HOW TO MANAGE NATURE-BASED SOLUTION ASSETS SUCH AS STORMWATER CONTROL MEASURES?

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According to Raymond *et al.* (2017) "nature-based solutions (NBS) are solutions to societal challenges that are inspired and supported by nature". Such solutions offer a great potential in addressing a variety of challenges in many domains (H2020, 2015), and providing ecosystem services (Nesshöver *et al.*, 2017). Regarding urban water, "NBS can contribute to sustainable urban water management by increasing infiltration, enhancing evapotranspiration, providing storage areas for rainwater and removing pollutants" (Raymond *et al.*, 2017). Such solutions are often applied at or near to the source of runoff: swales, infiltration trenches, green roofs or porous roads, etc. They have emerged worldwide in the last 30 years under many names such as stormwater control measures (SCMs), best management practices or sustainable urban drainage systems (Fletcher *et al., 2015)*. SCMs are integrated within the urban landscape, most often open-air and thus have high visibility and public accessibility. SCMs remain a poorly understood but relatively important asset in cities: Lyon Metropolis recently commenced such an inventory and identified 200+ SCMs to date in public areas, Bordeaux and Melbourne expecting 10,000+ SCMs (Bourgogne, 2015; Milenkovic *et al.*, 2012). Since the emergence of SCMs, operational and research questions have largely focused on design. After several decades of operation, there is, however, a growing concern regarding their medium and long-term performance and maintenance. This question is becoming a major disincentive for the adoption of SCMs, with local government, at risk of withdrawing from SCM implementation, driven by concerns about the long-term financial and operational sustainability of such systems (Morison *et al.*, 2010).

Managing nature-based solutions differently

While asset management of infrastructures such as drinking or wastewater pipelines have been deeply investigated, research on SCMs asset management remains a new field (Al-Rubaei, 2016; Cossais *et al.*, 2017; Werey *et al.*, 2017). Most of the present management of SCMs is based on the run-to-failure approach, partly due to resource limitation and lack of knowledge. It is for example not possible today to accurately predict the evolution of hydraulic parameters such as filter-media permeability (Gonzalez-Merchan, 2012). Limited resources don't allow for frequent or continuous monitoring of each SCM and utilities often choose to monitor the most important (in size or regarding the consequence of a failure). SCM asset management strategies must rely on the knowledge, experience and practices developed for "traditional" infrastructures. Such materials will however need to be adapted to SCMs in order to consider the specificities of nature-based solution such as SCMs, as presented in Table 1 below.

***Table 1**. Comparison between "traditional" water infrastructure (i.e. water or wastewater pipelines) and nature-base solutions such as stormwater control measures*

"traditional" water infrastructures	Stormwater control measures
Continuous system: the network is composed of pipes linked together	*Discontinuous system*: SCMs are often spread individually on the territory with the aim to manage stormwater "at source"
Single purpose: pipes are designed to convey water from one point to another	*Multi-functionality*: in addition to runoff management, SCMs can improve biodiversity, provide social services, etc.
Assets are "grey" (man-made) and depend on the civil engineering field	*Assets are "grey" and "green"* (nature-based) and depend on the civil engineering and the ecosystem fields
Immediate effect of rehabilitation: the asset is back to a normal functioning after the construction works	*Nature time-scale dependent*: any rehabilitation involving nature-based component may need time to fulfil completely its function
All assets are very similar and are often considered as homogeneous groups (cohorts)	*Each asset is unique* in terms of size, form and constitution and service delivered, and thus require a unique model
Assets are hidden underground: they are not visible but can be distinguished from other urban elements	*Assets are integrated* within urban environment, it can be a road, a playground, a sport field, a park, etc.
Assets are managed by one department which can be the water department or sanitation department	*Assets require a collaborative management between for example water department, cleaning department and green space service*

Water or wastewater pipelines asset management rely on models to predict the hydraulic performance or the physical deterioration over time. Such models enable the shift to a proactive management where the rehabilitation takes place before the failure. Regarding SCMs, shifting to proactive management in the shortterm is only possible by drastically increasing the monitoring (more asset monitored more frequently). This will allow anticipating failure and providing a better understanding of their behaviour.

Toward cost-effective solutions

Low-cost sensors and acquisition systems are emerging in many fields, such as agriculture (Fisher, 2007) and air quality (Morawska *et al.*, 2018). Their advent opens up the potential for entirely new approaches, where numerous sensors measure various aspects of SCM state and performance, generating alerts to those involved in their maintenance. Such sensors could control changes to system configuration to optimise performance relative to (i) operating conditions and (ii) maintenance state of the system. Delivering on this potential will require investigating new challenges and imagining innovative ways of monitoring. Among the other challenges, it will be necessary to consider the reliability of the sensors or the whole monitoring system, the skills related to customised hardware and programming and the management of large data sets. Low-cost solutions will however improve monitoring possibilities with real-time data acquisition, processing and alert, and with the increase of spatial resolution (more asset on the territory, more points for each asset). A key challenge is to optimise the use of these new technologies, not simply replacing the functionality of existing monitoring systems, as illustrated in the Table 2 below.

Table 2. *Functionalities related "low-cost" monitoring systems*

Functionality	Description
Cost-effective	Low-cost systems are often only considered as a solution to decrease monitoring cost
Open source	Each system can be programmed by the user and all programs can be publicly available; important communities are already sharing their ideas and codes
High modularity	With a large range of sensors on the market, the possibility to choose what component (sensor) will be installed and the control over the whole monitoring process
Low consumption	This remains a main driver for component development by manufacturers; many monitoring solutions already last several months
Real-time access to data	Communication capabilities enable to send the data online and access it from any computer or connected device
"Monitoring the monitoring"	Having real-time data enables to detect any problem (low battery, absence of new data, etc.) and avoid important loss of data
Interactive monitoring	A monitoring system "connected" means the possibility to change monitoring conditions such as measurement period or to trigger an action such as water sampling
Shared data	Online access to data opens up to sharing the measurements to any technical staff but also to a more general public, potentially leading to community awareness

Discussion

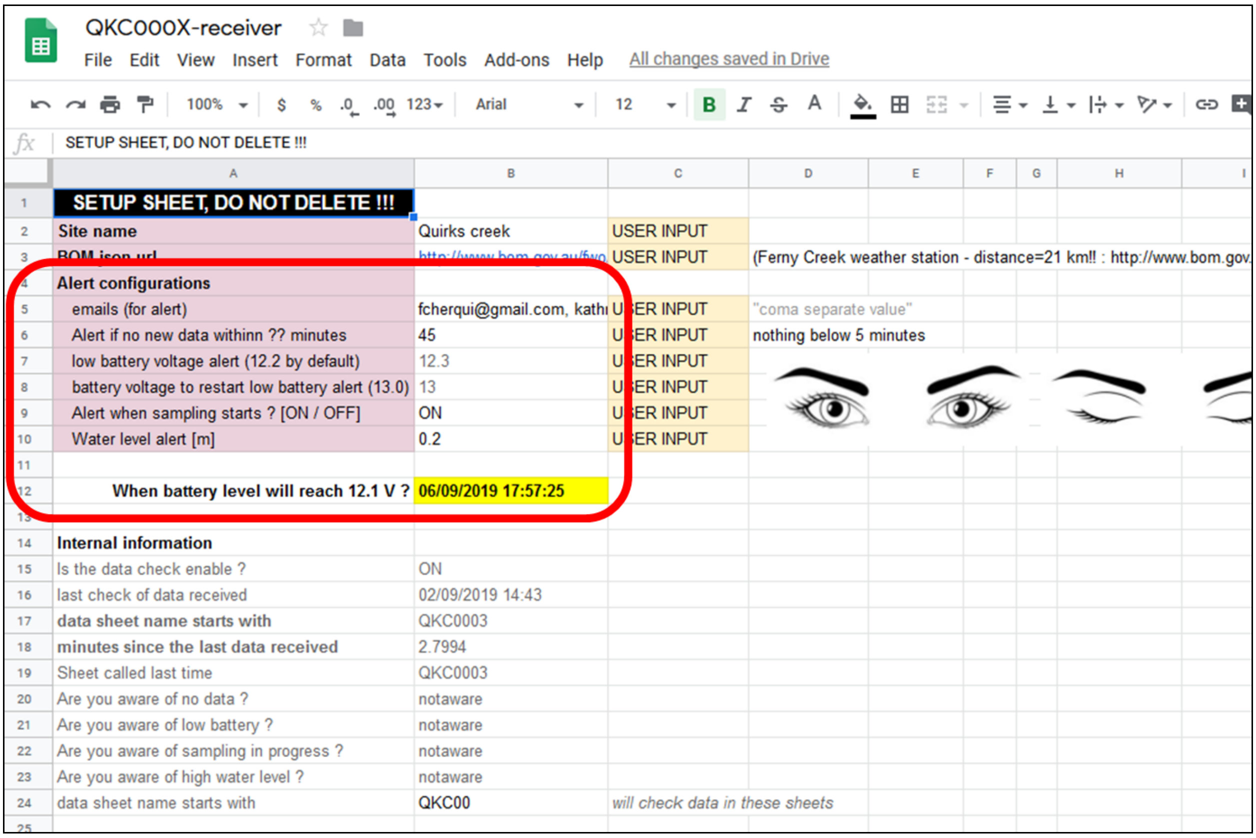
The important diversity of micro-controllers (e.g. Arduino-based, Pycom or Particle) is an opportunity to design a monitoring system that will exactly fit the purpose. It is for example possible to use "traditional" sensors and replace the data logger by a programmed microcontroller in order to choose when and how the measures will be taken and accessed. It is also possible to choose the set of sensors that will be installed on a site and based on what condition the measurement will be triggered. Some examples of monitoring systems are presented on the project website: https://mind4stormwater.org. Such modularity is also an opportunity to adapt to various site conditions: available communication networks, power supply, accessibility to the public, etc.

The important diversity of sensors is another opportunity, but it is in the same time the greatest concern because of the question of the reliability of the sensors or the whole monitoring system (Kumar *et al.*, 2015). Table 3 summarises the different parameters recommended for testing the performance of a proposed monitoring system. Such parameters are not specific to low-cost sensors but are often investigated when dealing with the latter. It is also "important that the sensors/monitors are tested under both laboratory and field conditions" (Morawska *et al.*, 2018), which should become part of best practices and quality assurance in metrology.

Table 3. *Reliability considerations for low-cost sensors (Cherqui et al., 2019)*

Parameters	Description
Longevity or stability	Time of operation before replacement (Kumar *et al.*, 2015)
Accuracy	Agreement between the measurement and true value (JCGM, 2012)
Repeatability	Measurement precision under a set of repeatability conditions of measurement (JCGM, 2012)
Reproducibility	Agreement between measurements of the same measure and carried out under varying conditions of measurement (JCGM, 2012)
Resolution	Smallest change in a quantity being measured that causes a perceptible change in the corresponding indication (JCGM, 2012)
Response time	Duration between a step change in condition and the first observable corresponding change in measurement response (JCGM, 2012)
Sensitivity to the environment	Effect of environmental factors (temperature, relative humidity) on sensor output (Rai *et al.*, 2017)

Maybe, one of the most promising possibility is the real-time access to data. Programming a microcontroller to send the data to a specific platform using GSM network or any other network (wifi, Bluetooth, LoRa, SigFox, etc.) is becoming a commonplace. When the data is online, it is then possible to “monitor the monitoring”: for example, the Figure 1 below presents the configuration sheet where the user can define parameters such as who will receive the email alerts, or what levels will trigger these alerts. Based on battery voltage data, it is also possible to estimate the remaining life of the system and anticipate maintenance actions.

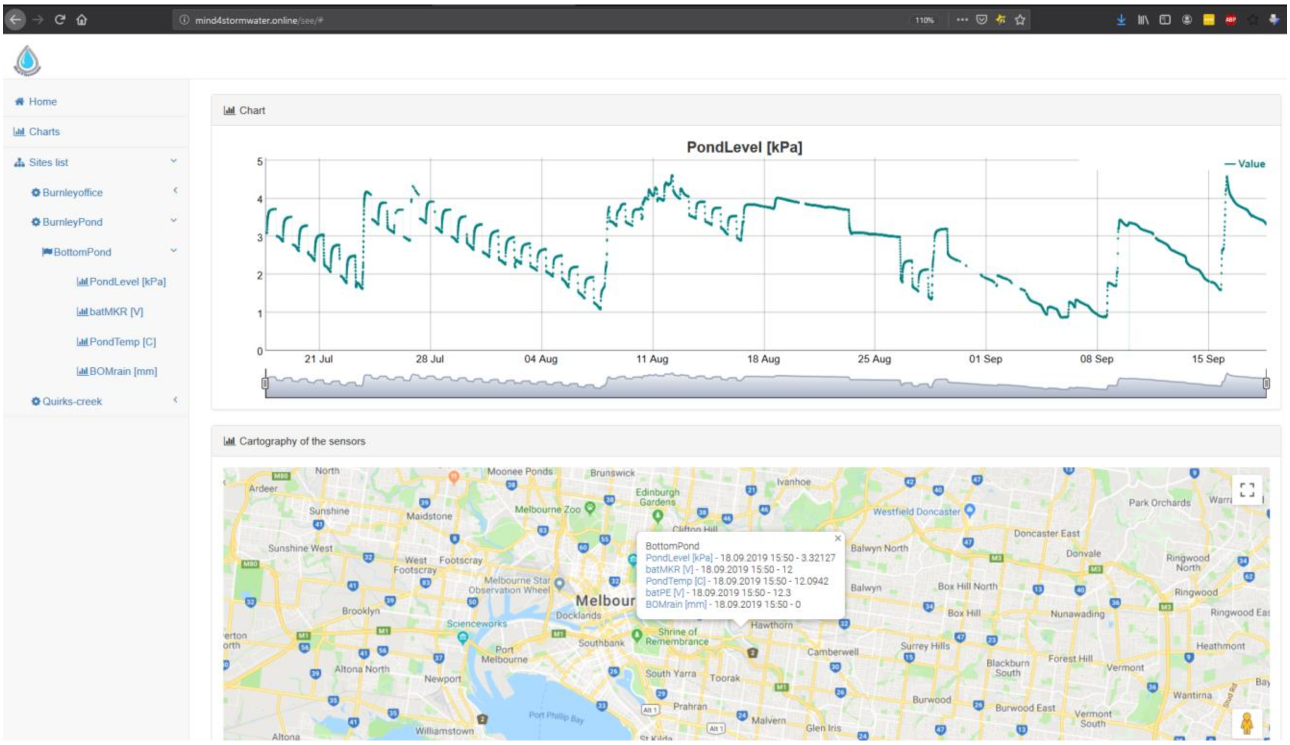


SETUP SHEET, DO NOT DELETE !!!

	A	B	C	D
1	SETUP SHEET, DO NOT DELETE !!!			
2	Site name	Quirks creek	USER INPUT	
3	BOM json url	http://www.bom.gov.au/fwo	USER INPUT	(Ferny Creek weather station - distance=21 km!! : http://www.bom.gov
4	Alert configurations			
5	emails (for alert)	fcherqui@gmail.com, kath	U ER INPUT	"coma separate value"
6	Alert if no new data withinn ?? minutes	45	U ER INPUT	nothing below 5 minutes
7	low battery voltage alert (12.2 by default)	12.3	U ER INPUT	
8	battery voltage to restart low battery alert (13.0)	13	U ER INPUT	
9	Alert when sampling starts ? [ON / OFF]	ON	U ER INPUT	
10	Water level alert [m]	0.2	U ER INPUT	
11				
12	When battery level will reach 12.1 V ?	06/09/2019 17:57:25		
13				
14	Internal information			
15	Is the data check enable ?	ON		
16	last check of data received	02/09/2019 14:43		
17	data sheet name starts with	QKC0003		
18	minutes since the last data received	2.7994		
19	Sheet called last time	QKC0003		
20	Are you aware of no data ?	notaware		
21	Are you aware of low battery ?	notaware		
22	Are you aware of sampling in progress ?	notaware		
23	Are you aware of high water level ?	notaware		
24	data sheet name starts with	QKC00	*will check data in these sheets*	
25				

Figure 1. *Example of google sheet dedicated to defining alerts related to a specific monitoring. A specific script is called when new data is received: emails alerts are triggered based conditions (low battery voltage, sampling in progress, water level reached). A background script enables regular data check and an email alert is triggered in the absence of new data.*

It is also possible to enable FAIR data (Findable, Accessible, Interoperable and Reusable), as defined in (European Commission, 2016). The Figure 2 below presents a public platform developed within the *Mind4Stormwater* project where any person can consult the real-time data of monitoring, locate the site, and download the data. Such platform combined data from different sites, sensors and using either the GSM network or the LoRaWAN network.



BottomPond
PondLevel [kPa] - 18.09.2019 15:50 - 3.32127
batMKR [V] - 18.09.2019 15:50 - 12
PondTemp [C] - 18.09.2019 15:50 - 12.0942
batPE [V] - 18.09.2019 15:50 - 12.3
BOMrain [mm] - 18.09.2019 15:50 - 0

Figure 2. *Public platform http://mind4stormwater.online. Anyone can consult the data in real-time, locate the sites, plot charts and download the data.*

It is possible to combine data from monitoring and data from other source such as weather stations. The Figure 3 below presents a chart of both the water level in a pond and the rainfall.

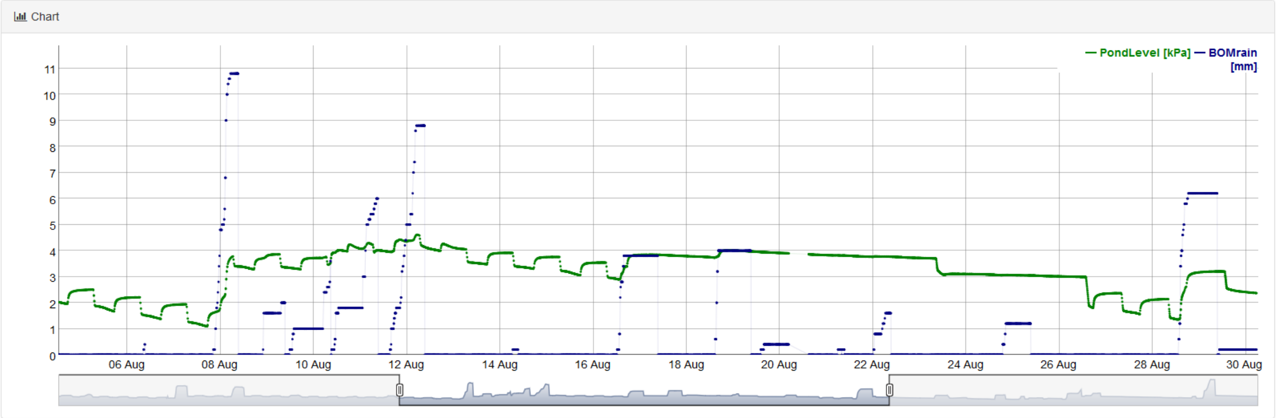


Figure 3. *Chart from http://mind4stormwater.online showing the water level in a pond receiving runoffs (in green) and daily cumulated rainfall (since 9am) from the closet weather station (in blue).*

Such chart can help understand the response of the system to a storm event or enable early detection of abnormal behaviour related to component failure. The Figure shows the increase in water level almost immediately after the rain event. The figure also shows a cyclic rise and fall of the water level, because the water is pumped to an upper pond (the level decrease during the morning when the pump is working and increase in the evening when the pump is stopped). The chart shows a pump failure the 16th of August, an attempt to restart the pump the 23th August, and a system back to normal the 26th of August.

Conclusion

Nature-based solution asset management offers new opportunities for the water sector. Existing thinking and practices will need to be adapt to such particular asset, leading to new research and business prospects. It is already clear that more monitoring will be required to shift from a run-to-failure approach to a proactive management. At the same time, low-cost technologies are opening new potentials for the monitoring of asset with the miniaturization and falling costs, allowing better spatial and temporal resolution. Such technologies can be the start of this “out of the box thinking”.

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