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HYDROGUARD

Autonomous and automated system for monitoring, management of coastal risks and water Resources

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Keyword: Hydroguard, autonomous technologies, coastal risks management, water resources monitoring

Abstract.

The HYDROGUARD project is being developed with a view to the efficient and rational management of means of preventing and combating flooding, pollution, and marine submergence. The first targeted regions are Languedoc-Roussillon and PACA. The project aims at developing autonomous technologies and equipment to be put in place across the territory (storm basins, streams, outputs from wastewater treatment plants, hydraulic structures, lagoons and shoreline...) in order to contribute to the monitoring and ongoing management of coastal and surface water bodies and territories, especially during crisis situations (flooding, accidental pollution, marine submergence). Topics taken into consideration in the framework of the HYDROGUARD project keep the focus on present concerns about risk management. The overall system, consisting of especially developed buoys embedding a brand-new reliable Decision Support System and high-speed telecommunicating facilities, can be static - located in sensitive areas - or dynamic - deployed over operational areas in the case of an alert. In case of an alarm, the proposed mechanism is the optimal tool for anticipating actions, contributing to decision-making, and guiding relief measures by means of the range of information acquired through the detectors / sensors. Once the alert is over, the system returns to relaying relevant information to State services, communities, individuals, managers of industrial sites and delegated services. The originality of the system lies in its decentralization, proximity, redundancy and interoperability with other existing systems. This project is directly linked to the recommendations of the French Ministry of Environment, Ecology, Energy, Sustainable Development and the Sea (MEEDM), regarding knowledge, prevention, prediction and early warning; and the Water Framework Directive, for which it is necessary to develop suitable devices, in particular with regard to monitoring, improving the chemical status of water bodies, and maintaining quality resources. Finally, an evaluation of the benefits of such a system will be assessed, by means of economic Costs-Benefit Analysis (CBA). The actual project team is multi-disciplinary. The end-users targeted by the system are municipalities and local authorities, ports, firefighters and other safety personnel, as well as engineers or industrialists in the framework of their missions of prevention, protection, fighting against floods, and management of water resources.

I. Introduction

I.1. Context

The project aims to develop autonomous technologies and equipment to be put in place across the territory (storm basins, streams, outputs from wastewater treatment plants, hydraulic structures, lagoons and shoreline...) in order to contribute to the monitoring and ongoing management of coastal and surface water bodies and territories, especially during crisis situations. The topics taken into consideration in the framework of the HYDROGUARD project are in keeping with present concerns and risk management.

The project has the label of the regional competitiveness cluster – Managing risk and vulnerability, being developed in partnership with ESECO Systems, Egis EAU, ARMINES-EMA (LGI2P & LGED), C2innovativ' Systems. It has received financial support from the State (Single Interministerial Fund) and the Languedoc-Roussillon and PACA Regions, in order to set up several pilot systems.

I.2. Aims of the project

The objective of the project is to develop a reliable, autonomous and automated monitoring system, for the rivers and coastline of Languedoc-Roussillon and PACA, and more generally to allow local communities to ensure sustainable management of water bodies and territories.

The originality of the system lies in its decentralization, proximity, redundancy and interoperability with other existing systems. The devices (detectors / sensors, power supplies, embedded communications and computing) can be fixed or mobile, mounted on buoys and deployed in sensitive locations, or portable to be placed at particular sites during alerts. To maximize return-on-investment, they are not used only in case of emergency (flood events and storms), but also in standard mode for detecting pollution, monitoring evolution of water masses and the coastline, or taking measurements concerning erosion or other indicators. They can be integrated appropriately into strategies for monitoring and alert, and management of water bodies. 2D/3D visualization and monitoring tools will be part of the system, enabling monitored areas to be visualized using appropriate visualization flows, synthesizing real-time data from the devices to the end users. This new approach is consistent with European legislation, and national standards and regulations.

If an alarm happens, the proposed mechanism is the optimal tool for anticipating actions, contributing to decision-making, and guiding relief measures by means of the range of information acquired through the detectors / sensors. Once alert is over, the system returns to relaying relevant information to State services, communities, individuals, managers of industrial sites and delegated services.

This industrial research and development project targets the local level, with one prototype site in Languedoc-Roussillon: Saint-Just (3 buoys in place) and two pilot sites in Languedoc-Roussillon: the City of Alès and the Thau Lagoon with its bordering communities. These areas are good examples of water body management problems, risks of flash floods, submergence by the marine lagoon, and rupture of the dune belt, with high stakes in terms of human factors, tourism, and economy.

Finally, an evaluation of the benefits of such a system will be implemented, by means of economic Costs-Benefit Analysis (CBA). The project team proposed is multi-disciplinary, and combines all the skills necessary for the successful completion of the project.

II. Literature review

The progress in the fields of wireless communication technologies (radio modem, WiFi, Bluetooth, ...) and autonomous power supplies have given rise to pervasive and ubiquitous computing applications (Parashar, 2010). These applications are characterized by the use of broad-based networks of devices that provide the functionalities of sensors or actuators for interacting with the environment in which they are deployed. Wireless links facilitate the

establishment of large-scale applications, e.g. in the field of industrial control (Marin, 2005; Platt 2008). They open applications dynamically defined by addition or withdrawal, or mobility devices, for example in the field of home automation (Nakamura, 2004; Wu, 2007). The management of the architecture of these applications requires solutions tailored to their complexity.

Traditional proposals are based on centralized architectures in which devices with very limited resources and capacities relay measurements to servers for the collection, storage and use of data (Marin, 2005). In such systems, the remote devices function according to the scenarios defined, monitored and executed by the servers. Such centralized architectures are suited to the use of simple devices, and are inexpensive, most of the computing resources and storage being concentrated on the server. Their disadvantage is that the server becomes a vulnerable point in the system in terms of performance and reliability.

The lower costs and higher performances now offered by computer platforms enable the development of decentralized architectures in which applications possess a set of intelligent (programmable) features which cooperate to collectively manage the corresponding execution scenarios. Some studies propose a fully decentralized architecture inspired by Peer-to-Peer (Nakamura, 2004). They make the assumption that all devices have sufficient resources to be programmed to interact directly with other devices. However, the capabilities of devices are still limited for reasons of cost. As a result, overall application scenarios are defined on a central server, which calculates their division into sub-scenarios that are deployed and executed locally by the various devices. The devices operate independently to run the applications but are not able to adapt to changes in their context of use (context-awareness) (Bolchini, 2007). The central server supports reconfiguration of scenarios based on changing needs (support for new applications) or the environment (appearance or disappearance of devices).

The other approach, which we advocate, is to develop a federated architecture, combining centralization and distribution (Wu, 2007; Abdelgadir, 2009). The concentration of computing and memory resources on some devices is crucial for the implementation of sophisticated mechanisms (autonomous, dynamic) management applications. These devices thus aim to optimize the use of these central mechanisms by means of sharing. To avoid introducing a vulnerable point in the architecture, the mechanisms are distributed redundantly over a set of devices with equivalent capabilities. The management of collaborations between devices then integrates mechanisms that enable the management of load distribution, dynamic reconfiguration of scenarios, and the reading and dissemination of information concerning the services (functions) available on a given device.

The federated architecture that we propose (Hamoui, 2009) combines the paradigms of agent-oriented programming (Wooldridge, 2002; Ferber, 1999), components (Szypersky, 2002; Briot, 2009) and services (Cervantes, 2004; Arevalo, 2008). The system is managed by all the embedded agents in control modules. Agents are defined to be modular and reconfigurable, using software components that can be deployed dynamically on the modules. Each module ensures detection and management of all the devices (sensors / effectors) located in its immediate environment. The module automatically reconfigures itself by the deployment or destruction of components depending on the context (appearance / disappearance of a device). Through the software components, agents perceive the devices as a set of uniform services (functions) that they can use to run scenarios (strategies, behaviors) for which they are responsible. Two dual strategies are typically proposed for access to a service. An agent can either move between two modules for local access to a service (mobility logic) or send a service request to another agent, located on the module where the service is localized (virtual mobility) (Wu, 2007; Abdelgadir, 2009; Braun, 2005). These strategies require the agents to possess "social intelligence", allowing them to find out about each other and exchange information on the existence and location of services. Conceptual and technical solutions have been proposed in the areas of multi-agent and peer-to-peer systems (Abdelgadir, 2009; Iribarne, 2004). The current performances of the

embedded platforms are sufficiently high for mobility management to be refined and generalized in pervasive environments. Beyond the mobility of agents, we study the mobility of services (components) and scenarios (behavior / missions).

Our goal is to define autonomic systems capable of being dynamically (re)-configured (Desnos, 2008) under the control of agents in order to take into account the evolution of their contexts of use (new sets of scenarios or devices) and to optimize their architectures (reliability, performance).

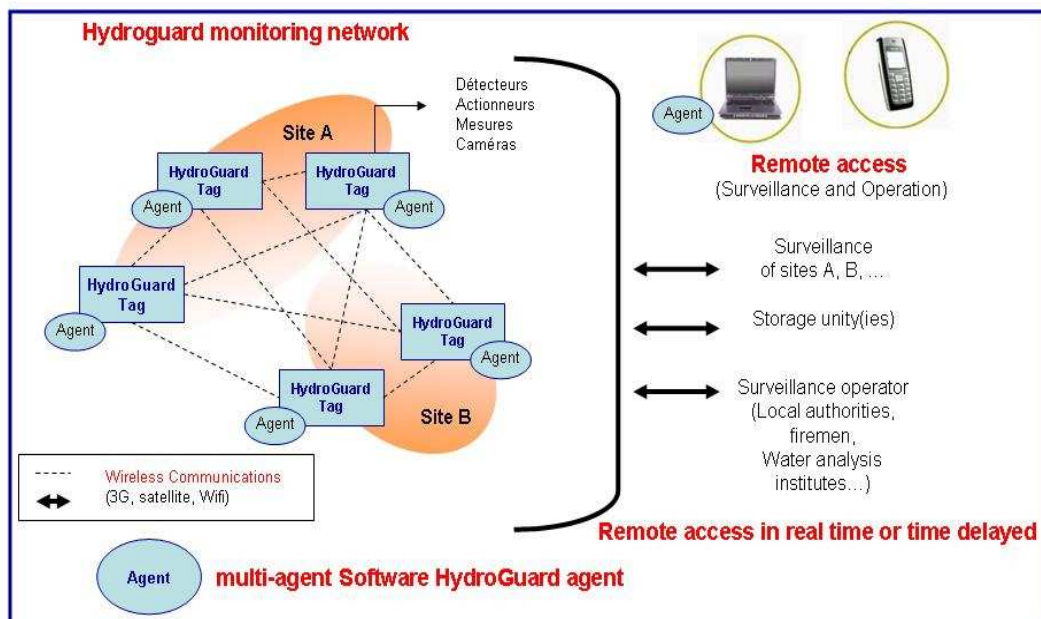
III. System infrastructure – Hardware and Software

The innovative system infrastructure of HYDROGUARD is protected by Patent N° WO/2006/087443 (Lovric, 2006), entitled —Intelligent Remote Multi-Communicating

Surveillance System And Method]], which defines a remote monitoring system that implements

an electronic network (referred to as "e-monitoring) in which multiple elements or components (detectors or sensors, for example) have their own intelligence localized in a microcontroller, and a means of remote communication. This monitoring system is able to reconstruct when one or more elements are faulty or damaged. Figure 1 shows this network and its structure.

Figure 1. The HYDROGUARD monitoring network



The system provides the following protected innovations:

- Networking a wireless mesh of installed equipment (ESECO SYSTEMS products and detectors / sensors) that allows the establishment of inter-and intra-device multi-agent security policies. It thus becomes possible to monitor the evolution of pollution and flooding or coastal flooding phenomena by providing real-time data, images or videos taken from the immediate area, without human intervention.
- The ability to geolocate and link the sensors using webcams or more elaborate cameras.

- The ability to move equipment if necessary (through wireless communication) or rapid deployment (less than 2 hours) over a disaster area (e.g. following a seawall failure or accidental pollution event).
- The transmission and secure storage of these flows, or remote consultation via mobile phones (PDA or PC) by authorized personnel.
- Local implementation of pretreatments based on simple initial diagnosis, without human intervention, to better filter the alerts relayed to operations teams and / or rapid deployment forces.
- Remote access to equipment with the ability to change security strategies or the behavior of a HYDROGUARD agent module, or one of the devices that it drives, "on the fly".
- The establishment of a collaborative and open platform (visible and easily readable from other field-specific applications) that centralizes data for better synchronization of the various stakeholders.
- The establishment of location-based tools that allow the pooling of the management of interventions regarding both equipment (such as maintenance technicians) and losses (e.g. fire).

IV. Applications: monitoring and warning systems

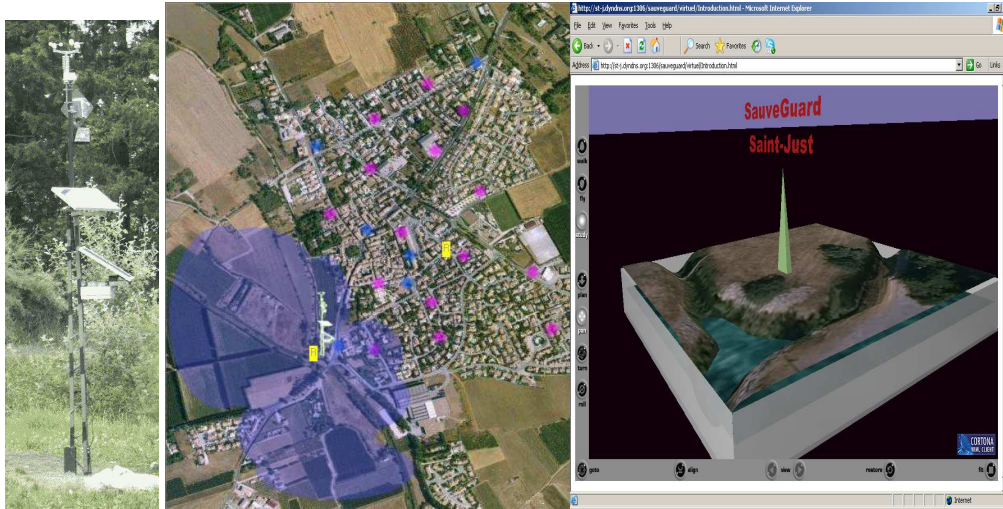
IV.1. Prototype site: Saint-Just

The prototype site aims at building an autonomous DSS against rapid flooding which brings major help for crisis management to first responders. The Hydroguard system is built around 3 buoys placed along the rivers which are likely to cause rapid flooding when severe thunderstorms occur in the Languedoc-Roussillon Region. The sensors provide information about water level, rain, water and air temperature, wind speed and turbidity. The buoys communicate with each other and with the city hall using radio links. Outdoor cameras are also used as a mean to certify the measurements before further processing.

To demonstrate the ability of Hydroguard to be integrated with already existing infrastructures, the videosurveillance cameras already in place for security purposes have also been interconnected with Hydroguard. The whole system constitutes the CityConnexion security management system. During the crisis, the whole DSS enters into a crisis management mode in which the CityConnexion application interface is simplified to avoid causing supplemental stress for first responders. To inform the people of the town, the buoys perform forecasts on the water levels, and communicate with the city hall to share the data. The system sends SMS information to the people of the zones which are likely to be damaged by the flooding in the next hours.

Hydroguard also activates early warning procedures. It can send SMS alerts and take control over the loudspeakers and sirens of the town if the crisis evolves too fast for a rapid human processing. The Figure 2 shows a prototype buoy in Saint-Just, a map of the city from CityConnexion with the different radio spots and a flooding forecast, and a 3D representation of the site.

Figure 2. A buoy prototype from Saint-Just, a map of the city and a 3D representation of the site



IV.2. Submergence: Thau Lagoon

The pilot project on this site aims to develop a warning system called Espadhom®, based on HYDROGUARD system infrastructure, with regard to the risk of submergence/flooding.

The challenges of the Thau Lagoon area are to anticipate the characteristics of storm surges at

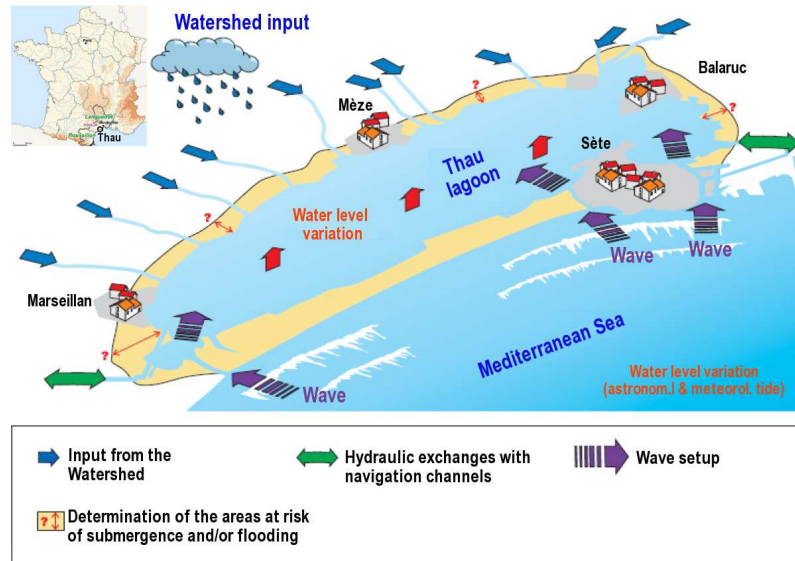
main risk areas located on the coast, along the “graus” (communications between the lagoons and

the sea), and inside the Thau lagoon. As a matter of fact, the coastal territory of the Gulf of Lion is characterized by a chain of ponds and lagoons separated from the mainland by a fine spit of sand, which is heavily populated in places (Thau lagoon, Leucate, Mauguio, Palavasian lagoon system, ...). It is particularly sensitive to erosion and flooding. This geomorphological configuration complicates the characterization of the submergence hazard over the territory, with coastal lagoons damping and shifting the storm surge wave over time. The mechanisms governing marine submergence are now well known, but still require significant computer resources for their detailed characterization. Figure 3 shows the description of the Thau lagoon area.

The surges at the shoreline depend on both, the morphology of the shoreline (average slope of the seabed, exposition / shape of the coastline, ...) and the weather conditions (wind, pressure). For instance, a drop in air pressure causes an elevation of the water level. This phenomenon is called the inverse barometer effect. A decrease of 1hPa is roughly equivalent to an increase in water level of 1cm. Wind stress on the sea/lagoon surface affects the water level (lowering or raising) and currents. According to the oceanographic conditions (offshore waves), by approaching the coast and breaking, the waves transfer their energy in the water column, causing an elevation of mean sea level (the "wave setup") of up to several tens of centimeters.

The water level rise caused by wind and barometric pressure effects is called "meteorological storm surge". The mean sea level during a storm results from all of these contributions, together with the astronomical tide (less than 30cm in the western Mediterranean). To obtain the maximum level reached by the sea, the swash must also be taken into account, that is to say the ebb and flow of waves across the beach or protection works. Run-up is the term for the maximum altitude reached by the swash. These phenomena cause coastal flooding, which can be increased by the erosion of the coastline, caused by wave action.

Figure 3. A description of the Thau lagoon area



In the lagoon, the surges also depend on the depreciation and the time lag of the marine flood wave, and the input of the inland watershed during rainfall events.

The development of the Espadhom® system will integrate the possibility of monitoring dunes and coastal protection works (increased risk of flooding in the event of failure of structures or of a dune, under the action of waves).

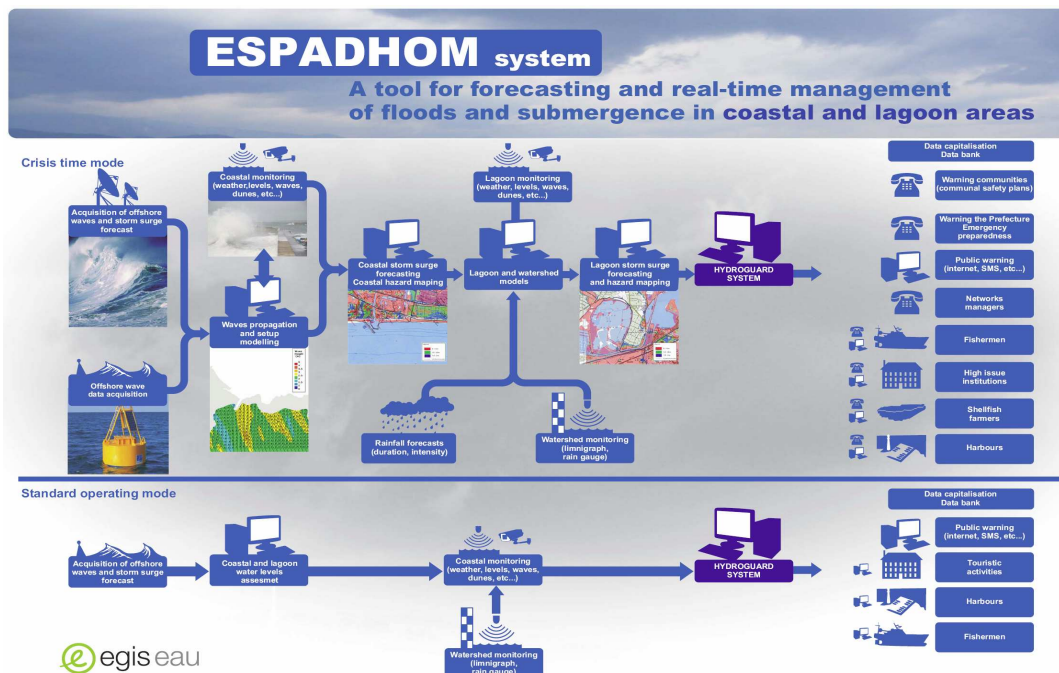
As described above, the buoys of the HYDROGUARD system communicate and deal independently with a variety of data from multiple sources, centralizing and making it consistent. For the needs of the Thau lagoon implementation, the buoys will use data from the existing operational forecasting systems (rain, weather, offshore waves, offshore water levels) and, also, from the onsite measurements obtained from embedded sensors or existing networks of sensors (rain, weather, offshore waves, nearshore water levels).

Figure 4 features the main steps and components of the HYDROGUARD-Espadhom® submergence warning system:

- acquisition, by HYDROGUARD's buoys, of 48-hour meteorological storm surge forecasts (due to wind and pressure).
- offshore wave data acquisition: in situ directional wave buoy located off Sète, and 48-hour swell forecast.
- acquisition of in situ and 48-hour forecast meteorological data (wind, pressure, rainfall).
- assessment of storm surges to be considered at the shore, by modeling the nearshore propagation of the waves, and calculating wave setup and run-up.
- assessment of the risk of dune rupture and overtopping volumes, for the lowest and most sensitive coastal areas (using a morphosedimentary model and empirical formulas).
- simulation of water level variation all around the lagoon shoreline in response to atmospheric factors (wind / pressure) and seaside conditions (changes in water levels in coastal areas, waves) to determine the water levels which may be reached during stormy events.

It is therefore a dynamic approach based on the analysis of the damping of the oceanometeorological signal between the sea and the lagoon, and of the conditions of equilibrium of the water level inside the lagoon. The simulations will be performed with a dedicated hydrodynamic model, which will include as well the forecasts of water supply from the watershed (in the case of simultaneous heavy rain).

Figure 4. The main steps and components of the HYDROGUARD-Espadhom® submergence warning system



The aim is to provide forecasts of water levels along both the seaside and lagoon shorelines, with time steps between two days and six hours. The estimates updated at one hour time intervals, will be:

- readjusted, based on real-time measurements carried out at sea, on coasts and in the lagoon: water level, wave, and weather sensors. The real-time shifting of the models on the observed values should provide a significant improvement of forecasts. However, this improvement can only be implemented if the hydrometric data are validated in real time, otherwise the possibility of erroneous data will eliminate the benefits of this process. Therefore, criticism and validation of data remains a critical step in system performance, particularly in times of crisis. In the proposed system, this validation will be implemented without any external action on the part of a local forecaster.
- transformed into maps at a scale fine enough (depending on the alert level) to allow public safety services and other stakeholders to obtain relevant information assessing the risk to users regarding the flooding/submergence hazard and, where/when appropriate, to coordinate protection and evacuation measure in the field.
- depending on the level of alert, the forecast will be made available to the public and professionals (fishermen, sanitation managers, ports, etc.) in the form of a website, or sent as a warning report with the hazard map, to municipalities, the Prefecture and civil security bodies.

The system combines alarms, redundancy and data capitalization.

IV.3. Flooding and quality: Alès

The third selected pilot site is located near Alès in the Cevennes region. This region is well-known for extreme events such as floods, which generally occur in autumn.

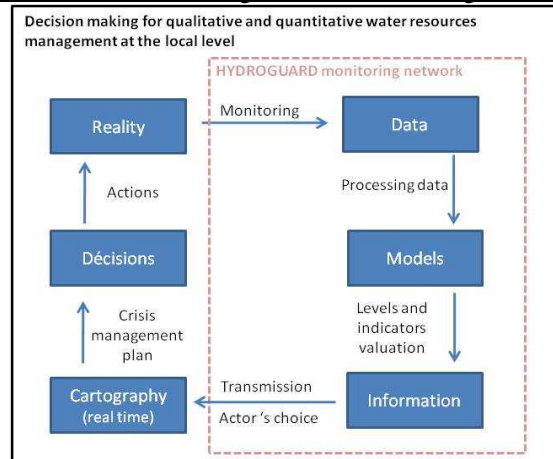
The main goal of the project developed in the framework of this pilot site is to:

- to set up over the studied territory an optimal number of buoys equipped with sensors to monitor not only quantity issues and flood prediction indicators (pressure sensors, pluviographs, cameras), but also quality issues using information given by physical and chemical sensors (conductimetry, pH-meter, detection of pollution).

- to develop an approach for establishing warning levels for flood prediction (Sauvagnargues-Lesage, 2007) and relevant indicators for pollution detection.

Effective surveillance of water bodies, from both a quantitative (floods, low-water mark) and qualitative point of view, requires reliable tools that enable real-time decision-making in order to support local authorities (management of flood and accidental pollution events). See Figure 5.

Figure 5. HYDROGUARD monitoring network for management of water resources.



The development of an integrated system (sensors / analyzers, signal transmission, acquisition and interpretation of data) enables effective operational actions to be set up in the context of the protection of water resources, and also in the case of crisis management (floods, accidental pollution).

In this context, the goal of the HYDROGUARD project is to select marketed sensors (Greenwood, 2006) suited to the constraints of surveillance monitoring (in situ measurement, robustness, and reliability), the representative parameters/indicators of water quality variability (pollution), and also potential events which drastically impact the ecosystem (flooding).

The challenge is therefore to develop systems allowing real time data acquisition (in situ measurements) together with spatial management of the information in order to insure a global overview of ecosystem evolution / modification (Roig, 2007). Moreover, the obtained data need to be reliable and robust in order to avoid erroneous decisions. The performances of the systems developed thus need to be regularly tested under real conditions (Gonzalez, 2007).

To comply with these operational objectives, it is also necessary to elaborate an approach to forecasting. Particular attention will therefore be paid to the transmission of information to targeted actors (local authorities, decision-makers, managers).

For each selected site (storm-water basin, river, urban stream, mining zone outlet), graduated warning levels will be established and indicators proposed to enhance water quality monitoring. These thresholds and indicators will be defined on the basis of models and field studies, and from the analysis of previous measurement campaigns. They will then be tested and validated over a two-year period within the framework of the HYDROGUARD project.

In function of the data provided by buoys for each observation site, it will be necessary either to define graduated actions to be integrated into existing decision-making processes (Municipal Protection Plan, crisis management plans) or develop specific methodologies (management of particular pollution events).

The final objective is to propose efficient tools to support targeted stakeholders in decision-making processes, and for crisis management. For this purpose, the data collected by buoys will be selected, processed and prioritized to facilitate dissemination and be more easily used by decision-makers. Data can be displayed through real-time mapping (cartography) of the status of

water resources according the level of information required by the targeted situation (flood, accidental pollution).

V. Conclusions and perspectives

We have seen that the HYDROGUARD project is developing a reliable, autonomous and automated system for the monitoring of coastal areas, and more generally offering local communities an effective way to ensure sustainable management of coastal risks and water resources. The components of the system, made up of especially developed buoys, can be static, located in sensitive areas, or dynamic, in order to be moved to operational areas in the case of an alert. The buoys communicate and independently deal with a variety of data from multiple sources, centralizing it and making it consistent. They are not used only in the case of an emergency (flood or storms), but also on a daily basis for monitoring and forecasting water levels and resources, detecting pollution and predicting its dispersion, or carrying out a wide range of measurements of other relevant indicators. The equipment can be appropriately integrated into strategies for protecting, monitoring and managing water resources, the shoreline and coastal protection facilities. The HYDROGUARD project is being developed in anticipation of extreme events that could be caused by global warming. The Xynthia storm and the recent severe weather events on the Riviera have shown that such situations are proving real and becoming concrete, in the short-term. And, unfortunately for the victims of such disasters, the serious human and material consequences underline the relevance of a system such as ours, and highlight the limitations of existing systems. The facts bear witness to the need for decision-making systems at the community level. However, the development of such a system raises new questions and issues, namely what powers of delegation can and should be provided to the system? The greater the power delegated to the system, the greater the gain in terms of reaction time. However, this brings into play notions of responsibility, complex legal issues, and moreover ethics. In conclusion, our system appears to solve challenging technical problems, but answers are still required in other areas, such as the law.

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