ADAPTIVE MICROFLUIDIC - AND NANO - ENABLED SMART SYSTEMS FOR WATER QUALITY SENSING

Use case description

D1.1

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Abstract

To ensure the monitoring of the quality of water intended for human consumption, all water suppliers make large number of analyses in consumers taps, in accordance with the stipulations in Directive no. 98/83/EC of 3 November, reverted to the national legislation of all European Union Member States (in Portugal is the Decree-Law 306/2007 of 27 August). This control only guarantees the water that has already been consumed, and through the high levels of compliance will yield some confidence to consumers.

Nevertheless the managing bodies and suppliers of water all over the developed world felt the need to seek preventive mechanisms to meet the water quality throughout its route, and anticipated the potential risks to consumer health, preventing the water arrives in inappropriate conditions. It thus emerged in the last decade Water Safety Plans (WSP), with great impetus from World Health Organization (WHO) and International Water Association (IWA), for water intended for human consumption. More recently similar plans were submitted for the residual and pluvial water sanitation.

Following the spirit of the Water Safety Plans, to anticipate changes in water quality quickly, it is essential to develop and deploy real-time measurement devices connected to systems of data collection and processing with alerts and alarms to trigger sequences of actions to reduce the risk to human health. To obtain the maximum efficiency of such systems, knowing and treating large number of variables in the networks is essential. To obtain such result, the sensors need to be well installed in the correct places. The sensors' cost, ease of installation and energy autonomy are very important factors conditioning the capability of the managers and suppliers to install them.

With a deployment in SMAS network as final target, this deliverable defines and details the main constraints and characteristics that Proteus project will take into account during the development of water quality monitoring devices. .

Disclaimer

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Revision History

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List of Acronyms

EC	European Commission
SMAS	Serviços Municipalizados de Água e Saneamento de Almada
WSP	Water Safety Plan
WHO	World Health Organization
IWA	International Water Association
SCADA	Supervisory Control and Data Acquisition
ERSAR	The Water and Waste Services Regulation Authority
PCQA	Program of quality control of water
PCO	Program of operational control
LIMS	Laboratory Information Management System
ZA	Supply zone
ZMC	Measure and control zone
ZPG	Management pressure zone
GPI	Infrastructure asset management
PVC	Polyvinyl chloride
PE	Polyethylene
PP	Polypropylene

Executive summary

This deliverable describes the requirements for the research and development activities that will be carried out within the PROTEUS project. These requirements were collected from the urban water management system implemented by SMAS in the municipality of Almada. These requirements are related with the Water Safety Plan implemented by SMAS, which among other directives, requires periodic measurements and controls of the water quality, specifies hazardous events and water quality operating ranges; coordinates activities not only dedicated to the monitoring and control of the water quality but also to the definition of procedures to prevent dangerous situations and to the improvement of infrastructures and protocols. Besides the Water Safety Plan, SMAS is also committed to Water and Energy losses management plan that focus on sustainability, defined according to its three components: social, economic and environmental. This plan promotes the efficient use of water and the sustainable use of energy resources, while ensuring the availability of water resources.

The requirements were derived from three use cases present in SMAS's system. In each of these use cases were identified the relevant and critical parameters that need to be monitored, as well as the periodicity in which each parameters must be measured and communicated to the SMAS's control system. These requirements are extremely important for the specification of the sensing hardware and parameterization of software, which together have great impact in the energy consumption of the device. The three use cases are:

- <u>Drink Water distribution network</u> –Refers to all the pipes that go from the points where water is collected from the underground to the points where water is delivered to the customers, passing by treatment stations and water tanks. As in this use case the water is delivered to consumers, must of the parameters are related to the quality of the water and are chemical (such as pH, chloride, nitrates, etc.), but physical parameters like water pressure and flow rate are also important since they allow to determine leaks and ruptures in pipes. Proteus will target the retail network, namely the part of the network close to the consumers, which is still lacking proper monitoring. On the contrary, the production network from the collection points to the distribution reservoirs is already fitted with sensors and monitored by SMAS.
- <u>Rainwater network</u> – This use case refers to the part of network managing the flow of rainwater into the river. The most relevant parameters are physical such as pressure and flow rate as they allow the detection of water overflows and obstructed pipes that may cause floods.
- <u>Wastewater network</u> – The last use case refers to the network of wastewater, collected from houses and routed to the proper treatment station. This use case requires the monitoring of both chemical and physical parameters that are used to ensure that the wastewater does not threaten the biological material at the treatment stations, as well as to detect water overflows and illegal discharges in the network.

A Validation Plan to test the capabilities of the devices developed in PROTEUS is described. This validation plan comprises three different stages of evaluation: a stage of lab tests where the first chips will be tested; one model deployment where prototypes will be tested in controlled conditions; and one real-world deployment where the devices will be placed within SMAS's network in order to evaluate the performance of the devices in each use case.

1 Introduction

The World Health Organization (WHO) through the *Guidelines for Drinking-Water Quality* and the *International Water Association* (IWA) through the *Bonn Charter for Safe Drinking Water* sought a new approach to the management of the quality of water intended for human consumption. This approach considers the whole process of production and distribution of water intended for human consumption, since the surrounding of capture to the final destination, doing an exhaustive evaluation and management of risks associated with all stages.

For the implementation of the Water Safety Plan (WSP), the SMAS de Almada accepted an invitation formulated by The Water and Waste Services Regulation Authority (ERSAR) at the end of 2008, so in conjunction with other management companies, with different typologies, develop the plan in an area of supply. The Board of Directors has appointed a working group to develop this WSP, with representatives from all the relevant areas, namely: production, distribution, quality control, project management, procurement and storage of materials and products, surveillance, training and communication.

Water Safety Plan is the greatest incentive to the need for devices that allow the measurement and control in various critical locations of the system. These devices can be used to implement a network of alerts and alarms, enabling a real-time management of the water distribution using the correlation between analytical knowledge and preventive measures to adapted to each situation. This requires continuous measurement in order to detect the dangerous events and hazards that may occur.

Another concern related with of the water distribution management is the water loss control, which is also very dependent on the installation of metering devices capable of measuring volumes of water, making it possible to carry out mass balances.

To manage the urban cycle of water more efficiently, SMAS developed a water and energy loss management plan, which articulates with a tactical plan of asset management infrastructure, using an explicit dynamic between them. To implement these plans, water management requires massive and low-cost monitoring means, coping with differentiated and evolving requirements. However, the majority of multifunctional water sensors only support predefined goals hindering interoperability. Moreover, these means are very expensive, blocking large scale deployments.

Achieving a reduction of the size of the devices, as well as the decrease of cost with respect to current practices, could allow a great qualitative leap in measurement networks, giving greater capabilities to management software and to the managers of network (production and distribution of water intended for human consumption, drainage of rainwater, drainage and treatment of waste water). In the near future, if the range of parameters allows, it may also provide an important incentive for the correct reuse of treated wastewater, in conditions of security for users.

With Proteus, the consortium seeks to develop reconfigurable microfluidic-and nano-enabled sensor platform for cognitive water quality monitoring. Innovative embedded software will provide reconfigurability of the sensing board to support several applicative goals while cognitive capabilities will manage evolving requirements during exploitation. Energy autonomy will be achieved through the use of harvesting water flow energy. In addition, low cost of additional sensing components will enable redundancy increasing life span of the systems.

2 SMAS water management plans

2.1 SMAS Water Safety Plan

2.1.1 Policy of water safety management system

The policy is to reduce the risks to public health, resulting from the consumption of water distributed, adopting and monitoring appropriate corrective and preventive measures.

For the pursuit of this policy, the SMAS also undertake to:

1. Ensure the functioning of the management systems, in compliance with the legislation in force and the requirements of applicable standards and regulations, in a perspective of quality and continuous improvement of the effectiveness.
2. Ensure the dissemination and communication systems policy to all interested parties.
3. Promote the involvement, awareness, training and employee participation in the implementation and maintenance of systems.
4. Ensure the periodic review of the policy systems.
5. Ensure the registration and control of documents of the systems.
6. Ensure the measurement, monitoring and evaluation of the performance of the systems.

Disseminate the results relating to the performance of the systems, giving to meet the commitment of the SMAS in the implementation of best practices.

2.1.2 Description of the water supply system

The water supply system of the SMAS de Almada is divided into 5 zones (ZA; see figure 1), with separate pumping stations. There are however several possibilities of interlinking, between some of the stations and distribution networks, with connection points in areas of influence of adjacent tanks.

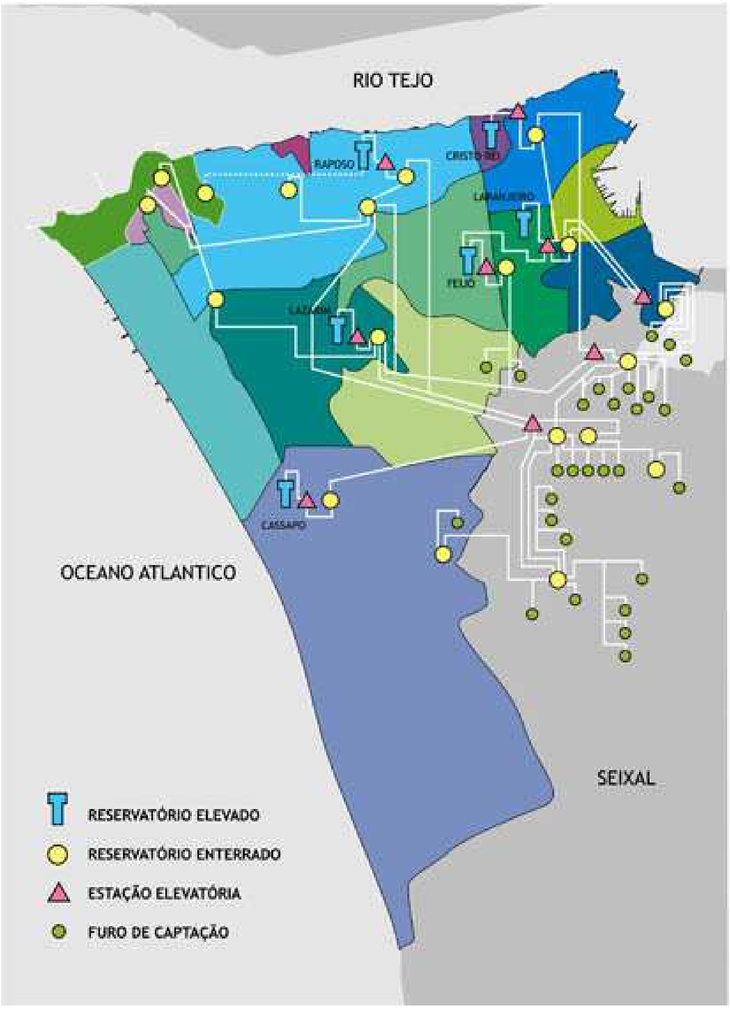

Figure 1 - Distribution system of Almada

The Constitution of systems along the route, from its origin to the distribution network is in general terms as follows:

1. Capture holes;
2. Primary Reservoirs;
3. Adductor Conduct;
4. Pumping Stations:
   - 4.1. Vacuum Chamber;
   - 4.2. Booster Group;
   - 4.3. Treatment System (chlorine gas);
5. Secondary Tank:

   5.1. Booster Group;

6. Air Reservoir;
7. Distribution network.

Figure 2 - Water tank in Feijó

Along the route, particularly in ducts, there are check valves and switching and the suction cups, accessories and various devices that can influence the quality of the water until their final destination.

The detailed description and control of all the components of production and distribution are distributed by:

1. TeleManagement system in bulk drinking water (since the borrowings out of shells)
2. Geographic information System (Geomedia)
3. Excel and other files of the WSP

The TeleManagement system considers all the fundamental organs of control of the process, from the electromechanical equipment, pumps, flow meters, electric current and voltage meters, level probes, analytical control probes (pH, temperature, nitrate, conductivity and residual chlorine), carries out historical records of all variables considered and management of anomalies through alarms.

In the Geomedia software is geo-referenced all equipment, considering the types of materials used, the date of installation and the water collection points as well as all customers that are sensitive for the lifting of the WSP, namely the following:

1. Elevatory stations
2. Funding
3. Fuel tanks
4. Extreme network
5. ZA1 production flowchart
6. ZA2 production flowchart

7. ZA3 production flowchart
8. ZA4 production flowchart
9. ZA5 production flowchart
10. Sensitive Customers
11. Fuel-distributing (fueling) pumps
12. Water fountains
13. Suction cups
14. Ornamental fountains
15. Gardens
16. Blind Joints
17. Swimming pools

2.1.3 Hazardous events, hazards and risk assessment

The survey of hazardous events and dangers are regularly in update, using for this purpose the information obtained from the comparison with other entities, case studies and knowledge of the SMAS´s network.

The stages of the network that are considered for hazard and risk are as follows:

1. Catchment
2. Primary Adduction
3. Primary storage
4. Chlorination
5. Secondary storage
6. Primary distribution > 100 mm
7. Home < 100 mm
8. Building Networks
9. Fire hydrants (hydrants watering and fire)
10. Green spaces
11. Decorative fountains and troughs

The risk assessment in all these steps is based on the following matrices (water quality and quality of service), which are based on Guide Water Safety in Distribution Systems of the World Health Organization. For the assessment of severity were considered parametric values of national law, namely Decree-Law 306/2007 of 27 August and Decree-Law 236/86 of August 1 and the Guidelines of the World Health Organization for the different physical, microbiological or chemical agents, which may be in question, or to supply disruptions.

Table 1 - Risk Matrix

		Severity				
	(A)	Negligible impact	Short-term impact	Chronic/permanent	Small fatality	Great fatality
	(B)	Minor (ultrapasagem alert limits/indicators	Moderate (organoleptic impacts)	High (legal Effect)	Major (reversible health damage)	Maximo (irreversible health damage)
Probability	**5 (> 80%) of day or 1 x**	5	10	15	20	25
	4 (1 x Week or 60 >)	4	8	12	16	20
	3 (1 Month or > 40 percent)	3	6	9	12	15
	2 (or 20 percent) > 1xyear)	2	4	6	8	10
	1 (1x5 years or 20 percent) <	1	2	3	4	5 *

Risk score:	< 6	6-9	10-15	> 15
Risk classification	negligible *	moderate	significant	very significant

	very significant	> 15
	significant	10-15
	moderate	6-9
	negligible	< 6

Notes: Risks with value greater than 6 or with maximum severity, lead to the respective stage of the process constitutes a control point (CP), soon will require that you set the operational monitoring of the respective control measures, as well as checking the effectiveness.

* When the occurrence is rare but the severity is maximum, the danger must be considered significant (Davidson et al., 2006) and treated as such.

The probability of each danger or hazardous event is determined by a function of known history or information collected in the reference, official bodies and the consequence according to the impact to human health that each agent can constitute, according to the WHO guidelines.

- Very significant risks are subject to actions aimed at their reduction.
- The significant risks will be considered for reduction actions, prioritized on the basis of their quantitative value.
- Moderate risks will only be considered if the risk reduction actions are intended for another purpose.
- Negligible risks require no actions.

The exhaustive survey of dangerous events and hazards, step, and risk assessment are usually represented in one Excel file of the WSP, like the one that IWA proposes.

2.1.4 Control measures

Online control measures are used as forms of reduction of risks as they allow short intervals of readings at affordable costs. The control measures used consist of alerts, barriers, rapid detection systems, and verification procedures. These control measures are considered for each event or dangerous cause and are implemented where appropriate and feasible. Control measures are described thoroughly in the Excel file of the WPS and are made available to the operational teams. The validation of the effectiveness of control measures is performed using records and treatment of evidence related to control measures implemented.

2.1.5 Re-pricing of risk

To account for the effectiveness of the control measures, the residual risk is then re-evaluated. This action is made jointly between the control measures, the corrections, preventive measures and support programs.

2.1.6 Improvement plan

If in the previous steps significant risks have been identified to the safety of the water (quality and quantity), or if it is shown that the existing controls are not effective, or are not implemented, plans should be drawn up for improvement. Based on corrections, preventive measures and support programs are defined in the WSP.

It is very important that their integration with the options in the plan of activities and with the multi-annual investment plan should be presented to the leaders before the preparation of the proposals for the following years. The lack of human and financial resources motivates some criteria to be prioritized in their implementation.

They are drafted annually and submitted on a quarterly basis to the state of implementation of the same, in the meetings of SMAS´s Directors.

They are described thoroughly in the WSP, considering:

1. Actions
2. Objectives
3. Goal in the current year
4. Goal the following year
5. Responsibility
6. Documents associated

2.1.7 Operational monitoring

Operational monitoring is based on two aspects.

1. Laboratory tests under the PCQA and PCO, followed by evaluation of trends and compliance with legal limits.
2. Measurement Records *online* with monthly assessment of trends and rates of compliance with the defined acceptance alarm limits.

In each measurement function provided, should be established in competency matrix the following aspects:

1. What will be measured
2. How will be monitored
3. When will be measured
4. Where will be measured and monitored
5. Who will perform the monitoring
6. Who will perform the analysis
7. Who receives the results of the monitoring

2.1.8 Verification of the WSP´s effectiveness

Once the actions defined in the improvement plan have been implemented, chemical, physical and microbiological analyses are carried out in specific operational programs to assess the effectiveness of the measures. There is an internal audit procedure that defines the actions and skills needed for its implementation. An annual report shall be drawn up, based on the annual cycle of continuous improvement, present to the top management before the review of the WSP.

As soon as the competent authority (ERSAR) has this installed capacity, or that there is a standard recognised and accredited certification companies for this purpose, external audits will be carried out.

2.1.9 Management and operating procedures

The following management procedures exist and are regularly updated (at least once per biennium):

1. Preparation of documents
2. Acquisition of materials and products
3. Storage of materials and products
4. Tank cleaning schedules
5. Access control of the enclosures of the critical places
6. Monitoring of unauthorized connections to your network
7. Communication of irregular analytical results
8. Acquisition of PE products
9. Acquisition of PVC products
10. Acquisition of FFD products
11. Acquisition of PP products
12. Internal audits
13. Corrective actions
14. Preventive actions
15. Control of records
16. SMAS Almada management system for water security technical specification

These documents should be shared on the server, in an area controlled by computer services (security, backups, and access profiles).

2.1.10 Support programs

These programs are activities that embody the development of workers skills and knowledge, both in its fundamental activities and in WSP-specific, strengthening the capacity of the production process and distribution of water, making it more robust to potential incidents.

These programs can be vocational training actions, research and development, standardization and calibration of equipment, using SMAS own resources or by external entities with close links to the technicians of the SMAS.

Some of these programs may have impact on several aspects of the diamond management system (quality, environment, safety and health, asset management of infrastructures).

PROTEUS falls within the scope of such support programs, as the knowledge of real-time data is essential and requires the large-scale implementation of sensors.

2.2 SMAS Water and energy losses management plan

This section presents the plan for management of water and energy losses. It formulates the link between strategic and operational levels, with a special focus on organizational processes that are relevant to the management of water and energy losses. It is developed in close articulation with the tactical plan of infrastructure Asset Management (GPI) using a very explicit dynamics between both.

It is developed for a horizon planning of 3 years (2015 to 2017) and for an analysis of skyline 18 years (2015 the 2033) (both coincident with the horizon defined in the Strategic and Tactical plans of the GPI).

The principle that has guided this management plan was sustainability, defined according to its three components, social, economic and environmental. It resulted in the following tactical objectives: ensuring the availability and access to water supply, ensuring the economic sustainability of the Fund Manager, ensuring the sustainability and infrastructure integrity, promoting efficient use of water and promoting the sustainable use of energy resources.

Through the analysis of different scenarios a set of tactics were selected, namely: non-infrastructural tactics, infrastructural tactics, infrastructure operation and maintenance. These tactics will be implemented at the operational level.

2.2.1 Organization of the plan

The Management Plan of water and energy Losses to 2015/2017 describes the following reference elements:

a) Preliminary characterization;
b) Setting goals and respective evaluation system;
c) Definition of scenarios[1];
d) Diagnosis;
e) Establishment of tactics;
f) Fundraising required;
g) Monitoring and review procedures of plan;

The present plan is accompanied by the following supporting documentation:

- Area of analysis documents;
- Document with compilation of results of applying the software **Water Balance**;
- Document with compilation of results of applying the software **Energy Balance**;
- The Characterization Counters document.

[1] Macro scenarios, like legislation changes.

2.2.2 Relationship with other planning tools

The Management Plan of water and energy Losses to 2015/2017 is related to the following plans of the Organization:

- Multi-annual investment plans;
- Study of General Concept of Inter-municipality bulk water System in the Setúbal Peninsula High 2013;
- Strategic Plan for water supply in the municipality of Almada 2013;
- Tactical Asset management plan for infrastructure 2014/2017;
- Water safety plan 2011;
- Plans arising from the design and implementation of integrated management system in the Organization (quality management, Asset Management, infrastructure management of water security, environmental management, management of safety, health and Welfare at work and Social commitment and organizational management);
- Studies of energy efficiency of facilities.

3 Use case description

Three use cases are present in SMAS's system. In each of these use cases were identified the relevant and critical parameters that need to be monitored, as well as the periodicity in which each parameters must be measured and communicated to the SMAS's control system. These requirements are extremely important for the specification of the sensing hardware and parameterization of software, which together have great impact in the energy consumption of the device. The three use cases are:

- Drink Water distribution network –Refers to all the networks that goes from the points where water is collected from the underground to the points where water is delivered to the customers, passing by treatment stations and water tanks. As in this use case the water is delivered to consumers, most of the parameters are related with the quality of the water and are chemical in nature (pH, chloride, nitrates, etc.), but physical parameters like water pressure and flow rate are also important since they allow to determinate leaks and ruptures in pipes. Proteus will target more specifically the retail network, namely the part of the network close to the consumers, which is presently still lacking proper monitoring. Indeed the production network from the collection points to the distribution reservoirs is already fitted with sensors and monitored by SMAS.
- Rainwater network – This use case refers to the part of network managing the flow from rainwater into the river. The most relevant parameters are physical as pressure and flow rate as they allow the detection of water overflows and obstructed pipes that may cause floods.
- Wastewater network – The last use case refers to the network of wastewater, collected from houses and route to the proper treatment station. This use case requires the monitoring of both chemical and physical parameters that are used to ensure that the wastewater does not damage the biological material at the treatment stations, to detect water overflows and illegal discharges on the network.

These Use Cases are representative of the typical water networks across Europe due to the strong need to comply with EU directives, as stated in the presented Water Saftey Plan.

3.1 Drinking water

3.1.1 Purpose

To comply with the EU directive on the control of the quality of water intended for human consumption, water is harvested from consumer taps harvests and analysed in accredited laboratories via methods with predefined technical specifications.This lets us compare the results across the European area with comparable criteria.

However, this evaluation does not yield useful perspective for preventive actions as requested in the water safety plans. For the implementation of the preventive perspective, real-time and reliable results are crucial.

The use case for drink water thus concerns the installation of sensors in the distribution network to determine a series of parameters described below. These sensors would be connected with the SCADA water production system already in place.

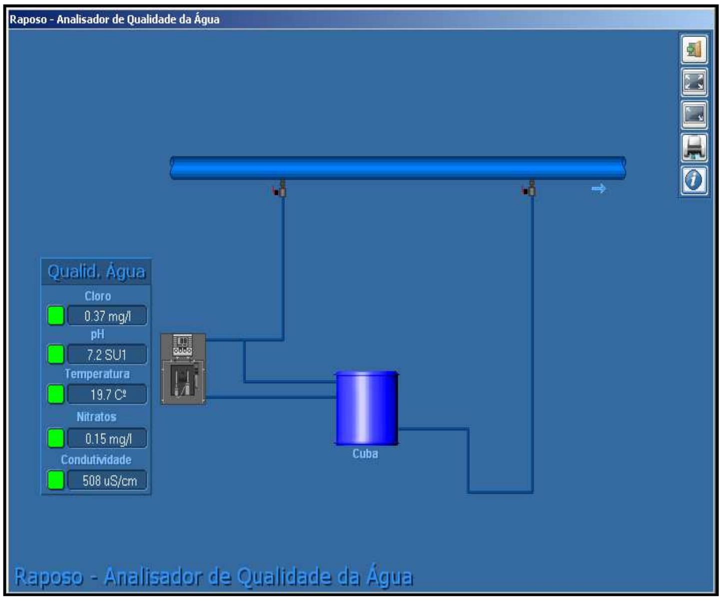

Figure 3 - SCADA software on bulk drinking water supply

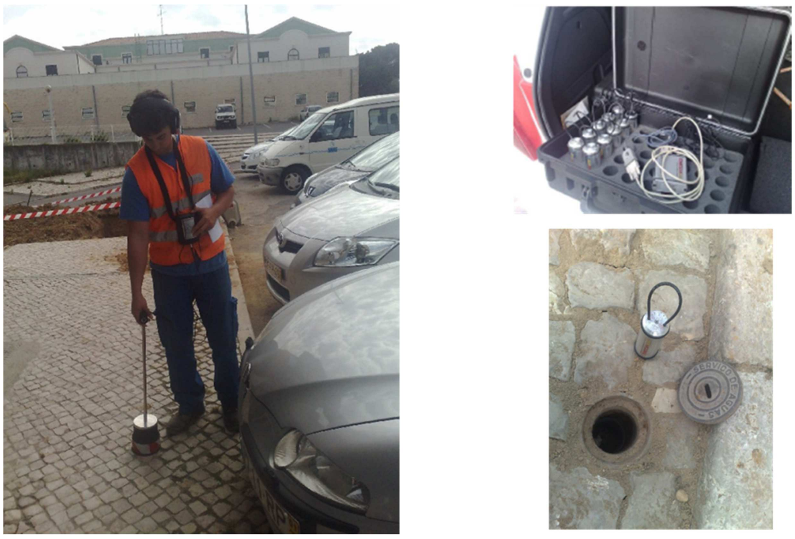

Figure 4 - Manual (pinpoint geophone) and data loggers to the noise detection

3.1.2 Scale

The SMAS is the entity responsible for catchment, treatment and distribution of the drinking water for the municipality of Almada, situated on the left bank of the river Tagus, in front of Lisbon.

- Area of 72 km^2
- 174 030 users
- 105.000 clients
- 16.090.000 m^3 of water produce in 2014
- Groundwater source
- 84 km of pipelines (391 sections)
- 882 km of distribution pipes (19624 sections)
- 7356 valve (209 for discharge and 7147 for sectioning)

Figure 5 - Sectioning valve

- 2804 end pipes (with possible stagnant water)
- 17 pressure reducers

Figure 6 - Water pressure reducer

- 156 suction cups
- 31000 extension line connections
- 16 distribution areas
- 4 measure and control zones (ZMC)
- 209 background discharges

Figure 7 - Suction cup and fire hydrant

- 173 flowrate meter
- 2430 fire hydrants
- 5700 watering hydrant
- 9 pumping stations

- 85.350 m^3 of total reserve of water (25 tanks)
- 1 laboratory for drinking water
- 16.643 analyses in the last year

3.1.3 Monitoring priorities

Monitoring priorities are described below, and they are aligned with the needs stated in SMAS Water Safety Plan.

- Conductivity
- Chlorine
- pH
- Temperature
- Pressure
- Flowrate (and volume)
- Chloride
- Nitrates

And if it is possible, those other ones are still interesting

- Residual noise
- Turbidity
- Hardness
- Calcium
- Magnesium

The conductivity is very important to have an idea of ion concentrations. In Almada the origin of water is underground, but near the ocean. If there is an intrusion of the sea water in the aquifer, the concentration of chloride increases as well as the conductivity.

Chorine is the disinfectant agent that SMAS use in all system, between the limits of concentration recommended by the regulator (ERSAR) and the WHO.

The majority of the distribution network is placed underground and remains cool throughout the year.. However in places where pipes are above the surface or uncovered, temperature may rise significantly. It is relevant because temperature values above given thresholds foster the growth of microorganisms in the water.

Assessing the pH is mostly relevant, in Almada's use case, to ensure that the water remains in the ideal pH range of disinfectant capability of free chlorine.

The pressure and the flowrate are two main variables to control the network system of distribution of water. With the integration of the flow function we can derive the water volume that passes at each site, and in the case of ZMC obtain mass balance sheets to manage the levels of water losses. This volume can be calculated on the device or in the SCADA management software.

Chloride ingress is a severe risk in Almada catchment, because of the proximity of the sea.

Nitrates are a significant risk in Almada WSP.

Hardness, Ca and Mg could become a significant risk in the future.

Turbidity is associated to stagnation problems in water.

Residual noise could help us to identify events ranging from small snapping to big leakages in pipes.

3.1.4 Requirements

For each of the parameters, it is important to define the typical range of operation to adjust the sensor design. A range of operation badly defined can influence the accuracy of the results.

Accuracy is also very relevant, because as real-time measurements are intended, even slight variations may have relevant meanings.

For the considered parameters, the following table gathers the minimum and maximum values as well as the precision.

Table 2 - Operating range and precision for drinking water parameters

Parameter	Minimum	Maximum	Precision
Conductivity	100 µS/cm	1000 µS/cm	3%
Chlorine	0,05 mg/L	1,25 mg/L	5%
pH	5,00	10,00	5%
Temperature[2]	5ºC	35ºC	5%
Pressure	0 bar	16 bar	5%
Flowrate	0 L/s	200 L/s	2%
Chloride	10 mg/L Cl	250 mg/L Cl	5%
Nitrates	2 mg/L NO_3	60 mg/L NO_3	5%

[2] This temperature range is for the water inside the pipes (usually between 10-25 ºC). The places to put the device outside may vary from 5-45 ºC.

Residual noise[3]	[4]		
Turbidity	0 NTU	10 NTU	5%
Hardness	10 mg/L $CaCO_3$	400 mg/L $CaCO_3$	5%
Calcium	5 mg/L Ca	100 mg/L Ca	5%
Magnesium[1]	3 mg/L Mg	100 mg/L Mg	5%

Expected lifetime for these sensors could depend on the installation conditions, but never less than 2 years.

The water should be returned to the pipe, after the measurement by the sensors is achieved in a bypass pipe (pipe in parallel with the system), in order to reduce the water and energy losses.

The materials that we could find on pipes are mainly:

- PVC
- PVCC
- PEHD
- Ductile cast iron (with cement or epoxide resin)
- Galvanized steel
- Brass
- Bronze
- Cement

The environmental conditions may affect the devices: they will be at high humidity, undergo a wide range of temperatures, in a highly oxidative atmosphere and difficult to access.

[3] The blue ones are less relevant for the purpose of Proteus than the others above.
[4] This information need to be treated before, if it´s necessary.

Figure 8 - Typical environmental conditions

3.1.5 Control levels

The ranges are already described in the previous sections; in this chapter we define the alerts and the alarms for each parameter.

The alerts are set to give an indication that some deviation from expected values has occurred. Values beyond the alert levels may indicate a significant change. It may have a preventive value, allowing to take early actions.

Alarms are barriers beyond which the absence of action can constitute a high risk to the health of water consumers. Hence the immediate knowledge of alarms is needed to contribute to reduce the probability of dangerous occurrences.

Given the importance of wasting as little energy as possible in the sensors, accounting for these levels can help reduce the frequency and volume of communication to the SCADA, by just sending the data deviations from their regular value or the data history stored during a certain period of time.

Table 3 - Control levels, drinking water

Control levels				
Parameter	**min alarm**	**min alert**	**max alert**	**max alarm**
Conductivity	< 6% ATL[5] 50	< 3% ATL 50	> 3% ATL 50	> 6% ATL 50
Chlorine	< 0,10 mg/L	< 0,2 mg/L	> 0,6 mg/L	> 0,8 mg/L
pH[6]	< 6,5	< 6,7	> 8,0	> 9,0

[5] ATL - average or trend of last measures, given the expected value for an integration time of 5 minutes

Temperature	< 7ºC	< 10ºC	> 20ºC	> 25ºC
Pressure	< 1 bar	< 10% ATL 50	> 10% ATL 50	> 6 bar
Flowrate			> 20% ATL 5	> 195 L/s
Chloride			> 10% ATL 50	> 240 mg/L Cl
Nitrates			> 10% ATL 50	>45 mg/L NO_3
Turbidity			> 20% ATL 50	> 4 NTU
Hardness			> 10% ATL 50	> 250 mg/L $CaCO_3$
Calcium			> 10% ATL 50	> 90 mg/L Ca
Magnesium		> 10% ATL** 50	> 70 mg/L Mg	

3.1.6 Workflow steps

In addition to the need to have sensors to carry out real-time measurement of various parameters, it is crucial that the devices allow the definition of alert and alarm levels.

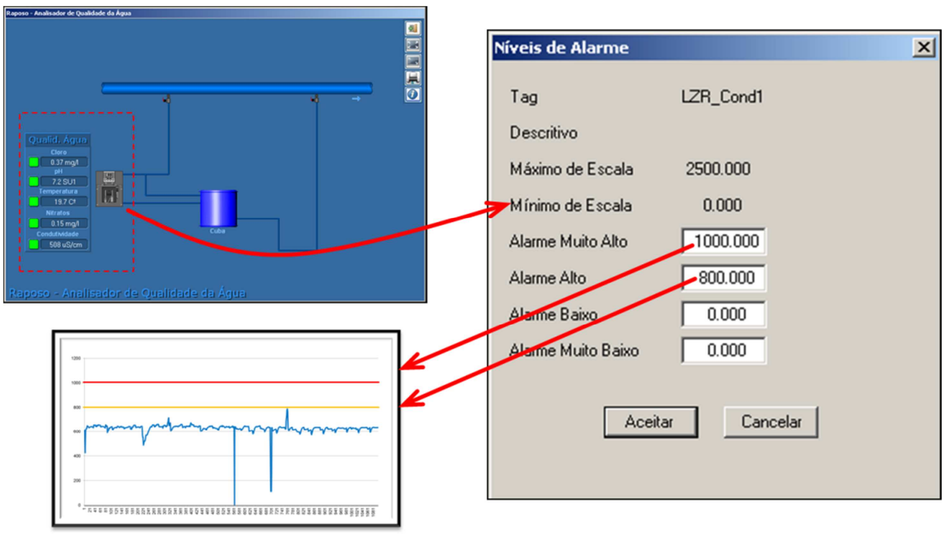

Figure 9 - Alert and alarm levels in bulk drinking water

This implies that the sensors must have "intelligence", which enables them to manage fairly rational energy consumption, to send data timely or to send relevant information to the remote system, and to

[6] Sorensen scale

have the ability to recognize the way in which they are to operate, possibly adapting their measurement range to specific cases.

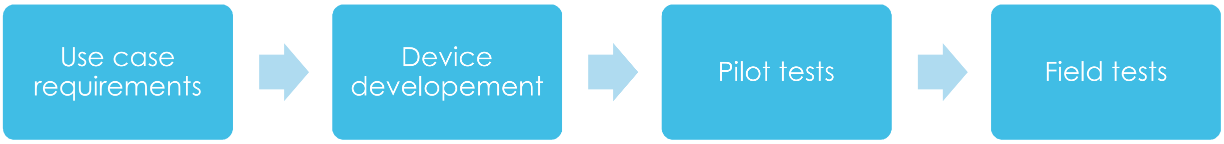

Figure 10 - Development process for drinking water device

3.1.7 Business Cases

The following table summarizes the main aspects of drink water-related business cases:

Table 4 – Drinking water business cases

Content	Description	Priority requirements	Actions by distributor	Parameters
Water loss	Small or large water leakage in retail network Accidental or voluntary	P1: detection P2: localization P3: volume evaluation P4: time pattern (to distinguish type and cause of leakage	Repair the leakage Periodic reports to authorities	Flowrate Pressure
Disinfection	Free chlorine levels are critical in WSP	P1: Detection P2: Time pattern (for analysis purposes)	Discharge of network or increase of chlorine level Study of chlorine behaviour in network to understand chlorine propagation patterns and optimize chlorine injection Periodic reports to authorities	Chlorine pH Temperature
Intrusion	Unauthorized ingress of matter (Accidental or	P1: detection P2: localization	Mitigation actions Interruption of distribution/Discharge	Conductivity

	voluntary)	P3: time pattern (to distinguish causes	of network Periodic reports to authorities	
Pollution (not for SMAS, but relevant in countries with open lines)	Type of pollution depends on risk assessment in the networks	P1: detection P2: localization	Interrupt distribution Periodic reports to authorities	Nitrates Chloride Turbidity Hardness Calcium Magnesium
Temperature control (not for SMAS, but relevant in countries with above ground lines)	Check whether temperature above 25°C	P1: detection	Distribution forbidden	Temperature

3.1.8 Monitoring profiles

Based on the use cases described above, with the goal of managing as efficiently as possible the energy consumption of the sensor node, it was specified the periodicity of measurements of the required parameters. The periodicity is shown in the following table:

Table 5 – Periodicity of parameters readings for drinking water

	Periodicity	
Parameter	**Read**	**send to SCADA**
Conductivity	1/min	1/day
Chlorine	1/min	1/day
pH*	1/min	1/day
Temperature	1/5min	1/day
Pressure	1/min	1/day
Flow rate	1/min	1/day
Chloride	1/5min	1/day
Nitrates	1/5min	1/day
Turbidity	1/5min	1/day

Hardness	1/5min	1/day
Calcium	1/5min	1/day
Magnesium	1/5min	1/day

* Instantly if they pass alerts or alarms

The parameters required for the drinking water use case can be classified in two types of profiles according to the required periodicity of measurements and communication. These types of profiles are critical and non-critical parameters.

Critical parameters:

- Flowrate
- Pressure
- Conductivity
- Chlorine
- Temperature for real-time compensation
- pH for real-time compensation

Non-Critical parameters:

- All the other

For critical parameters, the monitoring requirements are:

- 1 measurement / 1 min
- As long as the measurements do not pass the thresholds and alarms thresholds (below minimum and above maximum), send gathered information once a day (except for keep alive signals)
- If one measurement is between the alert and the alarm thresholds, raise the frequency of measurements to 2 meas/1min, and if this occurs 10 consecutive times, send this information immediately to the SCADA and then stop sending.
- If one measurement passes the alarm threshold, raise the frequency of measurements to 2meas/1min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator check this information (and then stop sending).

For non-critical parameters, the conditions should be:

- 1 measurement / 5 min
- As long as the measurement do not pass the alerts and alarms (below minimum and above maximum), just need to send information once a day (except for keep alive signals)

- If one measurement is between the alert and the alarm thresholds, raise the frequency of measurement to 1 meas/2min and if this occurs 15 consecutive times, send this information immediately to the SCADA and stop sending.
- If one measurement passes the alarm threshold, raise the frequency of measurements to 1meas/2min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator checks this information (and then stop sending).

Bidirectional communication

If it possible, enable the following actions from the remote centre (sorted by increasing complexity):

1. To pull one or several values from the sensing unit, with expected frequency of 1/month
2. To configure the sensor to operate based on over-the-air parameterization (define thresholds, alert and alarm levels, etc.)
3. To update the sensor code, over-the-air programming.

3.1.9 Participants:

List of the main participants in the process:

- Carlos Sousa (water production and quality control)
- Paulo Nico (quality control)
- Paulo Gonçalves (water production)
- Jorge Marques (water measurement)
- Ramiro Norberto (water network)
- António Barros (water network)
- Paulo Sapinho (water network)
- Paula Castro (safety and security)

3.2 Rain water

3.2.1 Scale

The SMAS are the entity responsible for the rainwater drainage on the municipality of Almada, situated on the left bank of the river Tagus, in front of Lisbon.

- Area of 72 km^2
- 174 030 users
- 105.000 clients
- 7 natural drainage basins
- 493,8 km of rainwater pipelines (approximately 30000 sections)
- Approximately 31000 visit boxes
- 20143 gutters

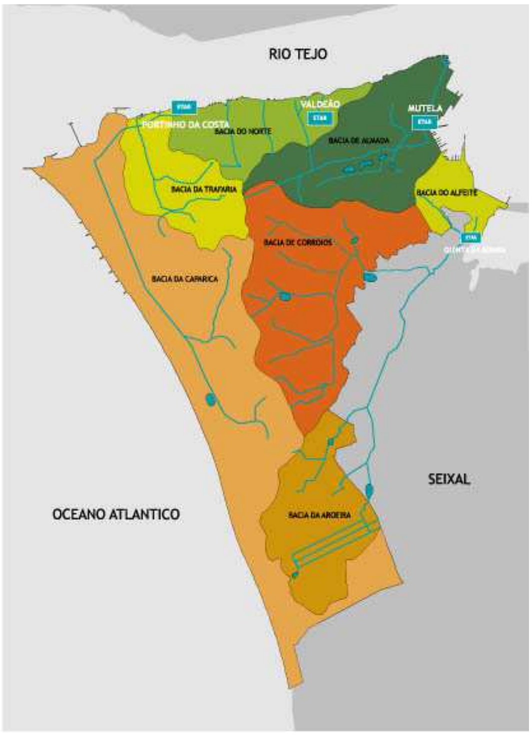

Figure 11 - Natural drainage basins in Almada

3.2.2 Monitoring priorities

The goal is to install in the rain water network sensors that will determine the parameters described below. They will be connected with the SCADA system already installed in wastewater treatment plants.

Priority measurements are listed below.

- Flowrate
- pH
- Salinity
- Pressure (in some cases)

3.2.3 Requirements

For the parameters considered, in the following table are described the minimum and maximum values, as well as the precision.

Table 6 - Operating range and precision for rainwater parameters

Parameter	Minimum	Maximum	Precision
Flowrate	0 L/s	2200 L/s	10%
pH	4	10	5%
Salinity	0 PSU	35 PSU	5%
Pressure	0 bar	5 bar	10%

Note: the temperature inside the visit boxes and surface near the cover may vary between 5ºC and 50ºC.

Expected lifetime for the sensors could depend on the installation conditions, but never less than 2 years, in order to be economically interesting.

The materials that we could find on pipes are:

- PVC
- PVC-U
- PP
- Concrete
- Reinforced concrete
- Cement

- Glass-reinforced thermosetting plastic based on unsaturated resin
- Epoxide resin

The environmental conditions may affect the devices, because they will be subjected to high humidity, wide range of temperatures, highly oxidative atmosphere and they will be difficult to access.

Figure 12 - Open drainage system for rainwater

3.2.4 Control levels

The ranges are already described in the previous sections; in this section we define the alerts and the alarms for each parameter, shown in the following table:

Table 7 – Control levels for rainwater

Control levels				
Parameter	**min alarm**	**min alert**	**max alert**	**max alarm**
Flowrate		< 50% ATL 5	> 1800 L/s	> 2150 L/s
pH	< 5	<6	>8	>9
Salinity			5 PSU	10 PSU
Pressure	< 50% ATL 50	< 20% ATL 50	> 120% ATL 50	> 150% ATL 50

The alerts are set to give an indication of some deviation from expected values. Values beyond alert level what may indicate a significant change has occurred. It provides preventive information that allow early actions.

Alarms are normally barriers beyond where if no actions are taken it can result in a situation of high risk to the health of water consumers, so the immediate knowledge is a factor in reducing probability of dangerous occurrences.

Given the importance of having a lower power consumption on sensors, if these levels are known by each device, then the frequency and volume of data to send to the SCADA can be reduced, by sending only deviations or the data history stored during a certain period of time

3.2.5 Workflow steps

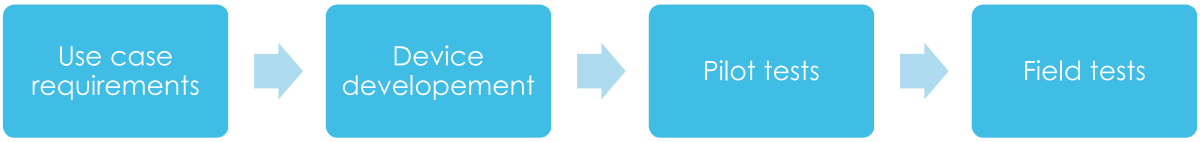

Figure 13 - Development process for rainwater device

3.2.6 Business Cases

The strategically Plan of pluvial water draining foresees a strategy of improvement of the management of the draining, based on the development of systems of monitoring and modulation, for the seven basins of draining of Almada municipality.

It is intended to deepen the control of:

- Direct discharges of excess of the domestic waste net to the pluvial one, with risk of contamination and pollution of the half receptors;
- Superficial draining of volumes that do not flow to the draining system;
- Flooding.

In this direction, the measurement of flowrate, pH, salinity and pressure can give a considerable contribution to the reduction of risks.

Further inquiry will be needed during the project to determine the data volume and accuracy required to derive a correct interpretation and to extrapolate conclusions on the state of the network. .

The following table summarizes the main aspects of rainwater-related business cases

Table 8 – Rainwater business cases

Content	**Description**	**Priority requirements**	**Actions by distributor**	**Parameters**
Blockage / collapse of pipes		P1: detection P2: intensity (level of liquid in blocked pipe; % of water	Punctual mitigation/repair actions Identification of	Flowrate Pressure

		flowing freely) P3: localization of blockage	recurrent factors for long term improvement	
Overflow	Water of the network leaving the network Often consequence of blockage, collapse or intrusion	P1: detection (water reaching top of visit chamber/street level) = localization P2: early detection (water fills the full diameter of pipe P3: identification of causes (nature of blockage) P3: flow rate in pipe P4: duration of overflow	Short term mitigation/repair actions Identification of recurrent factors for long-term improvement	Flowrate Pressure
Intrusion of sewage water		P1: detection P2: localization P3: flow rate of sewage water P4: History/kinetics of event	Short term mitigation/repair actions Identification of recurrent factors for long-term improvement	Salinity pH
Pollution	Intrusion from source outside of the network Accidental or voluntary Example: fire fighting water	P1: detection P2: time pattern: duration of event and 1st instant (to correlate with weather or other events) P3: nature P4: localization	Short term mitigation/repair actions Identification of recurrent factors for long-term improvement	pH Salinity

3.2.7 Monitoring profiles

Based on the use cases described above, with the goal of managing as efficiently as possible the energy consumption of the sensor node, it was specified the periodicity of measurements of the required parameters. The periodicity is shown in the following table:

Table 9 - Periodicity of parameters readings for rainwater

	Periodicity	
Parameter	**read**	**send to SCADA**
Conductivity	1/5min	1/day
Chlorine	1/5min	1/day
pH	1/5min	1/day
Temperature	1/min	1/day
Pressure	1/min	1/day
Flow rate	1/min	1/day
Chloride	1/5min	1/day
Nitrates	1/5min	1/day
Turbidity	1/5min	1/day
Hardness	1/5min	1/day
Calcium	1/5min	1/day
Magnesium	1/5min	1/day

The parameters required for the rainwater use case can be classified in two types of profiles according to the required periodicity of measurements and communication. These types of profiles are critical and non-critical parameters.

Critical parameters:

- Pressure
- Temperature for compensation
- Flowrate (might move later in the project to non-critical in case of technological issue related to power consumption of flow rate sensors)

Non Critical parameters:

- All the other

For critical parameters, the monitoring requirements are:

- 1 measurement / 1 min
- As long as the measurements do not pass the alerts and alarms thresholds (below minimum and above maximum), send gathered information once a day (except for keep alive signals)
- If one measurement is between the alert and the alarm thresholds, raise the frequency of measurements to 2 meas/1min, and if this occurs 10 consecutive times, send this information immediately to the SCADA and stop sending.

- If one measurement passes the alarm threshold, raise the frequency of measurements to 2meas/1min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator check this information (and then stop sending).

For non-critical parameters, the conditions should be:

- 1 measurement / 5 min
- As long as the measurement do not pass the alerts and alarms (below minimum and above maximum), just need to send information once a day (except for keep alive signals)
- If one measurement is between the alert and the alarm thresholds, raise the frequency of measurement to 1 meas/2min and if this occurs 15 consecutive times, send this information immediately to the SCADA
- If one measurement passes the alarm threshold, raise the frequency of measurements to 1meas/2min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator check this information (and then stop sending).

Bidirectional communication

If it possible, enable the following actions from the remote centre (sorted by increasing complexity):

1. To pull one or several values from the sensing unit, with expected frequency of 1/month
2. To configure the sensor to operate based on over-the-air parameterization (define thresholds, alert and alarm levels, etc.)
3. To update the sensor code, over-the-air programming.

3.2.8 Participants:

List of the main participants in the process

- Ramiro Norberto (rainwater network)
- Fernando Bacelar (rainwater network)
- Filipe Cruz (rainwater network)
- António Coelho (rainwater elevatory stations)
- Paula Castro (safety and security)

3.3 Waste water

3.3.1 Scale

The SMAS are the entity responsible for drainage and treatment of the wastewater for the municipality of Almada, situated on the left bank of the river Tagus, in front of Lisbon.

- Area of 72 km^2
- 174 030 users
- 105.000 clients
- 590,5 km of domestic pipelines (approximately 32000 sections)
- Approximately 32000 visit boxes
- 15 pumping stations
- 4 wastewater treatment stations
- 1 water laboratory for wastewater
- 7.791 analyses in 2014

3.3.2 Monitoring priorities

The goal is to install in the wastewater network sensors able to determine the following parameters. They should be connected with the SCADA wastewater production system already in places (one for each wastewater treatment plant).

Priority measurements are listed below.

- pH
- Flowrate
- Total dissolved solids[7]
- Temperature
- Pressure
- Dissolved oxygen

[7] This parameter could be calculate from Conductivity.

And if it is possible, other ones are still interesting

- Redox potential
- Salinity
- Conductivity
- Nitrates
- Turbidity
- Methane gas
- Hydrogen sulphite gas
- Oxygen
- Carbon monoxide

3.3.3 Requirements

For the parameters considered, are described in the following table the minimum and maximum values intended, as well as the precision.

Table 10 - Operating range and precision for wastewater parameters

Parameter	Minimum	Maximum	Precision
pH	3	10	5%
Flowrate	0 L/s	300 L/s	10%
Total dissolved solids	0	500 mg/L	10%
Temperature[8]	5ºC	35ºC	5%
Pressure	0 bar	5 bar	5%
Dissolved oxygen	0	12 mg/L O_2	10%
Salinity	0 PSU	10 PSU	5%
Redox potential[9]	0 mV	200 mV	5%
Conductivity	100 µS/cm	10000 µS/cm	5%

[8] This temperature is for the wastewater. The temperature inside the visit boxes and surface near the cover, where the devices are likely to be placed, may vary between 5ºC and 50ºC.
[9] The blue ones are less relevant than the others above.

Nitrates	2 mg/L NO_3	100 mg/L NO_3	5%
Turbidity	0 NTU	200 NTU	10%
Methane gas	[10]		
Hydrogen sulphite gas	[11]		
Oxygen	[12]		

Expected lifetime for these sensors could depend on the installation conditions, but never less than 2 years, to be economically interesting.

The materials that we could find on pipes are:

- PVC
- PVC-U
- PP
- Ceramic stoneware
- Cement
- Glass-reinforced thermosetting plastic based on unsaturated resin

The environmental conditions may affect the devices, because they will be subjected to high humidity, wide range of temperatures, particularly highly oxidative atmosphere. They will be difficult to access.

3.3.4 Control levels

The ranges are already described in the previous sections; in this section we define the alerts and the alarms for each parameter.

The alerts are set to give an indication of some deviation from expected values, beyond what may indicate a significant change, and could give some preventive information that allow taking early actions.

Alarms are normally barriers beyond where if no actions are taken it can result in a situation of high risk to the health of water consumers, so the immediate knowledge is a factor in reducing probability of dangerous occurrences.

[10] This information need to be treated before, if it´s necessary.
[11] This information need to be treated before, if it´s necessary.
[12] This information need to be treated before, if it´s necessary.

Given the importance of have a lower power consumption on sensors, if these levels are shown on devices, then the frequency of sending data to the SCADA can be reduced, being just sent the deviations and the data history stored during a certain period of time

Table 11 - Control levels for Wastewater

	Control levels			
Parameter	**min alarm**	**min alert**	**max alert**	**max alarm**
pH	< 4	<5,5	>8	>9
Flowrate	< 50% ATL 5	< 75% ATL 5	> 65 L/s	> 73 L/s
Total dissolved solids	< 50 mg/L	< 100 mg/L	> 400 mg/L	> 450 mg/L
Temperature	< 7ºC	< 10ºC	> 25ºC	> 30ºC
Pressure	< 50% ATL 50	< 20% ATL 50	> 120% ATL 50	> 150% ATL 50
Dissolved oxygen	<3 mg/L O_2	<5 mg/L O_2		
Salinity			> 1 PSU	> 3 PSU
Redox potential			> 10% ATL 50	> 25% ATL 50
Conductivity			> 5% ATL 50	> 10% ATL 50
Nitrates			> 10% ATL 50	> 25% ATL 50
Turbidity			> 25% ATL 50	> 50% ATL 50
Methane gas				
Hydrogen sulphite gas				
Oxygen				
Carbon monoxide				

3.3.5 Workflow steps

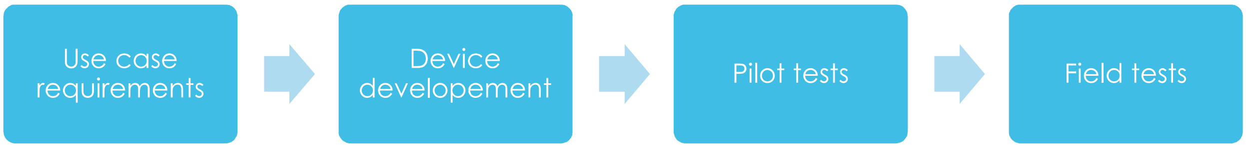

Figure 14 - Development process for wastewater device

3.3.6 Business Cases

The strategically Plan of draining and residual water treatment foresees a strategy of improvement of the management of the draining and of the treatment equipment. It will rely on the development of systems of monitoring and modulation, in the basins of draining of Almada municipality.

It is intended to deepen the control of:

- Improper linking of the domestic drainage system;
- Direct discharges of excesses of the pluvial net in the domestic waste net, suddenly increasing the volumes that arrive at the stations of residual water treatment;
- Superficial draining of volumes that do not flow to the draining system;

In this direction, the total measurement of pH, flowrate, dissolved solids, temperature, pressure and dissolved oxygen can give considerable contribution for the reduction of risks.

As for rainwater, further inquiry will be needed during the project to determine the data volume and accuracy required to derive a correct interpretation and to extrapolate conclusions on the state of the network..

Figure 15 - Video system setting in drainage collector

The following table summarizes the main aspects of waste water-related business cases

Table 12 – Wastewater business cases

Content	Description	Priority requirements	Actions by distributor	Parameters
Blockage / collapse of pipes		P1: detection P2: intensity (level of liquid in blocked pipe; % of water flowing freely) P3: localization of blockage	Punctual mitigation/repair actions Identification of recurrent factors for long term improvement	Pressure Flowrate
Overflow	Water of the network leaving the network Often consequence of blockage, collapse or	P1: detection (water reaching top of visit chamber/street level) = localization P2: early detection (water fills the full diameter of	Short term mitigation/repair actions Identification of recurrent factors for long-term	Pressure Flowrate

	intrusion	pipe P3: identification of causes (nature of blockage) P3: flow rate in pipe P4: duration of overflow	improvement	
Intrusion of water		P1: detection P2: increase of flow P3: localization P4: nature of intrusion (type of water) P5: time pattern of event	Short term mitigation/repair actions Identification of recurrent factors for long-term improvement	Salinity pH Total dissolved solids Temperature Redox Turbidity Nitrates Dissolved oxigen

3.3.7 Monitoring profiles

Based on the use cases described above, with the goal of managing as efficiently as possible the energy consumption of the sensor node, it was specified the periodicity of measurements of the required parameters. The periodicity is shown in the following table:

Table 13 – Periodicity of parameters readings for wastewater

	Periodicity	
Parameter	**read**	**send to SCADA**
Conductivity	1/5min	1/day
Chlorine	1/5min	1/day
pH	1/5min	1/day
Temperature	1/min	1/day
Pressure	1/min	1/day
Flow rate	1/min	1/day
Chloride	1/5min	1/day
Nitrates	1/5min	1/day
Turbidity	1/5min	1/day
Hardness	1/5min	1/day

Calcium	1/5min	1/day
Magnesium	1/5min	1/day

The parameters required for the wastewater use case can be classified in two types of profiles according to the required periodicity of measurements and communication. These types of profiles are critical and non-critical parameters.

Critical parameters:

- Pressure
- Temperature for compensation
- Flowrate (might move later in theproject to non-critical in case of technological issue related to power consumption of flow rate sensors)

Non Critical parameters:

- All the other ones

For critical parameters, the monitoring requirements are:

- 1 measurement / 1 min
- As long as the measurements do not pass the alerts and alarms thresholds (below minimum and above maximum), send gathered information once a day (except for keep alive signals)
- If one measurement is between the alert and the alarm thresholds, raise the frequency of measurements to 2 meas/1min, and if this occurs 10 consecutive times, send this information immediately to the SCADA and stop sending.
- If one measurement passes the alarm threshold, raise the frequency of measurements to 2meas/1min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator check this information (and then stop sending).

For non-critical parameters, the conditions should be:

- 1 measurement / 5 min
- As long as the measurement do not pass the alerts and alarms (below minimum and above maximum), just need to send information once a day (except for keep alive signals)
- If one measurement is between the alert and the alarm levels, raise the frequency of measurement to 1 meas/2min and if this occurs 15 consecutive times, send this information immediately to the SCADA

- If one measurement passes the alarm threshold, raise the frequency of measurements to 1meas/2min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator check this information (and then stop sending.

Bidirectional communication

If it possible, enable the following actions from the remote centre (sorted by increasing complexity):

1. To pull one or several values from the sensing unit, with expected frequency of 1/month
2. To configure the sensor to operate based on over-the-air parameterization (define thresholds, alert and alarm levels, etc.)
3. To update the sensor code, over-the-air programming.

3.3.8 Participants:

List of the main participants in the process

- Alexandra Sousa (wastewater treatment)
- Ana Paula Bubezes (wastewater treatment)
- Ana Cristina Furtado (wastewater treatment)
- Tiago Meirinhos (wastewater treatment)
- Ramiro Norberto (wastewater network)
- Fernando Bacelar (wastewater network)
- Filipe Cruz (wastewater network)
- António Coelho (wastewater elevatory stations)
- Paula Castro (safety and security)

3.4 Summary of requirements

In this section the operating ranges for each parameter, required by each use case, will be aggregated and summarised in order to provide support to the tasks of sensing hardware specification and parameterisation of the monitoring software.

3.4.1 Range of operation

The following table results from the compilation of the operation ranges required by each use case. The minimum operating range value for each parameter results from the minimum value required to satisfy the least demanding use case. Regarding to the maximum operation range and the precision required for each parameter, they correspond to the values required to satisfy the most demanding use case.

Table 14 - Maximum, minimum and precision for Drinking water[13]

Parameter	Minimum	Maximum	Precision
Conductivity	100 µS/cm	10000 µS/cm	3%
Chlorine	0,05 mg/L	1,25 mg/L	5%
pH	3	10	5%
Temperature[14]	5ºC	35ºC	5%
Pressure	0 bar	16 bar	5%
Flowrate	0 L/s	300 L/s	2%
Chloride	10 mg/L Cl	250 mg/L Cl	5%
Nitrates	2 mg/L NO_3	100 mg/L NO_3	5%
Turbidity	0 NTU	200 NTU	5%
Hardness	10 mg/L $CaCO_3$	400 mg/L $CaCO_3$	5%
Calcium	5 mg/L Ca	100 mg/L Ca	5%
Magnesium[1]	3 mg/L Mg	100 mg/L Mg	5%

[13] The blue ones are less relevant for the purpose of Proteus than the others above.
[14] This temperature range is for the water inside the pipes (usually between 10-25 ºC). The places to put the device outside may vary from 5-45 ºC.

Total dissolved solids	0	500 mg/L	10%
Dissolved oxygen	0	12 mg/L O_2	10%
Salinity	0 PSU	10 PSU	5%
Redox potential[15]	0 mV	200 mV	5%
Methane gas	[16]		
Hydrogen sulphite gas	[17]		
Oxygen	[18]		
Residual noise[19]	[20]		

3.4.2 Control Levels

The following three tables summarize the minimum and maximum threshold values for the alerts and alarms of the parameters required by each use case.

Table 15 - Control levels for drinking water use case

	Control levels			
Parameter	**min alarm**	**min alert**	**max alert**	**max alarm**
Conductivity	< 6% ATL[21] 50	< 3% ATL 50	> 3% ATL 50	> 6% ATL 50
Chlorine	< 0,10 mg/L	< 0,2 mg/L	> 0,6 mg/L	> 0,8 mg/L
pH[22]	< 6,5	< 6,7	> 8,0	> 9,0
Temperature	< 7ºC	< 10ºC	> 20ºC	> 25ºC
Pressure	< 1 bar	< 10% ATL 50	> 10% ATL 50	> 6 bar
Flowrate			> 20% ATL 5	> 195 L/s
Chloride			> 10% ATL 50	> 240 mg/L Cl

[15] The blue ones are less relevant than the others above.
[16] This information need to be treated before, if it´s necessary.
[17] This information need to be treated before, if it´s necessary.
[18] This information need to be treated before, if it´s necessary.
[19] The blue ones are less relevant for the purpose of Proteus than the others above.
[20] This information need to be treated before, if it´s necessary.
[21] ATL - average or trend of last measures, given the expected value for an integration time of 5 minutes
[22] Sorensen scale

Nitrates			> 10% ATL 50	>45 mg/L NO_3
Turbidity			> 20% ATL 50	> 4 NTU
Hardness			> 10% ATL 50	> 250 mg/L $CaCO_3$
Calcium			> 10% ATL 50	> 90 mg/L Ca
Magnesium		> 10% ATL** 50	> 70 mg/L Mg	

Table 16 - Control levels for rainwater use case

Control levels				
Parameter	**min alarm**	**min alert**	**max alert**	**max alarm**
Flowrate		< 50% ATL 5	> 1800 L/s	> 2150 L/s
pH	< 5	<6	>8	>9
Salinity			5 PSU	10 PSU
Pressure	< 50% ATL 50	< 20% ATL 50	> 120% ATL 50	> 150% ATL 50

Table 17 - - Control levels for wastewater use case

Control levels				
Parameter	**min alarm**	**min alert**	**max alert**	**max alarm**
pH	< 4	<5,5	>8	>9
Flowrate	< 50% ATL 5	< 75% ATL 5	> 65 L/s	> 73 L/s
Total dissolved solids	< 50 mg/L	< 100 mg/L	> 400 mg/L	> 450 mg/L
Temperature	< 7ºC	< 10ºC	> 25ºC	> 30ºC
Pressure	< 50% ATL 50	< 20% ATL 50	> 120% ATL 50	> 150% ATL 50
Dissolved oxygen	<3 mg/L O_2	<5 mg/L O_2		
Salinity			> 1 PSU	> 3 PSU
Redox potential			> 10% ATL 50	> 25% ATL 50
Conductivity			> 5% ATL 50	> 10% ATL 50
Nitrates			> 10% ATL 50	> 25% ATL 50
Turbidity			> 25% ATL 50	> 50% ATL 50
Methane gas				
Hydrogen sulphite gas				

Oxygen
Carbon monoxide

3.4.3 Critical parameters

The following table presents the operating range of the critical parameters for each use case, as well as the corresponding control levels.

Table 18 – Operating ranges and control levels of the critical parameters for each use case

	Parameter	**Min**	**Max**	**Precision**	**min alarm**	**min alert**	**max alert**	**max alarm**
Drink water	Flowrate	0 L/s	200 L/s	2%			> 20% ATL 5	> 195 L/s
	Pressure	0 bar	16 bar	5%	< 1 bar	< 10% ATL 50	> 10% ATL 50	> 6 bar
	Chlorine	0,05 mg/L	1,25 mg/L	5%	< 0,10 mg/L	< 0,2 mg/L	> 0,6 mg/L	> 0,8 mg/L
	pH	5,00	10,00	5%	< 6,5	< 6,7	> 8,0	> 9,0
	Temperature	5ºC	35ºC	5%	< 7ºC	< 10ºC	> 20ºC	> 25ºC
Rain water	Flowrate	0 L/s	300 L/s	10%		< 50% ATL 5	> 1800 L/s	> 2150 L/s
	Pressure	0 bar	5 bar	5%	< 50% ATL 50	< 20% ATL 50	> 120% ATL 50	> 150% ATL 50
	Temperature	5ºC	35ºC	5%				
Waste water	Flowrate	0 L/s	300 L/s	10%	< 50% ATL 5	< 75% ATL 5	> 65 L/s	> 73 L/s
	Pressure	0 bar	5 bar	5%	< 50% ATL 50	< 20% ATL 50	> 120% ATL 50	> 150% ATL 50
	Temperature	5ºC	35ºC	5%	< 7ºC	< 10ºC	> 25ºC	> 30ºC

3.4.4 Monitoring conditions

The following table summarizes the periodicity of readings and communications required to meet the requirements of each use case.

Table 19 – Periodicity of parameters readings for each use case

Parameter	Periodicity					
	Drink Water		Rainwater		Wastewater	
	read	send to SCADA	read	send to SCADA	read	send to SCADA
Conductivity	1/min	1/day	1/5min	1/day	1/5min	1/day
Chlorine	1/min	1/day	1/5min	1/day	1/5min	1/day
pH	1/min(*)	1/day(*)	1/5min	1/day	1/5min	1/day
Temperature	1/5min	1/day	1/min	1/day	1/min	1/day
Pressure	1/min	1/day	1/min	1/day	1/min	1/day
Flow rate	1/min	1/day	1/min	1/day	1/min	1/day
Chloride	1/5min	1/day	1/5min	1/day	1/5min	1/day
Nitrates	1/5min	1/day	1/5min	1/day	1/5min	1/day
Turbidity	1/5min	1/day	1/5min	1/day	1/5min	1/day
Hardness	1/5min	1/day	1/5min	1/day	1/5min	1/day
Calcium	1/5min	1/day	1/5min	1/day	1/5min	1/day
Magnesium	1/5min	1/day	1/5min	1/day	1/5min	1/day

(*) Instantly if they pass alerts or alarms

For critical parameters, the monitoring requirements are:

- 1 measurement / 1 min
- As long as the measurements do not pass the alerts and alarms thresholds (below minimum and above maximum), send gathered information once a day (except for keep alive signals)
- If one measurement is between the alert and the alarm thresholds, raise the frequency of measurements to 2 meas/1min, and if this occurs 10 consecutive times, send this information immediately to the SCADA
- If one measurement passes the alarm threshold, raise the frequency of measurements to 2meas/1min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator check this information (and then stop sending).

For non-critical parameters, the conditions should be:

- 1 measurement / 5 min
- As long as the measurement do not pass the alerts and alarms thresholds (below minimum and above maximum), just need to send information once a day (except for keep alive signals)

- If one measurement is between the alert and the alarm thresholds, raise the frequency of measurement to 1 meas/2min and if this occurs 15 consecutive times, send this information immediately to the SCADA and stop sending
- If one measurement passes the alarm level, raise the frequency of measurements to 1meas/2min, and if this occurs 4 consecutive times, send immediately to SCADA, until the operator check this information (and then stop sending.

Bidirectional communication

If it possible, enable the following actions from the remote centre (sorted by increasing complexity):

- To pull one or several values from the sensing unit, with expected frequency of 1/month
- To configure the sensor to operated based on over-the-air parametrization (define thresholds, alert and alarm thresholds, etc.)
- To update the sensor code, over-the-air programming.

3.4.5 Operating conditions

As previously described, in each use case the normal conditions in the places where the devices should be installed are harsh, with a high humidity levels and prone to corrosion.

Figure 16 - Operating condition of drinking water valves box

3.4.6 Casing

In the field, the expectation is to install the devices in several critical points of the network distribution system for the drinking water and in the network drainage systems for rainwater and wastewater.

The typologies are:

- Drinking water
    - Water pressure reduction
    - End pipes
    - Monitoring and measurement zones
    - Management pressure zone
    - Sectioning valves
    - Suction cups
- Rainwater
    - Visit box
    - Suspecting origins
- Wastewater
    - Visit box
    - Superficial discharger
    - Connections to some particular clients
    - Suspecting origins

3.4.7 Energy and network transmission

Typically there is no power source available in the places where the sensors will be installed, and given the high number[23] of sensors that are intended to be installed, the option for batteries that require substitution will involve a very considerable maintenance work, so it is very important to obtaining energy from renewable sources and on-site.

The communications have to be mainly done through wireless technologies, but in some cases, the private optical fibre network already installed in some places can be used.

The communications in the drinking water should be sent to Vale de Milhaços power plant SCADA (Citec software), in MODBUS form.

The communications in the rainwater and wastewater should be sent to Torrão power plant SCADA (Clear SCADA software), in MODBUS standard.

3.4.8 Others (Incl. standardisation and regulatory constraints)

To the drinking water control, it is important to observe the Council Directive 98/83/EC, of 3 November 1998, on the quality of water intended for human consumption.

[23] Probably three hundred

4 Validation plan

The following section presents a very short overview of PROTEUS validation plan. It will be further detailed in the Requirement analysis (D1.2) and in work package 5.

4.1 Lab scale

Early in the development (as soon as sensor chips are available), the performances of the sensor chips will be evaluated in a dedicated testbed built during the project (Work package 5). At this stage, only the sensing performances will be assessed.

The testbed will enable

- To evaluate sensitivity of each type of device to its parameter over the expected range
- To assess cross-sensitivity to temperature and pH (to build compensation algorithm)
- To assess cross-sensitivity to other parameters (to decide whether compensation strategies need to be implemented)
- To assess sensor drift by accelerated ageing

To do so, the testbed will be designed with a special focus on

- its compatibility to the sensor chip
- its swift switching capability from one parameter (hydraulic or chemical) to the other
- its range of acceptable parameters
- its capability to benchmark several chips at the same time, in a process as automated as possible

4.2 Model deployment

To test the full sensor node, they will be deployed in Sense-City model network.

Sense-City includes 400m² mini-cities with 2.5m underground; the water network will be implanted below the houses, roads and buildings. It will include retail components (distribution into buildings, monitoring bypass), as well as rainwater and wastewater network with visit chambers. The network specifications will be defined by a set of end users, primarily SMAS and PONSEL.

The scenarios of use will be designed in advance, in order to capture all the specifications for the network. The scenarios will cover two aspects: water typology (chemical content; hydraulic features) and event typology (intrusion, overflow..)

The deployment will enable to test:

- Optimized sensor node implantation
- Response of sensor node in quasi-real conditions. “Response” includes aspects such as sensing, energy management, communication
- Validation of adaptive features

4.3 Real deployment

In the end of the development, the sensors will be put on WSP critical points (to the drinking water), and in relevant places on rain and waste water, to made de field tests.

These critical points are:

- Drinking water
  - Pressure reductions (5 devices)
  - End pipes (10 devices)
  - Sectioning valves (10 devices)
  - Measuring and control zone (5 devices)
- Rainwater
  - Visit boxes (10 devices)
- Wastewater
  - Visit boxes (10 devices)

The validations in the first step will be done by comparing the results with another known system (like commercial devices for the same parameters), with precision features and better accuracy (but much more expensive) than the ones required for the Proteus devices.

The second step will be done collecting water samples near the devices to be analysed in the laboratory with the methods that have the best precision and accuracy, for each parameter to be analysed.

5 Conclusion

As a summary, we have detailed three use cases that SMAS is expecting to see solved via PROTEUS project. This work fall within the purview of the support programs to SMAS Water safety plans.

The description of each use case provides insight into the critical and non-critical parameters to measure, complemented with range of values, alert and alarm levels, expected precision, frequency of measurement, frequency of data transfer to SCADA, conditions of operations of the sensors.

The use cases also describe how the data can be exploited to solve concrete issues and needs encountered by SMAS during its operations.