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Sustainable management of the wastewater disposal system

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Abstract: The paper presents one possibility of applying Object Oriented Modeling in the function of sustainable management of the wastewater drainage system. The applied technique (tool) for the implementation of systematic analysis, modeling, simulation and analysis of the obtained results is object-oriented modeling (OOM) and software package STELLA, which is adapted to complex and dynamic systems, such as wastewater drainage and treatment. The paper uses an already developed and applied model consisting of physical components of the system, the model of water quantity and water quality of the drainage system, and then also upgraded with part of the socio-economic system - the system of operating and maintenance costs. This methodological approach to modeling (using models) and imitating the real system (simulation), and analysis of the obtained results of the simulation flow, using OOM, proved to be a useful and effective tool for managing and analyzing sustainable management of urban drainage systems. A model and methodology is proposed for the analysis and wider application of complex urban water systems.

Key words: drainage, wastewater treatment, object oriented modeling, sustainable development

Održivo upravljanje sustavom odvodnje otpadnih upotrijebljenih voda

Sažetak: U radu je prikazan jedna mogućnost primjene Objektno orijentiranog modeliranja (OOM) u funkciji održivog upravljanja sustavom odvodnje upotrijebljenih otpadnih voda. Primijenjena tehnika (alat) za provedbu sustavne analize, modeliranje, simulaciju i analizu dobivenih rezultata je objektno orijentirano modeliranje (OOM) i programski paket STELLA, koji je prilagođen složenim i dinamičkim sustavima, kakav je sustav odvodnje i pročišćavanja otpadnih voda. U radu je korišten već izrađeni i primijenjeni model koji se sastoji od fizičkih komponenti sustava, modela količine vode i kakvoće vode sustava odvodnje, a zatim i nadograđenim i dijelom socio-ekonomskog sustava – sustav troškova rada i održavanja sustava. Ovakav metodološki pristup modeliranja (korištenjem modela) i oponašanjem realnog sustava (simulacijom), te analizom dobivenih rezultata simulacijskog toka, primjenom OOM-a, pokazao se kao koristan i učinkovit alat za upravljanje i analizu održivog upravljanja sustava odvodnje urbanih područja. Model i metodologija je predložena za analizu i širu primjenu složenih urbanih vodnih sustava.

Ključne riječi: odvodnja, pročišćavanje otpadnih voda, objektno orijentirano modeliranje, održivi razvoj

1. INTRODUCTION

Wastewater drainage and sewage system is a subsystem of a complex urban water system. Management of these infrastructural components is a very demanding and complex task, because it is necessary to meet all the requirements related to the drainage of all users of water services (water supply), or to take all used water to the wastewater recipient. In the process, a number of conditions and limitations need to be met in terms of capacity, transport, socio-economic and social categories, without compromising the general natural environmental characteristics of the water regime or the natural ecosystem.
The goal is to achieve the best possible and sustainable levels of responsibility of the drainage system with regard to all basic parameters of the system, which includes the following:

- collect all wastewater used,
- transport it to the treatment plant,
- treat it and
- discharge it into the recipient

The paper will present a simulation of the operation and management of the drainage system in urban areas using object oriented modeling (OOM), or using the already built object oriented model [3], which was developed to manage the entire urban water system. A submodel - modified urban water system model, called SUSTAINABLE_DRAINAGE (ODRZIVA_ODVODNJA), adjusted only to simulate and present the operation of the sewage subsystem of wastewater drainage, taking into account all system sustainability components, was made for this case where only a part of urban water is used. The model was created using the software package STELLA, which is suited to complex and dynamic systems. The sewage system for the drainage of wastewater of the city of Mostar (BiH) was taken as an example for using an operation and management simulation. Thus, the objective is to present a simulation of the operation and management of a complex wastewater drainage system of an urban area - an integrated view and to present and explain the simulation results while providing guidelines and recommendations to improve the system operation in the context of sustainable development.

1.1 Previous experience in application of OOM and other tools for simulating the operation of drainage systems

The paper "Financially sustainable management strategies for urban wastewater collection infrastructure – development of a system dynamics model" [8] presents flow diagrams and causal loops developed for wastewater collection networks to identify complex interactions and feedback loops among physical, financial and social sectors. Causal loop diagrams are then incorporated into a novel system dynamics based decision support tool that can be used for financially sustainable management of wastewater collection networks. Data requirements to develop the decision support tool are discussed along with how can the decision support tool be used to manage a utility.

The paper "A combined model to assess technical and economic consequences of changing conditions and management options for wastewater utilities" [9] presents a simplified model that quantifies the economic and technical consequences of changing conditions in wastewater systems on utility level. It was developed based on data from stakeholders and ministries, collected by a survey that determined resulting effects and adapted measures. The model comprises all substantial cost relevant assets and activities of a typical German wastewater utility. It consists of three modules: i) Sewer for describing the state development of sewage systems, ii) WWTP for process parameter consideration of waste water treatment plants (WWTP) and iii) Cost Accounting for calculation of expenses in the cost categories and resulting charges.

Another paper illustrating a good tool for optimizing complex systems: "Integrated and Control-Oriented Simulation Tool for Optimizing Urban Drainage System Operation" [10]. The paper presents and introduces an innovative modeling software, Simuwater, which couples multiple principles, simulates multiple system components, and combines optimized control functions. The software was utilized in a real-time case-control study in one city of China, and it obtained significant optimized operation results to reduce combined sewer overflow (CSO) by making full use of the storage facilities and actuators.

The paper "A spatial multi-objective optimization model for sustainable urban wastewater system layout planning" illustrates a design of a sustainable city that has changed the traditional centralized urban wastewater system towards a decentralized or clustering one. The potential options are numerous for planning the layout of an urban wastewater system, which are associated with different costs and local environmental impacts. There is thus a need to develop an approach to find the optimal spatial layout for collecting, treating, reusing and discharging the municipal wastewater of a city. In this study, a spatial multi-objective optimization model, called "Urban wastewateR system Layout model (URL)", was developed. It is solved by a genetic algorithm embedding Monte Carlo sampling and a series of graph algorithms. This model was illustrated by a case study in a newly developing urban area in Beijing, China.

Previous research on the sustainability and modeling of drainage system operation is in most cases limited to using a particular model or existing software to simulate system operation and is related exclusively to simulating one component or only part of the components of the sustainability system. It is either just a technical - physical drainage system - wastewater quantity and quality system or just a financial and economic system or just water treatment - ecological subsystem. The problem is considerably more complex because it is a simulation of complex systems where the problem should be considered integrally in the context of the relationship of the drainage system with the socio-economic system, ecosystem and incorporate all this into legal frameworks and legislation. It is precisely OOM and the proposed model that can be used for complex systems including all structural and non-structural components of the sustainability of wastewater drainage systems in urban areas.

2. SUSTAINABILITY OF DRAINAGE SYSTEMS

Sustainability is the ability to maintain balance of certain processes or states in a system. Today, it is most commonly used in conjunction with biological and human systems, but it also applies to urban systems and their infrastructure. For humans, ecological sustainability is the basis for long-term maintenance of well-being, which in turn depends on the well-being of the natural world and the responsible use of natural resources. The city is a system that significantly consumes natural resources for human life and production and is one of the dominant drivers of negative environmental changes in space. Elements that drive negative impacts are, among other things, liquid and solid waste generated by populated areas, which is why they need to be disposed of in a way that does not jeopardize the sustainability of the environment and man. For this reason, it is important to understand the objectives and criteria of sustainability, as well as the factors that define sustainability. Sustainability has become a broad term that can be applied to almost all aspects of life on Earth, from the local to the global level and through different time periods. Definitions of sustainability often refer to "three pillars/factors", or social, environmental and economic sustainability in which each factor is of equal importance for the sustainability of man and society as a whole. [1]

Sustainability has been used since the 1980s in terms of human sustainability on planet Earth, resulting in the most commonly cited definition of sustainability and sustainable development adopted by the United Nations Brundtland Commission: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." It can be observed that this requires reconciliation of environmental, social and economic needs - the "three pillars" of sustainability. This concept is illustrated by an image with three overlapping ellipses indicating three sustainability pillars that are not mutually exclusive and can be mutually reinforcing (Figure 1).

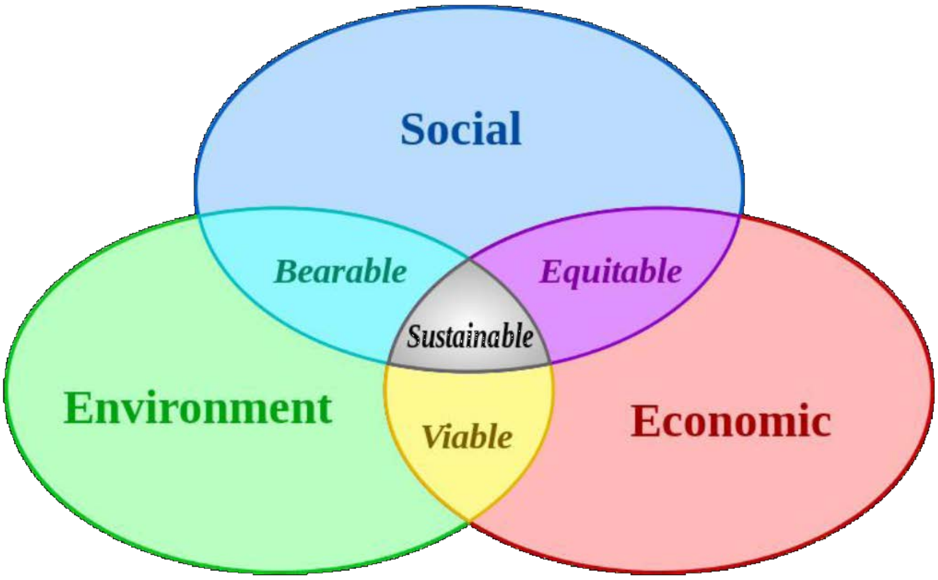

Figure 1. Basic elements of sustainability and their measures [12]

The primary goal is to reduce the amount of pollutants in used water that must be discharged into the environment at a level that is acceptable to public health and the environment. The system includes wastewater collection, treatment and discharge.

Conventional management involved the provision of a wastewater collection network (system of sewers) with discharge into the recipient (river, sea). The problem of environmental pollution is solved by providing centralized wastewater treatment plants. There are a number of limitations in such a model of used water drainage system [2]:

- wastewater treatment plants are very demanding and require large investments and staff and are difficult to construct and operate in smaller, poorer urban areas;
- secondary and even tertiary treatment leave unprocessed some nutrients and micro-pollutants that can still pollute the environment;
- problems with pollution increase if industrial waste is discharged into the network without prior treatment, because wastewater treatment plants cannot treat some special industrial substances that are strong pollutants (e.g. heavy metals);
- increased water consumption requires an increase in the network and capacity of wastewater treatment plants but this is often impossible due to lack of financial resources (it is very expensive);
- disposal of significant amounts of solid waste and sludge generated in the wastewater treatment process creates new environmental problems.

These issues shift the focus of water system management hierarchically to higher levels, or towards the policy and selection of management strategy, including governing structures and the public of the city, region or state.

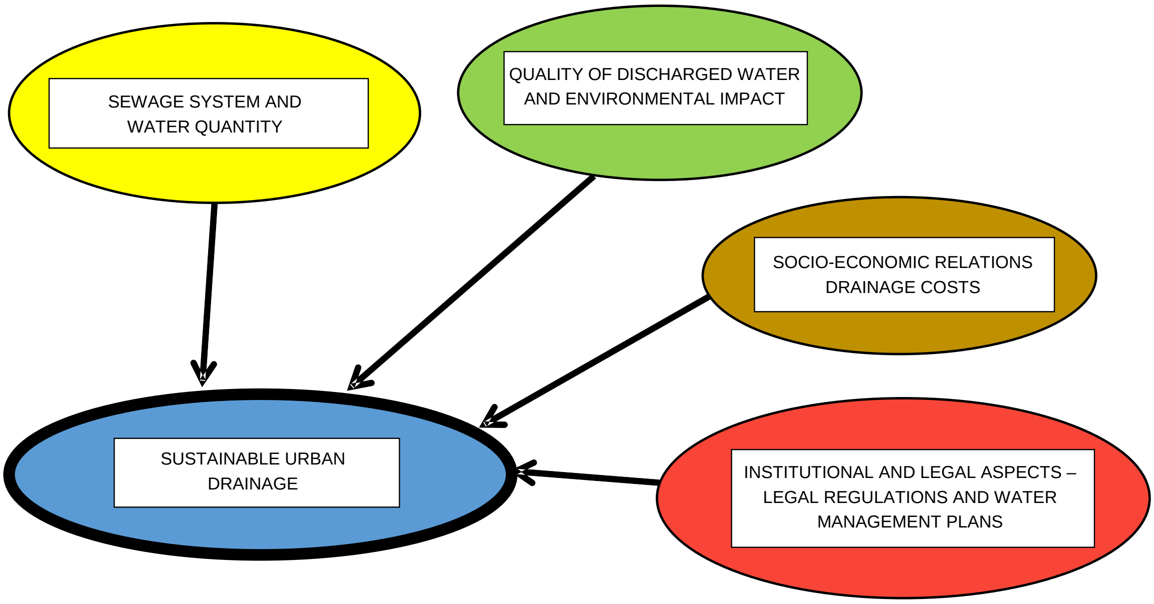

Figure 2. Influential parameters of sustainability and functionality of drainage systems

A possible solution to the drainage problem of urban areas (cities, settlements) can be realized through a systematic analysis of all wastewater that needs to be collected and taken to the plant, or to the outlet to recipient. Functional and sustainable wastewater drainage is influenced by a number of parameters, but only the basic and essential parameters, relevant for the illustration of sustainable drainage system operation and management, are used for the presentation of system simulation. Thus, it is a simulation model of the quantity and quality of wastewater (technical and environmental sustainability), as well as the segment of the socio-economic system of drainage (socio-economic sustainability), framed in the legal framework (legal sustainability). For this purpose, we can single out the following optimization functions of the objective that can ensure sustainability of the system (Figure 2):

a) Technical - technological sustainability includes:

- the maximum possible amounts of wastewater in the sewage system, which includes the following:
  - degree of connection to the sewage system (objective function: $Q_{kan} \rightarrow max$)
  - sewage system capacity
  - WWTP capacity
  - design quality and pipe material

  } (objective function: $KK_{kan} \rightarrow max$)

b) Environmental sustainability

- quality of water discharged into the recipient (objective function: $K_v \rightarrow max$),
- maintaining environmental capacity;
- sustainable use of renewable resources;
- minimal use of non-renewable resources.

} objective function: Uok → min

c) Socio-economic sustainability:

- minimum drainage costs (objective function: $T_{kan} \rightarrow min$);
- economic and financial security (objective function: EF → max);
- social justice (objective function: DS → max),
- price of drainage services (over the price of water for water supply) - social category and objective function: CJv → min

d) Legal sustainability - condition for all previous sustainability of the system:

- compliance with legal regulations (objective function: ZR → max)

3. SIMULATION OF WASTEWATER DRAINAGE SYSTEM OPERATION

Using **object-oriented modeling** [6] and adapted program **Stella**, and based on the overall analysis of the functioning and sustainable development of wastewater disposal, the initial physical-basic submodel of water quantity and quality of sewage system (technical and technological sustainability of the system) was developed. In a further structural upgrade, the model was supplemented - upgraded with certain components and elements of the management and planning - strategic system [7], which is a set of necessary and appropriate system parameters important for the functioning of the simulation of the real drainage system, as well as for presentation of the obtained results.

By entering certain input data and parameters, as well as some limitations related to the model operation, including time, or assumed or required time interval and time step, the model can monitor the current state of the system, as well as functional dependence over time interval of individual system components. The model can be calibrated and verified through a physical model and description of the current state of the system. Therefore, the paper will use the example of the urban water system of the city of Mostar, which was chosen solely for knowledge of the current situation, as well as input and output parameters, where an attempt will be made to check the model operation, and verify and analyze the obtained results.

Another important note is related to the application of the software package Stella, which makes it possible to view the current state (for t = 0) and future states (for a certain time interval, for example for 20 years). All parameters (input and output) can be graphically and tabularly presented as a functional dependence on time and time interval, as well as the time step that needs to be determined in advance.

The assumption is that it is a separating sewage system, so the management and optimization are done separately for wastewater used, and separately for storm sewage system. The subject of this paper is the simulation and operation of the wastewater sewage system.

The state of quality of water discharged into the recipient (ecological sustainability) is a reflection of the degree of wastewater treatment in the plant, and thus it is possible to directly influence this parameter, or the state of the environment in general (minimal environmental impact). All influential elements and parameters of the system, as well as output simulation results should be harmonized and in compliance with existing legislation [5].

Another important segment of environmental protection is the maximum possible use of renewable energy sources, so it is possible to observe the state of reduction of CO_2 emissions into the environment, if renewable energy sources (e.g. solar energy) are used instead of consuming electricity for pumping stations and operation of the plant.

Economic parameters having an effect on the management system (socio-economic sustainability) can be divided into several groups depending on the character and type of sewage system and wastewater treatment system. Minimization of costs would be an objective function in such a complex system, so groups of parameters affecting investment costs and system maintenance and operation costs can be defined based on this.

In order to be able to have system costs and to establish a safe and transparent financial management system, it is necessary to generate significant revenues from the sale of water and water services, including drainage and wastewater treatment as part of the water price tariff. All this should be part of the incorporated legal and social system, which represent the socio-economic sustainability of the wastewater drainage system [4].

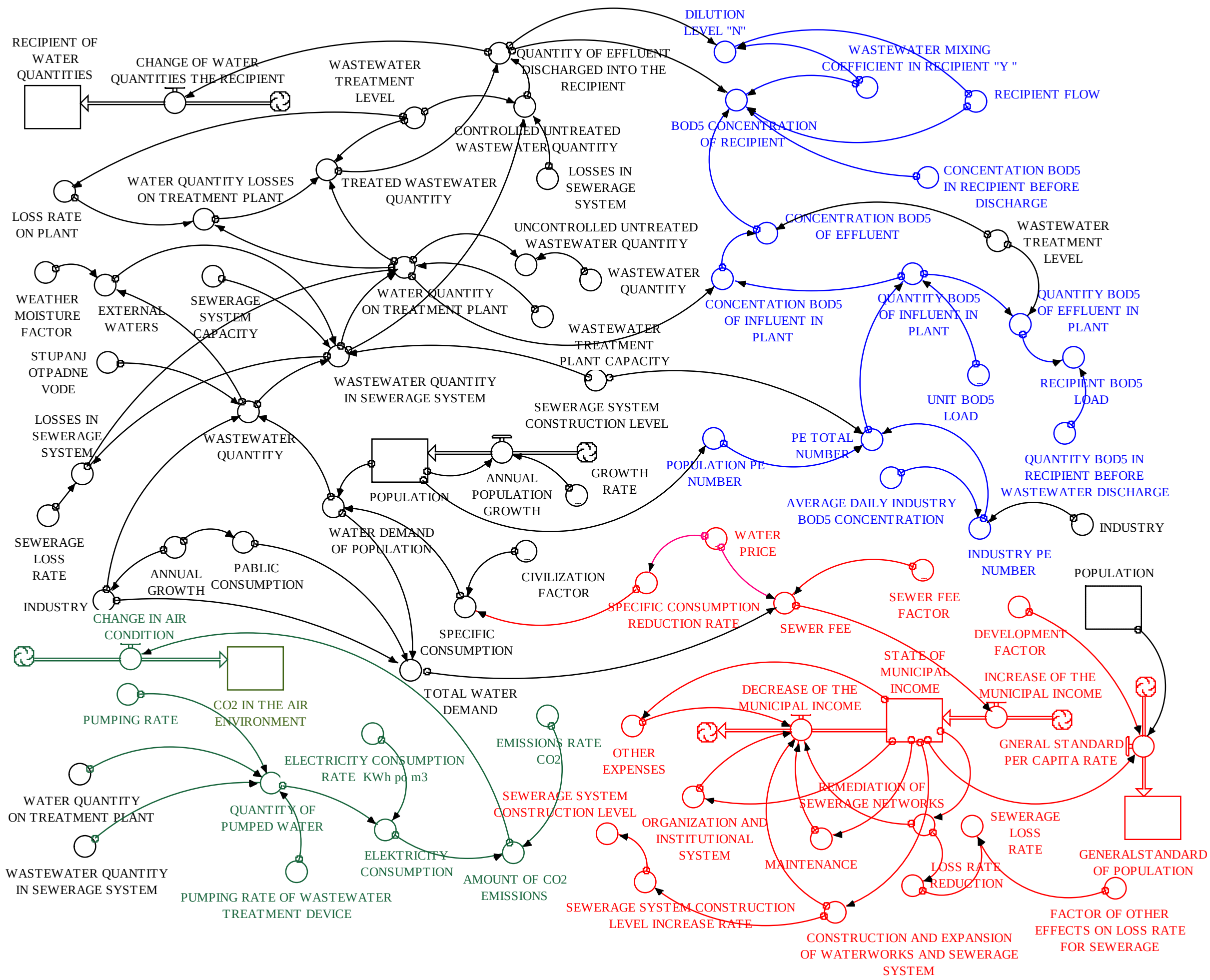

Figure 3. Schematic view of the model SUSTAINABLE_DRAINAGE [3]

When developing the concept of the sewage system management submodel, one essential question arises: how to create such a model for managing the wastewater drainage system that will meet all the objectives, conditions, limitations and tasks defined in the previous chapters, including two main concepts:

- integrity principle (integrated system) and
- the system sustainability and functionality principle [2].

Figure 3 shows the general model (called: SUSTAINABLE_DRAINAGE) of the sewage system and wastewater treatment system (used water from households and industry), with presentation and analysis of the investment, operation and maintenance costs of the system. The general **objective function** is the functionality and sustainability of the system, which is reflected in the following:

- functional to a maximum degree in technical and technological terms,
- minimal environmental impact, which means collecting maximum amounts of wastewater with maximum treatment, and additionally the possibility of using renewable energy sources,
- minimum possible costs while meeting all relevant social and legal aspects of system operation and management.

4. SIMULATION RESULTS AND ANALYSIS OF OBTAINED RESULTS

The results of the calculation and analysis of individual influential parameters can be presented graphically and tabularly. Only a few graphs of significant influences that illustrate changes in the system in terms of sustainability and improvement of system operation - sensitivity analysis - are selected.

For example, if the intention is to show the amount of wastewater in the sewage system, or the amount of wastewater coming to the treatment plant and the losses of wastewater from the sewage system are reduced from 30% to 20% (Figure 4), changes in the amount of wastewater for the selected period are observed (Example: City of Mostar).

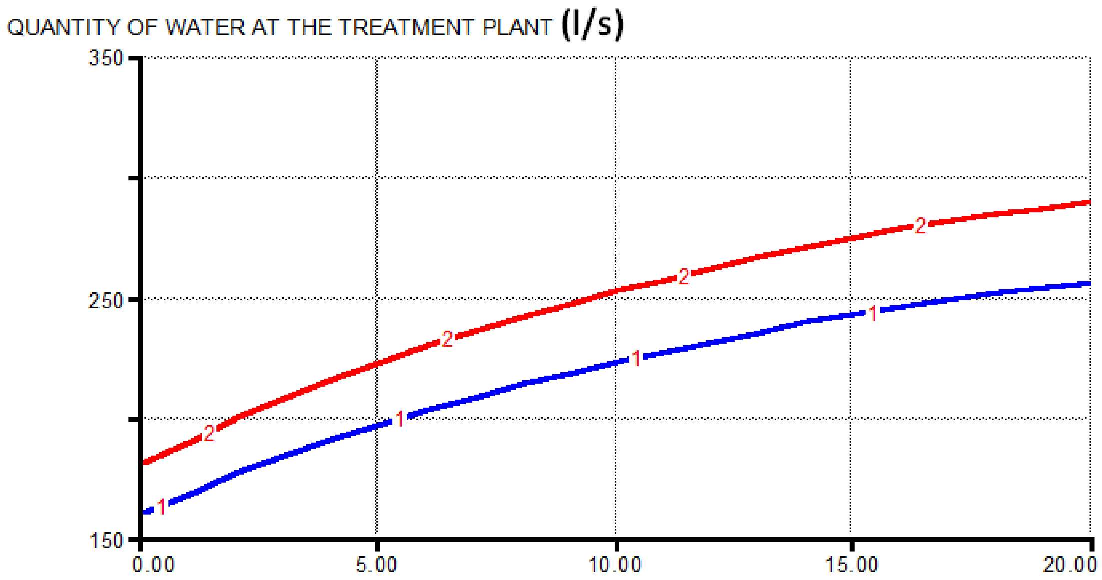

Figure 4. Graph of the amount of wastewater coming to the plant for the planned time period and for two different cases, when the rate of losses is: (1) - 30%, (2) - 20%

Graphs of the quality of water discharged to the recipient can be presented in a similar way. As an illustration, the change in wastewater quality is presented for three cases: a.) without treatment, b.) with mechanical treatment (BOD5 up to 30%) and c.) with secondary treatment (BOD% up to 90%), Figure 5.

However, if it is desired to reduce losses or increase the level of development of the sewage system or increase the degree of treatment, new investments in the construction and maintenance of the sewage system and plants are needed. Consequently, this increases the costs. The next figure (Figure 6) gives comparative diagrams illustrating the increase in costs if losses are reduced and level of development of the system is increased.

Therefore, if a high-quality and functional sewage system is needed, it is necessary to invest certain financial resources in the construction as well as in the maintenance and operation of this system. The question is how to find the optimal balance between costs and quality of the system, which is directly related to the environmental impact, or the environmental sustainability of the system, which can be shown by changing the quality of the water discharged into the recipient, or, for example, reducing CO_2 emissions into the environment if renewable energy sources are used (Figure 7). Electricity is often used in maintenance and operation of the system (pumps for pressure drainage and electricity for pumps and operation of the WWTP. If solar generators and solar energy (renewable energy source) are used instead of electricity, the negative effects of greenhouse gases can be reduced (13).

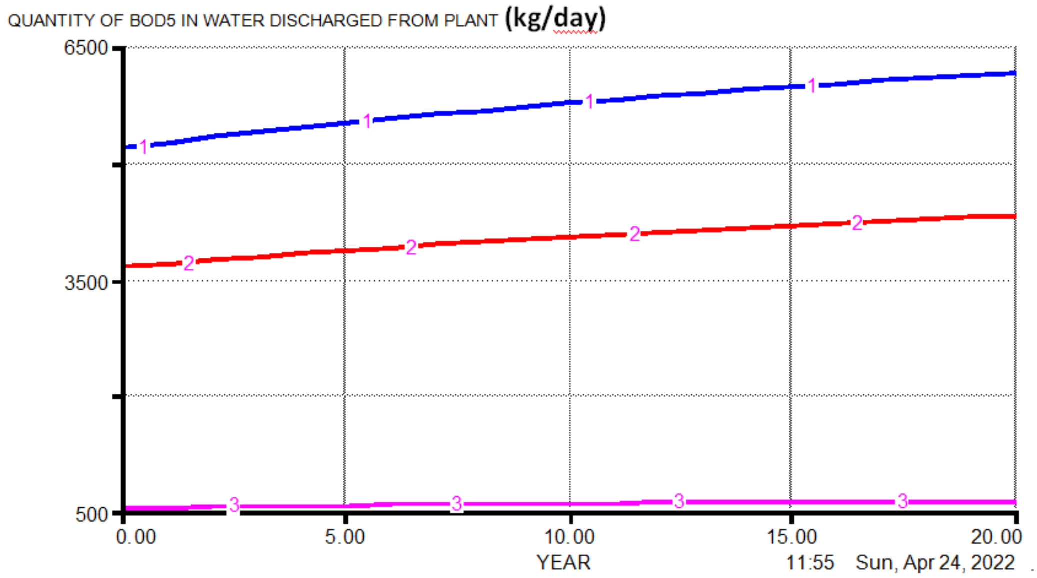

Figure 5. Graph of BOD5 discharge reduction for three cases: (1) condition without treatment, (2) mechanical treatment only - 30% reduction of BOD5, (3) secondary treatment - biological - reduction of BOD5 up to 90%

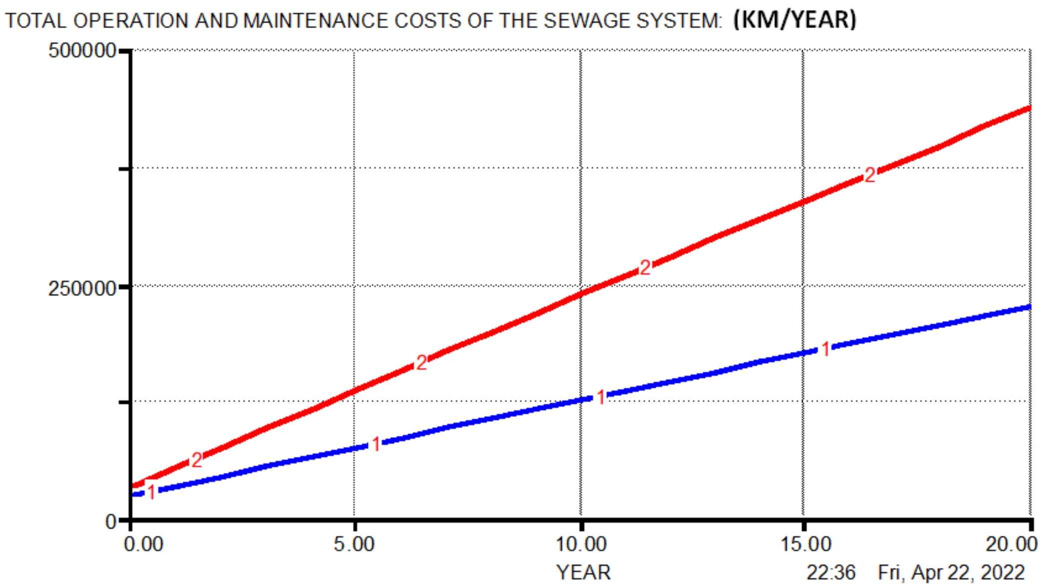

Figure 6. Graph of increase in costs of construction and maintenance of the sewage system for the planned period of time and for two different cases: (1) present state, (2) improved state (reduction of losses and increased level of development of the sewage system)

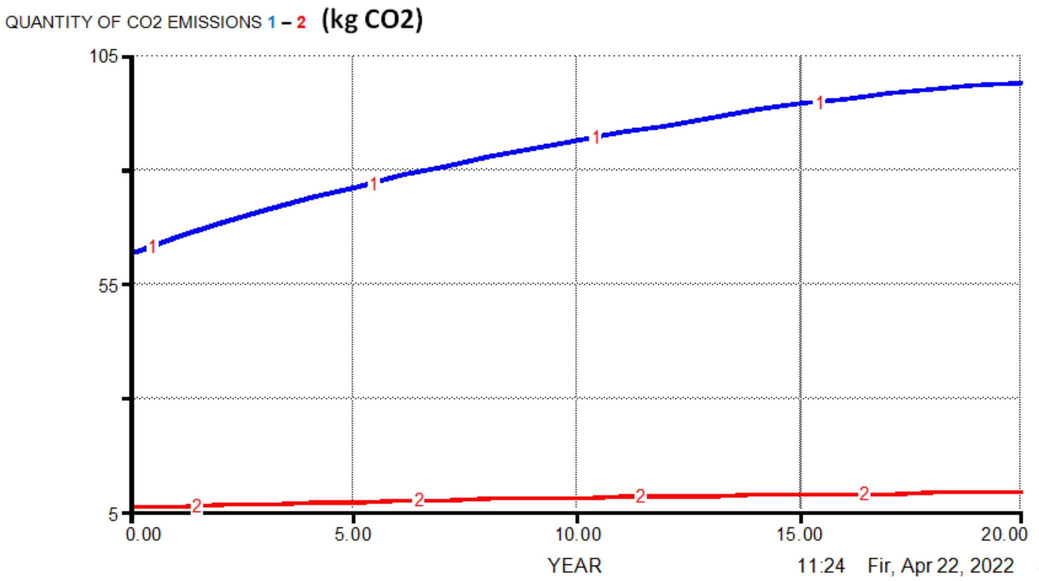

Figure 7. Graph comparing the emissions of kg CO_2 emitted into the air (kg CO_2) for the operation of pumping stations and operation of the WWTP for the case: (1) - used electricity from diesel or thermal power plants - coal and (2) - used energy - renewable energy sources - solar generators

A high-quality, functional and sustainable sewage system can be achieved with systematic and continuous analysis and integrated management of the system, taking into account all system components and influential parameters that can improve system performance and create realistic conditions for sustainability of the system. The paper has presented a possibility of simulating the operation of a drainage system and searching for a sustainable system operation variant in the context of optimum balance between the socio-economic benefits resulting from the operation of the system and the environmental impact.

5. CONCLUDING CONSIDERATIONS

The paper analyzes and presents the construction method and the applicability of OOM for modeling and simulation of drainage system operation. The submodel SUBSTAINABLE_DRAINAGE, which is part of a complex UWS model (3), was used to illustrate and present the procedures described above. By development of the simulation model, analysis and simulation, based on the systematic procedure and methodology as presented in this paper, some research results and new knowledge related to high-quality and effective sustainable improvement in the operation of the sewage system were obtained. Based on these results, it can be concluded:

- Sewage system management is a demanding, complex and difficult task, because in addition to technical, technological, environmental and economic sustainability, "management" involves sustainability in the development of the urban water system, as well as urban environment and society as a whole;
- With a systematic approach to the problem, while applying appropriate modeling techniques, it is possible to analyze the entire system, plan future system operation, but also advance (improve) the operation and sustainability of both sewage system

and wastewater treatment system, all with control and minimization of construction and maintenance costs, and system operation costs;

- The use of OOM has proven to be very successful and useful in implementation of systematic analysis, modeling and analysis of results, i.e. its applicability for simulating the operation of drainage systems is shown;
- The model used is flexible, dynamic and easily adapts to the actual (real) state and processes in the system;
- The use of the model, SUSTAINABLE_DRAINAGE and the application of OOM can help find the optimal strategy for the development and management of similar systems in cities in the context of an integrated consideration of the operation and functioning of the drainage system;
    - sustainability,
    - climate change,
    - circular economy,
    - green strategy, which can be the subject of further research.

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