Study and development of a novel Early Warning Monitoring System to ensure water quality supply in a drinking water distribution system

R. Guercio[1], E. Di Ruzza[1] and L. Sanfilippo[2]

[1] Department of Hydraulic, Transportation and Roads, Faculty of Engineering, University of Rome "La Sapienza", Via Eudossiana n.18, Roma, Italy
(E-mail: *roberto.guercio@uniroma1.it*, *eleonora.diruzza@uniroma1.it*)
[2] SYSTEA - Systems Technology Advance Srl, Loc. Paduni 2A, 03012, Anagni (FR), Italy
(E-mail: *luca.sanfilippo@systea.it*)

Abstract: An Early Warning Water Monitoring System has been designed and developed to take under strict real time control some inlet points of a potable water distribution system in the aquifer of Gran Sasso mountain chain, Italy. The system is suitable for an easy and flexible installation and use, working on a field reconfigurable layout of multiparametric water quality detectors, flow sensors, auxiliary sampling and network control equipment, including the use of an innovative on-line toxicity monitor. The paper reports system's instrumental, hardware, software and communication layout and its main functions and features. Measuring tests performed to characterize a commercial UV absorption spectrometer to detect inorganic and organic chemical compounds are described; medium terms preliminary field measurements on conventional quality parameters are reported too. A preliminary overview of the next applicable studies based on neural networks application, with the aim to upgrade the system to be expertise for a rapid and automatic detection of abnormal water characteristics are prospected.

Keywords: Early Warning Water Monitoring System; drinking water distribution system control; Water toxicity; On-line monitoring.

Introduction

The goal of an early warning monitoring system is to reliably identify low probability/high impact contamination events in source water or distribution systems. Monitoring water quality in real time allows an effective local response that minimizes the adverse impacts that may result from the event. Other desirable features of the water monitoring system include: affordable cost, low skill and training, coverage of all potential threats, ability to identify source, enough sensitivity to quality changes at regulatory levels, minimal false positive or negative responses, robustness, reproducible and verifiable results, availability of remote operation. Analytical chemical methods are usually target oriented; in other words, these methods can detect only a specific compound or a range of compounds having similar properties. Furthermore, analytical-chemical identification does not by itself give information about bioavailability and possible toxic effects, especially from mixtures of compounds. On the other hand, changes in the behaviour or properties of on-line biological early warning systems may indicate the sudden occurrence of a pollutant not detected in conventional, analytical warning systems.

The **E**arly **W**arning **W**ater **M**onitoring **S**ystem (EWWMS) here described was developed and field applied to ensure water quality protection for one of the inlet points of the Acquedotto del Ruzzo water distribution system, which mainly supplies drinking water to Teramo city (about 500.000 people) in Marche region, Italy. The first main goal of the monitoring system is to check accidental spills or contaminations coming from a temporary on-working activities carried on in one of the two car tunnels placed just above the water source; the second objective is concerning to detect potential accidental spills coming from the Italian Istituto Nazionale di Fisica Nucleare (I.N.F.N.), one of the largest international underground research laboratories in the world for Nuclear Physics and cosmic research, which is based inside Gran Sasso, placed under about 1400 m down the wonderful dolomite rock of the biggest mountain chain in centre Italy.

In 1969, the demand to build an highway crossing the Gran Sasso mountain chain required the decision of digging two parallel car tunnels, 10 km long, through the mountain. The realization of such ambitious project was performed with a lot of difficulties, due to large underground water reservoir placed just in the surroundings of the tunnels. As a consequence, during the tunnels construction, numerous geological and hydrological studies were performed in the site; these studies provided the background for the development of the EWWMS here reported.

The studies revealed that the main water sources, which are mainly used for potable purposes, are placed on the Teramo's east side.

On the other west side of L’Aquila there is a similar situation and the water drainage coming from the tunnels is used for potable use too. In fact, as verified by a series of analysis, the source water coming from Gran Sasso aquifer shows an excellent chemical-physics and bacteriological characteristics.

The motorway galleries crossing the mountain at about 1000 m height, were completed in 1980, but the gallery opening to car traffic in direction Teramo was settled on 1984, while the one in L'Aquila’s direction was started on 1993 only. The two parallel galleries are constituted by two central 8 km long straight sections, joined at the beginning and at the end by curves conducting to the respective inlets and outlets. The longitudinal profile of the tunnels introduces a double inclination of the two lines toward the entrances; it was required by a strong presence of water detected during the realization of the tunnels. Besides near the gallery in direction Teramo-L'Aquila, at around 1/3 of the tunnel length, under the maximum coverage of the 1400 m height rock of the mountain’s peak, there are three large experimental rooms, connected by various galleries, which constitutes the underground Laboratories of the I.N.F.N.. Important research primary level physics and cosmic studies are performed in these laboratories, which sometimes require the use of chemical substances potential dangerous for the environment. High risks of pollution for the aquifer can be originated also by new working activities started in 2005 inside the motorway galleries, with the aim to ensure a better protection of both source water introduced in the water distribution system and the rest of water flowing into a small river coming out from the underground aquifer on Teramo’s side.

The water company Ruzzo Servizi Spa has the public duty to ensure the control of the water quality parameters on the east side, for drinking use according the strict Italian and European regulations. At the end of the digging of the tunnels, a set of conventional physical and chemical on-line analyzers were already installed by Ruzzo Servizi, to monitor the inlet drinking water coming from the area of tunnels, because a large part of the water constituting the aqueduct was coming from the tunnels drainage itself.

Considering the importance of the water flowing around and under the highway galleries, the other risks previously underlined and due to recent limited time spills coming from I.N.F.N. laboratory, which were not detected by such conventional monitoring system, a new and evoluted real time EWWM system was decided to be designed and installed in a few critical points of the working area, to ensure the best possible level of security, to quickly detect a possible water contamination.

The project to realize this new on-line and first alarm water monitoring system was started in 2004 and it is actually in the field experimentation phase; in the following paragraphs system’s layout and the first experimental measurement will be described.

Methods

The new Early Warning Water Monitoring System was designed and developed by Systea Srl (Italy) to be completely modular, expandable and very flexible in its use, in order to be easily adapted and installed in different monitoring sites during the experimentation phase and the operative survey activity.

The monitoring system is based on an industrial PC hardware, Windows XP™ based, managed by a Visual Basic™ software application specifically studied and developed for this project. A main software module networks different sensors, analyzers and auxiliary devices constituting the water monitoring system using an innovative TCP-IP open architecture, where each single measuring device is managed by a customized software module dialoguing in real time with the main core of the program using a TCP-IP virtual port. The sensors, analyzers and any external device are connected by an hardware point of view by an expandable industrial I/O interface modular system, using a standard RS-485 bus and analog or serial communication connections to the control PC.

The basic layout of the Early Warning Water Monitoring System is composed by:

§ a 220 Vac / 12 Vcc external power supply, mounted in a IP-65 wall mounting box;

§ a local control unit made by a wall mounting IP65 plastic box, which contains the industrial PC and the I/O devices, the 12 Vcc power supply with back-up batteries and any auxiliary hardware device;

§ a multiparametric probe (YSI 6820, YSI Environmental Inc., USA) to measure standard physical-chemical parameters in water (temperature, pH, conductivity, turbidity) which can be placed, according to the specific site requirement, directly in the water source or working off-line mounted in a flow-through measuring cell, coupled with a well-proven peristaltic pump feeding the rest of the monitoring system with the proper water sample;

§ an in-situ UV spectrometer (Spectro::lyzer, s::can Messtechnik GmbH, Austria) mounted in a special horizontal flow-through cell, to detect organic compounds;

§ a water flow sensor, to be chosen according to the different installation site and application specification (Argonaut YSI/Sontek, (USA), electromagnetic flow sensors, in-tube mounting type ultrasonic sensors);

§ a 500 ml, 8 bottles automatic sampler, specifically designed in a IP-65 wall mounting layout, for the collection of water samples in presence of threshold alarms detected by the on-line measuring devices.

Based on this standard layout, the system is already designed to be easily integrated by:

§ an innovative on-line toxicity monitor, to automatically detect and validate trace water pollution alarms using luminescent bacteria technology (Micromac ToxScreen, Systea, Italy) actually in course of experimentation and characterization in laboratory by the University " La Sapienza"

§ one of more on-line chemical analyzers, where it would be the need to detect specific compounds potentially dangerous for water quality (Micromac C / MP, Systea Srl, Italy).

Depending on the specific installation site, each monitoring station is connected with an external Web server through the use of dedicated TCP-IP communication lines, automatically connected to the Internet through analog or digital modems, private DSL line coupled with a ISDN external line, using the actual cheaper and very flexible routing technologies.

Each monitoring station is also connected to an industrial GSM device to send to operator's and technician's mobile phones Short Messages, informing them of any alarms and parameter's thresholds overlaps, which will cause a reaction on the system with automatic closure of hydraulic valves mounted on the tubing, to quickly redirect the water to be discharged in spite of being introduced in the potable water distribution system.

Using the same SMS service, the main software allows the remote management of most of the function available on the system by the use of specific SMS commands, which can be prepared and sent by the operators' themselves using their own GSM phones.

According to the Designer's requirements, the following monitoring points have been defined and installed:

§ one station placed in the control room of the Acquedotto dell'Aquila (on the west side of the Gran Sasso mountain), to be used as a reference background source of data;

§ one station placed at the outlet point of the I.N.F.N. underground laboratories, placed inside the highway tunnel, to control the quality of the underground water surrounding this area;

§ two stations mounted near the large pools placed at the end of a 2.7 km long service tunnel inside the mountain, used for the collection of the water drainage at the east side of the aquifer and directly feeding the Ruzzo Aqueduct (Acquedotto del Ruzzo) distribution system;

§ one station (as alternative to one of the stations installed near the pools) placed just outside the service tunnel, to control a new inlet point of water feeding to the same distribution system coming from a new by-pass, which was recently done to allow the future upgrade of one of the water collection pools to ensure a better protection and filtration of the water source.

In the following pictures typical installation layouts of the designed monitoring are shown.

Examples of installation of EWW monitoring stations

Results and Discussion

The submergible UV/VIS spectrometer has been extensively tested in Systea's laboratory, with the aim to check the limits of sensitivity and the specificity (the ability to positively identify end quantify specific contaminants). We chose first to measure the Nitrates primarily used in agriculture, because their presence could reveal a contamination from the outside; then we measured the Benzene, because it could show pollution coming from the highway roads inside the tunnels. Another compound we characterized was the pseudocumene (also known as tri-methyl-benzene, an aromatic organic compound similar to benzene), because of possible accidental spills coming from the underground laboratories of the I.N.F.N. The measurements were performed in distilled water and using the water coming from the aquifer, to appraise the effects of the water matrix on the measurement.

We performed cross sensitivity tests between nitrate and benzene, and between nitrates and tri-methyI-benzene, to appraise their possible effects on the matrix itself.

The first two substances (nitrate and benzene) are two stable mixtures, soluble in water and giving the possibility to do a quali-quantitative analysis of them. Figures 1-4 show here below the sensibility and the interval of concentrations to which the they are linear. The straight lines of setting are been calculated, with errors below 2%.

For Nitrate the low limit is 0.1 ppm, and the maximum limit is 1 ppm; the regulation threshold limit is 11 ppm, so it means this tool can be affected by an error of 10%. The characteristic nitrate UV absorption peak is 220 nm. The measures in laboratory show the relationship between concentration and absorption is linear until to a value of 1 ppm, while for higher values the relationship fits better with a polynomial curve.

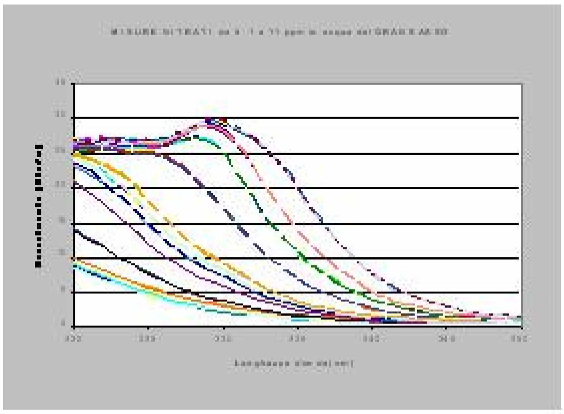

Fig.1 Typical UV spectra of nitrate

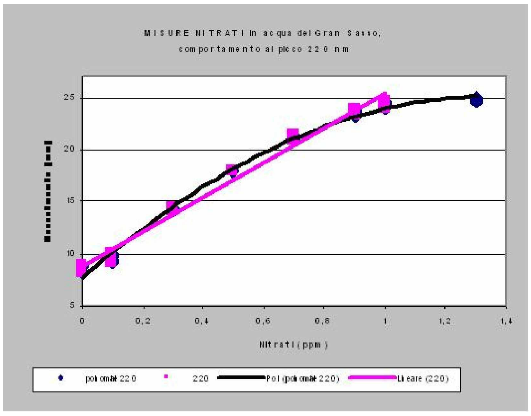

Fig.2 Nitrate UV absorption vs. concentration

For the Benzene the low limit is 1 ppm, and the maximum limit is 500 ppm; the regulation threshold limit is 1 mg/l, so it means this tool can be affected by an error of 25%. In this case, the matrix water of the Gran Sasso doesn't interfere on the measure having the Benzene the peak in the interval 238-260 nm. Also in this case the relationship between concentration and absorption results linear up to 500 ppm, while for higher values the relationship fits better with a polynomial curve.

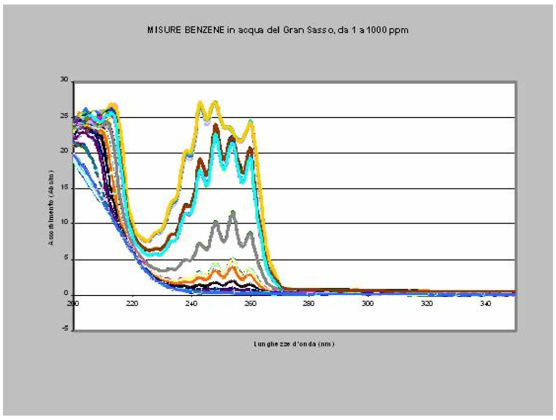

Fig.3 Typical UV spectra of benzene

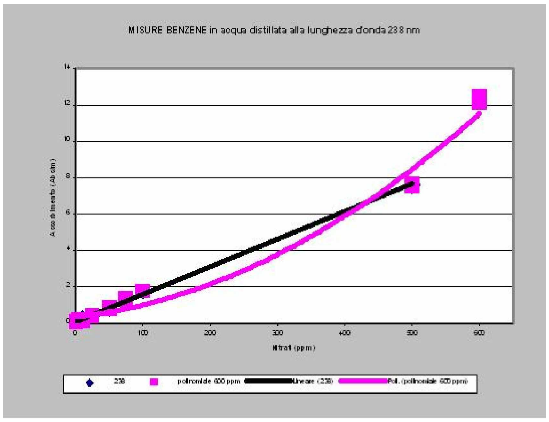

Fig.4 Benzene UV absorption vs. concentration

Regarding the Try-methyl-benzene compound, its extreme volatility in water doesn't allow to correlate with precision the absorption vs. concentration, even if the UV sensitivity to this compound seems extremely high (down to tens of ppb levels); for this reason we decided to consider these measurements by a qualitative point of view only.

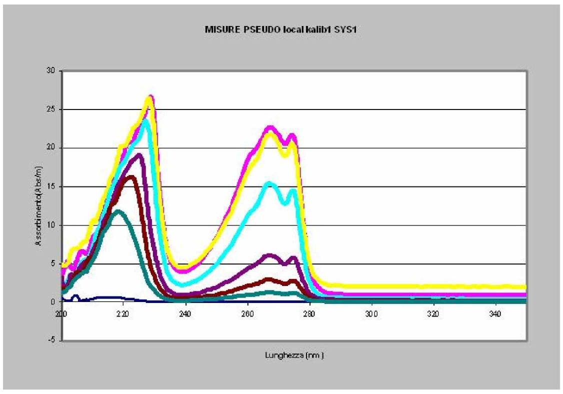

Fig.5 Typical UV spectra of tri-methyl-benzene

Conclusions

The characterization study revealed the UV absorption probe is able to detect the selected compounds, giving for each of them an evaluation of the LDL and the linearity of the measurement.
The standard software provided with the probe is able to detect a maximum of eight compounds, working on an UV absorption range between 200 and 400 nm. The maximum value of absorption over which the probe is not able to follow a linear correlation anymore is 25 Abs/ms; we tested the probe to an inferior pressure of 2 bar, between a temperature interval of temperature among 0-45 °C, and in a fluid that has an inclusive speed between 0.5 and 3 m/sec.
Main features are the following: the capability to provide a continuous UV spectra in 15 sec, its built-in turbidity compensation system, that allows the use for river water monitoring.

Regarding the standard multiparametric probe, we analyzed the real time data collected by the systems on field. Using this probe we can study the so called “surrogate alarm parameters”, which are pH, turbidity, temperature and conductivity as and their value changes could be used as an indicator of water quality.
The monitoring system was programmed to collect data from this probe every 5 minutes; here follows two graphics that represent one month of continuous analysis.

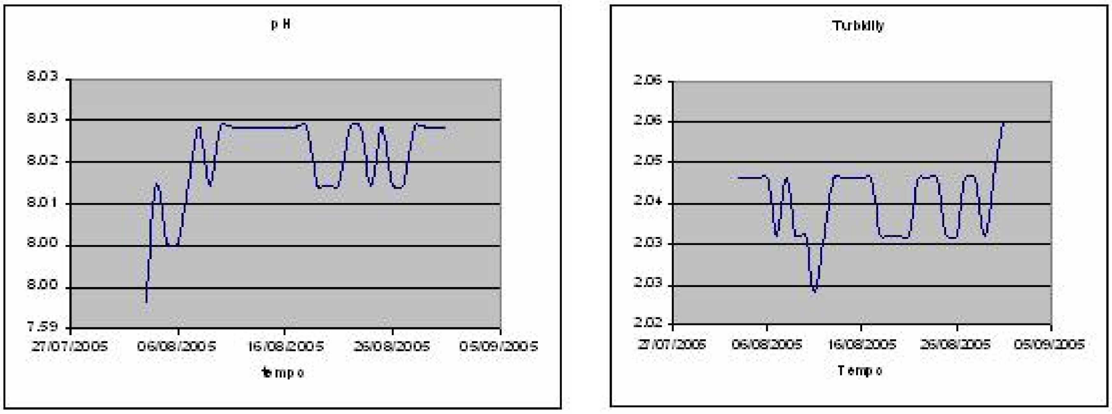

Fig 6: One month time series of pH and turbidity measurements

Rapid water matrix changes can be detected using this type of multiparametric probe, mainly because there are very small variations in water quality parameters during normal operation.

The next coming phase will be to test and characterize in laboratory the on-line toxicity monitor, we will aim to use of a second level field validation automatic device, after the rapid detection of any change in the primary water quality parameters measured by the multiparametric probe and the UV absorption probe.

The further step of our studies will be focused on the development and test of an automatic alarms recognition system based on a neural network approach, working on the base of the post-elaboration of the existing conventional and chemical parameters measured by the monitoring stations constituting the EWWMS, which will be integrated and validated in the near future with the automatic alarms generated by the toxicity on-line monitor.

As preliminary operative tests, we already focused on the rough UV absorption spectra given by the spectro::lyzer probe; even if we used for each absorption spectrum a restricted sampling set of only five wavelengths, a positive feedback about the recognition of positive alarms was given by an off-line software algorithm based on an easy-NN type neural network, giving an error of 4% only on the attended measurements.

The experimentation will continue in the following coming months, extending the number of wavelengths to be sampled and the pattern of chemical compounds used to train the neural network model itself.

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