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**REAL TIME MONITORING IN PEATLAND RESTORATION AS THE KEY FOR OPTIMIZATION
OF WATER MANAGEMENT SYSTEM**

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ABSTRACT The Institut de Recherche et de Développement en Agroenvironnement (IRDA) in partnership with Peatland Ecology Research Group (PERG) and the Hydraulic Laboratory of the Université Laval has been expanding the range of technology options for ecological restoration, including microgeneration of renewable energy, the use of low-cost equipment for experiment tracking, and data analysis in real time. The developments obtained over the past four years allow us to conclude that remote monitoring is an extremely useful tool in the management of restored sites that are far from urban centres. In this paper, it is presented to the implementation and operation of an autonomous monitoring system using solar panels. The actual system collects meteorological data, data from restored basins, also information regarding the regulation over certain equipment for the control of the groundwater in rewetted basins in Saint-Modeste (Quebec, Canada). Currently, it is currently possible to monitor an area of 0.15 ha. Real-time visualization and analysis of the results over temperature and relative humidity of air and water level in basins (water table position and water level in irrigation channels). Real-time, high-accuracy data of groundwater in restored basins has revealed the complex fluctuation of groundwater in restored basins after peat extraction. Such data are crucial for restoration success.

Keywords: *Sphagnum* farming, LoRaWAN technology, wireless communication, irrigation.

INTRODUCTION *Sphagnum* farming is the sustainable production of biomass in rewetted peatlands on a renewable and cyclical basis. Productive *Sphagnum* farming sites require water tables that are stable and permanently close to the moss surface (LaRose *et al.*, 1997; Price *et al.*, 2003). Although the water table remains high during snowmelt and early spring, it gradually decreases as temperature increases and can reach depths of up to 50 cm (Taylor *et al.*, 2016). Otherwise, flooding should be avoided during establishment

to prevent washout of material and stress from excess water (Rocheffort *et al.*, 2002) and at the same time, *Sphagnum* mosses in a permanently flooded state become etiolated. These changes may result in plants that are more prone to desiccation during periods of drought than individuals with a regular growth form (Campeau *et al.*, 2004; Rocheffort *et al.*, 2002). Therefore, infrastructure for irrigation and drainage is necessary.

The creation of an irrigation channel network is suggested to control the water table for the benefit of *Sphagnum* growth (Gaudig *et al.*, 2018; Pouliot *et al.*, 2015). In *Sphagnum* farming sites in Eastern Canada, it is common to find irrigation devices that border the cultivation basins (peripheral channel, Figure 1a) or cross the basins (central channel, Figure 1b). These irrigation channels are fed by an irrigation system that takes water from drainage channels from nearby extraction sites, or even from water bodies. For correct irrigation, these channels must be filled to a higher level than the level expected in the cultivation basins. Thus, the hydraulic gradient favors the movement of water from the channel to the basin. In the opposite case, when it is desired to drain the excess water, the hydraulic gradient must change, and the water level of the channel must be lower than the water table of the basin.

Since these sites are in regions far from urban centers, it is desirable to have remote access to the monitored variables (mainly the water table in the basins and the water level in the irrigation channels). Also, it should be considered that there is usually no electrical network available for the operation of the irrigation system components (e.g., sensors, pumps, actuators).

An attempt has been made to develop real-time technology for efficient irrigation of *Sphagnum* farming through surface irrigation (Gaudig *et al.*, 2018; Goulet, 2019). The activation of the pumping is done through a reading of the water level in the irrigation channel. Goulet (2019) sustains that real-time monitoring and wireless communication between devices in the field is necessary for the adjustment of the irrigation and drainage system performance and for the proper operation of the system. Goulet explored the ZigBee technology (a worldwide standard for low power, self-healing, mesh networks for automation) to enable communication between measuring instruments and equipment on the restored site. In his exploration, he reported some limitations concerning the range (readings up to 150 m in a straight line). Other than this case, little information and documentation are available regarding the design and operation of water control systems in *Sphagnum* cultivation basins. This paper presents a reliable, cost-effective, and scalable solution based on LoRaWAN technology. This document summarizes the work of four years of exploration of different communication technologies for the management of water systems in the *Sphagnum* farming. The architecture system is presented in the following sections, also showing the operation of irrigation and drainage systems commonly used in *Sphagnum* farming in Eastern Canada.

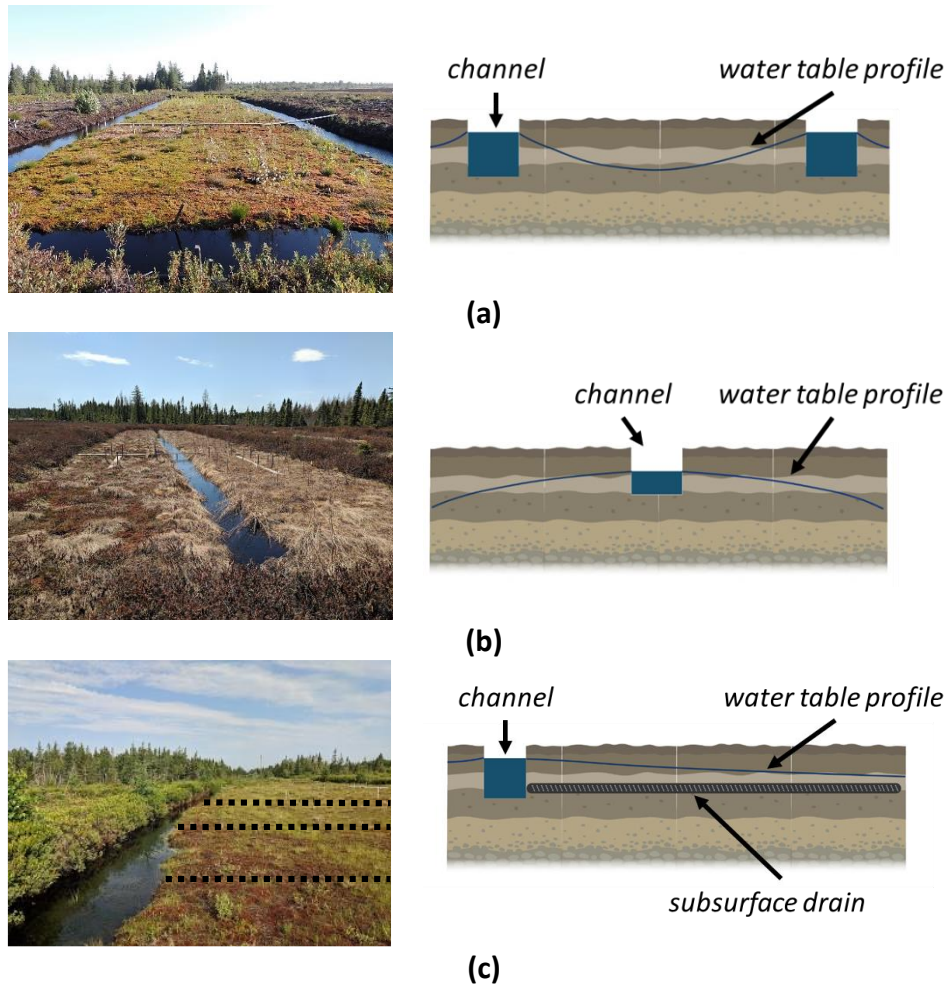


Figure 1. Common irrigation devices in *Sphagnum* farming sites in Eastern Canada. (a) peripheral channel, (b) central channel (photo by Remy Pouliot), and (c) subsurface drains (Dotted lines represent subsurface drains).

SPHAGNUM FARMING IRRIGATION To restrict the variation of the water table in the basins, an water management system is recommended (Guêné-Nanchen *et al.*, 2017; Pouliot *et al.*, 2014). In drained bogs, rewetting can be done by blocking the old drainage channel or even using the drainage channels as irrigation channels. For block cut peatlands, a network of surface channels or subsurface irrigation system can be implemented. In either case, the water table of the basin is conditioned by the water level in the channel.

To increase the retention time of available water after snowmelt and early spring, also to ensure a hydraulic gradient that favors the movement of water from the channel to the basin, three categories of channel blocking are identified: backfilling, damming, or installation of regulation devices (Landry & Rochefort, 2012). In *Sphagnum* farming, the damming and the installation of regulation devices is strongly recommended. A dam (Figure 2a) can be formed by a metal plate of varying size (in our case, 96" wide x 48" high x ½" thick or 2.4 m wide x 1.2 m high x 0.013 m thick). These should be buried to a depth of approximately 1 meter. The opening in the middle of the dam (in our case, 29 ½" x 14" or 0,75 m x 0,35 m) is also used to drain water. The maximum water level in a channel is

controlled by the wooden structure installed in the opening of the dam. In the case of the regulating device (Figure 2b), it consists of the same type of dam with an outlet at the bottom of the wooden structure which is connected to a float check valve. This regulating device is equipped with a float that opens the check valve in case the level upstream of the dam is too high. This opening level can be adjusted by the operator. Also, the opening of the check valve can be operated by a linear actuator. In this way, at any time the level of the channel can be lowered to allow rapid drainage.

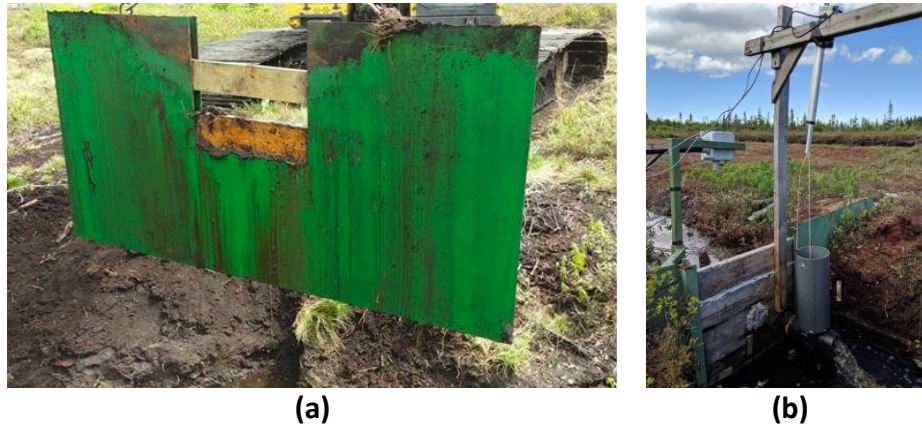


Figure 2. Suggested channel blocking in *Sphagnum* farming based on conditions observed in Eastern Canada. (a) damming and (b) the regulation device for controlled drainage.

As mentioned above, the hydraulic network of channels be composed of channels that border the cultivation basins (peripheral channel), lengthwise channels (central channel) or subsurface drains, connected to a side channel (Figure 1). Gaudig *et al.* (2017) recommended that the spacing of irrigation devices (drains and channels) should be 5 m in strongly humified peatlands. In lightly humified areas, spacing of irrigation devices should be 10 to 20 m (Brown *et al.*, 2017; Gaudig *et al.*, 2013). In areas where the peat is very humidified, the use of subsurface drains is not recommended. Drain clogging has been observed in subsurface irrigation when the peat has a high degree of decomposition.

These channels or ditches are fed by an irrigation system that takes drainage water from nearby extraction sites or also from nearby water bodies (e.g., lakes). As far as water quality is concerned, it should be considered that *Sphagnum* species grow optimally when their nutrient stoichiometry is balanced without nutrient limitation or excess (Andersen *et al.*, 2010; Fritz *et al.*, 2012; Temmink *et al.*, 2017). Solute inputs that would be insufficient to sustain conventional crop plants may be toxic to *Sphagnum* species, which has low nutrient requirements.

Considering that there are several water level sensors deployed in the field, and several actuators (pumps and linear actuators) to be controlled according to the water level measurements, a wireless real-time monitoring network is suitable to control the water level. It is worth mentioning that many popular systems and platforms can be used for water management in *Sphagnum* farming and peatland restoration, but they are too expensive even for smart agriculture context (Nóbrega *et al.*, 2019; Touseau and Sommer, 2019). This first LoRaWAN-based implementation was carried out for an experimental

moss culture located in Eastern Canada (Saint-Modeste, 47°49'55"N 69°27'55"W). There are a total of six 10 m x 50 m basins on site with controlled water table. However, for the sake of simplicity, this paper only explains the control system for two basins whose irrigation channels are directly fed by a centrifugal pump (Figure 3), explained in detail later. Water table was controlled through real-time water management and monitoring system. The basins were located at the edge of an industrial bog on slightly decomposed peat (H3-H5 on the von Post scale, mean peat depth of 1.6 m). Irrigation is achieved automatically employing a system equipped with photovoltaic cells that allow the operation of centrifugal pumps that feed channels with water from sedimentation pond which collected the drainage waters of the surrounding peat extraction fields.

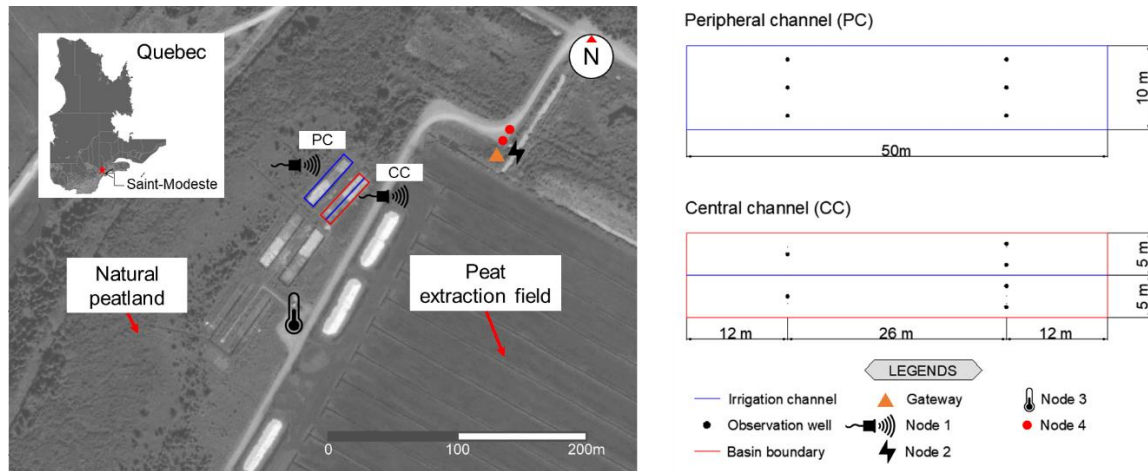


Figure 3. Map of the site with the location of the basins and electronic devices implemented.

SYSTEM ARCHITECTURE Figure 4 shows the different nodes of the tested IoT network. These nodes can be classified in five categories: the gateway which performs the core functions of data collection from the nodes via LoRa, and then sends data to the cloud (procedure not explained in this document); the node for water level measurement (node 1), the node for energy availability measurement (node 2), the node connected to the local weather station (node 3) and node for pump activation (node 4).

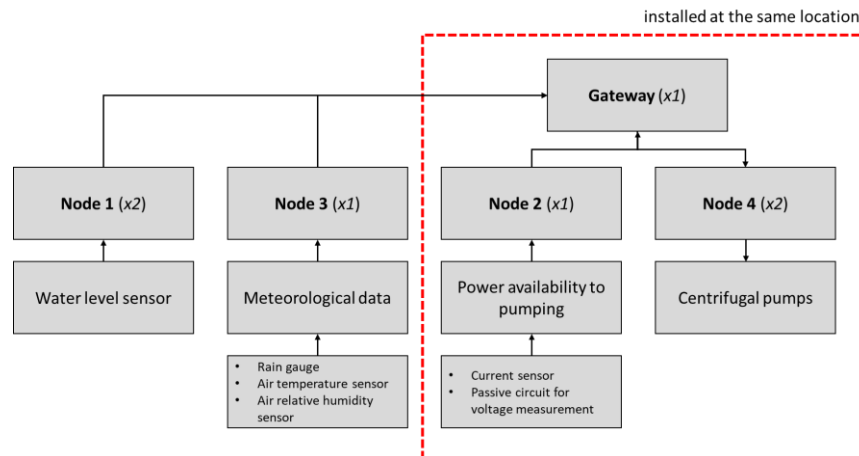


Figure 4. Experimented IoT framework. The numbers accompanying the node categories indicate the number of nodes of this type deployed in the *Sphagnum* farming site.

Gateway The Dragino LG02 Dual Channels LoRa 915Mhz (Dragino Technology Co., Limited, Shenzhen, China) was used as gateway (Figure 5). This model is an open-source gateway, based on a 400-MHz processor. This gateway is characterized by Low power consumption. The Dragino LG02 was configured using the mode *general LoRa transceiver*, but it is necessary to clarify that the *MQTT* and *TCP IP Client* mode can also be configured. For its power supply, a shunt from the battery set (4@6V) was used, which is explained in the *power system* section.

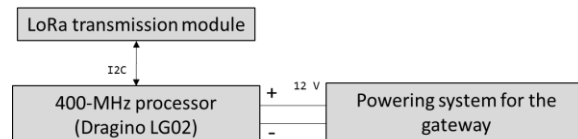


Figure 5. Block diagram of the proposed gateway.

Node 1 – water level in the Irrigation channel It comprises a Feather M0 microcontroller development board (Adafruit, New York, NY, USA), a Time of Flight (ToF) sensor (VL53L0X, Adafruit, New York, NY, USA), and an independent module for power supply based on photovoltaic panels with a lithium battery charger (Figure 6).

The VL53L0X sensor includes an invisible laser source (940 nm), and it calculates the distance based on the time it takes for the light to bounce back to the sensor. The VL53L0X sensor can measure 50 to 1200 mm in less than 30 ms, and, depending on the ambient light and distance, an accuracy of 3 to 12%. The sensor is used primarily to measure distance to solid objects. However, the configuration parameters were defined to have an accurate measurement of the water level (because the reflection of the water level is low). These parameters were: *measurement_timing_budget* = 66000 and *signal_rate_limit* = 0.01.

The Feather M0 development board has a 3.3V voltage regulator with a 500mA peak current output and a 915MHz LoRa RFM9x radio module for transmitting small data packets. The range of this module is 2 km line of sight with wire quarter-wave antennas.

The components of node 1 were placed in a 4.5" x 4.5" (10,16 cm x 10,16 cm) IP66 electrical box.

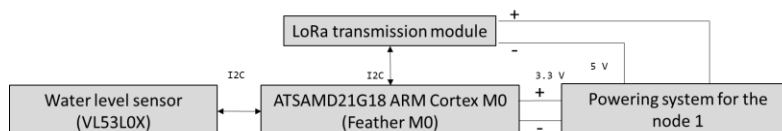


Figure 6. Block diagram of the proposed node 1 for water level in the irrigation channel.

Node 2 – energy availability The same type of microcontroller board were be used as node 1, but it was connected to two different sensors. A current sensor (INA169 Analog

DC Current Sensor, Adafruit, New York, NY, USA) and a voltage divider to calculate the voltage level coming from the batteries which powered the centrifugal pumps. Voltage divider is a passive linear circuit that produces an output voltage (V_{out}) equivalent to a fraction of the input voltage (V_{in}). Voltage division was composed of two resistors connected in series and the V_{out} was calculated as Equation 1.

$$V_{out} = V_{in} \frac{R_2}{R_1 + R_2} \quad (1)$$

Since the maximum V_{in} was 28V and the V_{out} should not exceed 3.3V for proper operation of the microcontroller board, the values of resistors R_1 and R_2 were 10 k Ω and 1k Ω , respectively.

This node (Figure 7) allowed to know if the state of the batteries and the photovoltaic system is enough to activate the pumping system. In any case, pumping should not be activated if the voltage level of the batteries is lower than 24V.

The 915 MHz LoRa RFM9x radio module was used to transmit the data packet to node 4 and gateway. Only one such node was needed, which was located near the photovoltaic power station that feeds the pumps. The components of this node were in a 4.5" x 4.5" (10,16 cm x 10,16 cm) IP66 electrical box.

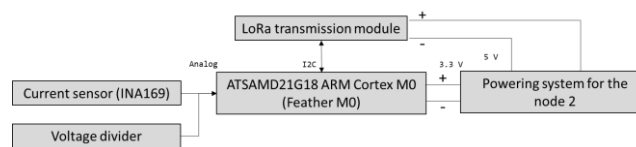


Figure 7. Block diagram of the proposed node 2 for power availability to pumping.

Node 3 – meteorological data Weather data were logged hourly by CR1000 Datalogger (Campbell Scientific, Logan, UT, USA) connected via the RX/TX port to a RFM95W LoRa radio transceiver breakout (Adafruit, New York, NY, USA) for data transmission to gateway. The proposed block diagram summarizes the components of this node (Figure 8). Rain was measured with a 6"-diameter (15-cm-diameter) bucket rain gauge (TE525-L, Campbell Scientific, Logan, UT, USA) and it was installed 0.5 m above the surface. Air temperature and relative humidity was measured with a digital air temperature and relative humidity sensor (CS215-L, Campbell Scientific, Logan, UT, USA). The components of this node were in a 12" x 14" (30,48 cm x 35,56 cm) electrical box.

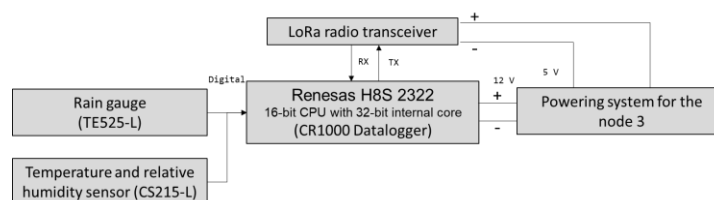


Figure 8. Block diagram of the proposed node 3 for meteorological data.

Node 4 – pump activation Two centrifugal pumps (50840-0024 Low Pressure Centrifugal Pump, Jabsco Gloucester, MA, USA) were located on a floating station (Figure 9a) to reduce the length of the suction piping, also to avoid pump unloading due to air ingress. This in turn increases the efficiency of the pumps.

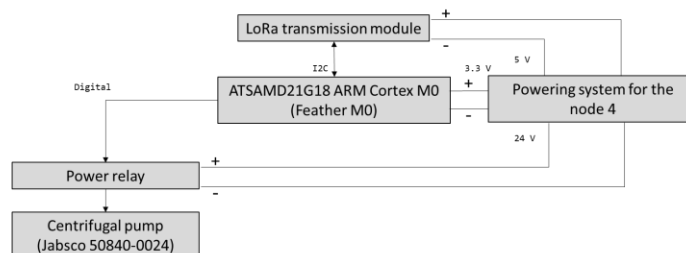
The activation of the pumps was controlled by a power relay (250VAC DC power relay FeatherWing, Adafruit, New York, NY, USA) controlled by a Feather M0 microcontroller board which received the information from the other nodes and activated the corresponding pump. Data packets were transferred via 915MHz LoRa RFM9x radio module. The pumping system was activated if the water level of the irrigation channel fell to two centimeters below the desired level. The pumping was turned off if a) the desired water level was reached, or b) after a time interval of 30 minutes the water level in the desired channel was not reached. This way the pump was not forced the pumping.

Power system This system for water table monitoring and control is powered by a stand-alone photovoltaic energy. Three types of photovoltaic systems were implemented according to the type of node. In summary, each system was composed of solar panels for electricity generation, battery bank for energy storage and MPPT solar charge controller for energy regulation.

Gateway, node 2 (energy availability) and node 4 (pump activation) were physically in the same place (Figure 3). Electricity was produced by two solar panels in series (EWS-250P-60 Solar panel, Enerwatt – Batteries Expert, Quebec, QC, Canada) connected to the MPPT solar charge regulator (TR-45 TriStar Solar Controller, Newtown, PA, USA) that allowed the charging of the battery bank (4@6V 2GC-210AH 105RC Battery, Batteries Expert, Quebec, QC, Canada). A step-down regulator 5V (24V to 5V 3A SuperNight, China) was used to power the Feather M0 microcontroller board, and another converter regulator (Hossen 24V to 12V 20A, Odysseus, China) was used to power gateway.



(a)



(b)

Figure 9. Node 4 for pump activation (a) floating station and (b) block diagram of the proposed node.

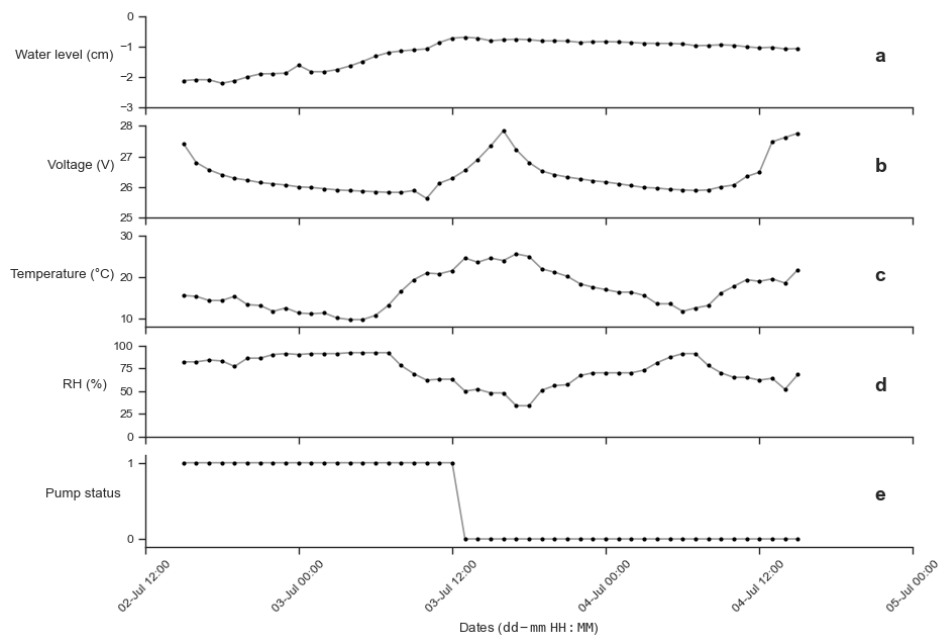
The power supply for node 1 (water level in the irrigation channel) was provided by a 3.5W solar panel (6V 3.5W Solar panel, Adafruit, New York, NY, USA) operating with at least 4.5 hours of sunlight. A 2 000-mAh lithium ion batterie was used, allowing a one-day autonomy. The batterie charge was controlled by a lithium ion/polymer charger (Adafruit, New York, NY, USA).

In the case of node 3 (meteorological data), electricity was produced by a 20W solar panel (Enerwatt – Batteries Expert, Quebec, QC, Canada) connected to a low-cost solar charge regulator (Phocos CM 4-10 A solar charge controller, Tucson, AZ, USA), the latter connected to a 12V battery (31 Bigred 130AH 200RC Battery, Batteries Expert, Quebec, QC, Canada). A step-down regulator to 5V was used to power the Feather M0 microcontroller board of the node.

OPERATIONAL TEST The proposed system for water table monitoring and control system was evaluated in the field and it allows to obtain the water table level of the irrigation channels, to operate the irrigation pumps and to transmit data using LoRa technology, with a distance between nodes up to 210 m. The nodes were placed as shown in the Figure 3. Then, data were collected from nodes 1 to 4 and sent to the gateway during 48 h. Figures 10 presents the water table level in one irrigation channel (captured by node 1), the voltage of the batteries supplying the pumps (captured by node 2), relative humidity and temperature of air (captured by node 3) and the pump status (On/Off, captured by node 4). When trial was conducted, no rainfall occurred, so the results of the rainfall are not shown.

Figure 10. Data collected by the LoRa-based monitoring system of *Sphagnum* farming site in Saint-Modeste, Eastern Canada. (a) water table level in irrigation channel, (b) the voltage of the batteries supplying the pumps, (c) air temperature, (d) relative humidity of air, and (e) the pump status (1 for ON, 0 for OFF).

As shown in Figure 10, the water level into the irrigation channel increased by 1.42 cm in 22 hours (From July 2nd 15h to July 3th 13h). The pump did not need to stop due to lack of voltage in the batteries, however, the control network can decide at any time if it is necessary to turn off the pumping to protect the batteries from deep discharge.



CONCLUSIONS This paper presents a solution using LoRa module a cost-effective and scalable water management system for *Sphagnum* farming in Eastern Canada. The system can continuously observe the measured water table level in irrigation channels and other interesting variables as voltage level for pumping, weather variables and pumping activation. The IoT node was tested in a 0.15 ha site in Saint-Modeste for 48 h. However, the same monitoring system could be used in a large area. Exploration solving this problem is already in progress. Finally, real-time, high-accuracy data of groundwater in restored basins has revealed the complex fluctuation of groundwater in restored basins after peat extraction. Such data are crucial for restoration success.

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