Chapter 3. Real-life applications of the FGM/IDM technique

In this Chapter we consider several real-life applications of the FGM/IDM technique. First, the concept of the real-life application of a decision support technique is discussed. It is illustrated with the application of the FGM at the State Planning Agency of the former Soviet Union in the first part of 80s. The second and the third Sections are devoted to decision support systems for water quality planning in large river basins in Russia. Supporting the screening of water quality plans in these systems is based on the FGM/IDM technique. They help engineers to develop water quality improvement strategies that can be used as proposals in the process of selecting the final plan.

3.1. On the real-life application of decision support techniques

In this Section we discuss the question that is extremely important for the developers of decision support techniques: what does a real-life application of such technique could mean? Often one comes across papers where authors argue that decision support tools find real-life applications fairly seldom. It sounds a bit strange since hundreds of real-life applications of tools based on such decision support methods as the goal programming (Charnes and Cooper, 1961, Ignizio, 1985, Romero, 1991) or the AHP (Saaty, 1996) have been reported. On the other hand, a developer of a method may sometime report a real-life application of the method even in the case when its application is restricted to demonstration that the method can be adapted to a particular real-life problem. Surely, such application is only illustrative. Moreover, one can find many examples where decision maker is informed concerning the research, but does not take its results into account in the decision process. In such case, a developer may declare real-life application of a method only since decision maker has found time to listen about the method and its possible application. Surely, one cannot consider such situation as the real-life application. So, a precise definition of the real-life application is needed.

Definition of the real-life application

Books and papers provide different definitions of the real-life application of a decision support method. Let us consider the definition used in the recent paper (Kasanen et al., 2000) devoted to the discussion of the role of MCDM techniques. The real-life application is said to be an “application where

- an actual problem of an actual organization is studied
- using real data,
- in which decision makers participate, and
- the results of which have been implemented.”

Though the above definition accurately reflects the modern state of common understanding of the topic, multiple real-life applications of the goal programming and the AHP, usually have nothing to do with the above definition. Decision makers, experts and other kinds of users apply these techniques without informing the developers about how they do it. Who knows what kind of problems do they study? Are those problems “actual”? What kind of data do they use? Do decision makers participate in it or not? Perhaps, experts prepare decisions to decision makers without their participation? Or, a university professor develops educational examples? What about the implementation? Do the techniques influence decision processes at all?

We cannot answer these questions: too many different institutions and private people use the methods in many different ways. It is known that in several cases, the attempts to apply the goal programming in a simple way were not successful. One of such cases is described in this Section. However, multiple successful applications of the goal programming are known, too. Many users buy the software based on the goal programming or develop such software by themselves. Therefore, we can assert that the goal programming has found real-life application. It is important that in this case, the quality of an application depends on user, but not on the technique.

So the above definition seems to be more related to the situation where a developer tries to test the applicability of a method, but not to its broad real-life application. For this reason, an alternative definition of the real-life application of a decision support method is needed. In the framework of this book, we use the following definition.

A decision support technique is said to have real-life application if some people have mastered it and apply it independently from the developer for a relatively long time.

Both goal programming and the AHP comply with this definition. It seems that other techniques that pretend to have real-life applications must comply with it, too. This definition rules out lots and lots of alleged applications, in which the analysts cannot identify the organization that employs their results. On the other hand, it does not require the involvement of the developers of a method into the decision process. It is important to stress that developers of the methods cannot require their involvement into decision process. Decision makers are not about to answer questions posed by them. Moreover, decision makers may consider involvement of the researchers undesirable. Decision makers may be afraid of techniques that ask too much about their preferences. It is clear that decision maker's openness may harm him/her.

Let us consider an example of real-life application of the FGM that illustrates the above ideas.

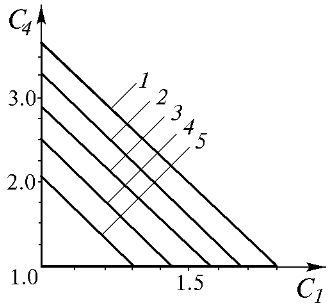
Example of real-life application of the FGM

In the beginning of 80s, a large research project was started at the State Planning Agency of the former Soviet Union. The aim of the project was to develop a computer-based decision support system for a medium and long-term national economy planning. The DSS was based on application of the hierarchical system of dynamic input-output models that described the development of the USSR economy with different levels of aggregation.

The most aggregated (upper level) model described possible development of the USSR production system during 15 years. The model was developed by experts of the State Planning Agency. It was a dynamic input-output model, in the framework of which 17 production industries were considered. The time-step selected by experts was equal to one year. Yearly outputs of production industries were equal to the sum of investments, imports, exports, final consumption, as well as row materials consumption of all other industries. The feasible labor was given in advance, and the capacities of production industries depended upon investment. The delay between the investment and the resulting capacity growth was given, its value depended on the industry. Decision alternatives in the model were related to distribution of labor force among industries, production of industries, production investments, etc (see Lotov, 1984, for details).

The upper level model was used for identification of the long-term national social-economic goals. For the particular goals, the values of several performance indicators of the national economic system were used. The performance indicators included consumption of several population groups, development of health care and educational systems, etc. In the early variant of the DSS, officials of the State Planning Agency had to identify the particular goals on the basis of their experience, without any computer support. As a rule, the goals identified by them were not feasible. Then, some optimization software was used to compute feasible criterion vectors that were the closest to the identified goals. Usually, the feasible criterion vectors were extremely distant from the goals identified by the officials. It was clear that the identified goals had nothing to do with the reality. The officials were disappointed with such result. After several attempts, they refused to use the DSS. It seems that the officials regarded such result as undermining their prestige since it might be attributed to their incompetence. It was clear for the DSS developers that an additional decision support tool was needed to help officials to identify feasible goals. They had an idea that visualization of a variety of feasible goals could help them to settle the conflict and to apply the goal programming.

The developer of the upper level model, Dr. Ilya S. Matlin did know about the FGM, and so in 1982 he hired two of the authors of the book. Their obligations consisted in the development of the FGM-based software that could be used in the framework of the DSS. It was decided to approximate the variety of potentially feasible social-economic goal vectors for the upper level model. At that time (at the very beginning of 80s) the State Planning Agency did not have any personal computers, and so the authors printed out a large number of collections of two-criterion non-dominated frontiers in the form of an album and provided it to Dr. Matlin. One of such pictures is given in Figure 3.1.1. Two of the criteria (payments per one employee, *C1*, and living room per capita, *C4*, at the end of the planning period) are given on axes. The values of the rest of criteria (fixed for a frontier) are given under the picture. All the criteria were measured regarding their values in the starting year of the planning period.



	C_2	C_3	C_5	C_6	C_7
1 -	1.0	1.0	1.0	1.0	1.0
2 -	1.3	1.3	1.15	1.20	1.06
3 -	1.6	1.6	1.30	1.40	1.12
4 -	1.9	1.9	1.45	1.60	1.18
5 -	2.2	2.2	1.60	1.80	1.25

Figure 3.1.1. A collection of non-dominated frontiers

Dr. Matlin said to the authors that their direct contact with the officials of the State Planning Agency is not needed and that the officials would study the album of potential social-economic goals by themselves. Indeed, it turned that the album of pictures worked sufficiently good without any support from the authors, and so their help was indeed not needed. Two years later, we met Dr. Matlin once again to discuss problems of further development of the DSS. He assured the authors that the album was used very intensively and helped the officials to apply the goal method (he even provided a proof of it – the album that looked dirty, greasy and crumpled). So, it seems that the method indeed was able to help the officials to identify the preferable goals. However, the following developments in the USSR ("perestroika") have made the planning system obsolete, and the application of the DSS was stopped. Totally, the officials had used the album more than three years.

Strategy of real-life application of the FGM/IDM technique

The above experience of the real-life application of the FGM helped us to develop our own strategy for application of the decision support techniques. First of all, we try not to be involved into decision procedures and not to interact with decision makers and other stakeholders. Instead, we interact with experts who support their decision processes. We teach how to use our technique, help experts to master it, and adapt our software to their needs. Sometimes we help to develop the models but avoid contacting decision makers directly. This strategy of the real-life application is illustrated in Figure 3.1.2 where we denote ourselves as analysts.

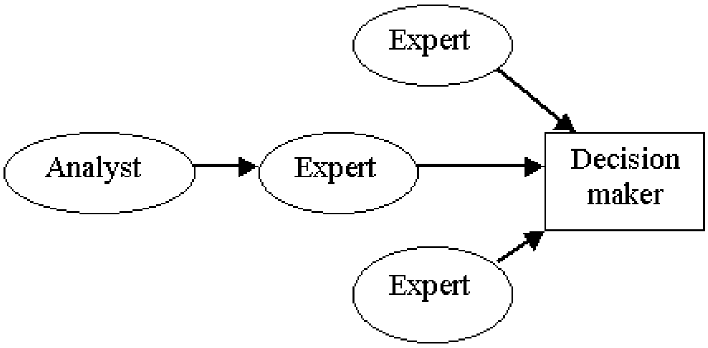


Figure 3.1.2. Possible scheme of interaction between analyst and decision maker

In the following two Sections, we describe real-life application of the FGM/IDM technique in the framework of two DSS. The first DSS described in Section 3.2 was used for water quality planning in several river basins in Russia in the first part of 90s. The DSS was developed on request of the Russia's State Institute for Water Management Projects (now private Institute for Water Information Research and Planning, Inc.). The DSS described in Section 3.3 was developed in the framework of Russian Federal program “Revival of the Volga River”. It is used now by engineers from the Engineering and Research Center on Water Management, Land Reclamation and Environment “Soyuzvodprojekt”, Inc., who develop water-related projects on request of organizations from in and outside of Russia.

These two DSS are based on special methodology for decision support in environmental problems. The methodology introduced in (Lotov, 1994) is discussed in details in (Lotov, 1998, and Lotov et al., 1999a). It is based on the application of the FGM/IDM technique and integrated mathematical models of the environmental systems.

3.2. DSS for water quality planning in river basins

Usually, a computer-based water-related DSS applies simulation of given decision alternatives. The FGM/IDM technique provides an additional tool that helps to select a small number of strategies for simulation. Multiple stakeholders, independent institutions and political groups that are involved into decision processes in water-related problems as well as experts associated with them can apply the FGM/IDM technique to assess all possible outcomes and screen possible strategies. Here, we restrict to water quality planning in river basins, which is an important problem in a large part of the world nations.

In water quality planning, decision screening requires integration of knowledge from a number of disciplines that provide information about different subsystems such as wastewater discharge, wastewater treatment, pollutants transport, the effect of pollutants on ecology, as well as economic impacts, environmental measures, and so forth. For this reason, simplified models are to be used in an integrated mathematical model applied for screening procedures. If an original mathematical description of a subsystem is provided, then a simplified model can be deducted from that description. In this case, a simplified model may have the form of an influence matrix. In different cases, expert judgments and empirical data may be used to help develop simplified models. As soon as in 60s, Robert Dorfman stressed the importance of supporting the decision screening in water management problems on the basis of simplified models (see Dorfman, 1965). In this Section, we describe a DSS for water quality planning in river basins that is based on the application of simplified models developed by experts. Section 3.3 describes a DSS that applies a more sophisticated approach of parameterization of comprehensive simulation models of river basins.

Problem

Problems of water pollution abatement in Russia's rivers in 90s have been aggravated by the difficult economic situation. The need for efficient application of environmental investment was very high. Moreover, to obtain even moderate investment, the engineers who developed the plans had to prove to federal and regional authorities as well as to owners and managers of industrial enterprises that the investment would result in substantial improvement of the environment. In the problem under consideration, recommendations were to be made regarding wastewater treatment in industries and municipalities located in a river basin.

Earlier, the engineers tried to apply single-criterion optimization procedures to obtain reasonable plans of wastewater treatment. They searched for plans related to minimal cost that would meet environmental requirements. Often it was impossible to find a feasible plan that met the requirements, and so the engineers had to change these requirements somehow. Moreover, in the cases when such plans had been found, they were often too expensive to be fulfilled. Therefore, the engineers had to “improve” optimal plans by deleting several investment proposals from the plan in accordance to their experience. This resulted in inefficient strategies, which were sharply criticized.

For this reasons, a new decision support technology of water quality planning was elaborated. In the framework of the technology, the measures devoted to water quality improvement were split into two phases:

- measures that had to be implemented immediately; they should be given by a water quality strategy that implements a balance between cost and pollution; and
- measures for final resolution of water quality problem.

The DSS was developed that provided a support for the search for a strategy that could be used at the first phase. A searching for a strategy that implements a balance between cost and pollution was based on screening a myriad of feasible plans. Along with the cost criterion, several water quality criteria were incorporated into the screening procedure. The FGM/IDM technique was used for displaying decision maps that provided the efficient (criterion) tradeoffs between cost and pollution criteria. Information on the criterion tradeoffs helped the engineers to identify one or several reasonable feasible goals. Then, they received the related investment strategies, which were displayed both in graphical and table forms as well as in a specially developed GIS.

Model

A river under consideration was split into a finite number of reaches. It was supposed that monitoring stations observed pollutants concentrations at the downstream ends of reaches. The production enterprises in the river basin were grouped into industries, which included the enterprises with analogous production technology and pollutants output pattern. The municipal services were grouped in the same way. Usually about 20 different types of industries and services were considered. The production enterprises and municipal services were grouped in accordance to the reach they belonged to.

The problem was reduced to the search for an investment strategy for constructing the wastewater treatment facilities. The investment (its volume was not given in advance) had to be allocated between production industries and municipal services in the reaches of the river. The current discharge was supposed to be known.

The integrated mathematical model that was used in the DSS consisted of two parts:

- of a pollution transport model that helped to compute concentrations of pollutants at monitoring stations for any given discharge;
- of two models of wastewater treatment that described the decrement in pollutant emission to the cost of wastewater treatment in an industry or a service.

The pollution transport model was based on empiric data and expert judgement. It was planned to substitute this model by another one based on parameterization of comprehensive simulation models of pollution transport. However, it turned out to be impossible to implement this desire at that time. It was implemented in another study that is described in following Section. Models of wastewater treatment were based on the description of wastewater treatment technologies. Decision variables described the fractions of wastewater treated by technologies in industries and services located in different reaches.

Water quality criteria were based on pollution concentrations measured at monitoring stations. Since more than twenty pollutants were considered, the engineers applied aggregated environmental criteria. To be precise, they considered several pollutant groups. The value of a criterion that described a pollutant group was calculated in the following way. Relative pollutant concentrations (*RPC*) were used. A *RPC* is defined as the ratio of the actual concentration to the so-called maximum admissible concentration, which represents *a priori* environmental requirements. The sum of *RPC* values for the pollutants, which were included into a group, was used as a water quality indicator. For the water quality criterion for a pollutant group, the maximal (i.e., the worse) value of water quality at monitoring stations was used. Desirable value was supposed to be one.

It is important to stress that such criteria provide only one example from a large number of possible criteria that can be used (different criteria are described in the next Section). The engineers provided the following grouping of pollutants:

- pollutants that lead to general degradation of water quality;
- pollutants that lead to degradation of fishing in the river;
- pollutants that lead to degradation of water quality related to the sanitation issues;
- pollutants that affect the toxicological issues.

Therefore, four pollution criteria were used in the study.

Exploration of decision maps

As usually in the framework of the FGM/IDM technique, decision maps were used to display information on potential criterion vectors and on the efficient criterion tradeoffs. Figure 3.2.1 provides an example of a decision map used by the engineers.

The non-dominated frontier in the Figure displays the non-dominated frontier for two pollution criteria, general pollution indicator, *GPI*, and fishing degradation indicator, *FDI*, for several values of cost. The prepared black and white copy of color display is given. The relation between the values of cost (millions of rubles of the year 1988 were used) and the shading is given in the palette.

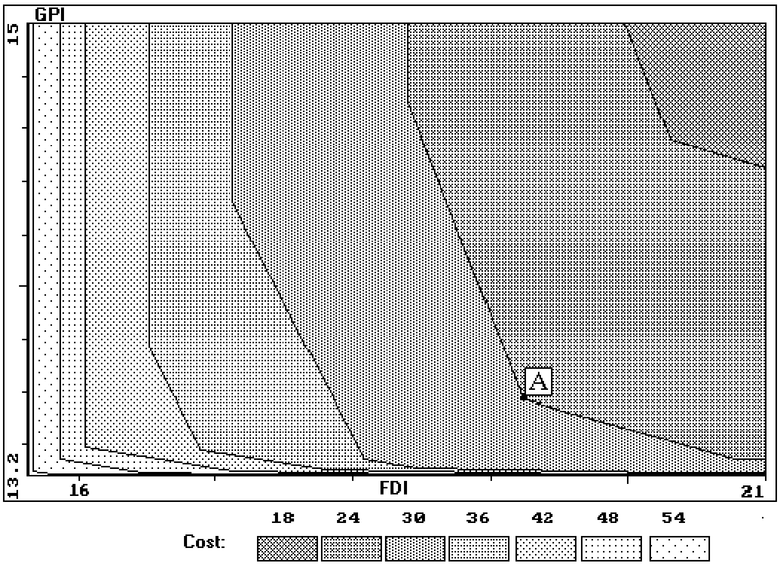


Figure 3.2.1. Non-dominated frontier for *FDI* and *GPI* depending on cost

Note that, in accordance to Figure 3.2.1, the minimal cost here is 18 million rubles. This value corresponds to the darkest shading. For this value of cost, the combination of *FDI* and *GPI* values should belong to the dark shaded variety placed in the upper right-side corner. In particular, the value of *GPI* is not less than about 14.6, and the value of *FDI* is not less than about 20. By adding 6 million rubles (24 millions in total), we provide a much broader variety of feasible values of *FDI* and *GPI*. In particular, 13.4 is now the feasible value of *GPI*. The combination of *FDI* and *GPI* values identified by point *A* (it will be discussed later) is feasible as well. If cost is not less than 30 million rubles, *FDI* can be decreased till about 17.25. Once again, the shape of the frontiers helped the engineers to assess how much the drop of *FDI* is related to the increment in *GPI*, and changing one frontier for another helped them to understand how the increment in cost results in the reduction of both pollution indicators.

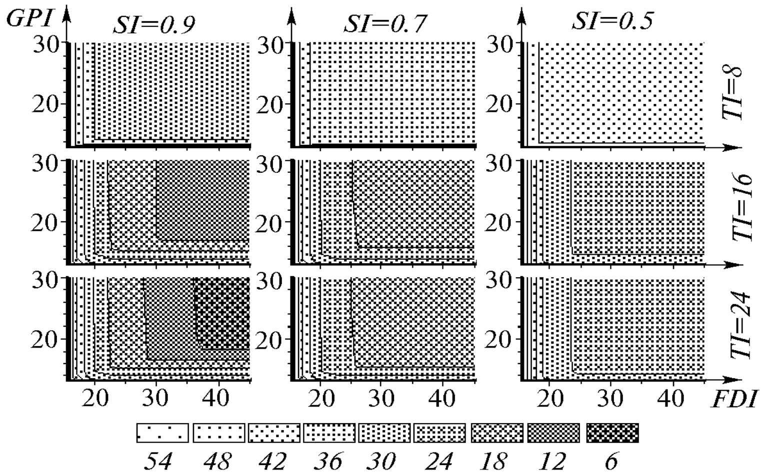


Figure 3.2.2. Matrix of decision maps

Five criteria were explored in the DSS (in addition to FDI, GPI and cost, sanitation indicator, *SI*, and toxicological indicator, *TI*, were explored). The engineers used to draw decision maps for *FDI*, *GPI* and cost for different constraints imposed on the values of *SI* and *TI*. Matrices of decision maps were used, too (Figure 3.2.2). Once again, any decision map of the matrix is related to certain constraints imposed on the values of *SI* and *TI*. These values are given in Figure 3.2.2 above the columns and to the right of the rows of the matrix. These values may be chosen by the researcher or automatically.

By comparing the decision maps for properly chosen values of constraints, the engineers understood the influence of the fourth and the fifth criteria on the variety of feasible vectors for the first three criteria. As we have already said it, any reasonable number of decision maps in a row or in a column may be presented (depending on quality of computer display).

Decision support system

The DSS consisted of five main subsystems:

1. Data preparation subsystem;
2. Subsystem for the EPH approximation;
3. Subsystem for exploration of the EPH and identification of non-dominated goals;
4. Subsystem for computing the associated strategies; and
5. Subsystem for display of strategies.

First, using the data preparation subsystem, the engineers prepared information concerning water balance and initial pollutant concentrations, parameters of pollution transport matrices, parameters of possible wastewater treatment facilities, etc. The subsystem provided a simple data compatibility test and converted initial files into an internal form of the software.

Constructing the EPH was performed by the second subsystem. Then, engineers explored particular decision maps and matrices of them. In the process of exploration, the engineers identified one or several feasible goals, say point ***A*** in Figure 3.2.1. Afterwards, the associated plan of wastewater treatment was computed automatically in the fourth subsystem. Computing the wastewater treatment strategy took several minutes even on computer that already looked obsolete for many years. The fifth subsystem displayed the strategy in the form of column diagrams. Moreover, icons were placed on the map of a river basin and the diagrams were drawn on it when the corresponding icon was clicked. Reference information related to the problem was requested and provided in the same manner.

Unfortunately, it proved to be impossible to arrange the FGM/IDM-based negotiations among real decision makers at that time. For this reason, the engineers had to construct several variants of the project, which they provided to the decision makers who took this information into account. Hopefully, this improved their understanding of the situation. Therefore, the engineers played the role of experts who screened the whole variety of feasible decisions. The FGM/IDM technique gave them an opportunity to do it on the basis of the information on potentialities of choice and efficient criterion tradeoffs.

The system was implemented for water quality planning in several river basins. In particular, the project for a small river in Moscow Region, named Nara River, was developed. The river was heavily polluted. In the framework of the old optimization procedure, the engineers failed to develop even a feasible plan, since the environmental requirements could not be met in this case. The DSS helped to solve this problem. Detailed descriptions of the model and of the DSS are given in (Lotov et al., 1997a). The DSS was applied in the case of large rivers, too, say in the case of Belaya River, which one of the major inflows of Volga River.

As we have said already, the study described in this Section was carried out in the first part of 90s. At that time, implementation of the projects developed by the engineers was facing institutional difficulties in Russia. The responsibility of the federal government for environmental quality was gradually shifting (jointly with financial resources) to regional and local authorities. Therefore, it was not clear what institution had to support regional environmental projects. Moreover, privatization processes in Russia that were under way at that time complicated the problem drastically.

Now, the studies of this kind are carried out by the private Russian institution "Engineering and Research Center on Water Management, Land Reclamation and Environment "Soyuzvodprojekt". In the framework of collaboration with this institution, a new DSS for water quality planning in river basins was developed. It is described in the next Section. The DSS was developed on the request of the Russian Federal Ministry of Natural Resources in the framework of the federal program "Revival of the Volga River".

3.3. DSS for screening of water quality improvement plans

The DSS described in this Section was developed on the basis of the experience received in the process of application of the DSS described in the previous Section. In contrast to the DSS described in Section 3.2, more attention was given to data preparation. This Section is based on the paper (Lotov et al., 1999c).

Introduction

The simplified integrated model used in the DSS for screening the strategies consists of three submodels:

- a wastewater discharge sub-model that describes the current discharge attributed to particular regions, river segments, industries or services; structure of the wastewater discharge is provided, too;

- a wastewater treatment sub-model that relates the decrement in wastewater discharge to the cost of construction and performance of wastewater treatment installation;
- a pollution transport sub-model that allows compute the concentration of pollutants in monitoring points for discharge given in all sources.

The first and the second submodels were developed by experts on the basis of statistical information. The third submodel was constructed by parameterization, i.e. approximation of input-output dependencies of an original model. In this Section, we discuss the development of the simplified integrated model; then we describe the DSS and application of the FGM/IDM technique in its framework.

As it has been noted already, the most important form of simplified models is the linear one. The simplified linear description of dependence of output vectors upon input vectors has the form of a matrix. It is named the influence matrix. First, we consider first possible ways of constructing the influence matrices. Then, we describe our practical experience of constructing the simplified pollution transport model by parameterization of the system MIKE 11, which is a well-known system for modeling rivers and channels.

The DSS described in this Section was calibrated for the Oka River, which is one of the largest tributaries of the Volga River. The length of the river is about 1,500 kilometer. The river has multiple tributaries. The flow in the river changes from 10 cubic meter per second during the dry summer period in the upper Oka River up to 1000 cubic meter per second in the lower Oka River.

Geometric characteristics, roughness and other parameters of the riverbed vary substantially along the river.

Figure 3.3.1. Map of the Oka River basin

In Figure 3.3.1, the map of the river basin is provided. Frontiers of seven regions located at the main flow of the river can be seen along with frontiers of several other regions. The riverbed was split into fourteen segments that approximately describe membership of riverbanks to the regions. Pollution concentration was studied at the downstream ends of the segments, which are given by numbers in Figure 3.3.1.

Constructing the influence matrices – general discussion

Let us start with the influence matrices for linear original models. Consider, for example, a stationary linear partial derivatives model that describes regional transport of a single pollutant from several pollution sources along a river. Assume that the pollution discharge per unit time is constant. Then, the model can be used to estimate the pollutant concentration at any point of the river.

If pollutant discharges are not known in advance, the point source method can be used. In the framework of the method, source functions can be constructed that provide concentrations resulting from the individual sources with the unit rate of discharge. Let us consider a point of the river. Since the pollutant transport model is linear, the pollutant concentration at this point resulting from an individual source equals to the product of the source function value on its discharge. Due to the same linearity of the model, one has simply to sum up concentrations resulting from all sources to estimate the total concentration at the point. In other words, pollutant concentration at any point (for example, at a monitoring station) is a linear function of pollution discharges.

Let us consider a particular monitoring station of the river and a particular discharge source. Then, the influence coefficient for this station and this source is the value of the source function at this monitoring station. The influence coefficients for all sources and stations provide the influence matrix. Let us consider the vector of pollutant concentrations at the monitoring stations. As shown above, the vector equals to the product of the influence matrix and the discharge vector. It means that we can simply multiply the influence matrix by the discharge vector to compute the concentrations instead of solving the problem in partial derivatives. It is important that the influence matrices can be constructed precisely in the linear case by using the values of the source functions.

In the non-linear case, an influence matrix approximates the discharge-concentration dependencies. The method for estimating an influence matrix may depend upon a particular scientific field. A universal approach may be based on the application of regression analysis of input-output dependencies, which can be obtained by simulation of non-linear models. Along with the approximation of input-output dependencies, simulation can provide their applicability ranges.

If there is no adequate mathematical model for a subsystem, an influence matrix can be constructed on the basis of result of statistical analysis of experimental or historical data. Sometimes, experts can provide both an influence matrix and its applicability range (as it was done in the previous Section).

A combination of influence matrices and other simplified descriptions as well as balance equations and constraints imposed on variables contributes to a simplified integrated model that describes the environmental system. Simplified integrated models are typically less precise than original models, but that fact is not of great importance since integrated models are used on the first stage of the decision process for screening of decision strategies. So, it is supposed that insufficient precision of the simplified models would be compensated on the stage of detailed analysis of the selected strategies.

Now let us describe our experience of constructing the influence matrices that describe transport of several pollutants along a river in the DSS under consideration. In contrast to the DSS described in the previous Section, the coefficients of the influence matrices were constructed through simulation of the pollutant transport model of the system MIKE 11.

Constructing the influence matrices for pollution transport

Constructing of influence matrices was started with calibration of the hydrodynamic sub-model (HD MIKE 11) of the system MIKE 11 to the stationary flow of the Oka River during the summer period with a minimal flow. There were 23 main tributaries considered in the model along with 33 conditional inflows that describe inflow from the neighboring land to the river. The water inflows were supposed to be given. The influence of the Volga River on the flow in the lower part of the Oka River was taken into consideration, too. It turned out that the geometric information and roughness coefficients used in the model were sufficient to determine the flow during the summer low-flow period. The hydrodynamic model of the river was used in the process of calibration of the advection-dispersion model (AD MIKE 11) of the system MIKE 11 that was used to describe pollution transport in the river.

Multiple sources of pollution do exist in the river basin. They include natural sources, industrial wastewater discharge sources, municipal point and non-point wastewater discharge sources, agricultural non-point sources, large animal breeding enterprises, etc. In accordance to the information we managed to collect, six most important pollutants were considered in the model, namely concentrations of suspension, phosphates, nitrates, oil products, and ferrous combinations as well as biological oxygen demand. Both discharges and concentrations of pollutants were used to calibrate AD MIKE 11 for the summer low-flow period. Data on wastewater discharge from large cities and banks of the river were collected partially from state statistical institutions and partially they were obtained as a result of expert evaluation. Known pollutant concentrations in large tributaries were averaged on the basis of data for several years. The rest of discharge was spread among small rivers proportionally to their flow. In the process of calibration of the model, the decay constants of the advection-dispersion model were adjusted. Sometimes it was needed to correct data on wastewater discharge.

The model AD MIKE 11 has an extremely important property: for a given water flow, a pollutant concentration at a monitoring station depends on the capacity of the pollutant sources in the linear way. One can prove this feature of the model theoretically, on the basis of its equations, or experimentally, by using simulation. This feature was used for constructing precise influence matrices for pollutants under consideration.

The procedure of constructing the influence matrix looks as follows. In a particular river segment, three types of pollution sources can be considered: sources located on the right and the left banks and sources located in the river segments up to the segment under consideration. According to it, the simulation experiment for a particular segment consists of four runs. In all runs, the pollutant flow was computed at the downstream ends of the segments. In the first run, the pollutant flow at the upstream end of the segment (i.e. at the downstream end of the upper segment) was set equal to the current value and the discharges from both banks of the river segment were set to be equal to the background emission. In the second and the third runs the background flow was set to be the pollutant flow at the upstream end. The discharge from the left-bank (or right-bank) region was set to be equal to the current emission, while the background value was equal to discharge from the region located at the opposite bank. In the fourth run the capacities of all sources of pollution were set equal to the current level. Since the pollution concentrations for the background discharge were given, the results of the three first runs were sufficient to estimate the coefficients of the linear model of the pollution in the segment. To be precise, the pollutant flow was the sum of the flow from the upper segment and of the discharges from the banks multiplied by the related coefficients. The fourth run was used only to check the results. Though usually the additional pollutant flow computed in the fourth run was the same as the sum of the additional pollutant flows computed in the previous runs, sometimes mistakes in data were found. By this it was experimentally proved that the influence of the pollution sources is linear. It persuaded those people who did not trust the theoretical results received by the analysis of the equations of the model.

Coefficients of the linear models for all segments provide sufficient information for computing the influence matrix of a particular pollutant for the whole river. Due to this, it was possible to compute the concentrations of a pollutant at the downstream ends of the segments by multiplying the related influence matrix by the discharge vector. The influence matrices approximately describe the pollutant transport. They relate the decrement in the wastewater discharge to the decrement in concentrations of the pollutants at the downstream ends in the integrated model.

Constructing the influence matrix was carried out by A. Buber and N. Brainin from “Soyuzvodprojekt”, A. Maksimov from the research institute VODGEO and R. Efremov from Computing Center of RAS.

Other submodels

Unfortunately, available data on wastewater discharge happened to be very rough. The wastewater discharge was attributed only to particular regions, but not to industries. So, in contrast to the DSS described in the previous Section, we had to restrict to a regional pollution model, though we keep on hoping to receive related industrial data sooner or later. It is clear that the influence matrices constructed in the framework of the development of the current DSS can be easily combined with a multi-industrial multi-services discharge model of the previous Section.

The model of wastewater discharge treatment was based on a concept of wastewater purification technologies. The concept provides an opportunity to include hundreds of possible technologies into consideration. Nevertheless, we had to restrict to a small database of discharge treatment technologies developed by Dr. A.Gotovtsev from the Institute for Water Problems of Russian Academy of Sciences using data given in (Henze and Oedegaard, 1995).

The technologies from the database were used in the model of discharge treatment installations. Thus, a decision variable of the model described an investment into a particular discharge treatment technology in a particular region at a particular river segment. Since the river was split into segments according to the borders of the main-flow regions, only one or two regions were attributed to each river segment. For this reason, it was possible to use influence matrices to compute the resulting concentration of pollutants at monitoring stations for a given strategy, i.e. for given values of decision variables. The total and regional costs could be computed, too.

DSS description

The DSS included codes of the main technique used for decision screening, i.e. FGM/IDM technique, as well as codes of auxiliary subsystems. Dr. L. Bourmistrova from Computing Center of RAS coded one of the subsystems and took care over the whole DSS. We describe the DSS on the basis of an example based on artificial data, which help, however, to understand how the DSS works.

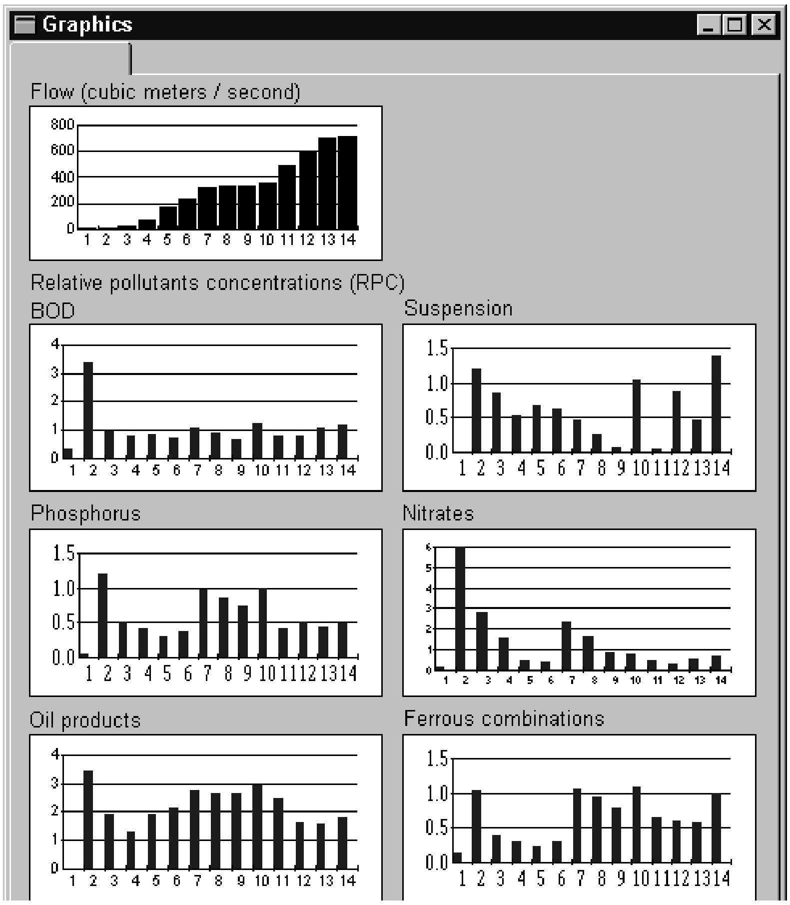
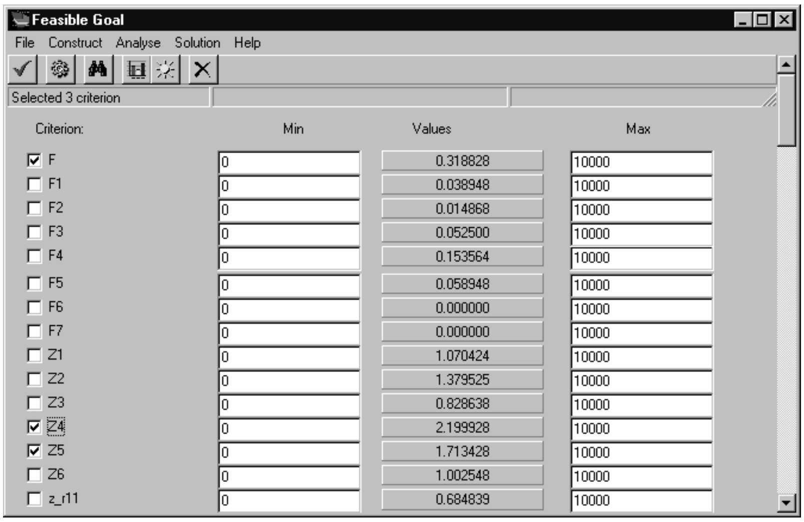


Figure 3.3.2. Current pollution concentration (PC) in monitoring stations. The upper black diagram shows the river flow during dry summer season.

The following subsystems were included into the DSS for screening of water quality strategies:

1. a subsystem for visualization of the current pollution in the river,
2. a subsystem for specification of screening criteria and constraints imposed on the values of performance indicators,
3. a subsystem for EPH approximation,
4. a subsystem for interactive display of decision maps and identification of a feasible goal,
5. a subsystem for computing the goal-related strategy,
6. a subsystem for visualization of the computed strategy.



Selected 3 criterion

Criterion:	Min	Values	Max
☑ F	0	0.318828	10000
☐ F1	0	0.038948	10000
☐ F2	0	0.014868	10000
☐ F3	0	0.052500	10000
☐ F4	0	0.153564	10000
☐ F5	0	0.058948	10000
☐ F6	0	0.000000	10000
☐ F7	0	0.000000	10000
☐ Z1	0	1.070424	10000
☐ Z2	0	1.379525	10000
☐ Z3	0	0.828638	10000
☑ Z4	0	2.199928	10000
☑ Z5	0	1.713428	10000
☐ Z6	0	1.002548	10000
☐ z_r11	0	0.684839	10000

Figure 3.3.3. Part of the list of performance indicators

The role of the subsystems is clear from their names. Only short comments are needed. Users receive information on the current pollution in the river in the form of diagrams, given partially at GIS-generated maps. Figure 3.3.2 contains black and white copies of several diagrams provided by the second subsystem. The upper (black) column diagram provides data on the flow during dry summer season at 14 monitoring stations (in cubic meters per second). Six other column diagrams display pollution at the stations in relative pollutants concentrations (RPC) that are defined as the ratios of an actual concentration to maximum admissible concentration, which represents *a priori* environmental requirements. So, the required value of the RPC equals to one.

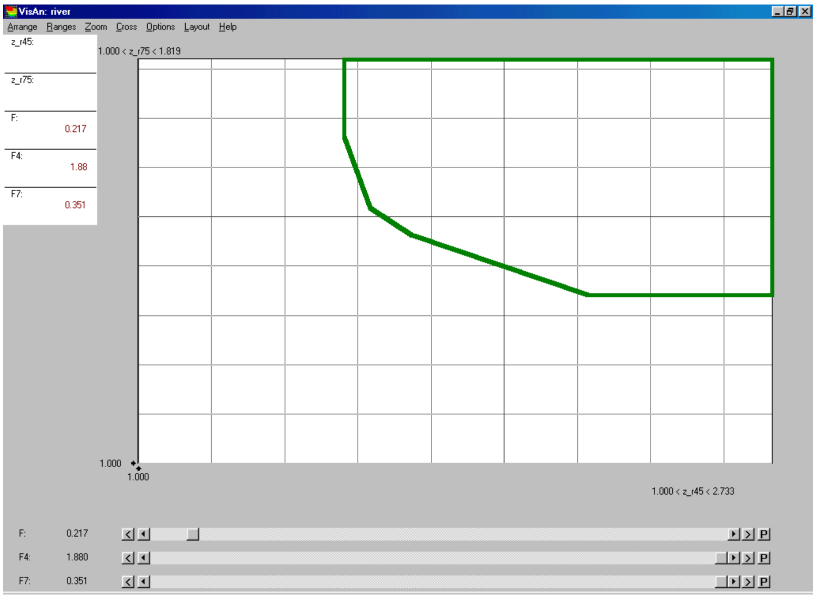
The information on the current situation is used in the process of formulation of a screening problem, i.e. in the process of specification of screening criteria and constraints imposed on the values of performance indicators. To satisfy different users with different interests, a large list of performance indicators is provided (part of it is given in Figure 3.3.3). The list includes two kinds of indicators:

- environmental indicators – regional or maximal concentration of pollutants in a region or in the river (in RPC),
- economic indicators – investment in particular regions as well as the total cost of an investment project (in billions of US$).

User can specify screening criteria directly in the list, choosing from two to seven performance indicators. Moreover, constraints on the value of any indicator may be imposed. To do it, one has to enter desired values into the left and right columns of the table. The central column also given in Figure 3.3.3 contains the performance indicators associated with a strategy that is the result of previous screening activities. At the very beginning, this column is empty.

Once again, we illustrate application of the DSS by an example, in the framework of which artificial data are used.

One can see in Figure 3.3.2 that the most drastic pollution problem is related to the upper part of the river (monitoring stations 2 and 3). This problem is related mainly to the low flow during the dry summer season. Another serious problem is related to pollution with the oil products – it is too high in any segment of the river. In this example, we are going to deal with the latter problem.



z_r45:

z_r75:

F: 0.217

F4: 1.88

F7: 0.351

F: 0.217

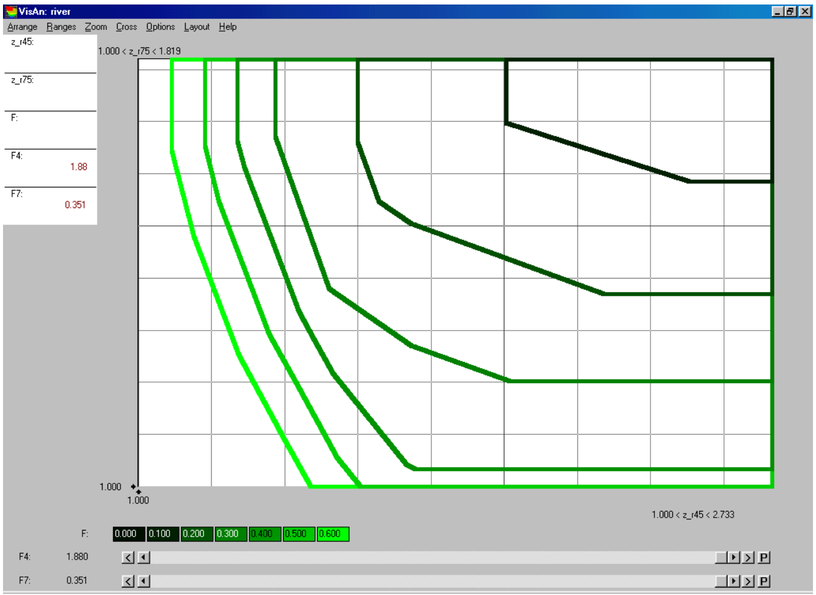
F4: 1.880

F7: 0.351

Figure 3.3.4. Feasible pollution concentrations at monitoring stations located in the *M*-region (horizontal axis) and in the *NN*-region (vertical axis) for the given cost of $217 million.

Let us consider an example of exploration the problem concerning investment into wastewater treatment facilities in the Moscow region (*M*-region) and Nizhny Novgorod region (*NN*-region). Those regions are economically most developed ones in the Oka River basin. The following five criteria were used in the study:

- maximal concentration of oil products at the monitoring stations located in the *M*-region (*z_r45*),
- maximal concentrations of oil products at the monitoring stations located in the *NN*-region (*z_r75*),
- total cost of the project (*F*),
- investment at the territory of the *M*-region (*F4*), and
- investment at the territory of the *NN*-region (*F7*).



F4: 1.88

F7: 0.351

F4: 1.880

F7: 0.351

Figure 3.3.5. Black and white copy of the decision map, for which total cost changes from zero up to $600 million

The EPH was constructed for the five criteria listed above. Let us consider several decision maps. Figure 3.3.4 displays the non-dominated frontier for concentrations of oil products at monitoring stations located in the *M*-region (horizontal axis) and in the *NN*-region (vertical axis) and its non-dominated frontier. The upper scroll-bar informs that the total cost is restricted by $217 million here. Constraints imposed on the values of *F4* and *F7* have no influence on the non-dominated frontier.

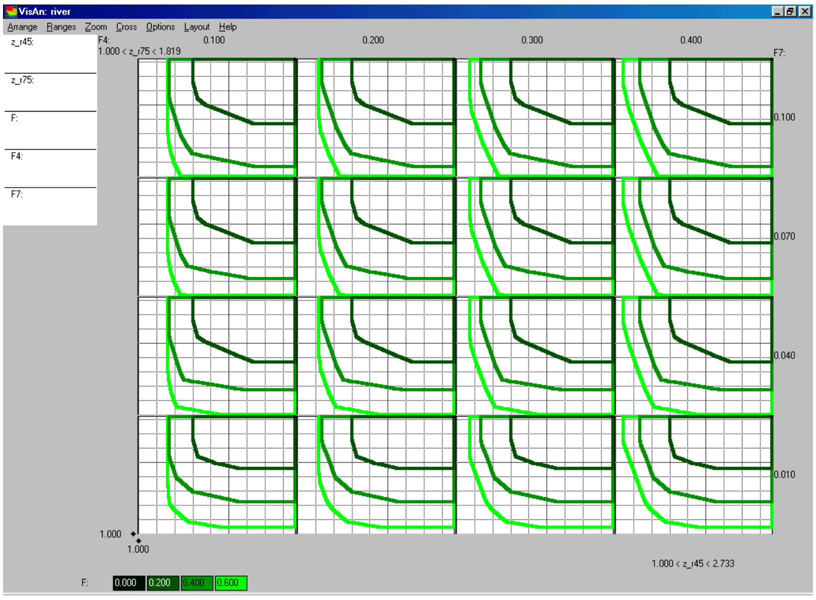


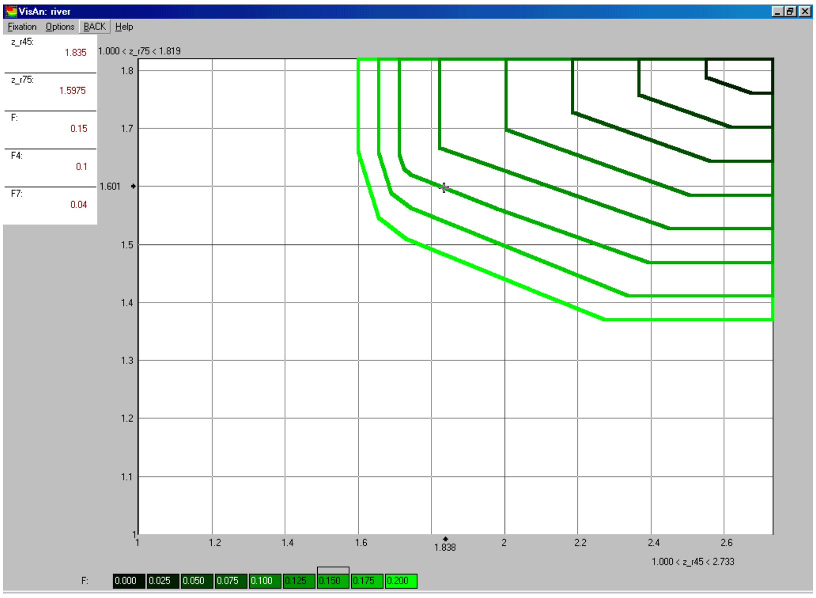
Figure 3.3.6. Black and white copy of the decision map matrix

One can see that there is a conflict between values of oil pollution in these regions when the cost of the project is restricted. Pollution in the *M*-region can be decreased from the current pollution of 2.7 till about 1.55 that is minimal for this cost. However, if *z_r45* is minimal, the pollution in the *NN*-region cannot be less than about 1.7. So, if \$217 million are applied in the interests of the *M*-region, the pollution in the *NN*-region can drop from the current 1.8 till about 1.7, but not less. In contrast, if \$217 million are applied in the interests of the *NN*-region, the pollution in it can be as low as 1.3. The non-dominated frontier among pollution in both regions shows the criterion tradeoff between these two criteria in a clear form.

Figure 3.3.5 contains a decision map, for which total cost changes from zero up to \$600 million. It is clear that the form of the non-dominated frontier substantially depends on total cost. Total cost of \$100 million solves the pollution problem to some extent (compare pollution values related to the frontier with those in the right upper corner that corresponds to zero cost). Additional \$100 million are very effective, too (the next frontier). For example total cost of \$400 million could practically solve the problem for the *NN*-region (minimal value of *z_r75* in this curve is 1.03) if the investment would be used according to its interests. At the same time, minimal pollution in the *M*-region for this cost is achieved while pollution in the *NN*-region is about 1.7. Nevertheless, administration of the *NN*-region can hope to persuade administration of the *M*-region to agree to move along the non-dominated frontier from point *z_r75=1.7* in the direction of the kink point (where *z_r75* equals to 1.03) using some concessions in a different field.

Now let us consider the influence of constraints imposed on regional investments, *F4* and *F7*. The decision map given in Figure 3.3.5 can be animated in accordance to the changes of *F4* and *F7* to estimate influence of the regional investments. However, we have to use here the matrices of decision maps that provide snap-shots of the above animations. In the decision map matrix given in Figure 3.3.6, columns are related to constraints imposed on the values of

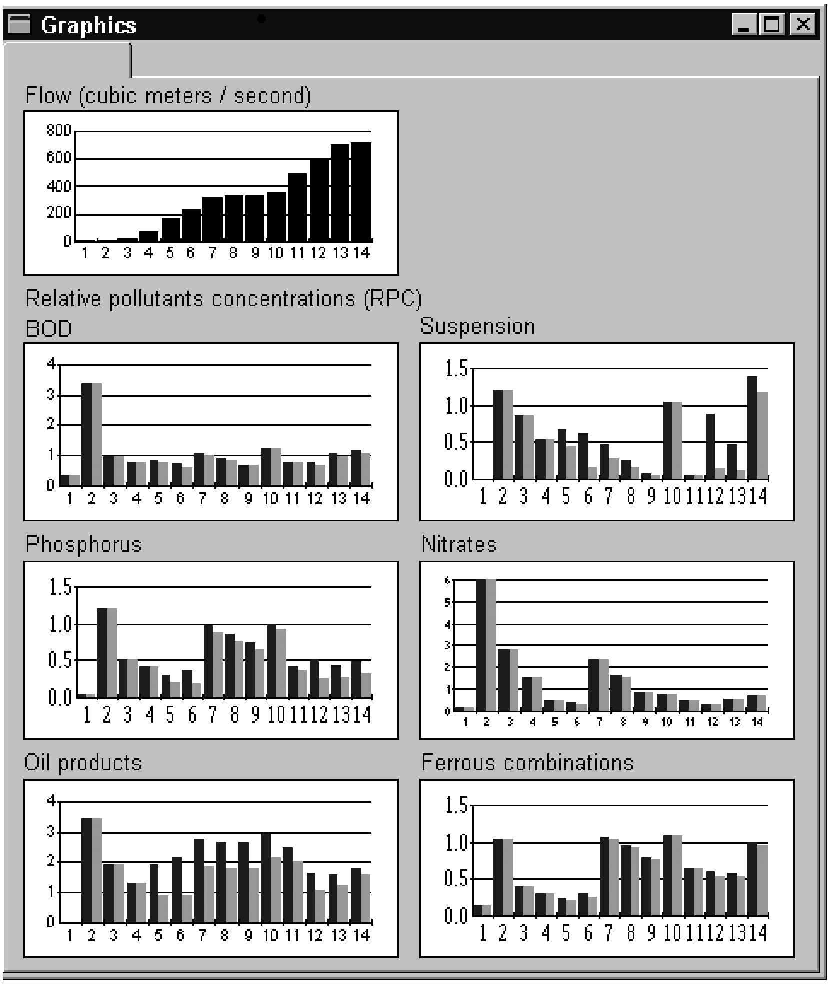
F4 and rows are related to constraints imposed on the values of *F7*. These constraints are specified above the columns and to the right of the rows.



z_r45: 1.835
z_r75: 1.5975
F: 0.15
F4: 0.1
F7: 0.04

Figure 3.3.7. Black and white copy of the decision map related to \$100 million investment in the *M*-region and \$40 million investment in the *NN*-region. The goal is given by the cross.

To make the picture clear, we provide only four possible values of *F* in a decision map instead of nine in Figure 3.3.5. These values are given in the palette under the matrix. The decision map displayed in Figure 3.3.5 can be associated with the decision map located in the upper row of the extreme right column, which is related to such constraints imposed on *F4* (not greater than \$400 million) and on *F7* (not greater than \$100 million) that still do not influence the decision map. By moving to the left in the same row, user can see the influence of the constraint imposed on *F4* while the *F7*-related constraint is fixed.



Flow (cubic meters / second)

Relative pollutants concentrations (RPC)

BOD

Suspension

Phosphorus

Nitrates

Oil products

Ferrous combinations

Figure 3.3.8. Black and white copy of the column diagram, which displays the pollution concentrations resulting from the strategy (gray shading) in addition to the current concentrations (black shading)

By moving downward in the same column, user obtains the knowledge on the influence of the constraint imposed on *F7* while the *F4*-related constraint is fixed. One can find various effects of such movement. For example, one can explore how a particular non-dominated frontier, say, the frontier related to the total cost of $600 million, depends upon those constraints. Additional effects can be found on color display. Once again, the number of columns and rows depends only on the quality of the display and may be regulated by user.

Different matrices of decision maps can be displayed and explored, too. Double click of a computer mouse on a decision map results in the selection of the decision map for a detailed exploration. Let us suppose that a decision map was selected, which is related to $100 million investment in the *M*-region and $40 million investment in the *NN*-region. Let us suppose that user decided to consider the range of the total cost between zero and $200 million split into 9 shadings (Figure 3.3.7). One can see how the increment in the cost influences the water quality.

A feasible goal is identified in the decision map by the cross. It is related to the total cost of $150 million. The strategy associated with the identified goal is displayed in Figure 3.3.8.

Figure 3.3.8 contains the same column diagram that is provided in Figure 3.3.2. However, in addition to the current pollution concentrations, the new pollution concentrations (i.e. pollution concentrations resulting from the goal-associated strategy) are displayed in gray. One can see that the pollution with the oil products is substantially less at the monitoring stations located lower than the Moscow region (stations 5, 6, etc.). Nevertheless, the problem of oil product pollution cannot be solved finally since investment is fairly low. It is important that the values of several other pollution indicators are improved, too. Spatial information on the selected water quality improvement plan can be given in a map (see Figure 3.3.9).

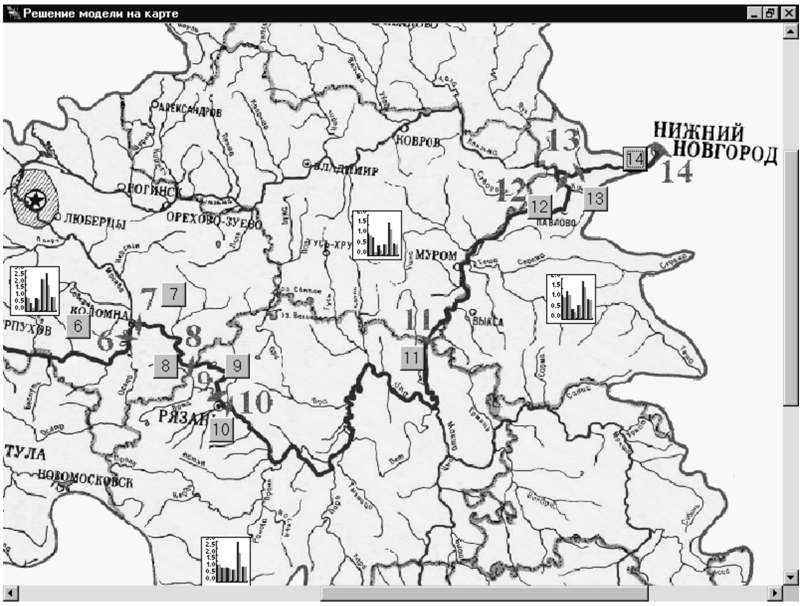


Figure 3.3.9. Black and white copy of the map of a part of the river basin. Icons provide an opportunity to receive information concerning regional pollution levels, investments, pollutant discharge, etc.

The map provided in Figure 3.3.9 displays a part of the river basin. It contains icons that help users receive information about regional values of discharge, pollution and investment. For example, these icons inform on the resulting investment distribution among the regions. It is very interesting that $150 million of total investment was allocated in such a way that the investment in the *M*-region was $56 million and the investment in the *NN*-region was \$16 million. The rest is used in other regions where investment turned to be efficient.

Since a simplified model is used on the screening stage, the selected strategies should be studied and refined in simulation experiments with MIKE 11 that provides an opportunity to explore them, in addition to the most important low-flow season, for other seasons as well. Influence of changes in precipitation scenarios can be explored, too.

Evolutionary mode of DSS application

In the above subsection, the simplest straightforward mode of DSS application is described. Users apply interactive (evolutionary) mode and several loops of strategy selection. The first loop may be related to the display of a strategy in the geographic maps. The map-based display of a strategy provides a better understanding of its features. Often such display results in the desire to change the specification of the screening problem. It means that user returns to the third subsystem, specifies new decision criteria and imposes new constraints on the values of performance indicators. Then, user goes ahead and to follow the screening procedure until the new strategy is generated and displayed.

Let us consider an example. Suppose that by exploring a strategy provided in a geographical map (say, given in Figure 3.3.9) user has found that the pollution levels are too high at several important monitoring stations. Then, user may decide to require ideal values (so called first class water) at those important stations. By this, user provides a new formulation of the screening problem. Exploration of different decision maps may result in a new goal and a new goal-associated strategy. The strategy can be displayed in the geographical map with icons. Information on the strategy can be used as a source of new formulations of the screening problem.

Another loop of the strategy selection procedure may be related to the modification of the integrated model used on the screening stage. As it has been said above, the generated strategy is studied and refined in simulation experiments on the basis of MIKE 11 for all seasons and precipitation scenarios. If the strategy happens not to be appropriate, user may want to broaden the integrated model by combining the influence matrices for the low-flow season with influence matrices related to other seasons and (or) precipitation conditions. We have already described how user can change the formulation of the screening problem by adding new (or more severe) constraints on pollution indicators. The option provided by the extended integrated model consists in an opportunity to formulate additional constraints on new pollution indicators of the extended model. Such loop of evolutionary exploration, however, has not been applied yet.

Real-life application of the DSS

As it was said already, the DSS described here was developed on the request of the Russian Federal Ministry for Natural Resources in the framework of the federal program “Revival of the Volga River”. The new DSS was developed jointly with engineers from the Engineering and Research Center on Water Management, Land Reclamation and Environment “Soyuzvodprojekt” headed by A. Buber. These engineers are the permanent users of the DSS.

The DSS turned to be a convenient and transparent tool for screening of water quality improvement strategies. During one of the meetings at the Russian federal ministry for Natural Resources in 1999, the Vice-minister in charge for internal water management, Mr. N.N.Mikheev required that the DSS should be used in all river basins in Russia. However, a broad application of the DSS is kept back by problems of data collection. Indeed, only a part of the data for the Oka River, namely the pollution transport model, is reliable.

The wastewater discharge pattern and the wastewater treatment technologies are still only plausible. The problem of data collection is vital to real-life application in other river basins, too. Investment into data collection activities may solve the problem. It is planned by the above federal program to provide financial resources for the years 2001-2003 aimed at improving of wastewater discharge data and data on the wastewater treatment technologies that are required by the DSS described in this Section.

Summary

In the framework of the DSS described in this Section, the models of the system MIKE 11 were applied as data preparation tools for the FGM/IDM technique. After selecting one or several strategies, user can apply MIKE 11 once again for simulation of them. Thus, the FGM/IDM technique can be considered as an additional system component that broadens the scope of decision support services provided by water quality simulation systems like MIKE 11.

Demo Web resources described in Section 1.4 show that the above DSS can be easily implemented on Internet. Federal and regional authorities could use it for negotiation preparation. However, it is even more important that millions of ordinary Internet users could be able to apply such Web server individually to obtain information on the whole variety of possible strategies. Such opportunity is discussed in Conclusions.