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Report on the technical performance and application of the automatic lake monitoring stations

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PU	Public	PU
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1. Background

Automatic instruments provide the ideal means of recording the responses of lakes to short-term changes in the weather. Thermally stratified lakes are particularly sensitive to changes in the weather since their mixing characteristics are regulated by the combined effects of the air temperature, the sun and the wind. In this report, we describe the construction and testing of a network of monitoring stations deployed in a number of UK lakes to quantify their response to changing weather patterns. It includes some examples of the high-resolution data acquired from three lakes: Esthwaite Water and Bassenthwaite Lake in the English Lake District and the Round Loch of Glenhead in south-west Scotland.

2. Objectives

1. To design and construct a prototype Lake Dynamics Monitoring Station (LDMS) that can be used to monitor the physical responses of a lake to short-term changes in the weather.
2. To construct, test and deploy a network of LDMS units in the UK and use these stations to support a range of climate-related studies.
3. To collate and analyse the high-resolution data acquired by the LDMS units
4. To produce a report on the technical performance of the LDMS units that highlights the value of automatic monitoring in climatic research.

3. The development of automatic monitoring stations at CEH Windermere

In the past ten years, the Engineering team at the Centre for Ecology and Hydrology (CEH) in Windermere (formerly, the Institute of Freshwater Ecology, IFE) developed a range of automatic monitoring stations that have been used to monitor the response of lakes to short-term changes in the weather (Table 1). The first stations ('Automatic Water Quality Monitoring Station' AWQMS Mk I) were designed for a project funded under the LIFE programme and were deployed on one lake in the UK, two in Ireland and a reservoir in the south of Spain. Significantly more sophisticated stations (AWQMS Mk II) were designed and installed in a number of European lakes to support a Framework IV project called REFLECT (the Response of European Freshwater Lakes to Environmental and Climate Change) that explored the effects of long-term changes in the weather on lakes in Northern, Western and Central Europe. These stations were further enhanced for a second LIFE project demonstrating the use of such monitoring as a tool for reservoir and catchment management. Upgraded versions of these stations were later used in the Framework V project CLIME (Climate and Lake Impacts in Europe) along with a simplified version (the 'Lake Dynamics Monitoring Station' LDMS Mk I) designed for use at a small number of less intensively studied sites. In 2003, the Natural Environment Research Council (NERC) funded a major expansion of the lake monitoring network in the UK. The cost of building the latest version of these simplified stations (LDMS Mk II) was covered by NERC infrastructure funds but there was no funding available for their long-term operation or maintenance. Our allocation in Workpackage 1 of this project was designed to meet at least some of these costs and facilitate the installation of the stations at sites where there was an established commitment to long-term monitoring.

TABLE 1 The development programme for the automatic monitoring stations.

Period	Instrument	Project
1995 - 1997	Automatic Water Quality Monitoring Station (AWQMS Mk I)	LIFE I
1998 - 2000	Automatic Water Quality Monitoring Station (AWQMS Mk II)	REFLECT
1999 - 2002	Automatic Water Quality Monitoring Station (AWQMS Mk II)	LIFE II
2003 - 2005	Lake Dynamics Monitoring Station (Mk I)	CLIME
2004 - 2006	Lake Dynamics Monitoring Station (Mk II)	Euro-limpacs

4. The design of the Lake Dynamics Monitoring Stations

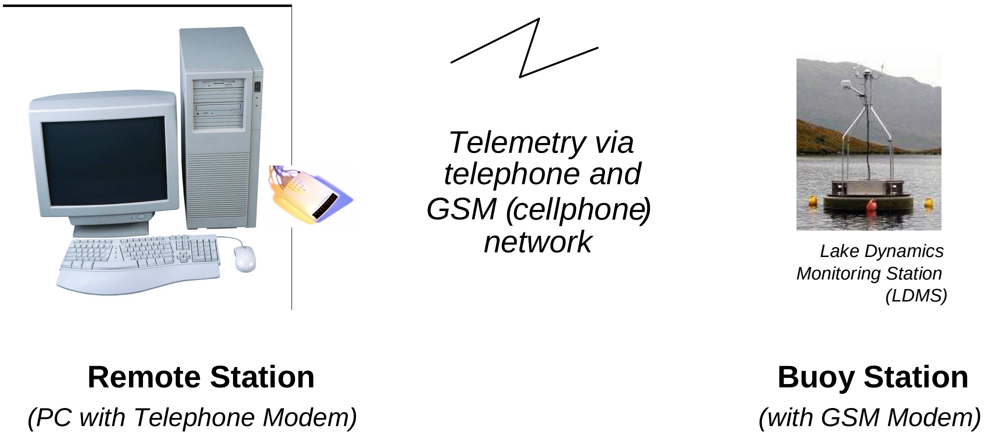


FIGURE 1 The components of the Lake Dynamics Monitoring Stations

The schematic diagram in Figure 1 shows the basic features of the Lake Dynamics Monitoring Stations developed by CEH. In functional terms, the system is based on two components: the Buoy Station deployed on the lake and the Remote Station used to download the acquired data to a remote site. An operator can use the Remote station (e.g. located in the laboratory) to contact the buoy station to retrieve recorded data or to examine measurements in real-time.

4.1. The Buoy Stations

Figure 2 shows the typical configuration of the buoy station. The buoy station comprises:

- A toroidal buoy secured to the lake bed using a three point mooring.
- Stainless steel housings mounted on the buoy containing rechargeable sealed lead-acid batteries to power the station and the stations electronic systems to record data and telemeter stored and real-time data via the GSM (cellphone) network.
- A mast supporting meteorological sensors and GSM Antenna
- A selection of water quality sensors suspended in the water column from the centre of the buoy.

A key aim of the design was to ensure that the stations are as versatile as possible. They can accommodate alternative sensors/instruments using either analogue or digital interfaces. Equally important was the need to minimise power consumption. Power to each sensor can be controlled by the data logger. This enables selected sensors to be powered down between measurements greatly reducing the power requirements of the station. A number of advanced remote diagnostic capabilities are also incorporated into the design, enabling engineers to identify many possible fault conditions by examining retrieved data sets or contacting the station in real-time. The mechanical design of the station is based on the proven configuration used in earlier versions. Some of the stations deployed under earlier projects have been deployed continuously for more than a decade, without any major mechanical failures. Care was also taken in the choice of connectors used to couple the sensors into the station. Military grade environmentally sealed connectors are used, which have proven to be extremely reliable in the harshest of conditions. Table 2 lists the transducers fitted to the LDMS together with some outline specifications. Most of the sensors are sourced from specialist companies and can be replaced with improved or additional sensors as and when these become available.

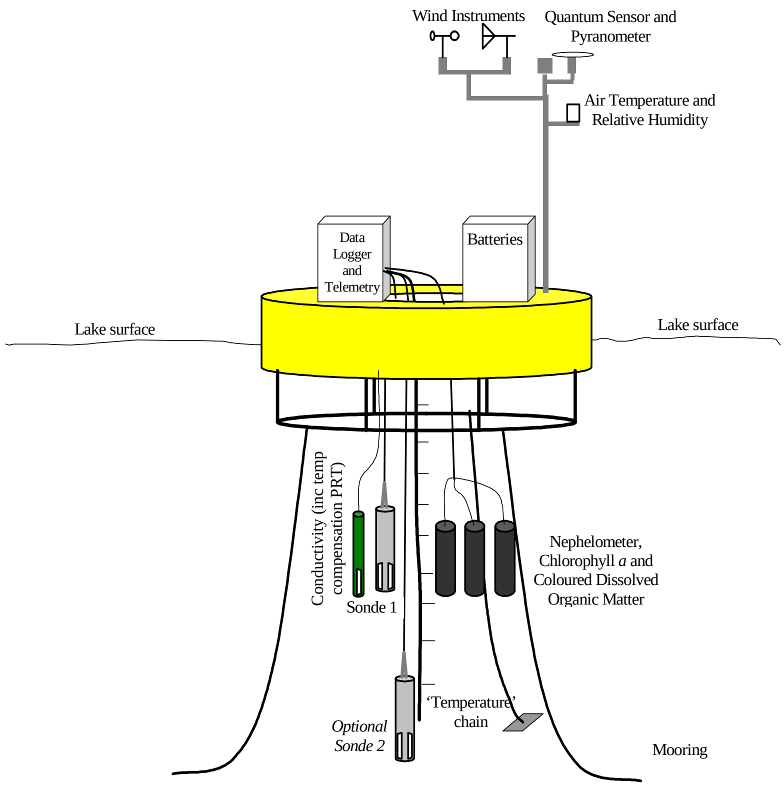


FIGURE 2 Schematic Diagram of a Lake Dynamics Monitoring Station (LDMS)

TABLE 2 Specification of the sensors included in the automatic Lake Dynamics Monitoring Stations

PARAMETER		SENSOR TYPE	RANGE
Meteorological	Wind Speed	Cup anemometer	0 to 50m.s^{-1}
	Wind Direction	Wind vane (Potentiometer)	0 to 360°
	Barometric Pressure	Semiconductor strain gauge	0 to 2000mBar
	Air Temperature	Platinum resistance sensor	-40°C to +60°C
	Relative Humidity	Semiconductor sensor	0 to 100%
	Photon Flux Density	Photodiode Quantum Sensor	0 to 3000 µmol, m^{-2}.s^{-1}
	Solar Radiation	Pyranometer	0 to 2000 W.m^{-2}
Water Quality	Water Temperature Structure (Water Column Stability)	Chain of Platinum Resistance sensors	-5 to +40°C
	Conductivity	4 Electrode Cell	0 to 100mS.cm^{-1}
	Water Temperature (for temperature compensation of Conductivity sensor)	Platinum resistance sensor	-5 to +40°C
	pH	pH	pH 1 to 14
	Dissolved Oxygen Sensor	Clark Cell	0 to 500%
	Chlorophyll *a*	Fluorimeter	Site dependent
	Suspended solids	Nephelometer	Site dependent
	Coloured Dissolved Organic Matter	Fluorimeter	Site dependent

4.2. Remote Station

The remote station consists of a PC connected via a conventional telephone modem. Software allows the operator to establish a connection through to the buoy station to retrieve stored data or view measurements in real-time. Data is stored in a simple comma separated value format that can easily be imported into standard spreadsheet or database software or, indeed, more advanced analysis tools.

5. Testing the Lake Dynamics Monitoring Stations

A prototype version of the Lake Dynamics Monitoring Stations was deployed on Bassenthwaite Lake (Cumbria, UK) in 2004. The sensors and the logging system were practically identical to those used in the 'production' versions but the instruments were mounted on an existing buoy installed on the lake for the Environment Agency for England and Wales. The station is used to monitor the responses of this shallow lake to short-term changes in the weather and Figure 3 shows some of the high-resolution results acquired by this prototype unit.

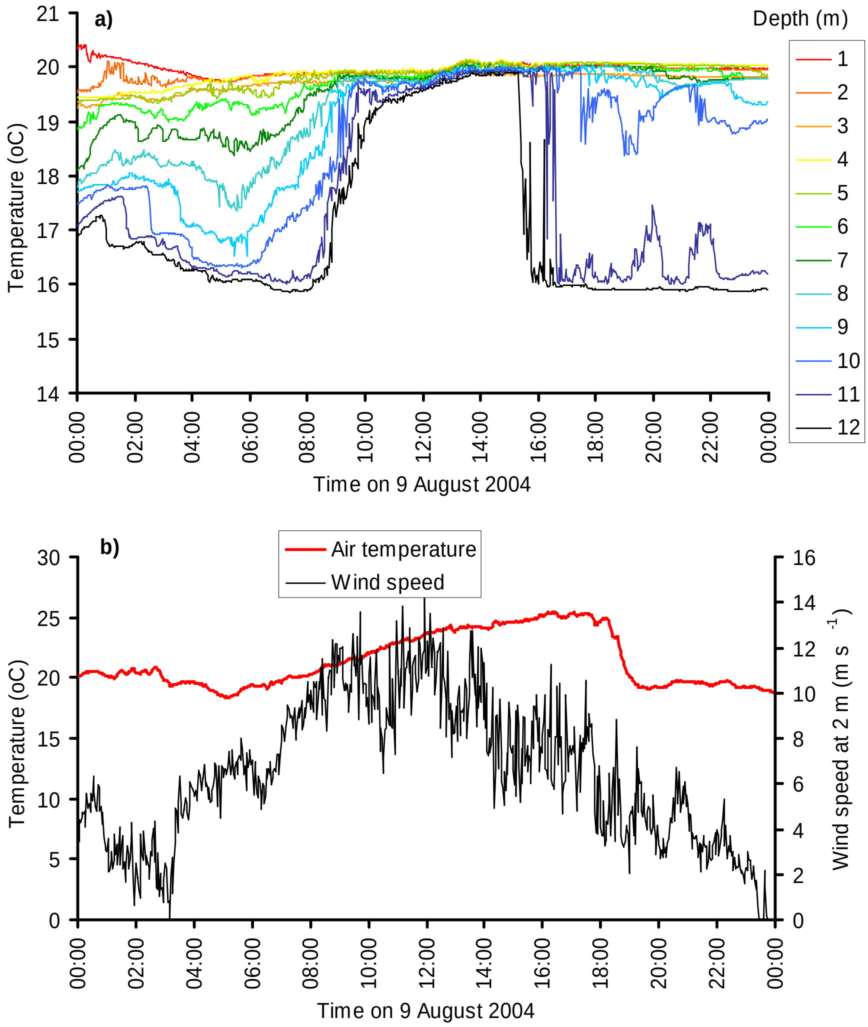
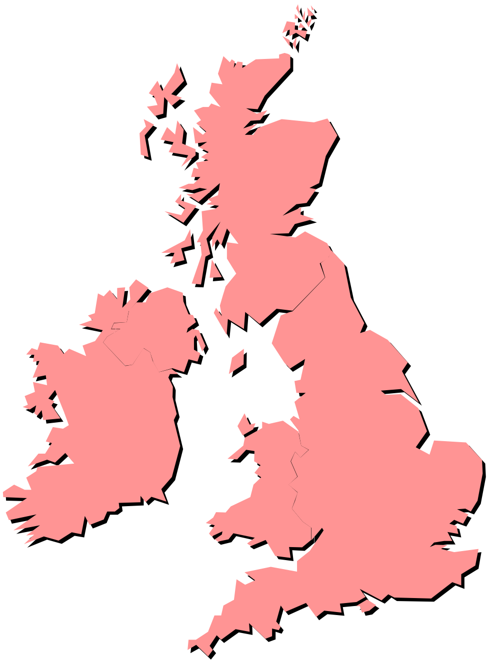


FIGURE 3 Some example LDMS data from Bassenthwaite Lake (August 2004).

Bassenthwaite Lake is too shallow to remain permanently stratified but short periods of thermal stratification are common and have important consequences for the chemistry and biology of the lake. The top panel in Figure 3 shows the vertical variations in the water temperature recorded by an array of temperature sensors suspended in the water column. The lower panel shows the corresponding variations in the air temperature and the wind speed. The results show the effect that a relatively short period of intense mixing had on the physical stability of the water column. The wind speed only started to increase at 03:30 but the water column was effectively mixed by 12:00. The declining wind speed from midafternoon restricted the wind induced mixing to the shallow depths enabling the stratification to re-establish later in the day.

6. The deployment of the Lake Dynamics Monitoring Stations

In March 2004, the design team based at CEH Windermere was disbanded and the remaining engineering staff transferred to a new site at the University of Lancaster. The workshop facilities at Lancaster did not become fully functional until September 2004 so the construction and testing of the 'production' version of the LDMS units was delayed by several months. Subsequent 'Health and Safety' problems with the new facilities resulted in further delays so a significant proportion of the assembly and testing work had to be allocated to external contractors. Eight LDMS units were eventually assembled in 2005 and a number of sensors changed to meet new operational priorities. Figure 4 shows the location of the sites now included in the LDMS network and notes the organisations responsible for managing the individual stations. Less than half the sites will now be managed by CEH Lancaster. Three of the sites are currently being used for climate-related studies in Euro-limpacs.



Loch Lomond (University of Glasgow)

Loch Leven (CEH Edinburgh)

Round Loch of Glenhead (University College London)

Bassenthwaite Lake (CEH Lancaster)

Esthwaite Water (CEH Lancaster)

Windermere South Basin (CEH Lancaster)

Llyn Conwy (CEH Bangor)

Rostherne Mere (University of Wales, Aberystwyth)

Llyn Tegid / Bala Lake (University of Wales, Aberystwyth)

FIGURE 4 The sites included in the LDMS network

By the end of 2005, three of these stations were fully operational and the remaining stations are due to be installed early in the New Year. Since most of these sites are in environmentally sensitive areas, acquiring the necessary planning permission has taken much longer than anticipated. In logistic terms, the most difficult installation was that organized by the team from University College London at the Round Loch of Glenhead. Figure 5a shows an LDMS unit being lowered on to this loch by a small helicopter. Since this loch is quite remote, this proved to be a very cost effective solution and the whole operation was completed in just a few hours. Figure 5b shows the commissioned station with the sensors installed.

a) b)

FIGURE 5 a) The deployment of the LDMS at the Round Loch of Glenhead by Helicopter and b) the installed station fitted with the sensors, loggers and communication system..

7. Some examples of the data acquired by the LDMS

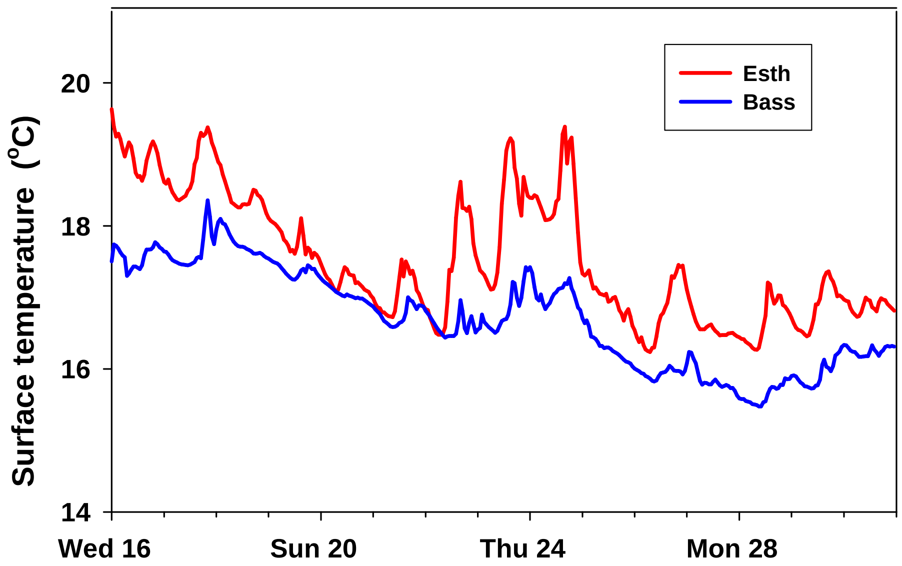
In Euro-limpacs, we have used the LDMS units already deployed to quantify the effects of week-to-week variations in the weather on the physical dynamics of lakes. Two of the lakes (Esthwaite Water and Bassenthwaite Lake) are located in the English Lake District while the third is an upland loch (the Round Loch of Glenhead) in south-west Scotland. Here we present some examples of the high-resolution acquired to demonstrate:

1. The extent to which lakes located in the same area respond in a synchronous way to changes in the weather.
2. The extent to which short term changes in the weather have a significant effect on the dynamics of a shallow lake subject to episodic thermal stratification.
3. The influence of short-term changes in the weather on the flux of heat at the Round Loch of Glenhead.

7.1. The synchronous behaviour of two lakes in the English Lake District.

Lakes located in the same geographic area frequently respond in a synchronous way to systematic changes in the weather. These responses are, however, influenced by the physical characteristics of the basins and their exposure to the prevailing wind. Figure 6 shows the way two very different lakes located in the English Lake District responded to the day-to-day changes in the weather observed in June and July 2004.

a)



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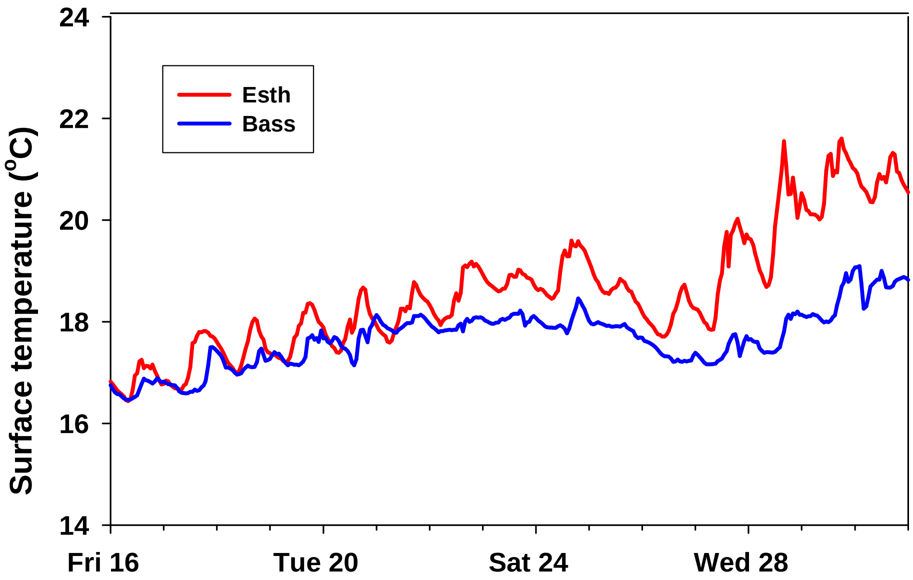

FIGURE 6 The short-term variation in the surface temperature of Esthwaite Water and Bassenthwaite Lake between (a) 16 June to 1 July 2004 and (b) 16 to 31 July 2004.

Esthwaite Water is a small lake situated in a relatively sheltered valley in the Windermere catchment. The lake remains thermally stratified throughout the summer and periodically develops secondary thermoclines that result in episodic increases in the surface temperature. Bassenthwaite is a much larger lake situated in a more exposed valley about 25 km to the north of Esthwaite Water. The lake is too shallow to remain thermally stratified throughout the summer but temporary thermoclines appear during calm periods on bright sunny days. Figure 6a shows the surface temperature variations recorded in the two lakes between 16th June and 1st July 2004. During this period there was a progressive decrease in the average air temperature but there was very little wind. Both lakes were stably stratified throughout the period and both experienced a marked increase in their stability on the 23rd and 24th June when a high pressure system influenced the weather over the UK. Figure 6b shows the surface temperature variations recorded in the two lakes between the 16th and 31st July 2004. For the first few days the lakes behaved in a synchronous way but the temperatures then diverged as the more exposed lake (Bassenthwaite) was mixed by the wind.

7.2. The impact of short-term changes in the weather on the thermal stratification of Bassenthwaite Lake.

Bassenthwaite Lake contains a rare species of fish, the vendace (*Coregonus albula*), whose spatial distribution and survival is strongly influenced by the temperature and oxygen content of the water. Short-term increases in the temperature of the water can thus have a significant effect on the well-being of the fish since the increased stability is frequently associated with the increased consumption of oxygen in deep water. In 2005, we used the LDMS station deployed in the lake to monitor the frequency and intensity of stratification and its potential effect on the spatial distribution of the vendace. Figure 7 shows the results acquired between the 1st June 2005 and the 31st August 2005. The measurements are hourly values based on measurements taken every 2 minutes. The outputs shown are for temperature sensors positioned at depth of 1, 4, 7 and 10m. In the summer of 2005, there were two periods of prolonged thermal stratification. During the first period (20th June to the 7th July) the surface temperature reached 20°C but the bottom temperature was still relatively low. During the second period (9th July to the 20th July) the surface temperature reached 24°C and there was a 1.5°C increase in the critical bottom temperature.

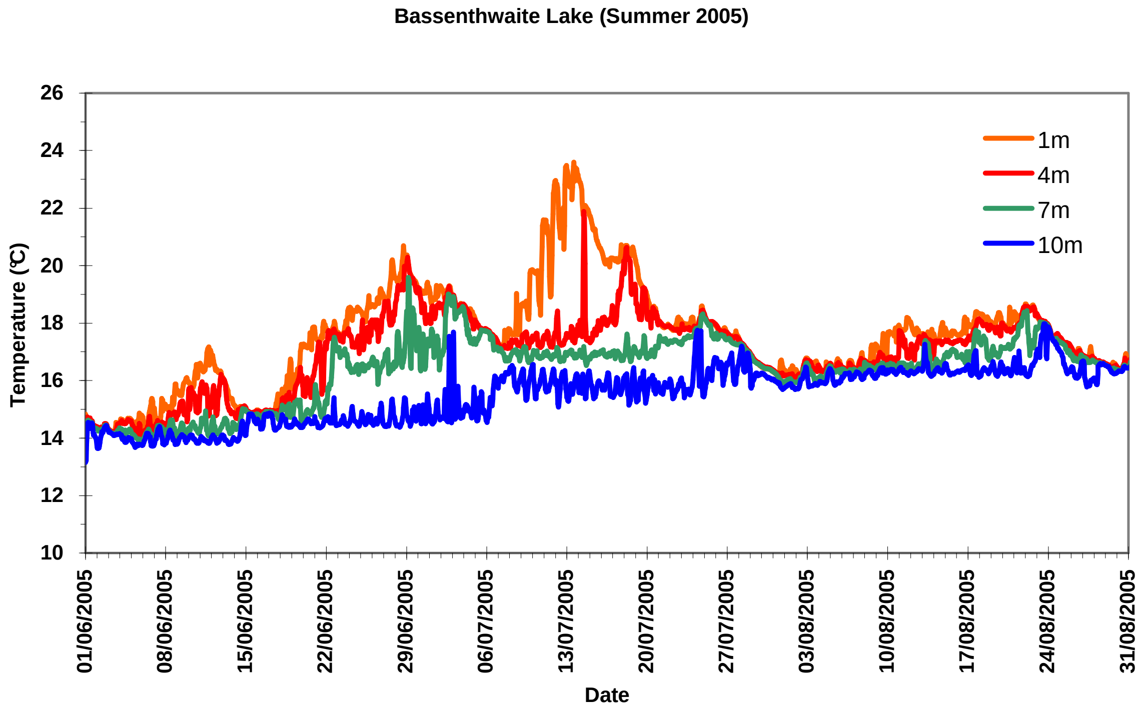

FIGURE 7 The temperature structure of Bassenthwaite Lake during the Summer of 2005

7.3. The flux of heat at the Round Loch of Glenhead.

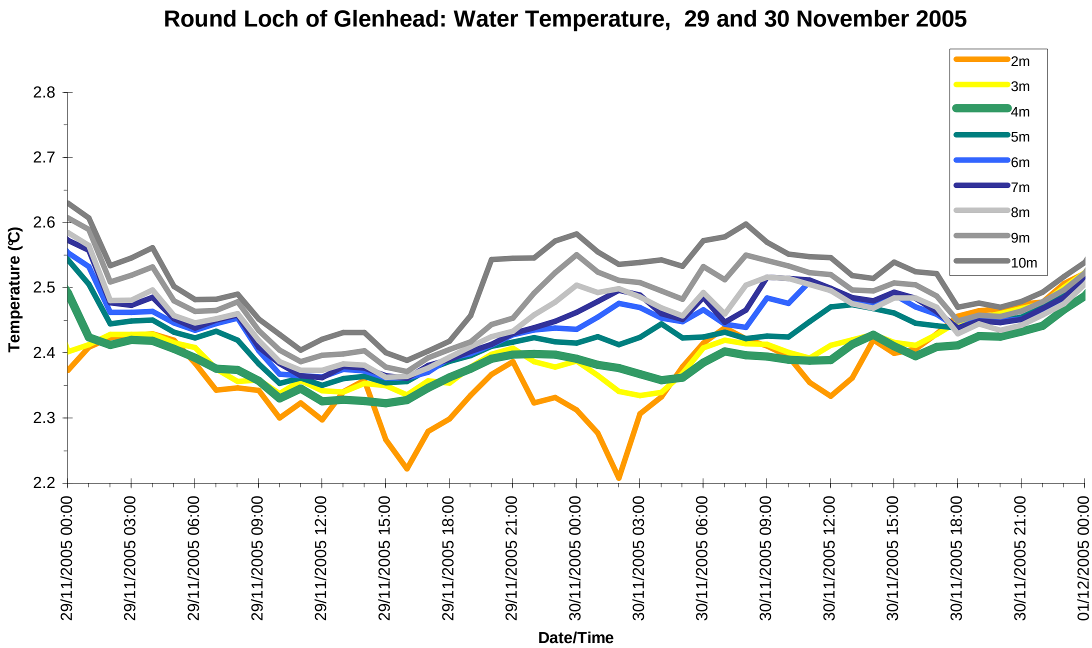

FIGURE 8 The thermal structure of the Round Loch of Glenhead on the 29th and 30th of November 2005

The Round Loch of Glenhead lies at an altitude of 295 m in the Galloway region of south-west Scotland. It covers an area of 12.5 hectares, has a maximum depth of 13.5 and forms part of the surface water acidification monitoring network co-ordinated by University College London. The LDMS deployed in 2005 was designed to monitor the seasonal variations in the concentration of suspended sediment as well as the lochs response to changes in the weather. Figure 8 shows the high-resolution temperature measurements acquired on 29th and 30th of November 2005. These results demonstrate that the elements used in the chain of platinum resistance thermometers were able to resolve temperature differences of *c.* 0.01°C and detect the reverse stratification that developed when the loch lost heat by convective cooling.

8. Conclusions

The Lake Dynamics Monitoring Stations built in the UK to support this Workpackage have proved very reliable and produce results with an even higher resolution than previous designs. The other stations proposed for the network will be deployed early in 2006 and the results used to support studies planned at other Euro-limpacs sites in Wales and Scotland. The data acquired by the stations deployed in the English Lake District is currently being archived for more detailed analysis. In 2006, we will use this data to quantify the effects of different weather types on the mixing characteristics of the lakes.