Climate KIC Innovation projects
Blue Green Dream (BGD)

Lake Créteil full-scale demonstration site
for new eco-services of urban lakes in sustainable cities

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1 Introduction

Lakes and reservoirs are very numerous at the surface of the Earth, they represent about 4.6 10^6 km^2 of the continent surface. Their number is largely dominated by small lakes of surface lower than 1km^2 (Downing *et al.,* 2006).

Lake and reservoir ecosystems play a key role in many environmental processes. They are involved in the carbon cycle through phytoplankton primary production, exchange of GreenHouse Gas (GHG), mainly CO_2 and CH_4 and burial of organic carbon in sediments (Lewis, 2011; Raymond et al., 2013; Ferland et al., 2014).

They also provide essential ecosystem services to human societies: regulation services (flood control, biodiversity conservation, and urban heat island mitigation), cultural services (recreational activities, fishing, tourism, and education) and ecological services (nature protection areas, etc).

In urban areas, most of lakes and reservoirs are small and shallow. Worldwide there is an increasing concern for their protection and their management as they have multiple specific functions. Many storm-water retention ponds are implemented in order to control the flood runoff but also to reduce the pollutant loads produced by impervious catchment and road runoff. At the same time, these water bodies are on the one hand essential recreational area for the city dwellers and on the other hand important spots of biodiversity in these heavily-anthropized regions. Therefore their water quality and their ecological state must be better understood.

The small lakes react strongly and rapidly to the external forcing, principally to the meteorological forcing; therefore they will be particularly affected by the climate change. Conversely, they also impact the local urban weather. But the research effort on the hydrodynamic and ecological processes in these small waterbodies is much lower than on large deep lakes and must be reinforced.

Concerning the urban lakes and ponds, the main research issues regard the following topics:

- Lake-Weather interactions: (1) impact of meteorological variables and climate change on lake hydrodynamic regime and (2) role of lakes on local urban weather (urban weather forecasting)
- Lake-catchment interactions: (1) Nutrient cycles and ecological functioning (eutrophication, algal blooms, …), (2) control of the runoff pollutant loading, (3) Urban lakes, ecological diversity and ecological continuity

As small urban lakes provide multiple eco-services, their number is increasing worldwide. The role that they play in GHG cycles (CO_2 and CH_4) is therefore a main concern. It is essential to better understand and control how and when they act as a sink or a source of GHG. But the scarcity of available data limits this knowledge. Finally, due to the strong interactions with the city dwellers, the social sciences are also increasingly addressing research on urban lake issues.

The scarcity of available data is a limiting factor for the management and the development of **new applications and eco-services, for example in the field of heat exchange (refreshing or warming of buildings in the lake neighbourhood) and energy (water power)**. The objective of Lake Créteil demonstration site is (1) to provide long-term time-series for monitoring and understanding the impact of local and global changes on the physical and ecological functioning of small urban lakes; (2) to provide high-resolution and high-frequency data for characterizing accurately the intermittency of turbulence in the water column and its impact on the biological processes and the fate of pollutants and (3) to provide enough data to validate coupled hydrodynamic-biological models (1D and 3D) used to assess the environmental impact of installations on a lake in a context of global change. The validation of such models on a small lake will increase the level of confidence in the environmental assessment of technical innovations.

Lake Créteil is one of the full-scale demonstration sites of Ecole des Ponts ParisTech in **Blue Green Dream** project. This demonstration site was developed in partnership with local authorities, the town of Créteil and the **department of Val-de-Marne** interested by the evolution of the lake water quality and the impact of the storm water inflow. It was also made possible by the support of our research centre LEESU (Ecole des Ponts ParisTech, UPEC, AgroParistech http://leesu.univ-paris-est.fr), of the OSU-EFLUVE (Observatoire des Sciences de l'Univers – Enveloppes FLUides de la Ville à l'Exobiologie http://osu-efluve.u-pec.fr) and complementary scientific projects (PULSE ANR CEP&S, PLUMMME Île de France R2DS).

2 Lake Créteil

Lake Créteil (48°46'34.2"N 2°27'01.9"E, Fig. 1) is located in an urbanized area in the south-east region of Paris, France. Its area is 0.4 km^2, its perimeter 4 km, its length 1.5 km; its width varies between 250 m and 400 m. Its mean depth is 4 m, with a maximum of 6 m, and its volume is 1.9 10^6 m^3. The northern part is shallower than the southern part.

The lake was created as an extraction quarry of gravel and gypsum between 1940 and 1976. The quarry was dug in the former alluvium of the Seine River, near its confluence with the Marne River. The quarry was transformed into an urban lake in the middle of the 1970s; it includes a recreation center of Île-de-France regional council with a park of 0.62 km^2 on the lake western bank and a boating center of the town of Créteil and the department of Val-de-Marne. The water of the lake is used to water the park on the western bank, to clean the roads and for roadwork.

The lake is surrounded by buildings in the North, East and South-East. The lake is fed by groundwater which flows from the Marne river to the Seine river due to a 1 m difference in the normal level of the navigation reaches, by storm water from a 1 km^2 urban area in the East and by direct precipitation. The water level is regulated by a fixed gate on the western bank.

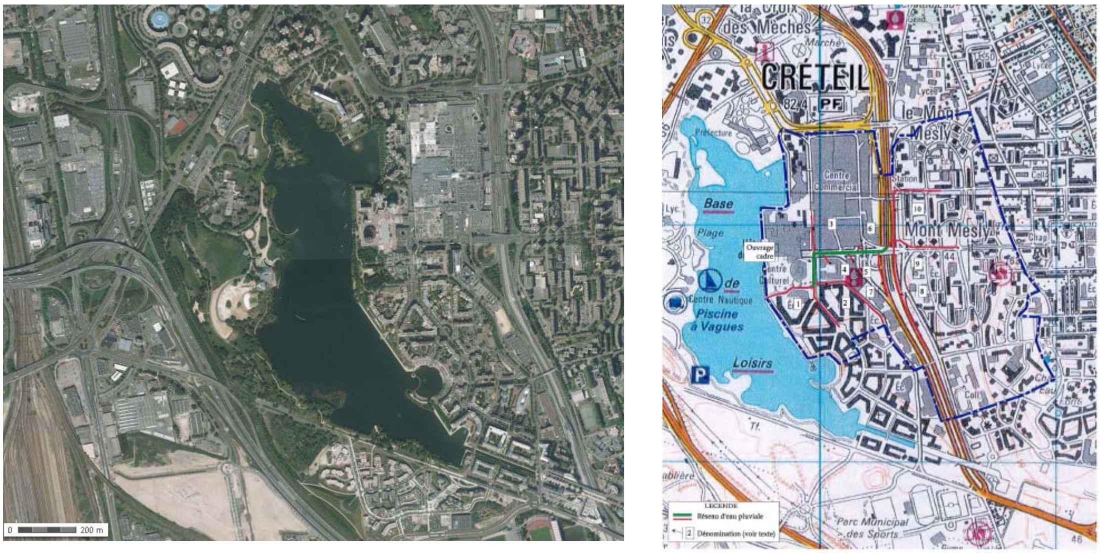


Fig. 1 : Lake Créteil satellite photograph (http://www.geoportail.gouv.fr © IGN) and map indicating the urban catchment in the East of the lake (blue line)

3 Measuring instruments

3.1 Design of the measuring setup

We intended to perform measurements at different locations on the lake and at different depths in order to monitor differences in temperature and fluorescence of the phytoplankton chlorophyll. These differences are used to test the numerical hydrodynamic-biological models and determine the relevance of a 1 or 3-dimensional model.

The long-term observation system deployed on Lake Créteil comprises autonomous permanently installed instruments aimed at acquiring long-term time-series and other devices which are deployed during particular periods for studying specific processes or for calibrating the long-term measuring instruments.

3.1.1 High-frequency and resolution permanent sensors

The main permanent observation platform is located in the centre of Lake Creteil since May 11, 2012; it consists of an **autonomous continuously measuring station** (Lake Environmental Sensing Platform, PME, USA). This station is equipped with a GSM data transmission module; it includes a weather station (Vaisala Weather Transmitter WXT520) located 2 m above the lake surface (wind speed and direction, air temperature, atmospheric pressure, vapour pressure, relative humidity, precipitation), a net total radiation sensor (Kipp and Zonen NR Lite2), and a chain of underwater high-resolution sensors (5 thermal sensors every meter from 0.5 to 4.5 m, 2 fluorescence sensors at 1.5 and 2.5 m depth and 1 sensor of active radiation for photosynthesis at 2.5 m depth). It is aimed at acquiring long term weather variables over the lake surface and the response of the lake itself. To our knowledge, no system of acquisition and transmission of such variables is presently installed on a urban water body in France and very few similar systems are deployed in Europe.

Two other similar **sensor chains** were installed on October, 25 2012. They are equipped with 2 thermal sensors (nke Instrumentation SP2T10) at 0.5 and 1.5 m and a multiparameter probe (nke Instrumentation MP_5) at 2.5 m which measures water temperature, dissolved oxygen and chlorophyll fluorescence. The data of the temperature sensors and of the multiparameter probe are stored on separate data loggers.

The fluorescence sensors of the measuring station and of the multiparameter probes are similar, as well as all temperature sensors of the other sensor chains, including those of multiparameter probes.

The position of these equipments presently deployed on Lake Créteil is presented on Figure 4. The three measuring points are located in contrasted environments: the point in front of the storm water outflow (P), the central point (C) and the point close to the reed bed (R). They are aligned and sensors are placed at identical depths to facilitate the relationships between distance and time in the spectral analysis of the timeseries.

All the characteristics of the measuring devices are gathered in Table 1.

The measuring devices have a high **accuracy** to be able to distinguish small differences in variables between the different points.

A high frequency of measurements is required for rapidly varying systems like shallow lakes. If we take the example of the storm water inflow, the short concentration time of the catchment, around 30 min, yields a short duration of the inflow. Even if the response of the whole lake can be much longer than the inflow, a measuring time step longer than the concentration time, *e.g.*, 1 h, would be too long to follow the impact of the inflow close to the inlet. Moreover, we intended from the beginning to process the measurements with spectral analysis. A short time step increased the spectral range of the measurements on the same whole measurement duration. The lowest frequency available on the autonomous monitoring station was **30 s**, which we adopted for all continuous measurements. We paid attention to the **response time** of the sensors required by such a high frequency. Among all the sensors on Lake Creteil, only dissolved oxygen sensors respond in more than 1 s.

3.1.2 Profilers

A set of **independent measuring devices** can be deployed for discrete profile measurements on the lake, in order to complement the continuous measurements or to calibrate the continuously measuring sensors:

- a multiparameter probe for measuring temperature, conductivity, pH and oxygen (Seabird SBE19),
- two fluorimetric probes (BBE): FluoroProbe for measuring 4 phytoplankton families and Algae Torch for measuring cyanobacteria and total chlorophyll,
- a probe of active radiation for photosynthesis (Li-Cor Li 193).

All the characteristics of the measuring devices are gathered in Table 1.

3.1.3 High-resolution hydrodynamics instruments

High resolution of the current meters is required since current speeds are very low (in the order of 1 mm/s). This supposes to use a rigid supporting structure (Figure 2) to avoid measuring only the vibrations due to the wind acting on its part above the surface and not due to the currents.

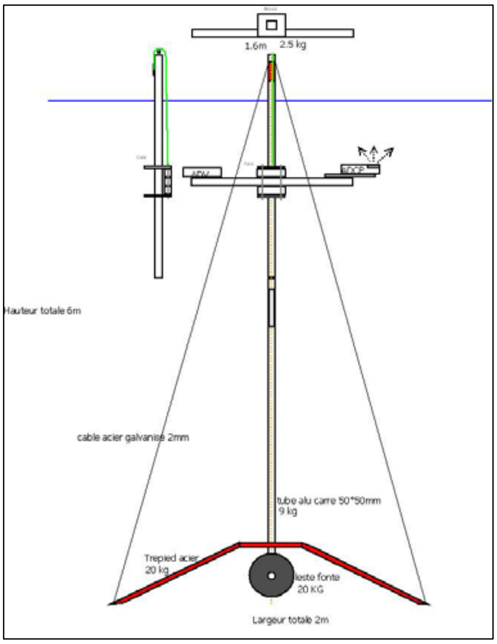


Figure 2 : Mast with the current meters

Figure 3 : Microprofiler (Scamp) coupled with ADV

- A high-resolution microprofiler (100Hz) for measuring temperature, conductivity and fluorescence (SCAMP, PME)
- An acoustic Doppler current meter (ADV Vector, Nortek): three-dimensional measurements of the components of the high-speed, high-resolution frequency (64Hz)
- An acoustic Doppler current meter (2 MHz Aquadopp Nortek ADCP): Profiles of current velocities can be measured on a depth range from 1 to 100m

All the characteristics of the measuring devices are gathered in Table 1.

The lake station and all associated measuring devices provide essential observations on the long-term functioning of urban lake ecosystems. They also provide measurements of the hydrodynamic, physical-chemical and biological processes occurring in lakes which are compulsory for performing extensive research on ecological processes and the fate of contaminants in urban lakes.

Equipments	Variable	Model	Range	Accuracy	Resolution	Response time	Manufacturer
Lake ESP Meteorological station	Air temperature	WXT520	-52 – 60°C	± 0.3 °C at 20°C	0.1 °C		Vaisala
	Barometric pressure	WXT520	600-1100 hPa	± 0.5 hPa between 0 and 30°C, ± 1 hPa between -52 and 60°C	0.1 hPa		
	Wind speed	WXT520	0-60 m/s	± 3 % at 10 m/s	0.1 m/s		
	Wind direction	WXT520	0 to 360°	± 3°	1 °C		
	Relative humidity	WXT520	0-100 %	± 3 % between 0 and 90 %, ± 5 % between 90 % and 100 %	0.1 %		
	rainfall	WXT520	0-200 mm/h	5 %	0.1 mm/h		
	Net total radiation	NR Lite 2					Kipp and Zonen
	SW and LW radiations						Kipp and Zonen
Lake ESP underwater chain	Water temperature		0-36 °C	0.01 °C	0.005 °C		
	Chlorophyll fluorescence	CYCLOP-7	0-50µg/l				
	PAR						
Lateral chains	Water temperature	SP2T10	-5 – 35 °C	0.05 °C between 0 and 20 °C	0.013 °C at 10 °C		nke
	O_2	3835	0-120%	<5%	0.01%	<8 sec (63%)	Anderaa
	Chlorophyll fluorescence	CYCLOPS-7	0-50 µg/l		<0.008 mg/l		Turner design
	Depth		0-20m	<0.06m	<0.006m		Nke
	Conductivity		0–2 mS/cm	<10µS/cm	0.04µS		Nke
Multiparameter probe	Water temperature	SBE19	5-35°C	0,01°			Seabird
	O_2	SBE43	0-120 %	5 %	0.01 %		
	pH	SBE18	0-14 u	+-0.1 u		1s	
	Conductivity	SBE19	0-70 mS/cm				
	Depth	SBE19	10000psia	0.015%			
Fluorimeters	Chlorophyll and Phycocyanin	Algae torch	0-200µg/l		0.1µg/l		BBE
	4 families of phytoplankton	Fluoroprobe	0-200µg/l		0.05µg/l		BBE
Currentmeters	ADV	Vector					Nortek
	ADCP	2 MHz Aquadopp	0-10 cm/s	1 %, ± 0.5 cm/s	0.01 cm/s		Nortek
Microprofiler	Temperature	Scamp	0 to 30 °c	+- 0.02°			PME
	Chlorophyll fluorescence						
	Conductivity		5E-2 to 0.1 S	+/- 5% scale			

Table 1: Characteristics of the measuring devices

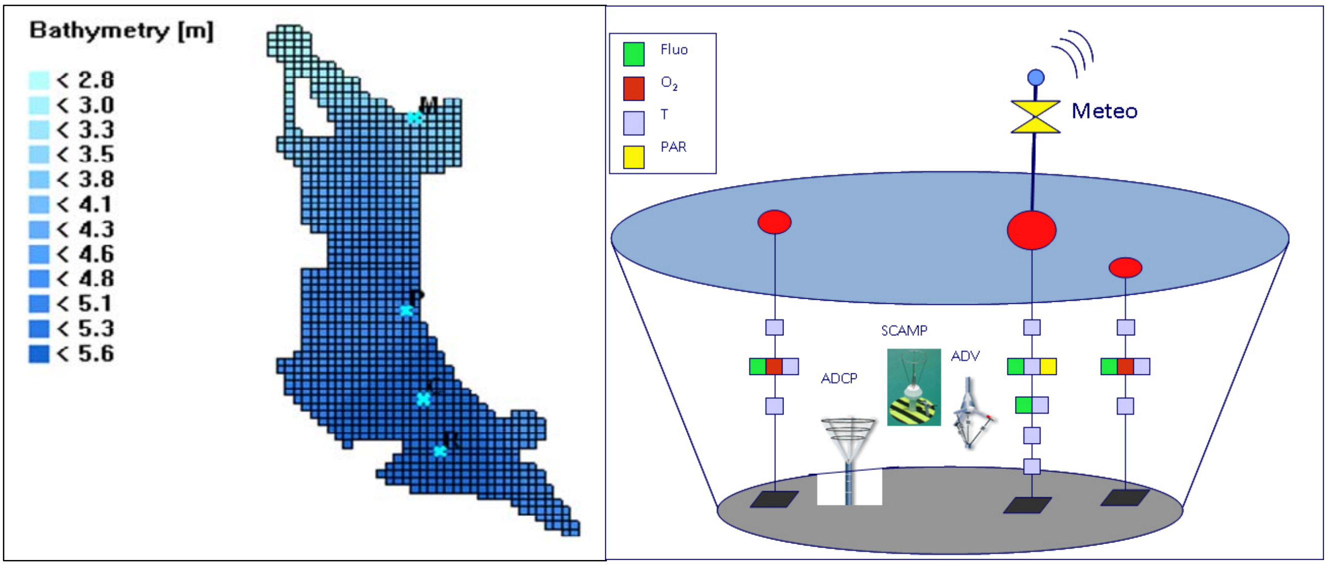


Figure 4 Permanent measuring instruments installed in Lake Créteil

3.1.4 Navigation

A Zodiac equipped with an electric motor and winch, GPS, depth bathymetry sounder.

3.1.5 Installation of continuously measuring equipment

The **autonomous measuring station** is equipped with a float which supports a mast with the meteorological station and the radiation sensor.

It is moored with a main ballast of 160 kg so that the distance of the sensors to the lake bottom is independent from the water level. Two side ballast of 40 kg maintain the orientation of the station (the wind direction is measured). Its energy is supplied by solar panels, an electric load regulator and a 12 V battery.

The sensors of the ***two other sensor*** **chains** are attached to a rope at different depths. The latter is linked to a 5 L float and to a 2-kg ballast. This measuring buoy is moored with a second rope and a 40-kg ballast.

3.1.6 Maintenance

Frequency and duration of the maintenance periods: the maintenance frequency was set to two weeks.

Large amounts of mussels and algae have to be removed from the underwater sensors, especially from optical sensors like optodes and fluorometers.

Maintenance specific to the measuring station: The solar panels are cleaned to maintain power production, as well as the radiation sensor to avoid drift. The measurements are downloaded from the data logger which keeps a copy of all teletransmitted files.

Maintenance specific to the two other sensor chains: the sensors are brushed to suppress algae, mussels and biofilm. Biofouling is limited by rolling copper foil around the sensors. The data are downloaded and the memory reinitialized.

This requires two hours for two people, excluding the journey from the laboratory. All sensors are regularly sent back to their supplier for verification and calibration.

Figure 5 : Cleaning the MP5 probe

Vandalism: the sensor chain located close to the storm water inlet probably disturbed anglers: its mooring was cut and the chain and buoy were found on the shore a few hundred meters away. The chain was then attached to a heavy load (a tyre full of concrete), which apparently solved the problem.

Loss of data: the batteries of the MP_5 muliparameter probes on the sensor chains at points P and R were found empty before their anticipated exhaustion several times. Even if a SSD card was present, all measurements were lost.

3.1.7 Data recovery

Measuring station: it sends its raw data every hour by GSM to a server at Leesu/Ecole des Ponts ParisTech. The station modem connects to the internet and then to the server.

The server converts the raw data into text files with a descriptive header. These measurement files are stored on a shared directory with limited access. Automatic backup and data compression happen daily.

The measurement files are used directly or visualized with a graphic interface software provided by the monitoring station supplier (Figure 6).

Sensor chains: The temperature sensors and the multiparameter probes have their own data loggers. The data are downloaded onto a laptop computer with an inductive or radio pencil during the maintenance periods. The measurements are verified on boat to detect any dysfunction.

Back to laboratory, these data files are stored on a shared directory with limited access.

4 Data acquisition 2012-2014

On Lake Creteil, continuous observation of the hydrodynamic and biological variables is going on. Since May 2012, high-frequency measurements of meteorological variables as well as underwater temperature, conductivity, pH, chlorophyll fluorescence, and dissolved oxygen, were collected at three points of the lake. These measurements are archived in a database. The data of the Lake platform are available on a shore computer via Internet (Figure 6) using a PME software (Plot Vega). The measurement of the two other sensor chains were collected regularly (see § 3.1.6).

In parallel to this continuous data acquisition, other series of measurements were carried out: monthly monitoring since May 2011 of nutrient concentrations (Nitrogen and Phosphorus), pathogens (E. coli and enterococci), trace metals and organic micro-pollutants (PAHs, PCBs, PBDEs); measurements of current velocity during several characteristic periods of the seasonal evolution of the lake.

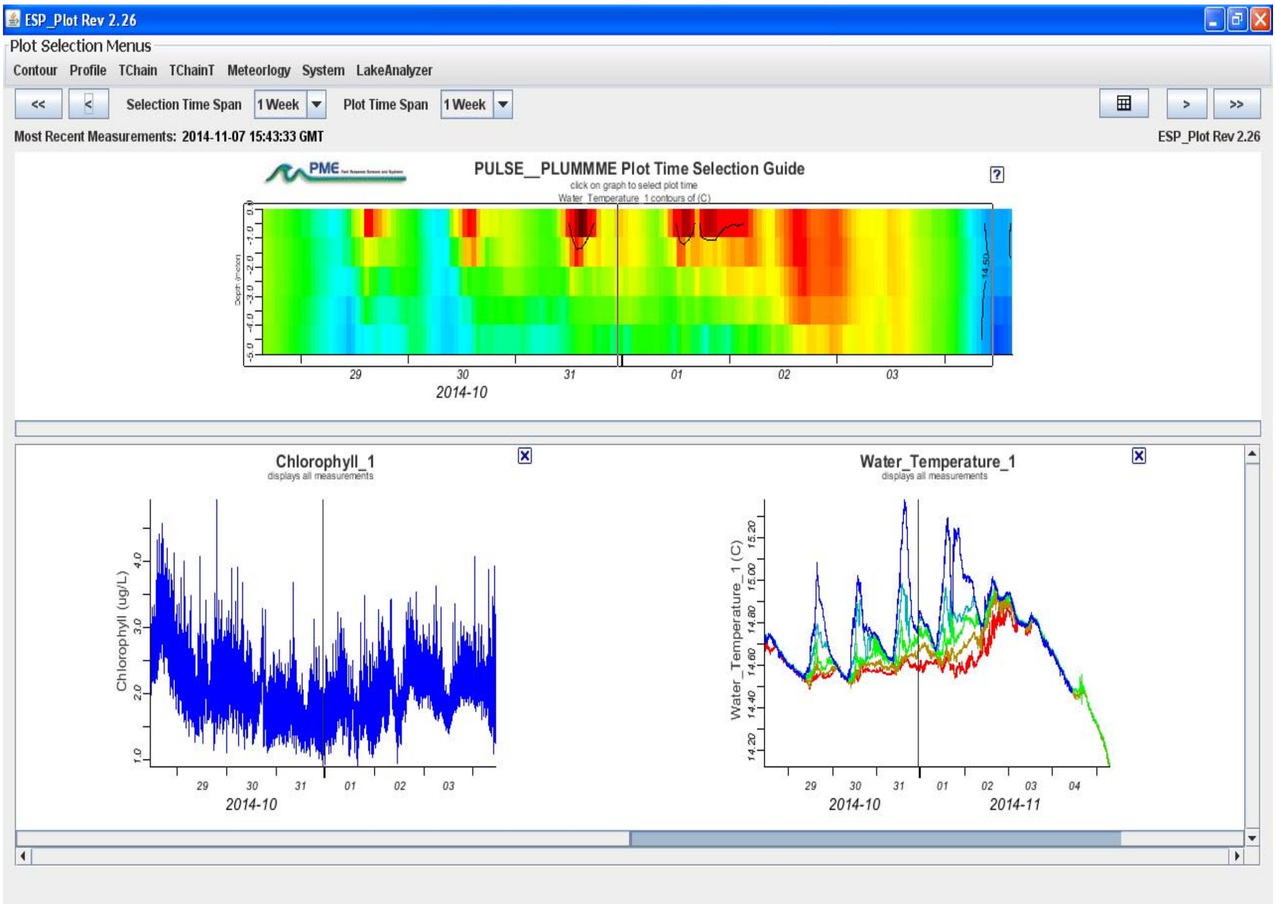


Figure 6 : Example of the Lake Platform user interface

4.1 Data files

Data are stored in ASCII files presented below. The time reference of recorded data is UTC (Coordinated Universal Time).

4.1.1 LakeESP files

Raw meteorological data and underwater sensor data are included in the same files (Figure 7). Treated data are included in three different files, one file for meteorological data (Figure 8), one file for water temperature data (Figure 9) and one for chlorophyll-a concentration data (Figure 10).

```
PME Data Pipeline Rev 1.01
Name:                PULSE__PLUMMME
Raw Data File:       4FAD123C.RAW
Calibration File:    CAL00001.TXT
EU File:             2012May11 132100 UTC.TXT
Time Zone Offset:    1.0 (hour)
Latitude:            48.7739066666667 (degree)
Longitude:           2.452625( degree)
Drift Distance:      20.655730579381046 (meter)
EngUnit Rev:         1.0

DATA BEGINS
    Time (Unix epoch 1970),              UTC_Date_&_Time, Approximate_Local_Date_&_Time,
                 (Second),                       (none),                        (none),
            System Clock,                  System Clock,                  System Clock,
                        ,                              ,                              ,

              1336742460,         2012 May 11 13:21:00,         2012 May 11 14:21:00,
              1336742490,         2012 May 11 13:21:30,         2012 May 11 14:21:30,
              1336742520,         2012 May 11 13:22:00,         2012 May 11 14:22:00,
              1336742550,         2012 May 11 13:22:30,         2012 May 11 14:22:30,
              1336742580,         2012 May 11 13:23:00,         2012 May 11 14:23:00,
              1336742610,         2012 May 11 13:23:30,         2012 May 11 14:23:30,
              1336742640,         2012 May 11 13:24:00,         2012 May 11 14:24:00,
              1336742670,         2012 May 11 13:24:30,         2012 May 11 14:24:30,
              1336742700,         2012 May 11 13:25:00,         2012 May 11 14:25:00,
              1336742730,         2012 May 11 13:25:30,         2012 May 11 14:25:30,
              1336742760,         2012 May 11 13:26:00,         2012 May 11 14:26:00,
              1336742790,         2012 May 11 13:26:30,         2012 May 11 14:26:30,
              1336742820,         2012 May 11 13:27:00,         2012 May 11 14:27:00,
              1336742850,         2012 May 11 13:27:30,         2012 May 11 14:27:30,
              1336742880,         2012 May 11 13:28:00,         2012 May 11 14:28:00,
              1336742910,         2012 May 11 13:28:30,         2012 May 11 14:28:30,
              1336742940,         2012 May 11 13:29:00,         2012 May 11 14:29:00,
              1336742970,         2012 May 11 13:29:30,         2012 May 11 14:29:30,
              1336743000,         2012 May 11 13:30:00,         2012 May 11 14:30:00,
```

Figure 7 : Raw data from LakeESP (yyyymmmdd HHMMSS UTC.TXT)

```
Time UTC    WDA (°)      WVA (m/s)    BP (hPa)    AT (°C)     RH (%)      P (mm)      PD (s)      PI (mm/h)
11/05/2012 13:21:00      325     3.7  1019.8      16.9  73.4  0.00    0     0.0
11/05/2012 13:21:30      307     4.3  1019.8      16.9  73.7  0.00    0     0.0
11/05/2012 13:22:00      321     3.7  1019.8      16.9  73.9  0.00    0     0.0
11/05/2012 13:22:30      316     3.6  1019.9      16.9  73.6  0.00    0     0.0
11/05/2012 13:23:00      321     3.6  1019.9      16.9  74.5  0.00    0     0.0
11/05/2012 13:23:30      306     3.8  1019.9      16.9  75.2  0.00    0     0.0
11/05/2012 13:24:00      340     3.9  1019.9      16.9  73.7  0.00    0     0.0
11/05/2012 13:24:30      333     3.2  1019.9      16.9  74.2  0.00    0     0.0
11/05/2012 13:25:00      322     3.4  1020.0      16.9  74.7  0.00    0     0.0
11/05/2012 13:25:30      343     4.2  1020.1      16.9  74.6  0.00    0     0.0
```

Figure 8 : Treated meteorological data from LakeESP (YYYY-MM_LakeESP_Vaisala_Tout_brut.txt)

Time UTC	WT1 (°C)	WT2 (°C)	WT3 (°C)	WT4 (°C)	WT5 (°C)
11/05/2012 13:21:00	17.6900	17.6590	17.5055	15.9245	14.3140
11/05/2012 13:21:30	17.6940	17.6730	17.4880	15.9050	14.3480
11/05/2012 13:22:00	17.6895	17.6715	17.5295	16.0145	14.2575
11/05/2012 13:22:30	17.6855	17.6690	17.5550	15.9460	14.2310
11/05/2012 13:23:00	17.6775	17.6610	17.5905	15.8855	14.1685
11/05/2012 13:23:30	17.6840	17.6605	17.5685	15.8470	14.1245
11/05/2012 13:24:00	17.6865	17.6580	17.5615	15.8965	14.1335
11/05/2012 13:24:30	17.6835	17.6655	17.5215	16.0275	14.1345
11/05/2012 13:25:00	17.6820	17.6710	17.5265	16.0120	14.1540
11/05/2012 13:25:30	17.6825	17.6705	17.5405	15.9865	14.1765

Figure 9 : Treated water temperature data from LakeESP (YYYY-MM_LakeESP_WT_brut.txt)

Time UTC	CA1 (µg/l)	CA2 (µg/l)
11/05/2012 13:21:00	3.811	4.954
11/05/2012 13:21:30	3.841	4.712
11/05/2012 13:22:00	3.662	4.168
11/05/2012 13:22:30	3.942	4.312
11/05/2012 13:23:00	3.711	3.880
11/05/2012 13:23:30	4.082	4.234
11/05/2012 13:24:00	3.501	4.052
11/05/2012 13:24:30	3.474	4.278
11/05/2012 13:25:00	3.535	4.130
11/05/2012 13:25:30	3.626	4.137

Figure 10 : Treated chlorophyll-a concentration data from LakeESP (YYYY-MM_LakeESP_CA_brut.txt)

4.1.2 Additional chains files

```
SP2T 10m PR sn:32021 121114F.TXT
Logging cadence   30    s
  WAY:0 Température (-5 +35°C) Unit=øC
  WAY:1 Profondeur 10m Unit=m
15.471      -0.035987   25/10/2012  16:35:36
15.456      -0.031989   25/10/2012  16:36:06
15.456      -0.031989   25/10/2012  16:36:36
15.456      -0.023992   25/10/2012  16:37:06
15.411      -0.023992   25/10/2012  16:37:36
15.337      -0.02799    25/10/2012  16:38:06
15.441      -0.023992   25/10/2012  16:38:36
15.575      -0.015994   25/10/2012  16:39:06
15.817      -0.0079972  25/10/2012  16:39:36
16.046      -0.0079972  25/10/2012  16:40:06
```

Figure 11 : SP2T10 sensors (water temperature and pressure) raw file

```
MP C/T/D/Do/Fluo sn:32019 121114P.TXT
Logging cadence   30    s
  WAY:0 Profondeur Unit=m
  WAY:1 Température Unit=øC
  WAY:2 Salinité Unit=mS
  WAY:3 Oxygène Unit=%
  WAY:4 Fluorescence Unit=ugL
  WAY:5 Vbatterie Unit=V
0.086764    16.151      3.2527E-5   95.89 0     10.715      25/10/2012  16:38:36
0.085622    16.213      3.2527E-5   95.74 0     10.766      25/10/2012  16:39:06
0.093043    16.333      0     95.78 0     10.772      25/10/2012  16:39:36
0.086764    16.348      3.2527E-5   95.82 0     10.773      25/10/2012  16:40:06
0.086764    16.243      3.2527E-5   95.77 0     10.769      25/10/2012  16:40:36
0.095897    16.329      0.00013011  95.64 0     10.769      25/10/2012  16:41:06
0.09761     16.363      0     95.74 0     10.769      25/10/2012  16:41:36
0.091331    16.336      0     95.96 0     10.766      25/10/2012  16:42:06
0.095326    16.478      6.5054E-5   95.89 0     10.766      25/10/2012  16:42:36
0.10389     16.663      0     96.05 0     10.765      25/10/2012  16:43:06
0.10446     16.726      3.2527E-5   96.2  0     10.765      25/10/2012  16:43:36
0.093043    16.61 6.5054E-5   96.42 0     10.763      25/10/2012  16:44:06
0.090189    16.479      0     96.42 0     10.763      25/10/2012  16:44:36
0.093614    16.484      0     96.52 0     10.761      25/10/2012  16:45:06
0.090189    16.358      9.7581E-5   96.34 0     10.76 25/10/2012  16:45:36
0.085622    16.183      3.2527E-5   96.39 0     10.76 25/10/2012  16:46:06
0.082768    16.233      0     96.32 0     10.759      25/10/2012  16:46:36
0.081627    16.187      0     96.13 0     10.758      25/10/2012  16:47:06
```

Figure 12 : MP5 (oxygen, conductivity, chlorophyll fluorescence, water temperature and pressure) raw data

```
Time UTC     WTP1 (°C)    WTP2 (°C)    WTP3 (°C)    WTR1 (°C)    WTR2 (°C)    WTR3 (°C)
26/10/2012  11:58:00      14.37 14.394      14.33 14.30    NaN      14.31
26/10/2012  11:58:30      14.37 14.388      14.33 14.30    NaN      14.33
26/10/2012  11:59:00      14.37 14.385      14.33 14.30    NaN      14.20
26/10/2012  11:59:30      14.37 14.382      14.33 14.30    NaN      14.34
26/10/2012  12:00:00      14.37 14.387      14.33 14.30    NaN      14.34
26/10/2012  12:00:30      14.37 14.382      14.33 14.30    NaN      14.34
26/10/2012  12:01:00      14.37 14.380      14.33 14.30    NaN      14.34
26/10/2012  12:01:30      14.37 14.383      14.33 14.30    NaN      14.34
26/10/2012  12:02:00      14.37 14.386      14.33 14.30    NaN      14.34
26/10/2012  12:02:30      14.37 14.387      14.33 14.30    NaN      14.34
26/10/2012  12:03:00      14.37 14.391      14.33 14.30    NaN      14.34
```

Figure 13 : Treated data (Water temperature at points P, C and R)

4.1.3 Current profiler

Several files are provided by the ADCP. The file dep0101.hdr contains the information for reading the measurement files.

```
[E:\PLUMMME\ADCP\20130418_dep01\dep0101.prf]
--------------------------------------------------------------------
Number of measurements            14401
Number of checksum errors         0
Time of first measurement         18/04/2013 10:00:00
Time of last measurement          23/04/2013 10:00:00

User setup
--------------------------------------------------------------------
Measurement/Burst interval        30 sec
Cell size                         23 mm
Orientation                       UPLOOKING SHALLOW WATER
Distance to surface               3.00 m
Extended velocity range           OFF
Pulse distance (Lag1)             3.06 m
Pulse distance (Lag2)             0.00 m
Profile range                     2.92 m
Horizontal velocity range         0.10 m/s
Vertical velocity range           0.04 m/s
Number of cells                   127
Average interval                  30 sec
Blanking distance                 0.101 m
Measurement load                  61 %
Burst sampling                    OFF
Samples per burst                 N/A
Sampling rate                     N/A
Compass update rate               30 sec
Analog input 1                    NONE
Analog input 2                    NONE
Power output                      DISABLED
Powerlevel first ping             HIGH-
Powerlevel ping 2                 HIGH
        ….. etc
```

Figure 14 : dep0101.hdr file

Time UTC	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Ce
12/09/2013 15:00	-0.0134	-0.0133	-0.0131	-0.0130	-0.0126	-0.0121	-0.0118	
12/09/2013 15:03	-0.0120	-0.0118	-0.0116	-0.0113	-0.0111	-0.0106	-0.0104	
12/09/2013 15:06	-0.0110	-0.0110	-0.0108	-0.0105	-0.0105	-0.0105	-0.0108	
12/09/2013 15:09	-0.0133	-0.0132	-0.0130	-0.0127	-0.0121	-0.0118	-0.0113	
12/09/2013 15:12	-0.0153	-0.0137	-0.0126	-0.0127	-0.0129	-0.0132	-0.0134	
12/09/2013 15:15	-0.0104	-0.0106	-0.0108	-0.0105	-0.0103	-0.0100	-0.0113	
12/09/2013 15:18	-0.0125	-0.0128	-0.0127	-0.0127	-0.0125	-0.0127	-0.0128	
12/09/2013 15:21	-0.0115	-0.0117	-0.0118	-0.0120	-0.0123	-0.0124	-0.0125	
12/09/2013 15:24	-0.0117	-0.0119	-0.0120	-0.0121	-0.0121	-0.0120	-0.0122	
12/09/2013 15:27	-0.0115	-0.0123	-0.0135	-0.0126	-0.0118	-0.0119	-0.0114	
12/09/2013 15:30	-0.0107	-0.0109	-0.0110	-0.0108	-0.0108	-0.0111	-0.0113	
12/09/2013 15:33	-0.0093	-0.0095	-0.0097	-0.0098	-0.0098	-0.0103	-0.0101	

Figure 15 : Treated data

Figures illustrating the time series of the different types of data are presented in the following sub-section.

4.2 Lake Platform

4.2.1 Meteorological data

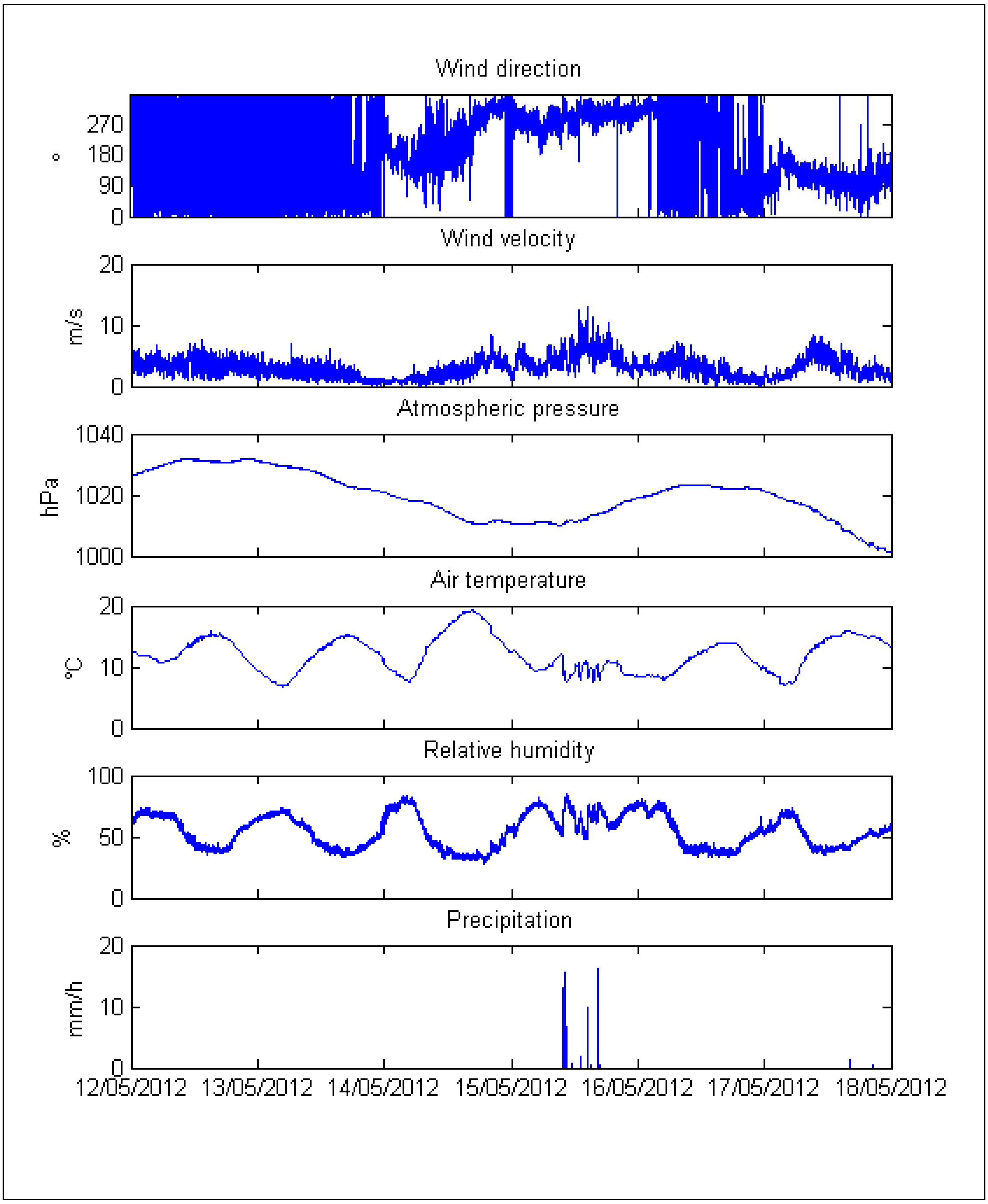


Figure 16 : Meteorological data recorded from 12/05/2012 to 18/05/2012

4.2.2 Water temperature

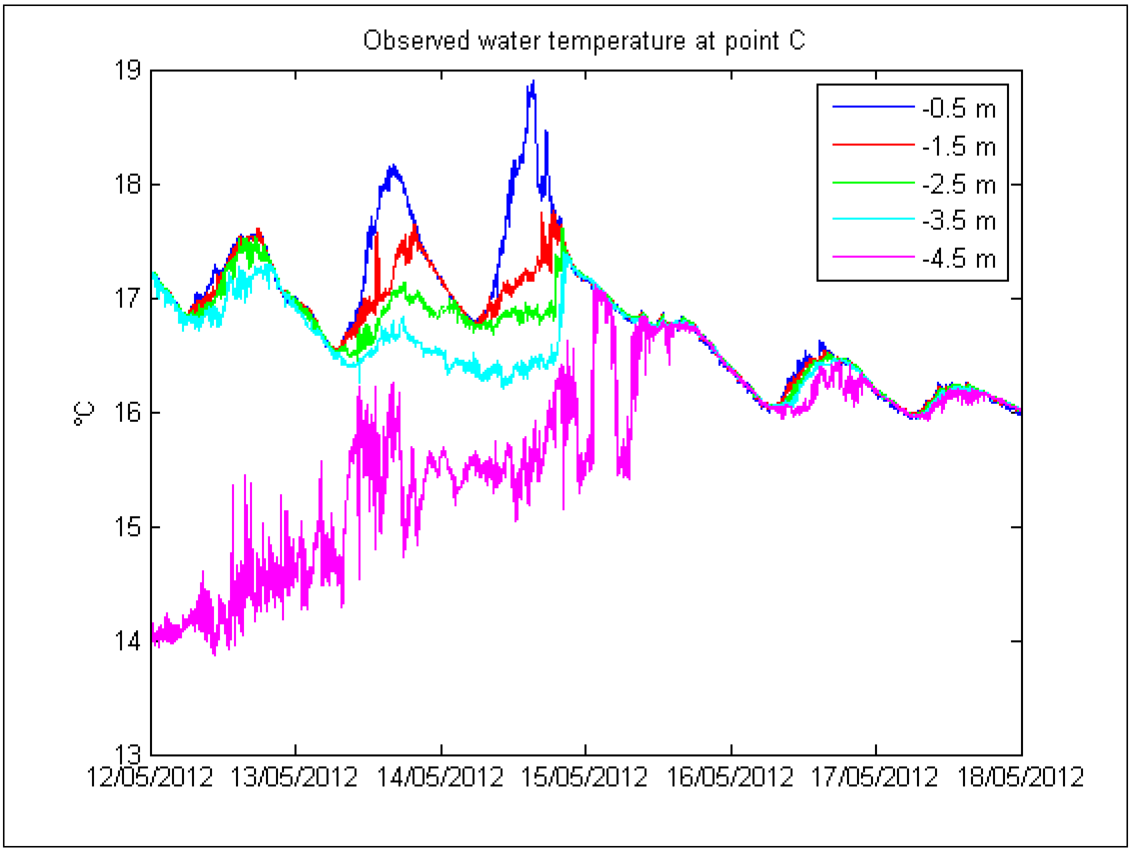


Figure 17 : Water temperature (12/05/2012 to 18/05/2012)

4.2.3 Chlorophyll fluorescence

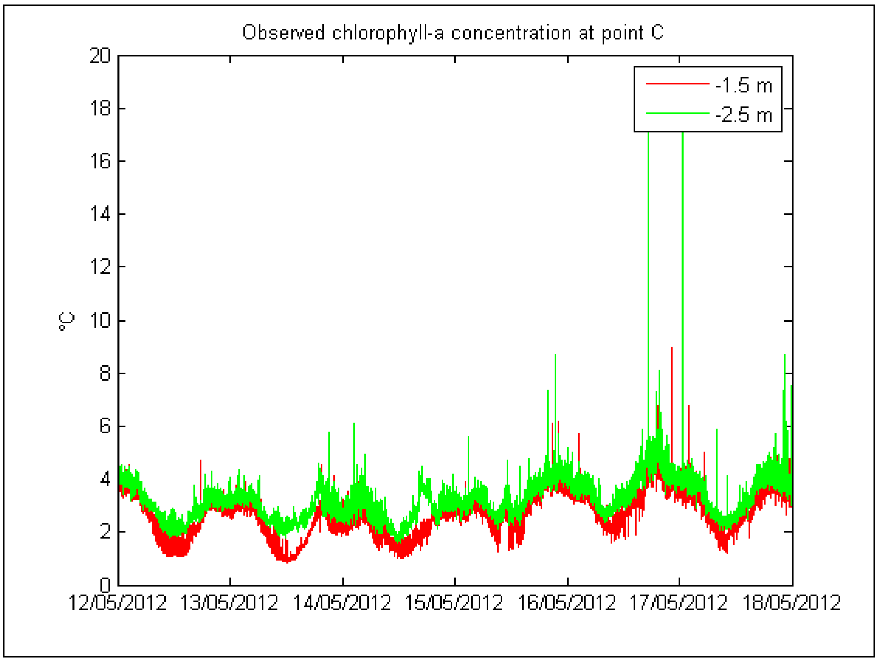


Figure 18 : Chlorophyll fluorescence (12/05/2012 to 18/05/2012)

4.3 Additional chains

4.3.1 Water temperature, oxygen and chlorophyll fluorescence

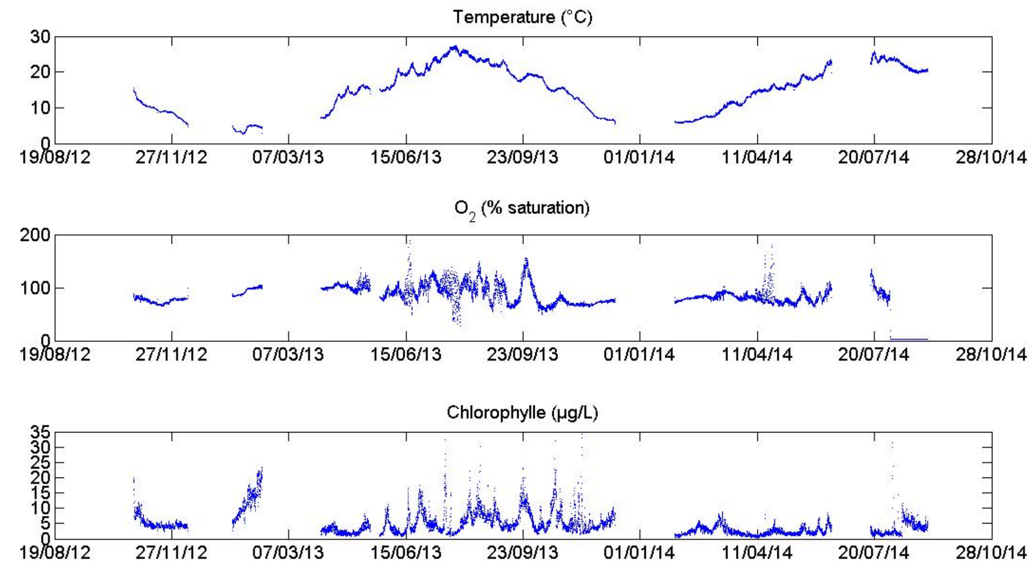


Figure 19 : Time-series of water temperature, oxygen and chlorophyll fluorescence measured at point P (1.5m depth) from October 2012 to August 2014

4.4 Current profiler

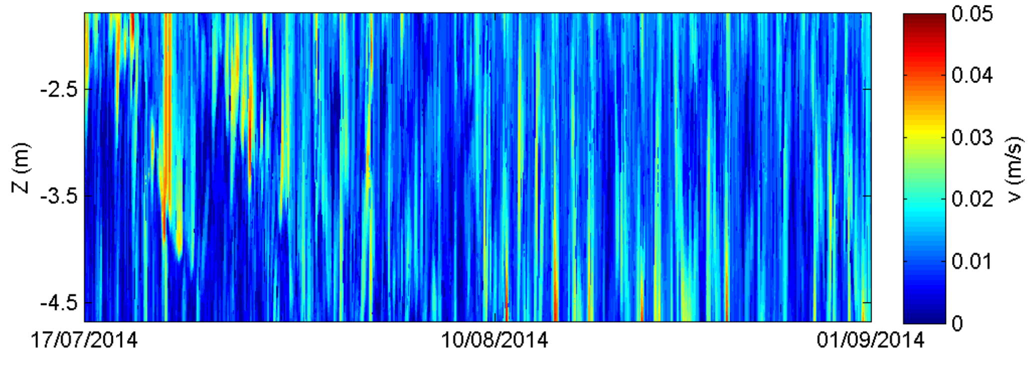


Figure 20 : Water velocity (17/07/2014 to 01/09/2014)

5 Conditions of data availability

The instruments which compose the long-term observation system for urban lakes on Lake Créteil were obtained through consecutive research projects funded by French public institutions. Therefore, the conditions of availability of the data can be different depending on the consortium agreement of each project. The two main projects which contributed to Lake Créteil observation system are the following: (1) "Peri-Urban Lakes, Society and Environment" (PULSE) funded by the French National Research Agency (ANR, program CEP&S) from 2011 to 2015; (2) Petits Lacs Urbains Mesures Modèles MultitEchelles (PLUMMME) funded by the region Ile-de-France research program R2DS from 2012 to 2014. The others equipments were acquired with the support of our research centre LEESU (Ecole des Ponts ParisTech, UPEC, AgroParistech http://leesu.univ-paris-est.fr) and of the OSU-EFLUVE (Observatoire des Sciences de l'Univers – Enveloppes FLUides de la Ville à l'Exobiologie http://osu-efluve.u-pec.fr).

The data produced within the PLUMMME project are included as text data files in a numerical appendix. Other data are available on demand and will be delivered accordingly to the ANR rules and French legislation on intellectual property.

6 Conclusions

Lake Créteil was equipped in October 2012 to be a full-scale demonstration site of the Blue Green Dream project: an autonomous lake measuring station and two sensor chains have yielded continuous series of measurements from October 2012.

The maintenance of the sensors is critical due to biofouling.

The data set is under processing to validate a 3D coupled hydrodynamic-biological model which could be used to test the impact of installations on the lake.

Bibliography

1. Downing, J. A., Y. T. Prairie, J. J. Cole, et al. 2006 The Global Abundance and Size Distribution of Lakes, Ponds, and Impoundments. Limnology and Oceanography 51: 2388–2397.

2. Ferland, M.-E., Y. T. Prairie, C. Teodoru, and P. A. del Giorgio 2014 Linking Organic Carbon Sedimentation, Burial Efficiency, and Long-Term Accumulation in Boreal Lakes. Journal of Geophysical Research: Biogeosciences 119(5): 2013JG002345.

3. Lewis, W. M. 2011 Global Primary Production of Lakes: 19th Baldi Memorial Lecture. Inland Waters 1: 1–28.

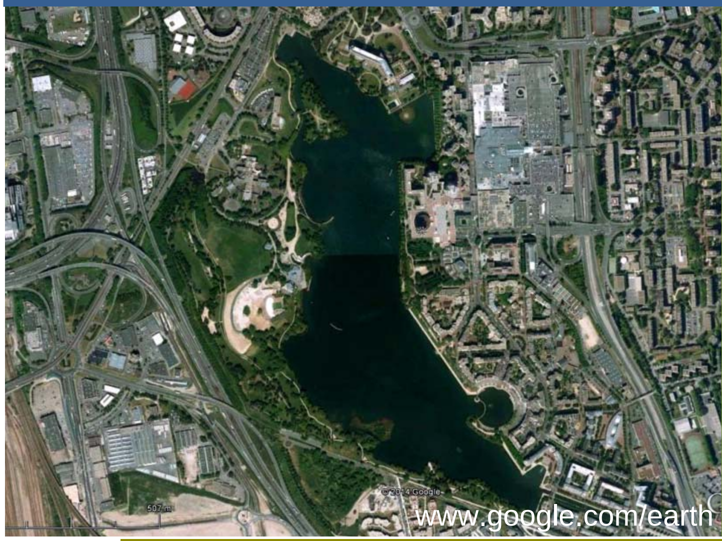
4. Raymond, P. A., J. Hartmann, R. Lauerwald, et al. 2013 Global Carbon Dioxide Emissions from Inland Waters. Nature 503: 355–359.

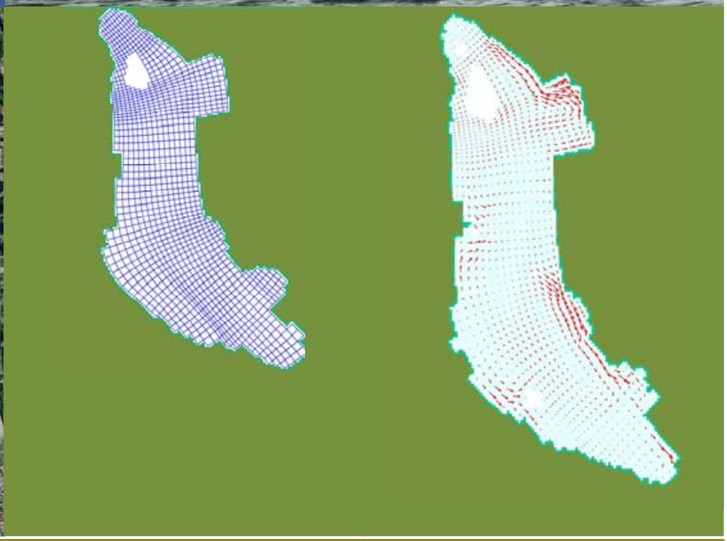
7 Appendix

7.1 Lake Créteil demonstration site leaflet

Urban Lake Monitoring: preserving lake ecosystems for sustainable cities

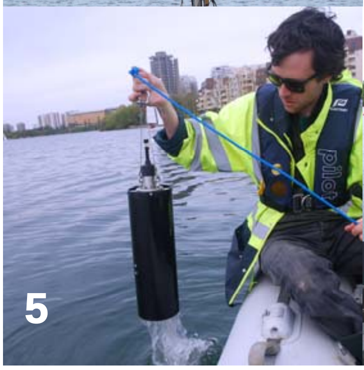
Case Lake Créteil

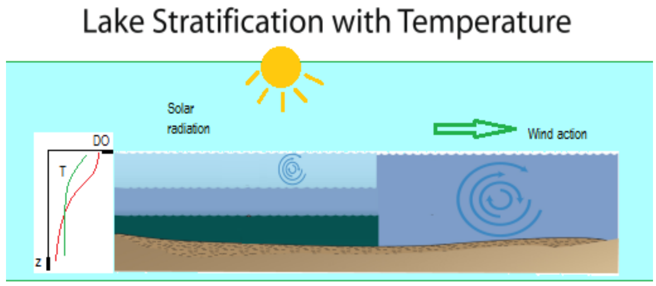




Urban lakes are vulnerable ecosystems that require constant monitoring:

- Urban lakes can provide several eco-services besides water supply, as flood risk reduction, humidity control, temperature cooling, birds and wild life support and preservation, leisure, recreation and landscape integration.
- Pollutants generated in urban areas affect lake behavior causing low oxygen rates, loss of water visibility, toxic algal blooms, sedimentation, unbalanced growth of aquatic plants, disease vectors habitats and fish death.
- Urban lake management is a challenge that involves public and private actions for waste water and solid waste control, public areas washing and cleaning, construction regulation permits and restrictions.
- Lake monitoring and modelling are efficient decision support tools for achieving a sustainable urban environment.





7

Figure 1. Meteorological Station collects air temperature, relative humidity, solar radiation and atmospheric pressure each 30s and transmitsdata using GSM network.

Figures 2 - 4. Submerged sensors tied to buoys collect automatically water temperature, water velocity and Chlorophyll concentration, storing data in flash memory cards.

Figure 5. Periodic water samples are taken to the Lab for nutrients and other chemical analysis.

Figure 6. Each 2 weeks, researchers recover data from data-loggers and send them to the LEESU for analysis and modelling.

Figure 7: Bloom of algae with toxic cyanobacteria darkens the water, dumping light and heath transfer, powering temperature stratification. Bottom water tends to stay cooler than surface waters, stopping vertical circulation that spread oxygen through water column. Pollutants at bottom tend to accumulate and the oxygen rate decreases. Wind action can turn over the stratification and redistribute oxygen but pollutants at bottom can be re-suspended.

Stratification, Pollutants and Water Use

Stratification occurs when the surface temperature of the lake is higher than the bottom. It has important implications for fishery management, phytoplankton (algae) populations, and water use in general.

As the sun radiation warms the lake surface through late spring and early summer, the temperature differences increase between the surface and deeper waters causing the reduction of the water density in the surface layers. In lake layers deeper than 3 to 5 m the temperature differences eventually create a physical barrier where the lighter water floats over the denser one, interrupting the vertical circulation and the oxygen supply to bottom layer.

Blooming of algae, caused by the excess of nutrients like nitrogen and phosphorus can color the water, avoiding light penetration and majoring the problems. Those nutrients are generated by urban and rural human activities.

Absence or loose sewer systems, lack of non-source pollution control, loose of pervious areas, erosion, wind blocking by buildings and accidents are among the main causes of lake degradation.

Continuous non planned city growing and climate changes are also important components to be taken into account in sustainable lake management.

The Ecosystem of Lake Créteil

Lake Créteil was originally an extraction quarry of gravel and gypsum between 1940 and 1976. The quarry was dug in the former alluvium of Seine and Marne rivers, near their confluence.

Excavations reached the groundwater surface that flows from the Marne River leading to the pond formation. At the end of 1970's the pond was transformed into an urban lake, now in an urbanized area in the south-east Paris.

Covering 40 ha and storing 1.9 Mm^3 of water, the lake is 1.5 km lengthwise and 250 to 400 m wide. The northern part is shallower than the southern and along its 4 km perimeter it is surrounded by buildings in the North, East and South-East banks. An artificial hill was built in the east to reduce the noise from the nearby motorway.

Direct precipitation and runoff from storm waters supply the lake as well as the groundwater. The water is used to watering the park at the west side and also in road cleaning. A recreational center is present and aquatic sports are regularly practiced on its waters.

The lake is temperature stratified every spring-summer period and shows the presence of plants (phytoplankton) and nutrients, that highlights the importance of its monitoring.

STUDY SITE
Lake Créteil

INSTRUMENTATION

Meteorological Station
Sensor Chains
Velocity Profilers

SCENARIOS

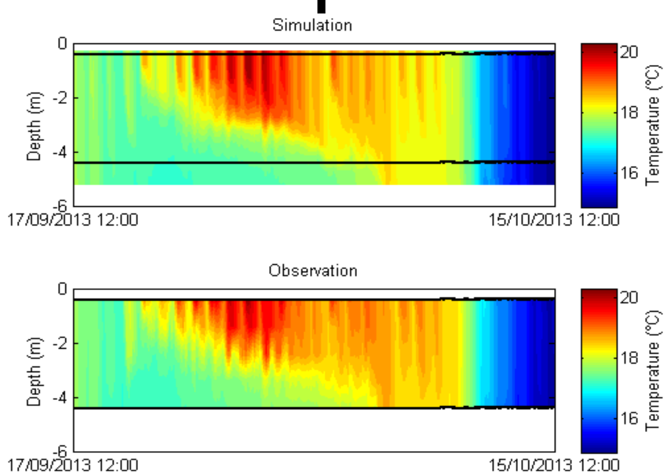
Floating Buildings
Air-Conditioning (DWSC)*
Heat Inter-seasonal Storage
Climate Change
...

DATA BASE

Meteorological Variables
Currents
Water Temperature
Chlorophyll *a* Concentration

MODELS

Hydrodynamic 3D Model: Delft3D-FLOW
Water Quality Model : DELWAQ



1

FORECAST

Scenario impacts on lake behavior
Emergency action plans

DECISION

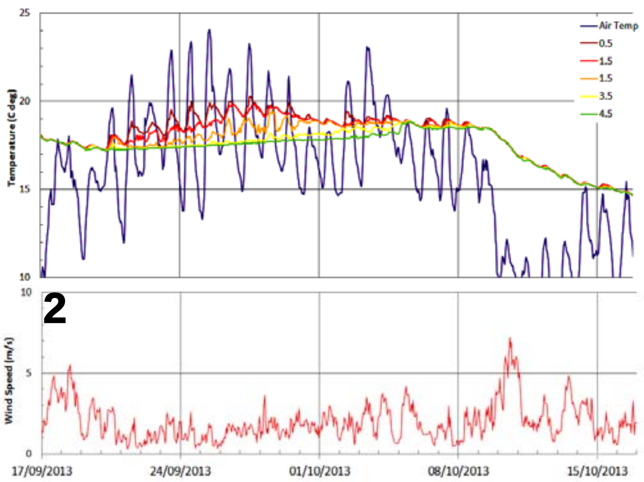


Figure 1. Temperature stratification observed and measured in central point of Lake Créteil.

Figure 2: Air Temperature and Wind are most important parameters governing stratification in Lake Créteil.

* DWSC: Deep Water Source Cooling

Learn more:
www.enpc.fr/leesu

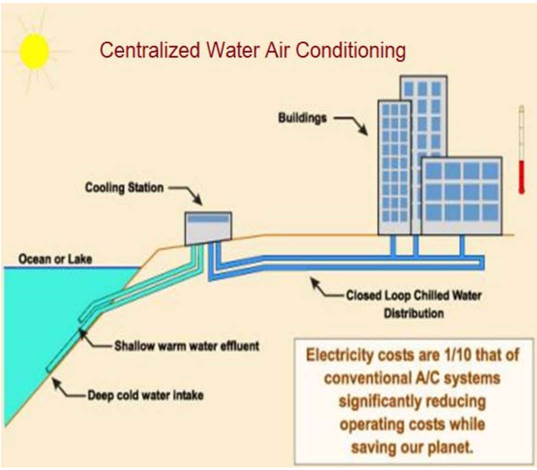
Contact:
Brigitte Vinçon-Leite
Researcher
bvl@leesu.enpc.fr

Applications

Urban lake waters can be used for several sustainable purposes that help save energy and preserve natural resources. Building air-conditioning can be done employing heat circulation pumps that conduct hot water from inside of the buildings through submerged cooling systems on the lake.

Electric energy production using water column temperature gradient or submerged turbines are alternatives to conventional oil and coal small thermic plants with less greenhouse gases emissions in the overall process.

Constant lake monitoring and modelling allow an optimized design of those facilities and limit its impacts over the lake ecosystem, contributing to a sustainable urban environ.



leesu
laboratoire eau environnement systemes urbains

École des Ponts
ParisTech

UPEC
UNIVERSITÉ PARIS-EST CRÉTEIL
EFLUVE

îledeFrance

AGENCE NATIONALE DE LA RECHERCHE
ANR

eit Climate-KIC

BGD

VAL de MARNE
Conseil général

7.2 Pictures

7.2.1 Meteorological station and sensors

Figure 21 : Lake ESP on Lake Créteil

7.2.2 Lake ESP underwater chain

Figure 22 : Chlorophyll fluorescence, photosynthetically active radiations (PAR) sensors (on the left) and water temperature (on the right)

7.2.3 Additional chains

Figure 24 : Multiparameter probe (nke MP5)

Figure 23 : water temperature and pressure sensors (nke SP2T10)

7.2.4 Current meters

Figure 26 : Nortek ADV

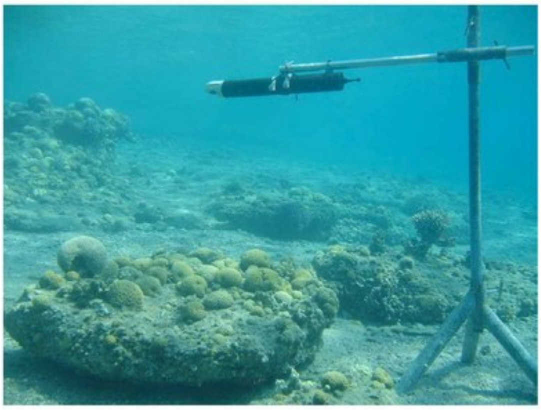


Figure 25 : Nortek ADCP

7.3 *Numerical appendix*

The numerical appendix contains data produced within the PLUMMME project. These data are included as text data files organised in directories (Figure 27). The time reference of recorded data is UTC (Coordinated Universal Time).

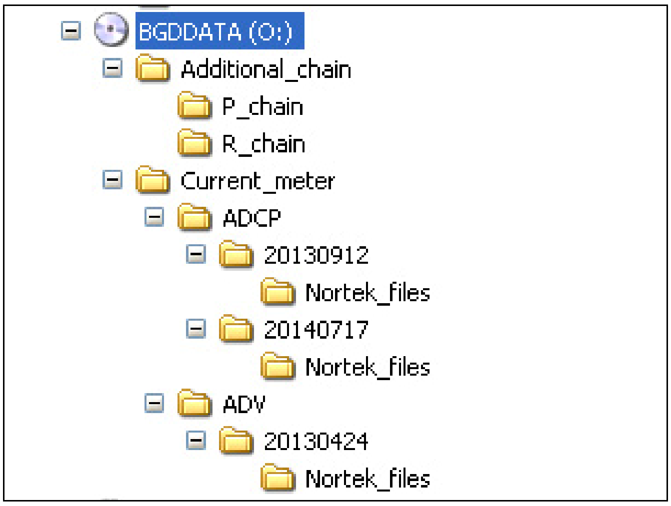


Figure 27: Data directories

7.3.1 *Additional chains files*

These data were recorded from October 2012 to November 2014 at point P (P_chain directory) and at point R (R_chain directory). The location and measuring devices are described in the report. Files yymmdd_.TXT contain raw data of water temperature and pressure (Figure 28). Files yymmdd_.TXT contain raw data of oxygen, conductivity, pressure, fluorescence and water temperature (Figure 29).

```
SP2T 10m PR sn:32021 121114F.TXT
Logging cadence   30    s
  WAY:0 Température (-5 +35°C) Unit=øC
  WAY:1 Profondeur 10m Unit=m
15.471      -0.035987   25/10/2012   16:35:36
15.456      -0.031989   25/10/2012   16:36:06
15.456      -0.031989   25/10/2012   16:36:36
15.456      -0.023992   25/10/2012   16:37:06
15.411      -0.023992   25/10/2012   16:37:36
15.337      -0.02799    25/10/2012   16:38:06
15.441      -0.023992   25/10/2012   16:38:36
15.575      -0.015994   25/10/2012   16:39:06
15.817      -0.0079972  25/10/2012   16:39:36
16.046      -0.0079972  25/10/2012   16:40:06
```

Figure 28 : SP2T10 sensors (water temperature and pressure) raw file

```
MP C/T/D/Do/Fluo sn:32019 121114P.TXT
Logging cadence   30    s
  WAY:0 Profondeur Unit=m
  WAY:1 Température Unit=øC
  WAY:2 Salinité Unit=mS
  WAY:3 Oxygène Unit=%
  WAY:4 Fluorescence Unit=ugL
  WAY:5 Vbatterie Unit=V
0.086764    16.151      3.2527E-5    95.89 0      10.715      25/10/2012  16:38:36
0.085622    16.213      3.2527E-5    95.74 0      10.766      25/10/2012  16:39:06
0.093043    16.333      0      95.78 0      10.772      25/10/2012  16:39:36
0.086764    16.348      3.2527E-5    95.82 0      10.773      25/10/2012  16:40:06
0.086764    16.243      3.2527E-5    95.77 0      10.769      25/10/2012  16:40:36
0.095897    16.329      0.00013011   95.64 0      10.769      25/10/2012  16:41:06
0.09761     16.363      0      95.74 0      10.769      25/10/2012  16:41:36
0.091331    16.336      0      95.96 0      10.766      25/10/2012  16:42:06
0.095326    16.478      6.5054E-5    95.89 0      10.766      25/10/2012  16:42:36
0.10389     16.663      0      96.05 0      10.765      25/10/2012  16:43:06
0.10446     16.726      3.2527E-5    96.2  0      10.765      25/10/2012  16:43:36
0.093043    16.61 6.5054E-5    96.42 0      10.763      25/10/2012  16:44:06
0.090189    16.479      0      96.42 0      10.763      25/10/2012  16:44:36
0.093614    16.484      0      96.52 0      10.761      25/10/2012  16:45:06
0.090189    16.358      9.7581E-5    96.34 0      10.76 25/10/2012  16:45:36
0.085622    16.183      3.2527E-5    96.39 0      10.76 25/10/2012  16:46:06
0.082768    16.233      0      96.32 0      10.759      25/10/2012  16:46:36
0.081627    16.187      0      96.13 0      10.758      25/10/2012  16:47:06
```

Figure 29 : MP5 (oxygen, conductivity, chlorophyll fluorescence, water temperature and pressure) raw data

7.3.2 Current profiler (ADCP)

9 measurement periods were recorded from April 2013 to July 2014. The data files are in the ADCP directory. Several files are provided for each campaign. The file dep0101.hdr (Figure 30) contains the information for reading the other data files.

```
[E:\PLUMMME\ADCP\20130418_dep01\dep0101.prf]
---------------------------------------------------------------------
Number of measurements          14401
Number of checksum errors       0
Time of first measurement       18/04/2013 10:00:00
Time of last measurement        23/04/2013 10:00:00

User setup
---------------------------------------------------------------------
Measurement/Burst interval      30 sec
Cell size                       23 mm
Orientation                     UPLOOKING SHALLOW WATER
Distance to surface             3.00 m
Extended velocity range         OFF
Pulse distance (Lag1)           3.06 m
Pulse distance (Lag2)           0.00 m
Profile range                   2.92 m
Horizontal velocity range       0.10 m/s
Vertical velocity range         0.04 m/s
Number of cells                 127
Average interval                30 sec
Blanking distance               0.101 m
Measurement load                61 %
Burst sampling                  OFF
Samples per burst               N/A
Sampling rate                   N/A
Compass update rate             30 sec
Analog input 1                  NONE
Analog input 2                  NONE
Power output                    DISABLED
Powerlevel first ping           HIGH-
Powerlevel ping 2               HIGH
                          ..... etc
```

Figure 30 : dep0101.hdr file

7.3.3 Current velocimeter (ADV)

ADV data files are within the ADV directory. The file ADVSCA01.hdr (Figure 31) contains the information for reading the other data files.

```
[E:\PLUMMME\ADV\20130424\ADVSCA01.vec]
------------------------------------------------------------------
Number of measurements              683564
Number of velocity checksum errors     1
Number of sensor checksum errors       0
Number of data gaps                 0
Time of first measurement             24/04/2013 10:45:00
Time of last measurement              24/04/2013 13:43:16

User setup
------------------------------------------------------------------
Sampling rate                    64 Hz
Nominal velocity range              0.10 m/s
Burst interval                   CONTINUOUS
Samples per burst                   N/A
Sampling volume                     14.9 mm
Measurement load                     82 %
Transmit length                   4.0 mm
Receive length                    0.01 m
Output sync                      VECTOR
Analog output                     DISABLED
Analog input 1                    NONE
Analog input 2                    NONE
Power output                      DISABLED
Output format                     VECTOR
Velocity scaling                  0.1 mm
Powerlevel                       LOW+
Coordinate system                   XYZ
Sound speed (user specified)          1525 m/s
Salinity                         35.0 ppt
```

Figure 31 : ADVSCA01.hdr file

For more information on the data, contact bvl@leesu.enpc.fr