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REAL-TIME MONITORING ON EVROTAS RIVER(LACONIA, GREECE): DISSOLVED OXYGEN AS A CRITICAL PARAMETER FOR ENVIRONMENTAL STATUS CLASSIFICATION AND WARNING

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The real time surface water quality monitoring network of Evrotas river has been operational in Laconia since July 2004. The experience of several months has shown that dissolved oxygen is one of the most useful parameters monitored, for both warning and quality status classification. Concentration of dissolved oxygen in surface water is known to be a critical parameter for water quality, and survival of organisms that live in it. At the same time, it provides an indirect indication of the organic load in water, as well as the potential eutrofication. Dissolved oxygen in surface water normally depends on the atmosphere pressure and temperature that directly affect oxygen solubility. Moreover, the depth under the surface where the measure is taken affects the measurements, once oxygen is reduced by depth. Real time monitoring provides a very useful option through data processing that could not otherwise be implemented by any conventional monitoring program, of any frequency. It is possible to monitor all daily variations of dissolved oxygen, thus replacing the unique value of one measurement in a conventional program, with a series of some 144 measurements (every 10 minutes) regressing around a moving average value. This form of time series permits monitoring of the daily amplitude of dissolved oxygen fluctuation, which is proved to be by itself an accessory indicator of the surface water quality status. At the same time, this frequency of measurements permits dissolved oxygen to be practically used as a critical warning parameter, especially when industrial waste and sewage is expected to enter the river system. Real time dissolved oxygen measurements time series can be very characteristic of surface water status quality, especially in relation to the corresponding time series of water temperature. With the above in mind, the time series graph of dissolved oxygen vs temperature is proposed as a representative graph for overview of surface water quality status. As it is shown in this paper, the forms of the plot concentrations are very characteristic of distinct types of conditions, and some very useful observations can be made at a glance.

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Real-time monitoring on Evrotas River (Laconia, Greece): dissolved oxygen as a critical parameter for environmental status classification and warning

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Abstract

The real-time water quality monitoring network of Evrotas River has been operational in Laconia since July 2004. The experience of more than a year of function has shown that dissolved oxygen is one of the most useful parameters monitored for warning and quality status classification. Concentration of dissolved oxygen in surface water is known to be a critical parameter for water quality and survival of organisms in it. At the same time, it provides an indication of the organic load in water, as well as the potential eutrophication. Dissolved oxygen in surface water normally depends on the atmosphere pressure and temperature that affect oxygen solubility. Real-time monitoring provides a very useful option through data processing that could not otherwise be implemented by conventional monitoring programs of any frequency. It is possible to monitor all daily variations of dissolved oxygen, replacing the unique value of one measurement in a conventional program, with a series of 144 measurements (every 10 min) regressing around a moving average value. This form of time series permits monitoring of the daily amplitude of dissolved oxygen fluctuation, which is an accessory indicator of the water quality status. This frequency permits dissolved oxygen to be utilized as a warning parameter, especially when industrial waste and sewage enters the river system. DO time series can be characteristic of surface water status quality in correspondence to the time series of water temperature. The graph of dissolved oxygen vs. temperature is proposed as a representative graph for overview of surface water quality status. The shapes of the plot concentrations are indicative of different conditions, and useful observations can be made at a glance.

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1. Introduction

In several countries around the world, namely USA [2,7], (Fig. 1), France [5] etc., real-time monitoring data are collected and provided to the public through the internet. Measurements include quantity and quality data for groundwater and surface water bodies, from water table and discharge to specific conductance, temperature and dissolved oxygen. Real-time monitoring networks provide data that can be used in multiple purposes, such as environmental hazard assessment, water resources management, natural hazard warning, etc [6]. Furthermore, large time series of data are accumulated and can be used for both short- and long-term trend analysis, especially when combined with periodical sampling and complete chemical, biochemical and ecological analysis.

Unfortunately, while in other countries there are long historical records to combine with the data collected with real-time monitoring measurements, a fact that has made the site selection for monitoring stations rather simple in the first place, this is not the case in Greece.

Extensive monitoring networks combining real-time monitoring stations and sampling sites form the basis of multipurpose environmental monitoring worldwide, and this is also the method proposed by the EU guidance documents for the implementation of the Water Framework Directive.

In Greece, there is no national real-time monitoring network for surface waters, and in fact the presented one is one of the very few that were ever set up, not to mention the fact that it seems to be the only one that was ever operational for more than a few months (Fig. 2). The network in Evrotas River was developed after a call of the Local Union of Municipalities and Communes of Laconia prefecture, and it was only funded in order to document environmental pressure that certain industries put on the river, in the form of waste disposal. At the same time, with the argument of comparison to natural reference conditions, the scientific team of the University of Athens convinced the local authorities to fund a total of seven stations covering more or less the whole length of the river. Apart from the three pre-decided sites, another set of four stations were set up on sites that were selected after consideration [1,2] of the geological, hydrogeological, hydrological and land use conditions throughout the river basin, along the main riverbed (Fig. 3).

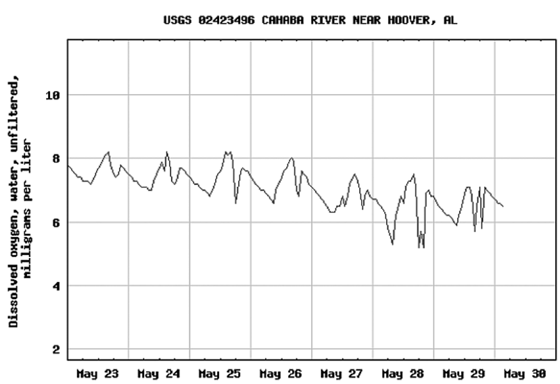

Fig. 1. Graph with real-time data for dissolver oxygen in Cahaba River, near Hoover, Alabama state, USA [8].

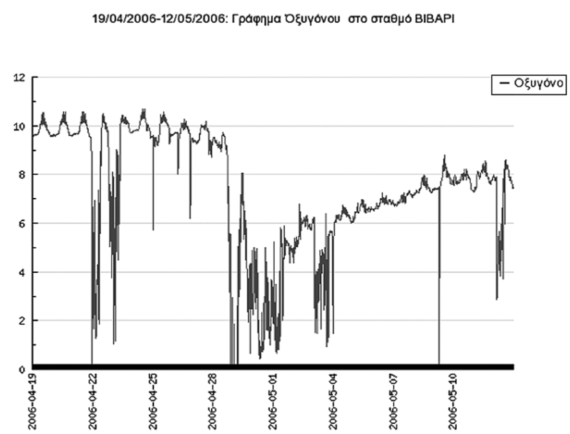

Fig. 2. Graph with real-time data for dissolved oxygen in Evrotas River, Laconia prefecture, Greece [7].

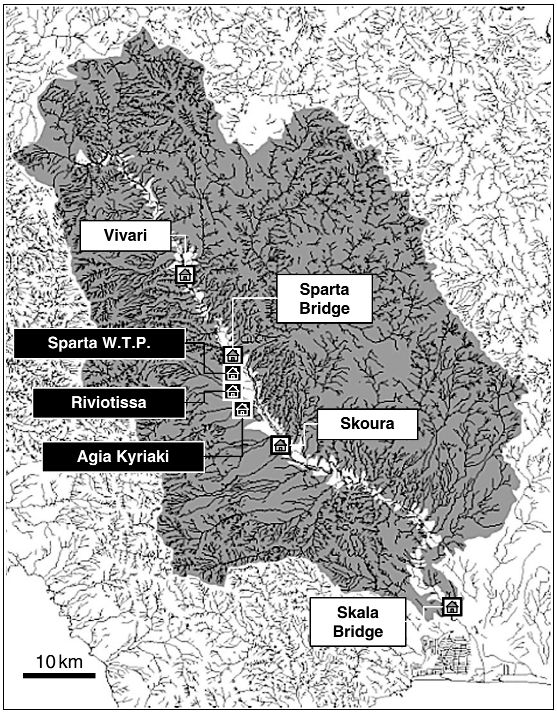

Fig. 3. Evrotas River basin and monitoring station locations (white label for stations on the riverbed).

Evrotas monitoring system includes seven stations located from the upper catchment area till the exit of the river to its delta area. The area between Sparta Bridge and Skoura is particularly sensitive because treated and untreated industrial waste (deriving mainly from orange juice and olive oil production) and municipal sewage enter the river system. Each station is equipped with temperature, pH, conductivity, dissolved oxygen and turbidity sensors, taking measurements every 10 min. Data are collected via GSM modems to the server at the University of Athens and the Local Union of Municipalities and Communes of Laconia Prefecture. The distribution of stations is

- Vivari Station. Monitoring of river water quality in the upper catchment area (reference station).
- Sparta Bridge Station. Monitoring of river water quality right after its junction with Oinous River and right before the plain of Sparta (urban and industrial area).
- Sparta W.T.P. (Wastewater Treatment Plant) Station. Monitoring of water exiting the plant and entering the river.
- Riviotissa Station. Monitoring of waste from adjacent juice production industry, on an estuary contributing to the river.
- Agia Kyriaki. Monitoring of waste from adjacent juice production industry, on an estuary contributing to the river.
- Skoura. Monitoring of river water quality downhill from the greater part of the plain of Sparta (urban and industrial area).
- Skala Bridge. Exit of the river to the delta area.

2. Methodology

For the measurements of dissolved oxygen the Oxyguard 420 Oxygen Probe was used. It is a "passive" two-wire measurement transmitter. When it is powered, its current consumption changes between 4 and 20 mA, corresponding to the oxygen concentration it senses. The probe can measure both dissolved oxygen and oxygen in gas. It can be calibrated so that the 4–20 mA corresponds to a wide variety of measuring ranges by placing it in air (and it is then calibrated in relation to air temperature) or other calibration gas and adjusting the calibration trimmer until the current is correct. This model contains galvanic isolation circuitry, so that the measurement cannot be disturbed electrically by other measurements. The specific type D033M of the used model provides values of dissolved oxygen in mg/L. The appropriate range is correspondence of the 4–20 mA to the range of 0–20 mg/L for the environment, and to the range of 0–10 mg/L for waste water.

The concept was for the stations to be all stand alone, so that no wiring would be necessary, firstly because some locations are remote from any cable network (power or telephone line) and secondly because extreme flow conditions could damage cable connections. Consequently, each station (Fig. 4) is self-powered by solar energy, and communicates with the server via GSM 900 telephony. GPRS technology was also considered, but until today the existing GPRS networks in Greece are not reliable for data transfer, and fail the monitoring network requirements. VHF/UHF communication was also left out because of the distance between the stations.

For the purposes of the different functions of the network, customized software was developed by the providers of the equipment, according to the demands of the scientific team. More specifically, the server software was designed to be programmable by the user so that different data collection schedules and alarm levels can be set up. Although stations collect data every 10 min,

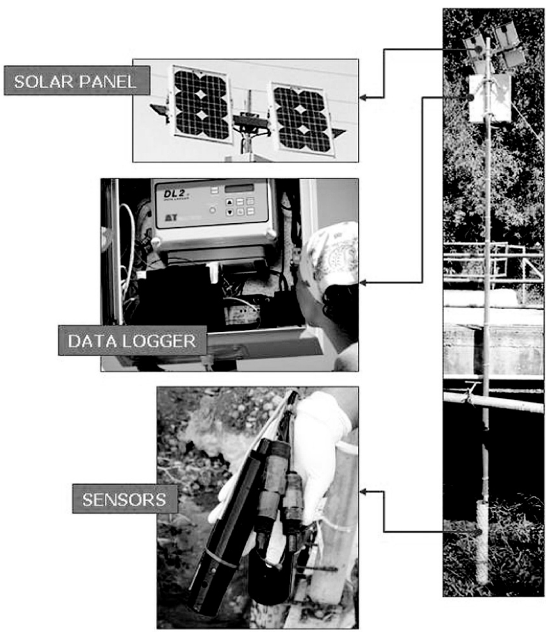

Fig. 4. The components of a typical monitoring station of the Evrotas River network (namely Station Riviotissa). The station is self-powered by solar energy provided by the solar panels (top). The set of sensors are protected within screens (bottom), and data are collected in the data logger, in the box where the GSM modem and battery are also secured (middle).

it is not affordable to keep them on-line in GSM lines, so, according to the surveillance level, different intervals of data collection by the server can be set up. The server, firstly stores data in ascii files and in daily, weekly, montly and yearly reports in the database, and at the same time it compares measurements to the predefined (or re-defined) acceptable limits set by the user. After that, it records all measurements or communication or functional errors in different files, and finally makes a call to a specific phone number, kept by the authorized user, so that he is aware that there have been alarm messages by the system (Fig. 5).

3. Dissolved oxygen measurements evaluation

Among a great number of water quality parameters [3,4], dissolved oxygen concentration and oxygen saturation is known to be a critical factor for the survival of organisms in the ecosystem. At the same time, oxygen provides an indirect indicator of possible eutrophication. Dissolved oxygen concentration is directly affected by the atmosphere temperature and pressure conditions. Moreover, the measurement depth should also be taken into account when it comes to absolutely accurate measurements.

Real-time monitoring provides us with an extremely useful capability, which cannot be obtained by any sampling program of any frequency. Monitoring of all daily and hourly variations of dissolved oxygen concentration is possible, replacing one unique measurement (even on a daily basis) with a series of measurements, regressing around a moving mean value. This form of time series permits the monitoring of the daily amplitude of oxygen values, which is now proved to be an extra indicator of the water quality status. This indicator is very characteristic when it is correlated with the variation of temperature. In this case, the graphical representation of oxygen fluctuation is “weighted” by the factor of temperature. The selection of the graphical

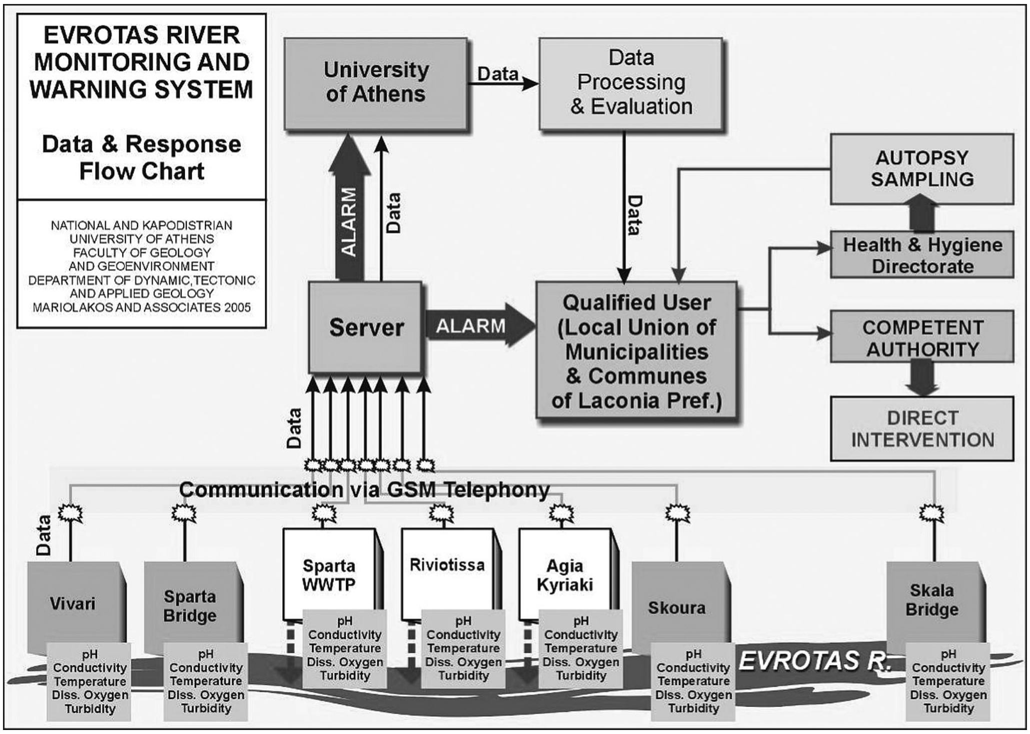

Fig. 5. Data and action flowchart of the Evrotas River monitoring network.

representation of dissolved oxygen values vs. temperature, regardless of time, was made on this basis. However, time (or, rather, season) is involved and revealed in the graphs, indirectly.

The results in these graphs were revealing, and the form of this kind of graph can be considered as representative of the river water quality, as far as oxygenation is concerned, and it also outlines a part of the natural processes that take place along the riverbed. As it is shown in the graphs in Figs. 6–12, the concentration of points representing the couples of oxygen–temperature measurements forms a different shape for each station, but similarities and differences among them are very distinctive. These characteristics can show at a glance the water quality status for each station for a large period of monitoring (in this case roughly 6 months), regarding oxygen.

The first basic observation can be made starting from the Stations Vivari and Sparta Bridge. These two stations meet the expected natural conditions in the river. The lower the temperatures, the higher the oxygen concentration, and

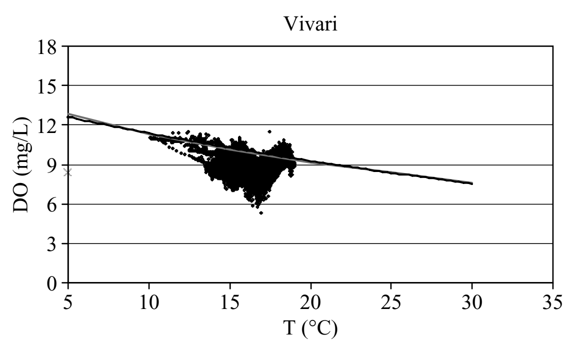

Fig. 6. Vivari measurements of DO vs. T (August 2004–January 2005).

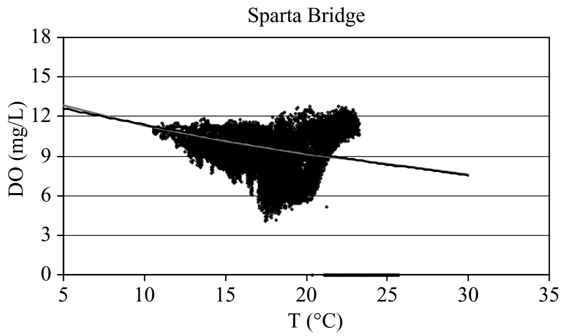

Fig. 7. Sparta Bridge measurements of DO vs. T (August 2004–January 2005).

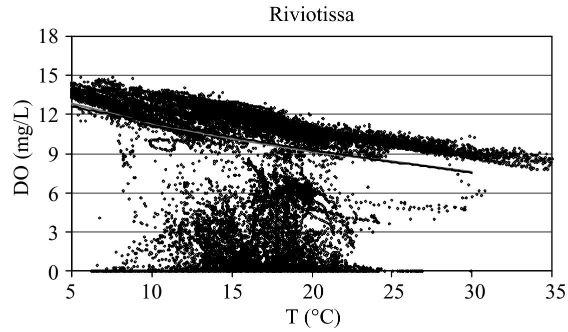

Fig. 9. Riviotissa measurements of DO vs. T (August 2004–January 2005).

the smaller the amplitude of deviation (and scattering of points) around the solubility curve (which is also represented in the graphs with a solid black line, referring to atmospheric pressure around 750 mmHg). The fluctuation of dissolved oxygen is controlled by the limits set by the minimum and maximum temperature of the day, combined to the biological metabolism during the 24 h. The fact that the points are gathering around and near the solubility curve shows high saturation. Thus, the form of the graph for "natural" conditions is a narrow inclined funnel, opening downwards to the right (to the higher temperatures).

Comparison between the graphs of Vivari and Sparta Bridge Stations shows the expected differences. In Sparta Bridge, the same funnel-like shape is present but the width is greater, that is, the daily fluctuation of oxygen in the summer has a larger amplitude, which is due to both temperature (higher water temperatures in Sparta Bridge) and biological activity. The latter is also expected because Vivari is located uphill and closer to the river springs, and affected less by nutrients derived from fertilizers, not to mention the fewer hours of direct sunlight influence, due to the morphology, in relation to Sparta Bridge. Apart from that, both stations show that the natural mechanism–process of oxygen fluctuation is not disturbed.

At the station located at the Sparta W.T.P. exit to the river, of course, the above conditions were

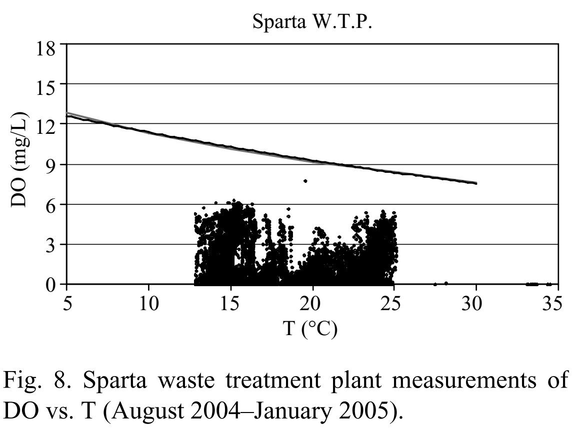

Fig. 8. Sparta waste treatment plant measurements of DO vs. T (August 2004–January 2005).

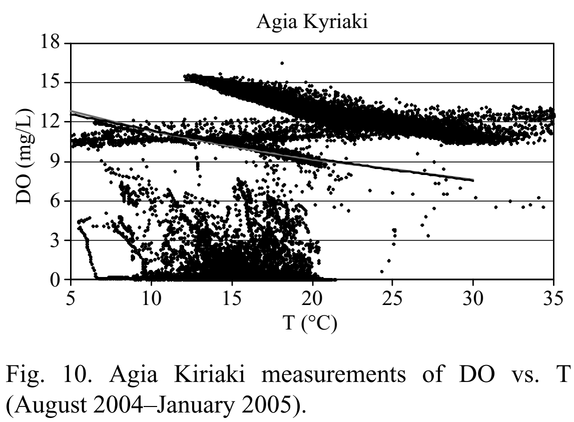

Fig. 10. Agia Kiriaki measurements of DO vs. T (August 2004–January 2005).

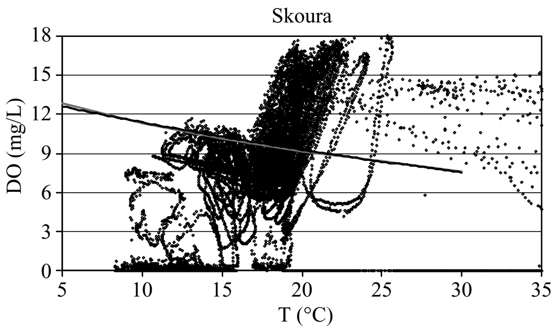

Fig. 11. Skoura measurements of DO vs. T (August 2004–January 2005).

not expected. Dissolved oxygen concentration here is not controlled by natural processes (except for the limits set by temperature, which are never reached) but by the function of the treatment plant, instead. The only observation that can be made is that oxygenation is very often below the desired standards [5], and great improvement could be made in the future.

The stations at Riviotissa and Agia Kyriaki are presented very differently from the previous ones but very similar to each other. Indeed, the two stations were expected to present similar conditions, since they are both located on streams of seasonal flow and, through large periods of time during the year, flow depends directly on the waste disposal of the two, respectively, adjacent industrial units. This hydrological mode is quite clearly presented on the oxygen–temperature graphs of these stations. More specifically, two similar concentrations of points are present in both diagrams. The first concentration is located above the solubility curve, and it is lengthened and parallel to it. The obvious explanation for this form is that these are the measurements made in the open air, that is, when the stream is dry. The second concentration shows a scattering of points, denser close to zero oxygen, which shows the flow of liquid waste in the streams, and less dense upwards, which rather refers to either less loaded waste load, or mixture of waste with natural stream flow (in winter and spring).

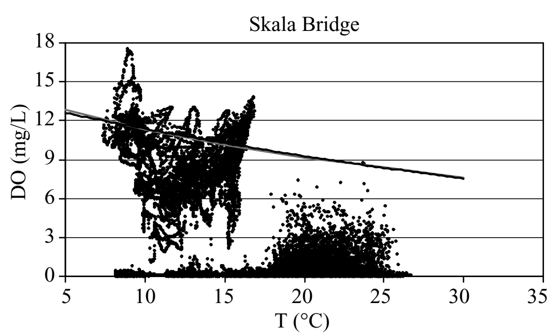

Fig. 12. Skala Bridge measurements of DO vs. T (August 2004–January 2005).

Skoura Station presents mixed characteristics in relation to the previous cases. The funnel-like shape tends to form again but, in this case, it is very disturbed. Above a certain temperature, the daily fluctuation of oxygen is too high (from anoxic conditions to high oversaturation), and it could be a strong indication of eutrophication conditions in the summer (low river flow and low water velocity). Moreover, there is a minor concentration of points near zero oxygen that represents unusual incidents of pollution.

Skala Bridge Station shows two very clearly distinctive modes, but in this case there are two concentrations of points representing the differential seasonal hydrological function of the river in that area. The funnel-like shape near the oxygen solubility curve is also present, responding to the wet period of the year, when there is a continuous surface flow in the river. The second concentration of points near zero oxygen responds to the dry period, when there is no continuous surface flow in the riverbed, and the (very low) flow at the station location is conserved by groundwater discharge at the nearby uphill area. These low oxygen measurements could be due to the very low flow velocity, but they could also be indicative of high organic load in the groundwater, deriving from the yearly recharge of the adjacent karstic aquifer by the river water, so further research is required for safe conclusions.

4. Warning based on dissolved oxygen daily evaluation

The frequency of measurements of this network (every 10 min) permits close monitoring of changes that could not be detected by sampling, even on a daily basis. All parameters are changing continuously and very quickly, since a river is a highly sensitive, open, dynamic system. Among the parameters that can be monitored automatically with this frequency, some show a natural daily periodical fluctuation, within certain limits. The most interesting among them is dissolved oxygen, due to its high sensitivity to organic pollution (which is a major problem in the area). This fluctuation is very vividly outlined with the certain frequency of measurements of the Evrotas monitoring network, and deviations from the "natural" condition limits are detected.

In the graphs of the Figs. 13 and 14, these fluctuations are shown for an indicative period of time, for the Stations Vivari and Riviotissa, respectively. These two stations are very representative for their kind (Vivari Station as a natural conditions reference station, and Riviotissa Station as a surveillance station, monitoring a certain area with known pollution sources). In Fig. 9, temperature and dissolved oxygen show a daily periodical fluctuation, reflecting the temperature and biological function. This smooth fluctuation around very good values is an obvious indication of the absence of severe environmental pressure.

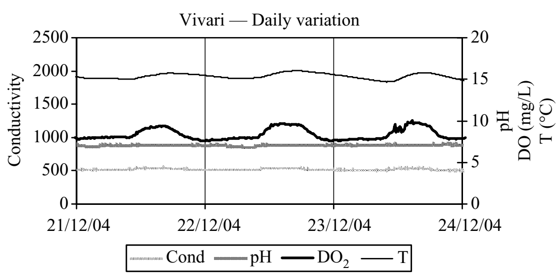

Fig. 13. Daily variation of parameters at Vivari Station (21/12/2004 to 24/12/2004).

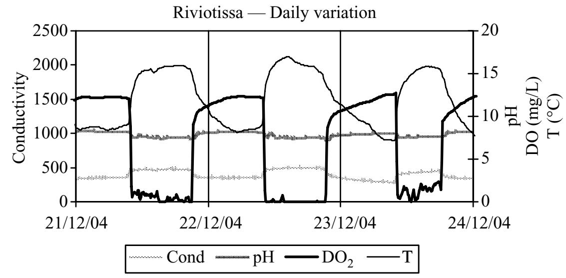

Fig. 14. Daily variation of parameters at Riviotissa Station (21/12/2004 to 24/12/2004).

On the contrary, the case of Riviotissa (Fig. 13) is representative showing very clearly the human-induced environmental pressure on an estuary contributing to the main riverbed. As it was noted before, the flow is seasonal in this stream, and for the most of the year it carries little or no water at all. In these periods, measurements show open-air conditions (high oxygen values, conductivity near zero values, relatively high-temperature fluctuation). The liquid waste disposal by the adjacent industry results in water flow in the stream in periods when there would be no flow under normal conditions. Once the industry operates in certain days and hours, the results in the time series are rather spectacular. More specifically, at the exact time when waste disposal in the stream begins, dissolved oxygen falls from the high values of open-air conditions to near zero values, and conductivity increases simultaneously, while pH and temperature are also clearly affected. The result, as shown in the graph, is a combination of curves with the form of "square pulse" (as in alternating electrical current graphs). This form shows exactly when polluted water enters the stream and it is one of the most reliable alarm "triggers" for the warning system.

5. Discussion

Although quality and accuracy of real-time monitoring equipment cannot be compared to laboratory analytical methods, such systems provide very useful and totally new tools of monitoring natural dynamic changes, as much as dramatic point or diffuse source pollution events, with very good focus on the timeline of such events. Site selection is critical to the success of the set up, not only because of the cost of the equipment, once funds are always limited, but also for the monitoring of both reference and disturbed conditions, as well as for the safety of the equipment in cases of extreme weather conditions, which, by the way, have been twice encountered in the prefecture of Laconia, in one season. Furthermore, depending on the local flow, pollution, flora and fauna conditions, servicing schedules should be programmed, so that the measurements are always kept within acceptable error limits. Specifically for the network of Evrotas River, it has been concluded that sensors should be cleaned once a month, and pH and dissolved oxygen sensors should be calibrated at least every 2 months. Especially, pH measurements have presented drifting after 2 months operation without calibration. In cases that organic load is heavy, membranes of oxygen sensors should be changed roughly twice a year, but the solution should be replaced more often. Unfortunately, the use of turbidity sensors, which were considered very useful in the first place, did not provide any dependable results, and under the circumstances, turbidity measurements are not being taken into consideration.

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