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Future of Sensoring at KWR

KWR Watercycle Research Institute

BTO

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Summary

Within KWR renewed effort into sensoring is under consideration to keep up with a dynamic water sector and technological developments in e.g. nanotechnology and ICT. Work into sensoring needs to be programmed in an integrated, multidisciplinary fashion to serve the sector most effectively. This document outlines the background of sensor-related research, at KWR and the sector, and analyzes barriers for the (widespread) implementation of sensors in the water sector. Next, it outlines activities that KWR can potentially employ to overcome identified barriers. Furthermore, it analyses the context of KWR and the Dutch water sector regarding the subject of sensoring and describes the positioning of the work within the Dutch water sector and KWR as an organization. Finally, the documents outlines a vision for the future work on the sensoring subject at KWR, the implementation thereof in the organization and a number of key aspects that will be emphasized in the definition of new projects in the future. As supplementary information, an extensive list of potential project ideas is compiled in the appendix of this document.

Main inference from the performed analysis is that sensors can be employed within the broad categories of Safeguarding Human Health and Process Control. The specific application areas demand a different approach to development with more emphasis on legal compliance in the case of Human Health. Implementation of sensors in both categories has mainly been hindered by a lack of definition of needs by the sector, technology drawbacks, not enough emphasis on the complete sensoring system (including data analysis, decisions and feedback) and resulting problems with data handling. To overcome the identified difficulties, within the BTO programme KWR aims to actively participate in the innovation chain of sensor implementation by coordinating between technology suppliers and the water sector. With this, KWR will be streamlining the needs of the water sector, scouting and testing new technologies, connecting technology with data and organization and finally validating and implementing sensor technology at utilities. To this end, KWR will closely collaborate with sensor developers and the sector and internally adapt an integrated KWR-wide approach.

Contents

1 Introduction

1.1 Applied Research into Sensors

Exploration of the capabilities of water-related sensors has been performed during the last decade based on the foreseeable implementation of real-time measurements and data analysis, resulting in immediate useful information to reduce costs of operations or to make predictions of processes. Sensor research is based on a broad spectrum of disciplines. Research has therefore been driven by developments in various fields, with roots in chemistry, physics, biology and engineering. Initially, progress was driven by miniaturization and automation of laboratory techniques (Workman et al., 2009). Recent advances in microfluidic lab-on-a-chip applications (Mark et al., 2010), e.g. for point-of-care medical diagnostics (Neuzil et al., 2012; Chin et al., 2012) or particle and cell analysis by cytometry (Huh et al, 2005), as well as advances in nanotechnology (Walt, 2009; Joo & Brown. 2008; Liu et al., 2012) have demonstrated that, by combining the state-of-the art of these various disciplines, new devices can be realized that approach the analysis quality of laboratory techniques.

Sensor measurements can conceivably be used for early-warning of water quality, monitoring of water treatment, monitoring saltwater intrusion for efficient storage of water in freshwater aquifers, preventing the discharge of unsuccessfully-treated wastewater in the environment or safeguarding the microbiological stability of drinking water. Added value of the use of sensors is an increased (real-time) insight in water quality compared to sampling routines, increasing chances to find contaminants and reducing reaction time, leading to lower health risks. In addition, transport of samples and the amount of laboratory analyses are reduced and large amounts of data are generated. Proper combination of data from different sensors and improved data analysis can lead to renewed insights in processes or the human health risks of various types of water. A general trend that is observed is the increased demand from users for sensors that measure more generic parameters or a resulting effect as an early-warning. It has been realized that it not possible to achieve a universal sensor or a multitude of sensors for the ever increasing list of targets. Therefore, emphasis has shifted to semi-generic 'fingerprint' sensors combined with a proper decision support system for on-line detection. In the future, monitoring of water quality is envisioned to occur foremost on location in the field, preferably real-time. On-line or at-line systems, both chemical and microbiological oriented, can initially be used for prioritization of sampling locations with the detailed chemical and microbiological analyses still performed by an efficient routine-laboratory. Next, increasingly more generic analyses are thought to move into the field, concurrently turning the nowadays routine-laboratory into a specialties-laboratory for detailed follow-up after initial screening results from on-line monitoring.

Different sensor technologies for the determination of chemical and microbiological water quality have been evaluated within the Netherlands, both by KWR and the Dutch water utilities. These technologies have been based on a diverse set of physical measurement principles (Storey et al., 2011; Van Wezel et al., 2010; Lopez-Roldan et al., 2013). Examples of evaluated technologies include sensors based on optical measurement techniques such as absorption (Van den Broeke et al., 2008), interferometry (De Graaf et al., 2012; Puah et al., 2011) and Raman spectroscopy (Van de Vossenberg et al. 2013; Van Leest et. al., 2012). In addition, electrochemical techniques (Van der Gaag, 2011), surface plasmon resonance based sensors (Homola, 2008; Van der Gaag, 2009) and cell-based techniques (Appels et al., 2007; Eltzov et al., 2009; Woutersen et al, 2001; Woutersen, 2013) have been studied. Within the realms of these different measurement techniques, various stages of the maturity of the technologies have been probed by setting up collaborations with technology suppliers such as Optisense, S:can, AquaExplorer and MicroLan. These collaborations have resulted in a small number of implementation pilot projects at sites such as the Vitens Innovation Playground and the SenTec center of WLN.

Concurrently, with the wider availability of commercial water sensors, the emphasis of sensor-related research has shifted to ICT-related problems for efficient data analysis as well. It will be impossible and cost-ineffective to place sensors everywhere. Therefore, effort has been put into the identification of scenarios for sensor placement in order to obtain an optimal ratio between installation costs, the amount of retrievable information and potential exposure of the population to contaminants (Van Thienen, 2012; Van Thienen, 2013). Furthermore, after sensor placement an overwhelming amount of data can be produced that should be transferred to useful information. Therefore, tools for data analysis and interpretation have been increasingly investigated. In general, it is recognized that an integrated approach to the implementation of sensor technology is necessary.

The output of all efforts have until now not yielded the desired widespread implementation of sensor technology throughout the sector. Underlying problems for this, as analyzed in Chapter 2, include not only intrinsic technology related issues. Surrounding issues concerning the laboratory, policy and legislation, data handling and ambiguity in business-cases are responsible as well. This means that effort into the understanding of the potential applications and implementation potential of sensors and sensor technology still remains relevant, as can also be concluded from various innovation roadmap documents of *e.g.* Vitens, and the proposed ambition program for water sensors initiated by a consortium within the northern provinces of the Netherlands.

1.2 Process Outline

Within this document a renewed vision on the field of sensor technology in the water sector is formulated. Identification of 'knowledge gaps' and key problems for the implementation was realized using internal KWR workshops, conversations with external partners within the sector, attendance to the international congress 'Sensors 4 Water', participation in the NanoNext workshop 'Sensoring Demands' and participation in the GWRC workshop concerning the 'Global Sensors Compendium project'. The process behind the new formulation of vision is envisioned to be iterative. In the course of time a focus is obtained, which is shared with external partners for feedback, resulting in a renewed sketch. The current document is a summary of these internal and external interactions. It is the intent of KWR to keep the dialog that has been started with the sector regarding this subject at KWR alive. The renewed dialog is ideally held within the 'Themagroep Nieuwe Meetmethoden en Sensoring', while specifically interested partners are cordially invited to participate.

1.3 Structure of the Document

This document commences with a perspective how sensors could benefit the sector. Next, the translation from business to innovation and development is made and challenges for the implementation of sensors are identified. These problems can be divided into various categories and the potential role of KWR in solving a subset of the determined issues is discussed. Next, contextual aspects of the Dutch water sector and KWR as an organization are analyzed in order to finally conclude with a balanced view on the future for of sensoring at KWR, the implementation in the organization and key aspects that will be emphasized during the definition of new project proposals on the subject. The document ends with an appendix with an extensive list of potential project ideas as supplementary information.

2 Sensors: Drivers, Demands and Potential

2.1 Key Business Drivers

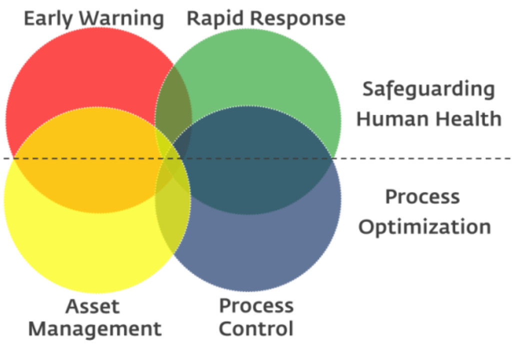
In a survey conducted amongst 39 water utilities and suppliers, Michael Storey of Sydney Water, Australia investigated the main reasons for the use of (on-line) sensors within the surveyed companies (Storey, 2013). The response resulted in a list of key business drivers prioritized by the percentage of responders citing the specific driver as relevant. The distinct key business drivers for sensor technology are shown in Table 1. As an indication Table 1 is representative for European utilities as well, although more emphasis on event detection was informally recognized.

Table 1. Key business drivers for sensor technology.

Parameter	Percentage of Response
Process Control & Optimization	100%
Regulatory	77%
Event Detection & Response	60%
Safety	34%
Asset Protection	25%
Planning	15%
Maintenance	2%

The different drivers can be accommodated into 4 broader business categories that have a direct value for water utilities (Figure 1). The categories 'Early Warning' and 'Rapid Response' deal with the (real-time) determination of water quality and the response to signs of abnormal behavior. Water quality is of course key priority for the delivery of sound drinking water, safeguarding human health. Driver for sensor technology in this respect is increasing the efficiency of monitoring and reduction of the accompanying costs. The categories 'Process Control' and 'Asset Management' deal more with the business side of water utilities. Here optimization of the operations is key, resulting in a reduction of operational costs. The distinction of the business drivers into the two themes Safeguarding and Process Optimization is critical since it determines the necessity for legal compliance of technology.

Figure 1. Business categories where key business drivers exist for sensor technology.



Examples of particular applications within the realms of the above business categories can be found in a priority list of water utilities as a result of discussions at the Sensors 4 Water conference, as well. Major issues that were raised where utilities would like applied developments to focus on include:

- Modeling of the distribution network (early warning, rapid response, process control)
- Quick restoration of the water supply after incidents (rapid response)
- Effect-based detection (early-warning)
- Monitoring and subsequent decision support system (early-warning & rapid response)
- Closing of feedback loops for decisions and processes (process control)

2.2 Technological Demands for Sensors

Based on the business areas described above where sensor technology can yield appreciable added value, the device parameters for sensors can be determined (Table 2). While very specific parameters depend on the area where the sensor is applied, a number of general demands can be pinpointed. Nevertheless, a particular sensor might not necessary fulfill all the demands but ideal (combinations of) sensors will fulfill a large number of demands.

Table 2: Technological demands for sensor devices.

Key demands (No particular order)	
Sensitive	Specific
Reproducible	Inexpensive
Simple (Handling for Staff)	Low Maintenance
Robust	Environmental Tolerant
Portable	Low Power
Minimum Reagents	(Self-) Calibrated
Stability	Reliability (False-Alarms)
Non-Destructive	Demonstrate Business Benefits
Integrate in Existing Technologies	Perspective for action

In the development stage of technology, care should be taken not to over-interpret these demands and the current status of technology in terms of ideal situations. In general, the development of a commercial sensor starts in the laboratory with a new instrumental analysis. This measurement technique is subsequently automated and mechanized. If this can be successfully achieved and if there is demand to perform the specific measurements at multiple locations at low costs, effort is put in the miniaturization, the energy consumption and the cost effective production of the technique.

2.3 Identified Problems for Implementation

Over the course of the past decade, a number of main problems were identified for the fact that widespread implementation of sensor technology within the water sector has been mostly unsuccessful up until now, although several implementation projects are in progress. These main problems, and the subsequent approaches to tackle them, should function as a red line for the joint research program in the implementation process. The subjects, shown in Table 3, can be categorized in business-related issues, issues concerning policy and legislation, and scientific and technological problems.

Table 3. Identified sector-wide problems for the implementation of sensor technology in the water sector and approaches to tackle these problems.

Problems	Approach
Business-Related:	
1. Market pull instead of technology push is needed 2. Combination of sensor development with business management 3. Focus too much on sensor instead of whole system	Business cases Realization water quality = Value
Governmental:	
4. Certification 5. Convincing legislators technology is worthwhile	Validation of technology Push / lobby for legislation changes
Scientific / Technological:	
6. Conversion of data into information 7. On-line detection of chemicals and bacteria not sensitive enough 8. Sensor placement & required (non-)specificity 9. Robustness	Technology development

The issues raised in Table 3 are collected as problems for the implementation of sensors in the water sector in general. It is, however, necessary to recall the two main themes for the use of sensors, because while the issues raised in the table can all be regarded as problems for the use of sensors for safeguarding of the health, internal process optimization is far less strict regarding legal compliance. Therefore certification and legal compliance can in these applications be considered a non-issue.

The business-related issues in general are concerned with a lack of experience and knowledge of what sensors can be of value for utilities. Feedback from actually use of sensors demonstrates that expectations of the application of sensors need to be managed very carefully. The layman's view on sensor implementation is that sensors will help out by easy installation and operation, while no maintenance is needed. To the contrary however, as with any technology, for sensors it is crucial to have rightly skilled personnel and an appropriate organizational structure for proper installation, operation, calibration and maintenance as well. Interestingly, for the case of maintenance, the specific application area can decide for a particular sensor whether maintenance is considered a burden or not. For real-time control, the appreciation of good data and process control seems to warrant proper maintenance while for regulatory compliance any maintenance is considered excessive.

Regarding the governmental and technological issues, these are mainly based on the fact that developed technology is not capable of performing its foreseen purpose yet. The reason for this can be the fundamental technological limitation or a restriction of its use.

2.4 Potential Contributions from KWR

Based on the identified problems, we can analyze where KWR can *potentially* take a role in order to accelerate the implementation of sensors in the sector. KWR might currently not be equally-welll equipped to take up the various roles. Yet, the analysis results in a number of approaches to choose from for the future of sensoring at KWR.

2.4.1 Scientific / Technological Issues

An area where KWR can potentially remain active is technology development. In recent years KWR has invested time and money in the development of fundamental principles for new sensors and techniques for increased sensitivity of commercial sensors. To minimize the problematic technology push and enable a more market pull to operate, it is critical to obtain a clear view where relevant issues exist. Four critical question need to be answered to recognize the niches for development of sensor technology. A proper combination of responses can yield an interesting opportunity for innovation. The first question concerning why sensor technology might be of interest has been analyzed in section 2.1. Next to this, three additional questions need to be answered: Where, What and How? If successfully combined, the combination could yield a fruitful proposal for new technology development.

While being relatively successful with a number of technological development projects in the past years, this effort at KWR has not lead to implementation of sensors in the sector. A number of commercially-backed instruments have currently passed the development stage and found their way into a number of pilot projects. From this it has been realized that development of a technology from fundamental technique into an implemented product takes a vast amount of (venture capital) investment and a critical mass of experts in an organization. This capital and personnel is currently not present at KWR.

2.4.2 Governmental Issues

Experience with validation of technology has been gained within KWR by participating in a number of projects with suppliers of sensor technology. This line of work can be continued in the future and should help the sector evaluate available sensor technology and with subsequent certification. Additionally, with the realization of a number of demonstration sites at drinking water companies (Vitens Playground, SenTec, Beerenplaat and Weesperkarspel) validation tracks can be performed more efficiently and in more realistic environments.

With respect to the effort to push for legislation changes, a role within the sensoring subject in the joint research program can be foreseen as well. For the successful integration of technology for the safeguarding of human health into legislation is a proper validation roadmap is necessary. Even in the case the technology is shown to be sound and robust, additional effort has to be taken to assimilate the technology in a legal framework. KWR has well-established connections with relevant legal entities (RIVM, Ministerie en Inspectie van Leefomgeving en Transport, Rijkswaterstaat) in order to streamline this effort. Communication of the status of technology and knowledge in an early stage facilitates the eventual mobilization of these people to act. To achieve effective implementation of technology a concerted effort between multiple departments inside and outside KWR is necessary with a proper incorporation of sensor research and technology into broader-oriented projects.

2.4.3 Business-related Issues

With the identified lack of experience and knowledge of sensor implementation in the sector a role for KWR can be to streamline the needs from the sector. KWR and the water utilities can work in close cooperation and perform analyses on the economic and societal benefits of the implementation of sensors via business-cases and scenario studies. KWR can help out as a consultant on what issues need to be considered for proper implementation in the sector for either safeguarding human health or for process optimization as well. Within this area, KWR has been involved in the realization of an online compendium of sensors for the water sector describing case-studies, parameters that can be measured and lessons for good practice.

2.4.4 Concept Development – Connecting Sensors, Data & Organization

A critical observation from table 3 is that effort in the past has been mainly focused on detection technologies, while a complete systems-approach has been lacking. Cross-cutting issues regarding business, organization and data management in combination with modern technology have been under-represented. A niche can be found for KWR in guiding a combinatorial and multidisciplinary approach of scouting and testing new technologies, combining these sensors into a system with data management and decision support, and validating and implementing this complete system into an organization. The implementation process is critically influenced by business-cases, considering necessary personnel and maintenance, where to finally place sensors in a specific environment and legal considerations. As a broad notion, this concept development will initiate from well-developed sensors and involve critical input of other (less technological) expertise in order to incorporate technology in a broader scope. Actively, this includes the incorporation of sensor-related work throughout the whole organization of KWR to put fundamental technology in perspective within applications. KWR is involved in the development of soft-sensors and the design of monitoring strategies using broad screening of chemical contaminants, where sensors have not yet been considered to be of added value. The use of control procedures for sensoring can be evaluated as well, such as HACCP (Hazard Analysis and Critical Control Points) which is an approach to prevent hazards in food production.

2.5 Pitfalls & Solutions

In order to come to a balanced view of the future direction of sensoring at KWR, it is worthwhile to acknowledge background organizational issues that need to be tackled. Where KWR meets challenges on the sensoring subject, these challenges extend into the whole sector. Adaptation of the proposed approaches of Table 3 has been difficult because of some inherent characteristics of the sector. These weaknesses have been specifically addressed and collected in Table 4 below in order to make amends for the future.

Table 4. identified Weaknesses of the sector and proposed solutions.

Weaknesses	Solutions
Collaboration / Duplication / Poor leverage	Collaborate
Communication – internal & external	Actively involve partners and know agenda
Conservative sector	Think in solutions
Promises & Expectations	Provide realistic prospects
Definition sensors & sensor research	Challenge existing paradigms
Data Handling / Communications	Demonstrate benefits
Address existing water quality issues	Discover other sectors (Food, Oil & Gas, Automotive, Medical)
Articulation of needs	

It may seem relatively simple to act upon the proposed solutions written down in Table 4. Nevertheless, a number of these actions will take a significant amount of time, such as making a renewed connection with the sector, exploring other sectors and setting up collaborations. KWR actively approaches this challenge and concurrently manages expectations from the results of effort within the joint research program.

An important issue to manage is the definition of sensor research and the thin line that exists between sensors and new measurement techniques. In this respect, the research on new analytical methods should be better connected with the development of sensors. Emphasis will not be on sensor technology, but on solving existing challenges using technology.

3 Dutch Water Sector Context

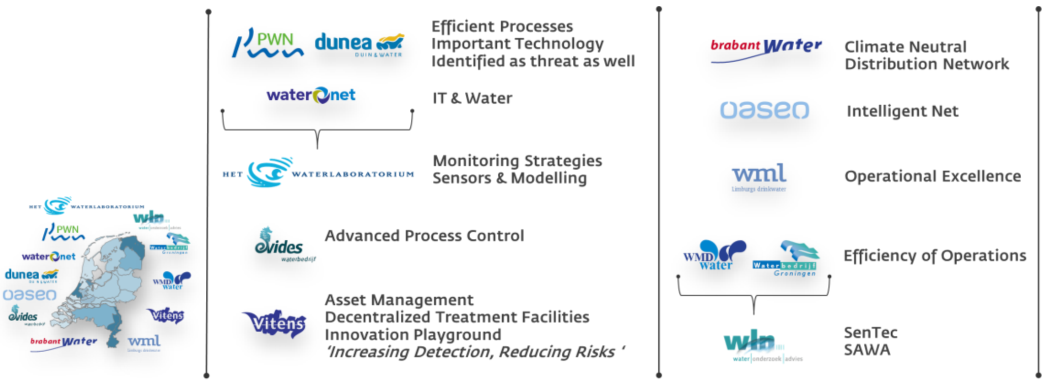
In order to arrive at a balanced future for sensoring at KWR, in addition to business- and technology-related issues other contextual aspects of the Dutch water sector and KWR need to be discussed as well:

- Innovation themes of the Dutch utilities
- Objectives of KWR
    - Chemical Water Quality & Health
    - Water Systems & Technology
- Shareholder opinions
- Internal ambition of KWR
- Required Expertise
- External network
- Funding and Scope: BTO and external subsidies

3.1 Innovation Themes of Dutch Utilities

The separate Dutch water utilities have each identified a number of innovation goals that are considered of key importance for a sustainable and (more) efficient supply of drinking water in the future. Remarkably, as observed from Figure 2, at every water utility in the Netherlands an innovation theme can be identified that is closely related to increased reliance on sensoring. Two main categories can be discerned, dealing with operational efficiency and the intelligent distribution network. Operational efficiency can be progressed by advanced process control and real-time insight in processes that is achieved, amongst others, by increased sensoring. The implementation of an intelligent distribution network, capable of monitoring water quality in real-time throughout the network, is crucially dependent on the implementation and future potential of sensor-based monitoring.

Figure 2: innovation themes of the dutch water utilities with a strong link to sensoring.



As a critical note, PWN indirectly considers sensor technology as a threat as well. Better and real-time monitoring of water quality will increase the visibility of contaminations and incidents, which could harm consumer confidence in the cleanliness of the drinking water supplied by the utilities.

3.2 Objectives of KWR

KWR as an organization has defined objectives for the main research groups to focus on to serve its shareholders, the Dutch water utilities, with high-quality research and implementation of (societal) innovation. Sensoring should play a pivotal role in the organization in the future as the subject is closely connected to these objectives of the separate research groups.

3.2.1 Water Quality and Health

KWR has a long history studying the chemical and microbiological water quality and related health issues. KWR serves as the guardian for water quality for the drinking water companies and signals emerging issues relating to chemistry and (micro)biology. The research group excels in human health research, development of effect-based monitoring techniques and analytical chemical analysis methods, e.g. the Orbitrap mass spectrometer. In order to better guard water quality, the sector aims to have faster measurements results, more reliable data and more integrated data management, leading to cheaper monitoring strategies. Within this effort, the identification, development and implementation of new sensor technologies for Dutch water companies and other partners in the water cycle is essential.

3.2.2 Water Systems and Technology

Sustainable organization and control of the water cycle are central to the Water Systems and Technology group. To this end a right balance exists in the group between field specialisms and an integrated technological approach. The technological specialisms within the research group deal with the efficient and sustainable treatment of drinking water and wastewater, while the field specialisms focus on the knowledge of the environmental water bodies in the water cycle that are both the source of drinking water and the accepting bodies of wastewater. Sensoring within the technological part of the group fundamentally serves the aims of the group by advanced process control, the (real-time) determination of water contaminants and monitoring of the efficient removal thereof, either in industrial settings, drinking water treatment plants or the distribution network. Furthermore, (real-time) monitoring of assets (infrastructure) is key for the group. For the field specialisms sensors can gather field data ranging from point scale to catchment scale, with the aim to understand the hydrological cycle and its associated changes in water chemistry – processes that are either not visible to the human eye, or hard to study on the relevant spatial and temporal scales. Measurements can be scaled up using thermal infrared cameras and satellite observations. Field data processing is addressed with software enabling gap-filling, extrapolation, detection of systematic errors, interpretation of causes of the observed variation and graphical interpretation.

3.3 Shareholder Opinions

Using the open communication with external partners, opportunities were taken to gauge the prevailing opinions on the proposed sensor-related activities within KWR. A general consensus exists within the sector that sensor-related effort should be programmed. Different opinions prevail, however, whether this effort should be programmed within the joint research program at KWR or at other institutes and laboratories in the Netherlands. Drinking water companies, the shareholders of KWR, are unanimous that for sensoring fundamental technology development should not be pursued at KWR. However, the opinions seem to differ on what is the envisioned niche for KWR further in the technology chain.

KWR as an organization has been presented with the assignment to perform high quality scientific research, with organizational goals defined by parameters such as the number of peer-reviewed scientific publications, and to act as a collective platform for visibility of the Dutch water sector in Europe. The organization and board are pleased with the fact that KWR has gained a leading position in several scientific areas. Prevailing opinions in the consultation boards such as the 'Themagroep Nieuwe Meetmethoden en Sensoring' seem to indicate, however, that the niche that KWR as an organization targets, *i.e.* in between fundamental scientific development and validation, is not considered ideal for the sensoring subject. It is considered that the approach of KWR has been too scientific in the past, instead of serving the Dutch waters sector with implementation of sensor technology. Shareholders therefore feel KWR should particularly be involved with the testing and validation of advanced (commercially-available) sensors in order to gain widespread support within the sector. Additionally, in close connection with validation, it is envisioned that KWR should employ its connections and influence in order to alleviate the identified legislational problems. To this end, KWR and its laboratory could cross-check newly developed sensor-based analyses against legal standard analysis techniques as a scientific basis to ascertain legal compliance of the technology.

3.4 Internal Ambition

The ambition of KWR is to collaborate with the sector towards the successful implementation of new (sensor) technologies at its shareholders. From a broad perspective this includes concept development, validation and implementation studies and the coordination of legal assimilation for the sensor applications related to safeguarding human health. The goal is a right balance between pure validation and implementation on one hand and the necessary enabling effort on the other, in order to demonstrate the added-value of sensor technology for the sector. To achieve this, an integrated approach should be adapted and sensors need to be incorporated as an integral part of other activities within KWR. Sensor can yield substantial added-value within a wide variety of applications and the subject should therefore be connected with other competences within KWR. The complete innovation chain for the implementation of sensor technology should be served, from scouting technology, concept development, data handling and validation to a finished implemented product. The realization needs intensive coordination with various knowledge groups and the sector, for which KWR acts as the platform.

3.5 Required Expertise

A wide range of competences and experiences is necessary to successfully address the issues surrounding the implementation of sensor technology in the water sector. Figure 3 compiles this expertise, either present at KWR or in the sector, demonstrating the complexity of the innovation process for the implementation of sensors.

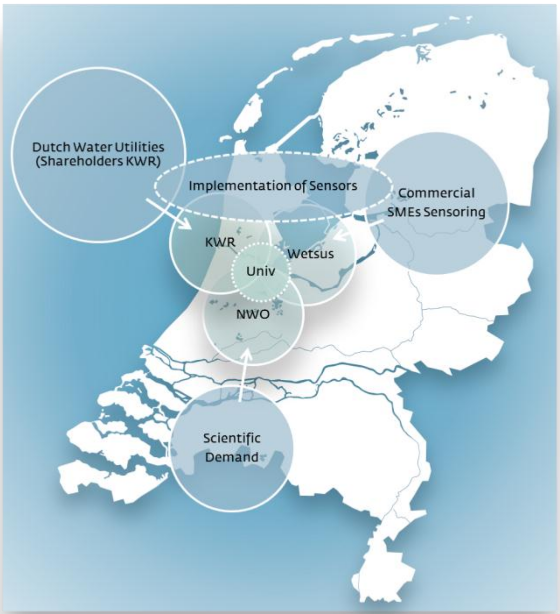
Figure 3. Required expertise, at KWR and in the Sector, for succesful sensor implementation.

KWR as an organization has a broad base of multidisciplinary knowledge, specifically in field of chemistry, microbiology, nanotechnology, data analysis and modeling, and trend studies. Additionally however, organizational experience, legislational connections and work floor feedback on the use of sensors are of key importance in connection with the previous expertise. Much of this knowledge is largely present within water utilities and technology suppliers. Therefore, it is vital to organize the knowledge and competences present in different organizations in the sector around the implementation issue.

3.6 External Network

KWR as an organization is positioned in between the Dutch water utilities, commercial technology suppliers and knowledge institutes, in order to effectively mediate between the needs from the sector and the supply of technology while concurrently putting joint innovation on the agenda. Figure 4 demonstrates the spectrum of knowledge organizations that effectively guide the demand for knowledge, development and innovation from societal, commercial and scientific viewpoint via different channels in the Netherlands.

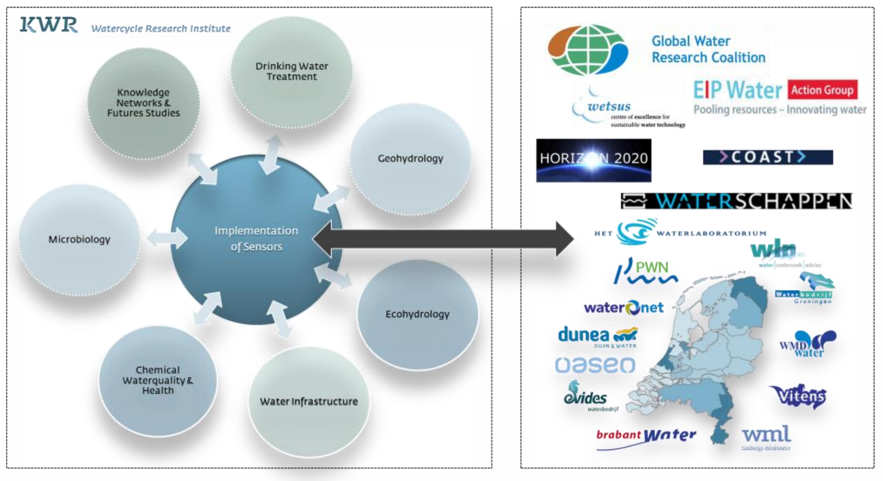
Figure 4: Positioning of the sensoring effort within the societal, commercial and scientific demand definition structures in the Dutch water sector.



Based on the realization that development of technology at KWR has not lead to widespread implementation of sensors, leading to the general shareholder opinion that a renewed scientific pursuit is not considered feasible, the network to unlock for KWR will be oriented towards the commercial side of the spectrum. Since Wetsus, centre of excellence for sustainable water technology, is aimed at a channeling the commercial demands from (small and medium) businesses into research and development, a close collaboration between KWR and Wetsus is envisioned for the subject of sensoring.

Critical for the communication with the external network will be the organization of the knowledge and expertise from within KWR and the alignment of this knowledge with the needs and potential from external partners such as water utilities and sensor companies (Figure 5).

Figure 5: Channeling of internal KWR expertise regarding sensoring towards external partners.



3.7 Funding & Scope: BTO and External Subsidies

The financing of the effort into sensoring is foremost considered to arrive from the joint water sector research programme of the Dutch water utilities (BTO). This programme is based on solving communal problems and the sharing of information, with KWR acting as the platform to achieve this (cost-)efficiently. In addition to this BTO programme, KWR can acquire external subsidies from a number of relevant subsidies programmes such as TKI, Wetsus, EU-projects and other Dutch national financing instruments. A secondary financing pathway for the work on sensoring can realistically be pursued at KWR to supplement the BTO financing to such an extent that enough funding for a basic sensoring agenda is realized. For the secondary funding, the scope of the instruments needs to intrinsically be considered in order to successfully lay a claim to either of them. Balancing the relative sizes of the separate funding and the related work is important. The renewed dialog with the sector regarding sensoring will be applied to keep the sector informed and present the ability to steer the activities at KWR.

4 Future of Sensoring at KWR

By weighing the various factors of the aforementioned analysis in Chapter 2 and 3, KWR has defined the following vision for the future of the subject of sensoring at KWR.

4.1 Mission

The sensor-related effort within BTO at KWR serves the water sector with the implementation of (new) sensors by:

- Providing business-cases for the use of sensors
- Scouting and testing of new technologies
- Concept development – connecting technology, data and organization
- Validation and implementation of sensors

Within the approach, KWR coordinates between technology suppliers and the water sector. Additionally, KWR acts as a platform of the sector for knowledge on sensoring and collaborates with partners in well-structured, multidisciplinary projects.

4.2 Preconditions

The sensor-related work should be integrally positioned within KWR. The work is partially based on knowledge that is gained within other teams and on knowledge in the sector. This knowledge needs to be properly compiled to provide more momentum. To this end an expert group can be created in order to yield effective internal and external communication.

The focus of KWR is on the mid-end of the technology chain. A prerequisite for projects will be the active involvement of technology suppliers, water utilities and water boards. As a result, projects are relatively short (1-2 years). With this KWR chooses a new direction with more focus on the implementation of sensors instead of fundamental research.

The new direction of KWR is integrally connected with a close collaboration with the water utilities. Collaborative consortia directly spawn implementation in the sector since the utilities are well-informed about the (implementation) potential. Furthermore, the definition of needs from the water utilities can be more effectively channeled by existing associations.

In addition to the implementation-focused BTO programme, a secondary externally-funded programme is aimed for to streamline fundamental technological developments into the Dutch water sector and to sustain a relevant network with more fundamental expertise. Financing via TKI and a partnership with Wetsus are foreseen as vehicles for these envisioned public-private partnerships. The complete agenda is summarized in Figure 6. Balancing the two programmes should be performed in consultation with the shareholders of KWR.

Figure 6: Schematic representation of the envisioned balanced portfolio of sensoring projects at KWR, funded by both the BTo and external subsidies.

4.3 Emphasis in Project Proposals

To substantiate the abovementioned mission and preconditions with actual projects, specific matters need additional attention. Emphasis in the definition of projects is put on the following topics.

Matching Needs & Capabilities

A key problem that has been identified is the lack of experience and knowledge at utilities what sensors can bring to the water sector. Projects come together successfully when the needs from water utilities are properly coupled to capabilities of commercial sensors or sensor systems. This matching must be effectively addressed in order to yield proper projects. KWR can assist the water utilities in the process before the definition of actual projects.

Safeguarding Health vs. Process Optimization

The time to implementation critically depends on the use of the sensor system. For process optimization legal compliance can often be considered a non-issue. For safeguarding (human) health projects, legal compliance must be a key part of the projects and needs to be considered from an early stage.

Chemical vs. Microbiological Contaminations

For microbiological contaminations, the monitoring process currently takes far longer (up to days) than for chemical contaminants. Therefore quick, specific and sensitive microbiological detection is prioritized. Here, the legal compliance aspects need to be addresses as well.

Perspective for Action

Implementation of sensors is more relevant if a follow-up with data analysis and appropriate actions is integrally considered beforehand.

Type of Project – Validation, Pilot or Development

In the BTO financed programme, validation and implementation via a pilot project is key priority. Development will only be financed if in collaboration with Wetsus or via a TKI structure.

4.4 Conclusion

A large amount of effort is still very necessary for the widespread implementation of sensors in the watercycle. Within the BTO programme KWR aims to actively participate in the innovation chain of sensor implementation by coordinating between technology suppliers and the water sector. With this, KWR will be streamlining the needs of the water sector, scouting and testing new technologies, connecting technology with data and organization and finally validating and implementing sensor technology at utilities. In realization of the described agenda, during 2014 the sensoring subject is gradually introduced in the 'Themagroep Nieuwe Meetmethoden en Sensoring' and the relation with sector and the 'Thematafel Sensoring' of Wetsus is (re-)developed. In 2015 a balanced portfolio of projects, financed by BTO and external subsidies, should be realized.

As supplementary information for the reader, a broad scope of project ideas and proposals has been compiled in the Appendix of this document. This compilation can serve as a basis for future sensoring projects.

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Appendix I Projects Ideas

Nutrient sensor (Acquired)

External Partners: WLN, Interline, Hoogheemraadschap Hollands Noorderkwartier

Project aimed at the characterization and validation of a commercial (Liqum) electrochemical sensor. The sensor is used for the determination of a water quality fingerprint. The sensor measures the redox potentials of combinations of several ions in water, including nutrients as phosphate, ammonium, nitrate and nitrite. The sensor, however, combines all signals into a general quality parameter. The current project aims to disentangle the separate signals via the development of algorithms. Practically, the sensor will be tested with known concentrations of nutrients. The aim is to correlate the known concentrations of the Liqum electrochemical signals with the future algorithms, in order to arrive an evaluation of the sensitivity of the sensor for these specific nutrients.

TA-COAST In-Flow Multidimensional Particle Analysis & Characterization (Acquired)

External Partners: VU University Amsterdam, University of Utrecht, Rijkswaterstaat, RIKILT, Radboud University Nijmegen, DELTARES, CytoBouy, Beckman Coulter

Detection of microscopic-sized particles remains priority for water utilities. Effects of these particles on the environment and human health are not well-known. Therefore, the safest route that has been chosen nowadays is to try to track the particles and ideally remove them from the water cycle. In order to achieve a more detailed view on the presence of these particles, a versatile platform needs to be developed to detect and analyze micro-particles. To this purpose, the goal is to improve Flow Cytometry (FC) technology to such an extent that it can be used to isolate, sort and analyze micro-particles of smaller size than presently possible and with greater selectivity and sensitivity. This will be realized with a combination of spectroscopic measurement techniques including Raman scattering techniques and fluorescence.

Innovative pH Sensors (Acquired)

External Partner: Holst Centre

The goal of the project to establish initial links with Holst Centre, a leading open innovation institute in the Netherlands that develops generic technologies for wireless autonomous sensor technologies and flexible electronics, and evaluate the status of their current technology using pH sensors as a benchmark. Current pH measurements suffer from stability and robustness of the devices. The sensors need to be recalibrated regularly in order to yield reliable measurements. As with any sensor, they are prone to biofouling which leads to necessary regular maintenance to clean the sensors. Sensors that require significantly less recalibration and maintenance therefore are interesting mainly for more reliable measurements and cost reduction. The current project will create a benchmark for the status of the sensor technology developed by Holst Centre. The detailed characteristics of the pH measurement itself, its short-term stability and longer-term drift will be specified, while concurrently determining the timeframe for (re-)calibration. Additionally, the biofouling potential of the sensors will be investigated, giving an indication for the robustness of the sensors in realistic environments and the amount of maintenance for proper functioning.

Remote Sensing for the Acquisition of Detailed Hydrological and Ecological Information on Ground water and Nature reserves (Acquired)

External Partners: Wageningen UR, EU Interreg project Smart Inspectors

Evaporation of water from the surface of the earth is the main water loss mechanism for the replenishment of the ground water stock, while knowledge on the amount of extractable water is vital for the continuity of the supply of water to customers. A detailed (eco)hydrological understanding of the terrain is therefore necessary for the efficient management of the ground water reserves. Developments in Unmanned Airborne Vehicles (UAVs) and remote sensors carried by UAVs have vastly accelerated the ability to closely observe Earth's surface. In addition to satellite observation, the use of UAVs offers new possibilities to monitor, model and manage (nature) reserves used for the extraction of drinking water. The current project will explore the added-value of remote sensing using UAVs, in combination with satellite images, for the extraction of (eco)hydrological information in order to improve the management of different terrains of interest. Using airborne photography, detailed spectral imaging and remote thermometry, parameters such as moisture content, evaporation rate, oxygen stress, drought stress, pH and nutrient concentrations of the soil will be remotely obtained and compared with measurements performed locally on the ground.

Cost effective hydro-chemical analysis of lysimeter drainage water (Acquired)

External partners: Eijkelkamp Agrisearch Equipment, STOWA en Alterra Wageningen UR

The quality of water that percolates to the saturated zone is strongly correlated with the amount of water that evaporates at the soil surface. Higher evaporation leads to higher concentrations of dissolved substances in soil water, as solely water molecules evaporate. This evaporation effect is dependent on weather conditions and the vegetation composition. KWR developed a weighing lysimeter that is able to measure evaporation with 0.1 mm precision. This project aims to extend the lysimeter system with Sorbisence (Eikelkamp Agrisearch Equipment) sensors to analyze the water quality of percolation water. The Sorbisense technology provides an innovative, cost-effective solution for measuring water quality and supplements or replaces traditional grab sampling. The performance of the Sorbisence technology will be evaluated versus standard water quality measurements and, concurrently, the effect of vegetation, soil and climate on the chemical composition of groundwater bodies will be assessed.

Quality control of (pressure) sensor data collected for groundwater monitoring (Acquired)

External partners: TNO, Alterra Wageningen UR, Dutch Provinces

The only fundamental law that really applies to errors in groundwater head data unfortunately is Murphy's law: everything that can go wrong, will go wrong. Sources of errors occur in every step of the monitoring process, from (manual) data collection in the field to the final storage in databases. The increasing use of (pressure) sensors for groundwater monitoring calls for specific knowledge and methods to (re)calibrate sensors and validate collected data. KWR and TNO are involved in developing methods and software for automating and improving data collection, storage, error detection, analysis and quality control processes, in order to improve the quality of collected groundwater data on the local and national scale.

DNA Aptamers as Selective Transducers in the Optisense Minilab Platform

Potential External Partners: Optisense, NFI, University of Amsterdam, Radboud University Nijmegen

Cocaine and other drugs of abuse are a problem for society. Monitoring is currently performed via collection of samples on location and analysis in the laboratory. Therefore, there is a need for on-site (on-line) monitoring instruments that quickly and selectively detect target compounds. The Minilab sensor platform of the company Optisense enables on-site selective detection of various compounds by means of commercial antibodies. The project aims to substitute these antibodies and integrate so-called DNA aptamers in the sensor platform. Aptamers are versatile DNA sequences that can be relatively easily engineered via the SELEX process to be selective for specific target compounds. The project will start with adaptation, integration and validation of cocaine-selective aptamers in the sensor platform. If successful, new aptamers will be developed resulting in a sensor platform with flexible sensitivity towards compounds such as other Drugs of Abuse (DOA) and (counterfeit-) pharmaceuticals, but in a broader context also other compounds are considered such as, for example, metformin and carbamazepine.

Automated Combination of Solid Phase Extraction and CALUX Bioassays

Potential External Partners: BDS, MicroLan, Waternet, Vitens

Bioassays are important tools for the determination of chemical water quality. For the generic detection of human toxicity, usually mammalian cell lines are used. Most laboratories of the water utilities do have the ability to perform these bioassays. Recently an automated toxicity sensor has been developed using bacteria as sensitive organisms. Up until now it has not been realized to include mammalian cells into an automated sensor setup, thus effective performing an automated bioassay. Nevertheless, progress has been made with the use and storage of human cell lines and with the development of automated sample preparation techniques (Solid-Phase Extraction). The project aims, in collaboration with water utilities and commercial suppliers, to combine automated sample pre-concentration (solid-phase extraction) with automated (human cell-based) bioassays in order to realize a proof-of-principle demonstration of an automated platform that performs an ER CALUX analysis as an at-line monitor for toxicity.

Continuous Liquid-Liquid Micro-Extraction

Potential External Partners: Micronit

Many sensors and monitoring systems lack enough sensitivity to determine contaminations in (drinking) water to a satisfactory extent. Mutagenic or endocrine compounds, for example, can result in significant effects at concentrations that are lower than the detection limits. Continuous sample preparation and concentration techniques therefore are of interest to lower the detection limit of these compounds. An interesting technique to achieve this is continuous liquid-liquid micro-extraction (CLLME). Here, two separated flows of water are brought into contact with each other. Due to confinement in a micro-channel and detailed control of the flow, the two streams can be kept separated from each other, while exhibiting a boundary surface where exchange of dissolved substances can occur. This technique can be of importance for two reasons. First, it can be used as on-line concentration methods.

Second, it can be used as a filter before target substances get it contact with the eventual sensor, decreasing the potential for biofilm formation on the sensor. Within the project the feasibility and applicability of CLLME will be investigated.

On-line Concentration of Bacteria using Optical Cavities

Potential External Partners: Wetsus Thematafel Partners (incl. Vitens, WLN)

KWR engages within Wetsus as a partner in the 'Thematafel Sensoring'. KWR aims to maintain connections with Wetsus and the participating knowledge institutes and SMEs involved in the project group. Within this structure the TU Delft has expressed interest in a follow-up on a finishing project investigating the use of optical cavities for the identification of bacteria in water. The application of this type of technology will be far ahead in the future. However, on the road towards realization of the concept, optical cavities need to be more elaborately investigated. Especially, parallel integration of a (large) number of cavities is necessary. Without any detection of the type of particles that are trapped, this intermediate stage of the final envisioned technology can possibly be used as an on-line concentration method. Particles from the original aqueous medium will be trapped in the cavities and released after switching the flow over the cavities to a smaller volume carrier stream that can eventually be led over a sensor. The details of the concept and a possible project proposal will need to be elaborated in the future.

Biofilm and Ca^{2+} Monitoring in Relation to Nano-Filtration Membrane Fouling

Potential External Partners: PWN, Inven Technology

Micro- and nanofiltration techniques are increasingly investigated for the purification of water. Membranes are prone to fouling and resulting clogging of the pores, reducing the efficiency of the membranes and the lifetime. Within KWR, biological activity and the presence of Ca^{2+} ions have been investigated as responsible parameters for accelerated clogging of pores in the membranes. Monitoring of biofouling and the presence of these ions could in a multidisciplinary fashion serve progress in the application of membrane-filtering techniques in the sector. Accurate (real-time) monitoring of the relevant parameters can yield valuable information for process control, optimization and maintenance resulting in possible reduction of costs of exploitation and assurance of constant water quality. A biofouling sensor will be implemented in a pilot filtration setup and will be evaluated as early warning. Concurrently, measured data will be used to obtain new insights in the formation and possible prevention of biofilm formation.

MbOnline ColiGuard

Potential External Partners: Vitens, HWL

The ColiGuard is considered as a promising sensing / monitoring technology for the determination of the presence of a faecal contamination in water. The ColiGuard detects specific enzymatic activity in the medium. This is indicative for the presence of E.Coli or related microorganism since the specific enzyme, from which the reaction is monitored, exclusively exists in these organisms. Problems however remain with interpretation of data within old paradigms of cell culturing. If properly assimilated in business and legal processes, the technology might yield significant progress for the sector. KWR can take a role in validating the new technology and setup connections with legal entities to assess the necessary effort for proper legal incorporation. Vitens has performed some validation experiments already using the system. The project could start with a meta-analysis of the acquired data. Next, the necessary validation experiments can be assessed and planned. Additionally, preparations for legal authentication of the technology can be started.

Standardization Protocols of Particle Counters

Potential External Partners: Hach Lange, Interline, PAMAS

Water utilities use particle counters in the water cycle to, for example, guard the quality of water sources, membrane clogging and the quality of final drinking water. Different particle counter from various suppliers are used throughout the sector. Therefore it is difficult to make comparisons between measurements by different utilities and thus differences in water quality as well. In order to streamline these measurements, development of standard measurement and good practice protocols for the different counters is proposed that will result in comparable measurements and intepretation. KWR, as a representative of the Dutch utilities, is ideally situated to perform validation experiments, coordinate the process and generate collective support from suppliers and users for a standardized measurement.

Detection and Prediction of Resuspension of Sediment

Potential External Partners: Optisense, Brabant Water

Brownish water is generated by resuspension of sediment that has been built up in the distribution network. The chance that this brownish water will occur therefore depends on the amount of sediment and how easily it is suspended by, for example, changes in flow in the network, *i.e.* the resuspension potential. The resuspension potential is commonly determined by water utilities as input for process control. However, the so-called Resuspension Potential Method (RPM) is quite elaborate. It is necessary to isolate part of the network, change the water flow in the isolated section and measure the resulting change in the number of particles, generally by means of turbidity. Therefore it would be very useful to have a miniaturized version of this concept that is less invasive in the distribution network and can yield more frequent data. This will need an integrated solution of particle detection and a (miniature) sediment resuspension technique. As detection principle a particle counter or the Optisense Mach-Zehnder interferometry chip is considered. Solutions to perform a local distortion in the tubing to generate shear stresses will need to be investigated. As a next step, the integrated system should be validated against the standard RPM method.

Laser Induced Breakdown Spectroscopy (LIBS)

Potential External Partners: TNO

Laser Induced Breakdown Spectroscopy is a versatile measurement technique that in essence performs an elemental analysis. The technology has been, in a limited way, applied in aqueous environment for the detection of dissolved material and investigated for the identification of bacteria in water. The technique is versatile since it probes (almost) everything that is present in the water. Therefore, in principle, a lot of information will be contained within a measured spectrum. Key will be to extract the information of interest with mathematical algorithms and determine the resulting sensitivity. What is interesting as well is that the technique thus measures more than is of interest at a specific moment. However, if in the future new parameters become relevant, the possibility exist to innovate the data analysis to extract new information from already existing spectra. This also opens the opportunity to trace back in time and find trends that previously were not of interest and therefore hidden. In principle, no new measurements need to be performed and no big technology development is necessary to become sensitive for a new parameter.

Development of a Policy Strategy for the Implementation of Sensor Technology

Potential External Partners: VEWIN, Dutch Government (RIVM)

A main problem for the implementation of sensor technology for the determination of water quality has been legislation. Technologically sound sensors may not be implemented if the use of the technique is not incorporated in the laws regarding water quality. Furhtermore, it has been realized that adaptation of the laws is a slow process. In order to streamline and accelerate implementation of technology, a roadmap should be generated that, in dialog with legislators, outlines and discusses the required process to arrive at a certificate of equivalency for new sensor technology. Main advantage will be that this roadmap can be used for various new initiatives and that the process does not need to be re-invented for every new technology.

Event-Detection in the Distribution Network with I::scan Sensors

Potential External Partners: Water Utilities, S::can

UV-absorbance-based sensor probes have been successfully introduced to the market by the Austrian company S::can. A comprehensive sensor probe, the spectro::lyser, can determine a wide range of water quality parameters, such as NO3-N, COD, BOD, TOC, DOC, UV254, NO2-N and AOC. A newer, slimmer and cheaper probe based on a smaller wavelength window, the I::scan probe, has been realized for smart grid applications. Additionally, event-detection software has been developed concurrently, yielding a potential interesting system for water-quality monitoring in the distribution network. A number of sensors can be implemented in a test network to gather information on the usability, reliability, added value and cost-efficiency of such a system.