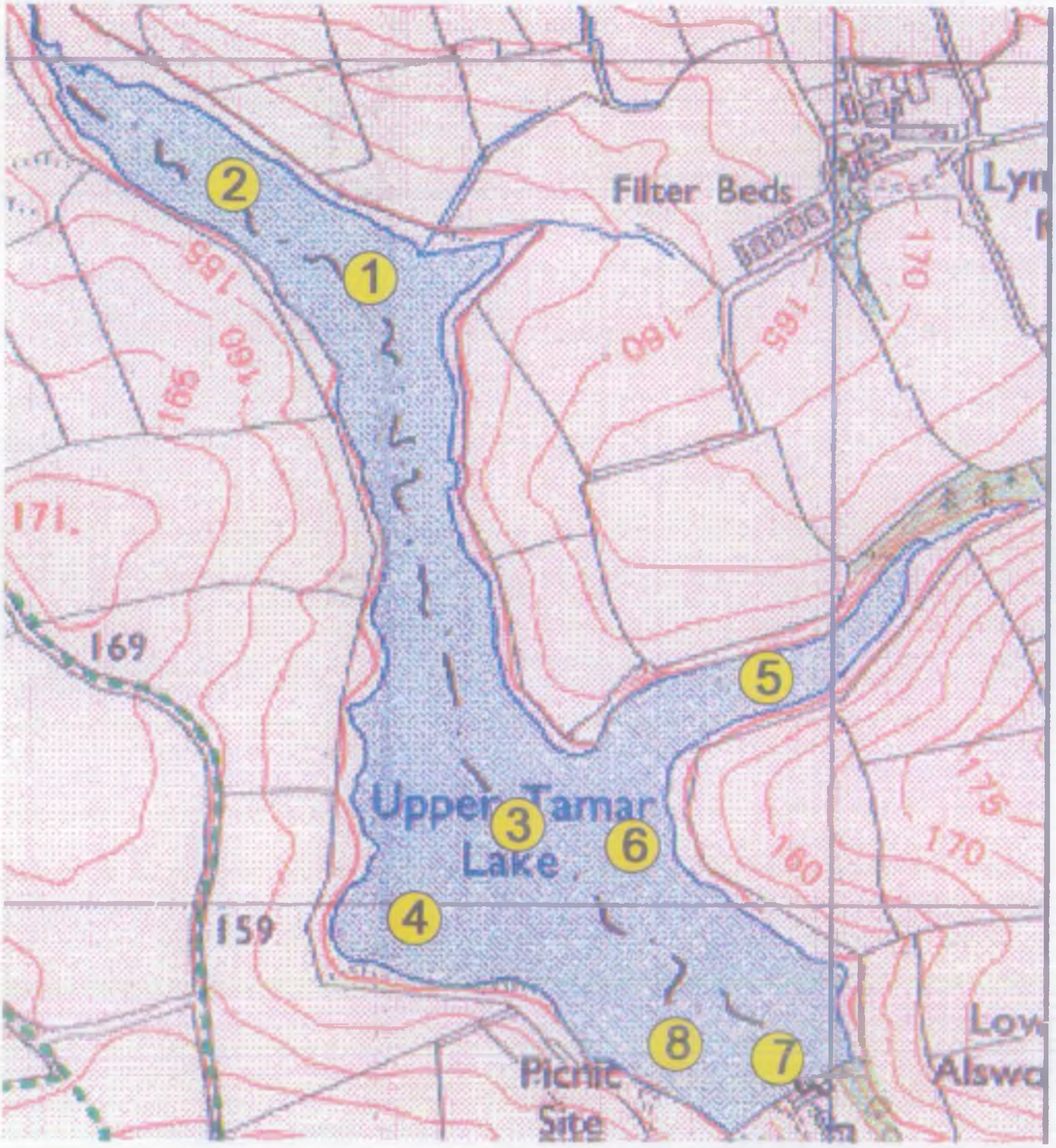

Figure 1 - Position of Aquapack profiling sites on Upper Tamar Lake

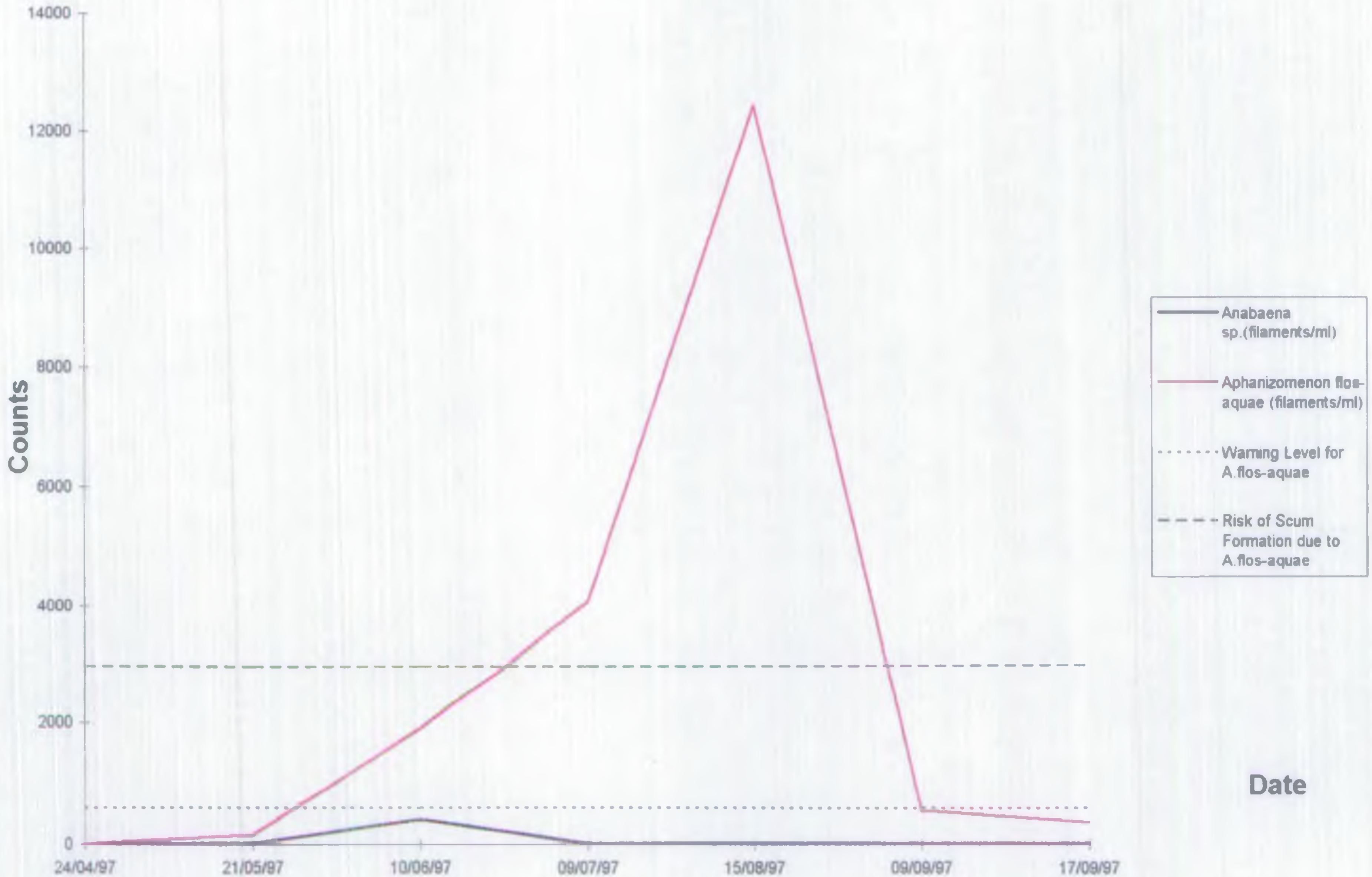

Figure 2 - Sucession of blue-green algae at Dam wall (Site 7) Upper Tamar Lake 1997.

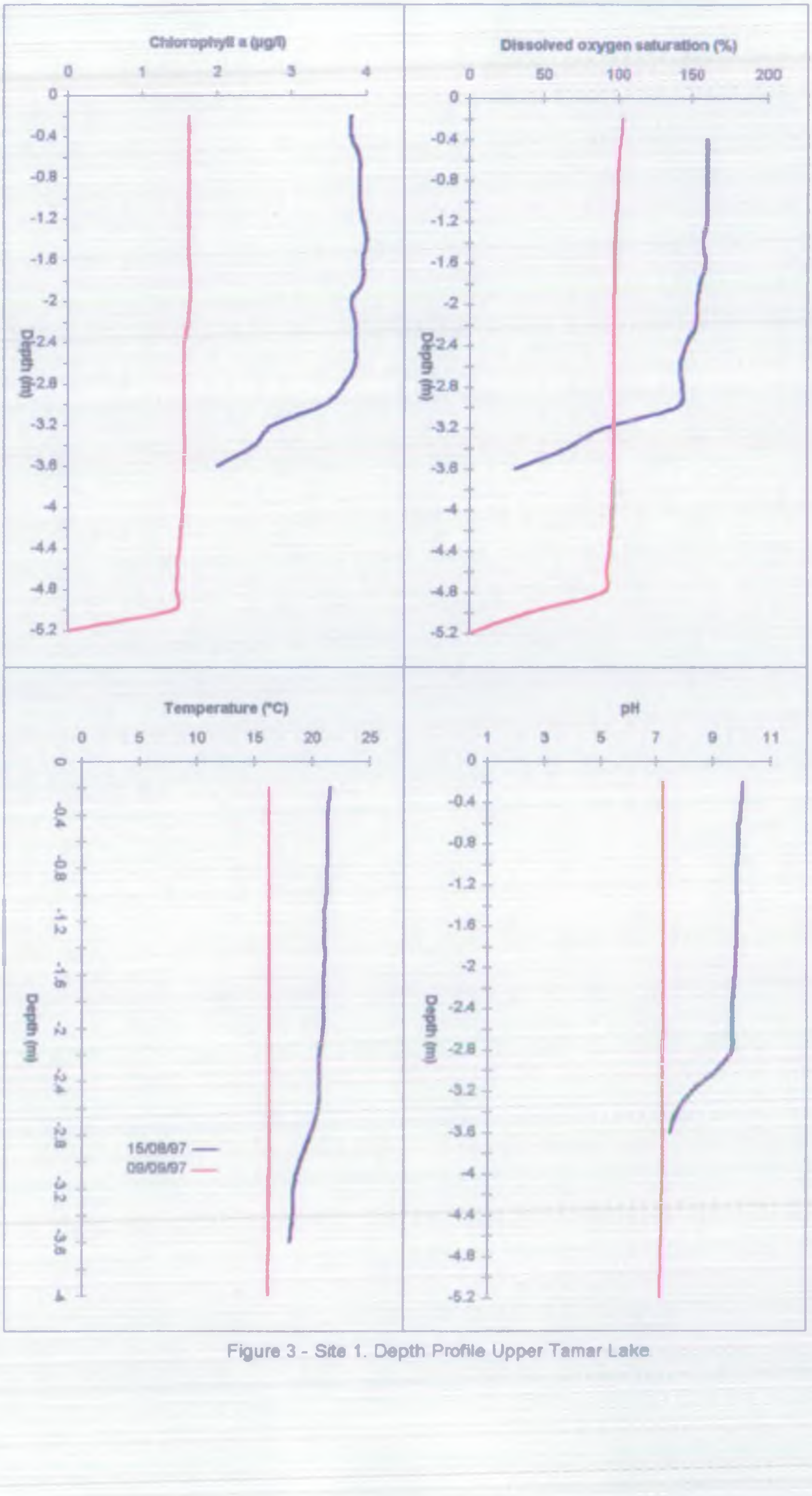

Figure 3 - Site 1. Depth Profile Upper Tamar Lake

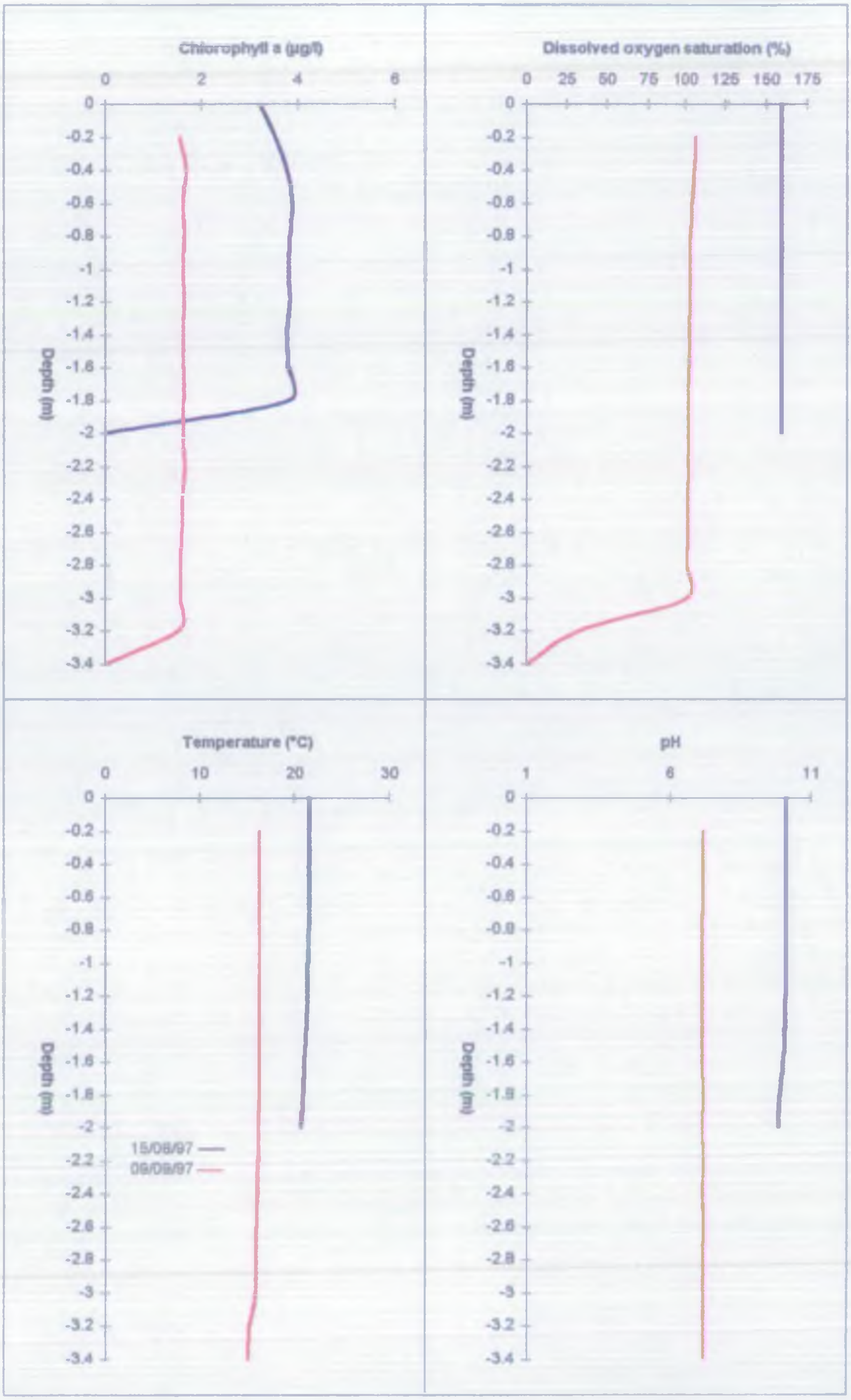

Figure 4 - Site 2. Depth Profile Upper Tamar Lake

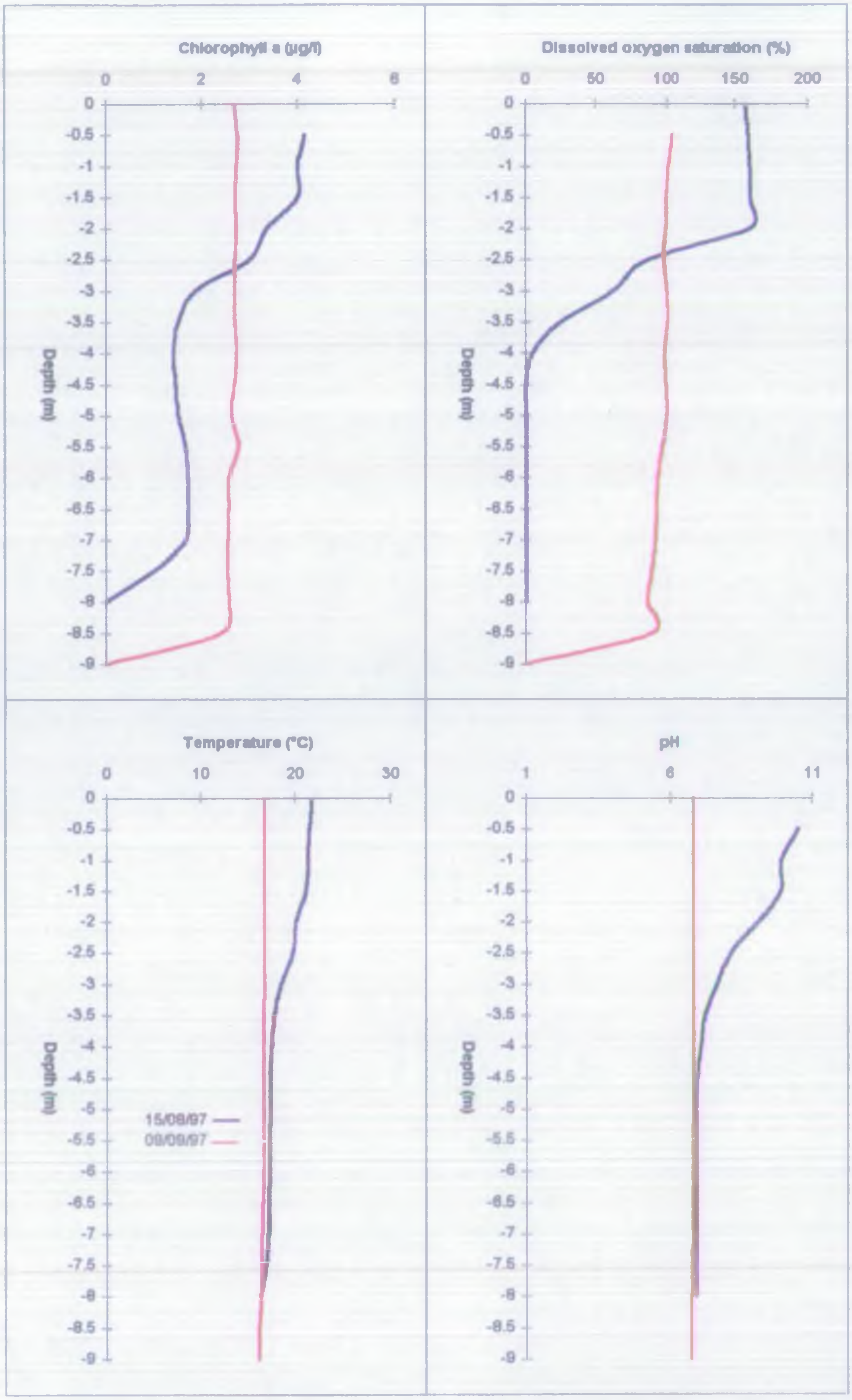

Figure 5 - Site3. Depth Profile Upper Tamar Lake.

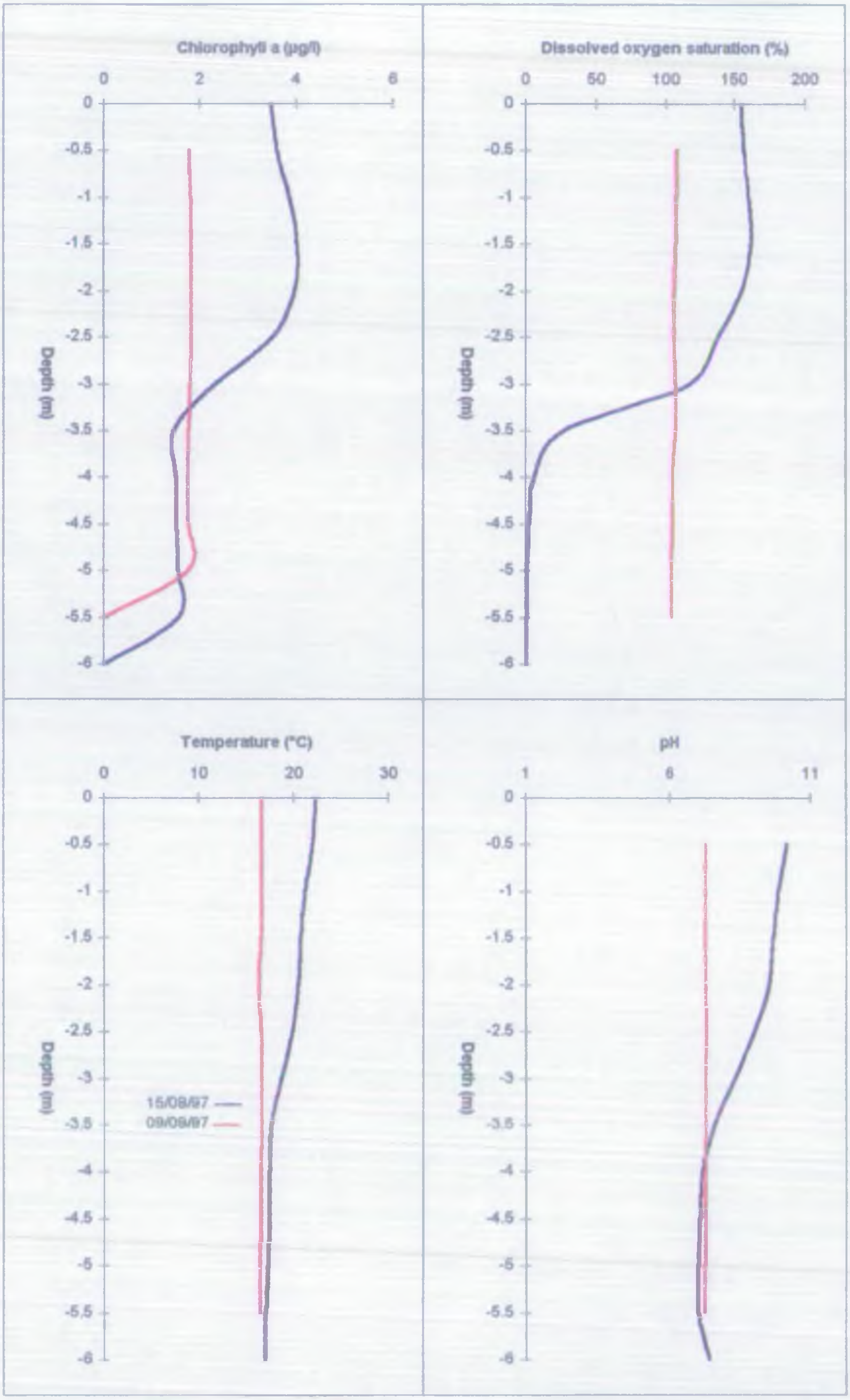

Figure 6 - Site 4 Depth Profile Upper Tamar Lake.

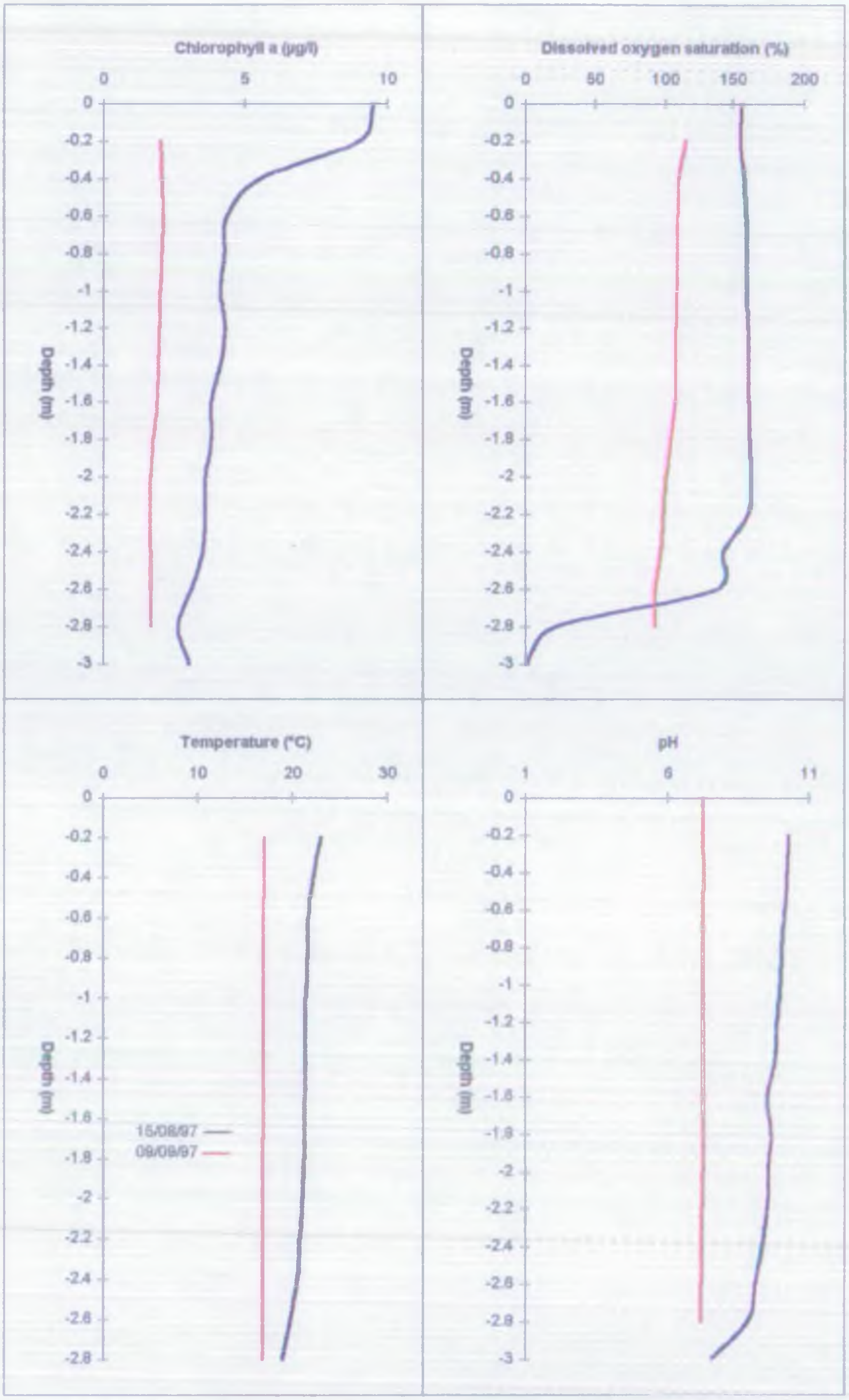

Figure 7 - Site 5. Depth Profile Upper Tamar Lake

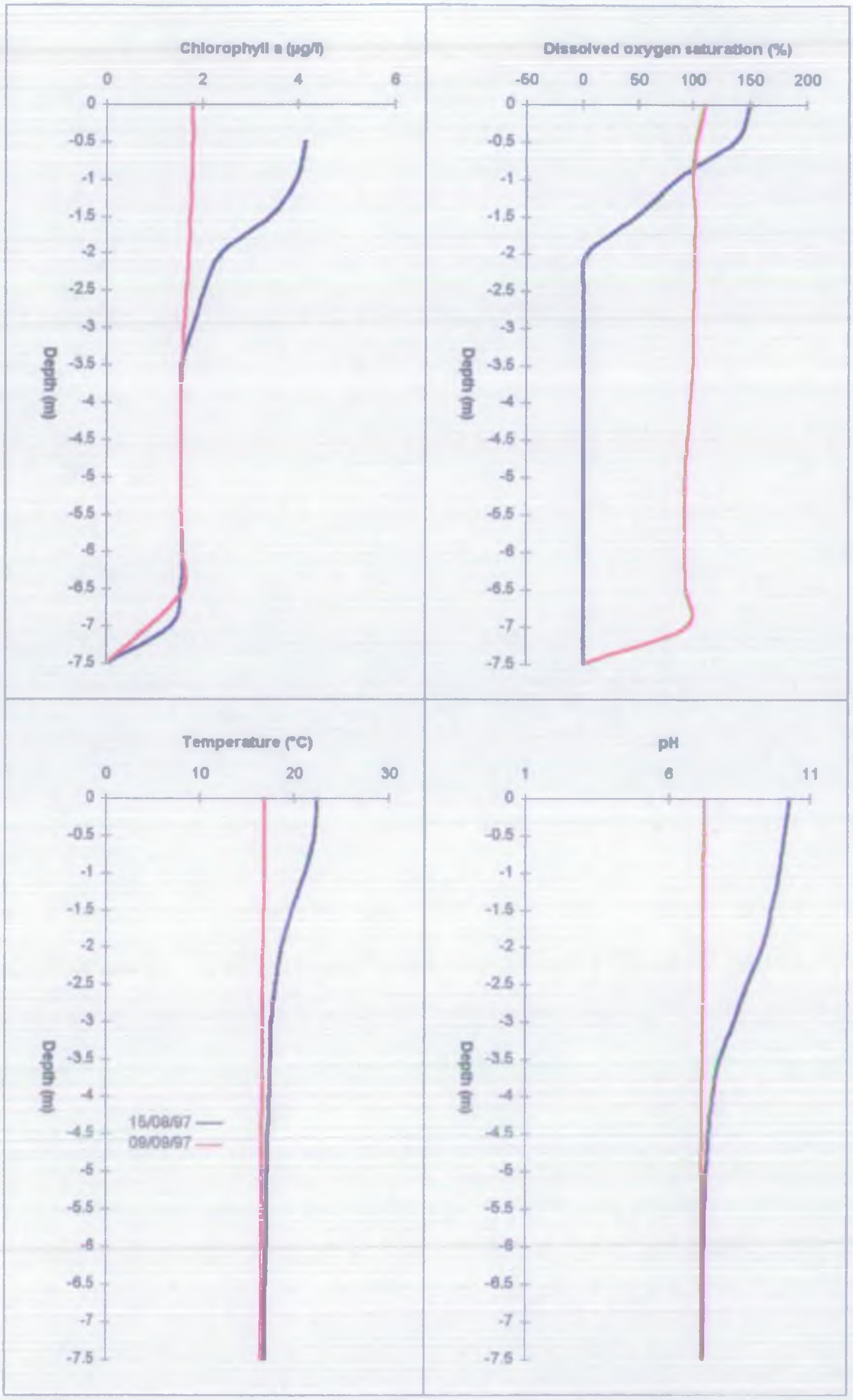

Figure 8 - Site 6. Depth Profile Upper Tamar Lake

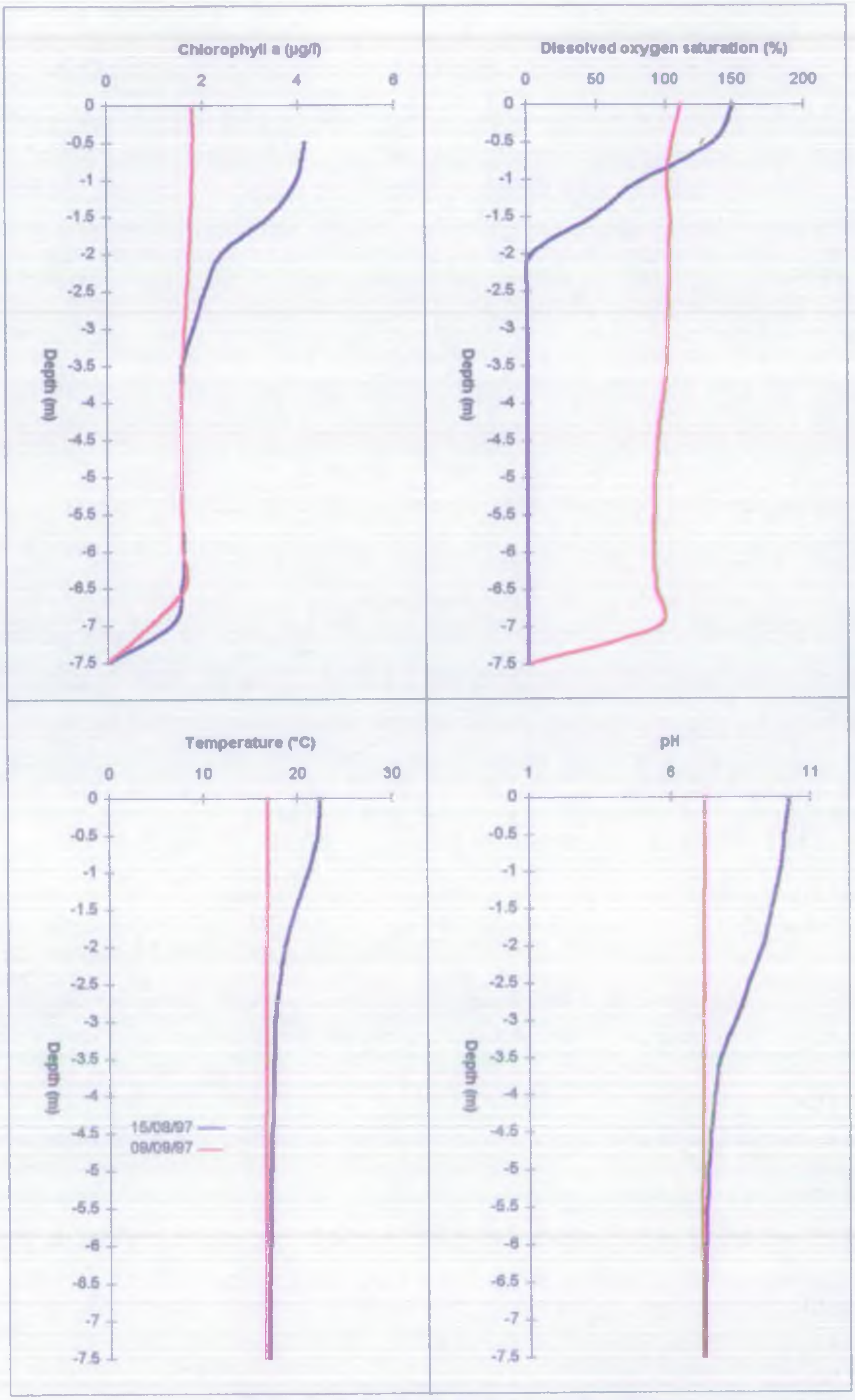

Figure 9 - Site 7. Depth Profile Upper Tamar Lake.

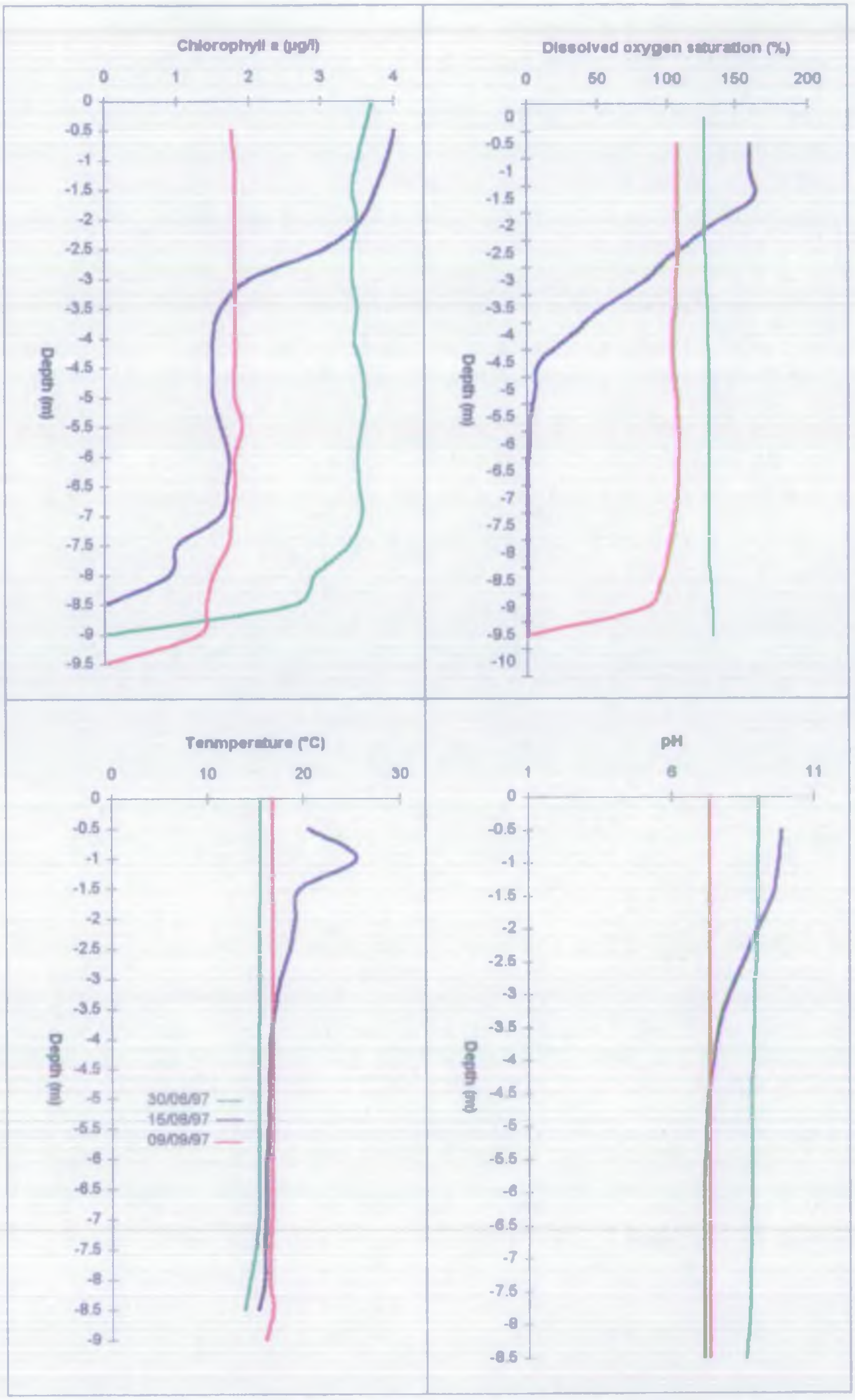

Figure 10 - Site 8. Depth Profile Upper Tamar Lake.

River	[illegible]	TDI	%PTV
Tamar	West Youlstone	49	6.3
Tamar	Ham Bridge	68	[illegible].6
Tamar	Buses Bridge	56	21.9
Tamar	d/s Upper Tamar Lake	69	14.6
Tamar	d/s Lower Tamar Lake	66	5.9
Tamar	Dexbeer Bridge	85	9.7
Lympscott Tributary	prior to Upper Tamar Lake	60	28.7

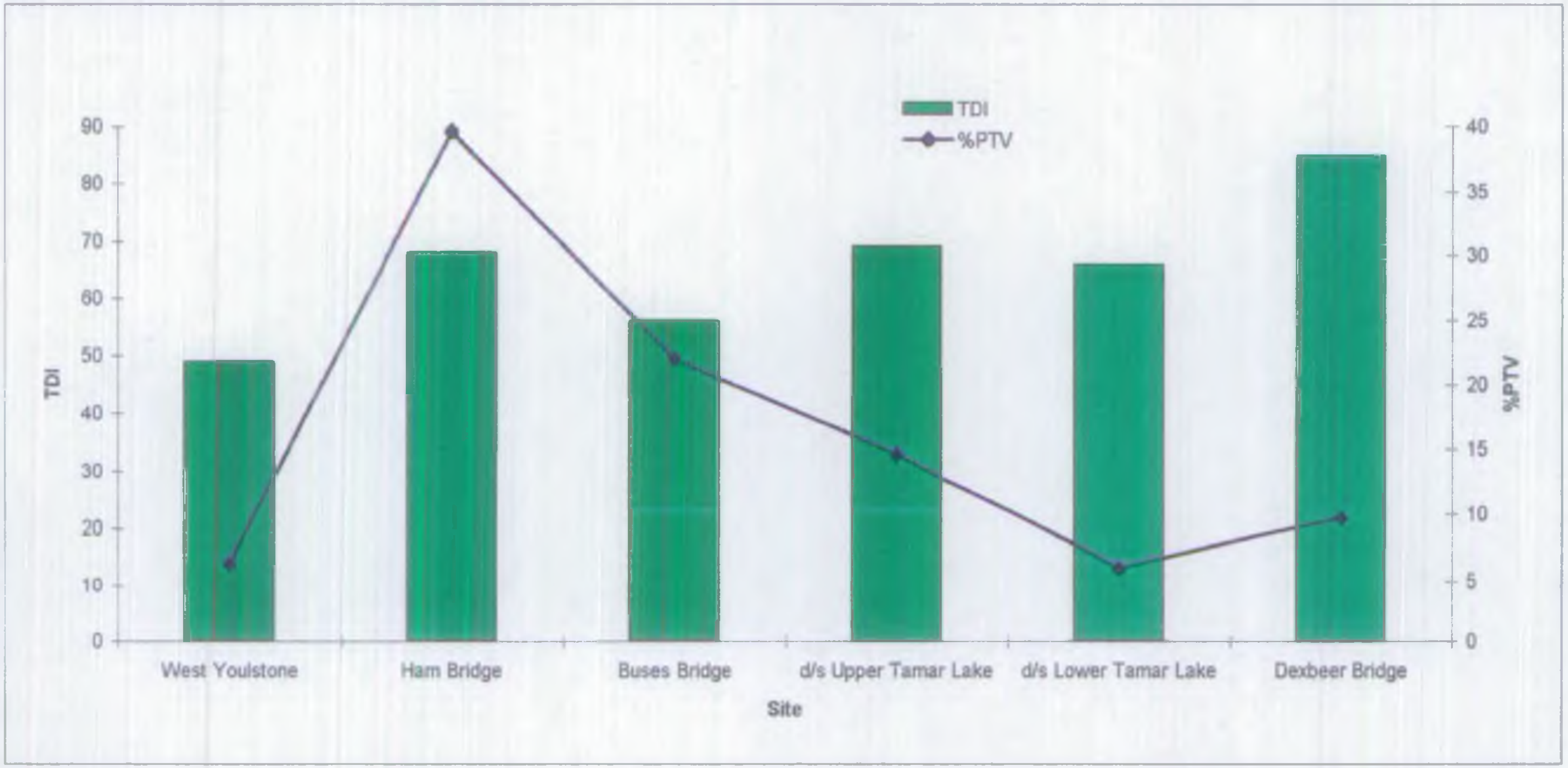

Figure 11 - TDI results from the Upper Tamar Catchment (25/09/97)

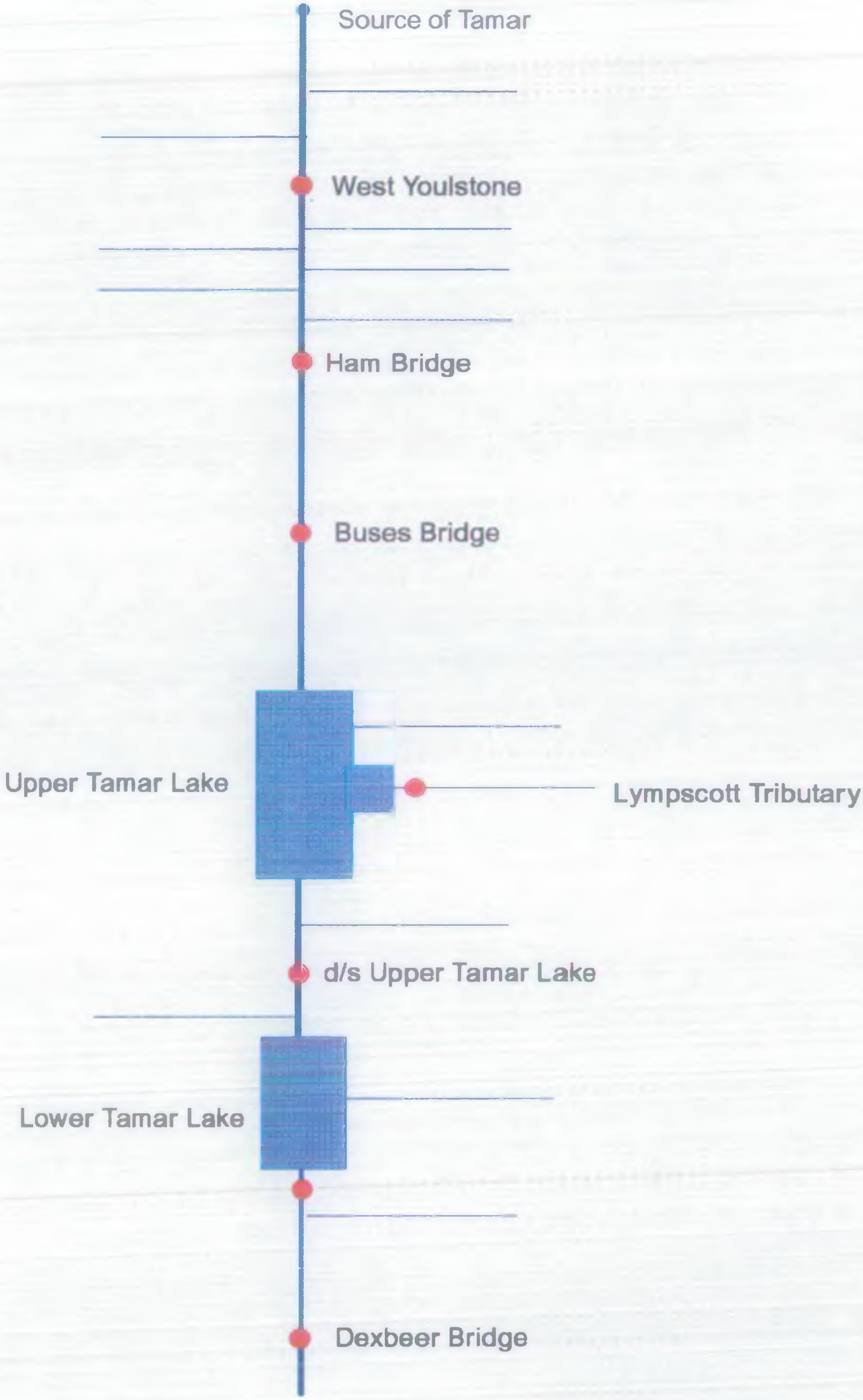

Figure 12 - Schematic map showing position of TDI sampling points.

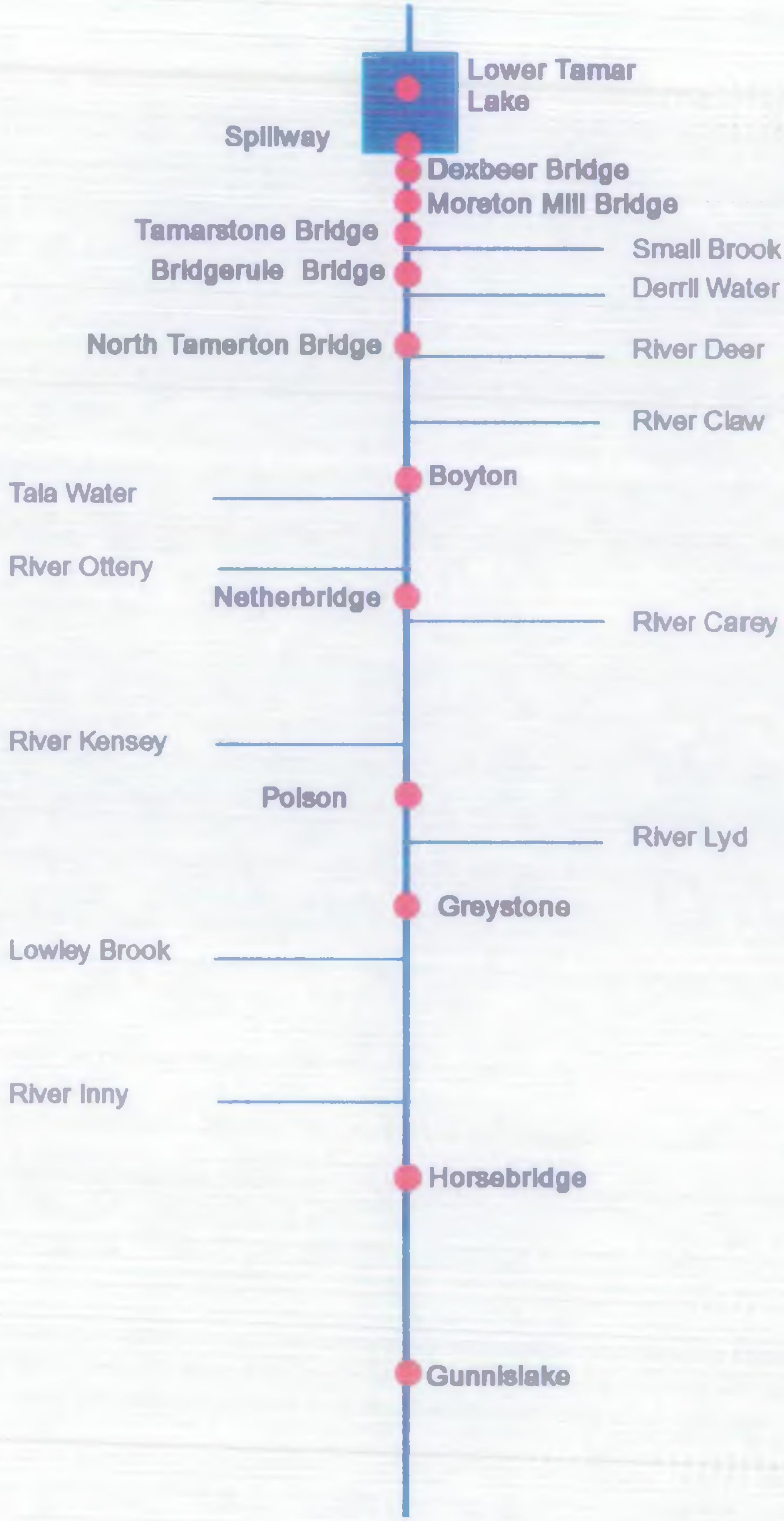

Figure 13 - Schematic map showing position of 1995 algae sampling points.