REAL TIME WEBGIS SERVICES OF A SENSORS NETWORK FOR WATER RESOURCES MONITORING SYSTEM AND CRISIS MANAGEMENT

A. Ortolani[a,b], C. Brandini[a,b], L. Costanza[a,b], L. Innocenti [a,b*], R. Costantini[a,b], F. Sabatini[a], L. Angeli[a,b], R. Ferrari[a,b], B. Gozzini[a,b].

[a] CNR Ibimet, Via Giovanni Caproni 8, 50145 Florence, Italy
[b] Consorzio LAMMA, Via Madonna del Piano 10, 50019 Sesto Fiorentino (Florence), Italy - www.lamma.rete.toscana.it

KEY WORDS: water monitoring, crisis management, in-situ measurement, real-time, inter-operability, SWE, GMES, webGIS

ABSTRACT:

This paper describes the application carried out for underground water monitoring and environmental crisis management through Sensor Web Enablement (SWE) services, under the EU-funded OSIRIS project (Open architecture for Smart and Interoperable networks in Risk management based on In-situ Sensors), in the context of the GMES European programme. The project has developed a service oriented architecture, accessible through INTERNET, with high levels of automation and interoperability, for the remote management of heterogeneous sensors (fixed and mobile) and the data processing for monitoring and managing environmental crises arising from natural hazard as well as industrial accidents (water pollution, urban air pollution, forest fires, etc.). The experimental system implemented at Santa Fiora (Grosseto, Italy) water springs, allows data acquisition and early identification of crises in the drinking water supply system, for supporting the assessment of proper intervention plans.

RÉSUMÉ:

Ce travail décrit l'application réalisée pour la télésurveillance des eaux souterraines et pour la gestion des crises environnementales par l'usage de Sensor Web Enablement (SWE) services, sous le Projet Européen Intégré du Sixième Programme-cadre OSIRIS (Open architecture for Smart and Interoperable networks in Risk management based on In-situ Sensors) dans le contexte du Programme Européen GMES. Le projet a développé une architecture de services web accessible par INTERNET, à haut niveau d'automation et interopérabilité, pour la gestion à distance de capteurs hétérogènes (fixe et meubles) et l'élaboration de données pour la télésurveillance et la gestion de crises environnementales, soit en relation aux désastres naturels, qu'à incidents industriels (pollution des nappes phréatiques, pollution de l'air, incendie dans une forêt, etc.). Le système expérimental implémenté près des sources d’eau de Santa Fiora (Grosseto, Italie), permet d'acquérir données et déterminer rapidement les situations éventuelles de crise à la charge du système d'approvisionnement idropotabile, au support de la définition d'étages opportuns d'intervention.

1. INTRODUCTION

1.1 Motivation

Quantity and quality of underground water, often used for potable purposes, is stressed by multiple factors such as natural and human induced pollution, or water table recharge decrease due to climate changes. Approaches of constant monitoring and management of water resources shall promote actions implementation that may prevent irreversible damages to the resource and guarantee its availability and quality.
In the province of Grosseto (Tuscany), as well as in many other world areas, the level of attention on managing water resources is particularly high as, for a few decades, a dramatic decline in quantity of fresh water reserve has been experienced, because of increasing water consumption and decreasing resources recharge. In addition major concern is expressed by local authorities about fresh water quality degradation due to heavy metal contamination in some specific areas of the province (Dall’Aglio et al., 2001).
Moreover, heavy metals detection in public water supplies has recently received regional attention following the National law that brings down the allowable arsenic (As) limits in drinking water from 50 parts per billion (ppb) to 10 ppb.

1.2 Aims

Monitoring systems to assess water resources quantity and quality require extensive use of in-situ measurements, that have big limitations due to the difficulties to access and share data, and to customise and easily reconfigure sensors network in order to fulfil end-users needs during monitoring or crisis phases. With the purpose of address such limitations, new technologies for smart sensors deployments and use have been developed and applied to different environmental context under the OSIRIS project.

1.3 OSIRIS Project

OSIRIS (Open architecture for Smart and Interoperable networks in Risk management based on In-situ Sensors, www.osiris-fp6.eu), coordinated by THALES Communications SA – France, is an European Integrated Project founded in the Sixth Framework Programme, in the context of the GMES (Global Monitoring for Environment and Security http://www.gmes.info) European programme. The project has involved 13 partners (from research institutes, enterprises, institutional and operational users) of 7 European countries. Particularly, the water pollution application was under the Italian responsibility by the Foundation for Climate and Sustainability and LAMMA Consortium.

* Corresponding author: innocenti@lamma-cres.rete.toscana.it

The main objective of OSIRIS was to create a monitoring system to manage different environmental crisis situations, through an efficient data processing chain where in-situ sensors are connected via an intelligent and versatile network infrastructure (based on web technologies) that enables end-users to remotely access multi-domain sensors information.

OSIRIS is aligned with GMES for the implementation of an European capacity for Earth observation that provides services based on satellites data and a range of in-situ sensors including airborne observation systems as well as ground-based systems (e.g. water analysers, air analysers, seismographs) to improve environmental knowledge to contribute to the security of every citizen.

OSIRIS project was structured around four key areas of major environmental risk: forest fires, industrial risks (fire in industrial buildings), unexpected fresh water pollution and air pollution in urban areas.

The OSIRIS solution was deployed in these areas, leading to four live experiments, complementary in:

- environmental concerns,
- time constraints,
- sensors - based on mobile or fixed platforms,
- data produced by the sensors.

These live demonstrations constitute the essential aspect which drove the OSIRIS project. Thus, OSIRIS did not only address architectural concepts or simulations, but it implemented these concepts and tested them in real deployments. These experiments allowed to validate the architectural concepts of OSIRIS in conditions close to the reality with a set of innovative sensors (however, with the implementations limitations due to the R&D context of the project, its budget and time schedule).

This approach presents the essential advantage to conciliate an R&D programme with the objectives of having pre-operational results, according with GMES lines.

1.4 OGC's SWE standards for Legacy Sensors Network Upgrade

Environmental management policies are nowadays increasingly supported by the use of real time data.

While long-term data sets analysis can possibly be handled offline (for example, in climate change studies), the use of real-time data requires the adoption of technologies that make data readily accessible, allowing the user to know the status of remote sensors or to control them (i.e. sampling frequency, position and orientation of mobile sensors, etc.).

Most state-of-art monitoring systems consist of aged analogue coupled to modern digital data logger. In support of real-time data processing and dissemination, many sensors networks have now been updated for telemetry. Operational phases efficiency is greatly improved by such remote monitoring of the sensors, simplifying data gathering process and enabling an efficient scheduling for the repair and maintenance visits.

Unfortunately, almost all the environmental agencies have their own isolated network made by different hardware installed independently using different equipment and software, so that their data will remain unpublished and not online in ways that make them effectively discoverable, accessible and usable by other users. The upgrade or expansion of such monitoring network most often requires major efforts by the qualified personnel, who should redesign the system architecture according to needs strictly linked to those of the particular community that uses the data.

A growing number of scientific communities or institutions (geosciences, industry, government, …) may require the use of the same data set, or even across different disciplines. The interoperability of the sensors as components of isolated sensors network, that requires discovery and use of such sensors and sensors data by other users, is severely hampered without *a priori* knowledge of the sensor system. To meet the needs of all these different communities and at the same time to have an open system architecture that enables to easily expand the system in an intelligent, flexible and economical way, consensus-based open standards are increasingly accepted.

The use of these open standards will help reduce costs, make sensor data easier to manage and share, and support rapid addition of new sensors.

According to Open Geospatial Consortium (OGC) (http://www.opengeospatial.org) definitions, "a Sensor Web refers to web accessible sensor networks and archived sensor data that can be discovered and accessed using standard protocols and Application Program Interfaces (APIs)" (Botts et al., 2006). Sensor Web achieves the goal of making the sensors (single sensors, sensor network, and the repository of data from sensors) searchable, discoverable, accessible and controllable via the World Wide Web (WWW).

The term of SWE (Sensor Web Enablement) refers to a range of services through which the sensors are connected to the web and accessible via standard protocols. In particular, the OGC SWE framework has been defined trough well defined standard model encodings (such as the eXtensible Markup Language - XML, or the Sensor Model Language - SensorML) and standard web service interfaces, as it is typically expected to be implemented on the WWW.

The OGC's Sensor Web Enablement (SWE) initiative has focused on developing standards that now includes a number of services for exploiting Web-connected sensors and sensor systems of all types. Thanks to SWE encodings and web interfaces, new defined sensors systems and processes (simulations, models, …) can be dynamically added to the web and then easily discovered, accessed and tasked using sensor web enabled application software. The use of standard encodings allows sensor systems to be self-describing, capable of being configured and tasked, autonomously capable of sending alerts based on observation or to respond to alerts sent by other sensors (following the typical concept of active sensors, even for sensors born to act as passive ones).

Moreover, the interfacing to the Web through OGC standards enables many legacy sensor networks and sensor control systems to be integrated with other Web-based sensor networks, that will help to increase the utility, reuse and mobilization of new sensors. The new Service Oriented Architecture (SOA) is much cheaper to implement and requires less project management and less coordination among the users of the distributed resources, since developers of web-based sensor systems working from OGC standards will spend less time on requirements analysis and custom coding. Standards-based software components are more reusable and can easily incorporate open source tools and components (Bacharach, 2008).

1.5 Legacy Sensors Network Upgrade Related Works

A review of some of the projects that have been implementing sensor webs using the OGC's interoperability framework for Web-based discovery, access, control, integration, and visualization of online sensors and sensor data is done by Bacharach (2007). Examples of application where the OGC's SWE standards have been implemented, include an ocean

observing system and a hydrologic information system. (see http://www.opengeospatial.org/pressroom/pressreleases/934, and http://his.cuahsi.org/).
Such demanding geosciences applications deal with large data sets from distributed and heterogeneous sensor networks: applications of SWE standards show how it is possible and practical to build a scalable system that implement open interfaces and encodings.

2. GROUND-WATER MONITORING APPLICATION

2.1 Santa Fiora Underground Springs

For the Water Quality Management demonstration in OSIRIS, a pilot area was chosen as representative of a number of problems rather typical of many aquifers characterized by good water quality for drinking water use, particularly vulnerable, and with a rather old (mostly manual) monitoring system. Management needs requires the adoption of monitoring state-of-the-art technology for continuous measurement of hydrological, geochemical and hydraulic parameters.
The selected aquifer, located in the Mount Amiata fractured volcanic rocks, is the major one of the Grosseto province, as it feeds numerous aqueducts in the provinces of Grosseto, Siena and also in the Northern part of Lazio Region.
Particularly we have taken into consideration the portion of the Mount Amiata aquifer feeding the Santa Fiora springs (by far the most important in this aquifer), under the management of the Acquedotto del Fiora (AdF). The local monitoring system is managed by different entities (Tuscany Region Environmental Protection Agency - ARPAT, AdF, Tuscany Functional Centre for Civil Protection) and based on measures of water quality mostly manuals (water samples analysed in chemical laboratories), and hydrologic/hydraulic measures that only recently have been updated on an ongoing basis.
The good quality and quantity of this water supply has to deal with elevated contents of toxic trace elements (e.g. As, B and Hg) deriving from hydro-geochemical anomalies. In addition to these "natural" processes, the risk of accidental potable water contamination has to be taken into consideration: in the last decade some events of risk of ground-water contamination, due to leakage of a fuel station tank and spill of hydrocarbon from a truck-tank over the major potable source of water of the region, have been reported.

2.2 The Implemented monitoring system

The experimental monitoring system implemented for a portion of the Monte Amiata aquifer allows a remote and continuous acquisition of water quality and quantity data, and early identification of crises in the drinking water supply system. The monitored chemicals in Santa Fiora springs are polycyclic aromatic hydrocarbons, whose contamination can arise from accidental events (gas stations or residential buildings underground cisterns breaks, tank-track transit) and arsenic, common in volcanic rocks but whose origin in that area is still controversial.
Together with a hydro-geological model, applied for the area and carefully calibrated, all data gathered by the upgraded sensors network become essential for supporting the assessment of proper intervention plans.

3. MATERIALS AND METHODS

3.1 End-users Requirements

The innovative solutions implemented for OSIRIS address some key requirements expressed by the local operational users, that can be summarised as:

- the sensor network must be remotely accessible, i.e. the system must support remote interactions with in-situ sensors;
- portable additional sensors must be remotely manageable as the fixed one and they should allow to replace in-situ manual activities (except for routine maintenance);
- every object of the network must operate with high autonomy and marginal probability of service interruptions;
- timely delivery of fresh data is necessary as well as archiving capabilities for the sensor observations and processed products (for off-line data mining and analysis).

The end-users requirements expressed above are met combining the deployment of a heterogeneous sensors network with the achievement of a communication and services driven architecture, into a high-tech remote controlled monitoring system.

3.2 Demonstration Phases

The demonstration consisted of a unique Water Monitoring Phase and two distinct Crisis Phases for two different scenarios:

- Ground-Water Monitoring Phase: Arsenic concentration data, as well as hydrocarbon levels, are regularly detected in water samples (taken automatically) and archived.
- Crisis phases: this is a simulation demo of two distinct cases of chemical emergency management, with concentrations exceeding allowable thresholds.
    1. Arsenic Pollution Scenario: is a specific activity of the monitoring phase based on a system able to control arsenic quantity in water, and to send alerts automatically in the event that legal limits of arsenic concentrations will be approached or exceeded.
    2. Tanker-track Accident Scenario with Hydrocarbon Spill: simulates a case of chemical emergency management due to a sudden release of a hydrocarbon compound (resulting from a transportation accident) in a vulnerable area just above the fresh-water springs serving the aqueduct; in this scenario the monitoring system has been upgraded to support and include hydrocarbon sensor measurements, in order to observe contaminations and to forecast pollutant behaviour.

The simulations have focused on two main sites where the arsenic and hydrocarbons concentration measurements are made:

- the main water capture gallery (Galleria Nuova) (Fig.1) for the continuous monitoring of arsenic concentration: in three of the five branches of the gallery automatic sampling systems have been realized; they are equipped with peristaltic pumps and are connected with the arsenic analyser through a hydraulic network built by the AdF;

Figure 1. Galleria Nuova

- a ground area above the water capture gallery close to the main road access to Santa Fiora (Fig.2), for the oil spill simulation: in this area the piezometer network for the monitoring of groundwater levels has been intensively used.

Figure 2. View of the site for the oil spill simulation

3.3 Legacy Water Monitoring Network Upgrade

To upgrade legacy sensor networks, integration of new sensors with existing ones (already part of a monitoring network and often managed by different institutions) is required, as in the underground water monitoring demonstration.
The sensors of the legacy network used in the demonstration are:

- a Venturi pipe (Fig. 3), that measures the water flow in the main capture gallery that is transmitted, through internet (FTP) from the local AdF office, to the Control Room in the AdF offices of Grosseto;

Figure 3. Venturi pipe

- two wireless Phreatimeters (Fig. 4), managed by the Tuscany Functional Centre for Civil Protection (TFCCP), to get a continuous measurement of the groundwater level and temperature transmitted to the TFCCP via GSM connection through short messages. Thanks to a dedicated application (at TFCCP level), these data are daily transmitted to the Control Room in the AdF offices of Grosseto via Internet (FTP).

Figure 4. Wireless Phreatimeter

In order to upgrade the legacy sensor network, the following sensors have been additionally deployed:

- Arsenic analyser (fixed) (Fig.5). It is an unattended monitoring system for a continuous measurement of trace and high concentrations of arsenic in fresh water. It can cyclically process three different water sources. This device is placed in the main capture gallery and transmits the arsenic concentration values of three most significant sampling points of the gallery through internet (FTP) from the local AdF office to the Control Room in the AdF offices of Grosseto;

Figure 5. Arsenic Analiser

- Hydrocarbon probe (Fig. 6) (portable but used as fixed in the monitoring phase) that consists of a fluorometer for high precision measure of UV-fluorescence for measuring polycyclic aromatic hydrocarbons concentration in water. The instrument, sold as a handheld device, was upgraded, in order to continuously work, with a “Measurement and Control System CR800”, as acquisition and transmission component, that was programmed in order to transmit periodically the data by a GSM modem through short messages to the Control Room in the AdF offices of Grosseto and to manage an external relay to periodically switch on and off the probe.

Figure 6. Hydrocarbon probe

- Portable meteorological station (Fig. 6) for local meteorological measurements in places where information is needed from (crisis phases). The weather station includes sensors for the principal meteorological parameters, namely air temperature and humidity, global solar radiation, wind speed, wind direction, rainfall. The station is equipped with a GSM modem that transmits the required data through short messages to the Control Room in the AdF offices of Grosseto.

Figure 6. Portable meteo station

Even though the sensors employed in water quality monitoring could be considered "normal" sensors that can be find "out-of-shelf" on the market, the way they are integrated in the network architecture implemented for OSIRIS produces smartness properties. Thank to this, new sensors can be easily plugged in the OSIRIS innovative architecture able to connect heterogeneous type of sensors in an unique system. Particularly, using the specific SWE applications customised for the OSIRIS system, both arsenic analyser and hydrocarbon probe can rise alarms when measured compounds exceed given thresholds.

3.4 Data Processing and fusion: the Hydro-geological model

Because of the complex nature of the water cycle dynamics, as well as of pollutant behaviour, in the water management application the data processing step is more a data merging process than a single parameter retrieval. The data merging techniques must provide information more exhaustive than single measurements, in order to match user needs.

The approach used to process the main information gathered with the upgraded water monitoring network, is through an integrated Hydrologic and Hydro-geologic (HH) model system. This system describes all fundamental processes that have to be taken into account for monitoring purposes and to meet the requirements for proper groundwater (quantity and quality) management. Through this approach, all information collected by in-situ measurements and model simulations benefit from each other: not only the model, calibrated with in-situ data, is able to spatialize geo-data giving a fundamental added value to the upgraded sensors network (following our data merging procedures), but it can also guide the positioning of mobile sensors, as in the demo crisis scenario, or even of new fixed sensors (to avoid redundant data, identify where in-situ data are more desirable, etc.).

Particularly, the hydro-geologic component of the integrated HH modelling system, which is the slow one, is aimed to define the groundwater regime, forecast the groundwater flow and give the forcing needed by the groundwater quality model. In order to formulate and construct such a groundwater flow model, all the geomorphological, geological, meteoclimatic and hydro-geological information have been collected to build up a first conceptual model of aquifer and aquitards structure, water levels, base flow, presence of contaminants. A detailed 3D structure of the aquifer has been built (types and structure of geological units, hydraulic properties such as storativity and conductivity, etc.), together with a hydro-geological characterization, from larger to local scales, including known aquifer recharge mechanisms and springs output.

A conceptual scheme for the surface and groundwater flow was developed, following a previous study by Giuseppe Pizzi (1998), commissioned by the AdF.

Such an aquifer structure, especially in a mountain environment, is rather complex, and our pilot area is near the border where the aquifer volcanic rocks outcrop on an impermeable substrate. We have chosen to work with models that make use of flexible discretisation and integration techniques, such as the finite elements model FEFLOW® (Finite Element subsurface FLOW system, Diersh, 2006).

Three models were constructed, which run sequentially (Fig. 7):

1) a large scale model, which includes all of the aquifer of Mount Amiata, running on a climatology. The calibration of this model was conducted by forcing the recharge on the basis of climatological (reconstructed) rainfall and evapotranspiration data, and then comparing the calculated levels with available geophysical (geo-electric) data, in order to describe the large-scale hydro-geological dynamics, and better identify the hydrological sub-basins;

2) a sub-model, whose boundaries were drawn according to the outputs of the climatological model described above, that is forced by hydro-meteorological (current) data; a more detailed calibration is then used to reconstruct the hydraulic conductivity field;

3) a local model, close to the Santa Fiora springs, which reads the boundary conditions from the previous model, by adjusting the values according to the level measured continuously by the installed TFCCP phreatemeters.

Figure 7. The three models constructed

At this development stage the hydrological interface in the HH model is simply modelled using a number of soil layers (whose horizons and characteristics were experimentally determined) and then following an approach based on the Richards equation. This is very important in local application, e.g. for the hydrocarbon spill scenario, where moisture profiles must be estimated in order to determine the infiltration rate of pollutant in saturated/unsaturated groundwater conditions.

Following the above procedures, the local HH-model is able to run in an almost operational way (unless a still not-automatic calibration procedure that shall be periodically performed).

Value-added results, in the form of maps (for water level, hydrocarbon contaminations), are obtained through the combination of several levels of information and for different

impact scenarios and are directly uploaded on the Web Map Display of OSIRIS web portal through Internet (Fig. 8).
End-users can perform a number of actions, such as critical interpretation of results, analysis of model data to different forcing conditions, definition and evaluation of several scenarios, realisation of risk maps under the most likely scenarios conditions.

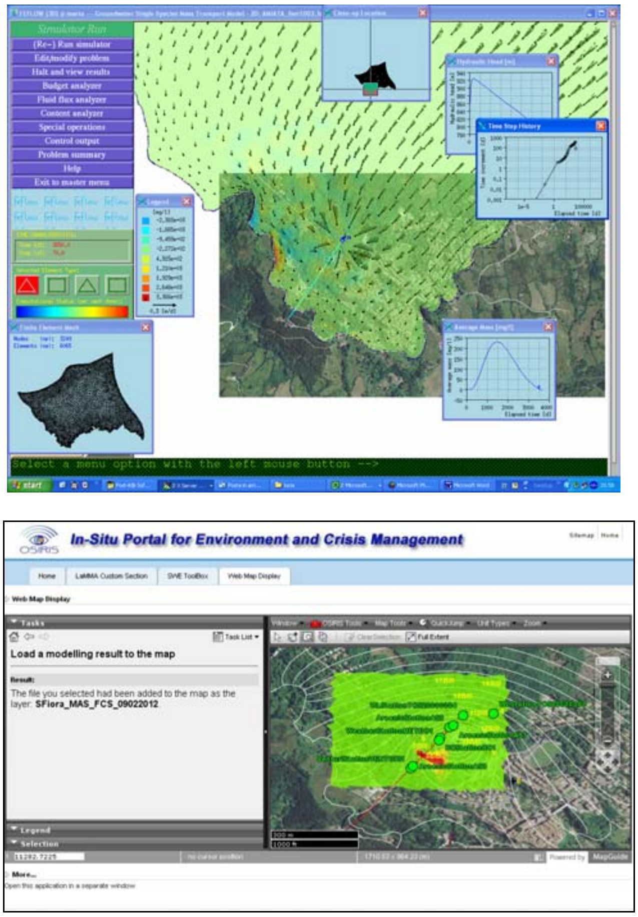

Figure 8. Hydro-geological model outputs

4. ARCHITECTURE

OSIRIS provides a Service Oriented Architecture (SOA) addressing the smart deployment, use and reconfiguration of in-situ sensor. In order to match such objectives the OSIRIS architecture is scalable to allow for easy integration of new sensor data, when it is necessary to further improve the quality of services and fit users' needs.
A main advantage of the architecture is that it can be easily reconfigured to pass from the monitoring to the alert or the crisis phase, by changing sampling frequencies of interesting parameters, or deploying specific additional sensors on identified optimal positions.
The Water Monitoring Sensor Network, developed during the project for the Santa Fiora aquifer, was based on heterogeneous sensors (Fig. 9), measuring different parameters, a part of them being located underground and another part deployed on demand in selected places (i.e., mobile sensors in the sense of being transportable). As a consequence various communication solutions have been adopted in order to interconnect the sensors at the network level, to enable integrated data processing.
At this aim we have exploited the principal characteristics of the OSIRIS architecture, that are to be a flexible architecture which abstracts from the underlying sensors technologies and that supports fast and simple deployment as well as addition of new platforms.
The other set of goals addressed by the OSIRIS architecture are the efficient distribution of the query processing and combination of sensor data, as well as the dynamic adaptation of the system configuration during runtime with minimal effort. These capabilities have been necessary during the transition from the monitoring scenario to the two crisis ones, and thus they have been proved in occasion of the project demonstration event.

Figure 9. Sensor network architecture implemented in Santa Fiora for the OSIRIS water monitoring application.

4.1 OSIRIS Services

The Web Services of the OSIRIS architecture allows interfacing with different sensors, based on SWE standards, according to the OGC requirements. Some SWE service standards, to access to data and to remote capabilities such as tasking and alert notification, have been upgraded thanks to the project developments.
The OSIRIS services have been categorized into three groups, according to the problematic addressed:

- *Sensor Services*, based on the SWE for accessing sensor data and controlling sensors;
- *System services,* providing additional capacities upon sensor services at the system level, such as: SOS (Sensor Observation Service) for data storage and access to the stored data interface; NAS (Notification Alert Service) for alerting through SMS or email; System of System Service Layer, that is a set of services for "gluing" the other services, allowing registration and supervision of the various services, data flow organisation, service integration;
- *Operational services*, addressing in particular the display of the sensors data and System Services information (data display, alert display etc.).

The main services operated during the underground water demonstration are SOS and NAS (Fig. 10), allowing respectively the measurements access and the alarm management (providing alerting messages by delivering notifications to Subscribers, i.e. an e-mail in our application). Among the other operated services we cite the Data Storage Service, for storing model results coming from the Hydrogeological Model, and the Registry/Catalogue SIR (Sensor Instance Registry), belonging to the System of System

Service Layer, for storing the sensor list, thus allowing users to access available sensors and capabilities, as well as their status.

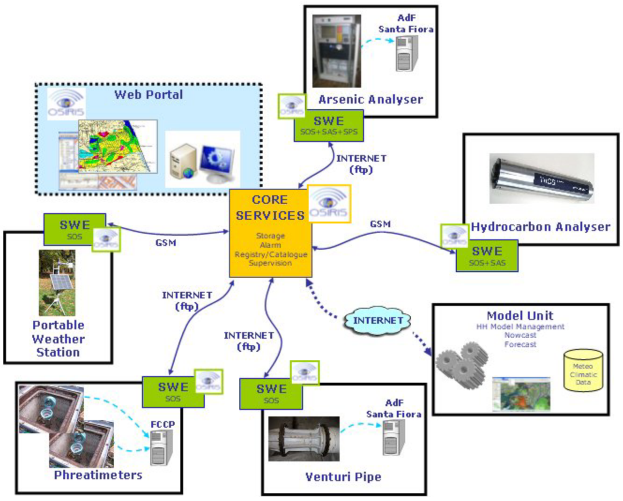

Figure 10. OSIRIS services in the water monitoring application.

4.2 Communication Means

For connectivity and protection reasons, the OSIRIS infrastructure is included in the AdF local network in Santa Fiora, that works as a node in the data flow for the Arsenic Analyser and the Venturi pipe data.

Sensors data are transmitted to the OSIRIS system located in the AdF Control Room in Grosseto, via (Fig.11):

- GSM communication for the portable meteo station and the hydrocarbon system;
- Internet communication (ftp) for the phreatimeters (through the TFCCP dedicated application that directly receives the sensors data via GSM);
- Internet communication (ftp) for the arsenic analyser and the Venturi pipe (through a wired communication from the sensor to the AdF building in Santa Fiora).

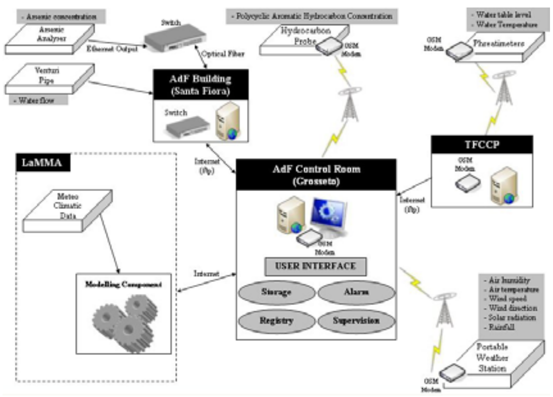

Figure 11. Scheme of the adopted communication solutions.

The link to the system for the model component is made through internet, both for accessing the data to be processed and for delivering products to the system.

4.3 Operational Display

To make OSIRIS services easily usable, an interoperable user interface has been adapted in order to integrate human and technical resources (Fig. 12).

This web application allows to access, monitor and supervise OSIRIS services, sensors and data. The user is able to manage: all sensor data at some fixed or relocated points (in the case of emergency scenarios) and the data produced by the numerical models. In addition through the application interface, the operator is able to visualise and manage several type of sensors status: the Sensor Status (ON/OFF) that indicates if the sensor is working or not, the Sensor Functioning Status, and the Sensor Alarm Status.

The Web Map Display is composed of a cartographic GIS oriented display, where different layers can be added, together with a set of buttons that offer classic map display operations. The application integrates several cartographic layers and offers basic map display operations (pan, zoom, select etc.). The application offers also a real time visualisation of some graphical output (time series) of sensor measurements, accesses the sensors supervision capabilities, and actively visualises alerts.

Figure 12. Screen shot of the Web Portal display.

5. DEMONSTRATION EXECUTION

The aim of the Ground Water Monitoring System Demonstration was to prove the OSIRIS architecture through different scenarios dealing essentially with water quality, that is with the issue of ensuring good quality drinking water supply. The demonstration allowed to deploy in real conditions the OSIRIS system from acquisition to exploitation. It involved the deployment of a set of sensors implemented with OSIRIS architecture that updated the legacy sensor network of the aqueduct (Fig. 13), namely:

- an arsenic analyser provided with an alerting system allowing to send arsenic concentration measurement to the AdF Control Room;
- a portable hydrocarbon sensor made by a probe for measuring the concentration of polyciclic aromatic hydrocarbons in water (through measurement of induced fluorescence emission), equipped with a measurement, control an power supply system developed by LAMMA for data acquisition and transmission in indoor and outdoor conditions;
- a portable meteorological station equipped with a battery supplied with solar panel, a data-logger and a GSM modem for data transmission.

All OSIRIS phases (monitoring, alert and crisis response) were addressed.

The tests were performed in Santa Fiora with one day of public live demonstration (February 18, 2009), to whom nearly 40 invited people took part.

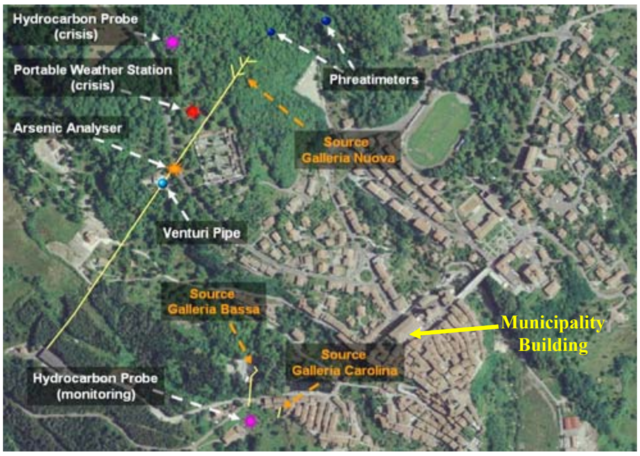

Figure 13. Demonstration location and instruments deployment places for the monitoring and crisis phases.

5.1 Monitoring Phase

This phase aims at assessing the water quantity and quality of the aquifer. About water quantity the upgraded sensor network gives information of the water flow for the Galleria Nuova and the water table heights for two relevant points. About water quality the upgraded network controls arsenic and hydrocarbon concentrations in water.

The arsenic concentration is real-time monitored for three selected sampling points by means of the arsenic analyser positioned in the main capture gallery of the Amiata Mountain (Galleria Nuova). Measurements of arsenic concentrations are also stored by the system to be available for different purposes, e.g. for assessing arsenic trends and for comparison with other water data (e.g. water flow, pH, redox potential, etc.), looking for dependencies on other parameters.

Water contamination due to hydrocarbon is controlled by means of collecting and storing polycyclic aromatic hydrocarbons concentration in a sand-sieve basin that collects the water coming from two galleries located below Santa Fiora town (vulnerable spot that can be contaminated for example in case of hydrocarbon pollution due to spills from domestic use tanks), using a specific sensor. This phase allows to take into account the variations due to water elements concentration changes, instrument calibration, etc.

Periodically the hydro-geological model calibrated for the site is run on the basis of the available data, in order to produce a present view and future estimations of water flows in the aquifer. The model results are uploaded on the OSIRIS web portal through Internet.

5.2 Scenario 1: Arsenic Crisis Phase

In order to activate the arsenic crisis phase scenario a measure over the fixed threshold of arsenic concentration has been simulated, just giving as input in the arsenic analyser a sample of water enriched with arsenic.

While an alarm was visualised in the specific user interface of the Web portal, the AdF operator received an alarm e-mail and initialise the crisis activities that consist of gathering data from all sensors as for the monitoring phase. Through the results of the HH model (run by an expert LAMMA operator) the AdF Control Room was able to control the current situation and infer the behaviour for the following days (for the moment just on the basis of past experiences).

In the future, the amount of accumulated information (on water flow, arsenic levels, etc.) will open the possibility to operate correlation analyses with the aim of predicting the evolution of the arsenic concentrations for the main water sources and eventually for the aqueduct distribution nodes (the latter using OSIRIS products as input of the Hydraulic Model* owned by AdF).

5.3 Scenario 2: Hydrocarbon Crisis Phase

For the hydrocarbon crisis phase scenario we simulated an accident with a spill of a liquid pollutant from a tanker-truck and an alert message consequently received by the AdF Control Room from the fire-brigade, that notifies such accident and the relevant information. Location, time and type of pollutant spilled out, plus a rough estimation of spilled quantity and spilling rate of the pollutant are assumed to be provided by the personnel in charge to intervening on the accident place.

The AdF operator then activate the deployment of the portable meteo-station on the accident location and gets data from all sensors deployed in the monitoring phase with the addition of the meteorological data measured at the spilling point. The AdF operator gets all data available and requests to the LAMMa operator the HH model simulation in order to forecast the pollutant distribution and to identify the vulnerable areas of the aquifer with the purpose of assessing the piezometer with major risk of contamination, where the portable hydrocarbon probe has to be firstly deployed.

In the case of hydrocarbon detection (we simulated adding traces of gasoline in the water sample analysed by the hydrocarbon sensor), the OSIRIS system notifies an alarm to the application, together with an e-mail to the AdF operator, who consequently can proceed activating the proper Civil Protection protocol for the identified water contamination crisis.

In the crisis phase, various HH model simulations initialised with updated measurement results allow to assess the ongoing situation and scenarios of contamination predictions.

6. CONCLUDING REMARKS

OSIRIS has brought a new monitoring and control capability for environmental emergency applications. It provides remote access and control over a distributed and heterogeneous sensor network, combining sensor technology and data communication in a flexible system. Its capability was proved through very different applications involving completely different sensors responding to various requirements.

The main tasks of the demonstration on the OSIRIS Ground Water Monitoring application were achieved successfully: the functionality of the OSIRIS architecture in order to manage different phases (monitoring and crisis) concerning water quality vulnerability was proved, and as a consequence more generally it was demonstrated that Sensor Web Enablement standards can be applied to efficiently upgrade and manage legacy sensors networks.

The demonstration also showed how web services can discover and access heterogeneous data sources and that, through the web application developed for managing and exploring hydrologic and meteorological data, it is possible to

* It has to be specified that the Hydraulic Model simulation is part of the crisis management phase that falls under the competence of the Acquedotto del Fiora, not demonstrated in the OSIRIS context.

automatically aggregate data from diverse sources into spatial data layers for different purposes.

The integration of the HH model outputs can dynamically represent the infiltration/contamination scenarios of the pollutant in case of a spill accident, giving a great support during crisis management.

Thanks to a Web Portal, upon specific authorization, end users are able to access, manage and display data from sensors, model and other products, using any web access everywhere in the world.

The demonstrations on the Ground Water Monitoring System was fully successful from a technical point of view and also in terms of the interest expressed from users either actively involved in the demo or simply coming from different institutions to attend the event and evaluate the system capabilities. The end-user manifested the firm will to maintain the system working after the project end with a plan to improve it, while various stakeholders (from different communities) present to the live demonstration manifested their interest in the project.

6.1 Future Improvements

Some lessons have been learned from the demonstration implementation that could improve the deployed water quality monitoring sensor network.

For example in order to better evaluate the pollutant degradation and infiltration properties, soil moisture measurements should be acquired. This means that at least a soil moisture probe should be added to the portable meteo-station. Thanks to the station architecture and data acquisition and transfer solution this should be very easily accomplished.

About the Hydrological Hydro-geological model, it is important to clarify that its component is part of an "open" monitoring system that can be implemented in the future. It needs to be upgraded (primarily to be calibrated with larger data sets) in order to produce more reliable information in all cases of interest for the aqueduct management and as a valuable support for the civil and environmental protection actions. The OSIRIS system is presently accumulating a detailed data sets on water and arsenic behaviour. Thanks to the increasing amount of this information provided by the new installed sensor and thanks to the water quantity forecast that is possible with the HH model, there is the prospective to calibrate a future arsenic-concentration (statistical) prevision model to discover the arsenic concentration variation dynamics related to the water quantity.

A more complicate task is the issue of improving the capability of modelling hydrocarbon spill infiltration and water contamination, because this could be addressed only through specific experiments (that are not planned for the moment) or through real contamination events.

7. REFERENCES

Bacharach S., 2007. New Implementations of OGC Sensor Web Enablement Standards. Sensors. http://www.sensorsmag.com/networking-communications/government-military/new-implementations-ogc-sensor-web-enablement-standards-1437#sidebar1

Bacharach S., 2008. Sensors and the Environment. V1 Media Magazine. http://www.vector1media.com/articles/features/4358-sensors-and-the-environment

Botts M., Percivall G., Reed C., and Davidson J., 2006. OGC Sensor Web Enablement: Overview and High Level Architecture. OGC White Paper, July 2006

Botts, Mike; Alex Robin (Oct. 2007). "Bringing the Sensor Web Together". Geosciences. pp. 46-53

Dall'Aglio M., Barbieri M., Bazzoli P., Venanzi G., 2001. Drinking Water Quality in the Grosseto Province, Tuscany, Italy. An appraisal on the basis of the study of water rock interaction. Proceedings of the Water Rock Interaction (WRI-10) International Congress. Cagliari, June 2001. Vol. 2, pp.1059-1062

Diersh, H. J. G. FEFLOW 5.3, 2006. Finite element subsurface flow and transport simulation system. WASY Institute for Water Resources Planning and Systems Research. LtdGmbH.

Pizzi, G., 1998. Modello di Simulazione Finalizzato allo Studio della Vulnerabilità dell'Acquifero che Alimenta le Sorgenti di S. Fiora. Final report for Acquedotto del Fiora. May 1998.

8. ACKNOWLEDGEMENTS

The demonstration could be prepared thanks to the strict collaboration of the Acquedotto del Fiora staff and thanks to the support of the Comando Provinciale di Grosseto del Corpo Nazionale dei Vigili del Fuoco (fire brigade of Grosseto).

We wish to thanks also THALES Communication for the development of the web-portal dedicated to the Ground Water Monitoring System.