Development of a Monitoring Environment for a Large-scale Surface-Flow Constructed Wetland

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Abstract: The instrumentation implemented to monitor a large-scale surface-flow constructed wetland (6 ha) devoted to reclaimed wastewater improvement and urban rainwater treatment is described and discussed. Flowmeters, conductimeters, light sensors, fluorometers and automated cameras have been deployed to provide information on flow patterns, water quality and vegetation. The latter is also monitored by remote sensing with satellite imagery.

Keywords: Conductivity; Constructed wetland; Fluorescence; Remote sensing; Vegetation.

1. INTRODUCTION

Constructed wetlands (CW) are nature-based systems (NBS) intended to treat wastewater as well as urban run-off. Biological, physico-chemical and photochemical phenomena taking place in these structures. Different types of NBS exist but a general characteristic is the limited number of control handles, i.e. influent flowrate and its eventual distribution.

Nevertheless, these constructed wetlands should be monitored as much as possible to evaluate their efficacy, to schedule their maintenance (vegetation and sediments removal), as well as to develop models.

The monitoring scheme developed for a large-scale (6 ha) surface-flow CW located downstream the wastewater treatment plant of Grand Reims (470,000 equiv. inh.) in France is hereby described and examples of the analysis of the collected data to explain the functioning of the CW are given. This pilot-scale NBS, designed within the AZHUREV project (**A**ménagement d'une **Z**one **HU**mide à **R**eims pour l'**E**puration et le **V**ivant, i.e. Development of a Wetland in Reims for Purification and Living) receives about 7% of the total reclaimed wastewater. The results obtained at that scale in terms of treatment efficacy and monitoring design will be expanded in the future to deal with the totality of the reclaimed wastewater and urban runoff of Grand Reims.

The in-situ instrumentation was selected in order to monitor the hydraulic residence time, the water quality and the vegetation. The data collected with the in-situ instrumentation are complemented by monthly sampling campaigns. Finally remote sensing using satellite imagery has been tested to monitor vegetation.

2. SITE DESCRIPTION

Three rectangular basins (B1, B2 and B3, 50 m x 350 m each) constitutes the AZHUREV constructed wetland (Figure 1). The depth varies in each basin between 20 and 50 cm. The basins were designed to be equally fed either by reclaimed urban wastewater (by dry weather) or by urban runoff (during rain events) through the switching of two valves. The soil of the basins has been sealed by compaction to avoid infiltration from the water table and exfiltration to the water table. They differ by the initial amount of planted vegetation.

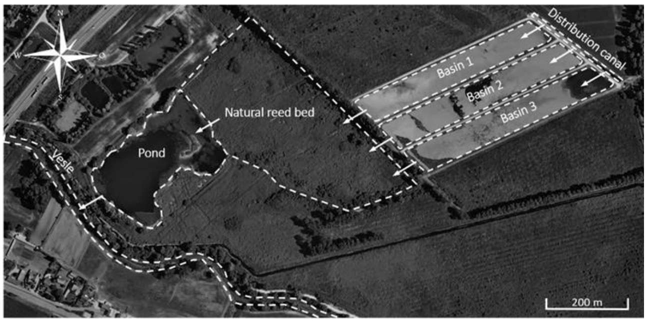

Figure 1: Aerial view (June 18, 2018) of the constructed wetland (modified from Google Earth)

3. INSTRUMENTATION

The hardware selection has been made within the following constraints: i) all sensors should be battery-powered, ii) risks of vandalism by unauthorized visitors should be minimized, iii) risks of destruction by wildlife (coypus, muskrats) should also be minimized (no cable should be visible).

Flowmeters (Mag8000, Siemens) have been installed at the inlet and outlet of each basin. The hourly flowrates are collected daily (24 values) via a GSM system. Daily flowrates of reclaimed urban wastewater and urban runoff are also available (offline).

A WatchDog (Spectrum Technologies, Aurora, Illinois) weather station has been installed on the nearby WWTP. The measured variables are rainfall, wind speed and direction, temperature and photosynthetically active radiation (PAR) between 400 and 700 nm (data capture period: 30 min).

Conductivity – Temperature – Depth (CTD) sensors (Diver®, Van Essen, Waterloo, Canada) have been set at the inlet of B2, at the exit of the three basins (in chambers) as well as in the middle of B1 (Figure 2) (data capture period: 15 min).

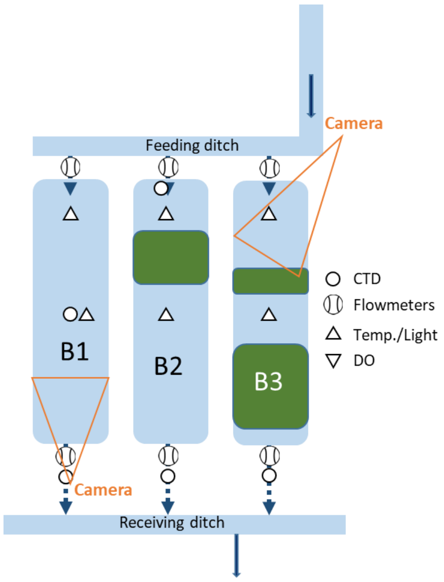

Figure 2: Position of the sensors. The green zones correspond to the areas where *Phragmites australis* develop.

Two Waterproof HOBO Pendant (Onset, Bourne, Massachusetts) loggers for temperature and light are placed in each basin (Figure 2) at a depth of 20 cm. The sensor measures light between 200 and 1200 nm every hour. A HOBO dissolved oxygen (DO) sensor (accuracy 0.2 mg/L) has been installed in B1. The data are collected monthly.

ECO fluorometers (Sea Bird Electronics, Bellevue, Washington) have been deployed occasionally to monitor the dissolved organic matter (DOM) (excitation at 370 nm, emission at 460 nm) at the inlet and outlet of the basins, in the chambers used for the CTD probes (data capture period: 15 min).

Two different techniques are used to monitor the vegetation: cameras placed on pre-existing hunting stands, to monitor part of B3 and B1 (XTC-720P, Active Media Concept, Vallauris, France) by daylight and satellites images. Full-resolution RGB camera images (2592 x 1944 pixels) are stored on SD cards and low-resolution images (640 x 480 pixels) are sent via a GSM system once per hour between 9am and 5pm.

Monthly series of full-resolution images are analyzed using Visilog9 (FEI, Hillsboro, Oregon). A region of interest is defined with five points on the first image of each series and serve as the basis of a triangular tessellation. In order to monitor the coverage by floating aquatic plants (mostly duckweed) the centroid of each triangle pixel is defined as green when the green channel intensity is larger than the blue channel intensity by 80, each color channel having 255 possible values.

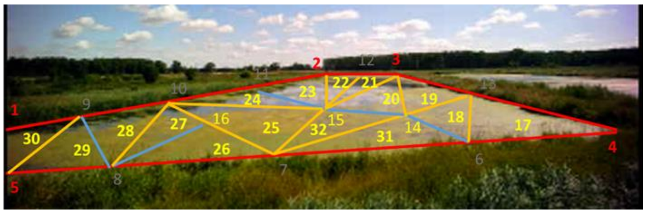

Figure 3: Definition of the points (centroids of triangles) for the assessment of the coverage by aquatic vegetation at the exit of B1.

The Sentinel-2 satellites constellation, operated by the European Spatial Agency, provides an image of the zone of interest every three days in average. The images are freely available on the Copernicus website (https://scihub.copernicus.eu/). The red (R) and NIR bands provided by the multispectral instrument of the satellites enable to calculate the Normalized Difference Vegetation Index (NDVI), which is an indicator of the alive vegetation:

$$NDVI = (NIR - R)/(NIR + R) \quad (1)$$

The ratio of the intensities of green and blue channels (G/B) of the True Color Image (TCI) is a global descriptor of the extent of vegetation over the basins, whatever the state of the plants (dead or alive). The images are analyzed using QGIS (https://www.qgis.org/fr/site/). Regions of interest have been defined for each basin and the average NDVI and G/B of each basin is computed.

4. RESULTS

4.1 Flowrates

The first goal of the daily monitoring of the flowrates is to check whether water is correctly flowing into the basins. Aquatic vegetation can be torn out along the 1 km-long ditch transporting the water from the WWTP and clog the screens protecting the flowmeters. A warning can be issued to the WWTP staff for cleaning the screens. A key issue in the installation of the AZHUREV CW has been the sealing of the soil of the basins to avoid the contamination of the aquifers. To verify that the sealing is effective the ratio of the inlet to the outlet daily flowrates has been computed for each basin. To take into account the average hydraulic residence time of five days, the 5 days-moving mean values are given in Table 1, as well as their coefficient of variation (CV). The mean values are close to 1, being slightly larger for B3. This slightly larger value is attributed to the effect of transpiration, as B3 is the basin with the larger amount of emerged vegetation. The large CVs are linked to the irregularity of the feeding: the clogging of the screens induces a large variability of the distribution of the water between the basins. Nevertheless, it has been concluded that the sealing by compaction was efficient to prevent exfiltration of the CW water towards the aquifer.

Table 1. Mean values of the inlet to outlet flowrates ratio for 2020 and 2021

Basin	B1	B2	B3
Mean	1.06	1.05	1.07
CV (%)	14	17	19

4.2 Conductivity

The conductivity sensors enable to monitor the nature of the water feeding the CW and to evaluate the hydraulic residence time in each basin.

An example of the variation of conductivity and temperature in function of the nature of the feed is given in Figure 4. The runoff valve opens as soon as the water depth in the upstream storage area is higher than a set value. Runoff water has a much lower conductivity than reclaimed wastewater and the change of nature of the feed, due to a succession of two rain events, is clearly visible on October 2, 2021 and again on October 5, 2021. Runoff water is also colder than reclaimed water and a decrease of the temperature can be seen. The runoff valve was again opened on October 15, 2021 (no occurrence of a rain event at this date) and cold water with high conductivity was fed to the CW. The height of the water table can cause groundwater, which has a high conductivity due to the nature of the soil (limestone), to infiltrate the runoff water network. Therefore, we assume that for this event, the CW was fed with a mixture of urban runoff and groundwater during two days.

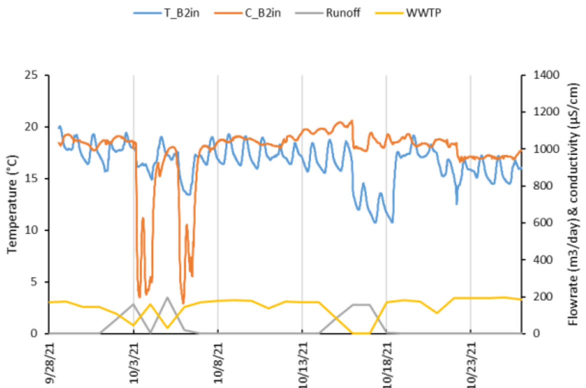

Figure 4: Variation of conductivity (orange line) and temperature (blue line) at the inlet of B2 in function of the reclaimed wastewater (grey line) and runoff (yellow line) flowrates

The comparison of the conductivities measured at the inlet of B2 and the outlet of the three basins is shown in Figure 5 for the same period as in Figure 4. The two sharp decreases of conductivity at the inlet of B2 are completely damped at the exit of the three basins. The exact volume of water contained in the basins is not precisely known as the water depth is fluctuating in response to the changing flowrates (Table 2). The position and seasonal extent of the reedbeds and the wind effect on large open water areas modify the water circulation patterns in the basins and make them complex. The water residence time is estimated between four and seven days.

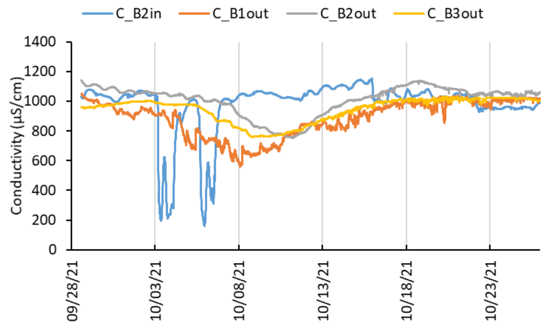

Figure 5: Comparison of conductivities at the inlet of B2 (blue line) and at the outlet of B1 (orange line), B2 (yellow line) and B3 (grey line)

Table 2. Mean values of the inlet flowrates for 2020 and 2021

Basin	B1	B2	B3
Mean (m^3/h)	61	53	40
CV (%)	35	42	43

4.3 Fluorescence

Tests have been made with ECO fluorometers to monitor the dissolved organic matter. No temperature sensor is incorporated in the probes but fluorescence is inversely dependent upon temperature, which means a correction is needed (Ryder et al., 2012). Figure 6 depicts the variations of fluorescence for the same period shown in Figure 4, with a ECO fluorometer located close to the conductivity sensor at the inlet of B2. To correct the effect of temperature, the period between Oct 7 and Oct 11 was used. It was considered that the composition of the incoming water was rather stable between those dates. A linear relationship was obtained between the fluorescence intensity and temperature with a coefficient of determination of 0.85 (Figure 7).

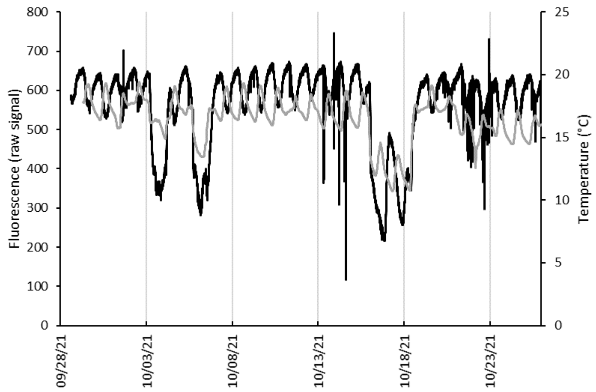

Figure 6: Variation of fluorescence (black line) and temperature (grey line) at the inlet of B2

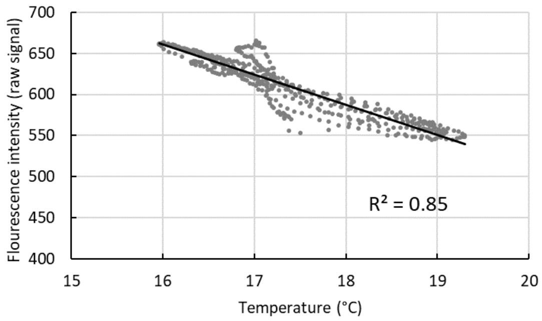

Figure 7: Estimation of a linear relationship between fluorescence and temperature

The temperature correction was then applied to the full period (Figure 8). It can be seen that during the three events (Oct 2, Oct 5 and Oct 15) differed not only in terms of conductivity but also in terms DOM concentration. Investigations are on-going to verify the origin of the water which was discharged between Oct 15 and Oct 18.

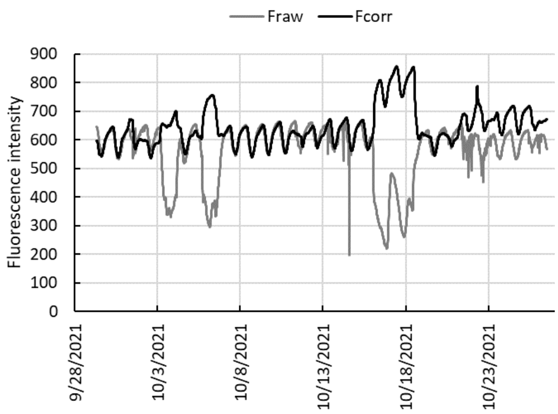

Figure 8: Correction of temperature applied to the DOM fluorescence signal

4.3 Vegetation monitoring

Remote sensing based on satellite imagery has raised interest in applications to water bodies to monitor features such as turbidity (Ren et al., 2018), nutrients (Li et al., 2017) or chlorophyll (Le et al., 2009; Song and Zhang, 2021). In large-scale surface flow constructed wetlands, the monitoring of vegetation is often complicated by their size and by the different types of plants, which can be involved. Remote sensing using satellites images are of great help to monitor the global coverage of the basins by floating (duckweeds) and emerged (phragmites). As measured by the simple Green/Blue ratio or by the NDVI, the coverage by vegetation is minimal in winter in B1 (no emerged plants). The main limitation is the necessity to obtain cloudless images: they are more difficult to get in winter. Another limitation might be the spatial resolution of the satellites images (10 m for the Sentinel-2 images) with respect to the constructed wetland size or shape.

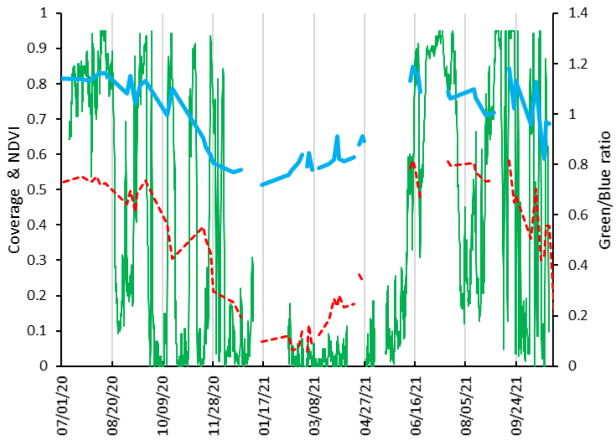

Figure 9: Vegetation extent on the downstream section of B1 (green line) and global vegetation assessment using satellites images (Green/Blue ratio (blue line) and NDVI (red dotted line)

A more detailed monitoring is provided by the automated cameras, with the limitation that they can see only a part of the basins and that there is a high parallax effect (Figure 3). However, they can operate in almost any weather conditions. Images might have to be discarded in case of morning fog and raindrops on the lenses. Large and rapid fluctuations of the coverage on the downstream section of B1 can be observed on Figure 9. They are due to the displacement of duckweed induced by the changes in wind direction. East winds (direction ≈ 270°) are pushing the duckweeds towards the downstream section and west winds (≈ 90°) are pushing them upstream (Figure 10). The sensitivity of duckweeds to wind depends upon the presence in the basin of submerged vegetation (such as *Ceratophyllum* species) which restrains their displacement.

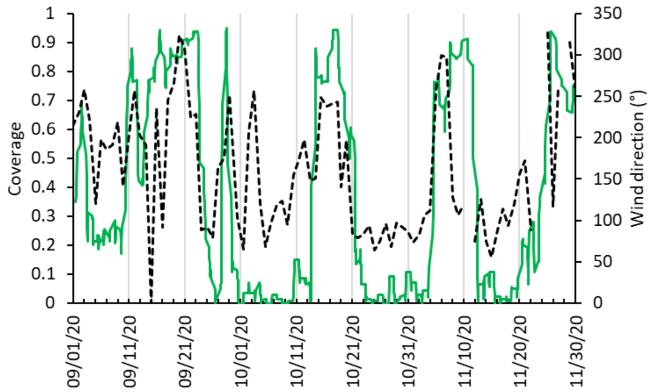

Figure 10: Displacement of duckweed on B1 induced by the wind. Green continuous line = coverage. Black discontinuous line = wind direction

4.5 Photosynthesis

Sunlight-driven phenomena such as photosynthesis and photolysis are key phenomena in constructed wetlands. Photosynthesis is driving the plants development, above, on and under water. Photolysis participate to the modification of dissolved organic compounds such as humic substances and organic micropollutants. Sunlight is detected at mid-depth in the water column between early February and the end of April, as seen in Figure 11. The global PAR is steadily increasing in the meantime, favoring the development of plants. A low level of light is detected at the end of March and at the same period a high oxygen saturation is measured (Figure 12). This corresponds to the period of the year with a high development of algae, which are producing oxygen by photosynthesis and which occupy a large part of the water column. The sensor is buried in the algae and not able to see the light. Later, duckweeds are developing and gradually overlying algae. This would suppress algal photosynthesis and induce their senescence.

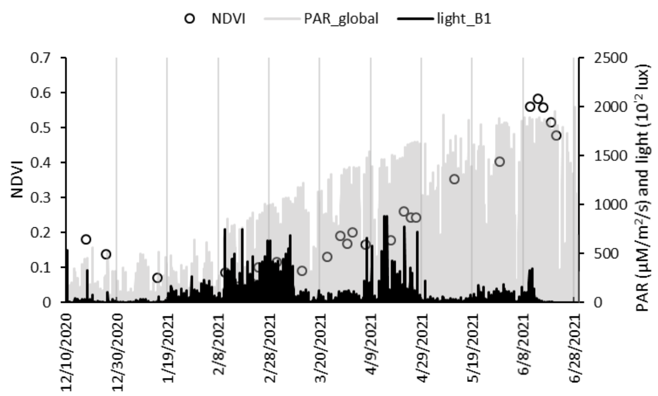

Figure 11: Comparison of light intensity at mid-depth of B1 (light_B1) (upstream location) with the global PAR measured at the weather station and the global NDVI measured on B1.

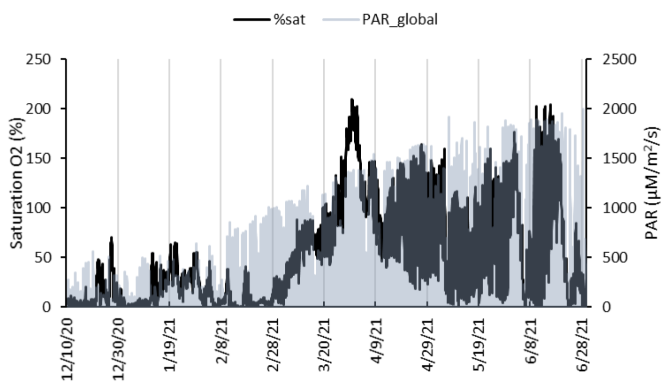

Figure 12: Comparison of the saturation in oxygen at mid-depth of B1 (%sat) (upstream location) with the global PAR measured at the weather station on B1.

5. CONCLUSIONS

Flowmeters communicating via GSM are essential to monitor at distance (250 km between Reims and Nancy) the flowrates and to detect critical situations such as clogging of the grids.

Automated cameras are very useful to monitor vegetation, even when their angle of view is limited. Their images are complementary to satellite images, which are dependent upon the presence of clouds. The risk of vandalism should not be ignored.

Conductivity sensors enable to understand better the nature of the water feeding the constructed wetland, in addition to the flowrates.

If the previously listed devices (i.e., flowmeters, conductivity and temperature sensors, automated cameras) will stay implemented in the long term and will be probably implemented when the constructed wetland will be extended, light sensors, dissolved oxygen sensors and fluorometers are only deployed to help to build a dynamic model of the constructed wetland, in complement of sampling campaigns.

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