Environment Administration

City of Gothenburg

The LoV-IoT project: Air and water monitoring with Internet of Things

Water

Report number R2020:19

Preface

The project Air and water monitoring with Internet of Things, LoV-IoT, is an innovation- and development project which has examined the possibilities of using sensors and Internet of Things to develop the environmental monitoring of air and water within cities. One aim of the project was to develop an effective system for gathering information on air and water quality in cities to contribute to better health among the citizens.

The project was running for three years, between autumn 2017 until autumn 2020 and it was financed by the Strategic Innovation Program IoT Sverige, as a part of their work within IoT for societal benefits.

This report describes the work done within work package five and will answer to the deliverables within that work package.

The LoV-IoT project: Air and water monitoring with Internet of Things
Water

City of Gothenburg, Environment Administration

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Photos: The LoV-IoT project

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Summary

The LoV-IoT project has explored how sensors and IoT can be used to monitor stormwater and sewage systems in a city. This has been done through several measurement campaigns including both laboratory studies and in the field. The focus has been on water level and turbidity measurements, but also sensors for measuring pH, conductivity and temperature have been tested.

The project showed that to be successful with utilizing the possibilities with sensors and IoT for measurements of stormwater and sewage systems there are important factors to be considered. Firstly, to be able to implement the use of sensors and IoT in sewage systems network coverage even down in wells are needed. Dedicated IoT networks, such as LoRaWAN, can provide this. Secondly, low battery consumption for communication enables long service life and reduces the maintenance required. Thirdly, the IoT devices that support off-the-shelf sensing probes are relatively inexpensive, resulting in low total cost of ownership per measurement. Lastly, the sensors placed in the water are exposed to residues and harsh environments during maintenance operations such as pipe cleaning with high-pressure water.

A challenge in the project was to gain access to stormwater and sewage systems for testing. To enable further research and product development it would be beneficial with a test bed of wells that researchers and product developers could test the products in real environment, without affecting the operation.

The LoV-IoT project showed that massive deployment of low-cost sensors is an attractive method for collecting data and get visibility of a vast infrastructure such as stormwater and sewage systems in a city. From the work in the project, it was identified that predictive maintenance in sewage systems is a process where the possibilities with sensors and IoT can be utilized.

It is likely that in the near-future more cost-effective sensors will be available. This due a volume demand for sensors and with the makers movement for sensor automation. The sensors need to be evaluated and characterized for which application they can be used for, and whether the accuracy can be improved with machine learning algorithms. This development can enable innovation for the control of stormwater and sewage systems in a city.

Sammanfattning

Projektet LoV-IoT har utforskat hur sensorer och Internet of Things (IoT) kan användas för att övervaka dagvatten- och avloppsvattensystem i en stad. Detta har gjorts genom flertalet mätkampanjer som innefattat både tester i laboratoriemiljö och tester ute i fält. Fokus har legat på mätningar av vattennivå och turbiditet, men sensorer för mätning av pH, konduktivitet och temperatur har också testats.

Projektet visade att, för att vara framgångsrik i att tillgodogöra sig möjligheterna med sensorer och IoT för mätningar i dagvatten- och avloppsvattensystem finns det viktiga faktorer att ta hänsyn till. En viktig faktor att belysa inledningsvis är nätverkstäckning nere i brunnar som är avgörande för att kunna använda sensorer och IoT för denna typ av övervakning. Specifika IoT nätverk, så som LoRaWAN, kan möjliggöra nätverkstäckningen. En annan viktig faktor att belysa är vikten av låg batteriförbrukning för kommunikationen för att möjliggöra lång livslängd och för att minska underhållsbehovet. Ytterligare en faktor som projektet påvisade var att de IoT enheter som stödjer färdigutvecklade sensorsonder är relativt förmånliga, vilket resulterar i en låg totalkostnad per genomförd mätning. Avslutningsvis visade projektet att sensorer som är placerade i vatten är utsatta för skräp och hård miljö speciellt vid underhållstillfällen, såsom rörrengöring med högtryckstvätt.

En utmaning i projektet var att få tillgång till dagvatten- och avloppsvattensystem för att genomföra tester. För at möjliggöra framtida forskning och tester vore det fördelaktigt med brunnar som kan fungera som en ”testbed” där forskare och produktutvecklare kan testa produkter i verklig miljö, utan att påverka driften.

Projektet LoV-IoT visade att en omfattande användning av förmånliga sensorer är en attraktiv metod för att samla in data och ge synlighet åt den utbredda infrastruktur som dagvatten- och avloppsvattensystem i en stad faktiskt är. Projektet kunde konstatera att ett användningsområde där sensorer har stor potential är för att underlätta det prediktiva underhållet av dagvatten- och avloppsvattensystem.

Content

1 Introduction and background

The LoV-IoT Water project, is a sub-project to Luft- och vattenövervakning (Air and water monitoring) – Internet of Things (LoV-IoT), which is one of seventeen projects within the Strategic Innovation Program IoT Sverige. The project is supported by Vinnova, Sweden's Innovation Agency, the Swedish Energy Agency and Formas, with the overall goal of making the public sector in Sweden a world leader when it comes to using digital tools for society.

The innovation project is based on public sector's needs in environmental supervision of water, with a focus on storm- and wastewater infrastructure and operation. The main stakeholders are the department for sustainable water and waste management in Gothenburg and the environmental departments in the City of Gothenburg and Uppsala Municipality.

2 Targets and stakeholder requirements

2.1 City of Gothenburg – Sustainable Waste and Water

Combined Sewer Overflows (CSOs) are the main contributors of recipient water quality impairment. The Department for Sustainable Waste and Water Management, in the City of Gothenburg, has only a few measuring points at the three main pumping stations in the city to quantify the volume and quality of CSOs from the largest discharge points in the city. However, over a hundred CSOs are activated during intense or longer lasting rainfalls that discharge mixed waste/stormwater into the main recipient river, the Göta River, and its tributary rivers. The discharge volumes of these CSOs are modelled and annual discharge loads are reported to the Environmental Administration in the City of Gothenburg. Such models are based on precipitation data and resulting standard values for discharge volumes and quality, based on pipe capacity and land use. Nevertheless, local aspects like leakage due to pipe aging, temporary incoming discharges from unknown sources as well as local activities in the city (construction sites, industrial activities and traffic) are not represented in such models, therefore such flows are monitored and collection of real-time data is crucial to characterize CSO in complex sewer systems such as in the City of Gothenburg.

The goal of the Internet of Things (IoT) project was to develop smart monitoring system solutions for CSOs including sensors and communication platforms. The IoT platform should collect information on both water volumes and water quality in selected CSOs and deliver input data for calibration of existing models. Smart pipe monitoring solutions should be part of the system approach to achieve good surface water quality standards according to the European Water Framework Directive (EU WFD, 2000) and counteract deterioration of surface waters with already good water quality standards. In addition, smart monitoring platforms should be visualized and shared with citizens in accordance with the data transparency policy of municipalities and state institutions, as well as act as information platforms to understand the underlying urban water systems and processes. In a long-term perspective smart and transparent monitoring systems based on IoT solutions should contribute to a livable and healthy urban environment where citizens have the chance to understand the impact of each and everyone's actions and contributions.

The requirement for such sensors that should be part of the CSO's monitoring system is twofold; 1. The system should be able to estimate the CSO volumes discharged during rainfall events through water level measurements. 2. CSO discharge quality monitoring should be included in the system in form of turbidity, conductivity, pH and temperature measurements, turbidity being identified as the most important quality parameter to focus on. Further requirements were to focus on affordable solutions that municipalities can apply in many more CSOs, which are not monitored today, and both contact- and contactless sensors should be evaluated due to the special issue of clogging and waste transport of CSOs in the system.

2.2 Environmental Administrations, in Uppsala and in Gothenburg

The purpose of Uppsala Municipality's participation in the project is to make it possible to make a comparison with own measurements in surface water to assess whether sensors can be a complement in the future testing of turbidity sensor in stormwater as a knowledge base for future technology choices for measurements in stormwater and follow-up of stormwater facilities.

2.3 Vendor scope and requirements

2.3.1 Talkpool AB

The goal for Talkpool, as a specialist in IoT, low-cost sensors and sensor network, was to learn how the public sector works with IoT, smart city platforms and what benefits they are looking for. IoT enables massive deployment of battery-powered sensors, with low cost of ownership. IoT enables a paradigm shift from measurements with reference instruments, at few locations and for a limited time, to a continuous measurement of low-cost sensors in many places. The challenge was to find measurement parameters that are simple and cost-effective to measure, to find deviations as an early warning system, which can then trigger where and when to measure with the reference instruments to get scientifically correct measurements. In addition, the technology enables coverage deep into the infrastructure, where previous wireless connectivity has not been a viable option.

2.4 Uponor Infra AB

The scope was to develop an IoT prototype for monitoring in multiple locations in the storm and sewer network. The project aims to learn how to measure water columns, (possibly sulphuric gas (H_2S)), temperature and lid opening. With intelligence we believe that more insights as gravity flows can be estimated and used.

Uponor aimed to understand the possibility to monitor sewer water quality based on optical turbidity and conductivity. Uponor would also have the opportunity to learn about new communication principles, in this case LoRaWAN or the cellular technology NB-IoT.

This is identified as an opportunity in Uponor Infra's strategy for connected offers.

Uponor has an opportunity to create a service for our clients to get insights for

- Sewer overflow (can be used to offer attenuation systems)
- In-leakages (to help understanding renovation needs)
- Blockages for maintenance need
- Attenuation utilization
- Sewer parameters
- Stormwater quality
- Customer notification based on detected incidents

Uponor, one of the owners of Rent Dagvatten, took over as project partner, since Rent Dagvatten could not full-fill their scope in the project.

2.5 Research institutes

2.5.1 RISE Research Institutes of Sweden AB (RISE)

The purpose for RISE, and their departments *Sensors and Materials* and *Sensor systems* (formerly Acreo), to participate in this project was to test and evaluate sensors in real settings in the city's sewer system. The concept of IoT requires good sensor data and connectable sensor systems. In this project, selected sensors were first commercially available sensors, but the aim was to develop better, inexpensive and smaller sensors etc. after evaluating the results of the commercial sensors, in such cases the development could be done. The incentive for RISE was both to gain knowledge about the challenges and opportunities of placing sensors in the sewer system and also to learn more about the needs from the environmental departments and especially from the Department for Sustainable Waste and Water Management perspective. The goal was to put together sensor systems that are useful for the municipalities that are monitoring IoT platforms. We see an opportunity to increase our collaboration with municipalities, data platform developers, sensor companies and data handling/transfer companies as partners in this project and as part of the Division Digitalisation at RISE we are focused on enabling Internet of Things (IoT) and digitalisation by developing sensors and sensor systems.

2.5.2 IVL Swedish Environmental Research Institute

IVL Swedish Environmental Research Institute is a non-profit, independent research institute with a long experience in water measurement and data analysis. With regards to the development goals for the water domain, we contribute with expertise regarding water analysis, pollutant understanding and data analysis.

For IVL, it is important to understand the stakeholders' needs when it comes to water management and to see how new technologies and data analysis can be used.

IVL also contributes with its patented sensor for measuring turbidity and water level without being in contact with the water. The benefit is less maintenance since there is no buildup of dirt on the sensor optics. The sensor is in an early stage of development and is being evaluated together with a commercial instrument, the OBS501 turbidity sensor from Campbell Scientific.

3 Architecture

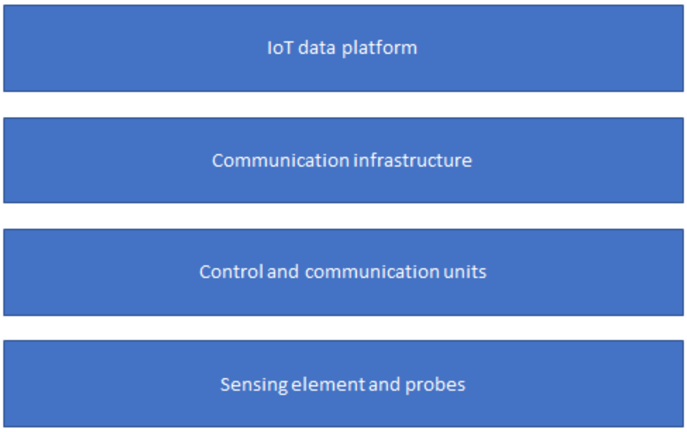

Figure 1: Layered architecture of the solutions

Traditional measurement instruments, or sensing systems consist of the two bottom layers: “sensing element and probes” and “control and communication units.” The term sensor in this document refers to “sensing element and probes.”

3.1 Sensing elements and probes

A search of available sensors for measuring water level was conducted the beginning of the project to select which sensor to buy (see Appendix A). There are different techniques used in different sensors, such as measuring the water pressure, which gives the water level above the sensor that is at the bottom or measuring the distance to the water surface from above with radar, ultrasonic or magnetic techniques. The selection of sensors was mostly based on the price and that it was possible to connect to different communication and control units.

Other important parameters were power requirements, reliability of the measurement and low maintenance. To be placed in a manhole, on a street, the sensor would desirably have a low power requirement and be able to sit there for a long time and measure the parameters without having to be maintained, such as cleaning, recalibration, battery replacement or similar. The sensor set-up should also not be too large, require expensive installation, durable to handle pipe cleaning, and not be clogging the pipe by stopping residuals such as paper and plastics.

When it comes to measuring turbidity, most commercial sensors are optical, which is the most common technique for measuring turbidity. Since the focus was to find inexpensive sensors, to be able to implement many in a city later on, we selected a sensor usually used in dishwashers, which is also rather small. There are many expensive instruments that measure turbidity available on the market, but we chose to evaluate the output from this cheap "dishwasher sensor" and to compare it with reference system measurements on a few occasions. The next step would be to develop an improved cheap sensor, possibly based on another technology, as a challenge with optical sensors is that they require cleaning - especially if they are placed in the water as this "dishwasher-sensor" needs to be.

3.1.1 Water level sensors

Water levels in Combined Sewer Overflows (CSOs) were the main goal from the stakeholders. The interest is to monitor the following events:

- Typical water levels during the year
- Size and intensity in "first flush" during a rain, which usually is the most polluted water
- Number of overflow events during a year
- Volume estimates of overflow

In addition, the sensors should have:

- Low total cost of ownership (low cost, long life, low maintenance cost)
- Flexible placement (not dependent on local power or connectivity)
- Nonobstructive for waste or residue
- Durable in harsh environment and cleaning with high pressure hose
- Handle foam on water surface
- Handle algae and microbiological growth

3.1.1.1 Hydrostatic pressure sensor

The water levels are measured with a hydrostatic pressure sensor. The sensor outputs a 4-20 mA signal, which is linear with the water level. The hydrostatic pressure sensor has a short stabilization time before a reliable level can be read. The power consumption is significantly higher than for the on/off floating switch but is still relatively low. The hydrostatic pressure sensor provides accurate measurements of the water level and handles foam, but it must be placed in the water, which increases the risk of impeding the water flow.

3.1.1.2 Floating on/off switch

To capture the “first flush”, a low-energy measurement of critical events was made with an on/off floating switch. The floating switch detects if the water level is above a threshold, which then triggers a measurement of the water level with other sensors. The energy consumption to read if the on/off floating switch is activated is very low so that it can be measured every 30 seconds for 5 years.

3.1.1.3 Ultrasonic water level sensors

Another method of measuring the water level is with an ultrasonic water level sensor. The advantage of the sensor is that it is placed above the water surface, so it does not obstruct the water flow and is less sensitive to algae growth. An ultrasonic sensor CRM+600/IU/TC/E from Hemomatik was selected for the project. A disadvantage of an ultrasonic sensor is high power consumption and that the accuracy is less accurate if there is foam on the surface.

3.1.1.4 Radar water level sensors

A Senz2 radar sensor, WLR05-2G/001, from Staal Instrument (formerly Omniradar), which measures water level and air temperature, was selected for the project. It is a hermetically glued box that contains a battery, a global SIM card, which works with 2G and a GPS on board. The sensor does not even have a control button but is activated by using an external magnet at the point of a hidden magnetic switch inside the box and all configuration is done remotely. In this way, no water intrusion is possible at all. The advantage of the sensor is that it is placed above the water surface, so that it does not obstruct the water flow and is less sensitive to algae growth. A disadvantage of this radar sensor is that when the battery is empty, it is not possible to change the battery, instead you need to buy a brand-new radar sensor box.

3.1.2 Turbidity Sensors

Turbidity is a measure of a liquid's suspension of particles and is measured in NTU (Nephelometric Turbidity Unit) or FNU (Formazin Nephelometric Unit). Turbidity describes how muddy or clear the water is. The turbidity of the water is correlated with the suspension of heavy metals, nutrients and sedimenting material in the water, so it is the most interesting water quality parameter to monitor.

3.1.2.1 Turbidity ultra-low cost

A simple and inexpensive turbidity sensor, Amphenol washing machine sensor, TSD-10 was tested. The sensor was powered with 5V and the output signal was measured with HP34401A multimeter. Measurements require a dark environment. The transmitter of the sensor is an IR LED and the receiver is an IR transistor. The sensor type is a pass through, so the receiver sees direct and reflected light.

3.1.2.2 Turbidity low-cost sensor type I (IVL)

Patented turbidity sensor that is developed by IVL (Figure 2). The sensor measures turbidity with laser and camera. It is not in contact with the water that is measured and can be mounted a few meters above the surface. The sensor requires a dark environment and in addition to turbidity also measures the water level.

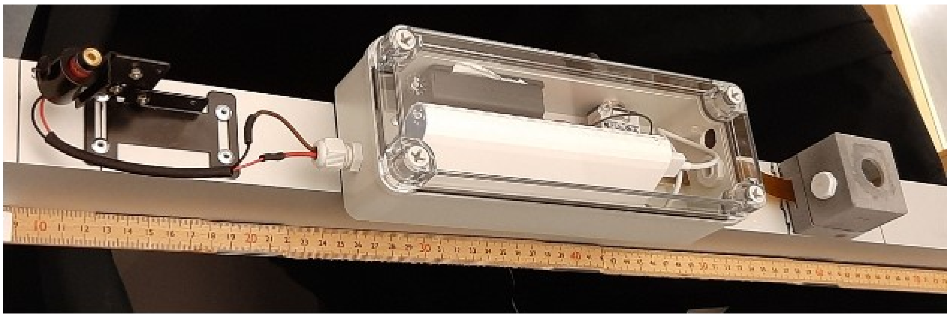

Figure 2: Turbinator with laser to the left side and camera on the right side. The sensor is developed during the project and may look different on other images. Image courtesy of Jens Wilhelmsson, IVL.

3.1.3 Conductivity, pH and temperature sensing elements

Standard sensing probes with analog output for conductivity, pH and temperature were evaluated. Industry grade, rugged hydrostatic pressure submersible transmitters were evaluated, with analog output 4-20mA. Inexpensive, but precise and well packaged temperature sensor Maxim-Dalls DS18B20 were also evaluated, with a one-wire serial digital interface. Package and cabling should be changed for a harsh environment.

3.2 Control and communication unit

Electricity and wired connectivity are typically only available in the pumping stations and not in the rest of the sewage system. Therefore, the most existing measuring points are at a few pumping stations and no data is available further out in the sewage system.

The traditional wireless communication networks are not designed to provide coverage in the sewage system. Furthermore, mobile communication systems such as 2G/3G and LTE consume a lot of battery power.

Water sensors for mass deployment should therefore use a communication technology with extended coverage, and low power requirements on the devices.

3.2.1 LoRaWAN control and communication unit

LoRaWAN wide area network provides 20 dB extended link-budget compared with traditional cellular networks, further the system is designed for ultra-low power consumption. A LoRaWAN control and communication unit “OY1400” was designed and produced. The device can support two external sensors,

0-10 V, 4-20 mA or digital threshold detection. The unit was used with the following probes:

- On/off floating switch (digital threshold)
- Hydrostatic pressure sensor (4-20 mA)
- Ultrasound sensor (0-10 V)
- Low-cost turbidity sensor (0-10V)

The unit is powered by two CR123A LS 14250 3.6V 1.2 Ah lithium-thionyl chloride batteries (Li-SOCl2), which provide 2.4 Ah energy. This is sufficient for both the communication part and to feed the sensing probe. An external battery can also be connected to further extend the life.

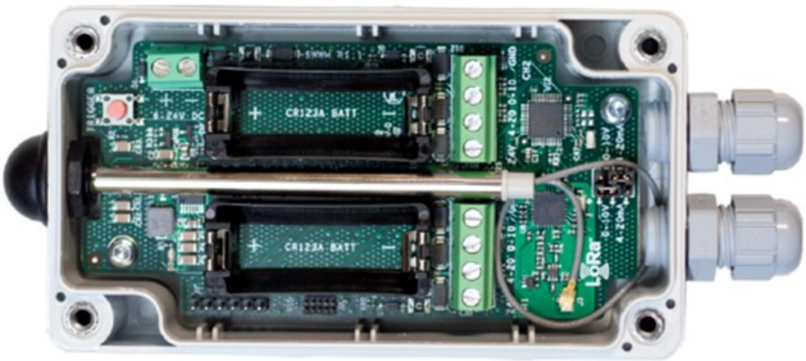

Figure 3: LoRaWAN control and communication unit OY1400.
Image courtesy: Stefan Lindgren,Talkpool

3.2.2 GSM 2G/3G/LTE CAT M1 modem and modem enable measuring boxes

GSM 2G and 3G GSM modules/modems were also used. 2G is now a very old technology, but still has a good physical range (it worked in a concrete well, under a metal plate which is known to add huge attenuation of a radio signal) and can save battery for low number measurements - transmissions per day. The radar sensor used in this project is one example, which has a calculated life of 5 years with 1 measurement - 1 transmission per day. However, that measurement frequency is applicable for very slow processes in a water or solid filled tank, but not good for relatively fast fluctuations. When the measurement is set to every 15 minutes and transmission every day, the battery lasts for more than a year. One good thing is that the radar sensor is very compact, an all-in-one-solution; radar sensor, wireless modem, GPS and Bluetooth for external triggering (for example, floating switches, or water temperature, or other). Another good thing is that Li-battery capacity per volume has almost doubled in a few years and continues to increase further.

GSM 3G measuring box is used in places where the main power is available. This is because the current consumption is too high for any type of battery to last for an extended period of time. The box also needs to be in a good place for radio and GPS reception (if needed). Otherwise, it is a very flexible solution, that can accept many sensor interfaces supported by the industry, as well as provide general digital-relay inputs and outputs. It is also possible to have an RJ45 port for Ethernet/Internet cable attached (fixed or via another 3G/4G/5G modem or WiFi), which provides communication options and security when used with integrated 3G.

Supported interfaces are:

- 4–20 mA
- 0-5V
- DC Resistance
- One wire
- Modbus
- Digital Input/Output on/off (relay output for feedback and control)
- Wireless remote sensor inputs-outputs extender 433/868MHz

GSM 3G is also an old technology, so the next generation will use the LTE CAT M1 as a communication option.

3.3 Communication infrastructure

3.3.1 LoRaWAN radio network

Gothenburg’s LoRa network provided by Talkpool was used in the project. The network is dimensioned for surface coverage in the greater Gothenburg area, and deep indoor coverage in the central city.

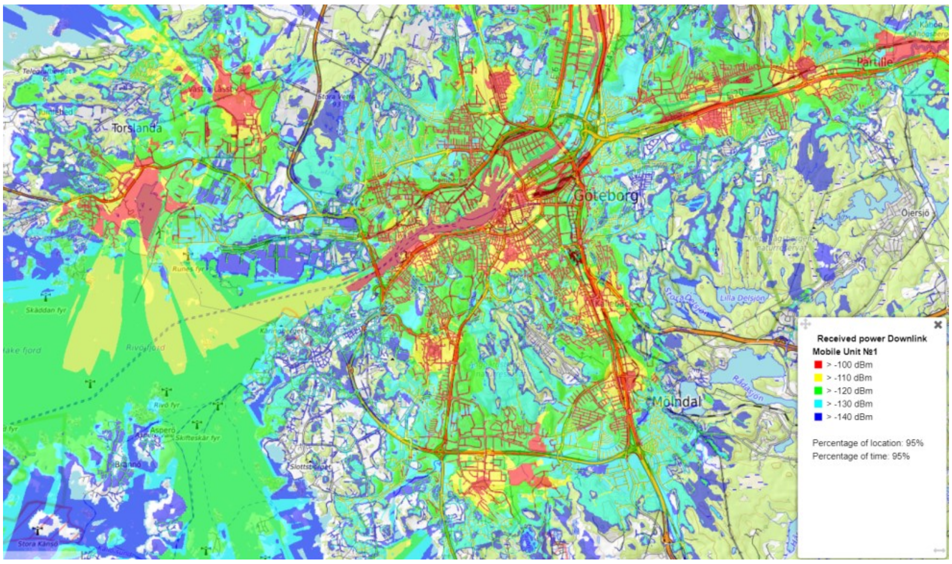

Figure 4: LoRaWAN Radio coverage at street level in Gothenburg.

The attenuation to reach down to the sensor placed under the metal lid in the sewage system is significant, about 30 dB. The expected coverage is about 1 km from a gateway to the manhole. From simulation Figure 5 and Figure 6, an approximately 5-20 dB margin is expected for the sensors placed inside the manhole.

Figure 5: Calculated signal strength at street level, by manhole in Haga/Vasagatan.

Figure 6: Calculated signal strength at street level, by manhole at Seminariegatan.

3.3.1.1 Data Protocol Interface

The data was transferred to the IoT platform as JSON messages over MQTT. A FiWare agent was developed to natively connect the FiWare context broker. More information can be found in the LoV-IoT project work package 6.

3.4 Data storage and processing

The security aspect of the IoT platforms are covered in the LoV-IoT project work package 6.

3.5 IT and data security

Digitalization is a megatrend that provides higher efficiency and better services. As more processes are digitalized, it is important to secure the solutions and give confidence in the system through security and traceability. This is important both internally in an organization to ensure that data and process are correct, as well as for the external parties and the general public to gain acceptance and give confidence in the system.

As data drives more processes and algorithms make autonomous decisions, trust must be built into the system. Ensure that the data is accurate and from legitimate sources and provide traceability of data as well as decision-making algorithms and models.

The data from smart meters and sensors must be confidential, integrity checked and authenticated to ensure that the sensors and meters have not been tampered with, nor that the data has been modified during transport or storage and that the data originates from the correct source. If decisions are made about incorrect or false data, it can have a huge impact on authorities, businesses or individuals.

Digitalization processes within an organization and between organizations increase quality and efficiency. The solutions must give the partners confidence that guarantees correct data, actions, transfer of information, responsibilities or payments can be made more efficiently.

Additional traceability is important for managing responsibility as well as the ability to recreate data and decision-making algorithms to understand the entire system and provide root cause analysis.

3.5.1 Securing the device and data

The data from IoT sensors and meters must have the following features to secure the device data:

Certificates and keys. All good security systems are based on security certificates and keys. The keys must be individual for each sensor and well protected in the device, e.g. in dedicated secure elements, which provide state-of-art protection of keys both from hardware-based attacks, such as probing in the device for keys or listing on internal communication buses. The solution must also protect from software-based attacks by e.g. by reading out memory contents or injecting new code into the device. The keys should never be handled in clear text, not during production, start-up or in working memories during run time.

Encrypted firmware. To protect devices and meters, the firmware image must be encrypted. If the firmware is readable, it allows a hacker to create attack vectors to hack a device, either to provide malfunctions and data, or to provide bots that attack the system from within.

Secure boot. The device should check that the correct firmware is loaded and executed in the device to ensure correct functions and data, as well as protect from turning devices into bots. This is done by using the cryptographic function "hash". The hash function is the basis in blockchain technology, and the cryptographic function provides a unique signature for the firmware. If any part of the firmware is changed, the hash of the firmware is changed. During boot, the firmware is hashed and checked before loaded. The device should be able to report the firmware hash for the running firmware.

Disabled ports. To minimize attack vectors, all device ports should be disabled by default. If ports are available, there is a greater risk of data injection by dumping the runtime code to find attack vectors.

Device integrity. The device firmware is secured by a hash signature. The device should be able to report the firmware version and the hash it uses, proving that the device integrity is maintained.

3.5.2 Communication system

The data from the sensor is sent over a communication system. The data must be protected from injection of false data, replay of old data, or information leakage.

Confidentiality. The data should never be sent in clear text over a communication link. A radio link is easy to pick-up, but also cables are easy to eavesdrop on if you have physical access. Therefore, all data should be ciphered with at least AES-128 bit ciphering.

Integrity. The data must be integrity protected, proving that the data is not modified or altered during the data transfer. Further the system must protect toward replay attacks, e.g. with frame number check and "salt" in messages. The integrity should be protected with AES128 bit or higher.

Authentication. The smart meters and sensors shall be authenticated, proving that the sender is the correct device. The authentication is done with unique IDs and keys. The authentication shall be of strength AES128 bit or higher.

4 Test set-up

4.1 Water level sensors

4.1.1 Hydrostatic pressure water level sensors

The hydrostatic pressure water sensors were installed in a CSO, at the separation wall between the main pipe and the overflow pipe.

Figure 7: Typical manhole and CSO. Image courtesy of Stefan Lindgren, Talkpool.

The LoRaWAN control and communication unit OY1400 was mounted on the well wall under the lid. Both channels were used, where one channel was connected to the on/off float switch. The switch was sampled every 30 seconds to identify high water levels and the first flush. When the float switch was activated, the exact water depth was measured with the hydrostatic pressure sensor, or every six hours to get statistics of normal flow.

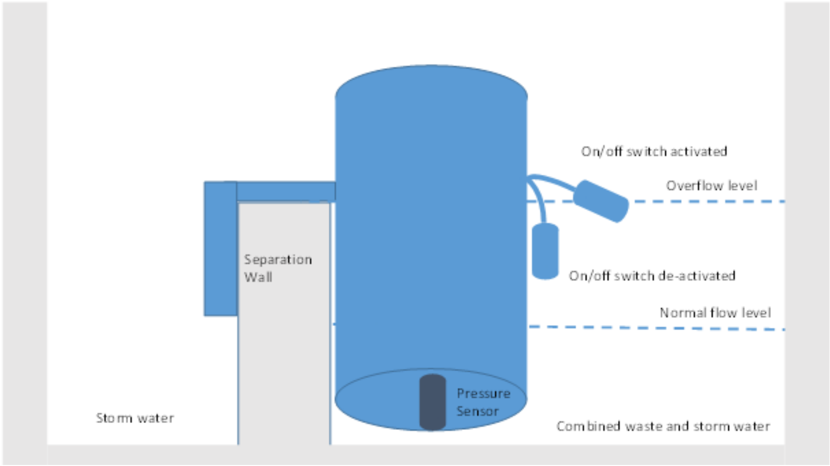

Figure 8: Schematic figure of combination of on/off float switch and hydrostatic pressure sensor.

The hydrostatic sensor is placed in a tube for fixation and protection of the sensor from solid waste in the water. The on/off floating switch is mounted on at a trigger level, when exact measurements should be done.

4.1.2 Ultrasonic water level sensors

An ultrasonic sensor CRM+600/IU/TC/E from Hemomatik was mounted on the inside wall of the manhole (the sensor to the right in the picture below) and connected to an OY1400 controller unit for transfer of data via the LoRa network.

4.1.3 Radar water level sensors (2G)

A Senz2 radar sensor, WLR05-2G/001, from Staal Instrument (formerly Omniradar), measures water level and air temperature. It is a hermetically glued box with a battery, a worldwide SIM card, a working with 2G, and a GPS on board. It was mounted on the inside wall of the manhole as seen in the image, Figure 9 (radar sensor to the left).

Figure 9. Radar sensor (fully equipped with radar, battery, GSM 2G communication, GPS, Bluetooth) and Ultrasonic sensor (cable not attached). Both sensors are non-contact ones, so no garbage collection and no maintenance are needed. Image courtesy by Dimitar Kolev, RISE AB.

4.2 Turbidity Sensors

4.2.1 Turbidity ultra low-cost

The ultra low-cost turbidity sensor, based on an encapsulated Amphenol washing machine sensor TSD-10, connected to a Talkpool OY1400 was installed.

4.2.2 Turbidity low-cost sensor type I

The IVL-developed turbidity sensor was mounted in a manhole outside of Uponor in Fristad, Sweden. The water flowing through was stormwater that had already passed through Uponor's water cleaning system, located a couple of meters away. The manhole was about six meters deep and the sensor was mounted about three meters above the surface, see images below.

Figure 10: Images from the installation point in Fristad, outside of Uponor's office. Image courtesy of Jens Wilhelmsson, IVL.

Besides the low-cost sensor developed by IVL, a Campbell Scientific OBS501 turbidity sensor was mounted, which is depicted in the image below. In contrast to the low-cost sensor, it is not contactless. It needs to be in contact with the water and was therefore mounted hanging in a rope as can be seen in the image.

Figure 11: Image from the installation point in Fristad, outside of Uponors office. Image courtesy of Jens Wilhelmsson, IVL.

The Turbinator was also installed in a stormwater well, close to a big infrastructure project, The West link project (Västlänken) in Gothenburg. A similar installation as the one made in Fristad was carried out here. The sensor was mounted a couple of meters above the water surface. The reference turbidity sensor Campbell Scientific OBS501 was used here as well.

Figure 12: The Turbinator mounted in a stormwater well in Gothenburg. The cable on top of the sensor is a connection to another sensor and is not a part of the Turbinator. Image courtesy of Jens Wilhelmsson, IVL.

4.2.3 Turbidity low-cost sensor type II

Uponor sensor, which is a camera-based system normally used for drinking water, was not optimal to use for stormwater. The camera lens became covered with sediments/biofilm way too fast to be of any practical use in stormwater applications. We have not received any results from the test that can be used for further development.

In Pilot 3, different quality sensors (Uponor, Talkpool, IVL) were tested in parallel with traditional flow sensors. The traditional flow sensors were proportional to laboratory tests in two chambers at Uponor Infra B in Fristad. These two chambers are located downstream from a rain garden installation and a sedimentation chamber installation.

5 Installation

Essential for every sensor project is installation, maintenance and reliable collection of measurement data. Careful installation is also important, so that no obstacles or damage on existing infrastructure occur during installation or removal of the sensors.

Initial examinations of several wells were made, and one observation was that almost all sites/facilities have different designs and structures. Due to this, different installation variants for fixing sensors and communication boxes had to be done. It was clear that external power supply is generally not possible, so the only options were to use batteries and smart measurements/send data over LoRA and GSM networks. Therefore, all sensors and communications with high power consumption were not practical or not even possible to use. Furthermore, power or antenna cables were not an option either - except in specific cases such as the Flottsund bridge, where main power is located.

The initial setup consists of hydrostatic pressure water level sensor and floating level switch. The advantage of hydrostatic level sensors is that they are made for an aggressive water environment, have a linear response, fast time, minimum power consumption to the first valid measurement, reliable and durable. Level switches have the same characteristics and it is an absolutely passive device, so no power consumption at all. During periods when the water is below the critical level, the measurement interval is relatively long, but once a flooding event occurs, the floating switch detects it and the measurement interval becomes much shorter, giving a better time resolution of the flooding event. When the flooding episode is over, the floating switch indicates this, and the level signal measurement time will go back to long report intervals.

Hydrostatic level and floating level switch sensors have 5-meter long cables, which are usually enough for most of the installations. The cables are soft and thick, so they are tailored to survive aggressive environments (water, oil, acids and animals) underground and at the same time be easy to work with.

Even though a hydrostatic level sensor is industrial and durable, it needs some additional protection and care – especially when used for measurements in waste-/rain- water environments. This is done by using standard water plastic pipes, which facilitates a few important things:

- easy installation
- protects sensors from direct hit, mud, and all kinds of floating artefacts
- easy visible water level (centimeter marks, not visible on the picture)

Figure 13: Hydrostatic sensor in the tube and floating switch outside, plus LoRa control and communication box. Image courtesy of Dimitar Kolev, RISE AB

Once installed, the hydrostatic and floating switch sensors do not require much attention. However, the cable that connects them to the LoRa control and communication box sometimes needs to be cleaned and flushed with water, since big, small, soft and hard garbage get stuck to the connecting cables, and can stop normal function of sensors or even normal waterflow. This maintenance requires time and possibility to flush water.

The radar level indicator consists of a battery, a radar sensor, a beam forming lens, an air temperature sensor, processing and communication, plus a GPS and a Bluetooth device for external sensors. There are no keys for opening it up, there is just a magnetic switch under the box cover to turn it on. It is therefore not possible for water or grease to enter the unit.

Figure 14: Well at Sävenäs/Renova. Image courtesy of Dimitar Kolev, RISE AB

Figure 15: All water sensors installed at the Flottsund bridge in Uppsala. Image courtesy of RISE AB. From left to right: 1. 3G sensor box / water hydrostatic level (depth) / pH / TDS-Conductivity / water temp / air temp-humidity (RISE). 2. Turbinator (IVL) 3. Water level radar (RISE) 4. Conductivity (Talkpool). Image courtesy of Dimitar Kolev, RISE AB

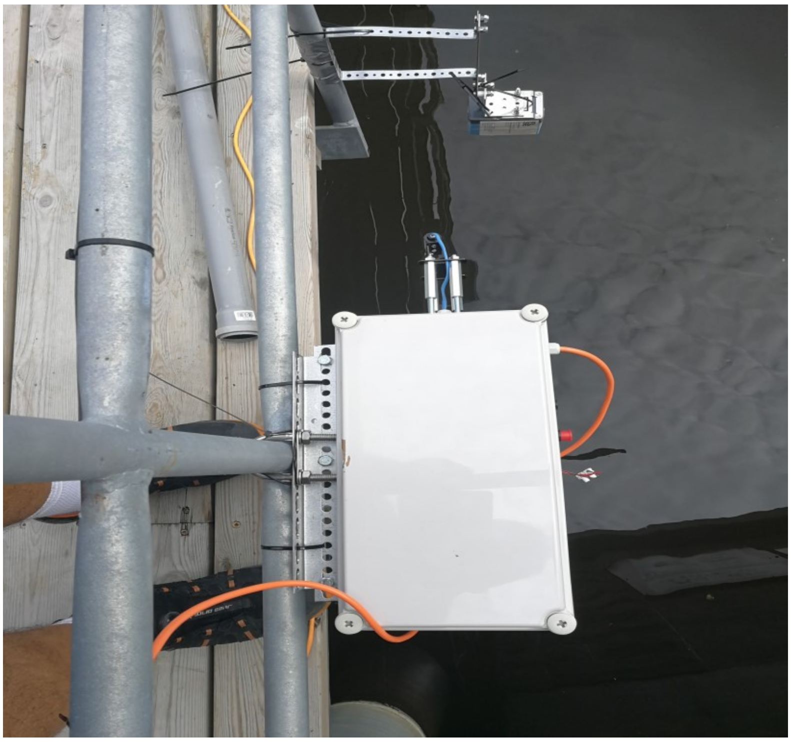

Figure 16: Turbinator and radar installed at the Flottsund bridge in Uppsala. Image courtesy of Dimitar Kolev, RISE AB

Figure 17: Flottsund bridge and sensors in perspective. Image courtesy of Dimitar Kolev, RISE AB

Packaging of control/communication units is important and is preferably done in boxes with good environmental protection, in IP67-class or similar. It is also desirable to use boxes of good UL class grade, which indicates fire protection, and high resistance against drops, hits, vibration and other possible damaging factors.

The current installation used IP67 boxes, and sometimes “box in a box” concept, with the appropriate cable glands for the sensor cables. The best case is fully enclosed cases, such as the radar sensor used in this project, which is a hermetically glued box. Using glued or ultrasonic/thermosonic sealed boxes is very good from a protecting point of view, but not that good in terms of availability for maintenance and service events.

The batteries used are usually primary LiIon sources with high energy/high capacity (without charging). It is therefore important to have batteries short circuit protected, as it is very possible that they could get water intrusion or short circuit of any kind during their lifetime and it should not cause excessive temperature rise or fire if they are short circuit protected.

Boxes used in this project is the IP67 type, with transparent lid and the possibility of two internal sections, which are also waterproof. Easy configuration change is ensured by an additional insert plate with measurement electronics mounted on spacers or by another appropriate stand. The box also has a mounted standard hook, which makes it universal and easy to hang/fix to different types of fences and guard structures near the water. All cables are passed through the appropriate cable glands.

Sensor cables should always be flexible, thick enough to survive aggressive mechanical and any possible chemical incidents. To fix the cable correctly is also important, as accidental slipping of a cable can give incorrect or even false results. Cables should also be fixed so that that they do not obstruct normal water flow or other permanently fixed devices at the measurement place. The installation should also take place in a safe way, both for the sensors and for anyone or anything (for example marine vessels) in the environment.

When using batteries, there are usually no external power cables and thus no possible connection and safety problems. However, when relatively fast measurements are performed in the long term, batteries are not enough. This always requires an external power supply and a few important things should then be considered. For maximum safety, always use a certified electrician or electrical engineer who knows what to do and how to install connections. Always use high voltage mains cables that are as short as possible and power splitters that are as protected as possible. When longer cables are unavoidable, use safe, much lower DC voltages (5-24VDC) or similar. Color and labeling are also strongly recommended, so that all technical personnel can distinguish between a sensor cable and a power cable and how these can be handled in an emergency.

Last, but not least, all measurement instruments/boxes should have water and weather resistant ID labels, with address, telephone number, e-mail address to someone who can respond as fast as possible 24/7, in case of emergency.

6 Results

All measurement series have an ID which are used in this chapter. The measurement campaigns are listed in Appendix B.

6.1 Water level sensors

6.1.1 Quantitative results

Between 2017.06.04 and 2018.08.25, the combined sewer overflow (CSO) at Vasa/Hagagatan [M1] had an overflow event 22 times. A typical event is shown below. The overflow threshold is 0.5 meters. The first overflow lasts for approximately 30 minutes, then the water level drops, but when the rain continues and the sewage system fills up, a longer overflow event occurs that lasts for about 4 hours.

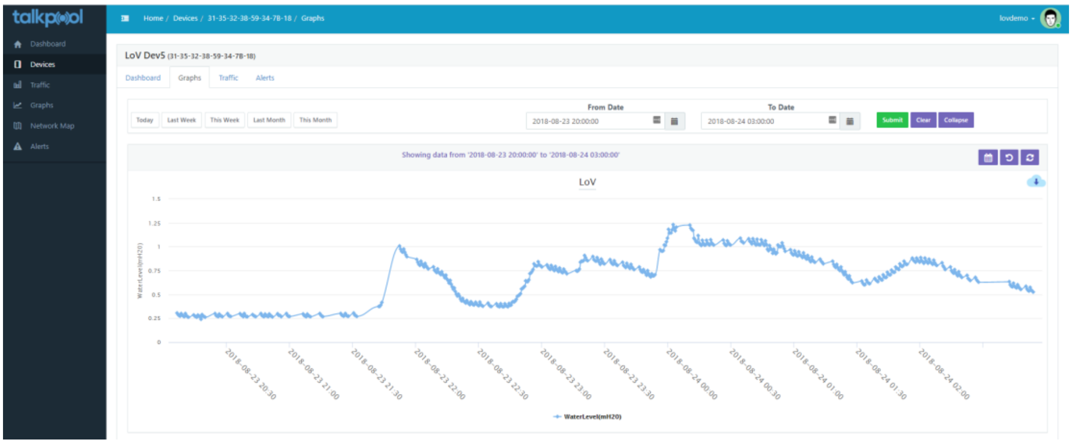

Figure 18: Typical overflow event at a CSO. The overflow is at level 0.5 m.

Comparison of the results [M1] for the entire period with SMHI's open data for rain per 15-minute interval mostly shows good correlation.

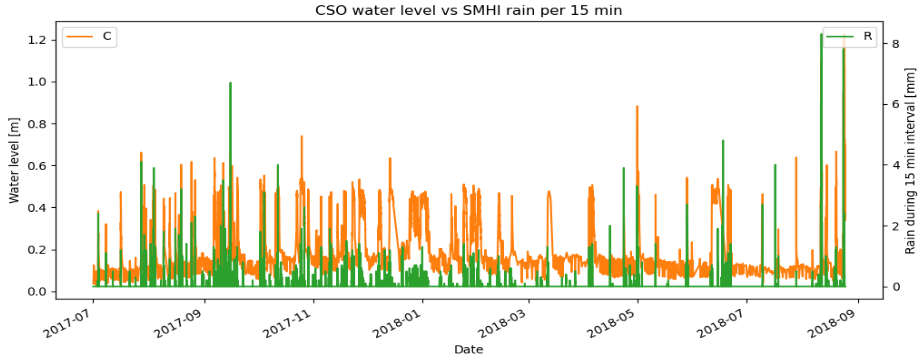

Figure 19: Overflow and water level in CSO (orange) compared with SMHI accumulated rain per 15 intervals at station Göteborg A.

6.1.2 Comparison between different measurement techniques

The water level was measured using various techniques. A comparative measurement [M6] shows good correlation in Figure 20. The absolute values differ since no common reference point was used. In most applications, the relative water levels are of interest and not the absolute level.

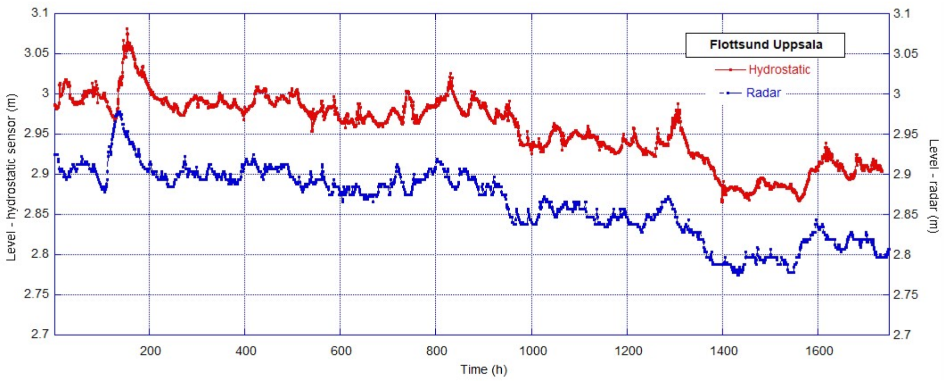

Figure 20: Comparison between the hydrostatic and the radar level sensors monitored at Flottsund in Uppsala during the summer of 2020 [M6]. As can be seen from the data from both sensors, the results from each of the sensors are quantitatively very similar.

6.2 Turbidity Sensors

6.2.1 Quantitative result

The turbidity was measured at Uponor [M13] & [M16] using a Campbell Scientific OBS501 turbidity meter, along with the Turbinator from IVL. The following time series are from the Campbell Scientific sensor.

Unfortunately, there were two problems with the mounting point at Uponor in Fristad. The first one was that the water passing through the manhole was very clear, see the image below to get an idea of the measured turbidity. The "spikes" in the first figure below are most likely outliers. The reason for the outliers could be that it was not sure that the sensor was always submerged, as the water level was observed to be very low.

The second problem was the water flow. The water level was not high enough for the low-cost sensor to make any measurements, since it requires a laser beam to propagate through a couple of decimeters of water. Lower turbidity also requires a higher water level because the laser beam propagates longer in clear water. Therefore, the results shown in the figures below are from the reference sensor (Campbell Scientific OBS501) used together with the low-cost sensor.

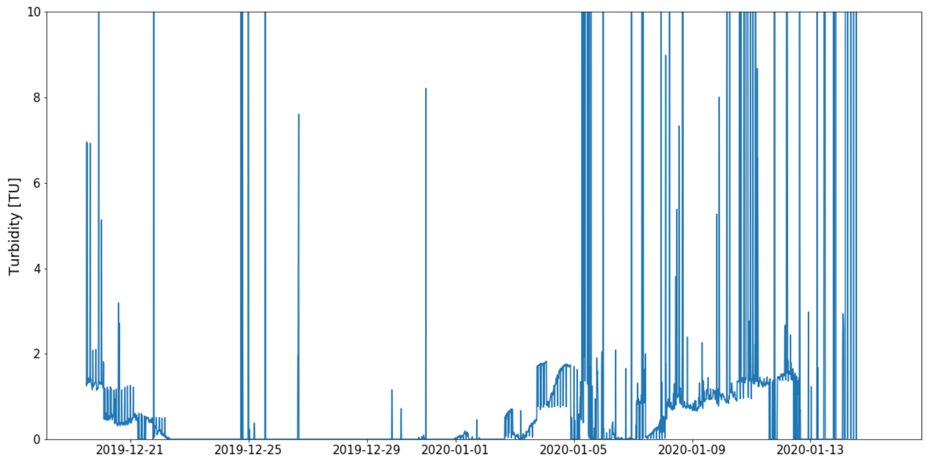

Figure 21: Turbidity over time measured at Uponor with Campbell Scientific OBS501 [M13]. Many peaks that look like outliers with zero values - possibly because the sensor is not always submerged and thus measure the thin air. The sensor does not have a way of knowing if it is submerged or not. The short periods of continuous measurements, for example around 2020-01-09, indicate the actual turbidity level which is about 2.

What can be said about the results presented above is that the turbidity after cleaning at Uponor is very low. It also points out that the Turbinator requires a certain water level to be able to measure turbidity.

6.2.2 Comparison between different measurement technologies

6.2.3 Turbidity ultra-low-cost

The individual behavior of the ultra-low cost sensors were measured in the laboratory in various concentrations of turbidity reference mixture [M19].

The results in Figure 22 confirm that inexpensive sensors are probably good for measuring turbidity, however each sensor must be characterized, calibrated and confirmed against standard turbidity meter (for example Hanna HI-93703) and turbidity calibration. Color/reflectivity of the measured particles has also influence on measurement. Proper water encapsulation (these sensors can be under 5 meters of water or more) should also be performed. Finally, a good mechanical or other cleaning method should be implemented, since organic buildup (biofilm) from waste/stormwater will grow and lead to incorrect results in the long run. Short time periods of a few weeks have shown that they do not affect the measurements, even if the sensor was placed in a biofilm-friendly environment.

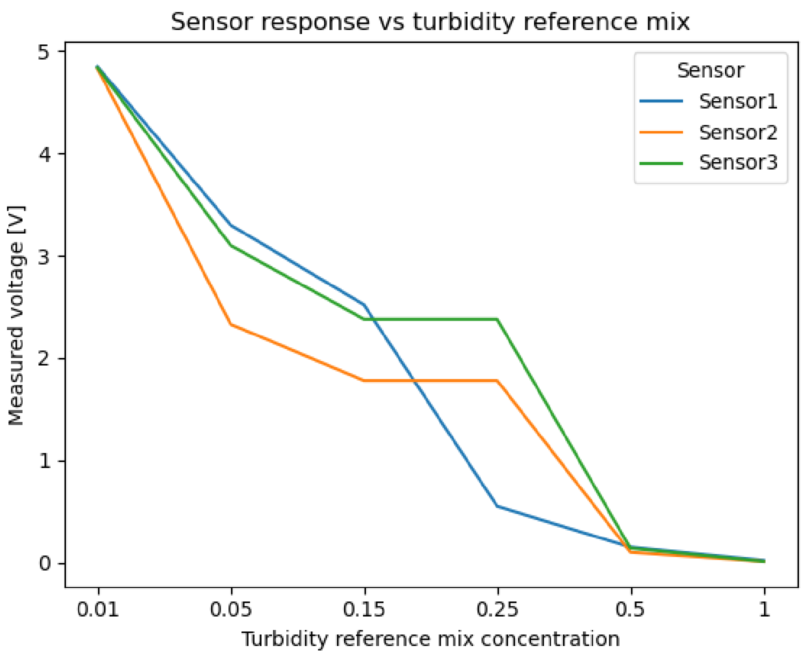

Figure 22: Ultra-low-cost turbidity sensors measurements [M19] in the laboratory environment.

The following two figures are from a measurement [M7-M11] which was conducted during the summer of 2019, in Patric Kristiansson's independent well. The red and green lines are from the ultra-low-cost turbidity sensor and the blue line is from a reference turbidity measurement (Campbell Scientific OBS501).

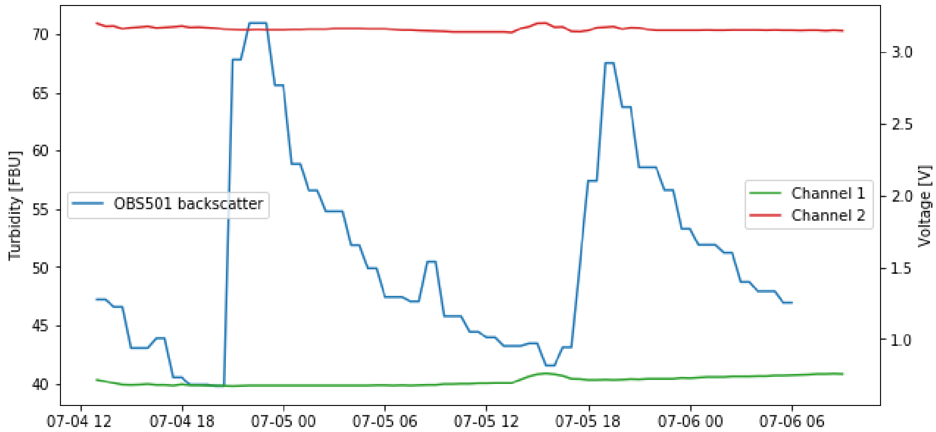

Figure 23: Backscatter is the measured turbidity from the Campbell Scientific OBS501 turbidity sensor [M8]. The voltage "Channel 2" is from the ultra-low-cost sensor [M9]. There is no clear correlation between the ultra-low-cost sensor and the reference sensor.

Based on this data collected over a few days, it is very hard to find any correlation between the reference sensor and the ultra-low-cost sensor. If one were to assume that the blue peaks are real, it would indicate that the ultra-low-cost sensor is not working properly as no correlation can be seen.

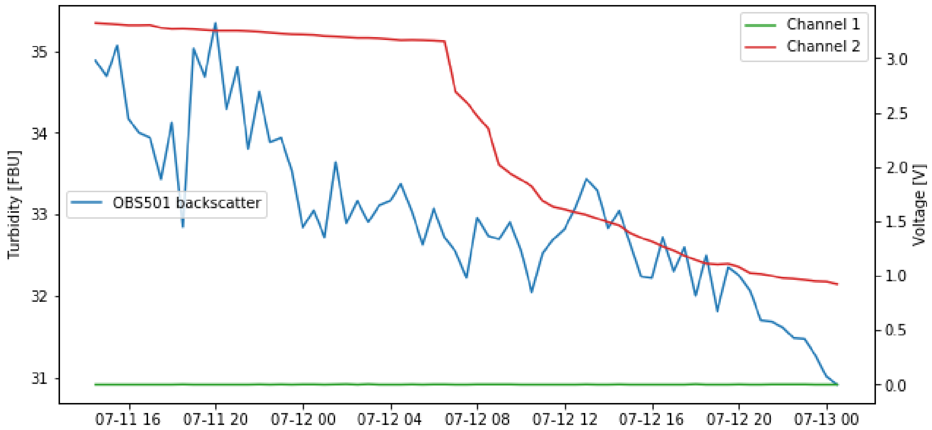

Figure 24: Backscatter is the measured turbidity from the Campbell Scientific OBS501 turbidity sensor [M8]. The voltage "Channel 2" is from the ultra-low-cost sensor [M9]. A slight correlation can be seen between "Channel 2" and the reference sensor measurements, indicated by the fact that all of them are constantly decreasing.

However, when looking at the data from the second measurement period, which is presented in Figure 24 above, it is clear from the blue line that the turbidity is slowly decreasing. The "Channel 2" signal can also be seen decreasing during the current time period, which implies that there is a correlation. "Channel 1" is not connected. This result indicates that the ultra-low-cost sensor may be used to indicate high/low turbidity but may not be with higher precision than that.

6.2.4 Turbidity low-cost sensor type I

The figure below presents the results from when the Turbinator [M16] measured alongside the Campbell Scientific OBS501 turbidity sensor in the stormwater well, located near the large infrastructure project "Västlänken" in central Gothenburg. It is important to notice that the Turbinator is a prototype sensor, based on image processing using AI. To generate the results below, data from the time period three weeks prior to the the x-axis periods was used as training data. Without going into too much detail, this means that the results from the Turbinator can be improved through more extensive training because its performance under certain conditions is related to how much it has been trained under similar conditions.

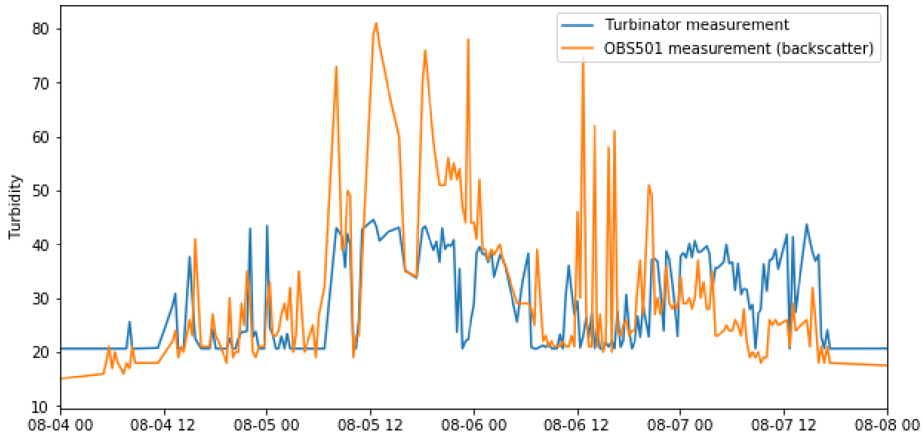

Figure 25: Turbidity measured by both the Turbinator and the Campbell Scientific OBS501 turbidity sensor in the stormwater well in Gothenburg [M16], located close to the large infrastructure project "Västlänken".

The Turbinator seems to have a tendency to output turbidity levels around the average turbidity for the measurement period (about 40 turbidity), which fits the AI theory well – it is a matter of minimizing the error between the actual turbidity (OBS501) and the Turbinator measurements.

The reference sensor measurements (the orange line in the figure above) are fluctuating relatively much. It is natural that the turbidity fluctuates quite a lot in the stormwater system, but at the stormwater well there is also a pumping station located nearby that can increase the effect. This behaviour from the pumping can be clearly seen in Figure 30, which has the same measuring position and time period.

A key finding here is that the accuracy of the Turbinator measurements presented in the figure above is considered useful for in applications with storm water wells, although better accuracy is of course desired.

6.3 Sensors results from pH, conductivity and level measurements

Measurements in the open water recipient, the river Fyrisån were done at Flottsund. The data were compared against a measurement setting made by SLU, the Swedish University of Agricultural Sciences in Uppsala.

For about 3 weeks, the readings of the inexpensive conductivity sensor and the reference measurements [M6] follow each other quantitatively very well. However, after about 3 weeks the signal from the inexpensive sensor drops suddenly (within 1-3 hours) and remains stable but at a much lower level compared to the reference readings. We do not understand the possible cause of this sudden signal drop. In contrast to pH sensing, conductivity sensors are mechanically simple and robust and should be able to withstand harsh conditions in the field. We hope to more clarity after inspection the sensor when it returns to the laboratory.

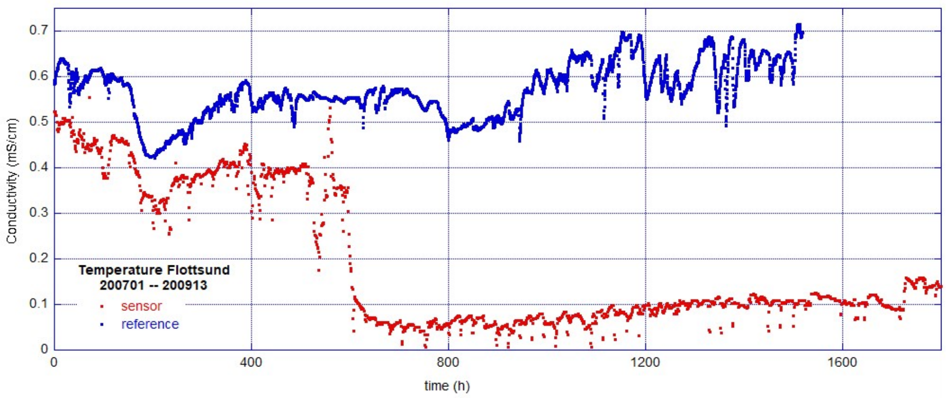

Figure 26: Conductivity measurement [M6], low cost conductivity probe compared to reference instruments.

The pH measurements [M6] in Figure 27 shows that the cheap pH sensor performs poorly. Already after 1 week, the sensor seems to require hands-on support. Its reading becomes unstable and deviates from the stable pH level measured by the reference. This is probably due to problems with the sensor reference electrode, such as a need to change KOH fluid or a recondition of the Ag-reference electrode is required.

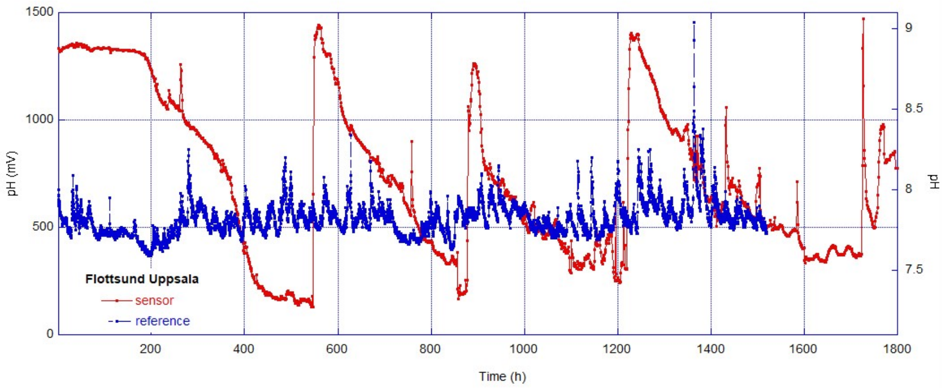

Figure 27. Measurements of pH [M6] shows that the cheap pH sensor performs poorly. Already after 1 week, the sensor seems to require hands-on support. The period is 01Jul-15thSept 2020. The log interval is 1 hour. The maximum variation in pH in the figure corresponds to 6.5 to 8.5.

“Aging” of reference electrodes is a well-known bottleneck when using pH sensing in the field and/or for prolonged continuous measurements. It will be very interesting to investigate the status of the sensor after it returns to us, as it will bring more clarity to why it failed.

Due to limited mobility related to the Corona-virus, we could not personally investigate the installation site, and therefore failed to install additional sensors, e.g., pH sensors. We have one non-commercial pH sensor that was designed to last for months. We have confirmed its performance during a few weeks at the laboratory and it worked well. Therefore, it would have been of interest to investigate this design.

Temperature measurements [M6] compared to a reference used by SLU were very good. During this period, the water temperature varied only by 4 degrees, and was 20C+-2C. This implies (roughly speaking) that the influence of temperature variations on the readings of pH sensor or conductivity sensor, respectively, was negligible.

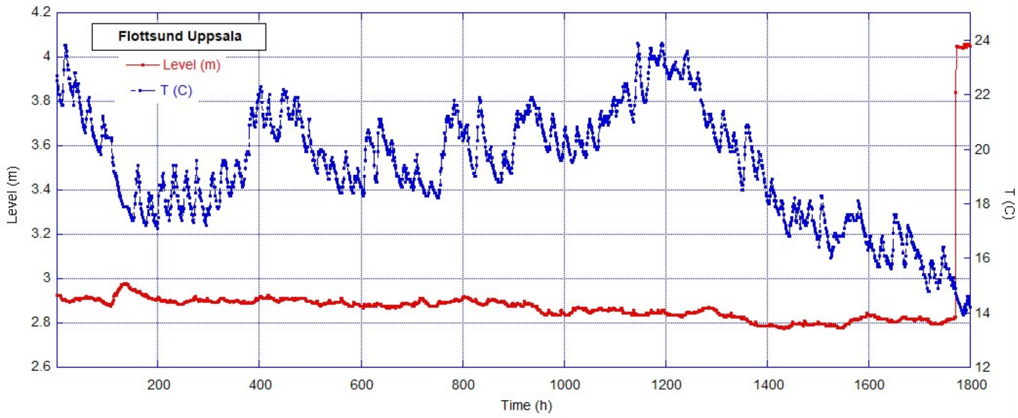

Figure 28. Measurements of water level [M4.1] and air temperature [M6] at Flottsund in Uppsala. The period is 01Jul-15thSept 2020. Hydrostatic sensor (4-20mA) on the bottom layer (the red line) and air temperature near the water surface (the blue line). Day and night variations of surface air temperature are clearly visible, as is increased water levels during July. The log interval is 1 hour.

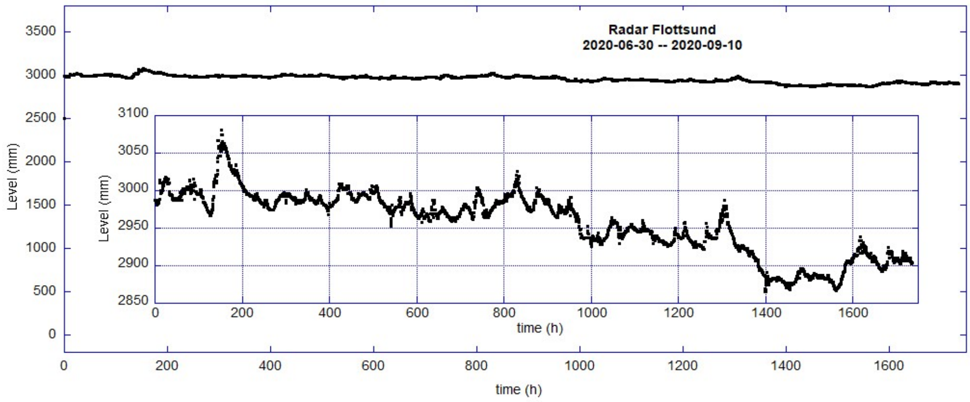

Figure 29. Measurements from radar water level [M4.2]. The period is 30Jun-15Sep 2020. The log interval is 1 hour. The initial peak and slow decrease can be seen, as on the previous data from the hydrostatic sensor.

6.4 Indirect measurements

Turbidity is a key parameter as it is a good measure of early warning of pollution and can also be used as an indicator for other pollutants. Most counter measurements at construction sites for cleaning the water are also based on the removal of particles. The indication of other pollutants is very specific depending on location and the type of sources of existing pollutants, correlation models need to be developed for each location or application.

Measurement of the most important water quality parameters was difficult to measure at low cost and acceptable accuracy. Previous studies of the correlation between the "difficult" parameters for turbidity, pH and nutrients (NO3-N and NH4-N), against simple parameters such as water level, conductivity and temperature, are low in stormwater applications. Further reading of the correlation between different water quality parameters are described in the report The LoV-IoT project - Water.

At the measurement site in Gothenburg, which is located at the construction site for the large infrastructure project (Västlänken), turbidity and water level was measured in a stormwater well to see potential correlations between the two parameters over time. The results [M16] can be seen in the Figures below.

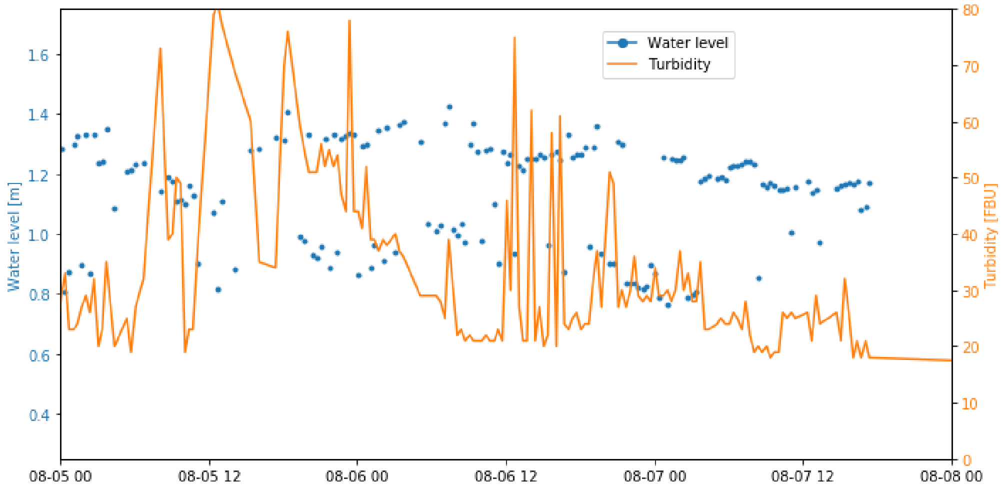

Figure 30. Water level measured with Turbinator and turbidity measured with Campbell Scientific OBS501 [M16]. The water level is "jumping" between two clear levels at about 0.9 and 1.3 meters, which probably indicates some kind of pumping or similar since the behaviour is too recurring to be precipitation.

The water level is fluctuating between two clear levels, about 1.3 meters and 0.9 meters. This is likely the result of a nearby pumping station and not caused by precipitation.

Turbidity and water level do not need to be correlated because in heavier rain we will have an effect of high concentrations early, which is then diluted over time depending on the situation. The interesting thing is to see changes over time in correlation and behavior. That may be an indication that the system needs to be cleaned due to a heavy load of particles and flow that has built up material in the pipe.

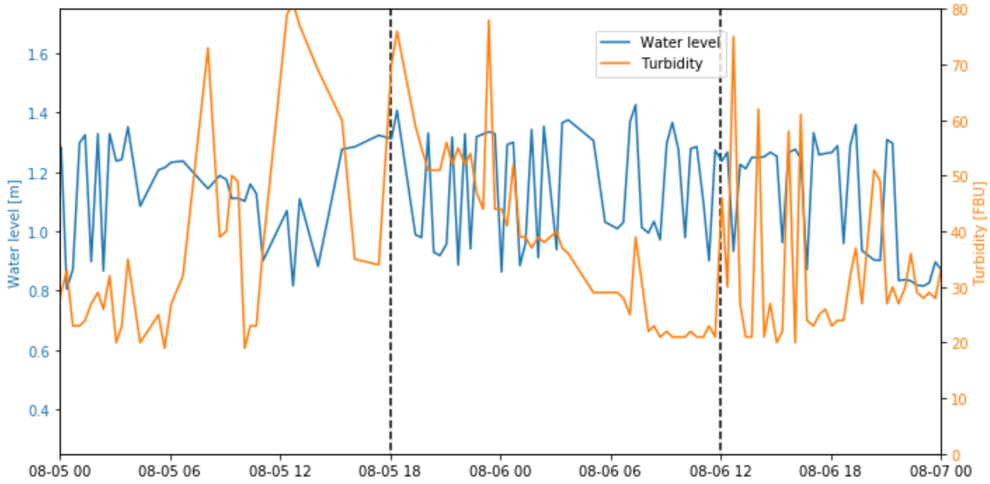

Figure 31. Water level measured with Turbinator and turbidity measured with Campbell Scientific OBS501 [M16]. Notice the time period between the black dotted lines where the two signals deviate which is likely to be because of that the water gets cleaner over time after a period with more rain.

6.5 IoT measurement technologies

The use of the LoRaWAN communication technology enables increased link budget and long battery life.

An OY1400 LoRa control and communication unit from Talkpool, with 2.4 Ah battery was connected to an on/off float switch and a hydrostatic pressure sensor. The floating switch was sampled every 30 second and the pressure sensor once per measurement report. The unit was able to measure the on/off switch 1.2 million times and the hydrostatic pressure sensor 47 110 times and transmit 47 110 measurement reports over a period of more than one year [M2].

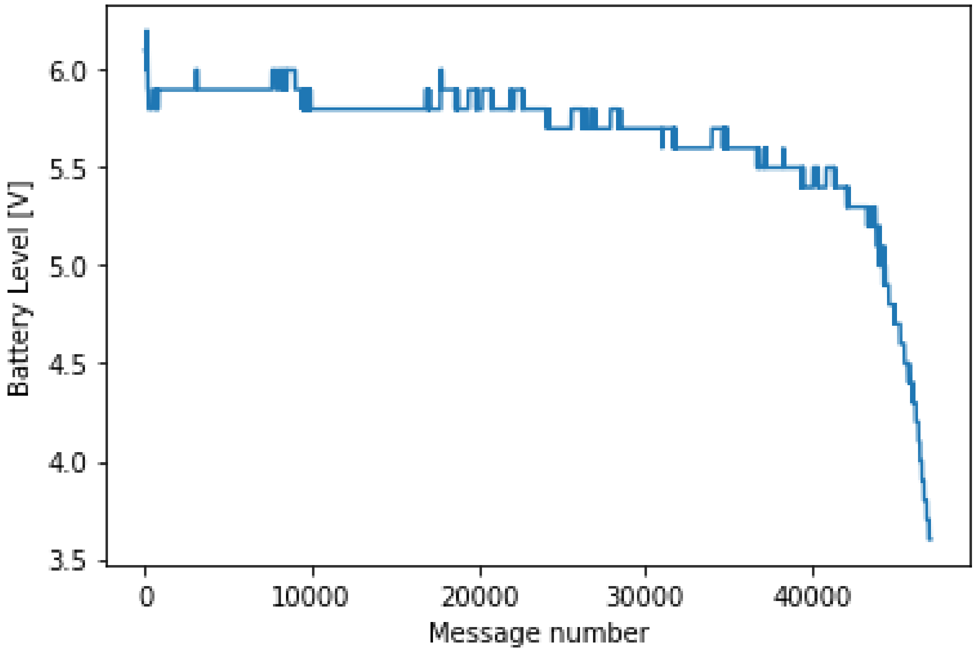

Figure 32: Battery voltage on OY1400 vs transmitted report [M2]. The OY1400 was powering one on/off float switch sampling every 30 seconds and a hydrostatic pressure sensor sampling once per measurement report.

6.6 Experience from operation and installation

The maintenance department for Sustainable Waste and Water, Gothenburg, has been involved in the follow-up of measurement points used in the project and their experience can be summarized as follows:

1. All sensors tested in the overflow wells could be inspected visually throughout the measurement period
2. The mounted sensors that were in contact with water (level pressure sensors) had collected a large amount of wastewater residuals (toilet paper, etc.)
3. The maintenance personnel did not have a clear picture of how the tested sensors are maintained, how often and by whom
4. The contact sensors can cause a blockage in the overflow wells and contactless sensors are preferred due to the large amount of residues abundant in overflow wells.

Figure 33: Clogging effect by sensors placed in the water stream, stopping residuals such as paper and plastic. (Image courtesy of Dimitar Kolev, RISE AB)

In Figure 33, the installation at the center consists of cables and a tube for the hydrostatic sensor and floating switch. Cables inside the well will cause trouble when garbage gets stuck and obstructs the flow in some cases and needs to be flushed regularly to maintain proper function. There is a need for a different and better way of installation.

During the maturation of dedicated IoT communication networks, strategies for outages or lack of coverage in sewage systems need to be considered. This can be achieved with redundant coverage, or local storage of measurement data.

7 Conclusion and next steps

7.1 IoT sensors for environmental supervision

The project shows that massive deployment of low-cost sensors is an attractive method for collecting data and get visibility of a vast infrastructure such as stormwater and sewage systems in a city.

Dedicated IoT networks such as LoRaWAN provide sufficient network coverage even down in wells and in the sewage systems. Low battery consumption for communication enables long service life. The IoT devices that support off-the-shelf sensing probes are relatively inexpensive, resulting in low total cost of ownership per measurement.

The project also shows that the most important limitations for having a long service life, low maintenance costs and high measurement accuracy are due to the measurement probes. In particular, the sensors placed in the water are exposed to residues and harsh environments during maintenance operations such as pipe cleaning with high-pressure water. In addition, the measurement probes are usually more expensive than the communication and control units and have high battery consumption.

It is likely that in the near-future more cost-effective sensors will be available. This due a volume demand for sensors and with the makers movement for sensor automation. The sensors need to be evaluated and characterized for which application they can be used for, and whether the accuracy can be improved with machine learning algorithms. This development can enable innovation for the control of stormwater and sewage systems in a city.

7.2 Parameters for water quality

The evaluation of the interesting parameters for water quality versus cost per measurement are shown in the table below.

Parameter	Interest	TCO* per measurement	Correlating parameter
Turbidity	High	High	None
pH	High	High	Turbidity
Conductivity	Mid	Low	Nutrients
Water level	Mid	Low	Water flow
Water flow	High	High	Water level
Water temperature	Low	Low	None
Nutrients (NO3-N and NH4-N]	High	High	TurbiditypHConductivity

**TCO - total cost of ownership (an estimate of all the direct and indirect costs involved in acquiring and operating a product or system over its lifetime).*

Turbidity is one of the most interesting parameters, and it cannot be replaced by some cheaper indirect measurement method. The low-cost turbidity sensors developed in this research project do not provide sufficient accuracy and low maintenance to replace or complement the high-cost instruments, but the results suggest that further research and development can make it possible.

7.3 IoT impact on water issues in a city

The project was set up as an innovation project, with a focus of the environmental benefits that IoT can provide to a city. The environmental department focuses on high accuracy and standardized environmental reporting to the Swedish Environmetal Protection Agency (Naturvårdsverket) and the Swedish Agency for Marine and Water management (Havs- och vattenmyndigheten). Early warning systems for high emission in waste and stormwater are not included in the departments' work.

The project found that the greatest potential is the operational department, where clogging and preventive maintenance can significantly improve operations.

Today, the existing data harvested from SCADA systems and sensors at pumping stations, are usually only used for troubleshooting or documentation after a problem has arisen. The organization is not data driven, and the potential benefits from data e.g. preventive maintenance, early detection of leakage, clogging detection, emission, etc. are not quantified for the organization.

7.4 Standardized setups

A challenge in the project was to gain access to stormwater and sewage systems for testing. Installation and site visits required the assistance of the operational staff, who were not officially part of the project nor the budget.

The CSO's where the sensors were installed had different designs, so a challenge was to develop a good mechanical fitting, not impacting clogging nor maintenance work by the operational staff.

7.5 Recommended next steps

During the project, we have learned a lot in terms of both practical solutions for how to deploy sensors in a city and an understanding of how simpler sensors can be used for online measurements. The biggest advantage that the Department of Sustainable Waste and Water, can see is the use of sensors and IoT for predictive maintenance. To develop a solution for predictive maintenance, you need at least a water level sensor and preferably also a turbidity sensor to predict how much load there has been on a system over time. This prediction can be used to alert the operational staff that a system needs to be cleaned to maintain its performance. Some of these ideas is further developed in the EU project SCOREwater.

One recommendation is to run a strategy project to quantify the benefit of making the organization data-driven, and what parameters are needed to achieve each benefit. The strategy project should also prove the benefits of implementing a minimal valuable product.

For the low-cost turbidity sensor, which is currently being developed by IVL, it is crucial to harvest a lot of data as it is based on the principle of machine learning algorithms where data is required as training material. The more gathered data, the better performance of the sensor.

7.5.1 Test bed

To enable further research and product development it would be beneficial with a test bed of wells that researchers and product developers could test the products in real environment, without affecting the operation.

Appendix A

Sensing elements

Manufacturer	Name/product number	Sensing principle	Measures	Plc. #	Specification link	Current location	Previous location	Communi-cation
Delta Instruments	SP-520L	Hydrostatic pressure	Water depth, analog output 4-20mA		http://www.deltainst.com/uploads/pdf_english/SP-520L-e_new_405.pdf	In Uppsala	Gothenburg	Ext. LoRa and 3G
Hemomatik	Floating switch, HM-1C10M-R	Floating probe with rolling contact ball	2/3/4/ water levels, discrete sensing, on/off output		https://www.hemomatik.se/PDF/HM-1C10M-R_h2.pdf	X	Gothenburg	Ext. LoRa
Staal Instruments	Senz2, WLR05-2G/001	Radar and integrated thermistor	Water level and air temp, digital output, wireless		https://www.staalinstruments.com/project/wireless-level-radar/	In Uppsala	Gothenburg	Own, 2G
Microsonic	CRM-500/IU/TC/E	Ultrasonic	Water level, analog output 4-20mA, 0-10V		https://www.microsonic.de/en/distance-sensors/chemical-resistant/crmplus/standard-sensors/standard-sensors/crmplus600iutce.htm	Lab	Lab	Wired measurements only
Amphenol Sensors	TSD-10,0-4000NTU	IR-transmission	Turbidity, analog output, 0-5V		https://amphenol-sensors.com/en/thermometrics/turbidity/2958-tsd-10	Lab	Lab	Wired measurements only
DF Robot	TDS, conductivity	Simple dual electrode	Conductivity, analog output, 0-5V		https://www.dfrobot.com/product-1662.html	In Uppsala	x	ext. 3G
Szoway	Digital multi-parameter PH/TEMP/EC/CF/TDS water quality monitor OW-117, use only pH meter	Glass electrode gel filled	pH		http://www.szoway.com/New%20waterproof%20portable%20digital%20ph%20meter%20OW-099	Lab	Lab	ext. 3G
DF Robot	Haoshi H-101 with amplifier/processing board	Glass electrode, gel filled	pH		https://www.dfrobot.com/product-1110.html	In Uppsala	Lab	ext. 3G
WINSENSE	ISFET S010102 – S0101CB	FET	pH		http://www.winsense.co.th/item/item_image/winsense_isfet_ph_sensor_wips_datasheet.pdf	x	Lab	Wired measurements only
Hanna	Hanna Halo with pH and temp, Bluetooth	pH, liquid buffer, refilable	ph and temp, digital output, Bluetooth		https://www.hannanorden.se/shop/en/electrodes-ph-and-orp/10865-halo-the-worlds-first-ph-electrode-with-bluetooth-smart-technology.html?search_query=Halo-pH&results=355	Lab	Lab	Bluetooth
Joanneum Inst.'s			pH		Not commercial	X	X	?
Maxim	DS18B20	Temp	Contact, water, temp, digital interface, OneWire		https://ezesys.com/Temperature-sensor-with-digital-output			
Amphenol / Honeywell -/Aosong	?	Temp and Humidity	Airtemp and humidity, digital interface, Modbus		https://ezesys.com/RHTemperature-sensor-Modbus	In Uppsala	Lab	ext. 3G
IVL		Optical, laser	Turbidity		Prototype, patent filled	In Uppsala	Lab	3G/WIFI
Talkpool			Conductivity, 4-20mA?		Industry probe, which?	In Uppsala	Lab	ext. Lora

Appendix B

Measurement series

ID	Place	Sensor	Time	Purpose	Comments
M1	Haga/Vasa	Water level Hydrostatic + Switch	2017-2019	Level vs smhi Radio aspects	Sensor system
M2	Linne	Water level Hydrostatic + Switch	2017-2019	Level vs smhi Radio aspects	Sensor system
M3.1	Sävenäs	Water level - Hydrostatisk	2018-2019	Level measurement technique comparison	Sensor system
M3.2	Sävenäs	Water level - Radar sensor	2018-2019	Level measurement technique comparison	Sensor system
M4.1	Flottsund	Hydrostatisk	2020-07/09	Level measurement technique comparison toward SLU	Same EZEIO reference
M4.2	Flottsund	Radar	2020-07 / 09	Level measurement technique comparison toward SLU	Staal (Omniradar)
M6	Flottsund	pH, conductivity, Temp (luft T, rH)	2020-07 / 09	corr level, pH, Cond vs SLU	Same EZEIO reference
M7	Independent well	Turb IVL	2019-04 2019-08	Turbidity technique comparison	Bad data
M8	Independent well	Turb Ref	2019-04 2019-08	Turbidity technique comparison	Time sync issues
M9	Independent well	Turb low cost	2019-04 2019-08	Turbidity technique comparison	Time sync issues
M10	Independent well	Nivå hydrostatisk	2019-04 2019-08	Level measurement technique comparison	
M11	Independent well	Nivå Ultraljud	2019-04 2019-08	Level measurement technique comparison	
M12	Uponor (Well 1)	Turb IVL	2019-04 2019-08	Turbidity technique comparison	Too low water in system
M13	Uponor (Well 1)	Turb ref	2019-04 2019-08	Turbidity technique comparison	Too low water in system
M14	Uponor (Well 2)	Nivå UL	2019-04 2019-08	Level measurement technique comparison	
M15	Uponor (Well 2)	Turb low cost	2019-04 2019-08	Turbidity technique comparison	
M16	NCC	Turb (ref, IVL)	2020-02 2020-07	Turbidity accuracy	
M17	NCC	Nivå (hydr)	2020-02	Level accuracy	Pump controlled water levels

			2020-07		
M18	Lab	Turb IVL	2018-01 2018-02	Turbidity accuracy	
M19	Lab	Turb lowcost	2018-01 2018-02	Turbidity accuracy	
M20	Lab	Påväxt Lowcost	2018-01 2018-02	Turbidity maintenance	Result: Pass
M21	Lab	pH, cond	2018-01 2018-02	Accuracy	

Figure 1: Measurement points in Gothenburg

Figure 2: Measurement points in Uppsala

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