Hydrology and Earth System Sciences Discussions

Technical Note: Development of an automated lysimeter for the calculation of peat soil actual evapotranspiration

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Abstract

A limited number of publications in the literature deal with the measurement of actual evapotranspiration (AET) from a peat soil. AET is an important parameter in the description of water pathways of an ecosystem. In peatlands, where the water table is near the surface and the vegetation is composed of nonvascular plants without stomatal resistance, the AET measurement represents a challenge. This paper discusses the development of an automated lysimeter installed between 12 and 27 July 2010, at a 11-ha bog site, Pont-Rouge (42 km west of Quebec City, Canada). This system was made of an isolated block of peat, maintained at the same water level as the surrounding water table by a system of submersible pressure transmitters and pumps. The change in water level in millimetres in the isolated block of peat was used to calculate the water lost through evapotranspiration (ET) while accounting the precipitation. The rates of AET were calculated for each day of the study period. Temperature fluctuated between 17.2 and 23.3 °C and total rainfall was 43.76 mm. AET rates from 0.6 to 6.9 mm day^{-1} were recorded, with a ΣAET/ΣP ratio of 1.38. The estimated potential ET (PET) resulting from Thornthwaite's semi-empirical formula suggested values between 2.8 and 3.9 mm day^{-1}. The average AET/PET ratio was 1.13. According to the literature, the results obtained are plausible. This system, relatively inexpensive and simple to install, may eventually be used to calculate AET on peaty soils in the years to come.

1 Introduction

Few studies focus on the measurement or the calculation of actual evapotranspiration (AET) of peatland sites (Keleman and Ingram, 1999; Schwaerzel and Bohl, 2003; Schwaerzel et al., 2006; Petrone et al., 2007, 2008). However, this water flux represents a major component of the hydrological budget, making its quantification essential. Measurement and estimation of AET are challenging because sites are often

waterlogged and the vegetation includes nonvascular plants without stomatal resistance. The limited number of publications discussing peatland AET measurements confirms that it is difficult to obtain accurate data to quantify this hydrological process (Keleman and Ingram, 1999; Schwaerzel and Bohl, 2003; Lafleur et al., 2005; Nachabe et al., 2005; Schwaerzel et al., 2006; Petrone et al., 2006, 2007, 2008; Deguchi et al., 2008). Potential evapotranspiration (PET) is often calculated using semi-empirical formulas (Price and Maloney, 1994; Lott and Hunt, 2001; Pereira and Pruitt, 2004; Lafleur et al., 2005; Sumner and Jacobs, 2005; Schwaerzel et al., 2006; Petrone et al., 2007, 2008; Proulx-McInnis, 2010; Tardif, 2010), but these formulas tend to overestimate actual evapotranspiration (Lafleur et al., 2005; Sumner and Jacobs, 2005; Petrone et al., 2007, 2008; Tardif, 2010).

Lysimeters have been used mostly on agricultural or forest soils (e.g. Nachabe et al., 2005; Deguchi et al., 2008; Loheide II, 2008). These devices typically consist of a volume of soil material isolated in the field. The monolith, isolated in a thick geotextile fabric or a container, is not fed by runoff. The idea is to: (1) monitor the mass of the monolith block at regular intervals or (2) maintain the isolated monolith at the same hydrostatic pressure as the surrounding water table or at a fixed level. Water loss can be estimated by simple accounting. In the case of this study, an automated lysimeter, based on the second approach, was installed in a peatland in southern Quebec (Canada).

This technical note reports on the measurement of AET from a peat soil using an automated lysimeter system and the discussion of the strengths and weaknesses of the system.

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2 Methods

2.1 Study site

The study site selected for the installation of the proposed lysimeter system was a bog located in the town of Pont-Rouge, 42 km west of Quebec City (Quebec, Canada), 46°44′20.98″ N and 71°42′44.10″ W (Fig. 1). This site was chosen for its ease of access. The area of the bog, estimated using a GeoEye image (0.50 m resolution), is approximately 11 ha. The water table is relatively high (∼15 cm below the surface), although no structured ponds were found at the site. Typical vegetation of this environment consists of small trees and shrubs (*Picea mariana* (Mill.) BSP, *Larix laricina* (Du Roi) K. Koch and *Nemopanthus mucronatus* (L.) Trel.), heaths (*Ledum groenlandicum* Oeder, *Kalmia polifolia* Wangehn., *Kalmia angustifolia* L., *Vaccinium myrthilloides* Michx, *Vaccinium oxycoccos* L. and *Chamaedaphne calyculata* (L.) Moench) and sedges (*Carex sp.* principally) with a significant presence of *Sphagnum fuscum* (Schimp) Klinggr. and *Sphagnum rubellum* (Wilson). This macroporous sphagnum-dominated peat has a degree of decomposition varying between 1 and 3 on the Von Post scale. According to the climate characteristics of the weather station closest to the site (46°41′27.00″ N and 71°58′18.00″ W), the average temperature and precipitation for the 2005–2009 period of the coldest and warmest months (January and August) were $-11.8\,°C$ and 51.6 mm and $18.4\,°C$ and 108.1 mm, respectively.

2.2 Operating system

The principle of the lysimeter is to isolate a volume of peat material in a waterproof geotextile and to measure the inputs and outputs of water needed to maintain the system at the same water level as that of the surrounding environment. Water transfers are governed by a program operating from a datalogger, sending signals to the pumps which add or remove water. Water volumes in two containers (one providing water to the lysimeter and the other collecting the water coming out of it) were recorded using pressure transducers.

The lysimeter system designed for this study was largely inspired by that of Schwaerzel and Bohl (2003). However, their system was installed for the purpose of describing and quantifying water flows between peat layers, especially in the un-saturated zone. AET rates were noted manually each day and did not need to be as accurate as in the present study. Schwaerzel and Bohl (2003) installed TDR and ten-siometers to measure water retention and hydraulic conductivity, but these instruments were not installed in our lysimeter. The purposes of the two lysimeters were thus not the same and our system was greatly simplified. Modifications were made to allow for deployment in remote areas and large data storage requirements. The aim of our study was to measure hydrological budgets over a long period of time. AET rates needed to be accurately recorded without having to be physically close to the instrumentation system.

The environment was also different. Von Post scale of decomposition values were much lower than those recorded by Schwaerzel and Bohl (2003). The acrotelm is not very thick (∼15 cm) and the water is not stored for a long time in the upper part of the peat column. Water redistributes itself fast in a peat column such as the one used in our study (Bragato et al., 1998).

The sealed inlet and outlet reservoirs were installed directly into the ground and had a larger volume than that of the original design, allowing a greater autonomy. The volume of water in each reservoir was measured by pressure sensors and logged in a control unit, instead of manually at fixed hours. The major difference with the Schwaerzel and Bohl (2003) lysimeter was the control unit. Their differential pressure transducer only balanced the water levels between the lysimeter and the surrounding environment and did not log data. The modifications made to the lysimeter offered the advantage of recording data at specific time steps that can be downloaded whenever it is possible, which is of the utmost importance for deployment in remote areas. The control unit allowed a greater programming flexibility and opened the way to the use of additional monitoring instruments.

Compared to the lysimeters used by Roulet and Woo (1986) and Petrone et al. (2004), which are simple tanks of peat installed in situ and weighted at a specific time everyday to get the rate of water loss through evapotranspiration, the one installed in this study requires fewer manipulations of the medium. The peat monolith was also much larger.

The automated lysimeter system was installed at the study site between 12 and 27 July 2010. A cube of peat with dimensions of $72.0 \times 58.0 \times 48.0$ cm was isolated in a geotextile fabric in late June as suggested by Schwaerzel and Bohl (2003). The idea was to preserve as much as possible the natural integrity of the peat column (Fig. 2).

The system included a CR10X datalogger (Campbell Scientific, http://www.campbellsci.ca/) connected to a 12-V battery and a 20-W solar panel (Fig. 3). The lysimeter had four submersible pressure transmitters with a 5-m long wire (PS9800, Instrumentation Northwest, Inc., 0–1 psig, accuracy ± 0.7 mm, http://www.inwusa.com/). These sensors, robust and completely sealed against moisture, were connected to the first four analog ports of the CR10X. The first and second pressure transducers were installed in wells located inside and outside of the isolated peat, respectively. The third and fourth pressure transducers were inserted into the inlet and outlet water reservoirs (each having an 11-l capacity), respectively. Two submersible pumps (BW40C6, 115 V, 40 gph, http://www.aquaplantes.qc.ca/), connected to the CR10X by inverters (Motomaster, 12 V to 120 V), were placed in two wells located in the peat block and the water inlet, respectively. Table 1 presents the specifications of the instruments composing the lysimeter.

The isolated peat water level was readjusted by the pumps to maintain the same level as the water table outside the lysimeter once a day (at midnight). The first pump removed water from the lysimeter or the second pump added water, depending on the difference between the water level in the lysimeter and that outside the lysimeter. The volume of water added was measured by the third PS9800 probe (Fig. 3). The calculations are described in more details in Sect. 2.4.

A rain gauge (CS700 Tipping bucket rain gauge, Campbell Scientific, Inc., accuracy ±1 mm, http://www.campbellsci.ca/) was installed one metre away from the lysimeter. All data (water levels and precipitation) were recorded every fifteen minutes.

2.3 Programming and implementation

Figure 4 shows the flowchart of the code used to program the datalogger. The code is included as an electronic supplement.

The program consists of three "if" loops operating independently. Once a day, at midnight, the height difference between the water level in the lysimeter and that of the water table was calculated. An error margin of 5 mm between the two water levels was tolerated because according to tests performed in the laboratory, the minimum flow of the pumps was too high to allow for a margin smaller than 5 mm. If the difference was smaller than −5 mm, a signal was sent (the second pump signal). In this case, the number 5 was added to the difference between the measurements of the two probes (in the lysimeter and outside) to determine the water depth to be added to the lysimeter (in mm) and multiplied by 28 s. The pumping rate was $1/28\,\mathrm{mm\,s^{-1}}$ (calculated from the peat block dimensions). If the difference was greater than 5 mm, a signal was sent (the first pump signal). The value of 5 was subtracted to find the volume of water to be removed from the lysimeter and multiplied by 28 s. Finally, if both conditions were not met, the system idled for 24 h (until the next day).

The loop for the first pump (in the inlet water reservoir) was tested every second. If the signal was raised and the counter was greater than zero, the first pump started. The counter was then decremented by one each second until zero. If conditions were not met, the first pump signal was turned off. The loop of the second pump (in the lysimeter) operated the same way as the first.

After the program execution, we considered the water in the peat block and water table to be at the same level, always with an error margin of 5 mm.

2.4 Actual and potential evapotranspirations calculations

The following assumptions are made in the calculation of the AET rate: (i) the peat porosity is roughly homogenous along the profile; (ii) the variation in water level, logged by the first pressure transducer, represents the whole water column; (iii) AET occurs principally at the acrotelm-groundwater interface (rather than peat moisture in the unsaturated zone) and finally, (iv) the AET rate is representative of that of the surrounding environment. The difference between the two water levels was only explained by interflow, which was inexistent in the monolith isolated by a waterproof geotextile.

The AET rates were calculated for each day of the study period (Eq. 1):

$$\Delta WL_i + P_i = |AET_i| \tag{1}$$

where ΔWL_i, P_i and AET_i represent the change in water level recorded by the first pressure transducer, the daily rainfall and the actual evapotranspiration of each day (i) (in mm), respectively.

It is important to note that the AET_i results contain some uncertainty. A water level change recorded by a logger in a well does not necessarily correspond to a variation of the water quantity in the soil. Specific yield (S_y) can be defined as the ability of a porous medium to release water under the effect of a lowering of hydraulic head (Banton and Bangoy, 1997). The S_y is not constant throughout the peat column and there is no single value of S_y for peat soils (Price and Schlotzhauer, 1999; Hogan et al., 2006; Petrone et al., 2008). In the literature, the S_y varies between 0.19 and 0.48 (Price and Schlotzhauer, 1999; Hogan et al., 2006; Spence et al., 2009). Moreover, the lack of information about peat porosity of these environments has led us to assume a unit value for S_y, which is likely to lead to an overestimation of AET_i.

Each day at midnight, the water level in the lysimeter was balanced with the water level measured in the peatland. When the water level in the lysimeter was lower than the water level in the surrounding environment, the second pump started. The water level in the sealed inlet reservoir decreased. This amount of water, recorded by the third water level gauge, was pro-rated over the lysimeter surface. It is important to

note that the third and fourth pressure transducers (inlet and outlet reservoirs) are not required for the AET calculation. The measures can however be used to validate the calculation.

For comparison purposes, rates of PET were calculated using the Thornthwaite equation, which only requires air temperature data (Eq. 2). The calculation of PET with other semi-empirical equations was not possible because of a lack of data.

The air temperature and the number of sunshine hours are the only required parameters in this formula. In this case, the daily adaptation of Pereira and Pruitt (2004) was used:

$$\text{ET}_\text{m} = 16 \left(10 \frac{T}{I}\right)^a, \quad 0\ °\text{C} \leq T \leq 26\ °\text{C} \tag{2}$$

where ET_m is the monthly evapotranspiration (mm), T the monthly average temperature (°C), I a thermal index imposed by the local normal climatic temperature regime (T_n, °C) and a a function of I:

$$I = \sum_{n=1}^{12} (0.2 T_\text{n})^{1.514}, \quad T_\text{n} > 0\ °\text{C} \tag{3}$$

$$a = 6.75 \cdot 10^{-7} I^3 - 7.71 \cdot 10^{-5} I^2 - 1.7912 \cdot 10^{-2} I + 0.49239 \tag{4}$$

A multiplicative conversion factor is added to the original equation to get a daily PET:

$$C = \frac{N}{475} \tag{5}$$

where N and 475 corresponds to the number of sunshine hours for a given day and in the month of July, respectively.

3 Results and discussion

Figure 5 shows the diurnal and nocturnal precipitation (mm), maximum, average, and minimum temperatures (°C) and, finally, the rate of AET recorded between 12 and 27 July 2010. This time interval corresponds to a warm period at this location. The average precipitation was 2.7 mm day^{-1} (six days without precipitation). The highest daily precipitation rates were recorded between 13 and 16 July 2010, corresponding to 15.5 and 8.1 mm day^{-1}. During the first six days, the temperatures ranged between 17.4 and 30.6 °C. Subsequently, the temperature dropped and fluctuated between 9.5 and 28.4 °C.

Figure 6 shows the hourly water levels (mm) logged by sensors 1 and 2 during the study period. It can be seen that the levels fluctuate simultaneously in both environments (inside and outside the isolated peat block). Levels were balanced every 24 h but level increases associated with precipitation were concomitant. This is indicative that balancing the water level every 24 h is sufficient.

AET varied between 0.6 and 6.9 mm day^{-1}. The PET obtained by the semi-empirical Thornthwaite equation varied between 2.8 and 3.9 mm day^{-1}. The cumulative AET and PET were 60.5 and 53.7 mm, respectively (average AET/PET ratio of 1.13). The ratio of ΣAET/ΣP was 1.38.

The AET rates fluctuated in the study period and seemed proportional to the recorded temperatures, albeit influenced by rainfall occurrences. High daytime precipitation was associated with low AET (for instance, 13 July 2010, Fig. 5), while high night-time precipitation (e.g., 16 July 2010, Fig. 5) affected daytime AET which could reach high values. These fluctuations could be explained by the inability of the rainwater that falls during the night, to redistribute in the environment via lateral interflow. There was more available water for evapotranspiration since the system was balanced at midnight. Moreover, the days with daytime precipitation were generally cloudy with less radiation available for evaporation.

The AET rates obtained by the lysimeter seem quite plausible. According to a study by Lafleur et al. (2005) at a 2800-ha bog in Eastern Ontario (Mer Bleue, 45°40′ N and 75°50′ W), with an average temperature and total annual precipitation of 5.8 °C and 910 mm and similar vegetation, the rate of AET was between 4 and 5 mm per day, with extremes values on hot and dry days. These AET rates were calculated from Eddy covariance flux measurements. The results obtained at the Pont-Rouge study site ranged between 0.6 and 6.9 mm day^{-1}, which is comparable to those reported by Lafleur et al. (2005). On the other hand, the ratio AET/PET obtained by the latter is lower than the ratio obtained at Pont-Rouge (0.68 versus 1.13).

AET rates may vary from one site to another, as a result of several factors: topography, wind speed, rainfall, water table level, saturation deficit, net radiation and the vegetation at the site (Lafleur et al., 2005). In addition, the accuracy of pumps and probes (±0.7 mm) must be taken into account.

The rate of PET calculated using the Thornthwaite method was between 2.8 and 3.9 mm day^{-1}. However, the calculation of PET by this formula takes into account only two parameters: the average temperature (°C) and the number of hours of sunshine. Also, it is important to consider that several temperatures exceeded 26 °C (Eq. 2), thus constituting an additional source of uncertainty because in this equation, the temperature has to be between 0 and 26 °C. In addition, the nearest meteorological station was located close to the St-Lawrence River (Deschambault, Quebec, http://www.climat.meteo.gc.ca/), 25 km from the study site. The wind conditions and the albedo were therefore not necessarily always similar to those of the studied peatland, which can influence the temperatures measured at the meteorological station.

The calculation of PET is based entirely on meteorological data taken at a constant height. It is not taking into account the change of vegetation (i.e. type of species and density) in time and space (Lott and Hunt, 2001; Deguchi et al., 2008). These details, excluded from the calculation, affect the evapotranspiration rate estimates. PET generally overestimates the reality as exemplified by the AET/PET ratios that are less than unity (Lafleur et al., 2005; Sumner and Jacobs, 2005; Petrone et al., 2007, 2008;

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Tardif, 2010). However, some authors have highlighted AET/PET rates higher than one (PET estimated from Priestley-Taylor equation). Eggelsmann (1963) and Ingram (1983) found ratios higher than one on uncultivated sphagnum bogs at Bernau (Southeastern Germany) and Konigsmoor (North Germany). Eggelsmann's (1963) observations based on an eight-year study period, showed ratios of 1.5, 0.9 and 1.0 from September to March, from April to August and for the whole year, respectively. Quinton (1991) calculated a ratio of 1.67 on an elongated patterned wetland, 5 km north of Schefferville, Quebec (54°48′ N and 66°49′ W) and Price and Maloney (1994) reported ratios between 1.0 and 1.2 on a 0.05 km^2 sphagnum patterned bog located on the south side of Lake Melville, 65 km northeast of Goose Bay, Labrador, Canada (59″29′ N and 53′33′ W).

The water table was high at the studied bog site (−15 cm). Shallow water is more rapidly heated, encouraging convective energy losses (Price and Maloney, 1994). In sphagnum-dominated ecosystems, the movement of water occurs principally as liquid capillary flow (Price et al., 2009). The empirical methods of PET calculation are based on vascular plants environments and are not well adapted to peatlands. The latter have a higher capillary rise than vascular plants and therefore, have a larger ability to evaporate (Price et al., 2009). The actual evaporation rates can therefore be significantly greater than the PET estimates.

4   Strengths and weaknesses of the lysimeter system

Using an automated lysimeter for determining AET rates, as presented in this paper, has advantages and disadvantages.

Although simple, the isolation of a peat block requires precision and a relatively large workforce. This work cannot be done without disturbing the uniformity of the porous matrix. The lysimeter should represent as best as possible, local conditions, knowing that the process of block isolation results in disturbance and errors. It is also important

to ensure that the support of the datalogger is high above the ground and does not shade the plants of the peat block.

The assumption of uniformity of the peat porosity implies that water is stored uniformly and that there is no lateral movement of water in the monolith. However, porosity in a peat block of this size ($0.20\,\mathrm{m}^3$) may not be entirely uniform. An uncertainty may be associated with this assumption. The first sensor may have been installed in a place where the porosity is larger than elsewhere in the block and therefore where there is more water. This could overestimate the rate of evapotranspiration. In addition, the isolation of a monolith in a geotextile could also increase these rates. Indeed, rain water that accumulated in the monolith could not disperse laterally, whereas lateral flow is possible in the normal peat environment.

To measure the water variation in the peat block, a well formed by a PVC pipe containing a pressure transducer was used. As discussed by Proulx-McInnis (2010), the direct water table measurements do not represent adequately the storage of water in a peat column. In the literature, some researchers have estimated S_y values from similar sites, considering the horizontal and vertical compression of the peat. Price and Schlotzhauer (1999) estimated a S_y of 0.48 for a minerotrophic fen in the Lac St-Jean region of Quebec (48° N), Hogan et al. (2006) found a value of 0.26 for a minerotrophic fen near Prince-Albert, Saskatchewan (53° N), and finally, Spence et al. (2009) cited a value of 0.19 for a minerotrophic fen with a porosity of 80 % in the Northwest Territories. Thus, it can be seen that S_y values are highly variable and further research is required to capture the impact of this variability. The lack of information about the specific yield of these environments led us to assume a unit value, which resulting in an overestimation of AET and thereby AET/PET ratio.

Moreover, vegetation dries out following a few days of sunshine. During rain events, the porous matrix at or near the surface, composed of nonvascular plants, absorbs much of the water and there is not necessarily a continuum between this layer and the water table. Thus, the water volume stored in the top part of the acrotelm can be evaporated without being logged by the sensor. Indeed, the water level gauge at

the bottom of a well measures only the water that percolates by gravity and does not take into account the significant fraction of water in the capillary fringe and unsaturated zone (Banton and Bangoy, 1997). Nevertheless, in our case, the sphagnum peat had Von Post scale of decomposition values of 1 to 3. The water was not stored for a long time in the acrotelm and can be equilibrated in the peat column faster than in the case reported by Schwaerzel and Bohl (2003). For these reasons, the second and the third assumptions (the variation in water level, logged by the first pressure transducer, takes into account the whole water column and AET occurs principally from the groundwater, rather than peat moisture in the unsaturated zone) likely produced some bias in the measurements.

Compared to the methods used by other authors (e.g. the Eddy Covariance method), the automated lysimeter system put together in this study is relatively inexpensive (Baldocchi et al., 1998; Petrone et al., 2004; Lafleur et al., 2005). The cost of this lysimeter was approximately \$ 8000. The major expenditures are the datalogger and the four robust and accurate submersible pressure transducers. Furthermore, when comparing this design with that of Schwaerzel and Bohl (2003), it can be seen that our lysimeter had fewer sensors. The omission of TDR and tensiometers does not change the method of AET calculation. These instruments were installed by Schwaerzel and Bohl (2003) to measure water retention and hydraulic conductivity. These additional variables can provide insight in the detailed water apportionment within the peat block, but not on the final AET measurements. In our study, it was assumed that all water was located in the saturated zone and, therefore, measured by the pressure gauge. As mentioned earlier, water retained in the unsaturated zone could not be accounted for, and this may have caused a bias of about 20 % on the measurements, given the thicknesses of the unsaturated and saturated zones. The system has fewer components, so its simplicity brings less risk of experiencing problems when deploying the lysimeter in isolated areas.

The lysimeter autonomy depends directly on the volume of the inlet and outlets reservoirs. There is no need to be next to the instrument at fixed hours every day. The control

unit, once installed and programmed, can operate independently for long periods, requiring only a check from time to time. Finally, downloading data and calculation of AET is relatively fast and simple.

5 Conclusions

Few articles in the literature have discussed the estimation or measurement of AET from a peat soil (Ingram, 1983; Keleman and Ingram, 1999; Schwaerzel and Bohl, 2003; Schwaerzel et al., 2006; Petrone et al., 2007, 2008). Quantification of this major water flux is essential, even if it represents a challenge.

An automated lysimeter, inspired by Schwaerzel and Bohl (2003), installed at a bog site in Pont-Rouge, Quebec (Canada) allowed for the calculation of AET from 12 to 27 July 2010. This system is simple and represents an effective apparatus to obtain measurements of AET in a peatland, a medium that is often waterlogged where vegetation is dominated by non-vascular plants. The ratio AET/PET of 1.13, presented in this paper, is perhaps larger than those obtained by other authors, but appears to be valid for sphagnum-dominated ecosystems.

Supplementary material related to this article is available online at: http://www.hydrol-earth-syst-sci-discuss.net/8/5009/2011/ hessd-8-5009-2011-supplement.pdf.

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Table 1. Technical specifications of the lysimeter components.

Lysimeter components	Quantity	Company	Accuracy
CR10X Datalogger	1	Campbell Scientific	–
CR10 Datalogger	1	Campbell Scientific	–
Battery (12 V)	1	Enerwatt series	–
Solar panel (20 W)	1	Enerwatt int. product	–
Submersibles pumps (BW40C6, 115 V, 40 gal h^{-1})	2	Aquaplantes, inc.	–
75 W Inverters (12 V to 120 V)	2	Motomaster eliminator	–
Solid State Relay (10 A)	1	Crydom	–
Terminal Input Module (CURS100 Current Shunt 0.01 %)	4	Campbell scientific	±4 ppm/C (0 to +60 C) ±8 ppm/C (−55 to +125 C)
Submersible pressure transmitters (PS9800 models, 0–1 psig)	4	Instrumentation Northwest, inc.	0.1 % FS

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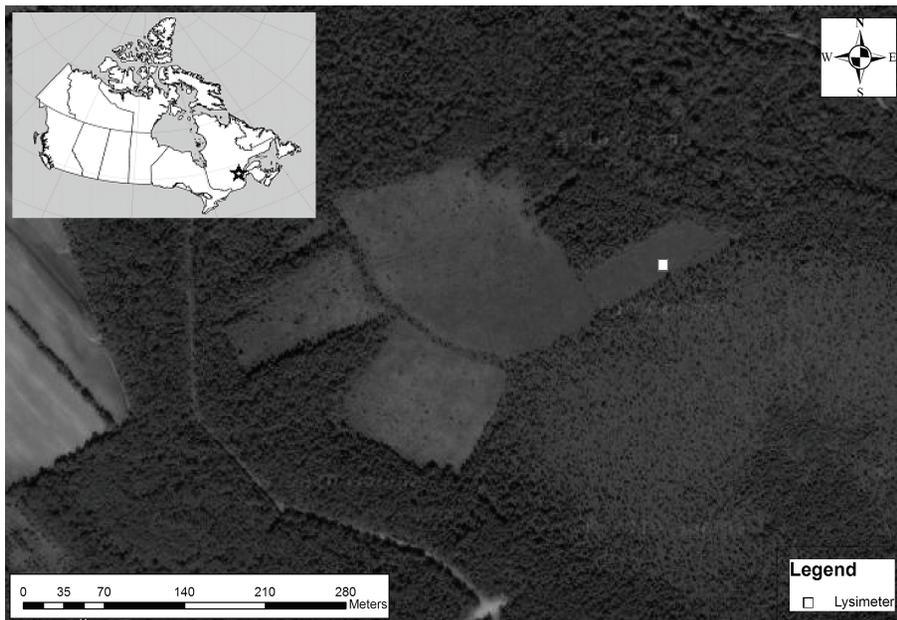
Fig. 1. The location of the study site, Pont-Rouge (Quebec, Canada) (46°44′20.98″ N and 71°42′44.10″ W). The bog was harvested in the 1950's, but the vegetation has grown back.
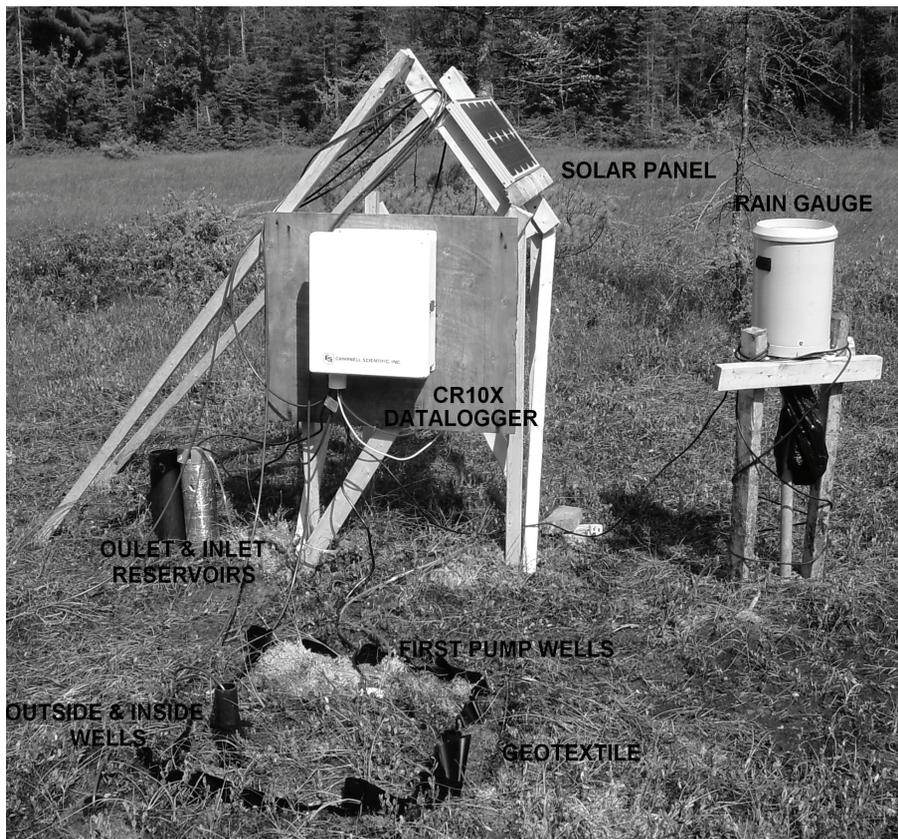
Fig. 2. Automated lysimeter system and rain gauge installed on the Pont-Rouge peatland.
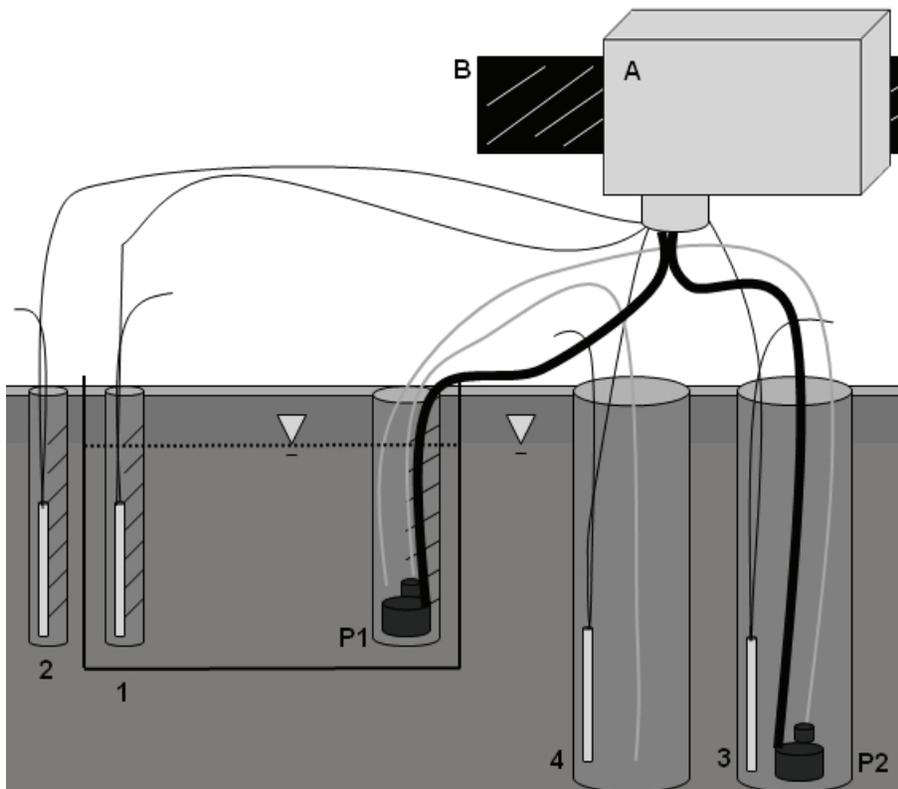
Fig. 3. Diagram of the automated lysimeter system installed at the Pont-Rouge peatland (A: CR10X, Campbell Scientific, powered by a 12 V battery; B: 20 W Solar panel; P1 and P2: Submersible pump, BW40C6, 115 V, 40 gal h^{-1} and 1 to 4: Submersible pressure transmitters, PS9800 model, Instrumentation Northwest, inc., they are corrected by atmospheric pressures).
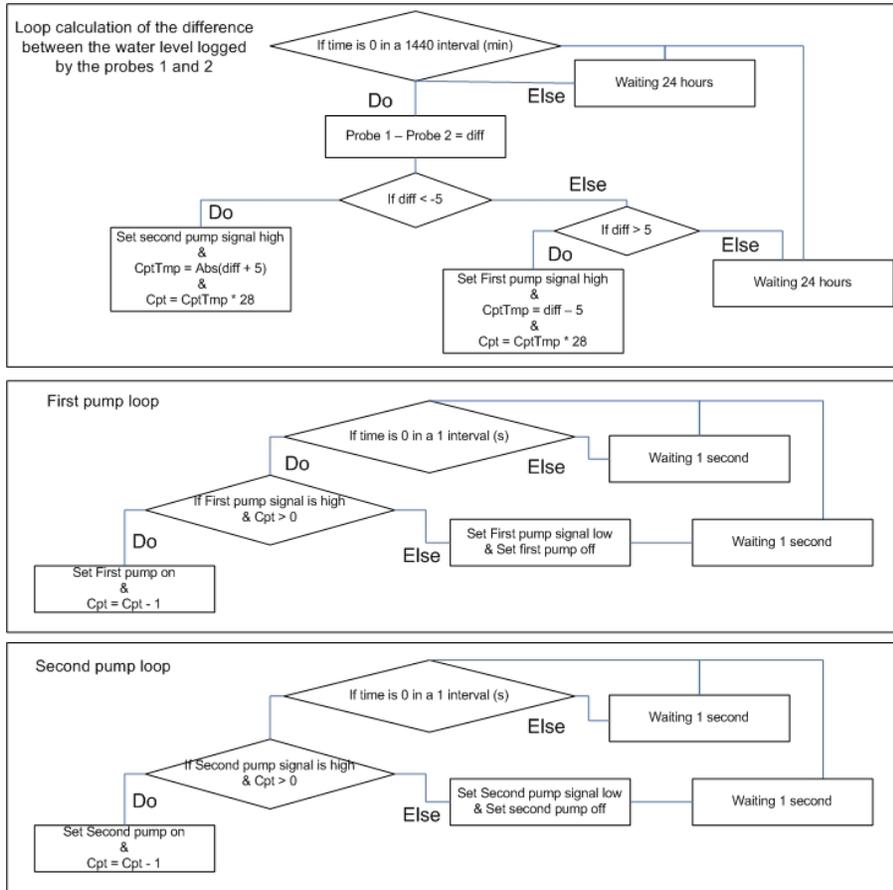
Fig. 4. Flowchart of the code sent to the datalogger. It is composed of three *if* loops.

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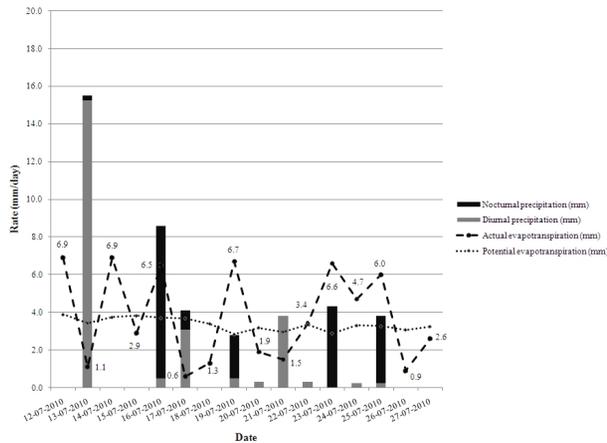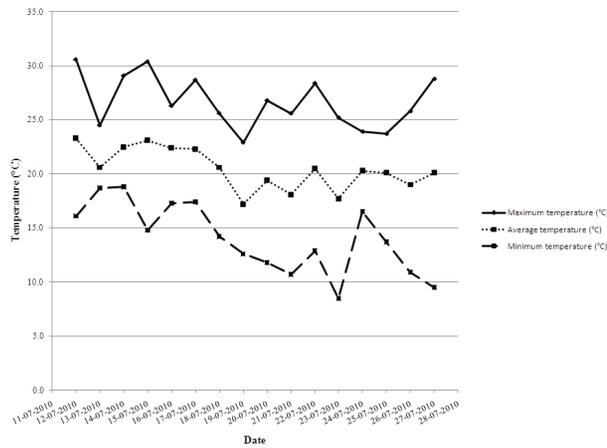
Fig. 5. (a) Diurnal and nocturnal precipitations (mm), actual and potential evapotranspirations (mm) and **(b)** minimum, average and maximum temperatures (˚C), from 12 to 27 July 2010.

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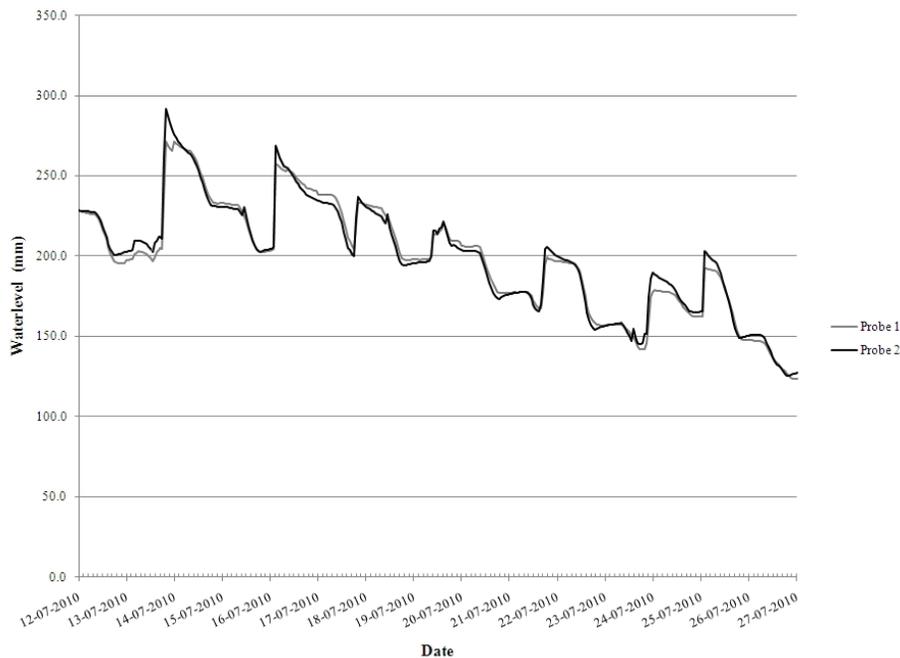
Fig. 6. Diurnal water level in the lysimeter (Sensor 1) and outside (Sensor 2) (mm), from 12 to 27 July 2010.