A SWE Architecture for Real Time Water Quality Monitoring Capabilities Within Smart Drinking Water and Wastewater Network Solutions

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Abstract. The world is facing a water quantity and quality crisis. These global concerns are addressing water sector operators to smart technological solutions that realize the so-called *smart* drinking water and wastewater networks. Water quality preservation is one of the essential services that smart water utilities have to guaranteed. The water quality monitoring systems include a variety of in situ sensors with several sensor protocols and interfaces. Sensor integration as well as real time sensor readings accessibility and interoperability across the interconnected layers of functionality needed for a comprehensive smart water network solution are the challenges should be tackled. The objective of this research work has been to develop a standardized OGC SWE (Sensor Web Enablement) architecture that enables the integration and real time access to the various continuous and networked sensors can be installed along drinking water and wastewater networks, and real time sensor data browsing, querying and analyzing capabilities across the components of a smart water network solution. Furthermore, a web based geo-console and a QGIS SOS client application have been developed ad hoc for supporting utilities to effectively manage their water treatment and optimize quality-testing processes.

Keywords: SWE framework · Sensor web · Smart water utilities (SWNs) · Water quality monitoring and modeling · Sensor networks · QGIS · SOS client · Map viewer

1 Introduction

Water is recognized essential to sustain life nevertheless the world is facing a water quantity and quality crisis, caused by continuous population growth, industrialization, food production practices, increased living standards and poor and unsustainable water use strategies as well as inadequate management systems and practices.

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These global concerns are addressing water sector operators to smart technological solutions that promise more efficient and sustainable water systems, realizing the so-called *smart drinking water and wastewater networks*.

A comprehensive smart drinking water/wastewater network solution involves several interconnected layers of functionality [1]. They are basically:

- measurement *and sensing instrumentation* that collects data on water flow, quality, acoustics, supply and other critical parameters;
- real-time two-way *communication channels* (e.g. two-way radios, cellular networks) that allow utilities to gather data from networked measurement and sensing devices automatically and continuously;
- *basic data management software* that enables utilities to process the collected data and present an aggregated view via basic visualization tools and GIS, simple dashboards or even spreadsheets and graphs;
- *real-time data analytics and modeling software* that enables utilities to derive actionable insights from network data. Dynamic dashboards allow utility operators to monitor their water/wastewater network in real time for hazards or anomalies. At the same time, hydraulic and water quality modeling software can help operators understand the potential impact of changes in the network and analyze different responses and contingencies. Pattern detection algorithms can draw on historical data to help distinguish between false alerts and genuine concerns, and predictive analytics allows operators to consider likely future scenarios and respond proactively and effectively
- *automation and control tools* enable water utilities to conduct network management tasks remotely and automatically. This layer provides tools that interface with the real-time data analytics and modeling software, leveraging communication channels and the physical measurement and sensing devices within the network. Many utilities have existing SCADA systems that can be integrated with smart water networks to further enhance their control over the network.

Thus, the smart water network technology arms the control room operators with a comprehensive and more effective set of decision-making capabilities for a sustainable and optimized water utilities management. Especially, these capabilities enable the operators to quickly assess events as they occur, identify potential problems before they reach a critical level, respond to operational challenges, and minimize downstream effects [2].

Among services to be provided by smart drinking water and wastewater utilities, the water quality preservation can be considered essential. A drinking water supply has to be safe as well as satisfactory.

A smart water network solution for drinking water quality preserving includes networked sensors for chlorine, pH, biological indicators and other chemicals as well as heavy metals along several network locations[3].

Chlorine is widely used as a disinfectant in drinking water systems for its advantages such as high oxidation potential, long-term disinfection until the water reaches the consumer, excellent disinfection effectiveness and relatively low cost. However, there are some disadvantages such as the decay of its concentration along the water distribution network and the formation of undesirable DBPs (Disinfection by Products) that are characterized by recognized toxicity and carcinogenicity.

The water quality dynamics can continuously be monitored and assessed by real-time modeling based on the *live data* (e.g. free chlorine) gathered by networked probes along the drinking water system [4], [5]. Thus, water system operators can quickly compare water quality data against regulatory requirements (e.g., maximum contaminant levels) over time and along the water network as well as identify water quality changes and anomalous events, forecasting potential hazards and adverse public health impacts .

Wastewater - spent or used water from farms, communities, villages, homes, urban areas or industry, if un-managed, can be a source of pollution, a hazard for the health of human populations and the environment. Wastewater can be contaminated with a myriad of different components: pathogens, organic compounds, synthetic chemicals, nutrients, organic matter and heavy metals, carried along the water from different sources. Unregulated or anomalous/malicious discharge of wastewater along the sewage network may affect the wastewater treatment plants operation and consequently pollute the receiving water body [6].

A continuous and real time monitoring of several water quality parameters along a sewage network by a distributed heterogeneous sensor network coupled with predictive water quality modeling capabilities, can enable operators of the wastewater utility to quickly assess contamination events as they occur, due to unregulated or anomalous/ malicious discharge into the network, alerting the wastewater treatment plants, eventually identifying the possible anomaly discharge points, and hence minimizing the environmental and social impacts [7].

Anyway, recent global smart water surveys still reveal a large gap between *need* and *reality*. Most of water utilities still rely entirely on manual collection of water quality samples, which can take several days [1], though they are strongly aware of the need of continuous real-time data on water quality integrated with predictive system dynamics scenarios for making informed decisions and not relying on experience and intuition.

Thus, a smart water network solution for water quality monitoring includes a variety of in situ sensors to be managed with several sensor protocols and interfaces. Sensor integration as well as real time sensor readings accessibility and interoperability become essential requirements to be meet within a such solution [8].

The recent OGC Sensor Web Enablement (SWE) framework could play a crucial role providing fundamental building blocks for developing the required capabilities [9], [10]. The focus of this research work has hence been to investigate and develop a SWE architecture for water quality monitoring capabilities in smart water/wastewater solutions which enables the integration and the real time access by the several smart components of the various continuous and networked sensors can be involved, as well as the retrieve of the events and alerts triggered through sensors. More specifically, the developed architecture realizes sensor related services and data delivery, enabling real time sensor data browsing, querying and analyzing capabilities across the components of data management as well as data analytics and modeling within a smart solution. A web based geo-console developed ad hoc enables the access to real time and time series observation data returned by SOS instances, visualizing the (near-)

real time sensor state through three hours graphs, popups, and hence the alert state and predictive water quality dynamics through thematic layers. Similarity, a QGIS SOS client application has been developed ad hoc for adding the same capabilities to the open source GIS desktop QGIS.

The developed architecture has been applied to two case studies that respectively involve the water quality monitoring and managing for real aqueduct of Santa Sofia (Southern Italy) and the wastewater network of the Massa Lubrense city (Southern Italy).

2 Developing the SWE Architecture

Within smart water/wastewater network solutions, the kinds of sensor resources to be managed can be stationary or in motion and gather data in-situ or remotely, while the sensor hardware, sensor protocols and interfaces are various. For implementing the sensor integration and interoperability requirements, we have exploited the OGC-SWE technological framework [9], [11].

2.1 The OGC SWE Framework

Sensor Web paradigm refers —Web accessible sensor networks and archived sensor data that can be discovered and accessed using standard protocols and application programming interfaces (APIs) [9]. Sensor Web can hence be seen as a huge internet based on sensor network and data archive[12], [13].

The SWE technological framework refers an infrastructure which enables an interoperable usage of sensor resources by their *discovery*, *access*, *tasking*, as well as *eventing* and *alerting* within the Sensor Web in a standardized way. It hides the underlying layers, the network communication details, and heterogeneous sensor hardware, from the applications built on top of it.

More specifically, the SWE framework makes available standard for encoding sensor data and metadata (OGC Observations & Measurements, OGC Sensor Model Language) as well as standards for service interfaces to access sensor data (OGC Sensor Observation Service); standards for subscribing to alerts/events (OGC Sensor Alert Service) and controlling sensors (Sensor Planning Service)[9].

Thus, within this framework, our objective have been to implement SWE services for water quality sensor observations gathered by *in situ* sensors virtually connected into a network infrastructure, based on web technologies, that enables us to remotely and real time access *live* sensor data using web. In this way, real time water quality data can be integrated into a spatial data infrastructure, an essential requirement for reliably water quality dynamics predicting and eventually dispatching time critical alerts.

2.2 The Architetture Design

The proposed SWE architecture provides functions ranging from integrating and real time accessing the various networked sensors and their observations, to retrieving events and alerts triggered through sensors, enabling observation data browsing, querying and analyzing capabilities within client application.

According to the functionality requirements to be implemented, this architecture (Figure 1) has been designed and developed including server components such as:

- a geodatabase for storing geospatial and sensor data;
- a map server for publishing on the web spatial and sensor data, thematic maps and predictive scenarios related to the hydraulic and water quality dynamics;
- SOS (Sensor Observation Service) Server for accessing descriptions of sensors and their collected observation data by standardized web service interfaces.

The client applications developed are both web that desktop. In particular, a web based geo-console (geospatial HCIs) has been developed ad hoc for accessing real time and time series observation data returned by SOS instances, visualizing them through graphs (time series) or popup (real time observations or predictive values at fixed time intervals), for analyzing the sensor state especially their alert state and the predictive water quality dynamics. Another client application is *QGIS SOS client application* developed ad hoc for adding the ability to the open source GIS desktop QGIS to access sensor to data served by SOS server and deliver them to the available simulation models.

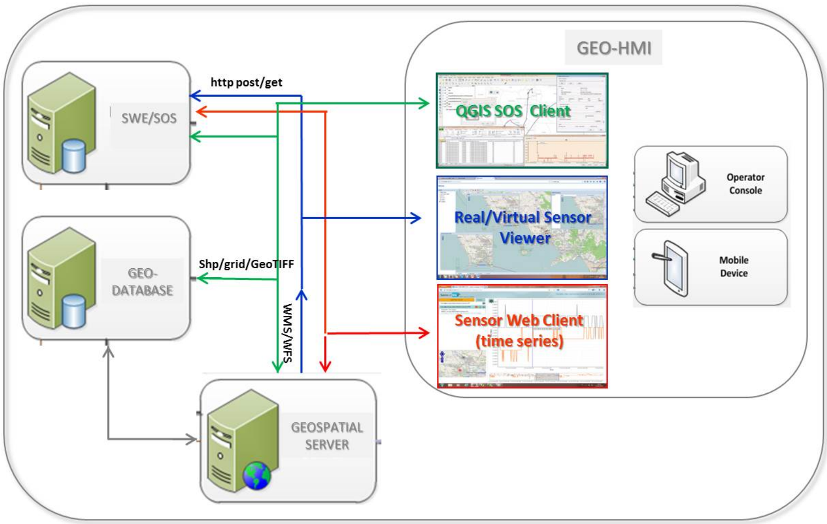


Fig. 1. The architecture design for water quality monitoring capabilities within smart water/ wastewater network solutions

As regards the SWE component of the proposed architecture, it consists of the services SOS (Sensor Observation Service), SES (Sensor Event Service) and WNS (Web Notification Service) (Figure 2) [9], [13], [14].

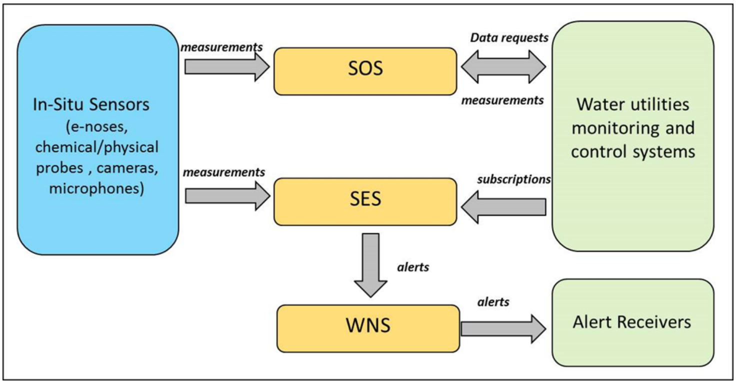


Fig. 2. Archietcture schema of theSWE componet of the proposed archietcture

The SOS component allows clients (e.g. QGIS SOS client developed ad-hoc by ENEA) to access descriptions of associated sensors and their collected observations by a standardized web service interface. SES provides notification services, with stream processing capabilities. Alerting and notification capabilities provides support for creating alarms and filter constructs by system users. Users hence use created alarm constructs to subscribe to live sensor feeds and continuously receive notifications once events are detected during live streams processing. The notifications are processed by WNS that notifies the user by sending an sms with the notification received by SES.

2.3 The Component Diagram

The software component diagram of the proposed architecture is showed in the Figure 3. In particular, the implementation of the proposed SWE component has been deployed by 52°North framework [15] version 3.x, customized using the standards OGC SOS 1.0 and 2.0. The deployed SOS endpoint uses a database PostgreSQL 9.3.1 with a spatial extension PostGIS 2.x to store observation values and sensor metadata.

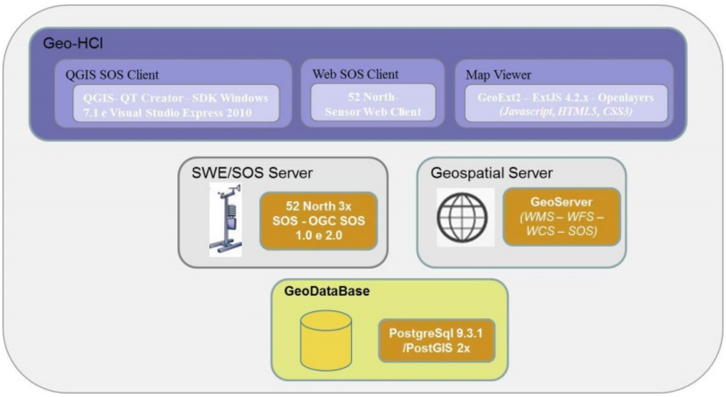


Fig. 3. Component diagram of the proposed SWE architectura

The *map server* has been developed by using GeoServer 2.6.x [16], an open source server for sharing geospatial data as web services that enables spatial data interoperability, publishing data from any major spatial data source using open standards. GeoServer is a OGC compliant implementation of a number of open standards such as Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS). Additional formats and publication options are available including Web Map Tile Service (WMTS) and extensions for Catalogue Service (CSW) and Web Processing Service (WPS).

Geospatial data within the case studies has been published by WMS e WFS.

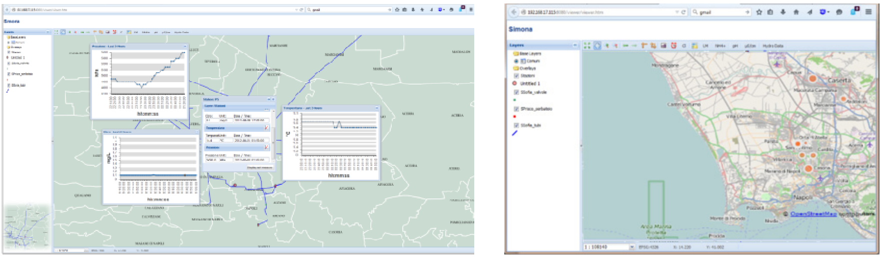
The implementation of the GeoDatabase component has been deployed by l'object-relational database PostgreSQL 9.3.1 with the spatial database extender PostGIS 2.x that adds support for geographic objects allowing location queries to be run in SQL.

The web SOS client application has been developed as a extending the open source Sensor Web Client while the QGIS SOS client has been developed by using Nokia QT libraries of the QT Creator [18], an integrated development environment which is part of the SDK for the Qt GUI Application development framework. The libraries have been compiled by using Microsoft SDK for Windows 7.1 and Visual Studio Express 2010, for Windows platform (32 bit and 64 bit) and Linux platform.

The map viewer has been developed by GeoExt2 [19], an Open Source JavaScript framework that enables building desktop-like GIS applications through the web. Through this framework GIS functionality of OpenLayers with the user interface of the ExtJS 4.2.x library provided by Sencha have been combined. ExtJS 4.2.x library anables the development of javascript desktop-like applications by using HTML5 e CSS3 standards.

3 The Application Layer

For accessing and browsing within maps the various continuous and networked sensors, and queering and analyzing the observation data both in real time and at prefixed time intervals, a web based geo-console has been developed ad hoc. By this console, the utility operators can visualize the measurements gathered by sensors really installed along the drinking water and wastewater networks as well as predictive measurements returned by on line hydraulic and water quality simulation models, served by SOS services. Within the viewer, monitoring parameters (e.g. H2S, chlorine, rainfall, etc.) are visualized by single layers. For the multi-sensor stations, the real time observations of all active sensors can be visualized as well as the last three hours observations by a graph (Figure 4a). The state of the sensors is visualized as thematic layer through the size and the colour of the related symbol. The colour scale associated to the different sensor states is *green* for normal state, *orange* for attention state and *red* for alert state then occurs when anomaly situations happen or prefixed threshold values are met (Figure 4b).



a) b)

Fig. 4. The web based geo-console. a) View of all real time observations (clorine, temperature, pressure) gathered by a multi-sensors station installed along the real acqueduct of Santa Sofia (South Italy); b) View of a thematic clorine state layer

Through a toolbar, user can access two specific viewers that act as application layers. One viewer handles the rendering by graphs of queried time series (Figure 5). Similarity, the other viewer handles the rendering of the on line modeling simulations by graphs and thematic maps.

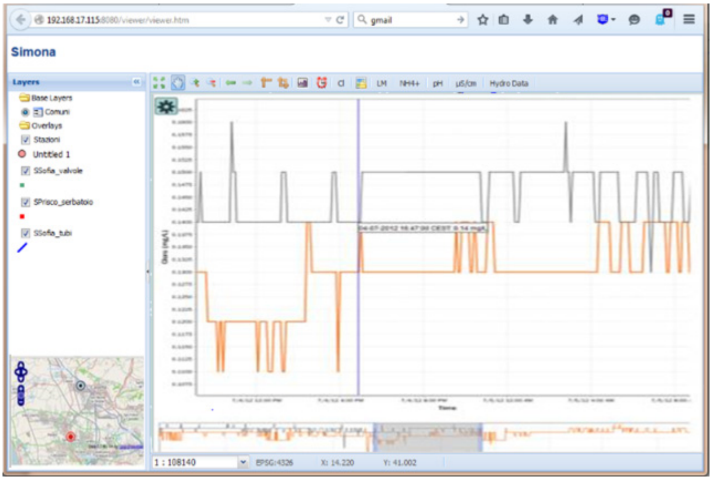


Fig. 5. The Web SOS Client: graphes of chlorine time series served by SOS istances

As a desktop client, a QGIS SOS client application (Figure 6) has been developed ad hoc for adding the ability to the open source GIS desktop QGIS to access sensor to data served by SOS and deliver them to the simulation models (i.e SWMM, Epanet/MSX), plugins of the QGIS software (e.g. GHydraulics) [20].

This client application offers easy to use interfaces within QGIS to run the *GetCapabilities* operation by SOS server, to request a service description containing the spatial and temporal extent of the offered observations as well as a list of the sensors and observed features.

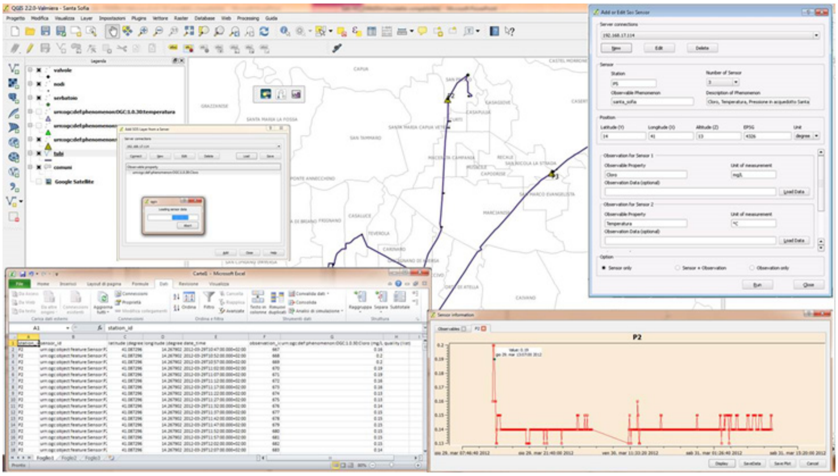


Fig. 6. The QGIS SOS client application: interface for adding sensors and editing observations into SOS server *(on the rigth)*; interface for browsing the observations data served by SOS services *(down in the window); interface for adding and quering SOS layes into QGIS view (on the left)*

Similarity, the *GetObservation* operation, the core functionality of the SOS, is run by a specific interface allowing to access to observations data within the QGIS viewer by table views. By another interface, new sensors can be easily registered and observations inserted, implementing the *Transactional profile* of the SOS specification.

Thus, this client hides technical details of SOS services and protocols, so that even non-experts can use all components of the developed SWE architecture, transparently, within a friendly GIS platform, coupled with the spatial analysis and geo-processing tools as well as integrated numerical modeling tools.

4 The Case Studies

The proposed architecture have been implemented within two application scenarios. One scenario concerns the water quality dynamics (i.e. DBPs formation as well as free chlorine decay) to be monitored and predicted along the real Santa Sofia aqueduct (Southern Italy).

The case study of Santa Sofia aqueduct involves a wireless network of sensors installed along the system which monitors in real time and continuously physical and chemical water parameters (i.e. pressure, residual chlorine, conductivity, temperature and pH) and delivers *live* data to online hydraulic and water quality models [4], [5]. Additionally, on-demand deployable sensor platforms for measuring DBPs are installed into specific locations along the water network.

The SWE architecture implementation encapsulates the different sensor types into the SOS server, so that the gathered data can be accessed as SOS services by the developed web based geo-console as well as the QGIS SOS client in the way described in the previous sections.

The alerting functionalities have been implemented by using a SES instance in conjunction with a WNS one. Thus, a sms is sent when critical scenarios occur i.e. water contaminants levels do not meet regulatory requirements (e.g., a disinfection residual higher than 0.2 mg/l for free chlorine and DBPs concentrations higher than 30μg/l).

This platform arms the control room operators of the Santa Sofia aqueduct with a comprehensive set of decision-making capabilities, enabling them to continuously monitor the drinking water quality integrity, confirm normal system performance, optimize emergency response. Just as an example, through the geo-console, the operators can visualize in real time the alert state of the chemical (e.g. chlorine) sensors by thematic layers as well as by the alert sms promptly sent. At the same time, they can assess the dynamics of the anomaly situation, observed in a specific location, along the network, visualizing the simulated observations as well as the impact of the emergence on the population, and so on.

The second scenario concerns the development of a monitoring and warning system for contaminations along the wastewater network of Massa Lubrense city (Souther Italy) [7]. Different sensor types are involved in this case study ranging from total immersion probes for monitoring qualitative and quantitative parameters such as PH, COD, NH3, and water level and conductivity to multi-sensor platforms composed by an e-nose for NH3, H2S, in conjunction with temperature and humidity sensors for adjusting the gas readings, and a microphone. The networked sensor platforms have been installed in strategic locations of the wastewater network.

By implementing the proposed SWE architecture, the control room of the Massa Lubrense sewage network is armed with real time and continuous monitoring capabilities of the state of the wastewater network that enable it to quickly assess contamination events as they occur, especially due to unregulated or anomalous/malicious discharge into the network, alert the wastewater treatment plants, and eventually identify the possible anomaly discharge points, and hence minimize the environmental and social impacts.

Through the developed SWE architecture, the displaying of real time and time series data gathered by the networked sensors installed along the sewage network is fulfilled by SOS instance. For the real-time notification, the sensor data are transferred to the SES instance which filters the incoming data with regard to alert criteria specified. Thus, if a matching alert condition is found by the SES, the according alert is dispatched, by sending the notification request to the WNS instance.

5 Conclusion

The water utilities integrity especially in the water quality preservation component is best assured by a real time and continuous monitoring of the physical and chemical parameters coupled with a real time modeling of hydraulic and water quality dynamics along water/wastewater networks.

While most of the water utilities have active automation and control systems, they still rely entirely on manual collection of water quality samples, which can take several days, for monitoring the water quality. Though they are moving to smart water solutions for water quality preservation and more generally for an more efficient and proactive management and control of the water utilities.

For enabling an interoperable usage of different sensor resources involved in smart water quality solutions, through their *access* as well as *eventing* and *alerting*, a SWE based architecture has been proposed. It has allowed hiding the underlying layers, the network communication details, and heterogeneous sensor hardware, to the applications (e.g. geo-console as well as system dynamics models) built on top of it. Thus, SWE services have been implemented within the two case studies for water quality sensor observations gathered by *in situ* sensors virtually connected into a network infrastructure, based on web technologies, that enables the application layers to remotely and real time access *live* sensor data using web. In this way, real time water quality data can be integrated into a spatial data infrastructure, enabling their access to water/wastewater networks dynamics models as well as systems for monitoring water quality and dispatching time critical alerts.

For the future, this architecture will developed for mobile devices (tablet, smartphone), enabling the operators to monitor the water quality integrity in situ.

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References

1. White paper online: Water 20/20 Bringing Samrt Water Network in Focus by Sensus. https://sensus.com/smartwaternetworks
2. Boulos, P.F., Wiley, A.N., Colo, B.: Can We Make Water Systems Smarter? (2013). Online paer: http://dx.doi.org/10.5991/OPF.2013.39.0015
3. HallJeffrey, J.S., Szabo, G., Panguluri, S., Meiners, G.: Distribution System Water Quality Monitoring: Sensor Technology Evaluation Methodology and Results. A Guide for Sensor Manufacturers and Water Utilities. Water Infrastructure. Environmental Protection Agency - EPA 600/R-09/076 (2008)
4. Fattoruso, G., et al.: Simulation of Chlorine Decay in Drinking Water Distribution Systems: Case Study of Santa Sofia Network (Southern Italy). In: Di Natale, C., Ferrari, V., Ponzoni, A., Sberveglieri, G., Ferrari, M. (eds.) Sensors and Microsystems. LNEE, vol. 268, pp. 467–470. Springer, Heidelberg (2014)
5. Fattoruso, G., et al.: Use of Kinetic Models for Predicting DBP Formation in Water Supply Systems. In: Di Natale, C., Ferrari, V., Ponzoni, A., Sberveglieri, G., Ferrari, M. (eds.) Sensors and Microsystems. LNEE, vol. 268, pp. 471–474. Springer, Heidelberg (2014)
6. Corcoran, E., Nelleman, C., Bajer, E., Bos, R., Osborn, D., Savelli, H.: Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal (2010). ISBN: 978-82-7701-075-5
7. De Vito, S., Fattoruso, G., et al.: An integrated infrastructure for distributed wastewater quality monitoring and decision support. In: Proceedings of the AISEM, Trento , February 3-5, 2015

8. Glasgowa, H.B., Burkholdera, J.M., Reeda, R.E., Lewitusb, A.J., Kleinmana, J.E.: Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies. Journal of Experimental Marine Biology and Ecology **300**, 409–448 (2004)
9. Bröring, A., Echterhoff, J., Jirka, S., Simonis, I., Everding, T., Stasch, C., Liang, S., Lemmens, R.: New Generation Sensor Web Enablement. Sensors **11**, 2652–2699 (2011)
10. Gibbons, P., Karp, B., Ke, Y., Nath, S., Seshan, S.I.: An Architecture for a Worldwide Sensor Web. IEEE Pervasive Comput. **2**, 22–33 (2003)
11. Delin, K., Jackson, S., Some, R.: Sensor Webs. NASA Tech. Briefs **23**, 90 (1999)
12. Delin, K.: The Sensor Web: A Macro-Instrument for Coordinated Sensing. Sensors **2**, 270–285 (2001)
13. Shafi, S., Reshi, A.A.: Real Time Sensor Web Enabled Water Quality Monitoring System Using Service Oriented Architecture (SOA). International Journal of Scientific & Engineering Research **3**(5) (2012)
14. Jirka, S., Bröring, A., Stasch, C. Applying OGC Sensor Web Enab lement to Risk Monitoring and Disaster Management. Online paper
15. 52° North Initiative for Geospatial Open Source Software GmbH
16. 52 North Sensor Web Community. http://52north.org/communities/sensorweb
17. GeoServer: http://geoserver.org/
18. PostgreSQL/PostGIS: http://postgis.net/
19. QTCreator: https://qtproject.org/wiki/Category:Tools::QtCreator
20. GeoExt 2: http://geoext.github.io/geoext2/
21. Fattoruso, G., Tebano, C., Agresta, A., Buonanno, A., De Rosa, L., De Vito, S., Di Francia, G.: Applying the SWE Framework in Smart Water Utilities Domain. In: Compagnone, D., Baldini, F., Di Natale, C., Betta, G., Siciliano, P. (eds.) Sensors. LNEE, vol. 319, pp. 321–325. Springer, Heidelberg (2015)