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INTEGRATED RIVER QUALITY MANAGEMENT USING INTERNET TECHNOLOGIES

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ABSTRACT

Monitoring and control of river water quality is approached as a distributed processing problem and the solution which is presented here shows how such a computing architecture can be implemented using current internet technologies. Based on the "intelligent agents" approach, the system includes several processing parts which can be deployed along the basin and constitute a distributed information system. In addition to a user-friendly graphical interface for developing the required configuration, the system can have different features for different type of users depending on their functions in the administration of the river system and the controlled discharges (wastewater treatment plants, water purification, dikes, etc.). The interaction with the system is through a normal web browser.

KEYWORDS

River water quality, Environmental management, Internet computing, Systems analysis, Wastewater treatment plant

INTRODUCTION

When river water quality begun to concern legislators, under the pressure of the general public, discharge management became a regulatory issue. This was first approached in the simplest possible way, and the only practical one given the technology of the time (the 70's) - at least in Italy - was to impose single discharge constraints. In this way the global impact on the river system could not be appreciated, let alone controlled. Other european nations (e.g. the U.K.) adopted more far-reaching strategies, in which some degree of co-ordination among discharges was envisaged. The superiority of the later solution in terms of river quality was clear, and was even demonstrated that it could lead to economic advantages in the allocation and sizing of wastewater treatment plants (Marsili-Libelli, 1982). Now the co-ordinated approach is undisputed at a regulatory level, in particular a new act of the italian parliament (Law 152/1999, following european directive n. 271/1991) imposes river stream - rather than discharge - standards, relying on the existing technology to provide the practical means for its implementation. The new approach requires, in addition to a fairly large set of sensors along the river, the availability of an integrated information system though which all the different authorities can co-operate, each within its own regulatory domain over the river basin. This is not a simple problem and the implication of co-ordinated discharge policies were analysed by Aalderink *et al*, 1999. Each manager requires its own system "view" with customised privileges and access to differing control tools, either managerial or operational, as in the case of wastewater treatment plant control (Ødegaard, 1993; Briggs, 1998). The solution which is envisaged in this paper is based on a new internet-based information system where models and control modules can be shared among several users according to their prerogatives in the river management role. It will be shown how this information system is organised in order to cater for the needs of all the possible management levels involved in the process, and how the combined use of internet technology and mathematical models has produces such an operational tool.

SYSTEM STRUCTURE

The general structure of the information system is shown in Fig. 1, which also shows the important elements of the river system: the river reaches, the wastewater treatment plants (WWTP) discharging into the river, and the water quality monitoring stations (MS). The main constituents of the information systems are dedicated databases for both WWTP's and MS's (Information Repositories) and a number of operational engines which will be described later. These can communicate via Internet links with a service centre where the supervisory system operates. This contains the knowledge base, the water quality models and the control policies. Each component does not need to be resident in the same computer, but can be deployed anywhere in the network, depending on system requirement.

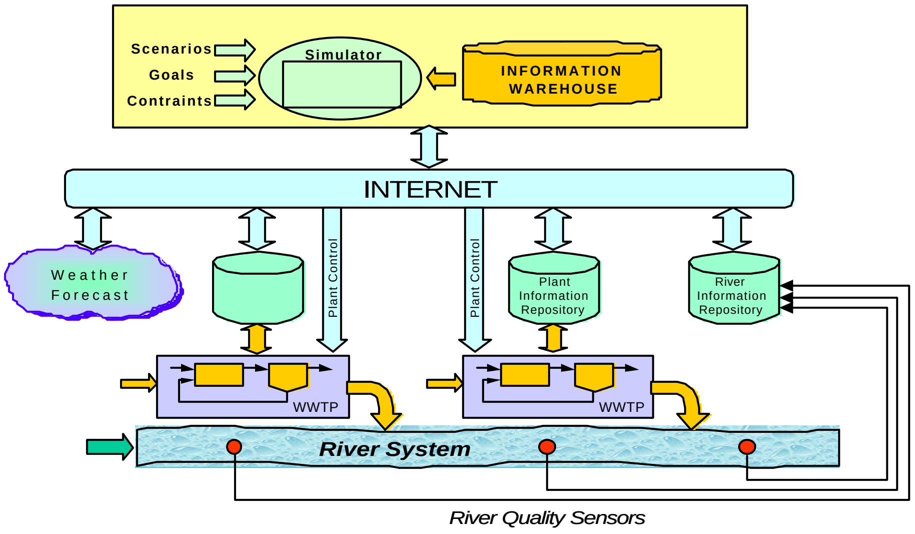

Fig. 1 - Structure of the river management system.

The system module communicate through the normal Internet protocol TCP/IP, since there is no need to guarantee "hard real-time" constraints and the variable latency inherent in the TCP/IP protocol does not represent a problem in this context.

Hardware configuration

The system hardware architecture is shown in Fig. 2. Each user, following in one of the three typical frames described below, can access the system through a browser, as in a plain internet connection. The user front-end is represented by the Application Server (AS), which makes the network services available and generates the HTML pages. The core of the system is represented by the combination of the Data Object Servers (DOS) and the Intelligence Servers (IS). The DOS system manages the objects and the classes required for communicating with the relational databases, whereas the IS implements the services behind the AS through the agents, which are configured and deployed along the network from this environment. It also supervises sorting algorithms for the correct interpretation and execution of block diagrams and generates run-time code for simulation and management. The typical user can access the system via a normal web browser, shown on the left-hand-side, whereas the system manager defines and maintains the system services through the dedicated access termed "workbench". On the right-hand-side there are some of the typical end-of-line objects which are supervised by the systems, such as databases and field devices for real-time control of peripherals such as aeration equipment, sludge recycle, carbon dosing, etc. The various system components need not to be located in the same computer, but can reside on different machines, which communicate via a TCP/IP protocol. This is accomplished by agents, which operate on libraries of models and procedures, and associate models with machine IP addresses.

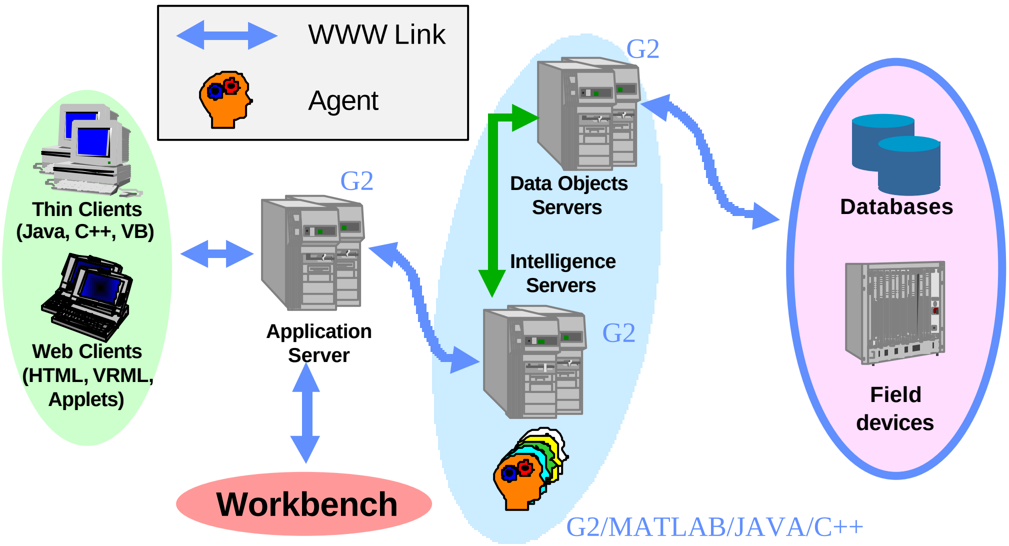

Fig. 2 - System architecture.

Thus, the innovative feature of this architecture is the use of *agents*, which can be described as self-contained software modules specialised in pursuing a set of goals by autonomously performing tasks on behalf of users or other programs. These tasks involve perceiving, reasoning and modifying the dynamic environment into which they operate. (Norvig and Russell, 1995; Bertsekas and Tsitsiklis, 1996). Figure 3 explains how the agents are deployed in the system, depending on the task which they are assigned to. Starting with a graphic interface where the problem is defined - in that example it includes a WWTP plus a river reach - the *data-flow manager* decomposes the block diagram representing the model and interprets the underlying functions. It then deploys appropriate agents along the system to perform these tasks. For example, if the user requires a simulation of the system diagram, the integration function will be supervised by an “ODE solver” agent which manages the integration of the model differential equations, after this has been decomposed into a collection of specialised agents implementing its components, e.g. river reach water quality, WWTP oxidation tank, WWTP settler, and so on.

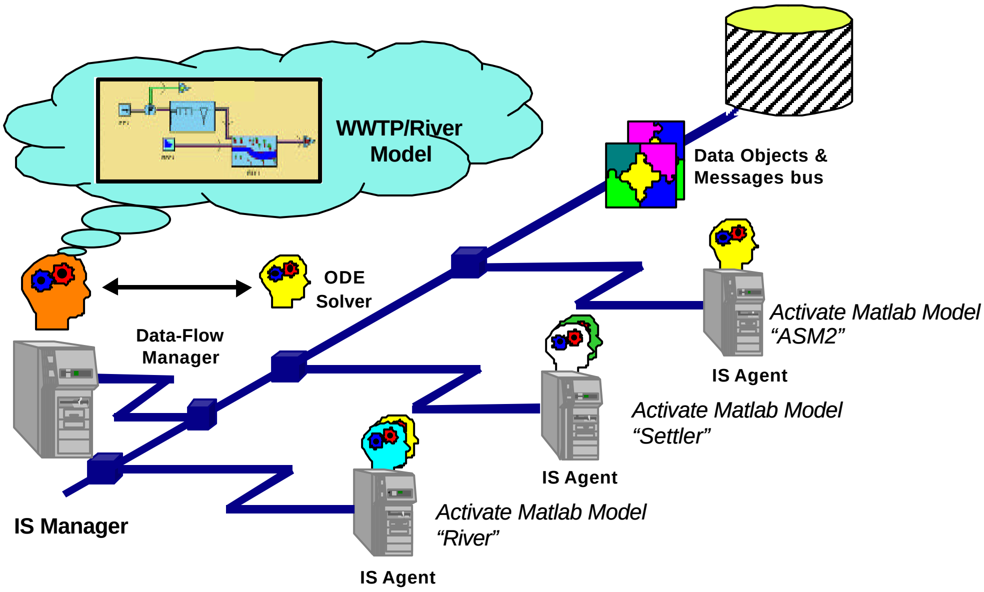

Fig. 3 - Deployment of agents along the system to process an assigned block diagram.

Several programming environments were involved in the development of the system. The core of the project is provided by G2 (GenSym Corp.), implementing the basic functions for block diagram definition and object-oriented programming. However, being an interpreter-based language, it lacks the required speed to perform such a complex task in real-time. Therefore, the model libraries, which will be described in the next section, were first developed in Matlab, then translated in C++ and compiled as DLL. The agents were developed in the Java programming environment to produce modular applets which could be easily deployed along the system, as required by the IS manager.

System functions

The network tasks are performed by agents, which provide the following services:

- ***Data warehousing.*** Normalised data acquisition from the peripheral sources according to the following protocol:
  - Functionality check on all sensors
  - Data acquisition and filtering
  - Definition of synthetic data
  - Data processing and storing in the relevant databases
- ***Data mining.*** It consists of knowledge-based data sorting through:
  - Data-oriented filtering
  - Model identification for data reconstruction
  - Model-based software sensors for data enhancing
- ***Configuration utilities.*** Defines the agents' behaviour according to the following procedures:
  - Model configuration
  - Parameter calibration
  - Configuration of scenarios, identification of control and disturbance variables
- ***Simulation service.*** Management of models, initial and boundary conditions, control policies. It defines the management policies for prediction, validation and system training through:
  - Open- and closed-loop simulation
  - Database updating with simulation output.
- ***On-WEB Reporting.*** The system output can be inspected through a normal web browser according to the following rules: each user can browse the resources which is entitled to access, including available data and simulation results. The system generates HTML pages with the results of the query.
- ***Remote control service.*** The system units can be remotely monitored through report generation containing the history of each component. Users with enough access privileges can also override current control actions and set control variables.

Three kind of users can be envisaged:

- ***Environmental Manager,*** typically an expert in environmental management, has access to both the river basin and the WWTP's. He can view the data coming from the field and stored in the information repository, launch and analyse simulations, take operating decision regarding the WWTP through communication with System Administrator and Environmental Engineer. Therefore he can use the following system functions: *Data-warehousing, Simulation, On Web Reporting*
- ***System Administrator,*** is typically an information technology expert and connects to the systems via a special web browser (*workbench* in Fig. 2). His task is river sensor management, including data acquisition and filtering, data mining supervision on the databases, simulation scenarios definition. He is also responsible for scheduling simulation tasks. Interacts with the Environmental Engineer making available, upon his request, scenarios, simulations, data. He uses the following system functions: *Data warehousing, Data-Mining, Simulation, On-Web Reporting*
- ***Environmental Engineer,*** is an expert in environmental systems, and river quality in particular. He is the person in charge for constructing, validating and maintaining mathematical models in the system. His

responsibility is also to define control policies and run simulations and perform web management of WWTP. He use the following system functions: *Data warehousing, Data-Mining, Simulation, On-Web Reporting, Remote On Web Management.*

SYSTEMS COMPONENTS

As already described in the previous section, G2 provides a knowledge-based core system and a graphical interface where models can be defined and assembled using a components palette whose basic elements have been defined. They include the main components of a typical WWTP (anoxic tank, oxidation tank, settler) plus a number of ancillary functions, such as measuring points (flow, temperature, pH, Dissolved Oxygen, etc.) and actuators (pumps, aerators, etc.). The basic kinetics of the Activated Sludge Models ASM2 (Henze et al., 1995) were all implemented starting from a Matlab model, then translated in C++ and compiled as a Dynamically Linked Library (DLL). A service function that had to be developed is an interface between input water quality files, which normally involve less variables (e.g. COD, particulate matter, ammonia, etc) with the detailed wastewater characterisation required by the ASM2 model, using a larger number of variables. The standard partition suggested in the original model formulation (Henze et al., 1995) was used. The integration methods were also implemented as independent C++ codes and then compared to the standard Matlab routines for numerical accuracy. Computational experiments showed that the two numerical engines (Matlab and the proprietary modules) performed exactly in the same way to eight decimal places. As to the settler, two models were implemented: the Takacs model (Takacs et al., 1991) and a simpler model based on solid flux theory (Marsili-Libelli, 1993). A river model was also implemented, based on the well-known kinetics of the QUAL2E model (Brown and Barnwell, 1987), but also the contribution of Tchobanoglous and Schroeder (1985), Thomann and Mueller (1987), and Chapra (1997) were included. An interface had to be provided between the ASM2-based WWTP models and the QUAL2E-based river model since these two models do not use the same variables. Therefore the correspondence of Table 1 was set up to convert the ASM2 output into variable usable by the river model. It should be noted that for the autotrophic masses of Nitrosomonas X_{NS} and Nitrobacter X_{NB}, two factors (α and β) were introduced to determine their organic carbon and nitrogen content, as a contribution to particulate BOD and organic nitrogen respectively.

Table 1
Conversion of variables between WWTP and river models.

ASM2	River quality model	Meaning and units
S_f, S_a	BOD_d	Dissolved BOD (mg O/l)
$X_s, X_H, X_{PHA}, \mathbf{a}X_{NS}, \mathbf{a}X_{NB}$	BOD_p	Particulate BOD (mg O/l) α fraction
S_i, X_i	BOD_s	Slowly Degradable BOD (mg O/l)
S_{O_2}	S_{O_2}	Dissolved Oxygen (mg O/l)
$X_i, X_S, X_H, X_{PAO}, \mathbf{b}X_{NS}, \mathbf{b}X_{NB}$	N_{org}	Organic Nitrogen (mg N/l) β fraction
S_{NH4}	N_{NH_4}	Ammonium-Nitrogen (mg N/l)
S_{NO_3}, S_{NO_2}	N_{NO3}	Nitrate- Nitrogen (mg N/l)
$S_{PO_4}, X_{PAO}, X_{PP}$	P	Total phosphorus (mg P/l)

Figure 4 shows the block implementation of a simple example including a river reach with an upstream discharge from a WWTP. The box in the upper right corner represents an exploded view of the WWTP model, showing its internal structure: an anoxic tank, an aerobic tank, a secondary settler, plus a flow meter, a recycle pump and a WWTP/river interface, according to Table 1. The system should also specify time series to perform the simulation: *WWTP input* and *Upstream river quality* represent synthetic time-series which are used as model inputs. During normal operation, these data can be drawn either from field sensors or from the databases connected to the system.

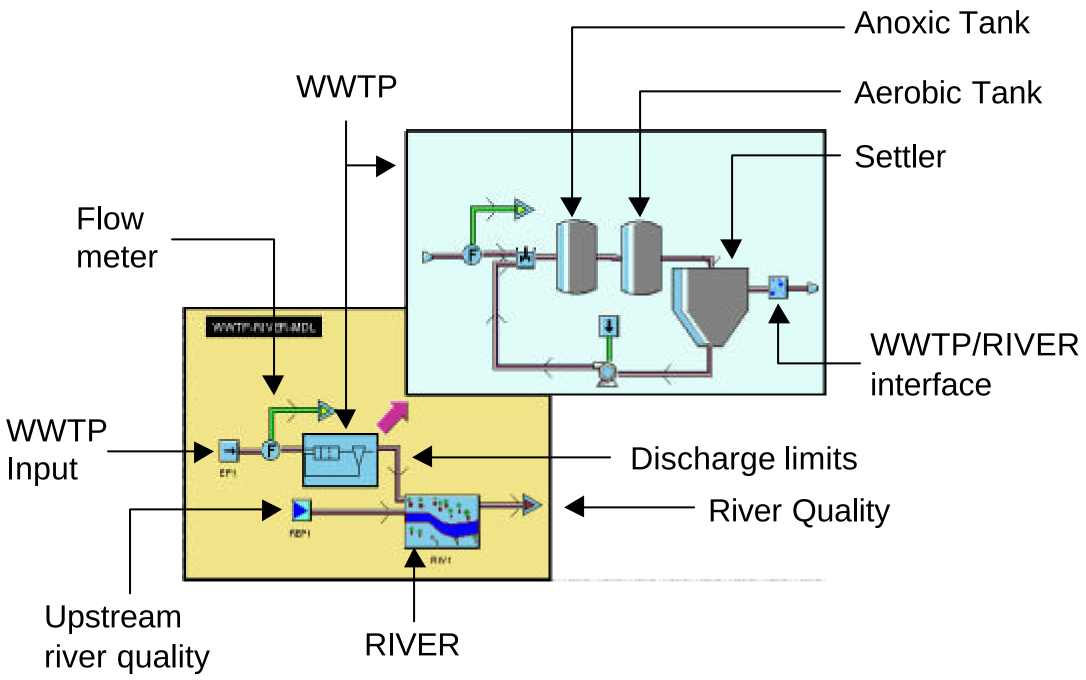

Fig. 4 - A block diagram representation of a river reach with an upstream WWTP.

Figure 4 also shows where the monitoring probes can be placed in the diagram. In fact the manager may want to look at the WWTP output to check its discharge compliance, as well as the downstream water quality. Furthermore, the modular framework in which the system operates, together with the model libraries, make it possible to construct a very complex diagram just connecting elementary blocks through the appropriate connectors. After the block diagram is specified, the sorting algorithm, administered by the appropriate agent, aggregates the state vectors of each dynamic block to form the augmented state vector, which is then passed to the ODE Solver agent for numerical integration. Figure 5 shows this process, together with the programming environments used to implement the process: the Javalink performs the parsing process of the block diagram, which is then routed to the Java-based agents acting on a library of C++ compiled models.

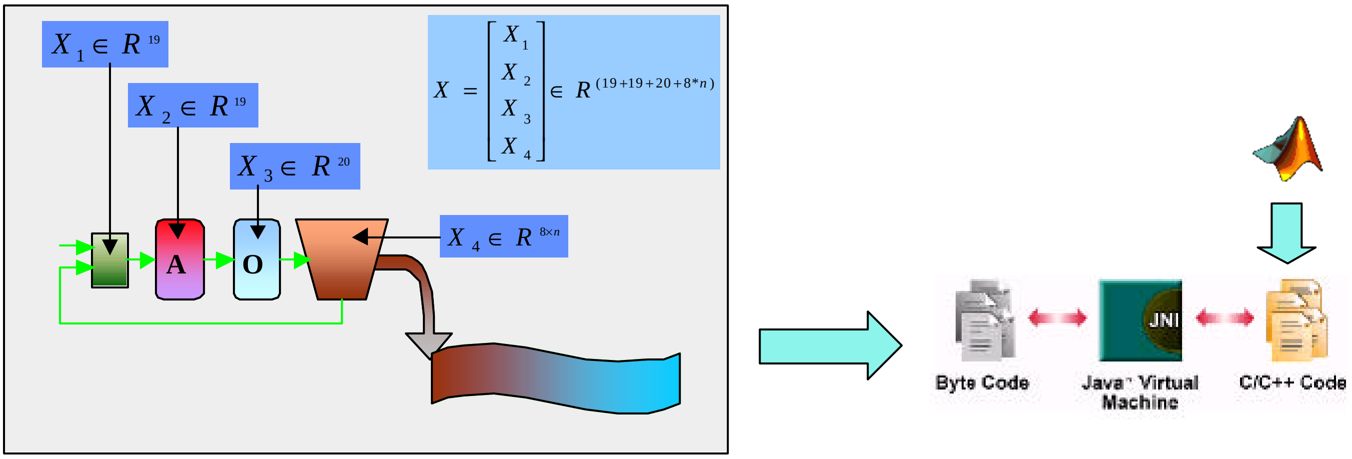

Fig. 5 - Block diagram processing.

Figure 6 shows a sample simulation run of the block diagram of Fig. 4. The time series on the left-hand-side represents the upstream water quality after mixing with the WWTP discharge. The effect on the river reach is shown on the right-hand-side of the figure in a joint time-space plot. The initial profile along the reach is shown on the right-hand-side edge and the time series is replicated on the left-hand-side edge. From this picture the Environmental Manager can assess the impact of the WWTP on the downstream river reach.

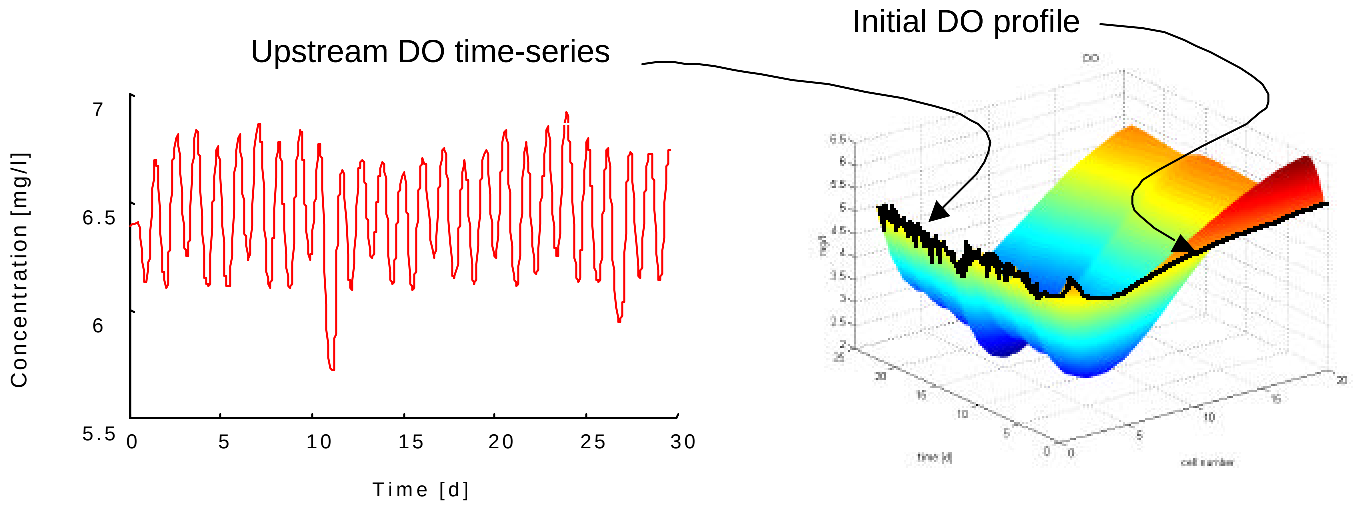

Fig. 6 - Joint time-space simulation of the block diagram of Fig. 4, from which the reach river quality can be assessed.

The typical user can access the system through a web browser and the results are presented as automatically generated HTML pages. In the example of Fig. 7, the BOD along the river reach is shown, with two planes defining two different water quality grades. In this way the user has an immediate visual appreciation of the situation.

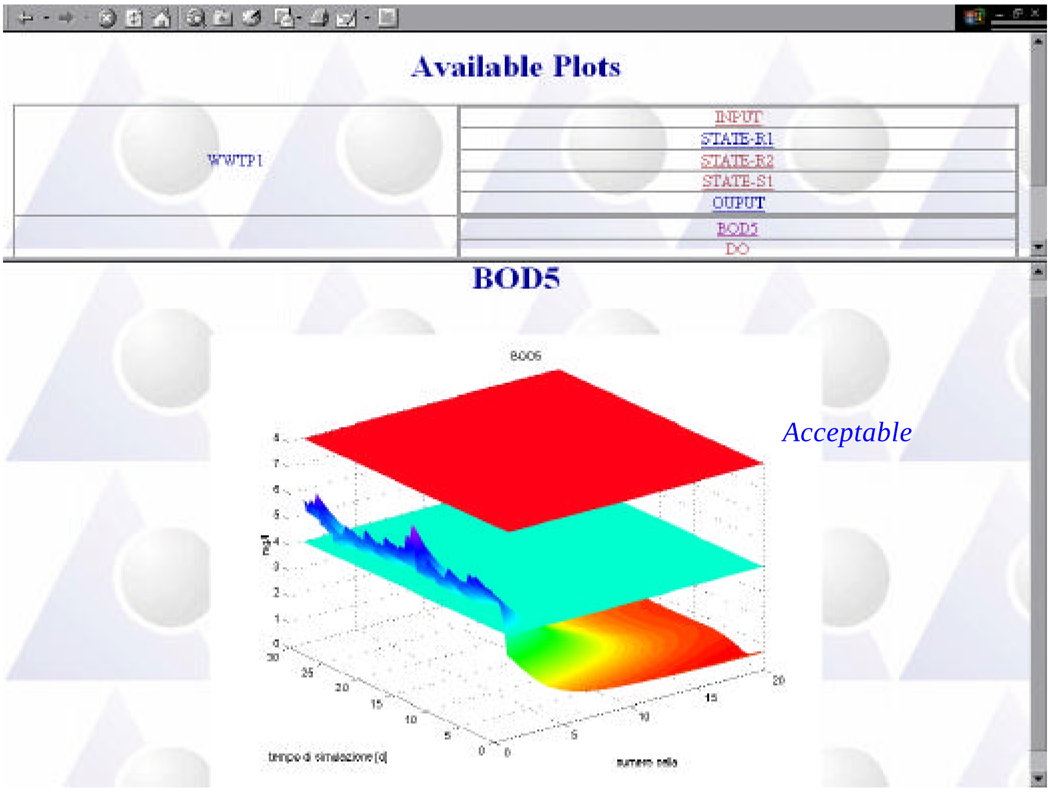

Fig. 7 - A sample Web page generated by the system, together with water quality indicators (horizontal planes). In this case the central figure shown one simulation response (Dissolved Oxygen), whereas the upper table shows the system blocks which can be queried by the user.

CONCLUSION

River quality monitoring and control is definitely a distributed control problem and the solution proposed in this paper falls within this philosophy. The proposed system provides a distributed architecture, since the various tasks are partitioned among many processor which can be hosted by more than one computer. The system functions are performed by agents, specialised software modules which can migrate over the network and activate the tasks which they are designed for. The system is conceived to operate as a comprehensive water quality management tool, with tasks ranging from database management to system modelling and control design, in order to provide a full decision support system. Differing kinds of users can access the system, and the resources available to each of them depend on their role in the river basin management organisation. The graphical user interface assists in defining the system structure, depending on the application, and the agent-based structure decomposes, interprets and executes the resulting commands. Each user can access the system through a normal internet browser and receive in return automatically generated HTML pages with the graphical representation of data and/or simulation that were requested.

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