KAUNAS UNIVERSITY OF TECHNOLOGY

LITHUANIAN ENERGY INSTITUTE

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WATER RESOURCE MANAGEMENT MODEL FOR A RIVER BASIN

Summary of Doctoral Dissertation

Technological Sciences,
Environmental Engineering and Land Management (04T)

Kaunas, 2005

The dissertation has been developed at the Institute of Environmental Engineering, Kaunas University of Technology in 1999 - 2004.

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The official defence of the dissertation will be held at the public session of the Council of Environmental Engineering and Land Management sciences trend at 11 a.m. on 2nd June, 2005 in the Dissertation Defence Hall at the Central Building of Kaunas University of Technology (K. Donelaičio g. 73 – 403, Kaunas).

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The summary of the doctoral dissertation has been sent out on 2 nd May, 2005.

The dissertation is available at the libraries of Kaunas University of Technology (K. Donelaičio g. 20, Kaunas) and Lithuanian Energy Institute (Breslaujos g. 3, Kaunas)

KAUNO TECHNOLOGIJOS UNIVERSITETAS

LIETUVOS ENERGETIKOS INSTITUTAS

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UPĖS BASEINO VANDENS IŠTEKLIŲ VALDYMO MODELIS

Daktaro disertacijos santrauka
Aplinkos inžinerija ir kraštotvarka (04 T)

Kaunas, 2005

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Disertacija bus ginama viešame Aplinkos inžinerijos ir kraštotvarkos mokslo krypties tarybos posėdyje 2005 m. birželio 2 d. 11 val. Kauno technologijos universiteto Centrinių rūmų disertacijų gynimų salėje (K. Donelaičio g. 73 – 403a.).

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Disertacijos santrauka išsiųsta 2005 m. gegužės 2 d.

Su disertacija galima susipažinti Kauno technologijos universiteto (K. Donelaičio g. 20, Kaunas) ir Lietuvos energetikos instituto (Breslaujos g. 3, Kaunas) bibliotekose.

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Introduction

Protection of water resources has been the environmental protection priority for a long period in Lithuania. All environmental protection programmes developed after Lithuania gained independence confirm this statement. Lithuanian Environmental Protection Strategy, approved by Lithuanian Parliament in 1996, says that construction of wastewater treatment plants is the priority for investments from national budget, loans and subsidies. The necessity to minimise pollution of surface and ground water, to reorganise water-financing mechanisms by implementing polluter pays principle and to develop appropriate legislation base is also highlighted in the strategy.
For realisation of this aim, most of investments have been directed for construction of wastewater treatment plants. Significant reduction of surface water pollution by untreated wastewater was achieved. Only 25% of wastewater has been treated sufficiently in 1989-1991, and 40% of sufficiently treated wastewater were discharged in 2000.
Despite pollution decrease due to improved wastewater treatment, the monitoring of surface water indicates that eutrofication of surface water bodies still remains one of the most significant problems.
In terms of drinking water quality, problems are evident almost in each town or settlement because of poor water networks' or dug wells' conditions.
In most cases, the main reason for existing water resource problems are management decisions based on insufficient analysis of interactive fields such as nature, economy and industrial development.
Principles of sustainable development oblige to ensure the equilibrium among socio-economic development and nature. Effective measures should be implemented in order to preserve air, land and water, at the same time promoting socio-economic development.
One of the most important aims of sustainable development in the water resource management area is to decrease pollution of surface and ground water resources by implementing measures, which would:

1. Reduce pollution by industrial and municipal wastewater, dangerous chemicals and pollutants from agriculture.
2. Improve quality of drinking water and conditions for recreation, as well as the state of all ecosystems.

In accordance with these statements, the overall goal is to develop a management model for implementation of sustainable development principles for management of water resources.

Research problem

Majority of surface water bodies are used for assimilation of the generated pollution (wastewater). Small rivers are especially damaged due to inadequate discharge of wastewater. The decline of qualitative parameters of ground water served for drinking purposes in water supply systems can also be mentioned as one of major water resource management problems.

These problems exist due to lack of integrated analysis of natural, economic and social issues in the process of water resource management decision making.
There is no model that would enable to perform an integrated analysis of water resource related problems for increase of decision making effectiveness in terms of improvement of the state of water resource while promoting socio-economic development.

Objectives and targets
The objective is to develop river basin management model that ensures integrated analysis of existing water resource problems and promotes implementation of sustainable development principles in water resources management.
Targets:

1. To identify principles that should be applied for the management model.
2. To develop theoretical model for the water resource management.
3. To evaluate practical application of the developed model in the river basin.

The scope of the investigation
The scope of the investigation is water resource management at national river basin levels, factors influencing the changes of the water resources' state, relations among water users, surface and ground water bodies, and regulating authorities. The scope of investigation is presented in Figure 1.

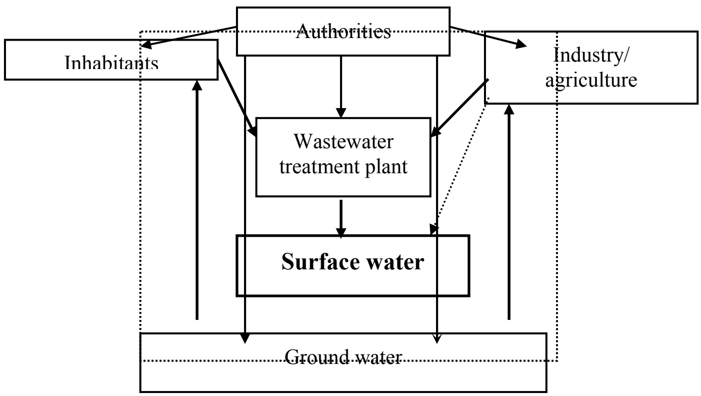

Figure 1. The scope of the investigation

The research methodology
Systems' theory and basics of mathematical modelling have been used for development of mathematical description of the model. Mathematical description includes the boundaries of the object, incoming and outgoing parameters, initial components, their relations and the description of interfering and managing parameters.

Deming's cycle (Plan - do - check - act) was used for the development of object's functional algorithm.

Developed model has been tested in practice using statistical analysis methods and specialised software: QUAL II Windows, 2001 and WEAP 21, 2003.

Original data sources or more than one information sources have been used to ensure reliability of the collected data.

Scientific novelty and actuality of the work

Experience in water resource management demonstrates that problems still exist despite investments in wastewater treatment or improved monitoring system. Inadequate anthropogenic load limits the use of surface water bodies for recreation and fishing. At the same time, drinking water that often does not meet quality requirements is supplied for inhabitants. These problems are typical for catchments of small rivers, where anthropogenic activities are intense and inappropriate to natural conditions. Water resources are used mostly in unsustainable way there. The lack of integrated evaluation in decision-making is the main reason. A number of scientific investigations have been performed in water resource area, but no investigations have been made on the interaction of the state of water resources and pollution, socio-economic and urban development in a river basin. Model for integrated management of water resource in a river basin is developed and presented in this summary. This is the first water resource management model for the river basin that enables to analyse water resource, socio-economic development, to select integrated decisions in the context of sustainable development.

The impact of socio-economic development on the state of water resources in Lithuanian river basins has been analysed for the first time, by performing practical testing of the developed model. Practical testing of the model sustained it's applicability for setting decisions based on integrated analysis of water quantity and quality, taking into account socio-economic conditions, urban development. This model enables to apply the extended approach for water resources management in river basin without separating natural conditions and socio-economic development.

Approbation of the research results

Presentations of the dissertation topic have been made in the following conferences and seminars:

- International Conference "CP Financing: Possibilities and Obstacles". *"CP in the River Basin "*. Proceedings: 1999, Kaunas: Technologija-26p
- International Conference-Exhibition "Small Wastewater Treatment Plant". *Opportunities and Barriers of Economical Analysis for River Basin Management in Lithuania*. Proceedings: 2002, Kaunas: -63p
- Seminar "Integration of Lithuania in to EU: Protection of water Resources", Kaunas. *"Implementation of Water Framework Directive in the Lielupė and Venta rivers basins", 27 11 2001.*
- Seminar "Development of Action plan for Lielupė Basin". *Program of Measures for Lielupė Basin.* 19 04 2002, Šiauliai.

STRUCTURE AND SHORT DESCRIPTION OF THE WORK

The work consists of 3 chapters, introduction, results and conclusions, list of references (105), list of publications and annexes. The text of dissertation is presented in 100 pages.

I CHAPTER – RECENT RESEARCH IN THE FIELD OF WATER MANAGEMENT

The aim of the first chapter is to review recent research in the field of water resource management and to identify basic requirements for the water resource management model that should be used to implement the principles of sustainable development in the water resource management.

This chapter reviews main principles of water resource management in the context of sustainable development. The most important aspects of water resource management that are crucial to ensuring the integration of interdependent fields for comprehensive water resource management in this chapter are highlighted. To make an overview the existing water resource management systems, the analysis of water resource management systems at selected EU countries has been performed and results have been compared with the existing system in Lithuania. This chapter also includes the overview of recent research performed in the field of water resource management.

The following basic requirements have been formulated in accordance to the results of the review:

- The model should enable to take integrated management decisions for particular problem solution, based on a comprehensive analysis of water resources and social-economic factors.
- River basin (or sub-basin) must be considered as the model application boundaries. Mathematical modelling should be used in the model development. Two types of mathematical models – a descriptive and a management model should be applied.
- The main management principle - Deming's cycle (Plan - do - check - act) should be applied for water resource management.
- Institutional structure is one of the main factors ensuring the application of the developed model.

II CHAPTER - DEVELOPMENT OF MANAGEMENT MODEL

The second chapter describes development of the water resource management model. The model will be applicable for the improvement of the state of the water resources. The improvement should be organised by setting up objectives and targets, ensuring the implementation and reviewing results achieved. Deming's cycle has been applied for identification of water resource management cycle elements. Water resource management cycle is presented in the Figure 2. The "plan" phase (1) is the most important, because main problems are identified, objectives for improvement are set and a program of measures is developed.

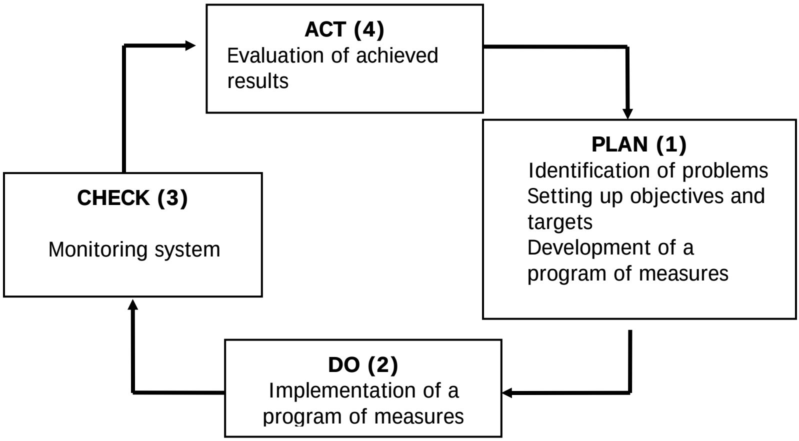

Figure 2. The cycle of water resource management

Selected measures cannot be implemented without the allocation of responsibilities and sufficient resources (2). The implementation process must be monitored to evaluate the results achieved (3). Based on achievements, the next cycle should start (4).
The management model should consist of object's description and its functional algorithm.
While setting up objectives for improvement the object's (river basin) description should be developed for identification of the main problems and for the support of decisions. The object's management algorithm should ensure water resource management cycle in accordance to Deming's principles.
Systems' theory and basics of mathematical modelling of ecosystems have been used for the object description development. Ecosystems' modelling provides a unique possibility to evaluate the impact of urban development on natural ecosystem by use of mathematical equations. Mathematical modelling is a tool, used to simulate and analyse ecosystems' processes.
Object's description development has been performed in accordance with the following steps (see Figure 3):

- problem formulation (initial data);
- conceptual model;
- mathematical description;
- practical application;

Problem formulation is understood as the initial data for object's description development. In accordance to the principles of sustainable development, the equilibrium between economic growth, social welfare and good state of water resources should be reached. Water resources should be used efficiently for fulfilment of society needs. The anthropogenic load to surface water bodies should be based on natural capabilities of water body to assimilate pollution. Drinking water of good quality should be supplied to inhabitants, without the deterioration of resources. Usually, the most unsustainable management of water resources occurs in catchments of small rivers, with big settlements and intense anthropogenic activities. Taking this into account, model application criteria have been defined. The model will be applied for a rather small river basin, where:

- intensive agriculture and industrial centres exist;
- combined wastewater collection system is used;
- ground water is used for drinking water production;
- socio-economic problems exist.

The model should describe the interaction of:

- urban development;
- socio-economic situation;
- state of natural water resources.

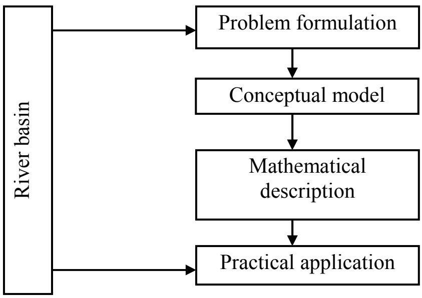

Figure 3. Steps of object description development

In accordance to basic requirements and initial data, **conceptual object description has been developed**. For this purpose system theory has been applied. The complex system was described as an interaction of individual components. The conceptual description of the object is presented in Figure 4.

The object is water resources in river basin. Object's boundaries are hydraulically based boundaries of the river basin. It is assumed that incoming parameters are the following:

- urban activity: inhabitants, industry and agriculture;
- natural conditions: precipitation that forms surface runoff and ground water runoff.

Object components that represent water resources are the following:

- surface water bodies (Assumption is made that only rivers are analysed).
- ground water resources.
- point and non-point pollution sources that discharge wastewater to rivers.

Outgoing parameters are the selected parameters of the water resource state, for example concentration of F_{tot} in the river. Economic conditions that affect the use of water resources have been identified as the main interfering parameter. Managing parameters describe how the impact of interfering parameters should be compensated.

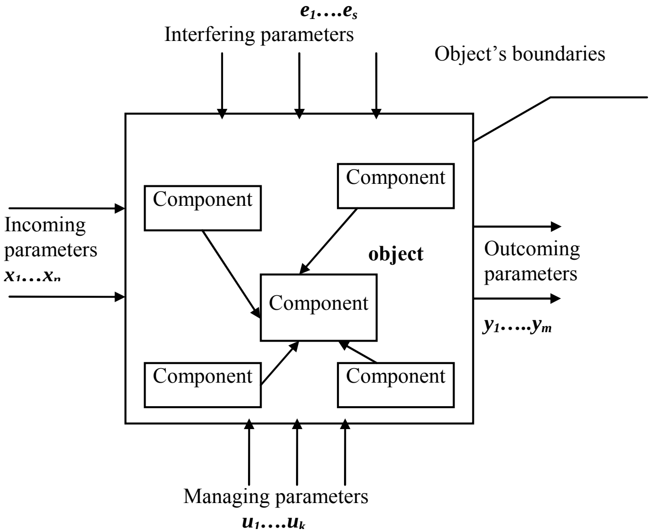

Figure 4. Conceptual description of the object

In accordance to the conceptual object description, mathematical equations have been used to describe the relation among the object components, incoming and outgoing parameters. The components are presented in Figure 5.

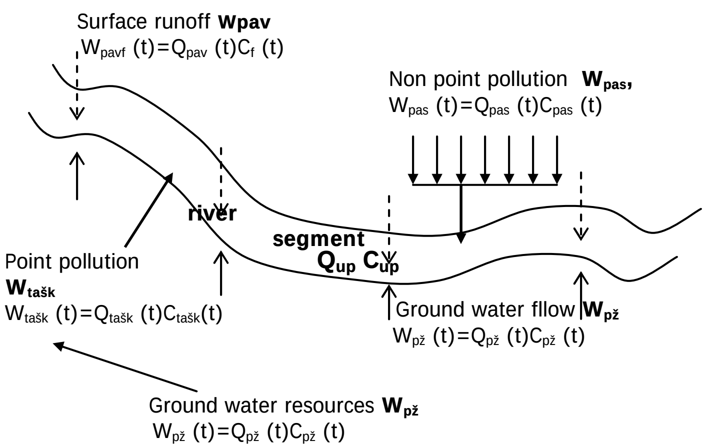

Figure 5. Components of the object

It is assumed that only the **ground water** is used for drinking water supply. Drinking water is used in industrial and municipal sectors. It is considered that the demand of drinking water in municipal and industrial sectors may be expressed with the following equations:

$$Q_{poz} = N_g Q_{sn}(1+\eta_t); \quad (1)$$

Q_{poz}- ground water that must be supplied for municipal sector (m^3/day);
N_g – number of inhabitants;
Q_g – norm of water use per capita(m^3/day);
$\acute{\eta}_t$ - losses in pipeline.

$$Q_{poz} = N_{pr} Q_{pr}(1+\eta_t); \quad (2)$$

Q_{poz}- ground water that must be supplied for industrial sector (m^3/day);
N_{pr} – number of production units per day;
Q_{pr} – norm of water use per production unit (m^3);
$\acute{\eta}_t$ - losses in pipeline.

The demand of ground water supplied for drinking purposes is influenced by economic factors. In accordance to the research analysis, the variation of GDP (Gross Domestic Product) may indicate changes in demand of ground water resources. And may be expressed by following equation:

$$\frac{\partial Q_{poz}}{\partial t} = k_{GDP}\frac{\partial GDP}{\partial t}; \quad (3)$$

Qpoz – demand of ground water (m^3/day);
k_{GDP} – coefficient;
GDP – Gross domestic product in the river basin (LTL).

Generation of wastewater in municipal sector is estimated using the number of inhabitants, the consumed water and the amount of waste generated per capita. Pollution from municipal sector is calculated using the following equation:

$$W_{nv\c{i}} = (K_{nv\c{i}} N_g Q_{sn}(1-\eta_t)C_g)/86.4\cdot 10^3; \quad (4)$$

$W_{nv\c{i}}$ – pollution load from municipal sector (g/s);
$K_{nv\c{i}}$ – efficiency of pollutants removal at wastewater treatment plant;
N_g – number of inhabitants;
Q_{sn} – amount of water used per capita (m3/day);
C_g – pollutants generated by one person (g/m^3);
$\acute{\eta}_t$ - losses in pipeline

Pollution from industrial sector may be expressed using the number of production units, water volume used for production unit and waste amount generated for one production unit. Pollution from industrial sector is expressed by using the following equation:

$$W_{pr} = (K_{pr} I_{p_r} Q_{pr}(1-\eta_t)C_{pr})/86.4\cdot 10^3; \quad (5)$$

W_{pr}– pollution load from industrial sector (g/s);
K_{pr}– efficiency of pollutants' removal;
I_{pr} – production units per day;
Q_{pr} wastewater amount used per production unit (m^3);
C_{pr} – wastewater pollution (g/m^3);

$\acute{\eta}_t$ - losses in pipelines.

Because of mixed wastewater collection and treatment, pollution load from municipal wastewater treatment plant is:

$$\frac{\partial W_{nvį}}{\partial t} = K_{nvi}((\frac{\partial (N_g Q_{sn}(1-\eta_t)C_g)}{\partial t}) + (\frac{\partial (I_{pr} Q_{pr}(1-\eta_t)C_{pr})}{\partial t}))/86.4\cdot 10^3; \quad (6)$$

Another source of point pollution is **rainwater** from urban territory. When rainwater is not treated before its discharge to surface water, pollution from this source of point pollution is described as follows:

$$W_l = K_n I_l C_l / 86.4\cdot 10^3; \quad (7)$$

W_l– pollution from rainwater pollution source (g/s);
K_n– coefficient of rainwater discharge into collection system;
I_l – rain intensity (m^3 / day);
Q_l – concentration of pollutants(g/m^3).

When rainwater treatment exists, the coefficient of the pollutant removal should be included in the equation.

Pollution from agricultural activities is considered in the evaluation of **diffuse pollution** and can be expressed as follows:

$$W_{PAS} = W_{NPį} - W_{NPIŠ}; \quad (8)$$

W_{PAS} – N and P load into the surface water body (g/s);
$W_{NPį}$ – N and P used in agriculture (g/s);
$W_{NPIŠ}$ - N and P assimilated by growing cultures (g/s).

Surface runoff is estimated in accordance to annual runoff. The annual runoff is calculated as follows:

$$Q_m = \frac{1000V}{At}; \quad (9)$$

Q_m - runoff from river basin (A) l/s km^2);
V – volume(l);
A – river basin (km^2);
*t – time (year – 31,5*10^6; day - 86*10^3.*

$$V = \frac{V_{kr}}{V_{išg}} V_0; \quad (10)$$

V_{kr} –rainfall;
$V_{išg}$ – evaporated water ;
V_0 - runoff from surface.

Pollution with water flow is calculated as a part of total annual runoff excluding the surface runoff. The ground water flow is expressed as:

$$W_{poz} = Q_{poz} C_{poz} A / 1000 \tag{11}$$

W_{poz} –ground water pollution load (g/s)
Q_{poz} – ground water flow (A) l/s km^2);
C_{poz} – concentration (g/l); A- river basin km^2

The surface runoff is expressed as:

$$W_{pavf} = (Q_m - Q_{poz}) A C_f / 1000 \tag{12}$$

W_{pavf} – background surface pollution (g/s);
Q_m - surface runoff (A) l/s km^2);
Q_{poz} – ground water feeding (A) l/s km^2);
C_{pavf} – concentration of pollutants in surface water (mg/l); A- river basin km^2

Outgoing parameters are the result of the interaction between components. Discharges from point and non-point pollution sources as well as from surface and ground runoff bring pollutants to the surface water body. The processes in the surface water body (river) that determines the outgoing parameters (organic matter, nitrogen and phosphorus compounds) is presented in the Figure 6.
For description of the processes, the river is divided in segments considering the following assumptions:

1. Surface and ground runoff is of the same intensity at each segment of the river.
2. Each segment operates as a continuously operating reactor (pollutants are mixed immediately and spread homogeneously).
3. The mixing along such river is described as longitude dispersion.
4. The transformation processes are described as a primary kinetic reaction.

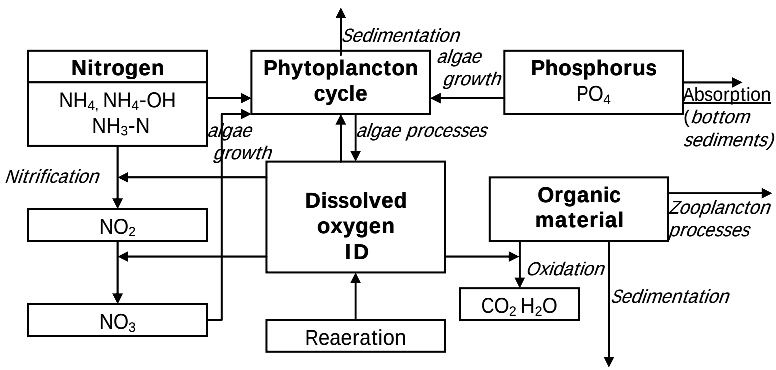

Figure 6. Object's processes

Processes illustrated in the Figure 6 are described by mathematical equations. The main equation, which illustrates changes in the concentration of a pollutant is based on mass balance:

$$\frac{\partial C}{\partial t}=\frac{\partial(A_X D_L \frac{\partial C}{\partial x})}{A_x \partial x}-\frac{\partial(A_X \bar{u} C)}{A_x \partial x}-\frac{dC}{dt}+C\frac{\partial Q}{\partial x}/A_x+\frac{W_{tašk}}{V} \tag{13}$$

C- concentration of pollutant;
x-length of segment;
A_x- cross-section of the segment;
t- time;
D_L – coefficient of dispersion;
ū- mean velocity;
V- external pollution volume;
$W_{iš}$ – external pollution load.

Economic factors, that influence the drinking water demand and pollution generation pattern in municipal and industrial sectors are identified as the main **interfering parameters**. The theory of consumer demand and production function has been used to describe water demand in municipal and industrial sectors.
Water price is the main factor regulating water demand. Therefore, the price mechanism is considered to be the **managing parameter**. Milestones for setting the right price, which covers expenses and keeps the necessary demand, are described.

The object's management algorithm has been developed with the aim to apply the Deming's cycle for water resource management in the river basin. The algorithm describes the decision making process. The algorithm is presented in the Figure 7.
The algorithm used to formulate managing measures Box 3 in accordance to momentary state of the object Box 2, is called functional algorithm or management algorithm.
The algorithm should ensure that the desired outgoing parameters are reached by implementing of the programme of measures. Outgoing parameters describe the state of the water resource, for example the concentration of organic mater in surface water or the demand of drinking water and should be described as objectives Box 1. Monitoring system Box 4 should be developed and used for evaluation of the results.

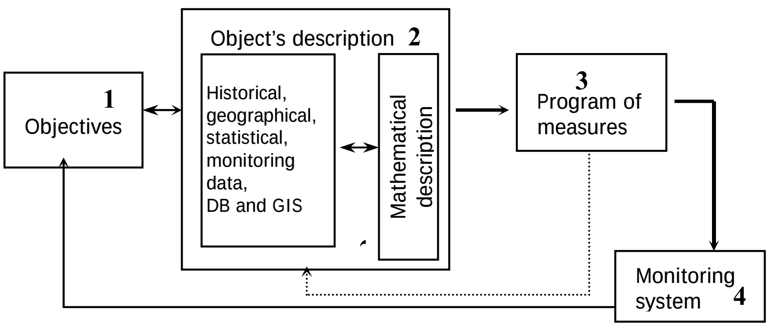

Figure 7. Object's management algorithm

III CHAPTER –APPLICATION OF DEVELOPED MANAGEMENT MODEL

Application of the developed model is overviewed in this chapter. Practical evaluation of the developed model applicability was performed in Mūša - Nemunėlis river basin, because it fulfils the criteria of the model application according to the results of analysis, performed in this river basin.

Practical evaluation contains the following stages:

- selection of software for object‘s description;
- development of data base for mathematical modelling using the selected software;
- development of object’s mathematical description, calibration and evaluation;
- evaluation of the object management algorithm.

Specialised software WEAP 21 and QUAL II was selected for development of Mūša-Nemunėlis river basin mathematical description.

Ground water supply for municipal and industrial sectors, water use, pollution generation and discharge to river has been evaluated using software WEAP 21 (Figure 8).

QUAL II has been used for estimation of pollutant transformation processes (Figure 6).

Database has been developed for application of the specialised software. It contains necessary data for mathematical description of Mūša-Nemunėlis river basin in the dry period (August, 2000)

Mathematical description of Mūša-Nemunėlis river basin (August, 2000) enabled to determine:

1. Drinking water demand in industrial and municipal sector. It was estimated, that drinking water demand equals to 7.152 thousand m^3 /year. The overexploitation of ground water resources is not expected in the future due to sufficient safe yield. Water use norm is about 0.055 – 0.09 m^3 /day per inhabitant.
2. Generated pollution and pollution load to surface water bodies discharged from wastewater treatment plants. It was estimated, that around 400 tones of organic mater (BOD_7), 52 tones of phosphorus (P_t) and 310 tones of nitrogen (N_t) compounds were discharged into the surface water of Mūša-Nemunėlis basin from municipal wastewater treatment plants in 2000. One inhabitant generates approximately:
   - 40 g/day of organic mater (BOD_7)
   - 9.9 g/day of nitrogen (N_t)
   - 1.8 g/day of phosphorus (P_t).

The impact of the pollution (wastewater treatment plants and other identified pollution sources) on the quality of the river Mūša was investigated. The ability of the river to assimilate the pollution has been analysed by determination the coefficients of pollution transformation reactions.

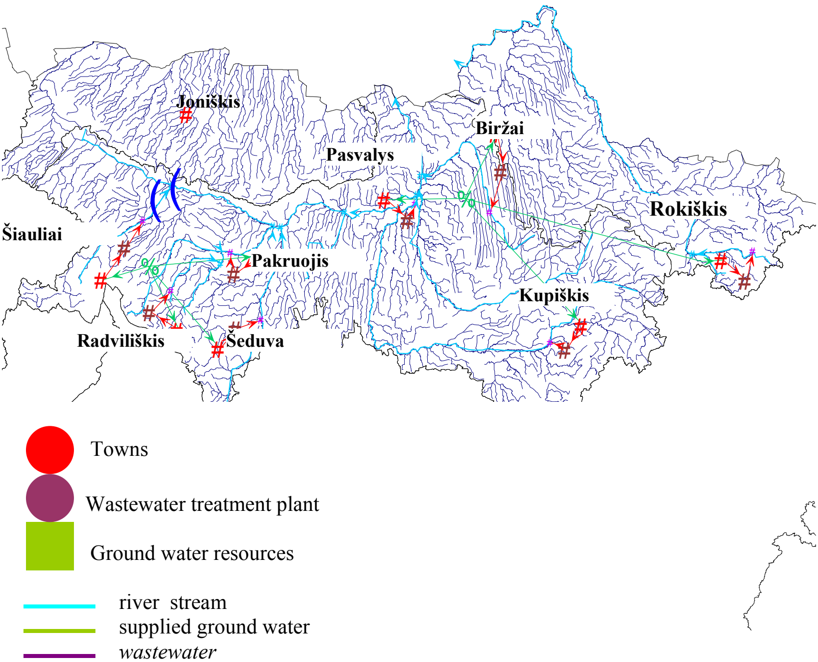

Figure 8. Mūša-Nemunėlis river basin mathematical description

Mathematical description of the Mūša - Nemunėlis river basin enabled identification of the Kulpė sub-basin as worst in terms of sustainable water resource use. Approximately 50% of all drinking water used and pollution generated is in Kulpė sub-basin. The water quality of Mūša decreases significantly after the confluence with Kulpė river.
Therefore possible changes of pollution load to Kulpė and respective changes of Mūša water quality have been analysed. Also the analysis of interferenting parameters in Kulpė sub-basin has been performed.

For the analysis of influence of the interferenting parameters the impact of selected socio-economic factors on water demand have been investigated. The following factors have been selected and their relation to water demand has been analysed by use of linear correlation:

1. Water price.

2. Average income, when the water price is constant.
3. GDP.
4. Inflation.
5. Number of inhabitants.

It is assumed that prognoses of water demand should not be done in accordance to variation of GDP or inflation in present economic situation. The water demand forecast may be created using the variation of water price, average income and number of inhabitants.

Changes in water demand have been analysed under circumstances when the price has risen by 10 % and 20 %, while the average income and the number of inhabitants remained constant.

For the analysis of the pollution load in the river Kulpė, 3 pollution scenarios have been selected.

1. How would the quality of Kulpė water change if the wastewater from Šiauliai municipal WWTP will be discharged in 7,5 km from the river springs (currently 0.9 km) when the flow is constant and concentration of pollutants is the following: BOD_7 – 12.6 mg O_2/l, P_t – 2 mg/l, N_t – 22 mg/l (in accordance to August, 2000 data).
2. How would the quality of Kulpė water change if the wastewater from Šiauliai municipal WWTP will be discharged in 7,5 km from the river springs (currently 0.9 km) when the flow is constant and concentration of pollutants is the following: BOD_7 – 4 mg O_2 / l, P_t – 1 mg / l, N_t – 18 mg / l.
3. How would the quality of Kulpė water change if the wastewater from Šiauliai municipal WWTP will be discharged in 7,5 km from the river springs (present 0.9 km) when the flow is reduced by 10% (due to decreased water demand) and concentration of pollutants is the following: BOD_7 – 4 mg O_2/l, P_t – 1 mg/l, N_t – 18 mg/l.

The results of the mentioned scenarios in comparison to the present situation are presented in the Figures 9, 10, 11, 12, 13, 14.

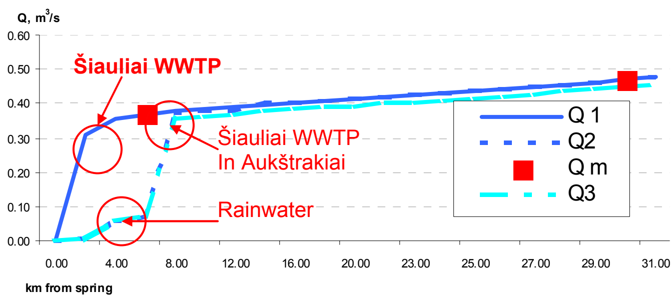

Figure 9. The river Kulpė flow (Q 1 –August, 2000; Q 2 – 1 scenario; Q 3 – 3 scenario; Q m – measured)

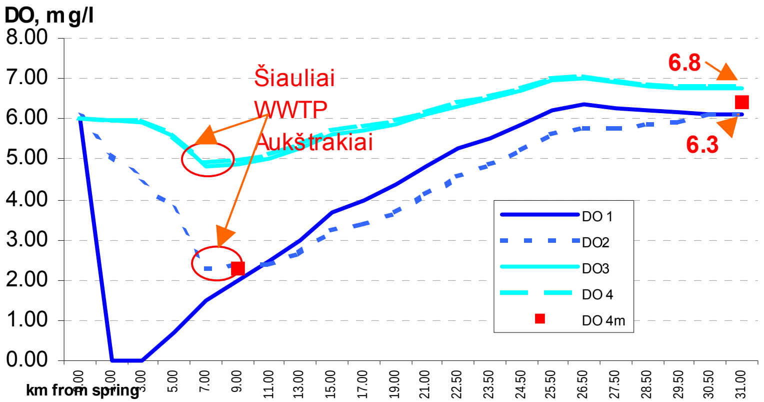

Figure 10. Concentration of dissolved oxygen in Kulpė river (DO 1 –August, 2000; DO 2 – 1 scenario; DO 2- 2 scenario; DO 3 – 3 scenario; DO m – measured)

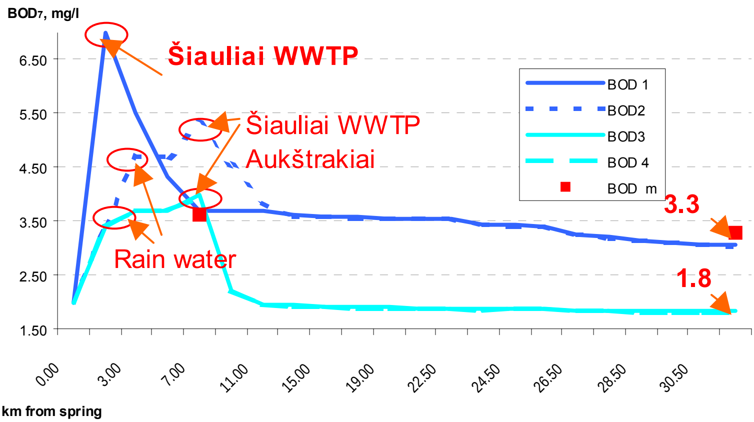

Figure 11. Concentration of organic matter (BOD_7) in Kulpė river (BOD 1 –August, 2000; BOD 2 – 1 scenario; BOD 2- 2 scenario; BOD 3 – 3 scenario; BOD m – measured)

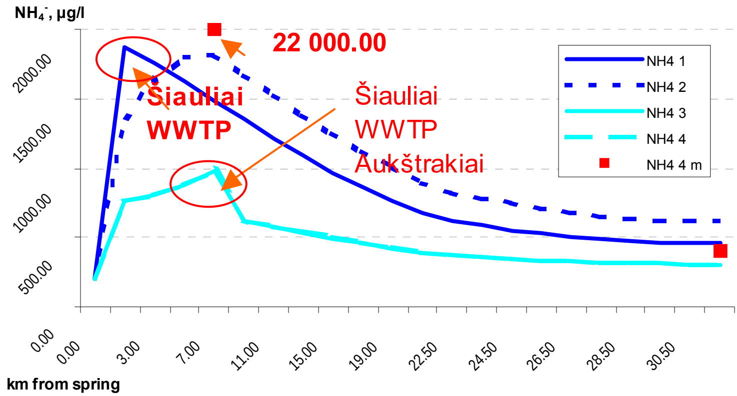

Figure 12. Concentration of ammonium (NH_4^-) in Kulpė river (NH4 1 –August, 2000; NH4 2 – 1 scenario; NH4 2- 2 scenario; NH4 3 – 3 scenario; NH4 m – measured)

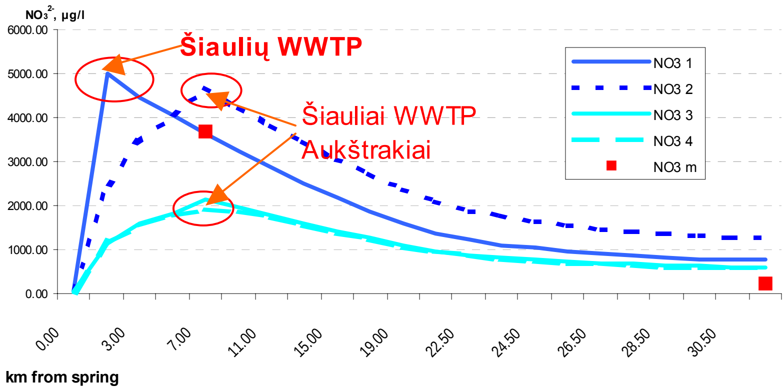

Figure 13. Concentration of nitrates (NO_3^{2-}) in Kulpė river (NO3 1 –August, 2000; NO3 2 – 1 scenario; NO3 2- 2 scenario; NO3 3 – 3 scenario; NO3 m – measured)

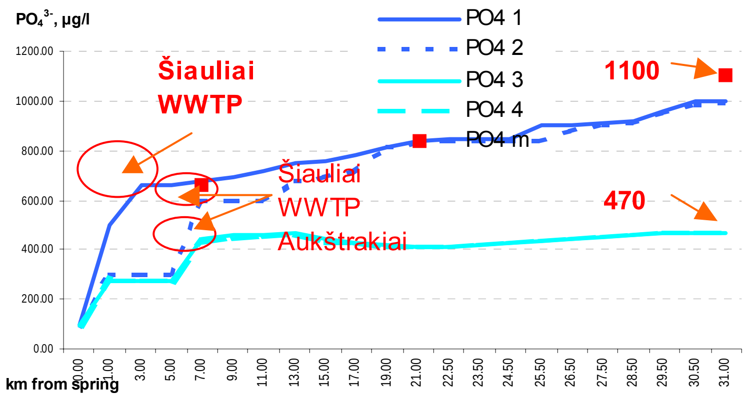

Figure 14. Concentration of phosphates (PO_4^{3-}) in Kulpė river (PO4 1 –August, 2000; PO4 2 – 1 scenario; PO4 2- 2 scenario; PO4 3 – 3 scenario; PO4 m – measured)

According to the base line scenario (August, 2000 modelling results), Šiauliai wastewater treatment plant (WWTP) discharge is clause to the river stream flow (Šiauliai WWTP discharge is 0.3 m^3/s; the Kulpė flow at the point of discharge is 0.38 m^3/s). The concentration of dissolved oxygen (DO) after Šiauliai WWTP discharge is reduced till 0 mg/l; BOD_7 rises till 7mgO_2/l; and PO_4^{3-} - 0.66 mg/l.
The probability of uncontrollable discharge of nitrogen compounds (NH_4^-) in the territory of Šiauliai city was identified during the calibration procedure. According to the calibration results, the nitrogen oxidation coefficient should be more than 10 / day and according to literature the variation range is 01-04/day. For exact evaluation special monitoring should be applied.
In terms of density of pollution sources, it's worth notice in 0 - 4 km from the river springs. There are 8 point pollution sources (rainwater). To reach the DO concentration at least 4mg/l in the Kulpė river, pollution by organic mater should be reduced by 60 % in that segment of the river. Additionally the location of the pollution sources must be evaluated when estimating the optimal pollution load.
When Šiauliai WWTP discharge the wastewater in 7.5 km from the river springs the improvement of Kulpe water quality is noticed. It is estimated that BOD_7 in the river Kulpė would not exceed 6mg O_2/l, PO_4^3 - 0,6 mg/l. The DO concentration in the river would be more than 4 mg/l starting from 16 km from the river springs, when effluent from Šiauliai WWTP is discharged at the same volume with the following concentration of pollutants: BOD_7 – 12.6 mg O_2/l; PO_4^{3-} - 1 mg/l.
When concentration of pollutants is the following: BOD_7 – 4 mg O_2/l, P_t – 1 mg/l, N_t – 18 mg/l (scenario No. 2), the significant changes in the Kulpe river may be noticed. In accordance to the modelling results, the Kulpė river may be classified as "carp water body of moderately good quality". Decrease of flow by 10% from Šiauliai WWTP would not influence the Kulpė river quality significantly. The changes of the Kulpė stream flow would also be insignificant.

The quality of Mūša was investigated due to changes in the Kulpė river (scenario No. 3). The results are presented in the Figures 15 - 20.
The analysis showed that the impact of improved quality of Šiauliai WWTP are evident in Mūša river also. The Mūša river in the confluence with the Kulpė river may be classified as a "carp water body of good quality" with exception to nitrogen compounds.

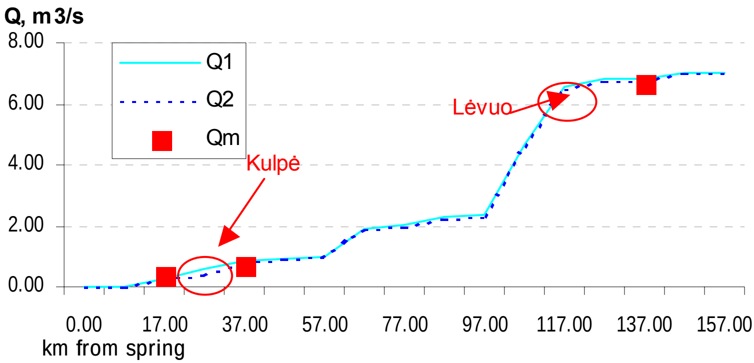

Figure 15. The Mūša river flow (Q1- August, 2000; Q2 –scenario No. 3 Kulpe)

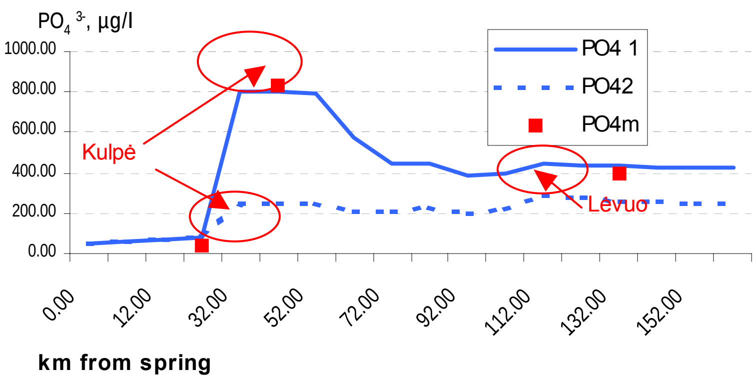

Figure 16. Concentration of phosphates in the Mūša river (PO4 1- August, 2000; PO4 2 –scenario No. 3 Kulpė)

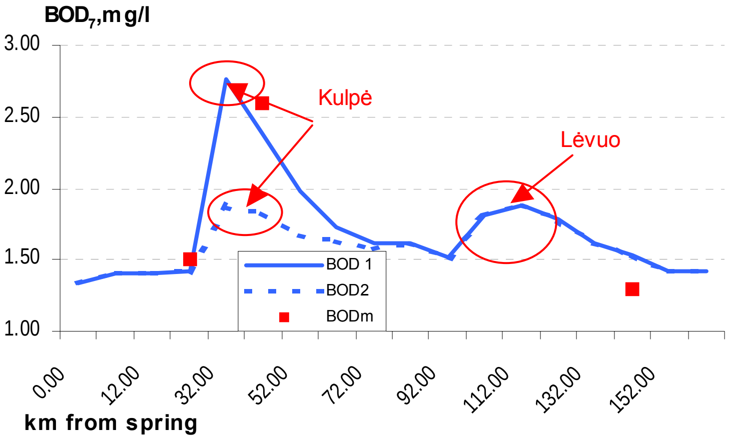

Figure 17. Concentration of organic meter in the Mūša river (BOD 1- August, 2000; BOD 2 – scenario No. 3 Kulpė)

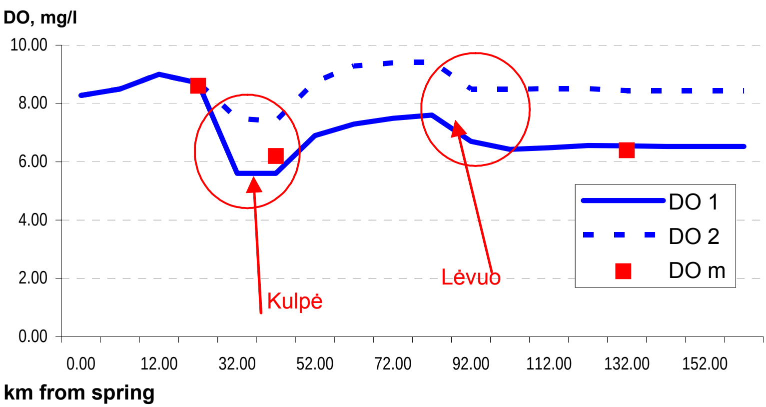

Figure 18. Concentration dissolved oxygen in the Mūša river (DO 1- August, 2000; DO 2 – scenario No. 3 Kulpė)

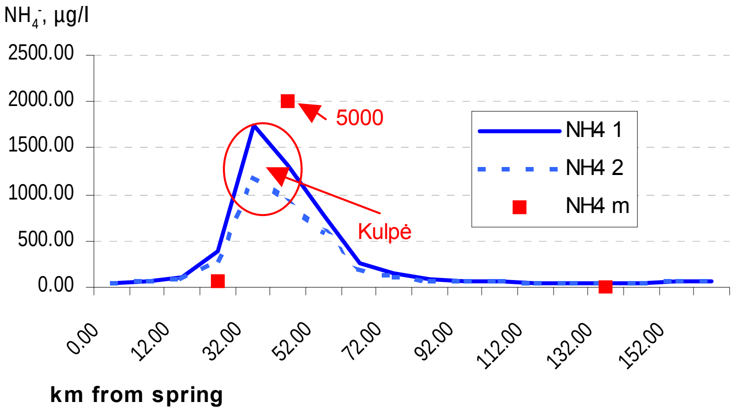

Figure 19. Concentration of ammonium in the Mūša river (NH4 1- August, 2000; NH4 2 – scenarioNo. 3 Kulpė)

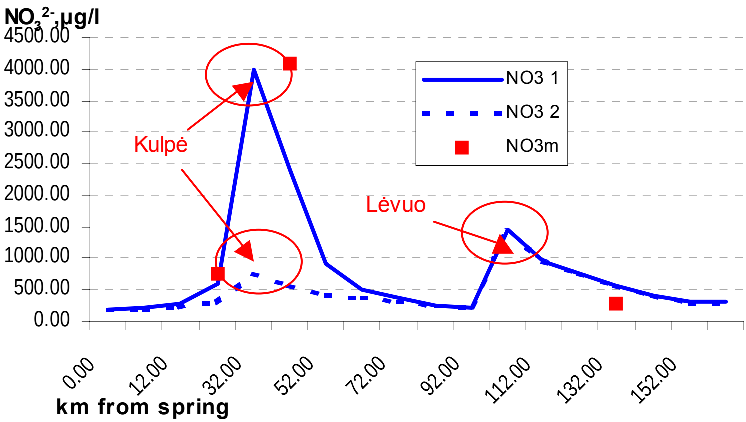

Figure 20. Concentration of nitrates in the Mūša river (NO3 1- August, 2000; NO3 2 –scenario No. 3 Kulpė)

The object's functional algorithm was developed on the basic principles of the Deming's cycle (Plan-do check-act). The basic requirements for the functioning of this cycle are the following: well developed information basis, clearly defined responsibilities, allocated material and human resources. Therefore, allocation of adequate resources, definition of responsibilities in water resource management have been analysed in Mūša - Nemunelis river basin. The institutional unit at the river basin level, database that combines data on the river basin as well as the adequate financing of the implementation oaf water management objectives have been identified as the main preconditions for the functioning of the model.

Conclusions

1. It was concluded that the management model, which promotes the application of sustainable development principles in the water resource management at a river basin level should enable to identify areas where conflicts between natural conditions and anthropogenic activities are evident. Such model must be based on water balance and developed using the systems theory, when a complex system is described as an interaction of different components. Mathematical modelling should be used for description of the interactions.

2. The model should ensure the identification of areas where water resources are used in most unsustainable way and setting up the objectives for the improvement of the situation

3. Developed model should consist of the object description and the object management algorithm. It has been decided that:
   3.1 The object description should include:
      – the following components: surface and ground water bodies, point and non-point pollution sources;
      – incoming parameters: anthropogenic activity, natural conditions of water resources (number of inhabitants, industry, agriculture, precipitation, and runoff);
      – outgoing parameters: parameters of the water resource state resulting from the interaction process.
   3.1. The object is influenced by external interfering parameter, i.e. economic development. For elimination of the impact of this parameter, the managing parameter (e.g. relevant water pricing) must be determined.
   3.2. The object management algorithm must be developed in accordance to the Deming‘s cycle.

4. The investigation of the developed model application have been performed in the Mūša – Nemunėlis river basin, because in accordance to the performed analysis, this basin fulfils the criteria of the model application:
   4.1. Big settlements are located in the basins of small rivers.
   4.2. More then 50 % of land cover is used for agricultural purposes.
   4.3. Drinking water problems are present.
   4.4. Socio - economic problems are present.

5. The model has been tested using specialised software WEAP 21 and QUAL II. Mathematical description of the Mūša – Nemunėlis river basin was developed and tested, preconditions for functioning of object’s algorithm have been defined. Results of practical testing lead to the conclusion that the developed model is applicable for promoting sustainable water resource management in the river basin. The model enables analysis of the influence of socio-economic factors for water resource management and analysis the capacity of water bodies to assimilate

pollutants. This conclusion is based on practical testing results, that are presented below:

5.1. The evaluation of socio-economic factors showed that GDP should not be used for the forecast of drinking water demand in the municipal sector, because the correlation is not sufficient (<0.7). Credible correlation was estimated for an average income (0.84), the number of inhabitants (0.86) and water price (0.95). It is the water price that most significantly influences water demand in the municipal sector.

5.2. The analysis of economic factors for water pollution when the waste generation and the efficiency of pollutant removal at wastewater treatment plants is constant showed that pollution volume would decrease if demand will decrease. It is recommended to monitor the changes of treatment efficiency depending on the concentration of collected wastewater.

5.3. QUAL II software was used for analysis of pollution. This software is suitable for evaluation of point pollution load and setting targets for diminishing the pollution. It is recommended to use this software in the process of issuing permissions for pollution.

6. After evaluation of the object‘s algorithm in the Mūša – Nemunėlis river basin, the following conclusions have been made:

6.1. It is necessary to establish the institutional unit at a river basin level responsible for water management to ensure the implementation of selected water management measures. The composition of such a unit must be diversified to ensure integrated decision-making. Additionally international relations should be defined in case the river basin is not in the territory of a single country.

6.2. Financing for water management measures must be coordinated at ariver basin level. The institutional unit responsible for water management at a basin level must be involved in the process of allocating of financing for water resource management. When analysing water supply, it is recommended to define the marginal losses in water supply systems and to motivate water supply companies to reach this value (minimise losses), by using environmental taxes to be paid by water supply companies.

6.3. Database based on the boundaries of a river basin must be developed to ensure the reliability of the used data. The database should contain the information about water resources, anthropogenic activity and socio-economic development.

Publications

The main findings of the dissertation are presented in the publications listed bellow. Publications include reviewed articles in the periodical scientific research journals and articles in proceedings of international conferences.

Reviewed articles in the periodical scientific research journals:

1. Vincevičiene V., Jelisejevienė E. *Nevėžis River Water Quality Modelling and Evaluation (ecological and environmental) in the Panėvežys region*. Environmental Research, Engineering and Management. 1999. No.3 (10). ISSN 1392-1649. Kaunas: Technologija. 26-37p.
2. Jelisejevienė E. *Analysis of Application of Preventive Measures for the River Mūša Basin Management.* Environmental Research, Engineering and Management. 2001. No.2 (16). ISSN 1392-1649. Kaunas: Technologija. 42-47p.
3. Vincevičienė V., Jelisejevienė E. *Integrated Management of Water Resource: River Basin Action Plan*. Environmental Research, Engineering and Management. 2003 No. 1(23). ISSN 1392-1649. Kaunas: Technologija. 3-12p.

Proceedings of international conferences:

1. E. Jelisejevienė. *CP in the river basin*. International Conference: "CP Financing: Possibilities and Obstacles". Proceedings, 1999 Kaunas: Technologija - 26p.
2. Vincevičienė V., Jelisejevienė E. *Opportunities and Barriers of Economic Analysis for River Basin Management in Lithuania.* International Conference-Exhibition "Small wastewater treatment plant". Proceedings, 2002 Kaunas: - 63p.

About the Author

Emilija Jelisejevienė graduated bachelor studies in Environmental Engineering at Kaunas University of Technology in 1997.

M.Sc.studies have been completed in the same area successfully in 1999 and the M.Sc. degree in Environmental Engineering has been awarded. The title of M.Sc. thesis - "Water Quality Modelling of Water Pollution of the Nevėžis River Basin in Panevėžys City Region".

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Currently Emilija Jelisejevienė is a researcher at the Institute of Environmental Engineering. Research areas: integrated water resource managements in the river basin, integrated (environmental, quality) management systems in enterprises.

Reziume

Dauguma paviršinių vandens telkinių yra naudojami su nuotekomis išleidžiamiems teršalams praskiesti. Dėl neadekvačios taršos ypač mažų upių vandens kokybės rodikliai (organinių medžiagų, azoto, fosforo junginių koncentracija) yra nepatenkinami. Požeminio vandens išteklių, naudojamų geriamam vandeniui tiekti, kokybė pablogėja tinkluose dėl gerokai sumažėjusios geriamo vandens paklausos. Ją lemia ekonominiai bei socialiniai veiksniai.

Šios vandens išteklių problemos egzistuoja, nes priimant jų naudojimą reguliuojančius valdymo sprendimus nėra integruotai vertinama gamtinė aplinka, ūkinė plėtra, ekonominiai bei socialiniai veiksniai. Nėra sukurto valdymo modelio, kurį taikant, būtų galima įvertinti ūkinės plėtros, ekonominių veiksnių bei gamtinės aplinkos (vandens išteklių) sąveiką ir vadovaujantis gautais rezultatais, priimti integruotus vandens išteklių naudojimą reguliuojančius sprendimus. Tokie sprendimai būtų pagrįsti, leistų gerinti vandens išteklių būklę siekiant subalansuoto jų naudojimo.

Tyrimų tikslas – sukurti upės baseino vandens išteklių valdymo modelį, kuris užtikrintų sisteminę vandens išteklių problemų analizę, integruotų valdymo sprendimų priėmimą, siekiant subalansuoto vandens išteklių naudojimo upės baseine.

Uždaviniai:

1. Nustatyti principinius reikalavimus vandens išteklių valdymo modeliui.
2. Parengti teorinį vandens išteklių valdymo modelį.
3. Įvertinti modelio pritaikymą, numatyti būtinas prielaidas funkcionavimui užtikrinti.

Tyrimo objektas

Tam, kad būtų sukurtas upių baseino vandens išteklių valdymo modelis, analizuotas vandens išteklių naudojimas valstybiniu bei upės baseino lygiu.

Tirti veiksniai, darantys įtaką vandens išteklių būklės kitimams (vandens sunaudojimas bei jį lemiantys ekonominiai, socialiniai veiksniai, nuotekų išleidimas), požeminio vandens telkinių, vandens naudotojų (pramonės įmonių, žemės ūkio, gyventojų) ir paviršinių vandens telkinių ryšiai. Analizuotas valdžios institucijų vaidmuo, reguliuojant vandens išteklių naudojimą. Vertintos esamos institucinės sistemos, teisinės, ekonominės vandens išteklų naudojimą reguliuojančios priemonės.

Tyrimo metodika

Vadovaujantis sistemų teorija bei matematinio modeliavimo pagrindais buvo apibrėžtos objekto ribos, nustatytos komponentės. Ryšiai tarp atskirų komponenčių buvo aprašyti taikant masių balanso, paklausos ir pasiūlos teorijas.

Sudarant objekto valdymo algoritmą vadovautasi Demingo ciklu „Planuok – vykdyk – tikrink – veik“

Siekiant nustatyti ekonominės raidos veiksnius, turinčius įtakos vandens paklausai, vadovautasi vartotojų prekių pasirinkimo teorija.

Vandens išteklių valdymo modelis patikrintas naudojant statistinės duomenų analizės metodus, taikant specializuotą programinę įrangą *QUAL II Windows aplinkoje, 2001* ir *WEAP 2*.

Tyrimo aktualumas, mokslinis naujumas

Ilgametė patirtis parodė kad, vien tik tobulinant vandentvarkos ūkį ir stiprinant stebėsenos sistemą, vyraujančios vandens išteklių problemos lieka neišspręstos. Neadekvati antropogeninė apkrova lemia nepatenkinamą paviršinių vandens telkinių būklę, dėl to apribojama rekreacija, vandens sportas, mažėja vandens gyvūnijos įvairovė. Gyventojams tiekiamas ne visus kokybės reikalavimus atitinkantis geriamasis vanduo. Priežastis dažniausiai yra pernelyg ilgas tiekiamo vandens buvimas tinkluose dėl sumažėjusios paklausos.

Paviršinio vandens kokybės problemos ypač aktualios mažų upių baseinuose, kur plėtojama intensyvi žemdirbystė, pramoninė veikla. Problemoms spręsti iki šiol taikyti nuodugnūs paviršinio vandens būklės tyrimai, pramoninės, žemės ūkio poveikio analizė. Tačiau nebuvo integruotai analizuotas vandens išteklių naudojimas upės baseine, apimant ūkinę veiklą, taršos šaltinius, procesus upėje, vertinant ekonominės, socialinės raidos įtaką. Sukurtas valdymo modelis skirtas upių baseinų vandens išteklių naudojimui valdyti, pasitelkiant integruotą analizę. **Tai pirmasis vandens išteklių valdymo modelis, leidžiantis analizuoti vandens išteklių būklę upės baseine įvertinant ekonominius, socialinius veiksnius. Remiantis šia analize galima valdyti vandens išteklių naudojimą, įprasminant subalansuotos plėtros principus.**

Taikant šį modelį, pirmą kartą analizuota ekonominės raidos įtaka vandens ištekliams upės baseine.

Modelis leidžia nustatyti problemų priežastis, užtikrina vandens išteklių būklės gerinimo sprendimų pagrįstumą. Ekonominės ir socialinės raidos veiksnių, turinčių įtakos sunaudojamo vandens kiekiui, nustatymas bei įvertinimas suteikia galimybę prognozuoti vandens paklausą, nuo kurios priklauso tolesni sprendimai, nustatant tiek technines, tiek kitas vandens išteklių naudojimą reguliuojančias priemones.

Išvados

1. Nustatyta, kad vandens išteklių valdymo modelis, kuris skirtas subalansuotam vandens išteklių valdymui įgyvendinti, turi būti sudarytas vadovaujantis sistemų teorija, pagal kurią sudėtinga sistema suskaidoma į atskirus komponentus, jų tarpusavio sąveika aprašyta pasitelkus matematinį modeliavimą, apimant ekonominės, socialinės raidos įtaką vandens ištekliams.

2. Modelis turi užtikrinti vandens išteklių būklės gerinimą, nustatant valdymo tikslus, priemones jiems įgyvendinti, kurios būtų pagrįstos integruota vandens išteklių, ekonominės raidos analize.

3. Sukurtąjį vandens išteklių valdymo modelį upės baseinui sudaro objekto (upės baseino) matematinis aprašas ir objekto valdymo algoritmas, pagal kurį formuojamas valdantysis poveikis, priklausomai nuo momentinės objekto būklės. Nustatyta, kad:

3.1. Objekto aprašą (upės baseiną) turi sudaryti:
   - šios komponentės: paviršinio, požeminio vandens telkiniai, sutelktosios ir pasklidosios taršos šaltiniai;
   - šie įeities dydžiai: ūkinę veiklą bei esamas gamtines sąlygas apibūdinantys veiksniai (gyventojai, pramonė, žemės ūkis, krituliai, nuotėkis);
   - vidinių komponenčių tarpusavio ryšių bei priklausomybės nuo įeitinių duomenų aprašymas;
   - šie išeities dydžiai: vandens išteklių būklę apibūdinantys parametrai, kurie gaunami kaip proceso rezultatas.

3.2. Objektui įtaką daro išorinio trikdančio parametro – ekonominės raidos veiksniai. Norint juos eliminuoti, turi būti nustatomi valdantieji parametrai, pvz., pagrįstas vandens išteklių kainų nustatymas.

3.3. Valdymo algoritmas turi būti sudarytas, vadovaujantis Demingo ciklu, pagal kurį parenkami atitinkami valdymo parametrai norimiems išeities dydžiams gauti ir užtikrinamos sąlygos planuojamiems rezultatams pasiekti

4. Sukurto valdymo modelio eksperimentiniai tyrimai atlikti Mūšos - Nemunėlio baseine, nes, atlikus analizę, nustatyta, kad šis baseinas atitinka modelio taikymo kriterijus.

4.1. mažų upių (baseino plotas yra 100km^2) baseinuose įsikūrę pramoniniai centrai, pvz., Šiauliai;

4.2. daugiau nei 50 % žemės naudojama žemdirbystės tikslams;

4.3. būdingos geriamo vandens kokybės problemos dėl sumažėjusios paklausos;

4.4. socialinės –ekonominės problemos

5. Modelio eksperimentiniai tyrimai atlikti, pasitelkiant WEAP 21 bei QUAL II programines įrangas. Nustatytos būtinos modelio funkcionavimo sąlygos, tobulinimo rekomendacijos. Gauti rezultatai leidžia formuluoti išvadą, kad modelis iš esmės yra tinkamas vandens ištekliams baseine valdyti subalansuotos plėtros kontekste, nes leidžia analizuoti ekonominių veiksnių įtaką, nustatyti galimą taršos dydį, kurį gali vandens telkinys asimiliuoti, esant tam tikram ūkinės veiklos intensyvumui Šį teiginį pagrindžia toliau pateiktos modelio taikymo išvados:

5.1. Ekonominių ir socialinių veiksnių įtakos vandens paklausai vertinimas leido nustatyti, kad BVP kitimas ir vandens paklausos koreliacija yra nepakankama (< 0,7). Vandens paklausos prognozės negali būti atliekamos, remiantis šiuo rodikliu. Patikimai vandens paklausos kitimus atspindi vidutinis darbo užmokestis (0,84) bei gyventojų skaičius (koreliacija – 0,86). Didžiausią įtaką vandens paklausai daro kaina (koreliacija – 0,95).

5.2. Ekonominių veiksnių įtakos paviršinių vandenų būklei vertinimas, formuluojant prielaidą, kad susidaro pastovus teršalų kiekis ir, valant nuotekas vandenvalos įrenginiuose, teršalų pašalinimo efektyvumas yra pastovus, leido pateikti išvadą, kad, mažėjant vandens paklausai, tarša iš vandenvalos įrenginių mažėja. Tačiau būtina nustatyti, kaip kinta technologinio nuotekų valymo proceso efektyvumas, keičiantis į valymo įrenginius patenkančių nuotekų užterštumui. Tai turėtų būti vertinama, analizuojant nuotekų valymo kaštus, kai pasirenkami pastovūs išvalytų nuotekų kokybiniai rodikliai. Taip būtų galima reguliuoti ir pramoninius išleidimus į vandenvalos įrenginius.

5.3. Nustatant galimą taršos dydį, naudota programinė įranga QUALL II. Nustatyta, kad, naudojant šia programinę įrangą, galima parinkti sutelktosios taršos šaltinių išdėstymą bei maksimalią taršą, taip pat galima nustatyti taršos mažinimo tikslus. Rekomenduotina šią programinę įrangą taikyti taršos į paviršinius vandenis leidimų išdavimo sistemoje.

6. Vertinant objekto funkcionavimo sąlygas, nustatyta, kad:

6.1. Yra būtinas baseino valdymo institucinis vienetas, kuris paskirstytų atsakomybes, įgyvendinant numatytas valdymo priemones. Institucinio vieneto sudėtis turėtų būti pakankamai įvairi, kad būtų galima visapusiška problemų analizė. Taip pat reikalingas tarptautinis bendradarbiavimas baseino valdymo klausimais, kai baseinas yra ne vienos valstybės teritorijoje.

6.2. Yra būtinas pakankamų materialinių išteklių paskyrimas. Tam reikia, kad, priimant sprendimus dėl vandens išteklių finansavimo, dalyvautų ir baseino valdymo institucinis vienetas, kuris turėtų tam tikrą įtaką. Analizuojant vandens paslaugų atsiperkamumą, siūloma nustatyti bendrosios vandens netekties ribinę vertę, kurios vandens tiekimo įmonės būtų skatinamos siekti, pvz., jų sumokėtų mokesčių už taršą sąskaita.

6.3. Viena iš būtinų modelio patikimumo užtikrinimo sąlygų yra bendros informacinės sistemos sudarymas baseino mastu. Taip būtų kaupiama informacija apie vandens išteklius, vykdomą ūkinę veiklą, ekonominę, socialinę situaciją baseine. Tai leistų tiksliau sudaryti matematinį objekto aprašą.

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UDK 502.6 + 556.531.4](043)

SL 344.2005-04-27 1 leidyb. apsk. l. Tiražas 70 egz. Užsakymas 179
Išleido leidykla „Technologija“, K. Donelaičio g. 73, 44029 Kaunas
Spausdino leidyklos „Technologija“ spaustuvė, Studentų g. 54, 51424 Kaunas