RIVER WATER QUALITY MODEL VERIFICATION THROUGH A GIS BASED SOFTWARE

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Abstract: Research and development attempts on water quality models created valuable resources in the sense of model calibration and verification techniques. Recognizing the current degree of pollution in rivers and the importance of the sustainable water resources management, the interactive river monitoring appears to be at the center of recent focus. However the available information in this area is still far from expectations. On one side, the Geographical Information Systems (GIS) are gaining widespread acceptance and on the other side fast and reliable water quality models and parameter estimation techniques are becoming available. However, previous work on integrating water quality models and GIS is very limited. This work brings an integrated platform on which ArcMap as a GIS and a water quality model in Matlab^{TM} are brought together in an interactive and user-friendly manner. The software developed allows the user to enter the data collected from the river, runs the dynamic model in the Matlab^{TM} environment, predicts the values of pollution constituents along the river, extracts the results and displays the water quality on the map in different forms. The software thus provides a considerable ease in future real time application for on site river monitoring and environmental pollution assessment.

Keywords: water quality modeling, GIS, GUI, water management, systems analysis.

1. INTRODUCTION

Water pollution is gradually becoming one of major threats for aquatic as well as human life. In order to assess the impact of wastewater discharges into the surface waters, mathematical models are of great importance. Over the past there have been considerable developments in the area of water quality modeling for rivers. A summary can be found in the review by Rauch *et al.* (1998) who gave the then state of the art in river water quality modeling. The most widely used model in the world is pronounced to be QUAL2E, which was developed by US Environmental Protection Agency (EPA), and known as almost the standard for river water quality modeling (Shanahan *et al.* 1998). In addition; WASP, SALMANQ and SIMCAT are probably the ones that have been frequently referred to in the literature. The water quality models can be classified from many perspectives, ranging from model complexity to the simulation method employed, and the number and type of water quality indicators incorporated. Just to give an idea, Cox (2003), for example, selected 6 models in conceptualization and solution for detailed comparison. Three of them were steady state and the rest was of dynamic character. Cox (2003) noted that water quality modeling was an active area of research around the world, and underlined that only few papers referred to specific models with majority of the papers reporting applications with QUAL2E.

In the authors' research group, a dynamic modeling strategy based on QUAL2E and coupled with a parameter estimation technique was introduced by Karadurmus and Berber (2004). The suggested strategy assumed that river reach could be modeled as a single CSTR. The model predicted and compared to the field data for 10 quality constituents observed; except those for the total coliform, total chloride and BOD_5, good agreement was obtained. Later a user-interactive software code in Matlab^{TM} (The MathWorks Inc., USA) named as RSDS (River Stream Dynamics and Simulation) for the implementation of the suggested technique was presented, and the model predictions were compared against experimental data collected in field observations along the Yesilirmak river basin in Turkey and predictions from QUAL2E (Yuceer *et al.* 2007). In a following work, a water reach was represented by a series of CSTRs rather than a single one. Taking the trade-off between the computing load and the prediction accuracy into account, the number of CSTRs to be used to represent a river section was determined. Then, for simulating a 500 m long reach of the river between the two sampling stations, 20 CSTRs were used (Berber *et al.* 2009). Furthermore, this work included a parameter identification study.

Despite the progress that has been observed in the field of modeling, only few reports are available in the current literature on integrated software development for river water quality monitoring. It is seen that the recent efforts are now concentrating on the incorporation of a geographical information system to water quality models. Within this framework, Marsili–Libelli *et al.* (2001) described the interfacing of a Matlab^{TM} based quality model to a popular geographical information system ArcView^{TM} (ESRI Inc., USA) by a communication protocol through which data could be exchanged between the two platforms. The same research group later provided a new software package developed entirely in the Matlab^{TM} platform based on the Mapping Toolbox^{TM} and reported enhanced interactivity and portability. The features of the program are illustrated through a case study (Marsili–Libelli *et al.* 2002).

From the perspective of using web-based technologies for remote monitoring, Cianchi *et al.* (2000) used internet technologies to follow water quality with river quality sensors. Data from sensor signals were transmitted to information warehouse by internet. In a more recent work, web based Geological Information System was used to visualize and assess water quality over the web for end user with minimum knowledge and computing experience (Ganapathy and Ernest, 2004). The spatial 'Decision Support System' developed for their study focused on the lower Rio Grand river basin.

The use of Geographical Information System (GIS) computing platforms, as they represent a process for looking at geographic patterns in data and provide nice display options, has been increasing. GIS incorporates computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. This rapidly growing technological field brings graphical features with tabular data in order to assess real-world problems. The opportunities that GIS systems provide may range from simple applications where one layer data display and analysis is done on a digital map, to more complex cases that mimic the real world by combining many data layers (Mitchell, 1999). Distributions of nitrate, nitrite and ammonium at various monitoring sites across the Humber basin were examined by Davies and Neal (2004) within a GIS framework. Empirical relationships between land characteristics and water quality for the whole catchment draining to each water quality monitoring site were established. The main water quality data source was the Land Ocean Interaction Study dataset. The land characteristics were classfied as lowland arable, urban, upland and coniferous woodland. The relationship between water quality and the catchment characteristics were assessed using linear regression. The study has proved success in showing the broad patterns across the region based on regression analysis of environmental measurements on the nitrogen species and simple land characteristics. (Davies and Neal, 2004). In a particular work by Ruelland *et al.* (2007) the Riverstrahler model that describes the biological functioning of an entire river system was coupled to a GIS interface to make the model entirely generic to be run on any river system for which a suitable database was available. They examined the effect of increasing the spatial resolution of the drainage network representation on the performance of the Riverstrahler model.

In this study we have developed an interactive GIS based software for water quality monitoring in rivers. The water quality model that has been previously developed in our research group was used for simulation and prediction. The software created has been tested with off-line water quality data gathered from a 36.5 km long section of Yesilirmak river in the central northern region of Turkey.

2. GIS PLATFORM INTEGRATING A WATER QUALITY MODEL IN MATLAB

A software has been created in this work to analyze the river water quality data in GIS platform. The program, called RSDS-C, and particularly designed to simulate Yesilirmak river in the central northern part of Turkey, allows user interaction and visual effects so that the predictions for pollution constituents can be represented on a digital map of the river. The River Stream Dynamic Simulation (RSDS) software previously developed in Matlab^{TM} in our research group (Yuceer *et al.* 2007) was used as the water quality model, and was incorporated into the GIS platform ArcMap^{TM} 9.1.

One critical point in combining a Matlab model with a GIS system is integrating the geographical data (which come from digital maps of GIS) with river pollution variables that are handled in Matlab. Data exchange between these two platforms requires that the graphical indications used to represent the geographical object in GIS be adapted to the data structure in the model embodied in Matlab. We used the data transfer strategy depicted in Fig. 1, which shows that the ASCII formatted text files were the medium of transfer between GIS (ArcMap^{TM}) and Matlab^{TM}. As ArcMap^{TM} employs database files for displaying the digital maps, Microsoft Access^{TM} was employed as the database-handling platform.

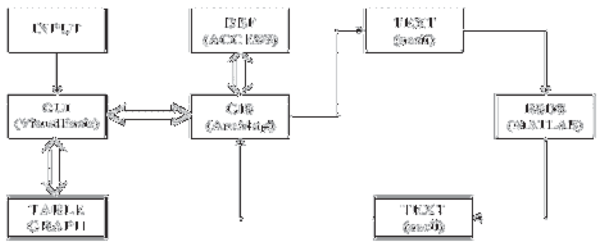

Fig. 1. ASCII file transfer strategy between different computing platforms.

A special graphical user interface (GUI) was designed for data input related to the river. The input comprise initial conditions for simulation, parameters related to integration of differential equations, flow characteristics of the river, or real measured data that has been observed at a particular location along the river (particularly when a parameter estimation study is intended). The GUI allows the user to interactively enter the observed quality of the river, which may be used as the initial conditions at the beginning of simulations, or as the experimental value for the embedded simulation algorithm in case if parameter identification is to be performed. As for the water quality constituents, we use 11 variables comprising dissolved oxygen, carbonaceous BOD, four nitrogen forms (organic, ammonia, nitrite, and nitrate), two phosphorus forms (organic and dissolved), coliforms, nonconservative constituent chloride and phytoplanktonic algae. Those are the state variables of the embedded rigorous water quality model (Yuceer *et al.* 2007). The entered data also include variables related to the physical conditions in the river such as flow rate, temperature, cross-sectional area; and numerical parameters pertaining to the simulation (integration time, step size, method, etc.). The data was combined with the GIS system and transferred to Matlab^{TM} platform for simulation. The simulations run on the Matlab platform determine the predictions of water quality along the river. Simulation results are relayed back to the GIS platform, and combined with the geographical data for display and analysis. The GUI was coded in Visual Basic^{TM}. The software allows the ArcMap and Access package programs to run interactively. This was accomplished through interlinking the ArcMap with Access (mdb) files, thus the data can be handled interactively. All graphics and tables were created from 'mdb' files.

In the previous work reported by Marsili–Libelli *et al.* (2002) data was transferred between the platforms by special 'avenue' script. This was appropriate in their case because the GIS platform that they used, ArcView (ESRI, 1996a), has a procedural language called Avenue (ESRI, 1996b) to define "scripts" that can implement the dynamic data exchange (DDE) procedure. However, the ArcMap^{TM} 9.1 used here reads 'txt' files, so the data conveyed in ASCII format from Matlab are known. This data is then converted into dimensional variables in Visual Basic to be represented in tabulated form. For this procedure, the following SQL statements were used. These database connection statements make the data such that it can be viewed in graphs and tables, and also be used for color coding of the river information in GIS system.

```
Set m_pAdoCon = New ADODB.Connection
        m_pAdoCon.Open
"Provider=Microsoft.Jet.OLEDB.4.0; Data
            Source=C:\...\....mdb;Persist Security Info=False"
        Set pRecset = New ADODB.RecordSet
```

First of these statements opens database connections, second shows 'mdb' file path, name and table; and the third one starts the actual connection procedure. With these SQL statements, data become interconnected to ArcMap tables.

All windows and menus of the GUI, which are illustrated in the following figures, were designed in Visual Basic editor of ArcMap. The opening menu of the program is depicted in Fig. 2 together with the input sheet for entering initial water quality conditions. The table on the left hand side of the window lists the water quality variables that can be monitored on the screen. Prior to any run for simulation and prediction, the user is expected to enter the initial water quality conditions at starting point of working area where the simulation will begin. If there is a point source to the river, it can also be taken into account and respective values can be entered via additional input sheets that will open.

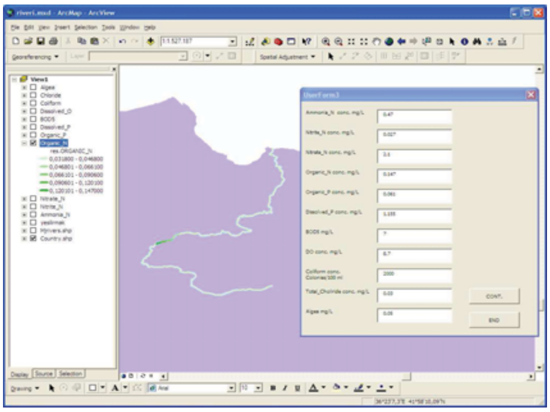

Fig. 2. View of the opening menu of the software (with the map of Yesilirmak river indicating the study area, and user input sheet).

Once the simulation is run, the user can select any variable from the list, shown in left hand side of the menu, to be displayed in table or graphical form.

The working area was divided into 100 parts of equal length to illustrate water quality variables, and thus the user can follow the concentration of the selected quality variable in different color at desired locations on map. The geographical point where the variables are sought is selected by the movement of the mouse along the river displayed on map. It then becomes possible to follow the water quality in terms of the selected pollutants along the river. For example, Fig. 3 depicts the change in the ammonia nitrogen concentration following a point source. With this feature, the simulation results are linked to the GIS database, and thus the user can easily follow the spatial distribution of the major constituents of river water quality. It is also possible to display more than one quality variable in graphical or table form at any location indicated.

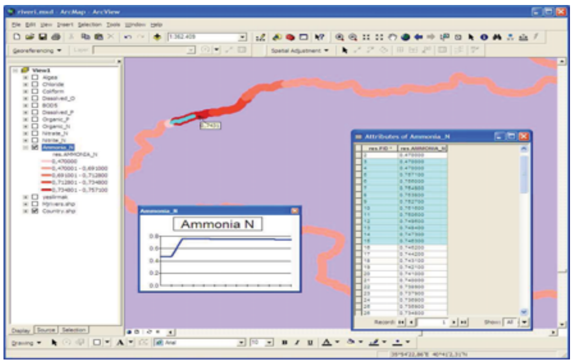

Fig. 3. Water quality display in table and graph form on the map.

In Fig. 3 the list on the left hand side shows the water quality variables considered. The user can select a location on the river map by moving the mouse, and if it is a point on the river the data table associated with this particular location opens on the screen. On the other hand, if the user scans a region along the river, the software allows the user to see the changes in the concentration of the selected quality variables along this site by different colors. The color intensity on the map changes from light to dark with increased concentration, and this feature makes keeping track of water quality very easy. The user can select the concentration range (maximum and minimum values) and the number of intervals between. The color codes corresponding to those selected concentrations may be also determined by the user. If no choice has been made, the software picks up the maximum and minimum concentration values encountered in the simulations, and allocates five intermediate color codes (as default) to 5 intermediate values between the maximum and minimum. This feature of the GUI is illustrated in Fig. 4. It is also possible to see the changes in concentration in graphical form.

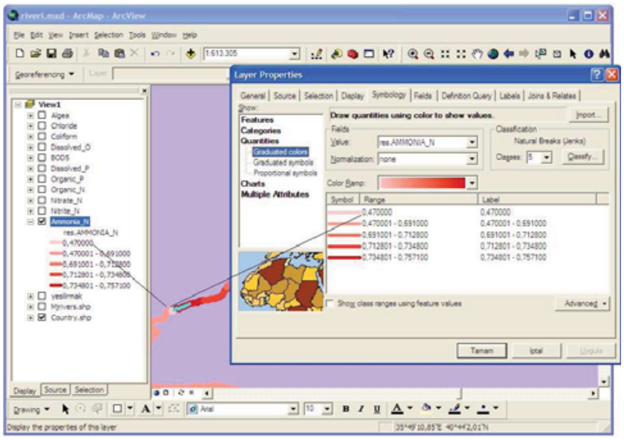

Fig. 4. Selection of color codes between maximum and minimum concentration intervals.

3. TESTING ON YESILIRMAK RIVER IN TURKEY

The software developed was tested with off line data collected from field studies around the city of Amasya along Yesilirmak river in Turkey. Yesilirmak is one of the major rivers in Turkey with 519 km length, and a basin of 36114 km^2 comprising 4.63 % of the territorial area of Turkey. Fig. 5 shows the study area on the river map. Pollution level in Yesilirmak affects the agricultural and rural development directly by distorting the ecological balance. The basin is a predominantly rural area and suffers from quite high level of pollution, in particular from agriculture, urban and industrial sources. Water quality in the river is classified in III and IV level according to the Water Pollution Control Act of Turkey, when physical, chemical, organic and bacteriological parameters are considered. An interactive river management decision support system for the region in order to protect the river from pollution becomes important for sustainable development in the future. Therefore, Yesilirmak was chosen as the study area, where our previous studies had also been concentrated.

The concentrations of ten water-quality constituents indicative of the level of pollution in the river were determined either on-site by portable analysis systems or in laboratory after careful conservation of the samples. For determination of dissolved oxygen, YSI Model 51/B portable oxygen meter in compliance with the Turkish Standard-TS 5677 were used. Nitrite, nitrate and ammonia forms of nitrogen were analyzed with HACH (Model DR2000) portable spectrophotometer. Total nitrogen was determined by Kjeldahl method. The organic nitrogen was calculated as the difference between the total nitrogen and the sum of ammonia, nitrite and nitrate forms. Phosphorous was analyzed by the methods of colorimetric ascorbic acid amino reduction and molibdo vanado phosphate (Greenberg, 1992) in the same spectrophotometer. BOD analysis and coliform analysis were done in the laboratory, after careful transportation of the samples, with manometric method in HACH spectrophotometer, and with multiple tubes and filtering method respectively. The chloride analysis was done in HACH spectrophotometer for free chloride and total chloride. Out of the 11 state variables, 10 were determined from field measurements. Only a representative data for the concentration of algae was taken from literature (Brown, 1987).

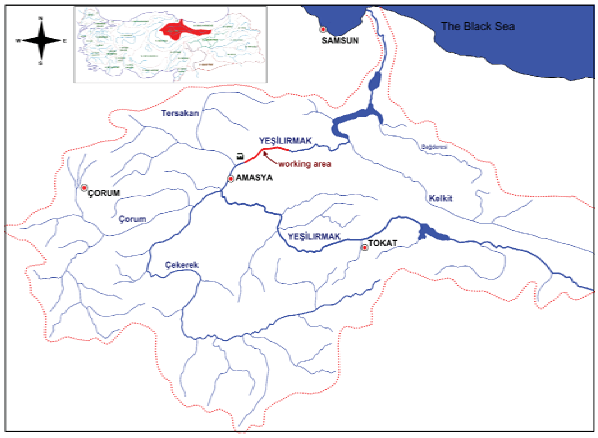

Fig. 5. Yesilirmak river basin and the study area.

During the dynamic sample collection period, the effluent from the wastewater treatment plant of a baker's yeast production plant was being discharged right beyond the starting point. Therefore, the results of the study indicated the extent of the pollution caused by the discharge from this industrial plant. In the simulations, addition of this discharge was considered as a continuous disturbance to the system, and its effect on the water quality, thus, was determined. Table 1 gives the characteristics of discharge from this local industrial plant.

Water quality data was collected for a 36.5 kms long section of the river adjacent to the city of Amasya. The study area started from the location 8.9 kms east of the city center where a baker's yeast plant was situated. The treated wastewater of this plant was considered as a point source to the river. The river water was sampled at 7 different locations in the downstream direction towards Durucasu gauging station of State Hydraulic Works (DSI) and the town of Tasova.

The initial conditions of the river and the characteristics of the point source as measured from points 1 and 2 indicated on Fig. 6 were introduced into the software, and dynamic simulation was run.

Table 1. Characteristics of discharge from the local baker's yeast plant

Variables	Waste water of baker's yeast plant
Temperature (°C)	25.3
Flow (m^3/s)	0.25
Ammonia-N (mg/L)	27.4
Nitrite-N (mg/L)	1.3
Nitrate-N (mg/L)	52
Organic-N (mg/L)	0
Organic-P (mg/L)	0.52
Dissolved-P (mg/L)	12.4
BOD (mg/L)	210
DO (mg/L)	7.2
Coliform, (colonies/100 ml)	2900
Chloride (mg/L)	0

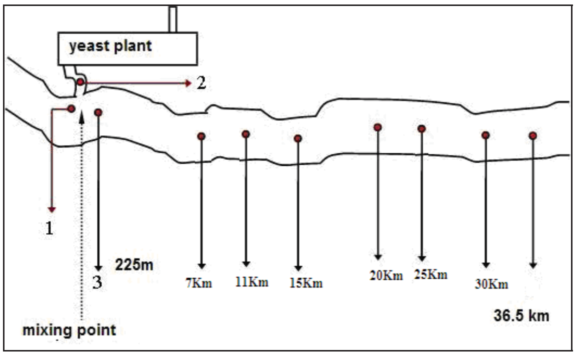

Fig. 6. Experimental study area for model verification, and sample collection points (distances indicated are measured from point 1).

Predictions from the software were compared to field data for a section of 36.5 kms of the river after the point source. Measured and predicted profiles of the pollution variables are shown in the following figures. Fig. 7, 8 and 9 reveal the pollution load due to the point source, and indicate that after some distance from the point where the effluent enters, remarkable recovery was observable. Fig. 10 shows the change in dissolved oxygen concentration along the study area. The points in the Figs. 7-8 indicate measurements whereas the continuous lines are predictions from the model.

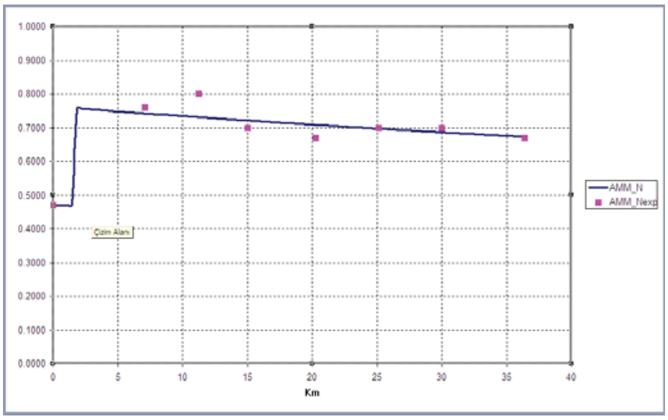

Fig. 7. Ammonia nitrogen profile.

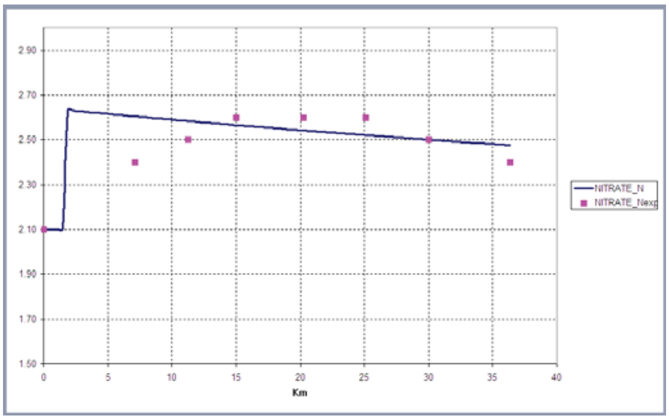

Fig. 8. Nitrate nitrogen profile.

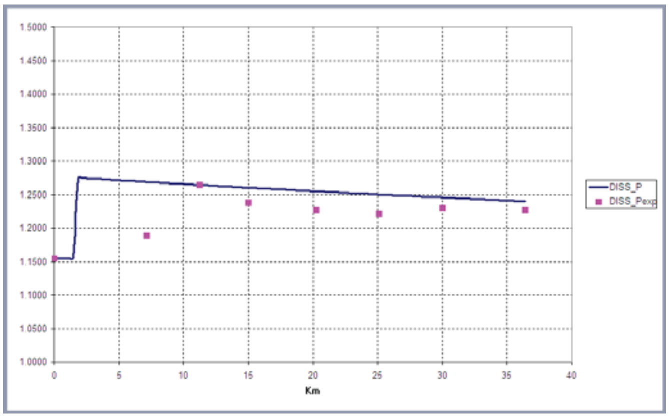

Fig. 9. Dissolved phosphorus profile.

For quantitative evaluation and comparison, Absolute Average Deviation (AAD) values were calculated. Table 2 indicates that, except nitrite nitrogen and chloride, the predicted values of all quality variables are in compliance with measured values.

Fig. 11 presents the predicted water quality results in tabulated form as a function of geographical space indicated on the first row. The columns represent the water quality variables predicted. The water quality data displayed can be viewed in graphical form or as color coded displays on the river map.

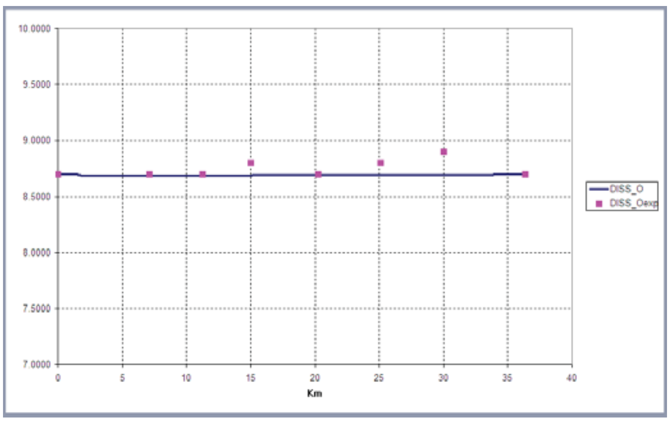

Fig. 10. Dissolved oxygen profile.

Table 2. Absolute Average Deviation (AAD) values for comparison of pollution variables

Water Quality Variables	(AAD %)
Ammonia Nitrogen	2.86
Nitrite Nitrogen	29.59
Nitrate Nitrogen	2.71
Organic Nitrogen	9.01
Organic Phosphorus	2.09
Dissolved Phosphorus	1.89
BOD	5.49
Dissolved Oxygen	0.64
Coliform	6.87
Chloride	20.19

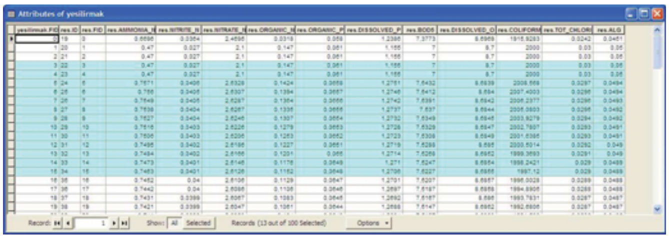

Fig. 11. Simulation results in tabulated form.

4. CONCLUSION

Although many models have been developed, they appear to be available to limited number of professionals who are capable of using and interpreting water quality simulation models. However, increased awareness in surface water pollution dictates that these models be used by non-experts who may be interested in knowing the consequences of various scenarios on river pollution. Availability and affordability of GIS systems offer alternative solutions to this problem.

Starting from this point, a software integrating a Geographical Information System and a water quality model in a single convenient package has been developed in this study. The effects of a discharge on the river can be predicted by simulation and the results are displayed on the map. The software was tested off-line with data collected from field measurements on Yesilirmak river in Turkey.

The integration strategy developed and the GUI created provide an interactive environment for the user and will help decision making process in river basin management systems, and can be fairly easily adapted to other rivers.

The results indicated that the model was able to satisfactorily estimate the water quality along the downstream section of a point load.

In our ongoing work, the software has been implemented for real time applications, and these results will be reported later.

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