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Small Hydro–A Part of Water Management

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Abstract. In the paper are presented, in short, natural aspects in Croatia on small hydroelectric power plants (small hydro) construction as a part of integral water management. It is stressed the advantage of small hydro with aspect of environment preservation. In material are shown problems in small hydro preparation and construction in Croatia, too. Also, it is presented some constructed small hydro in Croatia. Spatially are presented, for available small hydro locations in Croatia, disposed turbines application. At the end there are given conclusions and recommendations how to improve small hydro realization.

Keywords: Small hydro power plants (SHPP), regulations in SHPP development, disposed turbines application, VLH turbine

1 Introduction

Hrvatska elektroprivreda d.d. – HEP (The Croatian Power Board) has started with the development of small hydro-power plants (SHPP) in the Republic of Croatia in 1982. Until 1985 a *Cadastre of small water power resources – CSWPR* was elaborated by *Elektroprojekt d.d. Zagreb–EPZ (Elektroprojekt Consulting Engineers, Zagreb)*. On the base of topographic as well as hydrologic data 134 watercourses were analyzed for the 10 year period. From 134 watercourses 63 were selected according to the specific power criterion. On the selected watercourses 699 sections for potential exploitation were defined with a total capacity of 177 MW installed power and approximately 570 GWh annual production of electrical energy. In this process the suitability for the construction of small plants was considered, and appropriate sections were defined in accordance with an installed power range between 50 and 5000 kW.

Based on these materials the creation of a *Cadastre of Small Hydroelectric Plants – CSHEP* began and it was realized in two phases. In the first phase (EPZ, 1989) 17 watercourses with 50 potential hydro plant locations were taken into consideration, and 10 typical locations were chosen. The SHPP-s on the chosen locations were as conceived as prototypes on which different variants of solutions were analyzed, so that basic principles for the determination of the optimal plant capacity were established. Also specific types for the building of the hydro-mechanical and the electromechanical equipment were defined. The basic intention of this approach of SHPP design was an attempt to define typical solutions for the building and equipment as to achieve a faster, simpler and a more cost-effective serial production.

In the second phase the construction of SHPP-s for all remaining watercourses was planned, for which the exploitation was determined. The principles from the phase one were applied here. However, the second phase involved only some watercourses, and this part named *phase two-A* (EPZ) encompassed only four watercourses on which 17 plants were selected and elaborated.

Since 1994 the following government institutions have joined the SHPP program: *the Ministry of Physical Planning, Construction and Dwelling* and *the State Authority on Waters.* The first action undertaken by those new participants in the programme was the defining of the physical planning conditions for the exploitation of watercourses from the aspect of SHPP in the Republic of Croatia. In connection with this *the Institute of Urbanism* created a feasibility study called *Physical and Planning Documentation for the Evaluation of Watercourse Sections Suitable for the Location of SHPP in the Republic of Croatia* (1995). This study involved the systematization of all 130 watercourses, for which the physical planning documents were prepared; criteria and physical planning regulations were proposed concerning the exploitation of watercourses for construction of SHPP-s. Also the programme for further research activities was developed.

In 1997 the government of the Republic of Croatia initiated the national programme of power engineering efficiency and use of renewable energy sources which involved also the program of small hydro construction.

Under the guidance of *the Ministry of Economy* of the Republic of Croatia *the "Hrvoje Požar" Energy Institute* prepared in 1998 *the "Programme for constructing small hydroelectric plants – preliminary results and future activities".* The programme put forward the start of a "pilot programme" for selected 49 locations on 14 watercourses.

In 1998 *the Institute for Electric Power Utility and Power Engineering* developed further the Programme for the construction of small hydro – outlines for designing – SHP in which excerpts from the previous documentation CSHEP were elaborated regarding beforehand chosen watercourses and locations. Besides, new hydrologic analyses were performed concerning the estimate of a 'biological minimum' for every watercourse in consideration, and also for every location. An excerpt from this programme named *"Proposed magnitude of the biological minimum for potential construction locations"* was separately created *(Institute for Electric Power Utility and Power Engineering,* 1998).

During further work on the 'pilot programme', *the Hrvoje Požar Energy Institute* initiated the formation of two expert teams which inspected parts of the previously selected watercourses and construction locations (not including the Slapnica, Žrnovnica and Kupica Rivers) as well as some additional locations (Cetina – Čikotina Lađa, Zrmanja – Vrelo, Rumin Mali, Pantana and Vinalić). These teams analyzed the problem of nature preservation and conservation of cultural heritage, and accordingly drew same conclusions concerning the acceptability of constructing SHPP on discussed locations.

In the Report on inspection of potential locations for small hydroelectric power plants construction (2001), from 41 locations and 16 watercourses which were taken into consideration, 25 locations and 9 watercourses were acceptable.

In *the Report on acceptability of the SHPP project concerning conservation of cultural heritage (Ministry of Culture - Republic of Croatia, State authority on conservation of cultural heritage,* 2002) 35 construction locations on 13 watercourses were considered as acceptable, whereas 6 locations on 3 watercourses were considered as unacceptable.

Based on the cited reports, 11 locations on 3 watercourses were excluded from the 'pilot programme'.

During further work on the 'pilot programme' for SHPP (EPZ) conducted an analysis on ecologically acceptable flow discharges for 25 locations on 8 watercourses (2003), which was commissioned by *the Hrvoje Požar Energy Institute.* The analysis served as a basic precondition for upgrading of plant capacities considered in the CSHEP, and also for the study on the environmental impacts of these works.

In the final version of the 'pilot programme', commissioned by *the Hrvoje Požar Energy Institute,* and created by the EPZ, (2003) upgraded solutions for the remaining SHPP from the first 'pilot programme' *(Basic preliminary design)* were presented. This version involved also new technical solutions for SHPP-s from the CSHEP according to new hydrological directions (based on the analysis of ecologically acceptable discharges). This new version encompasses 22 locations.

Despite extensive research on small waterpower resources and possible construction of SHPP, the results remained less than modest; in the period from 1982 till today, only a few SHPP-s have been built, and an existing SHPP on Roški slap was reconstructed (Table 1).

2 Characteristics of Small Water Power Resources

The exploitation of water power is traditional in Croatia; it has been used in water-mills, saw-mills, weaving mills and for similar purposes; of course, for the production of electricity (since 1895). With the exception of the electricity production all other modes of water power exploitation have been abandoned, so most of the older objects have been neglected crumbling down or can be found in totally ruined condition.

It is characteristic of Croatia that suitable locations have been mostly exploited, and the remaining ones have a relatively good discharge, but small heads (from 1 m onwards).

During the last 27 years, since the research start-up on SHPP, the conditions of their construction have changed significantly, particularly regarding the preservation of nature and environment, and besides that, some locations have been already used or determined for other purposes.

A review of small hydroelectric power plants (power under 10 MW) which are in operation in Croatia is given in the following Table 1.

The Table 1 shows that HEP is the main user of small hydros. The remaining SHPP-s are mainly used by the industry and it is not known whether the power is used only internally or if the part of the production is delivered into the national system. The power plants used by single households have very small capacities. Only the *"Hidrowatt"* company owns a plant which was reconstructed (1998) and delivers electricity exclusively into to the national system.

Table 1. Small hydroelectric power plants (P < 10 MW) in Croatia

Name	Owner	Installed power [MW]		Operation started in the year
		per generator	total	
SHPP Zeleni Vir	HEP	2×0.85	1.700	1922
SHPP Jaruga	HEP	2×3.6	7.200	1904
SHPP Ozalj I	HEP	2×1.0 + 2×0.8	3.600	1908
SHPP Ozalj II	HEP	2 × 1.1	2.200	1952
SHPP Zavrelje	HEP	2.0	2.000	1953
SHPP Krčić	HEP	0.44	0.440	1988
SHPP Čakovec	HEP	0.34	0.340	1982
SHPP Dubrava	HEP	2×0.34	0.680	1989
HPP Golubić	HEP	2×3.75	7.500	1981
PHPP Fužine	HEP	4.6	4.600	1957
PHPP Lepenica	HEP	1.14	1.140	1985
SHPP Čabranka	Urh		0.008	
SHPP Kupčina	Bujan		0.045	
SHPP Cotton industry "Duga Resa"	Cotton industry "Duga Resa"	0.53+0.25+0.32	1.100	1937
SHPP Cement plant "10. kolovoz"	Cement plant "10. kolovoz"	2×0.6	1.200	1913
SHPP Finvest I	Finvest	4×0.315	1.260	1995
SHPP Finvest II	Finvest	0.03	0.030	1997
SHPP Roški slap	Hidrowatt	2×0.886	1.772	1909/1998
SHPP Mataković	Mataković	2×0.014	0.028	2004
HPP Varaždin	HEP	0.585	0.585	1975
HPP Čakovec	HEP	1.1	1.100	1982
HPP Dubrava	HEP	1.12	1.120	1989
Total			39.65	

The description of the hydro energy gross potential of concentrated watercourses defined with a longitudinal profile is indispensable for planning the exploitation of hydro energy potentials, providing a solid base for the analysis of exploitable energy and the desirable disposition of hydroelectric power plants. Consequently, the approach and the elaborations in the CSWPR are by all means a suitable base for determining sections of potential exploitation and location of SHPP.

All relevant data, both hydrological and topographical, can be analyzed anew. Although the available energy profiles can be used for the preliminary determination of sections of potential exploitation, it would be favorable to acquire all hydrological and topographical data available now and to elaborate a new longitudinal energy profile. Taken into consideration that the available longitudinal profiles of watercourses are based on geodetic documents using maps in the 1:25,000 scale, it is necessary for the purpose of determining locations and heads lower than 10 m to obtain longitudinal profiles of watercourses based on 1:5,000 maps. As those maps do not contain the vertical profile of the riverbed bottom, a more detailed survey should be made.

It is also necessary to determine altitudes for sites on which structures are already built: water-mills; sills; dams with storage basins which are not designed for energy exploitation; dams with retarding basins et al.

For such locations data bases should be created, respectively a cadastre with basic data. Croatia is a candidate for EU membership, and in the terms of EU directives for the preservation of nature and environment, small facilities with minor impact on the environment are more acceptable. Therefore, the sited locations have a chance to be selected in the further exploitation of gross potentials.

In the process of selecting sections for exploitation the demand for standardization of energy solutions should be omitted (for each section solutions were anticipated in the range of 50 to 5000 kW). This is reasonable because the recent development in turbine technology offers a variety of types, and on the other hand, with typified equipment the envisioned production-cost reduction cannot be achieved. Sections should be chosen, which are abundant in energy and the obtained segment should be advantageous from the following aspects: energy aspects; geological aspects (water impermeability); physical planning and preservation of nature and environment.

Besides the analysis of the longitudinal energy profile, already in this phase, it is necessary to analyze the actual status of the watercourse, the physical planning documents, the existing geological maps, and other constraints in the relevant zone as well.

In the context of water management all problems related to water are being solved. One of these activities is the maintenance of watercourses. On many watercourses in Croatia there are wrecks of mills and other objects for which the water intake was conducted with sills built in the riverbed. These sills define the actual status of the watercourses, and it is necessary to rebuild them in the process of watercourse regulation and rehabilitation.

The maintenance and regulation of watercourses can be rationalized by using sills for the construction of SHPP. In this case, of course, the efficiency ratio for the available power and energy will be significantly smaller than the ratio which could be realized with modern technology. However, a mutual compromise can ensure a good watercourse condition, acceptable energy output and a reasonable preservation of nature and environment.

According to the former conclusion the sills will be so reconstructed that the head would be the highest possible, while preserving the watercourse, the nature and the environment.

SHPP are run-of-the-river facilities: they are using the natural inflow without transforming it. To achieve a larger heads diversion-type hydroelectric power plants are built (even SHPP) with the consequence that the natural discharge is diminished between intake and restitution, and the status of this part of the watercourse is changed. In storage power stations (even SHPP), when working in the run-of-the-river mode, the volume and the distribution of water in the watercourse are not affected. Therefore, they are more acceptable from the aspect of nature and environment preservation. For every location, all possibilities of construction a HPP (SHPP) conforming to the regulations should be analyzed, and no solution should be a priori rejected.

Following the section defining (or a set of sections), and finding it promising in the terms of technical realization, physical planning conditions and environmental impact, more detailed materials should be elaborated so that further analysis can be performed. For the considered section or profile of exploitation this material should include relevant hydrological data, detailed topographical surveys and necessary geological data. The relation of the location according to the national ecological network should be determined, and the possibility of the connection to the national electric supply system should be verified. On the ground of these materials and data variants the solutions should be worked out and the appropriate analyses are to be carried out.

3 Conditions, Incentives and Issues in SHPP Development

Croatia adapted the concept of reforming the power engineering sector according to the legal and institutional demands of the EU, in order to approach Europe. In the sector of renewable energy and sources the Croatian Government adapted a package of delegated legislation which regulates it, on 22 March 2007.

Efficient use of energy, cogeneration and usage of renewable energy sources were established as the development path and interest of the Republic of Croatia in the new legal framework which regulates the relationships in the power engineering sector (NN 68/01 and 177/04) and strategic documents concerning its development and the protection of environment such as the *Strategy for Energy Development of the Republic of Croatia* (NN 38/02), *the National strategy for the protection of environment,* national energy programs etc. The new *Law on Energy* (NN 68/01, 177/04), the act 14, item 1 explicitly expresses an affirmative attitude towards the renewable energy resources (RER) and cogeneration, and indicates that their use is in the interest of Croatia.

Because of the specific features of RER and cogeneration, and their underdeveloped market position, a significant effort directed by the State and political will for encouraging new and clean technologies is required. This sector can only function in close working relationship and systems with regard to favorable price, period of energy purchase and removed administrative obstacles. For their development it is necessary to provide permanent care and monitoring of execution while acting quickly on the national and local scale.

The following items are very important for the adjustment of Croatian laws to the legal framework of the EU:

-*Stabilization and Association agreement* (2001) predicts activities in the fields of securing technical assistance for increased use of RER and attaining higher energy efficiency

-*European Commission Avis* – affirmative opinion and acquisition of candidate status for the EU emphasizes the need for energy efficiency and adequate strengthening of administrative capacity

-The beginning of entry negotiations with EU (2005)

-Screening – the procedure of evaluating the compatibility of Croatian legislation with the common legal system of EU as the basis for entry negotiations (2006). In the framework of power engineering the analysis subfields and the RER issues are taken into consideration. Preliminary investigations were conducted and the documentation concerning the legal framework and sector plans are prepared.

As it was mentioned, *the Law on Energy* specifies that the use of RER is interesting for Croatia. The programmes for implementation and stimulation of the RER according to *the Strategy of power engineering development* and programmes on the state level are being prepared by *the Ministry of economy,* work and business, and on the local level by respective bodies of local and regional self-government. Mentioned programmes contain stimulating measures for efficient power and RER implementation through the following activities: education, information, power engineering advising and issuing of power engineering publications.

On the session held on 22 March 2007 the Government prescribed, while coordinating regulations on renewable energy resources with the EU ones, that the minimal share of electric energy from renewable energy resources (RER) should be 5.8% in the total electric energy consumption by the end of the year 2010. It does not refer to large hydro power plants with installed power over 10 MW. The government also determined the fees for stimulation of electric energy from RER and cogeneration.

New regulations are:

-*Decree on minimal share of electrical energy produced from renewable energy and cogeneration resources, the production of which is going to be stipulated* (NN 33/07),

-*Decree on fees for stimulation of electrical energy production from renewable energy and cogeneration resources* (NN 33/07),

-*Tariff wage and salary system for electrical energy production from renewable energy and cogeneration resources* (NN 33/07),

-*Book of rules on the use of renewable energy and cogeneration resources* (NN 67/07),

-*Book of rules on obtaining the status of authorized electrical energy producer* (NN 67/07).

All those rules were enforced on 1 July 2007.

An incentive for renewable energy resources is also the trade with green certificates, already existent in Croatia. The HEP certified hydro power plants for green energy production. Significant emission decrease in this sector will be realized with establishment of emission quotas market. Emission quotas for individual installations will be determined by *the National Allocation Plan. The National Allocation Plan* will determine the emission decrease level for each individual installation on the basis of methodology and criteria accepted on the EU level. The regulations containing the EU directives on complete prevention and pollution control *(IPPC directive)* and voluntary certification schemes of the environmental management system will be relevant for existing and new facilities *(ISO 14001* and *EMAS).*

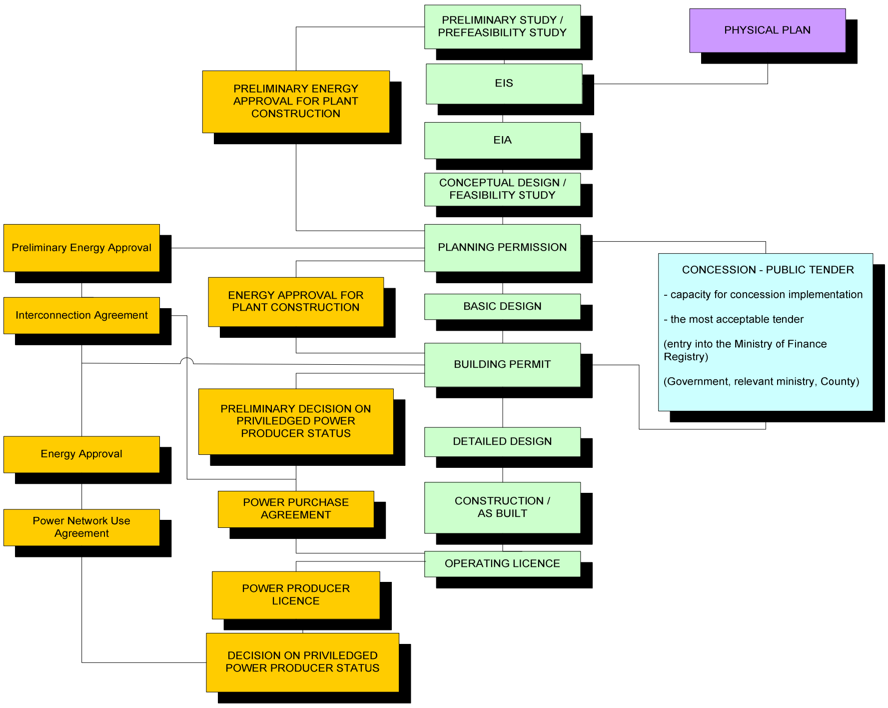

Fig. 1. Flow diagram of procedures in RER project implementation

Despite predicted incentives, the administrative procedures required to be applied for the construction of renewable energy resources and thus for hydro power plants, are very complex. Therefore, the investors quickly abandon such plans. Figure 1 gives a flow diagram of actual administrative procedures.

4 The Example of Two Small Hydro Power Plants

4.1 SHPP Roški Slap on River Krka

SHPP Roški Slap was built in 1909 to serve the mine in Siverić. In 1985 a Krka National Park was declared with the small power plant Roški slap within its territoy. The small power plant was operative until the Homeland War (1991) when the area was occupied, and the small power plant was abandoned and devastated. *Hidrowatt d. o. o.* started the reconstruction of the small power plant in 1997 on the basis of adequate projects and approvals, and completed it in 1998 as the plant was put into operation. All produced energy is transferred to EES on the basis of the Electric

Power Sales Agreement concluded with HEP. The small power plant is operating successfully.

It is especially important to point out on the example of the small hydro power plant Roški Slap that it has been operating for almost 100 years. After almost eighty years of plant's operation the national park was declared in this area. It indicates that the small hydro power plant has no undesirable effect on nature, and that it can exist there under appropriate conditions. The national park is a sensitive ecological system distinguished by special and adequate features (Fig. 2).

The same can be applied to other hydropower plants on the River Krka as well, with the hydropower plant Jaruga belonging to small power plants with regard to its capacity.

Since the start of operation till 2005 there were altogether 51.700.000 kWh electric power produced, or about 7 GWh annually.

All outlines and facades of the small power plant were retained and the changes were made only within the engine room, access tower, supply, intake and water outlet. Two Francis turbines were replaced by two cross-flow turbines Ossberger (type SH 1.174/22g) with the nominal power of 2x882 kW (1.764 MW) having adequate mechanical and electronic equipment.

Fig. 2. Roški slap on the Krka River

4.2 SHPP Ilovac on the River Kupa

The locations having sills already present in the riverbed offer themselves as possible locations for building small hydro on the Kupa River upstream from the town of Ozalj. The reasons that make these locations especially interesting for further analysis of exploiting hydro potentials are reflected in more convenient influence on nature, because there is presently an endeavor to affect the environment as little as possible. Apart from that, the rebuilding of the riverbed and sill that would be carried out in order to build small hydro power plant would present an additional benefit in the water management domain.

At the end of 2008 the Preliminary design of the small hydro power plant Ilovac (EPZ) was made. The location of this small power plant on the River Kupa is about 5 km upstream from the town of Ozalj. Since the River Kupa is the bordering with the Republic of Slovenia, the selection of the location was stipulated by the need to put all influences that this small power plant could produce under the competence of the Republic of Croatia. Thus, the most downstream location out of four sills at the section between the hydropower plant Ozalj – Republic of Slovenia was selected.

The backwater of the future small hydro Ilovac is limited due to the existing infrastructural objects in the hinterland area at that location (province's district road and railway). The existing sill in the Kupa's riverbed has been planned to be raised by 2,1 m. This superelevation is planned to be constructed using concrete with stone lining in order to integrate it into the existing sill in the best possible way. It has been planned to establish the operational regime of the small hydro power plant that would completely meet the limitations set with respect to the environmental influences.

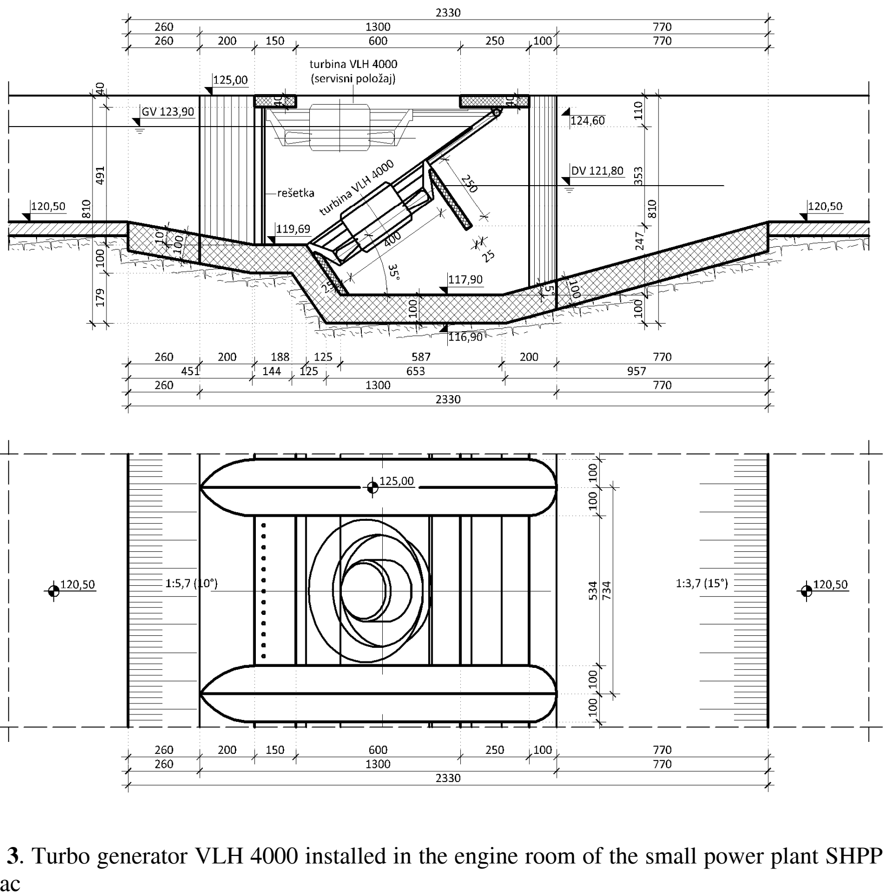

Fig. 3. Turbo generator VLH 4000 installed in the engine room of the small power plant SHPP Ilovac

It was therefore planned that Ilovac hydro power plant operates as run-of-the-river plant, i.e. to let all inflow of the River Kupa downstream through the turbines, actually by manipulating the 3,4 m high rubber dam placed in the 35 m long overflow area.

The production units foreseen at this plant are of the type VLH *("Very Low Head")* the development of which started in France and Canada in 2005, and the first VLH turbine was installed in 2007 in the small power plant in Millau in France. The characteristic of these turbines is successful usage of small heads for the production of electrical power, and their main advantage compared to conventional types of turbines are much smaller engine rooms needed for their installation. The turbine has been specially tested with regard to the passage of fish through the trowels. The research carried out so far has indicated satisfactory characteristics of the turbine in this respect as well, because fish can pass downstream while trowels are in operation without any consequences for them. Three VLH turbines are located in the canal each in its own field. The installed flow per units is 19,7 m^3/s (total of 59 m^3/s), and the designed head is 3.09 m.

Average annual production of energy is 6,75 GWh. Together with the estimated building costs and its size expressed by means of installed plant power of 1,4 MW, the investment quotient is approximately 2,600 €/kW, which corresponds to the expected order of values for hydropower plant with large flow and very small fall. The economic analysis has proved the cost-effectiveness of building this plant.

5 Conclusions

The results in the achievement of the small power plant have been left out in spite of large efforts and investment in the preparation of the construction.

It is to be concluded therefore that so far used approach to the preparation and processing of using small power plants needs to be re-examined, and adequate documents should be prepared for the investors interested in it with adequate compensation.

For researched and acceptable sites the state institutions need to provide suitable, acceptable solutions and invite concession tenders on the basis of prepared basic documentation needed for getting a planning permission. The invested funds can be obtained from the concessionaire.

The initiative of potential investors should not be neglected, and such activity should be supported as well.

Complex, partly vague or badly defined long lasting procedures have led to the situation today in which almost nothing of possible development has been achieved. Hence, the procedure needs to be unified, simplified and accelerated from the idea to the beginning of construction.

The incentives should also be dedicated in the first place to larger small hydropower plants ($P \geq 1$ MW) that are practically non-existent in Croatia (at least not those that could be accepted), therefore we should consider adjustments to Croatian conditions.

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The Role of Higher Education in Developing Awareness about Water Management

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Abstract. The Faculty of Civil Engineering as a component of the University of Rijeka is contributing to the promotion of sustainable development principles and awareness about environmental protection problems in the local community with organizing different types of activities. These activities mostly include lectures and workshops held by teachers and students that involve education and raising the awareness about sustainable development and environmental protection especially in the important area of water resources management. The involvement of students in these activities helps in developing students' professional knowledge and skills but also their generic and transferable skills, which are very important especially for those students that will on day become experts in water management.

Keywords: Water resources, sustainable development, education, public participation

1 Introduction

Water is one of the limiting factors for life on Earth therefore it is necessary to manage it conscientiously for ensuring enough reserves of good quality water for the future. It is an imperative that awareness of the value of water and water management is developed through all generations starting from pre-school age.

Sustainable development includes the integrated water management approach that can not be accomplished without public participation. The importance and the obligation of public participation in the water resources management, as well as guidelines on methods for successful public participation are published in many international and national documents and incorporated into legislation [4],[6],[7],[8],[9],[10]. From these documents it is obvious that the education of the public about water related issues and its preparation for the water management is necessary to assure its active participation in the water management in everyday life. This should also prepare them to take participation in more complex activities like creation of complex plans and projects such as river basin management plans, water supply or sewage systems projects, irrigation plans etc.

The University of Rijeka in its Strategy for the period 2007-2013 has made a commitment to make a contribution to sustainable development principles promotion and raising awareness about environmental protection problems in the local community [5].

The Faculty of Civil Engineering supports the University Strategy and contributes to the accomplishment of these aims. In line with the University Strategy, the Faculty of Civil Engineering has independently implemented many different types of activities (mostly lectures and workshops) in last ten years. Through these activities teachers and students are involved in educating the public about sustainable development and environmental protection importance especially in the area of water resources management. These activities of the Faculty of Civil Engineering in Rijeka will be presented in the paper as examples of good practice for developing public awareness about water and water management.

2 Education of the Public about Water and Water Management-Examples from the Faculty of Civil Engineering in Rijeka

Universities were traditionally primarily recognized as places of research and production of knowledge. In the last decades the focus of the Higher Education is not only on the knowledge but also on the recognized need for students to develop transferable skills in the process of learning.

Civil engineers must be educated in a way that assures the development of different skills. These are the understanding of the interaction between technical and environmental issues and ability to design and construct environmental friendly civil engineering constructions, take care of the safety of their structures and understand the impact of their solutions in a global and social context [11].

At Civil Engineering Faculties in Croatia, students are educated in different aspects of water management and engineering and some of them after graduation become experts in this area. In the last few years the Faculty of Civil Engineering of the University of Rijeka has been very active in this area through curricular and extra-curricular activities for teachers and students. These promote the importance and value of water resources as the foundation of sustainable water management through different levels of education from pre-school and elementary school to higher education, and also to the wider public. The activities include: organizing workshops related to water management problems (water characteristics, the water cycle, water usage, water resource protection etc.) by students and teachers for pre-school and elementary school children. Also popular public lectures are given by teachers during important public events (e.g. University of Rijeka Science Festival) and specific dates like World Water Day on 22nd March or Earth Day 22nd April.

2.1 Education of Pre-School Children – Workshops in Pre-School Institutions

The Civil Engineering Faculty of Rijeka organises different programmes for pre-school children with the aim of developing children's conscience about importance of water and water protection. At workshops children are involved in different activities and games in the way that they can recall what they already knew about water and than be able to learn more about it. Workshops are organized and conducted in collaboration with pre-school teachers on the basis of their own intiative or on the initiative from Faculty teachers.

Fig. 1. Workshop in a pre-school institution in 2005/06: a) the team, b) sewage system and waste water treatment plant model, c) the inflow of the *waste water* (water with send and earth) in the model, d) part of the model showing the disposal of water after treatment in the *sea*, e) and f) showing picture-books to children

During the academic year 2005/06 students from the hydrotechnical engineering study programme prepared different educational materials and organized a workshop in one of the pre-school institutions (*Sea gull*) with the aim to: develop children's awareness of the importance of responsible water usage in every day life, teach them about water supply and sewage systems and waste water treatment plants (Fig. 1).

The educational material mostly made by students consisted of picture-books, PowerPoint presentations, as well as a hand-made model of a simplified waste water treatment plant constructed with materials that children use every day and also recycled materials. The project was beneficial for both children and students. It showed that generational boundaries and differences can be removed easily when dealing with common problems and interests. It also showed that students can easily transfer their knowledge to others. Students succeeded in teaching children about water supply and waste water systems, waste water treatment plants, the importance of water rational usage and protection, and in the same time they developed some very important generic and transferable skills and competencies like: capacity to adapt to new situations, simple description of complex engineering problems, ability to work in a team, interpersonal skills etc. At the end of the project the students felt particular satisfaction with participating in a project with an additional social value and expressed willingness to participate in similar programmes again in the future.

During the academic year 2007/08 collaboration with another pre-school institution (*Dolphin*) in Rijeka city was established. As a part of the project, Faculty professors and assistants in coordination with pre-school teachers conducted an educational workshop about water and its importance. The first part of that workshop was a short presentation which showed different types of water resources (rain, lakes, rivers, sea) and explained the importance of water through educational pictures and films. In the second part a different material, like coloring-picture-books and funny labyrinths (all about water), were used to apply what they have learnt before.

2.2 Education of Elementary School Children–Workshops in Elementary School Institutions

Workshops related to water in elementary schools include short lectures given by Faculty teachers and showing a short film about water as a habitat for many animals, the importance of preserving clean waters in lakes, rivers and seas. All this aimed to stimulate children interest for this problematic so that they start to ask questions, discuss, find and suggest solutions for preservation of clean water and environment. These kinds of workshops were held in local elementary schools Ravna gora (2001), Srdoci (2003) and Fran Frankovic (2009) usually in connection with the World Water Day date.

Students of the hydrotechnical engineering study programme at the Faculty, in the academic year 2007/08, motivated by success of workshops in pre-school institutions given by earlier generations decided to get involved in the *Science festival 2008* in Rijeka that was devoted to the topic of *water*. Their participation included organizing a workshop in a local elementary school *Podmurvice* for 10-year old children [1]. Workshop topics were: hydrologic cycle, water properties (experiments about water density, surface tension, etc.), rational use of water, water and environmental protection (Fig. 2).

Fig. 2. Workshop in an elementary school 2007/08: a) the team with the poster in the back, b) classroom during the workshop, c) experiment (water density), d) hydrologic cycle, e) solid waste sorting, f) waste water treatment (filtration)

A big part of the workshop was organized through experiments with water using materials that are used in everyday life (water, salt, colour, paper, eggs, etc.). The problematic of water and environment protection from pollution was elaborated through examples of solid waste sorting and disposal in appropriate containers, making of simple filters for waste water treatment etc. Also a computer simulation of the hydrologic cycle was used. Students prepared a poster about the things that they did during the workshop and donated it to the class. They also donated all the material and instructions used for the experiments so that elementary school teachers could repeat all that was done in the workshop with other classes in the future.

The result was the same as for the generation before: satisfaction that they did something important for the others. Importantly, they also developed new skills and competences themselves.

The Faculty of Civil Engineering was also involved in creating a hand-book about water that includes many information about water resources in general and also about water resources in the surrounding area (local rivers, lakes, the Adriatic sea), hydrologic cycle and water protection, with instructions for many experiments with water that can be done at home, guidelines to preserve the quantity and quality of water, links to interesting web-pages etc. [3].

2.3 Developing Public Awareness – Public Lectures

Primarily task of university teachers is to teach undergraduate and graduate students. However, they can use their knowledge and teaching skills to educate pre-school children, elementary-school and high-school pupils and the public in general, all at different levels.

During 2008 within the already mentioned *Science festival* in Rijeka teachers of the Faculty of Civil Engineering held two lectures *Water: the source of life* and *The Ecosystem of the Rijeka Bay* [1, 2]. Both lectures were held with the aim to raise public awareness about the importance of water and clean environment for the future, to stress everybody's responsibility for the protection of the environment and that all people can and should be involved in water and other natural resources management.

2.4 Internationalization of Water Management Issues-Collaboration with Geography Students from Lancaster University, UK

The Faculty of Civil Engineering of the University of Rijeka has for five years collaborated with the Lancaster University, UK in delivering a field course *Water and environmental management in Mediterranean context*. The emphasis of this field course is on the management of water-related resources. The course features a combination of field trips and visits to provide understanding of the socio-economic and environmental context of two counties (Istra and Primorsko-goranska), presentations and site visits by the Croatian water authority staff, research into environmental problems in and around water bodies and research on human aspects of water and environmental management.

During the eight day trip, students gain insight into the present water management challenges and how these might be addressed, appreciation of the influence of a Mediterranean climate on the water resources and changes that might be expected in the Northern Europe given the northward migration of climatic zones due to global warming. This course develops skills such as competence and confidence of using range of different fieldwork techniques, data collection, analysis and working and presenting in a teamwork environment. Most of all, students gain experience of the distinctive environmental, cultural and socio-economic nature of the Istrian peninsula by speaking to representatives from the water agency, water companies, pupils in schools and inhabitants of villages that they visit.

While during previous visits, students from the Faculty of Civil Engineering in Rijeka contributed passively to this field course by attending final presentations from Lancaster students on outcomes of their research, they took an active role during the last visit in April 2008. Five of final year students from Rijeka joined Lancaster students in interviewing inhabitants of village Lovranska Draga about their water usage habits (Fig. 3). The village is still not connected to the main water supply system and households are using a traditional water supply from an underground storage of rain water called *cisterna*. They were also asked about their expectations and changes to their current water usage habits when they obtain water from the main water supply system. These social aspects are important to take into account when designing water supply systems and hence it was beneficial for the engineering students from Rijeka to learn about these different aspects related to water supply. At the same time, students from Lancaster could learn about engineering challenges in designing and providing water supply. Also, Lancaster students learned about traditional sustainable water supply that could be implemented as primary or additional sources of water supply in other areas. All of them learned that the water consumption increases with provision of water through pipeline systems and that this needs to be taken into account in design of water supply and management of water resources. All of students had a chance to practice their interviewing and team working skills, while students from Rijeka had also a chance to practice their English language skills.

Fig. 3. Geography students from Lancaster University interviewing pupils in the elementary school *Viktor Car Emin*, Lovran (left panel) and habitants of Lovranska Draga (right panel) in April 2008

3 Conclusions

Today we must all be aware that the sustainable development is the only possible way to live and work in accordance with the environment. In this sense it is very important to educate the public about it. Water resources management is just one part of the sustainable development. The Faculty of Civil Engineering of the University of Rijeka has found different ways to contribute to the development of the awareness about water issues, the importance of public participation in the water management in the local community and wider by educating the local population about this topics.

At the same time the changing conditions in which students will live and work are forcing universities and faculties to adjust and respond to different social needs instead of *just* teaching students their disciplines. These changes are influencing engineering higher education in different ways too. Besides developing engineering knowledge and skills engineering studies are obliged to develop student's social awareness, awareness about environmental issues and understanding of the interaction between technical and environmental issues in order to assure sustainable development. These demands can not be answered without bringing changes in teaching and learning processes. The main change is that students have to be active participants in the learning process. The Faculty of Civil Engineering in Rijeka is trying to find different ways to assure this activity. Collaboration with pre-schools and elementary schools in which students and younger teachers are involved as well as active participation of professors in different public projects dealing with environmental protection showed good results.

At the end it can be concluded that participation in different projects helps students to develop professional competence in water and environmental management and also some of important generic and transferable skills. At the same time both students and teachers contribute to developing the awareness of the importance of water resources and sustainable water management (especially in the segment of water saving and protection), because only the active involvement of the public in water management can improve it in the future.

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Flood Risk Management and Flood Zones System in Czech

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Abstract. Paper is focused on contemporary state of flood risk management in Czech Republic. Huge floods (occurred in 1997 and 2002) influenced the approach of various institutions to flood risk dramatically. Those institutions are mainly: government, flood authorities, municipalities, insurance companies as well as natural bodies. Flood in 2002 is considered as the biggest natural disaster over the whole world in the mentioned year. Interesting statistic data about floods in 1997 and 2002 are introduced. Authors deal with following issues mainly: flood risk prevention, flood losses determination, flood losses minimization and flood risk financial backing. Possibilities of flood losses' minimization and insurance specifics connected with flood risk are judged.

Keywords: Flood, risk, loss, financial backing, insurance

1 Introduction

Flood is one of the most important natural hazards, it is considered as the most important element in Czech Republic. Czech insurance market was strongly influenced by several floods during last 10 years. Floods from 1997 and 2002 can be even called natural disasters with total losses 2319 million EUR (1997) and 2704 million EUR in 2002.

2 Floods in Czech Republic from 1997

Property is threatened with various hazards; natural as well as man-made. Mainly elemental hazards are very frequent in connection with global changes of climate at the beginning of 21st century. Flood is the most hazardous element in Czech Republic followed by fire and windstorm.

Flood in 1997 caused damages mainly in Moravian region (rivers Morava, Ostravice and Odra), flood in 2002 hit more-less the whole are of Czech Republic (rivers Labe, Vltava, Dyje).

Dates from Table 2 show that the work of flood bodies is much better after flood in 1997. Even the flood in 2002 was bigger than 1997 and on greater area (see the comparison of highest flow speed) the amount of total losses was relatively smaller and mainly the number of victims decreased essentially.

Table 1. Comparison of flood losses in 1997, 1998, 1999 and 2002 in Czech Republic [1]

Year	Number of Insurance Events	Total Insurance Benefit	Total Losses	Average Loss
1997	117.000	359 million EUR	2.319 million EUR	3.071 EUR
1998	3.670	21 million EUR	67 million EUR	5.752 EUR
2000	7.494	70 million EUR	-	9.390 EUR
2002	82.000	1.370 million EUR	2.704 million EUR	16.712 EUR

Table 2. Comparison of main floods from 1997 and 2002 [2]

	1997	2002
Number of hit districts	34	43
Number of hit municipalities	538	684
Number of victims	60	17
Total losses	2.319 million EUR	2.704 million EUR
Highest flow speed	850 m^3/s	5300 m^3/s

Fig. 1. Flooded railway station “Ostrava hlavní nádraží” in 1997 by Odra River

3 Approach to Flood Risk

Flood risk cannot be eliminated entirely. On the other hand range of flood losses can be decreased by observance of the basic rules during preparation and realization of construction, building's operation, by quality prediction services, responsible work of flood bodies and skilled procedure during flood and after flood.

3.1 Flood Risk Prevention

Flood origin and extent depends on frequency and volume of atmospheric precipitation, absorption characteristics of area, river-basic capacities and condition of draining area. Flood losses extend is affected by various factors, mainly:

-way of building-up area;

-flood behavior (culmination flow rate, shape and volume of spring flood, duration of flood, …);

-river-basin capacity, condition and withstand capability;

-well-timed awareness about flood risk (forecast, warning duty);

-readiness and level of flood-protection operations.

3.2 Property Protection During Flood and After Flood–Flood Losses Minimization

Basic rule is saying: live saving takes priority over property saving. Before leaving building following acts should be done:

-windows closure control;

-water-checked apertures (sewerage drains, …);

-translocation of more valuable things to upper floors;

-gas seal, water stop closing, outage;

-dangerous chemicals storage and attachment on safety place;

-building lockout, [3], [4].

Professional work can be introduced on following case: water started to flood in ground floor of residential building under construction. Construction company made following protection measures to protect property: 361 sand-sacks fulfillment, barrier formation from sand-sacks and OSB panels. Such flood-protection operation saved 250 m^2 of plasters, only 28 m^2 had been damaged.

Total insurance benefit was 37.696,- CZK, loss extent without flood-protection operations was 221.150,- CZK. Construction company saved over 183.000,- CZK.

Table 3. Flood loss assessment (in CZK, 1 EUR = 27,2 CZK, 27.3.2009)

Item	Unit	Amount	Unit price	Total loss	Total costs
Plaster batter	m^2	28,00	47,60		1.332,80
Plaster completion	m^2	28,00	837,00	23.436,00	
Safety costs (material)	acc. to invoices				5.487,00
Safety costs (work)					7.440,00
Total				23.436,00	14.259,80

3.3 Flood Losses Determination

Flood have repercussions on property, health, live, environment etc. Flood losses classification is made in relation with various criterions. Particular criterions give us different information for consequence analysis, flood evaluation and principles of floor protection judgment in concerned area.

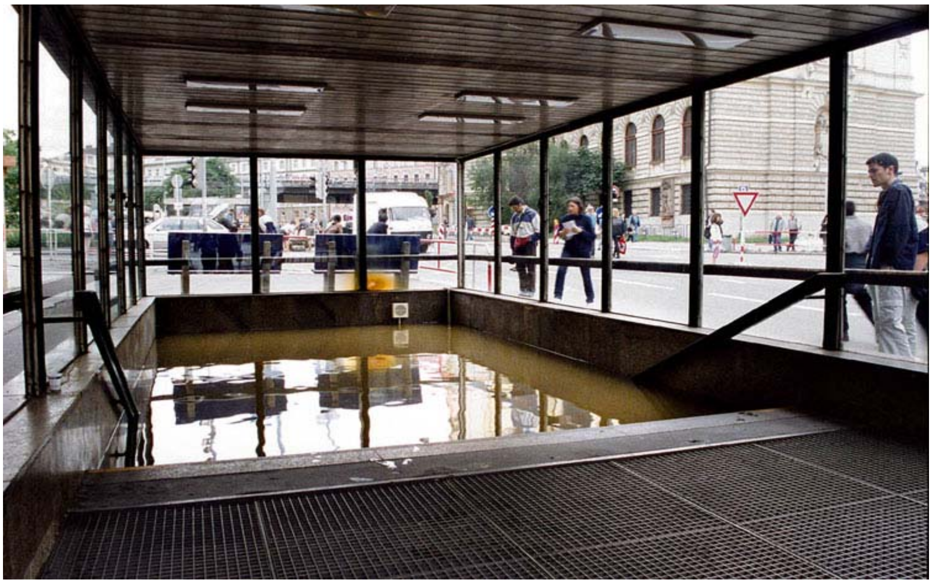

Fig. 2. Flooded entrance into metro station in Prague, 2002

It is impossible to calculate objective amount of flood losses because main part of losses cannot be evaluated detachedly or the valuation process is too complex hence is not used.

Flood losses distribution concerns:

- losses on human life;
- ecological losses;
- economical losses.

Each category is indicated with different unit. Number of victims and amount of economical losses in terms of money are basic indicators by which we can valuate range and weightiness of flood. Flood losses distribution from other point of view concerns:

- direct calculable losses (caused by immediate contact with water – property losses, contamination, …);
- direct non-calculable losses (caused by immediate contact with water - victims, losses on historical buildings, destruction of biotopes, subjective losses on property, …);
- indirect calculable losses (profit loss, purchasing power decrease, decrease of real property prices, evacuation costs, …);
- indirect non-calculable losses (social life failure – education, increased sickness).

Obviously main part of flood losses is in category non-calculable. Those losses exist but they are not scheduled in the list of financial losses. Thus official statistics measure only calculable losses predominantly (e.g. Table 1), [5], [6].

4 Financial Backings Used to Cover Flood Losses

There are several types of financial backing which can be used to cover flood losses. Those financial backings can be distributed among public (state budget, specific funds, funds from EU, etc.) and private (savings, credits, insurance).

4.1 Private Sources

People have to take into account that they cannot rely on public money when flood will damage their property. Nobody has legal claim to obtain financial help from state budget or EU funds (this help is usually conditioned and limited). Man has to shift for oneself, i.e. to ensure private financial backing. Each type has its advantages and disadvantages.

Insurance should be the basic financial backing for natural bodies as well as for corporate bodies; it provides the most effective financial protection of property, [7].

Table 4. Comparison of savings, credits and insurance

Type	Advantages	Disadvantages
Savings	Low costs Interest in prevention	Big amount of disposable money (cannot be invested) Incidentalness of damage
Credits	Inutility of reserves (money can be invested)	Downgraded prevention High costs (credit interest) Bank will not give a credit
Insurance	Inutility of reserves Money are at disposal immediately	Insurance benefit limit Expensive premium Exclusions

4.2 Flood Zones

Insurance companies distinguish between four flood zones according to the level of flood risk in particular area. Practically there are three flood zones in Czech insurance field. They are named usually as:

- First flood zone: non-flood zone
- Second flood zone: dangerous flood zone
- Third flood zone: risky flood zone
- Fourth flood zone: uninsurable

First flood zone is characterized by minimal level of flood risk. It is necessary to set frontier criterion to differentiate between Second and Third flood zone. Such criterion can be described e.g. whether the property has been deluged during last 20 years or not. Buildings located in Fourth flood zone are uninsurable against flood risk.

4.3 Insurance Rates

Calculation of insurance rates is made by insurance mathematic rules on the level of insurance companies. Such calculation takes into account various factors like average losses, loss courses, loss frequencies etc. The problem is that relevant data are not available on the market. Insurance companies consider these data as their business secret and part of their know-how.

Insurance rates can be stated by insurance market analysis from clients' point of view. Such approach is also difficult because certain insurance companies comprehend various extents of insurance risks into basic elemental insurance packet. Total insurance rate is calculated as the sum of partial insurance risks. Total insurance rate is calculated by following quotation:

$$IR = \sum_{1}^{n} IR_1 + IR_2 + ... + IR_i + ... + IR_n \quad (1)$$

where *IR* is total insurance rate as the sum of n partial insurance rates. Contemporary insurance practice distinguishes between basic insurance rate and flood insurance rate. As mentioned before, insurance companies examine flood risk separately from other elemental risks (e.g. fire, windstorm, hailstorm).

Insurance market analysis gives following results of insurance rates (those numbers are valid for family house), [8].

Table 5. Insurance rates in (‰) for family house in Czech Republic

Flood zone	I.	II.	III.
Basic insurance rate (BIR)	0,89	0,89	0,89
Flood insurance rate (FIR)	0,18	0,72	1,26
Total insurance rate	1,07	1,61	2,15

5 Conclusions

Flood is the most important hazard in Czech Republic. The situation of flood risk prevention and "flood experiences" (of people, government and flood bodies) was very weak. Approach to floor risk changed dramatically after flood in 1997 and also in 2002. Progress can be seen on statistic data: even flood in 2002 was more extensive then in 1997; number of victims decreased and also amount of losses is in the rate lower (in addition we don't take into account influence of inflation).

Dramatic change affects insurance field as well. Insurance companies made flood insurance more restrictive: flood zone system had been established, insurance rates had been increased and buildings in extremely threatened localities are uninsurable against flood.

In correspondence with increasing frequency and gravity of windstorm consequences big changes in windstorm insurance are anticipated in following years (including formation the windstorm zones).

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Anti-flood Operations in the Territory and Their Economic Efficiency

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Abstract. Floods belong to the most dangerous natural disasters in the Czech Republic. It is very difficult to avoid them, but it is possible to reduce their impacts by relevant anti-flood operations. Anti-flood operations can be in the form of various technical solutions, particular technical solutions can differ in costs connected with their realization and operation. Technical solution of anti-flood operations can be quite expensive, so it is very important to valuate the utility of these projects. The paper deals with the definition and utilization of the method for the valuation of the anti-flood operation economic efficiency. The solved method is based on the traditional basis of valuation of investment projects, but it respects specific features of this kind of projects, mainly in the area of the valuation of their benefits. Projects in the area of anti-flood operations are usually not connected with direct financial incomes, so the identification, the quantification and the valuation of project's benefits is the most important part of described method.

Keywords: Flood, protection, economic efficiency, investment project, costs, benefits

1 Introduction

The realization of anti-flood operations in the territory is one of possible ways, how to avoid terrible impacts of floods on people and the property in residential areas. By the realization of suitable anti-flood operations it is possible to minimize risk connected with flood danger and possible losses on health or property caused by the flood. There exist a lot of possible solutions of anti-flood operations realization, e.g.:

- realization and revitalization of polders, basins and dikes and assurance of their running including the maintenance and repairs;

- increasing of the flow capacity of watercourses, assurance of repairs, maintenance and running of connected objects and machinery;
- revitalization of ponds and increasing of their accumulative capacities.

Before the realization of particular anti-flood operation it is necessary to respect special conditions in the territory for the possibility to choose suitable solution. Next aspect that it is necessary to take into account it is the financial side of the problem. Most of solutions are from the financial aspect quite expensive, from this reason it is necessary to valuate, if the chosen solution brings more benefits then costs connected with its realization, maintenance and losses connected with impact of the project's realization on the environment, generally on the surroundings. This paper is focused on the evaluation of the economic efficiency of anti-flood operations not only from the aspect financial costs and benefits, but also from the aspect of the total impact of the realization of anti-flood operation on the whole society.

2 Principle of the Economic Efficiency Valuation

The economic efficiency valuation it is possible to base on the principle of comparison of total costs connected with the realization (investment costs) and next operation of the anti-flood operation and the total benefits that the anti-flood operation will bring. This comparison it is possible to complete by the theory of the time value of money, then the result is more accurate. The detailed description of the general way of the anti-flood operation's economic efficiency valuation is e.g. in [2]. It is possible to use following general relation coming out from the theory of the net present value (NPV):

$$NPV_E = \sum_{i=1}^{n} \frac{1}{(1+r)^i} \left[\sum_{j=1}^{m} p_j \left(C_{ij}^0 - C_{ij}^I \right) \right] - IC \qquad (1)$$

where:

NPV_E	economic Net Present Value
IC	investment costs
C^0_{ij}	j - kind of costs in zero option in i - time period
C^I_{ij}	j - kind of costs in investment option in i - time period
r	discount rate
n	life time of the investment project, event duration of the valuated project's time period (in years)
m	number of costs identified in the frame of the projects
p_j	probability of j - cost, it must be $\Sigma p_j = 1$

From the relation it is clear that for the economic efficiency assessment it is necessary to find out following values:
- investment costs;
- costs arising in the case of the zero option (the project of anti-flood operation is not realized);

- costs arising in the case of the investment option (the project of anti-flood operation is realized);
- probability with that certain cost arises in one year.

Total benefit (or total cost) caused by anti-flood operation in the certain year it is possible to calculate as a difference between costs arising in the case of the zero option and costs arising in the case of the investment option. If the result has positive value, then the project brings more benefits than costs, if the result has negative value, then the project brings more costs than benefits. Addition of results of all years of the lifetime of the projects respecting the time value of money decreased by investment costs brings the total impact of the project on the society. Zero or positive value mean acceptable project, negative value of the result means non acceptable project [2].

3 Costs and Benefits of Projects

As it was cited in previous chapter, the benefit of the project it is (in the case of solved problem) possible to define as a positive difference between costs arising in the case of the zero option and costs arising in the case of the investment option. Then the benefit is in the form of the “cost saving”. Costs arising in the connection with the project can be from the aspect of their expression differed in following way: appreciable costs, and non appreciable costs.

3.1 Appreciable Costs

Investment costs. Investment costs are connected with the own project realization during the preparative and realization phase of the project. Investment costs are usually in the form of costs for the realization documentation preparation, costs for supplies of building objects and costs for deliveries of technologies. For the expected investment costs assessment it is necessary to have the technical documentation of building object (drawings, design, technical report), for own evaluation of costs it is possible to use the price catalogue of building works and price catalogues of material for valuation of materials in specifications. Other possible way it is usage of prices agreed with sub-suppliers.

Appreciable operating costs. Appreciable operating costs of the anti-flood operation are connected with the assurance of utilization of anti-flood operation during its lifetime. The calculation of annual costs it is necessary to do individually respecting the type of anti-flood operation and its location in the territory.

Appreciable costs caused by flood. For the assessment of appreciable costs in the form of potential losses on the property in the territory caused by the flood it is possible to use e.g. Territorial Property Index characterizing an average value of the property per the square unit of the territory (e.g. m2) and damage curves determining the rate of the damage of property representatives in the territory depending up the flood intensity. More detailed information about the Territorial Property Index assessment and the way of the definition and the use of damage curves is available in [1].

3.2 Non Appreciable Costs

Beside appreciable costs arising during the project's preparation, realization, utilization or liquidation there exist certain number of costs that it is not so easy to express in monetary units. It concerns mainly about costs connected with the detriment of environment caused by the realization of the anti-flood operation, but these non appreciable costs can arise also from other reasons. The main problem it is the question, how to express these costs in the project's economic efficiency valuation. One possible way is to verbally describe these influences and this description then to take into account during the final decision making. More difficult way is to evaluate these costs and to give them some value expressed in monetary units. This process is not easy, but there exist some methods, with their utilization it is possible some non appreciable costs to evaluate. Methods are based on the evaluation of non-profit goods and it concerns mainly about pricing methods and valuation approaches that will be characterized in following chapters.

4 Approaches for Non Appreciable Costs Evaluation

4.1 Pricing methods

Pricing methods are represented by simple approaches that don't come out from the generally defined demand curve, but they set the value of the specific goods or events directly for the specific case. Those methods are not as direct and general as valuation approaches, but for utilization they are easier. It concerns mainly about methods using opportunity costs, costs for alternatives, shadow project costs and the other methods.

The opportunity costs method is based on the finding of the value that it is necessary to sacrifice for increasing of the amount of certain goods or events.

In the case of method based on *expenditures for avoiding of losses* there are expenditures, which individuals pay for purpose of avoiding of negative impacts on environment, considered as a simple expression of monetary value of these impacts.

Shadow project costs method deals mainly with the evaluation of environment and mainly losses on environment caused by realized projects. Principle of the method is based on the assessment of costs connected with the offering of alternative environmental goods in other place, then it was situated before and later by development project degraded. These costs express the value of environment that enters into costs of development project during its economic efficiency valuation. However by the choice of the shadow project it must be discussed and valuated the adequacy of chosen shadow project in comparison with the rate of devaluation of environment caused by the development project.

The dose - response method is probably the most difficult pricing method, because it requires a lot of statistical information. Basic principle of this method it is the identification of the relation between devaluation of environment (dose) and the rate of its damaging (response) caused by the project realization. However through quite high difficulty the dose - response method is not usually able to take into account all environmental costs caused by the project's realization. Usually it is possible to enumerate only economic losses, thus losses caused on goods appreciable by the market system [5].

4.2 Valuation Approaches

Valuation approaches offer more general way of evaluation of non profit costs and benefit caused by the investment projects' realization. Particular methods included in valuation approaches are based on common principles. The main principle of valuation approaches it is to assess, what value particular non-profitable goods, events or processes have for the society. The value it is in this case possible to characterize as a rate of utility, which individuals (or the society as a whole) feels during the utilization of valuated goods or at least in the case of possibility of the choice to use these goods. However the utility it is hard to measure and quantify, that is the reason, why for the expression of the utility it is used the magnitude called Willingness to Pay (WTP) for an existence and possibility to use particular non-profitable goods. There exists the supposition that individuals will be able to express the maximal amount of money, which they are willing to sacrifice for possibility to use particular goods. The difference between the willingness to pay (the rate of utility that individuals feel during the utilization of the non-profit goods) and costs connected with the acquisition of these goods (the difference between the sum that the individual is willing to pay and the sum that he must to pay) is called the Consumer Surplus (CS).

In the case of decision making about the realization of particular variants of public investment projects it is then judged the total change of the consumer surplus for the whole society [5, 6].

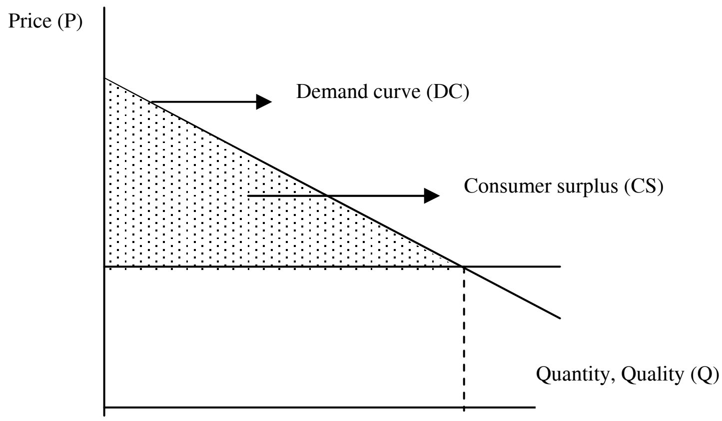

Fig. 1. Construction of Consumer surplus (CS)

Methods based on the valuation approaches can be e.g. [6]: expressed preference methods, and revealed preference methods.

Expressed preference methods. Expressed preference methods are based on the direct questioning of individuals, how much they evaluate monitored non-profit goods.

Really these methods are directly focused on the creation of real demand curve of particular non-profit goods. This creation is allowed by various methods of direct questioning (contingent valuation method, contingent ranking and stated preferences methods).

Contingent valuation method is based on researches, in the frame that particular respondents are directly asked, how much they are willing to pay for possibility to pump the benefit from the utilization of non-profit goods, or what financial compensation they would require in the case of non-possibility of their utilization. Contingent valuation method consists in the assessment of willingness to pay (WTP) for possibility to use the non-profit goods or willingness to accept (WTA) the compensation in the case of non-possibility to use this non-profit goods [5, 6].

Contingent ranking and stated preferences methods are based on personal interviews, when respondents choose between particular goods, from that each is described by many characteristics, from that usually one has the financial expression (price, costs, fees). In the case of *Contingent ranking method* the respondents are asked for expression of preferences by sorting of particular kinds of goods from the most preferred to less preferred. Each kind is described by several characteristics. And if one of characteristics is the price of particular goods, then it is possible, with the help expression of preferences by the sorting of particular kinds of goods, to express the value, that other characteristics have for the respondent. *Stated preference method* is usually applied for the assessment of value of the territory intended for recreation. In the case of this method respondents are acquainted with two or more recreation areas, from that each is described by many characteristics, from that some have the financial expression (travel costs, entrance fee, etc.). Respondents are next asked for the expression of preferences by choice, which of defined territory they prefer for leisure time activities. Analytics then evaluate how the preferences of respondents have changed with the change of particular characteristics expressed in monetary units. From this information they then define the value of each particular characteristics of the territory [5, 6].

Revealed preference methods. Revealed preference methods are focused on the definition of value of non-profit goods with the help of monitoring of amount by market valuated goods, which individuals acquire for possibility to use non-profit goods (e.g. petrol necessary for realization of the all-day trip outside). This information allows to analytics with the help of statistical processes the construction of the demand curve of specific non-profit goods and from this curve it possible to define changes in the consumer surplus caused by changes in offering of non-profit goods.

The travel cost method is used mainly for assessment of value of environmental goods. It uses costs caused by traveling of individuals for possibility to use non-profit goods for the purpose of expression their value. The value is derived from the price of market goods acquired by individuals. Really the travel costs caused by individuals for the purpose of achievement of valuated goods express vertical “price” axe of the demand curve graph. These costs consist from two parts, material costs (the consumption of petrol, fares, entrance fees etc.) and the value of the travel time. These travel costs determine number of visits of the specific place (horizontal axe of the demand curve graph).

By the monitoring of visitors of the specific place and by questioning for information including their travel costs, the quantity of visits for the defined time period, or next important factors, it is next possible to map the demand curve for the specific environmental goods [5], [6].

The hedonic pricing method starts from the hedonic pricing formula, which defines, that the price of the house is dependant on its next characteristics. Among these activities it is possible to include e.g. environmental characteristics (the esthetic level of environment, where the house is situated, the level of noise in this location or the quality of air. And just these non-profit goods are appreciable by the hedonic method. The hedonic pricing method it is possible do divide into two phases. The first phase consists in the creation of the hedonic pricing function. In this case there are used statistical methods, with their help it is found, in what amount they are the differences in prices of houses dependant on the amount of environmental goods that inhabitants of theses objects can use. The second phase is then focused on the creation of the own demand curve of the specific environmental goods [5], [6].

5 Conclusions

The realization of suitable anti-flood operations in the territory threatened by flood can be in many cases quite difficult for financing. This is the main reason, why it is very important objectively to valuate the economic efficiency of these operations and directly to determine the total economic impact of these operations on the territory. This paper in the first part describes the basic principle of the economic efficiency of anti-flood operations' valuation. There are also described particular kinds of costs that can arise together with the realization of these projects. In the second part there are in basic principles defined particular methods for valuation of non-financial benefits and non-financial costs connected with the realization of anti-flood operations.

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Management of Water Resources in Upper Ialomita River Basin (Carpathians, Sub-Carpathians, Romania)

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Abstract. Fitting Ialomiţa upper river basin began in the interwar period of the last century and was intensified after the flood that took place in the 70s during the same century. In this context, we can speak of an anthropized river system for 72 km of the river (from springs - altitude over 2400 meters, to the contact with the High Plain of Targoviste). Some water resources and reserves were reduced, making the degree of satisfaction to be between 50-75%. The karst hydrostructures from the mountainous area could meet the water needs of downstream consumers (subcarpathian area), but they are insufficiently controlled and estimated, both quantitatively and qualitatively. Totaled, the two resources - surface water and groundwater - reach a volume of water of 1.104 billion cubic meters / year (of which 824 million cubic meters / year is surface resource).

Keywords: Ialomita Upper River Basin, water resources, hydrostructures, lakes, management

1 Introduction

The basin area of upper Ialomiţa is 686 km^2, which represents 6.62% of the total basin area of 10,350 km^2. *Ialomita River*, originating in the Bucegi Mountains, at over 2300 m, crosses the mountainous and hilly area up to Targoviste, covering 71 km (17.03% of the total length of 417 km), going down a slope of approx. 2010 m. It presents a coefficient of sinuosity of 1.88 on its entire course, with values slightly lower in the mountainous and hilly areas (between 1-1.50). The density of the hydrographic network is between 0.100-0.260 km/km^2.

At the contact between the hills and plains, Ialomiţa has an average flow of 7.97 m^3 / s (11.61 l/s/km^2).

2 Water Resources

Groundwaters constitute an important resource of water, with superior characteristics by comparison with surface water. They are frequently used to supply water to population and economic units. Groundwater in the Carpathian and sub-Carpathian area belonging to upper Ialomiţa river basin is influenced by the geological formations (tectonic, petrographic variety, physical and chemical rock properties, thickness of the deposits, etc.) and so we encounter phreatic and deep water structures. They originate in the ford of the river, and take the form of various hydrostructures.

3 Alpine Hydrostructures

The hydrostructure of Bucegi Massif. According to the position of the permeable rock formations in relation to the waterproof formations in the foundation and to the drainage system, in the Bucegi Massif we can single out three types of hydrostructures (Al. Istrate, 2002):

Karst hydrostructures

- Bucegi north hydrostructure and Tatarului Gorge-Scropoasa hydrostructure, formed in the limestone deposits of the Jurassic and of the Cretaceous period, in the superior conglomerates facies of Bucegi;
- Lespezi-Orza and Rătei hydrostructures, formed in the Jurassic calcareous stones;
- Raciu-Piscu cu Brazi hydrostructure, formed in the calcareous breccias facies of Raciu and in the superior conglomerate facies of Bucegi.

Hhydrostructures with fissure-triggered primary and secondary intergranular porosity:

- Hydrostructure of Bucegi Cuesta
- Hydrostructure of Brânduşei micro-depression

Hydrostructures with intergranular porosity, delimited within the granular deposits

- Hydrostructure of the frontal till from the springs of Ialomiţa River
- Hydrostructure of the alluvial plain of Ialomita River.

The North Bucegi karst hydrostructure is supplied with water by the rain and the snow, by leakage of surface water from the Leaota crystalline and the direct infiltration of rainfall in the superior conglomerates facies of Bucegi. The drainage of this structure is located in the eastern slope, by the springs that appear in the alignment Morarului Valley in the north and Pelesului valley in the south, in the following points: Jepilor valley, Urlătoarea Mare valley and Urlătoarea Mică Valley, Babei Valley, Peleş Valley, which amount to a flow of approximately 500 l/s (Gh P. Constantinescu, 1980).

These springs occur at the same altitude as the springs of the depression of Padina: the spring upstream of Bears' Cave (Peştera Urşilor), Horoaba, Coteanu and Păstrăvăriei springs with water discharges oriented south and southeast. The hydrostructural water discharge east and southeast is influenced by the tectonics of the area, and by the faults oriented east-west or north-west - south-east.

The appearance of the crystalline fundament at the surface, due to the erosion of

Ialomiţa and of its tributaries from the right side (Horoaba and Coteanu) suggests that this hydrostructure is limited southwards. The southern limitation of this hydrostructure by the structural uplifting of the crystalline foundation could explain the overflow nature of the springs on the eastern slope of the Bucegi massif and even the karst springs of Padina depression. The existence of the breccias of Raciu in the basis could explain the high water-bearing potential of this zone. Already in 1969, D. Patrulius suggested that the water-bearing structure situated on the level of the breccias of Raciu allow the water to leak from Ialomiţa valley into Prahova Valley.

Currently, there are no systematic measurements on the flows of the springs on the eastern slope of the Bucegi Mountains, which have only been estimated at a minimum flow of 225 l/s and an average flow of 500 l/s (Gh P. Constantinescu, 1980). Point measurements were made by Al. Istrate the years 1984-1985, on the springs Horoaba, Coteanu and Păstrăvărie.

Horoaba spring is the most important spring in the depression of Padina, with flow values between 57 l/s and 160 l/s.

Coteanu spring comes second in the depression of Padina regarding the volume of water, with flow values between 62 l/s and 93 l/s.

Downstream of Cheile Mici ale Tătarului, on the right slope, there is Păstrăvăriei Spring, with flow values between 19 l/s and 53 l/s.

As a result, most of the flow of the North Bucegi hydrostructure is discharged towards Prahova Valley and only a part to Ialomiţei Valley.

South of Cheile Tătarului is delimited the *Cheile Tătarului - Scropoasa hydrostructure*, which overlaps the depressions of Bolboci and Zanoaga.

The storage and circulation of the groundwater is generated by the relationship between the crystalline foundation of Leaota and the sedimentary layer belonging to the flysch area and to the superior conglomerates facies of Bucegi.

The drainage occurs on the southern and south-western slope of Colţii Dichiului Mount and is given by two groups of springs. The first group discharges its waters in Ialomita River, and the second in Scropoasa Valley. So the flow of this hydrostructure reaches Ialomita River. The water-bearing potential of these springs in natural regime has a cumulative minimum flow of 220 l/s (95% assurance) and a maximum flow ranging around 800-1000 l/s. The flow of these sources is influenced by the water loss of Bolboci lake and could constitute a source of water in the area of water deficit situated in the Subcarpathians of Ialomiţa, between Ialomiţa and Cricovul Dulce.

South of the Scropoasa lake takes shape the Lespezi-Orzei karst hydrostructure, which is intersected by Ialomiţa River up to the crystalline foundation. At the contact between the crystalline and the limestone, there are several temporary, small springs. One of them is captured and used to provide with water the limestone quarry from Lespezi.

On the level of the depression of Rătei, a karst system develops in the northern slope of Rătei Valley, a tributary of Ialomiţa River. Following the loss of surface water of the valley, through a system of cracks and from the surface waters, the Rătei surface hydrostructure has been formed. It presents a spring that has been captured since 1910 and used to supply Targoviste town with water. Rătei Spring has a flow ranging from 16 l/s to 45 l/s.

In the eastern part of the Bucegi Massif is located a hydrostructure situated in Raciu syncline, in which we can distinguish: the depression of Raciu in the north and the depression Piscu cu Brazi in the south, extending towards Ialomiţa basin westwards, up to Ialomicioara de Sus Valley (Runcu).

In the depression of Raciu there is an initial spring at the contact between the calcareous breccias of Raciu and a crystalline plot that appears at the surface on the right side of the Ialomiţa River. This spring is intermittent, with a flow of 4 l/s and 5 l/s, being intersected by the upstream waterway Dobreşti-Gâlma. On the axis of Raciu syncline, there appear the Gâlma springs, in the left slope of Ialomiţa River, with a flow of 10-12 l/s and captured in the 1970s to supply with water the town of Pucioasa. On the southern flank of this syncline there are several more small streams, some captured for the Hydroelectric Power Plant Gâlma-Moroeni.

Also in Raciu syncline, there is a second group of springs with a flow of 5-7 l/s, located on Tâţa Valley, which was captured between 1987-1988 to supply with water the locality of Dealu Frumos. In the same syncline, there is also a smaller spring on the left of Ialomicioara de Sus Valley, downstream from the confluence with the Vaca Valley. It has a flow of 3-4 l/s and was captured in the years 1984-1985, to supply with water the village of Runcu.

The hydrostructures with fissure-triggered primary and secondary intergranular porosity are found in Albian deposits (Al. Istrate, 2002). They generate many springs with low flows, such as:

- diffuse springs from the left slope of Ialomiţa River, at the contact with the Scropoasa - Lăptici facies along the Bucegi Cuesta;
- springs of the Brânduşei Valley and Porcului Valley, at the contact between the gritstones of Babele and Scropoasa-Lăptici facies;
- spring of the western slope of Ialomita valley, downstream from the confluence with Tătarului Valley, with a flow rate of approximately 10 l/s, which occurs at the contact between the Bucegi conglomerates and the crystalline foundation;
- spring behind the Padina chalet, linked to the conglomerates of Bucegi.

If the previously presented hydrostructures situated in carbonated deposits, belonging to the Jurassic and the lower cretaceous period can be categorized as deep water-bearing structures, the hydrostructures with intergranular porosity delimited from the level of the Quaternary granular deposits are not situated deep underground (groundwater).

Among the latter, the most important is the *frontal till hydrostructure* from of the confluence of Ialomiţa Valley with Şugările and Doamnei valleys. Here we have lines of springs developed on the southern abrupt slope of the till, constituting a source of water for Peştera Hotel.

The hydrostructure situated in the Quaternary alluvial deposits of the Ialomiţei riverside upstream of Zănoagei Gorge is currently affected by Bolboci storage lake.

4 Subcarpathian Hydrostructures

The sub-Carpathian sector consisting of Myo-Pliocene formations with a wide variety of sedimentary rocks influences the position and the characteristics of the groundwater. The lithological makeup, characterized by an alternation of permeable horizons (conglomerates, grit stones, gravels, sand) and impermeable horizons (clays and marls) with non-homogeneous thicknesses and presence of faults, hydrocarbon resources and salt pits, influences the distribution, the location and chemical characteristics of the groundwater.

The sub-Carpathian area is characterized by an average groundwater-feeding potential in relation to the quantities of precipitation that are differentiated, depending on the altitude. The high degree of fragmentation of the relief and the non-homogeneous forest vegetation carpet reduce water infiltration, leading to a rapid drain on the inclined slope, favoring surface drainage rather than infiltration in the underground.

The Paleocene deposits, spread on extensive areas in the northern part of the Sub-Carpathian area, consisting of grit stones, marls and clays, have a reduced groundwater storage capacity due to poor water supply by means of the fissure systems. This favors the presence of springs along the fault lines situated at the contact of the Paleocene formations with the Miocene ones. Their flow rate is fluctuating, depending on the amount of rainfall in the area.

In the Neocene deposits formed from an alternation of grit stones, marls, conglomerates and Sarmatian limestone, there appear water-bearing horizons which are fed with waters coming from the strata ends or on the fault lines, and, because the water passes through salt-yielding and gyps-yielding clays, there appear springs with low flows and a high mineralization degree.

Important groundwater resources are present in the Quaternary formations. The aquiferous complex structures of these deposits are found in the interfluves, composed of the eluvia of the leveling surfaces and the diluvial and colluvial deposits of the slopes. Through the slope deposits takes place the drainage of the groundwaters from the interfluvial areas towards the terraces and meadows (Al. Istrate, O. Murărescu, 1999; Şt. Nedelcu A., 2000).

Along the main valley corridors have been developed groundwater aquifers in Quaternary alluvio-proluvial deposits. This type of structure favors the storage of large water quantities in the meadows of the rivers: Dambovita, Prahova and Ialomita. The alluvial deposits from the meadows of these rivers may reach thicknesses of 3-8 m, depending on which the piezometric level varies between 0.5 and 2 m, with the increasing of the thickness of the complex water-bearing structure from upstream to downstream. The implementation of storage lakes, such as those on the Ialomita river at Pucioasa and Doiceşti has influenced the groundwater level in the sense that it has recorded an increase upstream of these lakes and a decrease downstream (Loghin V., 1999).

In the area of terraces, the aquifers are fed by rainfall and natural discharge from the neighboring slopes. The piezometric level in the terraces varies between 3-10 m, and the drainage directions are generally towards the axis of the valley corridors.

In the structural-geological units of the Sub-Carpathians can be distinguished, based on the research conducted to date, several water-bearing structures:

- *the internal flysch area* has little groundwater, but it is drinkable. There are some occurrences of mineral waters in the area Dealu Mare – Dealu Frumos;
- *the external flysch area*, also with modest groundwater resources, but drinkable. Drinking water that could be used, but with a low potential, can be found in the Dacian-Romanian deposits in the axis of Valea Lungă syncline located north of Moreni town and in the axis of Gura Bărbuleţ syncline;
- the *trench area* provides favorable conditions for the storage and circulation of

the groundwater through the filling of the Dacian basin with river-lake deposits.

In the latter is separated the internal trench on the level of the Romanian- Upper Pleistocene deposits, where a highly dynamic hydrostructure appears, given by the contour conditions, which leads to the restoration of the groundwater reserve. This hydrostructure which has an average potential offers significant perspectives and occupies the interfluves Dâmboviţa - Arges and Prahova – Cricovul Dulce, on the level of Edera - Satu Banului syncline. It has an important water-bearing structure for the area, given the scarcity of the water resources in the area.

The external trench, which makes the passage to the Wallachian platform, which worked as an area of fluvial-lacustrian storage up to the Holocene, consists of Quaternary deposits with thicknesses of 100-300 m. In the latter can be separated several hydrostructures with a significant water-bearing potential:

- Upper Pleistocene hydrostructure, at the contact with the piedmont plains southwards: Targoviste, Pintenul Măgurii;
- Upper Holocene hydrostructure, along the main hydrographic arteries, up to the area of the internal flysch.

From the above, we remark an uneven distribution of the underground water resources, with a concentration in the southern and western sector and a major deficit in the sub-Carpathian flysch area.

Most important are the hydrostructures of the Lower Pleistocene, Upper Pleistocene and Upper Holocene.

The hydrostructure of the Lower Pleistocene is characteristic of Cândeşti gravel deposits, with an estimated flow of approx. 1500 l/s and Edera - Satu Banului syncline, which may provide a flow of 330 l/s, of which between 75-80% is exploited for the town of Moreni and the localities Măgureni-Filipeştii de Pădure.

The Upper Pleistocene hydrostructure is characteristic for the southern piedmont plains, with flow rates estimated between 100 and 750 l/s, exploited for the water supply of the towns in that geographic area. This hydrostructure represents as well a local water source for various institutions, particularly in the agriculture. The lack of systematic measurements makes it difficult to quantitatively estimate the water-bearing potential.

The *Upper Holocene hydrostructure* is situated close to the surface, and has been researched in the meadow and lower terrace area of the hydrographic network, in order to turn it into a source of water supply. This hydrostructure is affected quantitatively by the erosion and by the exploitation of the material from the meadows, which has led to a lowering of the water bed of approx. 1.5-3 m, while the main source of restoration for the groundwater is the water from the rivers.

It is estimated, for the meadow and the lower terrace of the Ialomita River, a flow of 67 l /s, upstream Fieni, also exploited at the surface.

5 Surface Water Resources

Average leakage is the most synthetic indicator of water resources within a hydrographic system. It represents the potential water resources of the rivers in the area under analysis, important in the valorization of the water resources for different socio-economic goals.

In order to assess this quantitative parameter and to highlight its aspects, we analyzed and processed series of average monthly and annual flows for different periods, depending on the duration of functioning of the hydrometric station. In this respect, we have analyzed the liquid flows from a number of 22 hydrometric stations, and noticed a remarkable variability in time and space of the average flow.

Ialomita River, along its 71 km course from its springs to Targoviste, has a module flow growing constantly from 1.15 m^3/ s at the entrance to Bolboci Lake up to 7.97 m^3/ s at Targoviste.

Because of the hydro arrangements along it, there appear a number of changes in the liquid flow regime, the affluent module flow in the storage lakes Bolboci, Pucioasa, Doiceşti being higher than the diffluent flow, which is dictated by the needs of water supply of the socio-economic units downstream. These lakes have the role of regulating the liquid flow along the year, in order to mitigate flood waves or draught phenomena that may occur.

So, if the module affluent flow into the Bolboci Lake is 1.15 m^3/ s, the diffluent one is 0.81 m^3/ s, increasing at Moroeni to 6.88 m^3/ s, decreasing again at Pucioasa to 5.58 m^3/ s and increasing at Tirgoviste to 7.97 m^3/ s .

From the alpine region, Ialomiţa receives only one important tributary, Ialomicioara Leaotei, which has a module flow of 0.81 m^3/ s in Fieni.

In the sub-Carpathian area there are a number of tributaries of Ialomiţa River, a part of them discharging their waters in this area and others in the southern plain. These rivers' module flows record average values ranging from 0.17 m^3/s (Slănic at Gura Ocnita) and 1.0 m^3/s (Bizdidel, at Pucioasa).

The variations of the flow from one year to the next reported to the mutiannual average differ from one river to another and from one region to another. The amplitude of the variation of the annual flow during the period under analysis is determined by the climate characteristics and the surface of the hydrographic basins that have a major role in regulating the flow. This is influenced as well by the role of regulator of the storage lakes present along the hydrographic arteries.

In the years 1981, 1990, 1991, 1997, 1998, there were recorded higher rates than the multi-yearly average for all the hydrometric stations in the area. Very low yearly flow averages were recorded in the years 1961, 1964 and 1968, at the existing hydrometric stations of that period, and during 1986-1990, 1993 and 2000, at all the stations situated in the area under analysis. This allows us to notice a succession of periods with high flows in the intervals 1969-1985 and 2005-2007, and with low flows - 1961-1968 and 1986-1990.

The liquid flow is influenced by the hydrotechnical constructions (Bolboci, Scropoasa, Pucioasa, Doiceşti), which impose an antrophized flow regime. So, at the entrance to Bolboci Lake, the average monthly flow with the highest values has been recorded during the period May-June (56%) and with the lowest values during the interval November-March (5.97%).

At the diffluence from the lake, the flows are highest during January-March (35.34%) and August-September (32.57%) and lowest during April-May (6.46%). This is due to the high needs of water supply of the consumers downstream during the above mentioned periods and the restoration of the water supply during the maximum alimentation of the lake.

Where the river enters the Subcarpathians, at Moroeni, high values of the liquid leakage are observed in the interval of April-June (39.63%) and in the months of August (8.85%) and February (8.23%). Volumes of water drained in February may be explained by the penetration of warmer air masses from the Ialomiţei valley, leading to the melting of the snow, and in August, due to torrential rainfall of short duration.

The lowest share of the liquid leakage is recorded in the months of October-November and January (4-5%) either due to evaporation, or the occurrence of the winter phenomena.

The influence of the storage lake from Pucioasa is felt in the monthly average of the liquid leakage in that the liquid leakage presents approximately equal values in the April-August interval (between 8-14%) and in December (9.31%). In the other months of the year, the liquid leakage is between 4-6%. This can be explained by the role the lake has in regulating the hydrological regime of Ialomiţa River, reducing flood waves and supplying with water the socio-economic objectives in the area of Pucioasa town.

At Târgoviste the highest volumes of water are recorded during April -June (41.5%). From June until November, the volume of fluid leakage decreases steadily, registering a slight increase in December, after which it decreases until April.

Concerning the tributaries that Ialomiţa receives in its upper basin, differences can be observed between Ialomicioara, which springs from the alpine area (Leaota), and those whose sources are found in the Subcarpathians.

Ialomicioara presents a rich liquid leakage in the April-June (40%), after which it decreases steadily, registering the lowest values in October and November (between 3-4%). In December, a slight increase (8%) is recorded, then follows a decrease in January, after which the values continue to go down.

Regarding the tributaries from the Subcarpathians, namely Bizdidel, Vulcan, Slănic and Cricovul Dulce, they have a similar evolution concerning the regime of the average monthly liquid leakage. Their largest volumes of water are recorded in March-April (between 30-40%), with a tendency to decrease in August, when we can note a slight increase (8-10%), followed by a continuous decrease until October, when the minimum value is recorded (1-2%). A significant increase is found in December (7-11%), followed by a decrease in January and an increase in February.

Regarding the *water quality and the sources of water pollution*, there is a distinction between the two major units of relief. In the mountains, most river courses are permanent, with a flow of over 0.5 m^3/ s, with a higher quality (hydrochemical type: calcic bicarbonated, with a mineralization around 200 mg / l or even lower in the high areas). These waters fall into the first category of quality, and in terms of saprobicity they belong to the oligosaprobic class (Ialomiţa up to DOBREŞTI).

Ialomita River is polluted by the limestone exploitation from Lespezi, an increased water turbidity being recorded due to the discharge in the river of the water used in this quarry.

Concerning the water quality in the area of the Subcarpathian Hills, we shall point out that most small arteries in the potential fall into the hydrochemical type of calcic bicarbonated waters, with a mineralization between 200-500 mg / l, except for some that are affected by chlorinated mineral springs, such as Vulcana, Slănic and Cricovul Dulce, tributaries of Ialomiţa. The latter belong to the hydrochemical type of calcic bicarbonated waters with a tendency towards sodium chlorinated, with a degree of mineralization of over 500 mg / l.

The oil-related activity in the area of the hydrographic basins of Slănic and Cricovul Dulce, in the southern part of the Subcarpathians, on the alignment of the settlements Aninoasa - Razvad - Gura Ocnita - Moreni, both through exploitation and through the oil transport and processing network, are sources of pollution for the surface waters.

The sources of pollution from the fruit-growing area of the Subcarpathians should not be neglected either, as a part of the treatment with insecticides-fungicides ends up in the hydrographic network, through superficial drainage.

In this context of the economic activities, the water quality of the autochthonous Subcarpathian rivers is low (categories II and III), but the lack of measurement points allows only for a subjective assessment. However, Cricovul Dulce up to Iedera, belongs to the first category of quality, and between Iedera and Moreni, to the 2nd category of quality.

As for the allochtonous rivers, they belong to the 2nd category of quality.

The important polluting sources for Ialomiţa River are the industrial activities, between Moroeni and Doiceşti and, of course, the household waste from larger settlements: Moroeni, Pietroşiţa, Fieni, Pucioasa, Doiceşti. Ialomiţa.

All along its subcarpathian route, Ialomiţa belongs to the beta-mesosaprobic category and downstream from Doiceşti in the beta-alpha-mesosaprobic category.

6 Lakes

Natural lakes are rare and generally temporary. Regarding the *anthropogenic lakes*, from upstream to downstream, without taking into account the moment of their execution, there are: Bolboci, Scropoasa, Brătei, Ialomicioara I, Moroeni, Runcu, Pucioasa, Bela, Doiceşti.

Bolboci lake is situated in Ialomita River, 10.75 km away from the source, upstream Zănoaga Gorge, downstream of the confluence with the river Bolboci, the tail of the lake reaching up to Tatarului Gorge. It was put into service in 1988. Behind the dam a lake appeared, with a length of 2.2 kilometers and an area of 97 ha, which amounts to a useful volume of 18 million cubic meters and a total volume of 19.4 million cubic meters, with an installed power of 12 MW .

The synthetic characteristics of flood waves, for different degrees of assurance are: 20% for a flow of 60 m^3/s; 5% - 120 m^3/s; 1% - 215 m^3/s, 0.5% - 265 m^3/s; 0.1% - 408 m^3/s, 0.01% - 648 m^3/s.

In the area of the Bolboci dam, the unitary hydrograph is characterized by a period of 36 hours, with a coefficient Cs = 0.28 and a basic flow with a value of approx. 10 m^3/s.

In the *Scropoasa-Dobreşti area*, downstream of a succession of narrow gorges and basinets, on a length of 2.5 kilometers, with a difference of altitude of 304 m, was achieved a dam behind which *Lake Scropoasa* was formed in the 1930s , with a volume of water of 0.55 million cubic meters, which provides for the weekly adjustment of Ialomita river. The lake, fed by the Ialomiţa river, has a flow of approx. 3 m^3/s in the section and to reach the installed flow of 7 m^3/s, an upstream waterway of 3.5 kilometers was built, bringing water from the Brătei dam.

By its installed power (16,130 kW) and its production capacity of 55 GWh / year, the hydroelectric power plant from Dobreşti was the biggest of its kind in Romania between 1951-1960 (Pop Gr, 1996). At the entrance in Orzei Gorges, on the Brătei River, there is *Brătei Lake*, at 1343 m from the sea level, with level difference of 84 m and a useful volume of water of 0.15 million cubic meters.

In the subcarpathian area there are a series of storage lakes, both on the Ialomita river and on its tributaries.

From the lakes of the tributaries we can enumerate: Ialomicioara I, on Ialomicioara-Bucegi, at 650 m from the sea level, with a level difference of 75 m and a useful volume of water of 0.15 million cubic meters; Runcu Lake on Ialomicioara Leaotei, at 790 m from the sea level, with a level difference of 76 m and a useful water volume of 0.10 million cubic meters; Bela Lake, on Bizdidel River, at 460 m from the sea level, with a level difference of 41 m and a useful volume of water 0.12 million cubic meters.

On Ialomita River, there are dams at: Moroeni, Pucioasa and Doiceşti, behind which were formed lakes of different sizes.

Moroeni Lake, at 650 m from the sea level, presents a level difference of 75 m and a volume of useful water 0.40 million cubic meters, was designed for the hydroelectric power plant from Gâlma, where the water arrives through a gallery that captures on the way the water of Rătei and Raciu River as well. The installed power of the hydroelectric power plant is of 15 MW.

Pucioasa Lake is located upstream of the town with the same name. The lake was put into operation in 1975. It has an elongated shape, with a maximum length of 2.3 kilometers, a maximum width of 0.4 km and an area of 90.54 hectares, for the normal level, and 115 ha, at maximum level.

The lake area and dam height lead to the storage of an initial volume of 10.764 million cubic meters. The main problem of this lake is the intense alluvial activity, because it retains most of the solid flow brought by Ialomiţa and its tributaries. The causes leading to this clogging situation are:

- change of the slope of the rivers at the passage from the alpine to the hilly area;

-increases erosion level, as a result of the building of the dam at 395 m (initially it was projected at 410 m);

-location downstream from the confluence with Ialomicioara Leaotei, whose hydrographic basin is developed, mostly in the deforested subcarpathian area which consists of easily erodable materials. So, from an initial volume of water in 1974 (11 million cubic meters), in 1999 the lake reached a volume of 5,033,259 cubic meters of water (48.9% clogged).

By the water intake located on the left side of the river is ensured the capture of water from the lake and its redistribution into river riverbed. Downstream of the dam are assured the necessary water supply for the consumers and for the hydroelectric power plant of Pucioasa ($Qi=12\ m^3/s$). In this place there is also a water outlet for the trout fishery of Pucioasa (on the right of the storage lake) and for the water treatment station, with a flow of 125 l/s.

Close to the place where the river gets out of the Subcarpathians, a small water storage was achieved, with a dam height of 2-2,5 m. It provides the necessary water for the operation the thermal power plant from Doiceşti.

7 Management of Water Resources

Compared with other natural resources, water is renewable, limited, permanently renewed in its natural flow. This process, however, presents a number of disadvantages: water can not be substituted, its time-space distribution is not uniform and it becomes harder to satisfy the increasingly significant water demand. Therefore, to ensure water has become a matter of great importance, as demands have increased due to the development and diversification of the socio-economic activities with implications on the ecological balance.

Given these considerations, below we are going to present the water uses, according to the types of resources.

The use of the water resources is maintained at a high level, both as volume and as diversification of the uses, a fact explained by the large number of human settlements, and the presence of large industrial consumers of water.

The uses of the water of the rivers. Running waters have the most numerous and varied uses, both for both for domestic and industrial purposes and for irrigations or fisheries. These uses involve large volumes of water; most of this water returns to the rivers, so that disturbances occur in their hydrological regime.

Using river water was mentioned in documents from the 18th century, for milling, wood processing, textiles etc.

An analysis of the uses of rivers highlights differences, from a hydrographic basin to another, imposed by the hydrological particularities and by the water demand.

Using river water for producing electricity. As far as the scheme of arrangement of Ialomita river is concerned, it began to be designed in 1929-1930. At that time the scheme included three steps: Bolboci - Scropoasa, which consisted of a dam and an storage lake, Scropoasa - Dobreşti and Dobreşti - Gâlma - Moroeni. The first step consisted in fitting the Scropoasa – Dobreşti sector, on a length of 2.5 kilometers and an altitude difference of 304 m. The installed flow, of 7 m^3/s, compared to only approx. 3 m^3/s in the river section, is assured by an upstream waterway coming from a distance of 3.5 kilometers from the dam, which provides water from Brătei River. By its installed (16,130 kW) and production capacity of 55 GWh / year, the hydroelectric power plant of Dobreşti was the biggest of its kind in Romania during 1951-1960 (Pop Gr, 1996).

In the period 1949-1953 is built the hydroelectric power plant Gâlma-Moroeni, downstream of Dobreşti. From the storage area, the water reaches the power plant through a gallery, capturing on its way the waters from Rătei and Raciu Valley. The hydroelectric power plant from Moroeni has an installed flow of 8.5 m^3/s and an installed power of 15 MW. As we have mentioned, the water required for operation is ensured by the intakes Rătei (Qi 0.4 m^3/s), Raciu (0.8 m^3/s) and several other small streams, with Qi 0.3 m^3/s. The annual production capacity of this plant is of 566 GWh. In Fieni, in order to meet the electricity needs of the cement factory, the hydroelectric power plant of Fieni I was built, with a deviation dam, weir and discharge flow of 1.5 m. The useful flow installed, namely 8.5 m^3/s, allows for a production capacity of 2.4 GWh / year.

In chronological order, in 1975, was put into service the hydroelectric power plant from Pucioasa, located at the foot of the dam with the same name, with an installed flow of 12 m^3/s and an installed power of 2 MW.

In 1988 was achieved the last phase of the arrangement project for the Ialomita River, when the dam and storage lake of Bolboci began to function. Embedded in the dam, there is a hydroelectric power plant with an installed power of 12 MW.

Using river water for irrigation is another important use of water resources, but outside the geographic analysis. We can mention that the water of Ialomita river is used for irrigation in some agricultural areas from the Subcarpathians, especially in fruit-bearing tree areas, such as the Voinesti-Gemenea, and the vegetable gardens in Targoviste area.

Another use of the river water is for fisheries in a natural system, without artificial food, of particular importance, given that we are in the chub and trout area. Salmon fisheries provided with river water are in Pucioasa.

The uses of the lakes' water. In the upper Ialomiţa river basin there are nine lakes, on the main river and on its tributaries: Brătei, the two Ialomicioaras and Bizdidel. All these are used mainly for electricity production. Complex storage functions have: Bolboci, Scropoasa - Dobreşti, Pucioasa and Doiceşti.

Bolboci lake, with an area of 100 ha and a volume of water of 19.4 million cubic meters, has complex functions as it was primarily intended to supply with water the consumers downstream, with a flow rate of 1.2 m^3/ s. If to this is added the storage lake of Brătei, a supplementary flow of 75 l/s is achieved, which gives a total storage of 1 million cubic meters.

Lake Scropoasa, beside its hydropower importance, aims to weekly regulate the liquid flow.

Pucioasa lake, with an area of 90.54 ha and a present water volume of 5.33 million cubic meters, was not designed to alleviate the high flood at the crossing of the lake, making its peak not overlap with those on the tributaries of Ialomiţa (Bizididel, Vulcan). The lake water is used to produce electricity, for the water treatment plant of Pucioasa (125 l/s) for Pucioasa town, source of water for industrial units in the same area, and for the thermal power plant Doiceşti and the industrial platform Târgoviste North.

Through water outlet on the left side of Ialomiţa River is fed the Trout Fishery from Pucioasa. In order to supplement the water provided to the thermal power plant of Doiceşti, on Ialomita River was arranged a small storage lake right near the locality with the same name.

The water of the man-made lakes mentioned above is used as well in fish growing, under natural conditions, having as well tourist and entertainment functions (mainly the lakes from Bolboci and Scropoasa).

The uses of groundwater. Groundwater, due to the advantages it presents in comparison with the surface water (most of them being drinkable, without requiring prior treatment, having constant flows in time, etc.) can represent the main source of water for human settlements.

In terms of hydrogeology, groundwater reserves are grouped into:

- crystalline-Mesozoic Area, from the Leaota-Bucegi sector, with aquifers related to the limestone and conglomerates deposits belonging to the Middle and Upper Jurassic;
- internal flysch area, with the emergence of water minerals, with a major deficit of potable water;
- external flysch area, with a low water-bearing potential, that could be used in the

future, yet still not sufficient, where there are mineral water reserves as well;
- external trench, with intense hydrodynamics, and hydrostructures with an important potential in the deposits belonging to the Pleistocene - Upper Holocene period.

Karst hydrostructures have developed in Bucegi Massif, in the Padina and Bolboci synclines. The cumulated flow of the springs is 1270 l/s (95% assured). The flow of these sources could meet the needs of more than 100,000 inhabitants and could be the source of water for the Subcarpathian area, primarily between Ialomita River and Cricovul Dulce. These are stocks for the future.

However, some waters are captured from springs with a low flow, to supply with water Peştera Hotel, the fishery from Padina depression and the limestone quarries from Lespezi and Mateiaşu.

The hydrostructure belonging to the Lower Pleistocene develops in the Piedmont of Cândeşti, Iedera - Satul Banului syncline and Silistea syncline.

The hydtrostructure of Cândeşti Piedmont has an estimated flow of 1.5 m^3/s and could meet the water needs of the localities in this area, and those of the town of Targoviste.

The hydrostructure from the Iedera - Satul Banului syncline can provide a 330 l/s flow, of which only 210 l/s (approx. 75%) is exploited for Moreni town and for several localities in Prahova County (Magureni, Filipeştii de Pădure).

The Upper Pleistocene hydrostructures are characteristic of the piedmont plain area. Their estimated flow is of approx. 750 l/s. Of this quantity, at present only a 330 l/s flow for the town of Targoviste, from the intake area Lazuri - Vacaresti and by means of approx. 80 wells which constitute local sources for the trading companies.

The hydrostructure of the Upper Holocene, situated close to the surface, has been extensively researched. It is located in the meadow and lower terrace areas of the main hydrographic network. Its potential is diminishing, especially in subcarpathian area, where the basic thickness has moved down lower by 1-3 m, as the source of recovery of this water deposit is the surface water coming from the hydrographic network. Along Ialomiţa Valley, it develops and is exploited, upstream of Fieni, providing a flow of 67 l/s, being fully exploited.

As noted above, in the flysch area there are mineral water-bearing structures, appearing at the surface in the areas: Pietroşiţa - Buciumeni (Dealu Mare - Dealu Frumos), Pucioasa, Vulcan, Moreni, Ocniţa, Campina and Slănic River basin. Among them, the mineral springs from Pucioasa and Vulcana Spa are used for therapeutic purposes. If the waters of Vulcana Băi are of local interest, those from Pucioasa have entered the national circuit.

The mineral waters from Pucioasa have been mentioned in documents since 1871, becoming part of the national spa circuit beginning with 1821-1828. The resort has 30 mineral springs, its sulphurous waters having the highest concentration in the country.

8 The Relation between Water Resources and Demands

Usually there is a relationship between knowledge and the exploitation of water resources and demand, determined by the socio-economic development of a territorial entity (commune, city, county, country). This relation is concordant, to a certain degree, because, although the water resource is renewable, however, it has quantitative limits in space and time.

Once the relationship is no longer concordant, there begin to appear disturbances which can lead even to instability and the reorganization of the structure and functions of the respective human ecosystem (rural, urban or regional).

From the analysis made on the resources of surface water and groundwater, the area of upper Ialomiţa, in the mountainous and hilly zone, we can make a series of quantitative and qualitative remarks. We must mention the fact that the administrative limits do not overlap on the limits of the three river basins or on the limits of the above-mentioned groundwater hydrostructures.

There are also rules and norms according to which the volume of water that can be used is made in view of maintaining a flow of dilution to ensure the survival of reophile ecosystems and the needs of the territorial units downstream.

Therefore, quantitative estimates are potential, not technically and ethically exploitable. Concerning surface water resources, the assessment is based on the flows and annual volumes at the confluence of the small arteries with the larger arteries and, in the case of large arteries, based on the flow of the respective river into and out of the area under analysis.

To the same context belongs Ialomita River at Targoviste, with 7.97 m^3/s (251.45 million m^3/year).

The groundwater in the area under analysis can be appreciated to be around 280 million cubic meters / year. The sum of the two resources totals 531.45 billion cubic meters / year.

This potential, which is relatively modest, is given by the average hydro balance of the three hydrographic basins and of the groundwater hydrostructures highlighted above.

After having analyzed the organization and layout of the hydrographic arteries in the two relief steps, estimating the quantity and quality of the groundwater and the surface resources, seasonally and annually, the flow regime and its impact on human settlements, we can make an estimative report between water resources and the localities' water demands.

The calculation of the water demand in the localities of Dambovita county was achieved considering the conditions of a centralized water supply system and in accordance with the legal regulations in force, namely according to the norms mentioned in STAS 1341/I.1991. It mentions a need of 100 l/day of hot water and 280 l/day cold water per person in the urban areas (380 l/day/person) and 110 l/day/person in the rural areas, in a system of individual cold water pumps (in the courtyards of the households) or 65 l/day of water in a street system of cold water pumps.

Given this standard, the number of inhabitants within each administrative unit, the available water resources and the water demands of the economic activities, we can notice many particular situations given by the four urban centers, 31 communes, plus the industrial and agro-technical economic units.

In the upper basin of Ialomiţa River, only in point of the need of water for the inhabitants there is a requirement of 649.55 l/s (478.59 l/s cold water and 170.91 l/s hot water), and if we add the industrial water demands, of 953.7 l/s, the result would be a need of 1603.25 l/s, which is satisfied between 50-75% depending on the possibilities of each urban center individually.

On the level of the communes, there is a need of 192.11 l/s (system of water in the courtyard with pumps) and 113.19 l/s (system of water with street pumps), but the possibilities for satisfying these demands are reduced. This is due to: the groundwater reserves still insufficiently outlined and estimated, in some cases diminishing reserves of groundwater and the presence of areas with shortage of groundwater resources. All these go along with an insufficiently developed centralized water supply system, but also with different requirements varying from one commune to the next, depending on the number of inhabitants.

The situation of the water supply in urban centers. In the town of Targoviste there is a requirement of 1,000 l/s, of which 437.55 l/s needed for the population daily (322.41 l/s cold water and 115.14 l/s hot water), the difference being given by the requirement industrial water. This is satisfied in a proportion of 65-90% from groundwater sources, which are located in the upper Pleistocene and Holocene hydrostructures, by the water-catching devices from Dragomiresti, Gheboieni, Lucieni and Lazuri-Vacaresti, and as sources of surface waters, by Ialomita river, which by the intake from Doiceşti, are used in the thermal power plant. Waste water from the thermal power station are treated in the water treatment station of Targoviste town, and then used as a source of industrial water.

In the case of Moreni municipality, water requirements are of 160 l/s, of which 102.24 l/s for the population (75, 34 l/s cold water and 26.90 l/s hot water), the rest being required by the economic units. The demand is satisfied in a proportion of 55%.

Some approximately similar situations are recorded as well in the cases of the other two urban centers.

Pucioasa town needs 125 l/s, of which 73.70 l/s for the population (54.30 l/s cold water and 19.40 l/s hot water), representing a fully satisfied water demand.

Fieni town has a water demand of 120 l/s, of which 36.01 l/s for the population (26.54 l/s cold water and 9.47 l/s hot water), met in a proportion of 65%.

As we can note, the needs of the urban centers exceed the supply of water resources.

For *rural areas*, the need is of 15 l/s (for each locality), in a non-centralized system, and if we refer to a centralized water supply system the need would be of 30-35 l/s, in the case of a network of individual pumps.

The geographic area under analysis (Dambovita County) faces as well a special situation, the existence of 14 communes and a town (Fieni) situated in an area with shortage of water resources. These localities have a total population of 72,534 inhabitants (according to a population census from 1.01.1996) and the need for water in a centralized water supply system would be of 81.55 l/s, in a system with courtyard pumps, and of 48.38 l/s in a system of street pumps. These locations could be included in the area fed by the karst hydrostructure Scropoasa - Colţii Dichiului.

In conclusion, we can appreciate that water requirements have increased due to the increase of the population, to the development of the settlements and to the economic activity. However, the water sources have remained the same, some having reduced substantially their reserves, which leads to a degree of satisfaction, as mentioned above, between 50-75%.

This is due to several factors, of which we can mention: the surface sources are only Ialomita River, and only in the area upstream of Fieni, as downstream, the river does not meet the quality demands, either due to economic activities (exploitation of oil and coal, discharge of industrial waters, etc.) or because of geological structures.

So, the most important water supply sources are represented by the groundwater, which, as we have mentioned, are insufficiently outlined and estimated quantitatively and qualitatively, and in some areas a reduction of these reserves can be noticed. To cover the water needs, we need an intensification of the hydrogeological research, to outline new hydrostructures, and a concern about the pollution sources and the adequate water treatment of the wastewater discharged into the hydrographic network.

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Flash Floods in Croatia

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Abstract. Due to geomorphologic and climatic characteristics a large part of Croatian territory is exposed to flash floods. Over the last fifteen years they have occured pretty frequently. There have been damages in nearly all counties, from Istria to Slavonia, from Međimurje to Dalmatia. Flash floods have often caused considerable material damages, but luckily, no human losses. Because of large hilly and mountainous areas with high rain intensity, fertile foothills, and insufficiently constructed and maintained protection systems, Croatia is extremely vulnerable to flash floods. From the aspect of local point of view, floods may be not so frequent, but globally they occur each year somewhere in Croatia. The flooded areas might not be large in size, but they are featured by massive material damages. The Croatian capital of Zagreb is also hazarded by flash floods from the Medvednica mountain. To protect it from flash floods, a construction of 52 detention basins on Medvednica and its slopes is planned and so far 19 detentions have been built. The present condition of flash floods protection systems in Croatia and planning the development of them is presented in the article.

Keywords: Flash floods, river basin, counties, flood frequency, damages, protection, detention basins

1 Introduction

The continental area of the Republic of Croatia is 56.538 km^2, with 35.131 km^2 (62 %) belonging to the Danube River Basin, and 21.407 km^2 (38 %) to the Adriatic Sea Basins. The surface water resources for water management needs usually have either the status of state waters or local waters. The system of state waters encompasses 41 interstate *(*international*)* watercourses *(*Fig.1*)*, 25 rivers running completely over Croatian territory, 15 large drainage and lateral canals, 6 natural lakes, 34 accumulations and detention basin, 11 karst fields drainage tunnels, and 11 large torrential watercourses of state significance. The total length of state watercourse network is 3.935 km, and local watercourses' total length is some 17.000 km. 934 registered torrential watercourses with length of some 7.500 km belong to local watercourses as well. Only 1037 km or some 14% of them have been trained. The flood protection and drainage systems have been completely constructed on the state watercourses running on 37% and partially on 42% of needed areas. On the local watercourses such systems have been built on only ca. 20% of endangered area. Within the protection system of flash floods 41 accumulations with scheduled *(storage)* retention space, 43 detentions from the total volume of 23 million m^3, 970 km of lateral and major drainage canals for intake and drainage of hilly waters, and 11 drainage tunnels for karst fields' drainage were constructed. Within the complex system for flood protection of the Srednje Posavlje lowlands (*Middle Sava Basin*) 5 large lowland retentions with the total volume of 1590 miliona m^3 were completely constructed, serving for an intake acceptance of Sava's water and large waters of Sava's hilly tributaries. 2415 km of dikes have been constructed along state watercourses, and along the local ones 1642 km dikes.

According to the Water Act, the territory of the Republic of Croatia is divided for water management purposes into departments of water basins and catchments' areas (Fig. 2). A water basin comprises one or more catchment's areas of major river watercourses, or parts of them, constituting a natural water management entity. The water basins in Croatia are as follows (Fig. 2):

1.Water basin of the Sava River catchment area (23.769 km^2)
2.Water basin of the Drava and Danube catchments areas (9.362 km^2)
3.Water basin of the Dalmatian catchments areas (12.785 km^2)
4.Water basin of the Littoral and Istrian catchments areas (8.622 km^2)
5. Water basin of the Zagreb county *(Croatian's capital)* (1867 km^2)

A catchment area comprises, within a water basin, one or more catchments of minor watercourses for which integrated water management is provided. Catchment's areas constitute territorial units for water management purposes and are determined by the Government of the Republic of Croatia.

Pursuant to the Act on the Organisation and Scope of Central State Administration Authorities (OG 22/05), the Ministry of Agriculture, Forestry and Water Management is responsible for implementing the water management policy.

According to the Water Act, the planning basis for water management is the Strategy of Water Management and four River Basin Management Plans for water basins [1],[2]. The basic concept of protection from flash floods encompasses construction of detentions and accumulations with scheduled retention storage, the building of lateral canals along perimeter of hilly areas for intake of large discharges of hill's watercourses. Here belongs the construction of major canals of drainage system. Hydroengineering tunnels for karst fields' drainage have been constructed for protection from floodings [1].

According to the Strategy of Water Management [2], the construction of facilities for protection from flash floods has been already scheduled. The plans include ranging from priority facilites' needs to middle- and long-term needs. The priority needs involve construction in most endangered settlements and fertile areas scheduled up to 2010. The facilities include 19 accumultions with storage retentions, 26 retentions, 16 lateral and major drainage canals in total length of 46,1 km, and a 1,1 km tunnel for the karst field drainage *(Vrbničko polje).*

The middle-term needs scheduled for the period between 2010 and 2015 involve the construction of 25 accumulations with storage retention space, 29 retentions, 17 lateral and major drainage canals with the total length of 70 km.

According to the long-term needs the construction of 58 accumulations with storage retention space, 66 retentions, 30 lateral and major drainage canals with total length of 88 km, and 2 drainage tunnels in the length of 2,9 km have been scheduled.

Fig. 1. Main rivers as the state borders of Croatia

2 Endangered Condition and Protection from Flash Floods

There have been pretty high flash floods risks in Croatia, but the public is still unaware of it. Potentially endangered land has often been inadequately used, and development and maintenance systems insufficiently cared for. There is practically no proprietary insurance from flash floods, and hydrologic trends are becoming more and more unfavourable due to global climatic changes.

So far the problem of protection from lowland rivers' and torrential watercourses floodings has been thoroughly approached in Croatia. Nevertheless, many adopted measures have not been carried out due to insufficient financial means. The present protection activities have been directed toward construction of accumulations, detention basins, lateral canals, drainage tunnels of karst fields, and numerous minor facilities on catchment areas, most of them being the structures for the protection from soil erosion. Most protective structures have been constructed on the catchement areas of the rivers Sava, Drava and Danube, whereas such structures are less frequently to be found on the Dalmatian, Primorje and Istrian catchments. The protection system from torrential floods is estimated to be conducted for 10% of total needs. This situation makes the construction of flash floods protection system one of Croatia's water management top priorities.

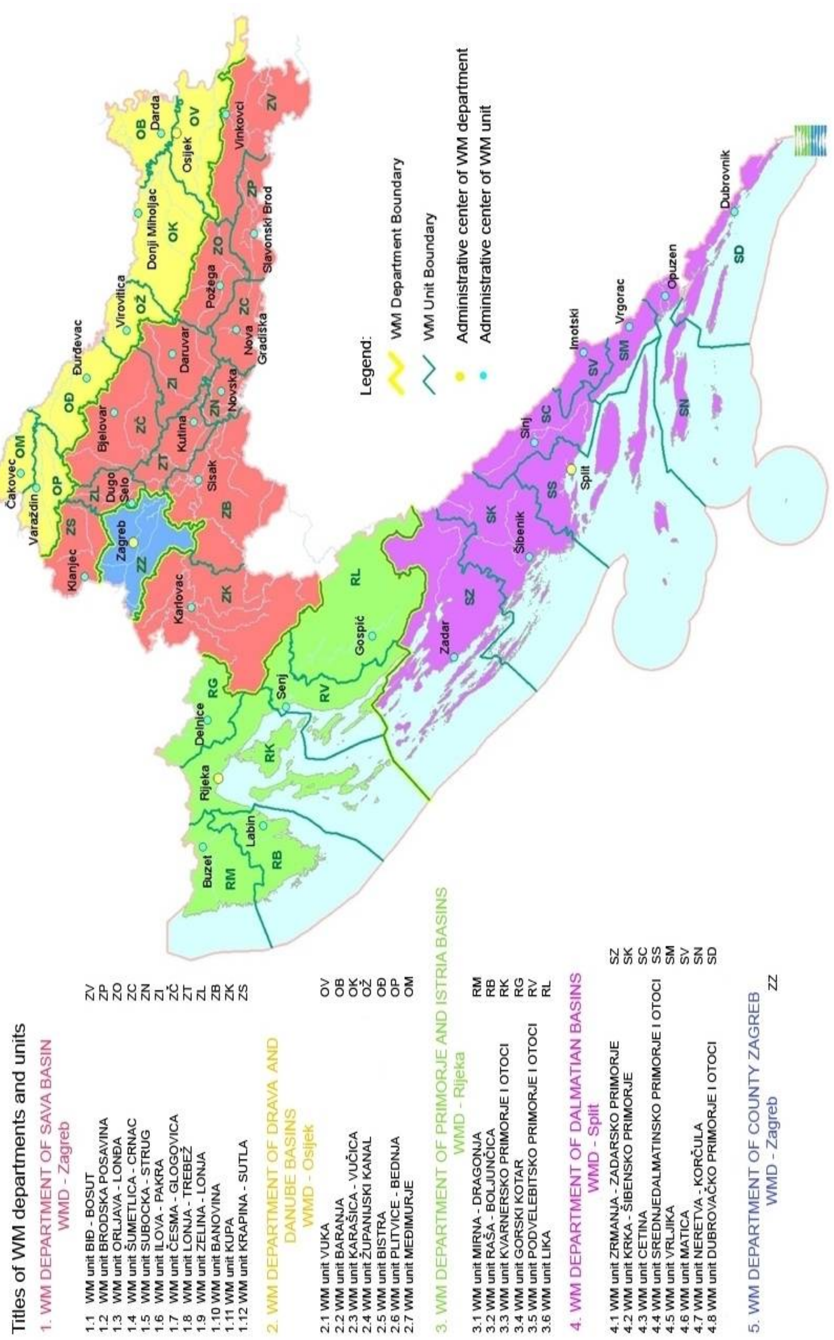

Fig. 2. Water Management Departments and Administrative Units in Croacia

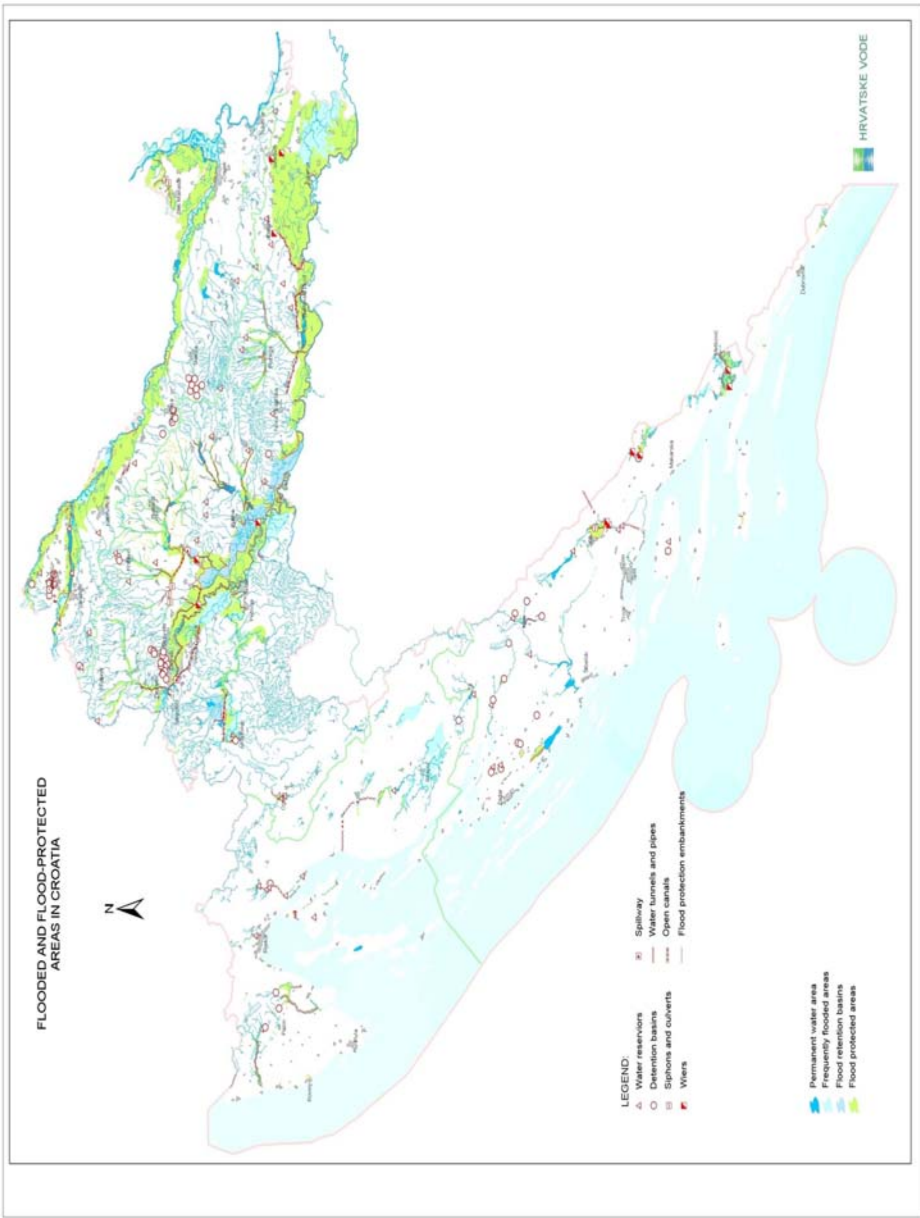

Fig. 3. Flooded and flood-protected areas in Croatia

Cartographic illustration of existing construction level of detention basins and accumulations with storage retention space for protection from flash floods, and construction plans are shown in Fig. 3.

Flood protection in Croatia is conducted according to the State Flood Protection Plan adopted by the Government of the Republic of Croatia. However, carrying out of flood protection of local waters systems rests on flood protection plans for river basins gradually adopted by county assemblies on the basis of proposals put forward by ''Croatian Waters''.

Flood protection plans include:

- list of measures to be taken prior or in case of flood occurrence;
- water levels at which certain sectors initiate preparation, regular protection;
- emergency protection or emergency status;
- regulations on the equipment and materials to be prepared for flood protection;
- list of companies which will conduct flood protection;
- list of experts involved in flood protection (names, duties, authorities and responsibilities);
- methods of informing the public on occurrences and measures during flood protection;
- survey of ice protection measures on watercourses.

''Croatian Waters'' company, which coordinates the work of individual services for protection against harmful effects of water within regional departments, is in charge of implementing operative measures of flood protection.

With regard to the variety of geomorphologic, vegetational and hydrologic characteristics of Danubian and Adriatic catchment areas the types and volume of flash floods issues differ in Croatia. A detailed description of these issues accrding to administrative departments of water basins follows.

2.1 Water Basin of the Sava River

Frequent problems arising in the area of flood protection in the Sava River basin in Croatia occur on small mountainous streams due to heavy *(thunderstorms)* rains and insufficient number of necessary detention *(retention)* basins. Torrents endanger even big urban units such as the Croatian capital of Zagreb, which was flash-flooded many times in the past by the torrents from the mountain of Medvednica.

From the total catchement area of the Sava river (95.551 km2) ca. 26,6% (25.769 km^2) belong to the Croatian territory. Some 51% (12.954 km^2) of this area belong to torrential watercourses catchments that are to some extent hazarded by soil erosion. They exhibit average torrential watercourses' features, while minor flash floods occur frequently. With regard to the Sava catchment relief there is an essential difference between left and right littoral areas. The left littoral part stretches from Croatian – Slovenian border to Serbian border. The right part is significantly shorter, and stretches from Slovenian border to the mouth of the Una river into the Sava, where Sava borders the Republic of Bosnia and Herzegovina (Fig. 1)**.** The left part features fewer hills than the right, so that torrential floods of Sava's right tributaries are more frequent and massive than the left ones. However, the most massive damages threaten from left Sava's triburaries in the area of Croatian capital of Zagreb and its county. It is due to the fact that the Medvednica mountain, *(maximum 1035 above sea)* some 900 m higher than the city plateau, and with 16 torrential watercourses in the city direction, stretches from the northwestern city border to the southwest – northeast direction - see item 2.5.

The Sava catchement on the Croatian territory includes 256 registered torrential watercourses on the total of 12.954 km^2 catchement areas. 155 torrents on 6.906 km^2 of catchement areas belong to the Sava's left littoral part, and 101 torrential watercourses on 6.048 km^2 belong to the right littoral part.

Altogether, 19 accumulations with storage retention spaces, 23 detentions with total capacity of 2,47 x 10^6 m^3, 80 lateral and major drainage canals of total length of 482 km, and 3 short drainage tunnels with total length of 760 m have been constructed on the Sava catchement so far.

The construction of 18 detentions, 6 accumulations with storage retention space and 4 drainage canals with total length of 17 km are planned as a priority on the Sava catchement. The middle-term plan includes another 13 detentions, 11 accumulations with storage retention space and 4 drainage canals with total length of 20,6 km. The long-term plan includes 45 detentions with total capacity of 34 millions m^3 and 28 accumulations with storage retention space.

2.2 Water Basin of the Drava and Danube Rivers

The basin consists of two sub-basins, e.g. of the River Drava's and direct Danube's sub-basens *(without Drava and Sava*).

Drava's sub-basin stretches from Croatian-Slovenian border, e.g. from the location where Drava enters Croatian territory to the Drava's mouth into Danube. The direct sub-basen of Danube stretches from Danube's entering onto Croatian territory on the border with Hungary to Danube's exit from Croatia on the border with Serbia.

Water sub-basin of the Drava River. The total area of the Drava River Basin equals 41.238 km^2 and about 17% is belonging to Croatia. Other parts of the Drava River Basin are located in Italy, Austria, Slovenia and Hungary. The Drava flows through Croatia in the length of 323 km and for the most part constitutes the border with Hungary , (Fig. 1).

Drava's main left tributary on Croatian territory is the Mura River, constituting partially a border to Hungary, and to a shorter part towards Austria. A chain of 22 hydroelectric power plants with total accumulation capacity of 774,2 x 10^6 m^3 was constructed upstream from the Mura mouth into the Drava River. Three of them with the total capacity of 151,9 x 10^6 m^3 were constructed in Croatia. These accumulations have also storage retention volumes for the intake of excessively large discharges. In this way, the protection from the Drava's 1000-year floods has been ensured upstream from the Mura's mouth with exception of minor areas along the old Drava riverbeds near diversion channel, which are subject to more frequent flash flooding by tributaries. The area along the Mura River in Croatia is in part protected by high riverbanks, and in part by dikes. The area is protected against 100-year flood period.

The flash floods from Drava's tributaries on the Croatian territory are more frequent and intensive in the western *(upstream)* part of the Drava, whereas less frequent in the central and eastern *(downstream)* part. It results from the fact that there is a hilly catchment area of the Drava's western part, whereas the central and eastern areas are mostly low-lying, and to a smaller extent hilly. 119 Drava's tributaries have been registered in total on the Drava's catchement on Croatian territory, some with more or less expressed torrential charater.

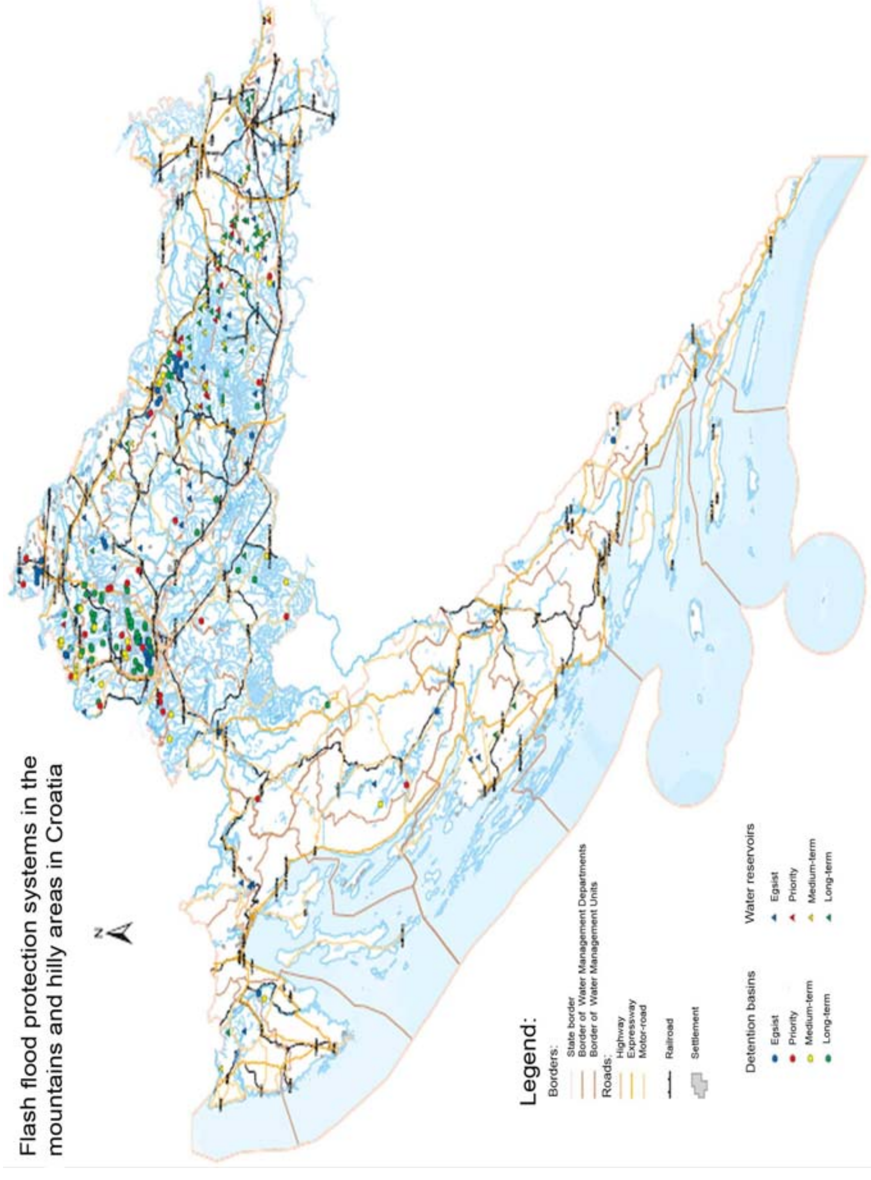

Fig. 4. Existing and planned structures for flash floods protection in Croatia

So far 168,3 x 10^6 m^3 detentions, 10 accumulations with storage retention spaces and 14 drainage canals with total length of 52 km have been constructed on the Drava's catchement on the Croatian territory.

The construction of 4 detentions, 8 accumulations with storage retention spaces and 8 drainage canals with total length of 19 km has been scheduled within priority plans for flash flood protection on the Drava's catchement in Croatia.

According to a middle – term plan the construction of further 13 detentions, 9 accumulations with storage retention space and 6 drainage canals with total length of 20 km has been scheduled. The long-term plan includes 20 detentions with total capacity of 6,9 miliona m^3, 15 accumulations with storage retention space and 13 drainage canals with total length of 50 km.

Water sub-basin of the Danube River. The Danube's sub-basin in Croatia *(area without the Sava and Drava Basins)* equals 2.213 km^2, with the main tributary being the Vuka River (1.120 km^2).

The Danube flow in Croatia constitutes the state border with Serbia (Fig. 1) with the total length of about 135 km. Dikes along the Danube River have been built on the Baranja section, from the Croatian - Hungarian state border down to the Drava River mouth, approximately 100 km in length. This area is mainly protected of 100-year flood period. In north-western vicinity of the Drava mouth into the Danube River, in the triangle of Danube and Drava Rivers and the Hungarian state border, there is the Nature Park "Kopački rit" as a natural retention *(wetland)* of 229 km^2. The area downstream of the Drava River mouth to the state border with Serbia near the town of Ilok is mainly protected by high riverbanks.

In addition to the Vuka river there are 4 minor torrential streams endangering this area by flash floods. So far, this area has been provided against flash floods with an accumulation with storage retention space and a 17 km long drainage canal.

Within the priorities of facilities construction in this sub-basin the building of 4 accumulations with storage retention space and 3 drainage canals with total length of 5 km was scheduled. A middle-term plan involves the construction of additional 3 accumulations with storage retention space and 7 drainage canals with total length of 30 km, whereas the long-term plan includes 11 accumulations with storage retention space and 8 drainage canals with total length of 9 km.

2.3 Water Basin of the Dalmatian Catchments Areas

In this area, the world-famous karst phenomena are present, such as karst fields; karst springs and swallow holes, sinking rivers, etc. The problems of erosion control and regulation of torrents in this area are more articulated than the problem of flash-flood protection. The entire flood prone area mostly in karsts fields is 341 km^2, out of which 200 km^2 of fertile land are still directly threatened at present. Erosion of varying intensity affects 1.881 km^2 of catchment's areas, where 339 torrents are identified.

The concept of flood protection is based on construction of dikes along major rivers *(Zrmanja, Krka, Cetina and Neretva)* and streams, and regulation of their channels is devised to increase the discharge capacity. The construction of channels or tunnels is designated to drain closed karsts fields, accompanied by more intensive erosion control works.

On the Zrmanja and Krka catchements the flash floods protection operations were partially conducted to provide protection for settlements, and to a lesser degree to protect agricultural land.

The protection systems at the Cetina catchement are relatively satisfying. They include the working regime of hydro-engineering system, the parts of which are located on the neighbouring territory of Bosnia and Hezegovina. The dikes were constructed along the Cetina river in the Sinj field, which enabled the agricultural development of the area.

In the area of the Lower Neretva River in Croatia, out of 155 km^2 of the total area, 45 km^2 are protected from floods. Dikes built during river regulation for navigation purposes protect these areas, but not satisfactorily. Particularly endangered are low lying parts of the right littoral area of the Neretva river with Metković, being the largest city here.

A 11,5 x 10^6 m^3 detention basin, 3 accumulations with storage retention spaces, 13 lateral and major drainage canals with total length of 53,5 km, and 5 karst fields' drainage tunnels with total length of 10,8 km have been constructed so far in Dalmatian basin.

Neither priority, nor middle-term construction plans for flash flood protection systems have been underway in Dalmatian basin. The long-term plans include 2 accumulations with storage retention spaces, 9 lateral and major drainage canals with total length of 28 km and a hydroengineering tunnel for karst field drainage *(Vrgorsko polje)*.

2.4 Water Basin of the Littoral and Istrian Catchments Areas

The flood control concept is basically the same as for the Dalmatian Basin. There are numerous mountain watercourses *(torrential streams)* with excessive sediment production and transport. The total area threatened by flash floods is 225 km^2, and the existing dikes protect only 81 km^2. Erosion affects 4.562 km^2 out of which erosion is very low on 3.100 km^2, and on the remaining 1.462 km^2 the intensity varies from weak to very strong. The concept of flood protection of fertile valleys and karst fields is based on dikes constructions and channels regulation along the major watercourses. It should be accompanied by constructions of mountain water reservoirs *(accumulations)* predicted with some retention capacity for temporarily keeping very quick runoff coused by extremely high precipitation. Main rivers of Istrian and Croatian Littorial Basins are Dragonja, Mirna, Raša, Rječina, Gacka and Lika.

So far, 3 detentions with total capacity of 400.000 m, 8 accumulations with storage retention spaces, 67 lateral and major drainage canals with total length of 322 km, and 3 karst field drainage tunnels with total length of 6,5 km have been constructed in the Littoral and Istrian catchments areas.

2.5 Water Basin of the Zagreb County

The Croatian capital of Zagreb is endangered from two sources. In the past there were massive floods of the Sava river. Located in the alluvial valley, Zagreb has been suffering quite frequently from wide-ranging damages. Therefore, the system for protection of the city from Sava's floods was carried out in the 70^s of the 20th century. The system is a part of the larger regional floods control system in the valley of Sava called ''Middle Sava Flood Control System''. Today Zagreb is protected from Sava's 1000-year floods.

On the other hand, Zagreb has been put at risk by flash floods caused by torrential watercources from the Medvednica mountain. The Mountain stretches along northwestern city slopes, with 16 major watercourses running down and directly endangering Zagreb with flash floods.

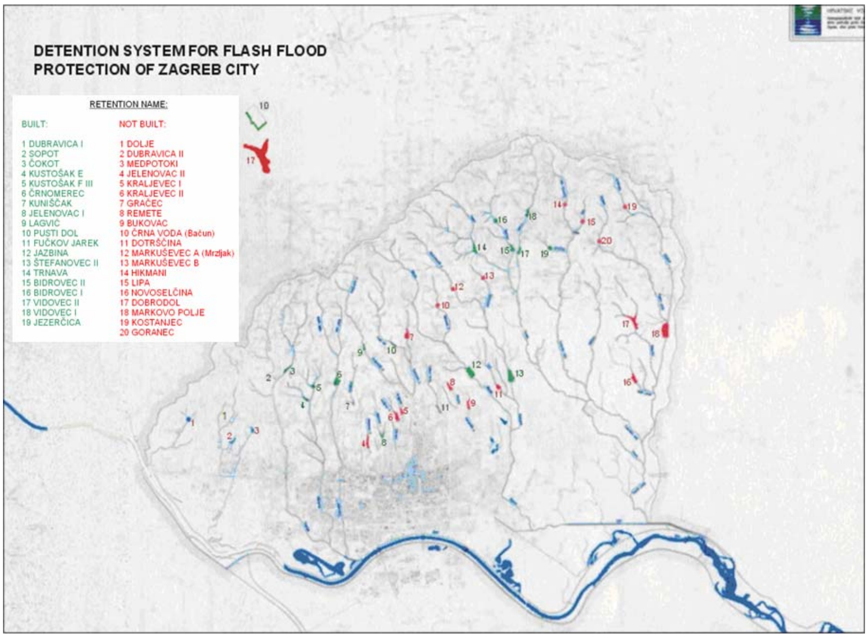

Fig. 5. Detention system for flash flood protection of Zagreb city

The protection of the city is planned with 52 detention basins with total capacity of $2{,}8x10^6$ m^3 that should be constructed on the Medvednica mountain, (Fig. 5). So far 19 detentions with total capacity of $1{,}9x10^6$ m^3, or 68% from the planned retention capacities have been constructed. In this way, the most of the central part of the city is regarded to be protected from 50 to 100 year flood period, whereas the peripheral parts are still at risk. The next step in the priority construction of protection systems from flash floods involves another 4 detention basins with total capacity of 670.000 m^3, and the long-term schedule includes additional 18 detentions with total capacity of $1{,}2 \times 10^6$ m^3.

3 Conclusions

Croatia is a country rich in water. According to UNESCO's predictions, its water richness takes the fifth place per capita in Europe. Hydrographic territory of the Republic of Croatia is divided into two major catchments: the Danubian (35.131 km^2) and Adriatic catchements (21.407 km^2). Hydrographic network is highly developed, particularly in the continental (Danubian) part of Croatia, and less in the Adriatic catchement, due to extensive karst phenomena.

As for the flood origins, there is a difference between long rivers' lowland floods *(the rivers Danube, Sava, Drava, Kupa)* and flash floods of mountainous torrential watercourses. Some 15% of Croatian mostly fertile and populated territory is endangered by floods, whereas the major part is protected with various measures. As for the large rivers' floodings, they are far less hazardous today than in the past due to constructed protective systems. On the other hand, there are 934 registered torrential, mainly hilly watercourses where the flash floods protective systems have been constructed to a lesser degree, which makes the flash floods issue highly actual today. The flash floods solution concept bases primarily on the construction of hilly detentions and accumulations with storage retention space, lateral and drainage canals, and dikes along main watercourses. In the karst regions of Croatia hydroengineering tunnels for karst fields' drainage have been constructed. So far 43 detentions with total capacity of $22,6x10^6$ m^3, 41 accumulations with storage retention space, 175 lateral and major drainage channels with total length of 917 km and 11 hydroengineering tunnels with total length of 18,1 km. for karst field drainage have been constructed in Croatia.

The main document on water management resources of Croatia is the ''Water Management Strategy''[2]. It anticipates, among other things, further construction of flash floods protection systems. 121 hilly detentions are planned to be built with the total capacity of 89 x 10^6 m^3, 102 accumulations with storage retention space, 204 km of 63 lateral and major drainage channels, along with 3 hydroengineering tunnels with total length of 4 km for karst fields' drainage.

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Impacts of Irrigation on the Environment

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Abstract. Environmental protection in last decade became an important issue in all hydro-technical project. Also, implementation of irrigation in agriculture has a high priority in the most countries. Besides the number of positive effects of irrigation, there are some negative effects which potentially can appear in the irrigation areas. The most important are: influences on hydrological regime caused by overexploitation of water resources or disruption of natural hydrological regime by manmade structures, water erosion caused by impropriate irrigation method on sloping fields and impacts of irrigation on surface and groundwater quality. Which type of negative impact and in what extent will appear depends on natural characteristics of the area, water quality used for irrigation and irrigation project itself. These possible negative effects can influence agricultural soil productivity, natural habitats, human health or landscape. In the Croatian conditions, irrigation is still in the more or less initial phase and it is possible to diminish the most of the unwilling effects of irrigation. In the continental part of the Croatia, which is mostly lowland with significant water resources available for irrigation, and intensive agriculture can be expected that deterioration of water quality is the most likely impact of irrigation. Because of that analysis of surface and groundwater quality was undertaken. According to Nitrates Directive 91/676/EEC, good agricultural practises includes water protection from surface leaching and surface runoff outside of the root zone in the irrigation conditions. Another reason why high nitrogen concentration must not be allowed in the surface and groundwater is the vicinity of Nature Park Kopački rit, an area of valuable wildlife. This paper is going to present results of the research on the few locations in Baranja region in the eastern part of Croatia, including irrigation water quality, surface and groundwater quality and recommended measures for further actions in environmental protection.

Key words: Irrigation, environment, surface and groundwater quality, nitrogen

1 Introduction

Considering the basic purpose of agriculture – ensuring of sufficient quantities of food with appropriate quality and unquestionable health soundness, the management of land should not sideline other aspects of land use including environmental and social aspects, so the special attention should be given to non-productive roles of agriculture and land [5]. As an answer to the current challenges of modern agriculture and rural development, until recently the most important role of agriculture – food production, is gradually being replaced by ecosystems sustainability and raising values of landscape and rural space.

As an undertaking which ensures optimal water supply for demands of agricultural production, the irrigation might have significant impacts on environment which should be foreseen, and targeted by use of economical acceptable activities in order to eliminate or lower those potentially negative impacts to the acceptable levels. The aim of every project of hydro-melioration system including irrigation is to ensure positive long term effects of implemented system which is achieved by: anticipation of potential problems, defining the means of monitoring, finding the ways of problem avoiding or reducing and promotion of positive effects.

According to the categorisation of environmental impacts, the expected impacts which arise due to application of irrigation are:

- According to the *type of impact*–impacts on natural assets, predominantly on water and soil (physical environment), but also on quality of life (social-economic impacts);
- According to the *duration of impact* – long term;
- According to *occurrence in time and space* - direct, since they occur on exact area which is being irrigated and during the period of irrigation, but also *indirect*, which means that they also impact the downstream and upstream soils, and frequently appear only after significant periods of time;
- According to the *number of impacts* - individual and cumulative.

All those elements make the impacts very complex and hardly predictable, while the intensity of their occurrence depends on properties of the watershed, water abundance, properties of soils, quality of water being used for irrigation, as well as depending on the applied methodology and means of irrigation. This implies that the application of irrigation may leave permanent (irreversible) consequences on the environment if the impacts are not recognised, foreseen and possibly mitigated or completely prevented. Some of the changes are easily noticed and quantified, but there is vast number of indirect impacts that are delayed in time after the prolonged application of irrigation and often appearing outside of irrigated area. The solutions lay in systematic planning, designing, construction and operation of undertaking. For this reason, undertaking of such large scale irrigation projects should include environmental impact assessment prior to the construction which will establish the possible alteration to the environment and assess the sustainability of the system.

2 Impacts on Water

The irrigation has quantitative and qualitative impacts on surface and ground waters.

2.1 Impacts on Water Balance

Any capture of water impacts the existing water balance. Considering the occurrence of water resources in time every uncontrolled capture, especially in dry periods, may result in undermining of minimum biological requirements of waterways. Majority of waterways in this region (Sava, Kupa, Una, Mirna, Rječina, Lika, Cetina, Zrmanja) have minimum flows at the time of vegetation growth when there is a need for irrigation. In smaller waterways and streams this issue is even more pronounced. Hydrologic regime of surface waters is directly related to the levels of ground waters[7]. During the dry periods, ground waters feed the waterways while in period of high water levels, surface waters feed the ground water. Intensive capturing of surface waters combined with usually water level slope result in increased hydraulic gradient in relation to ground waters. Impacts of capturing of water above renewable limits may appear after prolonged periods of utilisation and may result in lowering of ground water levels on wider area. In coastal areas lowered levels of ground waters may cause intrusion of salt water. Continuous lowering of ground waters, along with changes in water balance, may have effect on other economic activities and water customers. Such changes have significant impact on sensitive ecosystems, firstly on low-lying forests and wetlands.

One of the solutions for ensuring supply of sufficient quantities of water for irrigation is construction of water reservoirs. Such structures are considered to be very sensitive hydro-technical undertakings, especially if they are reservoirs with large volume and area, which may have significant impacts on the environment including both positive and negative effects. With construction of reservoirs there is a change in landuse of area [3]. Land area is being turned over into water surface, which changes the fundamental biological structure. Furthermore transition from natural to controlled regime of waterway after construction of reservoir causes number of changes. One of them is reduction of sediment transport which is being accumulated and deposited within reservoir along with increased kinetic energy of water which affects river bed and banks downstream. Reservoirs have positive effects on regime of low and high water level periods and consequently on replenishing of ground water resources in the downstream area.

Changes in hydrologic regime related to capture of water may increase concentration of water pollution and generally affect the good status of water quality. Areas exceptionally sensitive to changes in water balance are protected ecosystems whose subsistence is dependent on sufficient water quantities, water capture areas, waterways with decreasing characteristic water flow trends and coastal areas.

The main feature of spatial distribution of surface and ground water resources in Republic of Croatia is heterogeneity conditioned by terrain, climatic and geology properties. Potential use of surface waters is based on large rivers with glacial water regime including Drava, Danube and Mura using multipurpose reservoirs. Other waterways in Croatia have pluvial regime, with dry periods occurring in the time of vegetation growth, which without construction of hydro-technical structures may not present reliable water source for irrigation. Ground water resources have to be utilised in Adriatic agricultural region, but considering the fact that their efficiency may be slightly lower due to karstic properties of terrain. Far more stable sources are renewable capacities of alluvial water aquifers in watersheds of Drava, Danube and

Sava. When dealing with ground waters it has to be emphasised that their definitive primary use is for drinking water supply. Other methods of water capture are also possible primarily including rain water although its contribution to the total water potential is small. Use of water from natural lakes is not recommended. Some of the lakes in Croatia are already under protection, and there is an incentive to protect all natural lakes in order to preserve values of their ecosystems. Significant limitations to intensification of agriculture also referring to irrigation are areas under protection with total area of 588,800 ha, out of which 560.500 ha is land area. Protected drinking water areas in the Republic of Croatia, amount to 19% of land areas, while regulations are limiting agricultural production within zones I and II of sanitary protection, with zones III and IV of sanitary protection having no limitations. Meanwhile on water protection areas there should be no priority development of irrigation projects, because of protection applied to water resources aimed at drinking water supply. But currently there are 2200 km^2 of protected areas used for agricultural production, with different types and intensity of utilisation [7]. In the case that within protected areas, and in compliance with valid regulations, there is a justified plan for intensive use of land for agriculture and construction of irrigation system, it is required to complete the environmental impact assessment which will provide answers if the proposed technology of agriculture may have significant negative impacts on protected component of environment or on any other component of ecosystem. Possible protection measures may include:

- controlled capture of surface water along with preservation of biological minimum and other requirements (water supply, inland navigation);
- controlled capture of ground waters within renewable limits;
- ensuring of biological minimum in waterways on which reservoir are built;
- the preference is given to smaller reservoirs over bigger ones;
- discharge of sediment from reservoirs for safeguarding equilibrium within waterway;
- monitoring of ground water levels on wider area of undertaking;
- monitoring of low water flow trends.

2.2 Impacts on Water Quality

Water pollution is broad term but it is generally defined as reduction of quality due to introduction of impurities and potentially harmful substances. Agriculture is one of the largest non-point sources of water pollution which is generally hard to identify, measure and monitor. The irrigation is undertaking which impacts the changes in water regime of soil, and consequently on transport of potentially harmful substances to the surface and ground waters. Plant manure, residuals of pesticides and other components of agricultural chemicals in natural and irrigated conditions with changed water balance are subject to flushing from soil and as such they represent pollution threat to water resources. The speed and intensity of pollution transport from soil depends on number of factors related to hydrogeological and pedologic characteristics of the area. In this regard the especially sensitive are karst and alluvial areas with relatively thin topsoil layer.

According to the general categorisation of waters in Republic of Croatia, all water sources used for irrigation – ground waters, open waterways, natural lakes and reservoirs potentially meet the quality requirements for irrigation. Deviations occur only rarely and on some specific sites. Possible protection measures include:

- adjustment of existing regulations to international standards, or regulation of issues which are not so far covered by the laws [1];
- setting up of monitoring system especially in case where irrigation is present;
- setting up of efficient supervision system.

3 Impacts on Environment

Changes in landuse of area and changes within ecosystems for purposes of agricultural production, along with application of irrigation, have direct impacts on biosphere. Transition of non-fertile land with specific ecosystems developed (wetland, forest and meadow ecosystems with great biological diversity), which was common practice not so long ago is now forbidden and not practised any more.

Secondary or indirect impacts on biosphere as a consequence of irrigation may appear with significant reduction of ground water levels which impairs biological conditions within ecosystem. According to the *Law on environmental protection* (OG 82/94) the main aims of environmental protection are permanent preservation of biological diversity of natural communities and preservation of ecological stability, followed by preservation of quality of living and non-living environment and rational use of natural resources, preservation and regeneration of cultural and aesthetic values of landscape and improvement of environmental state and safeguarding better living conditions [2].

4 Case Study of Irrigation in Baranja

In Croatia the systematic application of irrigation has just begun, so has the monitoring of its impacts on the environment. The same case is with the small scale systems on smaller portions of land which do not produce significant environmental impacts. Using example of irrigation on Baranya watershed area the abovementioned statements may be easily proved. Subject area is interesting due to its vicinity to Nature Park Kopacki Rit which may be very sensitive to excessive introduction of nutrients since it would intensify the existing processes of eutrophication, and also affect the biosphere of exceptional values.

Irrigated areas are located within watershed of channel Barbara upstream from Old Drava river channel. Old Drava flows towards Kopačevo where it connects to the Lake Sakadas , a part of the Nature Park Kopački Rit, through constructed sluice gate. On Old Drava and Sakadas lake there is continuous water quality monitoring, and also there is ground water monitoring station in vicinity (Fig. 1).

There were two aspects of the problem considered – spatial and temporal. Spatial aspect of impacts of irrigation on water has the aim to identify transport of pollutants through open waterways. Temporal aspect has the aim to identify if there is any significant introduction of nitrates and nitrogen after the setting up of irrigation system (2007-2008) in comparison to the period before irrigation. The third aspect of the issue is related to the pollution of ground waters.

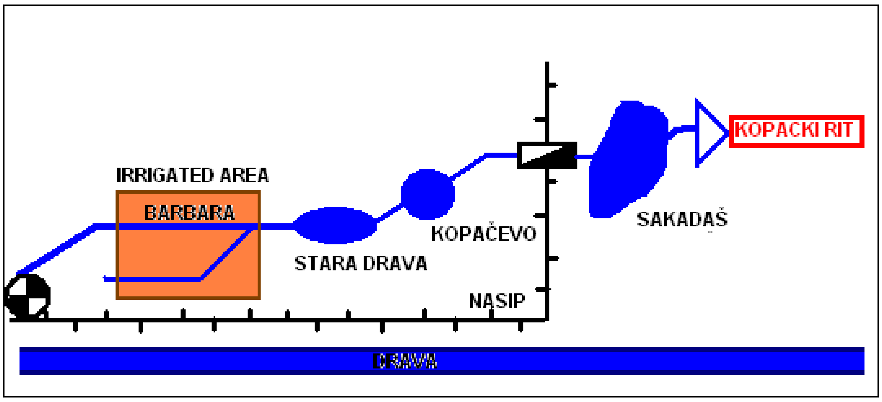

Fig. 1. Scheme of case study area

Out of all monitored parameters, nitrogen and phosphorus have been used since other parameters did not prove to be valuable. Concentrations of total nitrogen during irrigation show the spatial reduction (Fig. 2), which means that the vegetation in open channel network absorbs the part of the nitrogen content and water comes to Kopački Rit area with reduced nitrogen amounts (approx. 1mg/l).

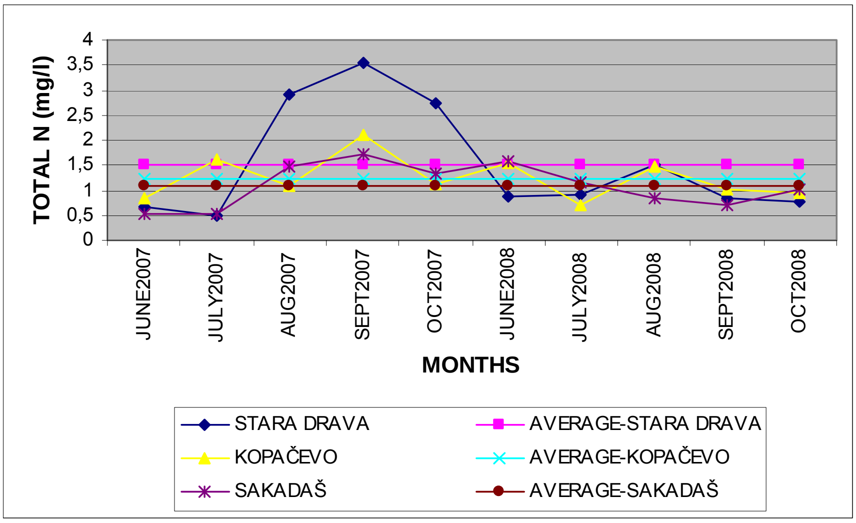

Fig. 2. Changes in concentration of total nitrogen

The similar situation is with total phosphorus concentration (Figure 3). It comes to the soil profile due to the mineral fertilizers and by soil erosion to the surface water. In this specific case, on the last observation point (Sakadaš Lake), the average concentration higher than on Kopačevo observation point.

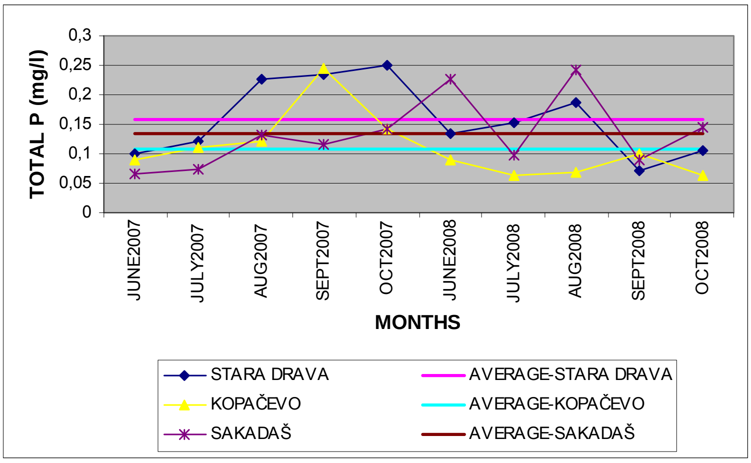

Fig. 3. Changes in concentration of total phosphorus

The second analysis of the surface water pollution treated pollution of surface water before implementation of irrigation and after that. The concentrations of total nitrogen observed on the location nearest to the irrigated field (Stara Drava) were less then before irrigation, what was very surprising (Fig.4).

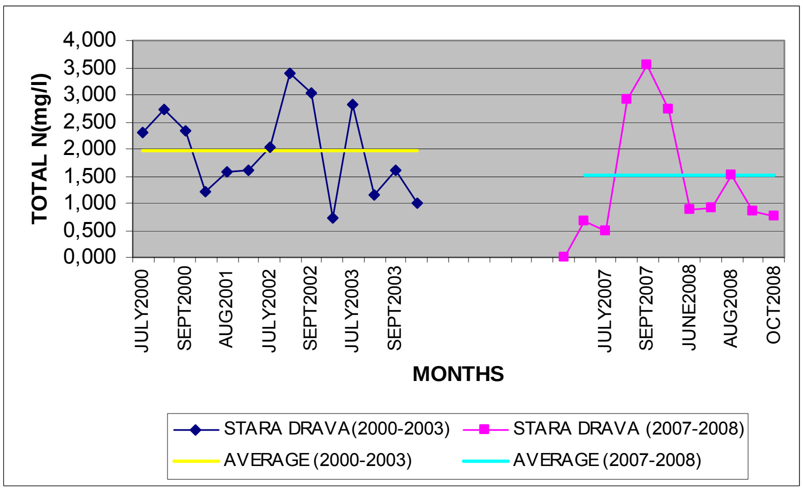

Fig. 4. Total nitrogen concentration before and after irrigation impementation

Finally, the pollution of subsurface water was analyzed. On the observation point nearest to the irrigated fields, during 2007 and 2008, all parameters were in the category of excellent quality with no any limitations in water consumption.

5 Conclusions

Besides the numerous potential negative side effects of irrigation described in literature and tested on the irrigated fields all over the world, the example described in this paper did not show any of them. It doesn't mean that observation of surface and subsurface water is not necessary, especially due to the fact that very valuable Nature Park takes place in the neighborhood of the irrigated agricultural land. It is only beginning of irrigation in this specific location and in the next few years it can be expected that irrigation will continue to development and side effects of irrigation could be more serious and significant.

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A Hybrid Neural Network Based Model for Synthetic Time Series Generation

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Abstract. An integration of artificial neural networks (ANNs) and a nonparametric method for resampling hydrologic time series was used to generate synthetic monthly streamflow sequences. The nonparametric used method was the *k*-nearest neighbor resampling algorithm. This resampling scheme generates synthetic time series samples by bootstrapping. The simulation strategy used in this paper was as followed. The dependence structure of the historical time series was assumed to be Markovian and a multilayer perceptron (MLP) network was developed for each month of year. The networks were capable to predict the mean streamflow for the next month from the three previous values. The *k* nearest neighbors of the current input vector was found and a discrete probability mass function was defined. Using this function, an input vector was resampled from the set of the *k* nearest neighbors of the current input vector. The scalar output of the resampled input vector was predicted, using the suitable network and the error of this prediction was calculated. The simulated value was obtained by adding the calculated error to the output of the current input vector. The current input vector was updated and the procedure was repeated for the next simulated values. The capability of the method was demonstrated by applying it to the historical monthly streamflow from the Karoun River in Iran.

Keywords: Stream flow generation, bootstrap, neural networks, *k* - nearest neighbors

1 Introduction

Streamflow simulation is one of the most important problems in the field of stochastic hydrology. Synthetic streamflow sequences are often generated by parametric time series models. However, hydrologic time series can exhibit behaviors such as multimodal conditional and marginal probability distributions, persistent large amplitude variations at irregular time intervals, amplitude frequency dependence, apparent long memory, nonlinear dependence structure between x_t and $x_{t-\tau}$ for some lag τ, and time irreversibility which can be a problem for linear autoregressive moving average (ARMA) models that are commonly used [3].

Understanding the disadvantages of parametric models has led some researchers to apply nonparametric techniques to some of the classical problems of stochastic hydrology. Vogel and Shallcross (1996) compared the moving block bootstrap technique with autoregressive models for generating annual streamflow series [10]. They showed that the moving blocks bootstrap, which simply resamples the observed time series in approximately independent blocks, can provide a very simple alternative to conventional parametric time series models. Lall and Sharma (1996) developed the *k*-nearest neighbor bootstrap for resampling scalar or vector valued hydrologic time series [3]. Assuming a known dependence structure and defining the current conditioning set, the *k*-nearest neighbor bootstrap method searches the observed data to find the historical nearest neighbors of the current conditioning set and subsequently resamples their successors. The *k*-nearest neighbor bootstrap technique captures any probability density function present in the data and preserves the dependence structure of the historical time series while bootstrapping [3]. Sharma et al. (1997) introduced a kernel based nonparametric Markov model of order 1 (NP1) to generate synthetic sequences of monthly flows [5]. The NP1 model is based on the fact that streamflow may be directly modeled from kernel estimates of the joint and conditional probability density functions of the historical data. Tarboton et al. (1998) formulated and used a nonparametric disaggregation model for generating cross correlated sequences of multisite annual and seasonal flows in a kernel density estimation framework [9]. However, the kernel based methods can suffer from boundary problems [8]. Prairie et al. (2006) proposed a modified *k*-nearest neighbor method of lag 1 for monthly streamflow simulation that blend the *k*-nearest neighbor time series bootstrap technique with a nonlinear local regression [4]. This method which is called the modified *k*-nearest neighbor bootstrap technique retains all the features of the *k*-nearest neighbor bootstrap, but the modification enables simulating values not seen in the historical time series.

In this paper, the *k*-nearest neighbor resampling algorithm and artificial neural networks (ANNs) are used to develop a new flexible nonparametric model for the simulation of seasonal streamflow time series. This model is aimed at generating values not seen in the historical records. The proposed model is applied to the historical monthly streamflow from the Karoun River in Iran and the results are presented.

2 Model Structure

2.1 The *k*-Nearest Neighbor Resampling Algorithm

The bootstrap is the simplest nonparametric technique for simulating the probability distribution of any statistics [6]. The key idea is to resample with replacement from the original data, either directly or through a fitted model to create replicate data sets, from which the empirical probability distribution of the statistic of interest can be found [1,6]. The bootstrap can be used as a nonparametric time series model but the challenge is to resample the records, in such a way as to assure that the dependence structure of the original time series is preserved [10].

The main goal of the *k*-nearest neighbor bootstrap is to preserve the dependence structure of the time series while bootstrapping. A brief explanation of the method is presented in the following paragraph (for more details, readers refer to Lall and Sharma [3]).

In the *k*-nearest neighbor resampling scheme, the time series is denoted by x_t; $t = 1,\ldots,n$ and a known dependence structure is assumed. Based on the assumed dependence structure, a conditioning set (or a feature vector) of dimension d is defined (D_i). The k nearest neighbors of the current feature vector are determined, using the weighted Euclidean distance between D_i and a historical vector (D_t). This distance is calculated as:

$$r_{it} = \left(\sum_{j=1}^{d} w_j (x_{ij} - x_{tj})^2 \right)^{1/2} \tag{1}$$

where: x_{ij} is the jth component of D_i; x_{tj} is the jth component of D_t; d is the dimension of feature vector (or historical vector); and w_j are weights (equal weights can be used). Then, a discrete probability mass function that gives higher weights to the closer neighbors is defined. Lall and Sharma (1996) evaluated a suite of weight functions and proposed the following weight function [3]:

$$K(D_{j(i)}) = (1/j)/(\sum_{j=1}^{k} 1/j) \tag{2}$$

where j is the ordered number. Using this function, a neighbor is resampled and its successor is recognized as the simulated value. The current feature vector is updated and the algorithm is repeated if another simulated value is needed

The performance of the *k*-nearest neighbor resampling algorithm depends on the value of k, the number of nearest neighbors of the feature vector. A value of $n^{1/2}$ which n equals the sample size can be used as a good choice for choosing the number of nearest neighbors [3].

2.2 Artificial Neural Networks (ANNs)

Artificial neural networks (ANNs) are computing systems that attempt to simulate the brain processing abilities. These models can be used in diverse fields including hydrology as a powerful computational tool for generating the relationship of the observed input variables and output variables. Multilayer perceptron (MLP) networks are the most commonly used ANNs in hydrological predictions. MLP networks consist of interconnected processing elements (PEs) arranged in an input layer, an output layer and one or more hidden layers. A numeric weight is associated with each of the PEs connections. The PEs process the input values to produce output values. In order to minimize the errors in the predicted values, the weighs are successively modified during a training process. The back propagation (BP) learning algorithm is often used for training the MLP networks. Fig. 1 shows a typical configuration of a three layer feed forward neural network consisting of M inputs, one hidden layer with N PEs, and P outputs.

In this study, a MLP network is developed for each month of year. These models are based on the assumption that the dependence structure of the historical time series is Markovian and the mean streamflow for the following month is dependent on the three previous values. The nearest neighbor resampling algorithm can be applied to the residuals of the developed neural network models. This idea is the basis for the presented approach in this paper. The proposed method is named the model based k-nearest neighbor bootstrap (MB k-NN B) and is described in the next section.

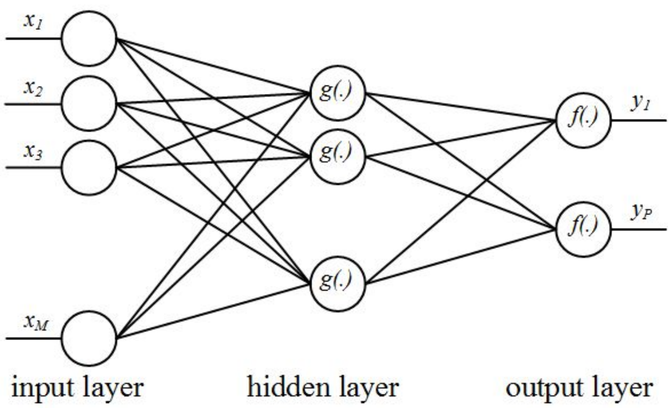

Fig. 1. A typical three layer feed forward neural network

2.3 The Model Based *k*-Nearest Neighbor Bootstrap

In this section, a new nonparametric approach for modeling periodic streamflows is presented. The algorithm of the proposed model follows the modified k-nearest neighbor method [4], except that the local polynomial is replaced with a neural network model. The following flowchart describes the algorithm of the proposed method:

1- Assume a known dependence structure for the historical time series and define a feature vector of dimension d. For example, if the time series is denoted by x_t; $t = 1,\ldots,n$ and the future flow is dependent on the two previous values, the feature vector will be (x_{t-2}, x_{t-1}).

2- Develop a MLP network that is capable of predicting the successor of the feature vectors (e.g., predicting x_t from x_{t-2} and x_{t-1}). If the time series is periodic, develop a network for each season.

3- Using the developed MLP network, predict the successor of the current feature vector (s).

4- Following the nearest neighbor resampling algorithm, find the k nearest neighbors of the current feature vector and resample a neighbor.

5- Using the developed MLP network, predict the successor of the resampled feature vector and calculate the error of this prediction (e).

6- Obtain the simulated value by adding e to s.

7- If another simulated value is needed, update the current feature vector and repeat the algorithm from step three.

3 Application

The proposed method was applied to monthly flows from the Karoun River in the south of Iran. The record length was 26 years (1977–2003). One hundred synthetic sequences of the same length as the historical time series were generated, using the proposed method and also a parametric model (an autoregressive order 1 model with periodic coefficients – AR(1)).

The performance of models was assessed by a variety of statistics including basic statistics (mean, standard deviation, coefficient of skewness, and lag 1 correlation), and marginal probability density functions. These statistics were computed from synthetic series and compared with those of the historical data.

Box plots are used for graphical comparison of simulated and historical statistics. A box plot consists of a box that is divided by a horizontal line at the median, and two whiskers that extend to the 5th and 95th percentiles of the synthetic sequences statistics. The length of box shows the interquartile range that is the range in which the central 25% to 75% of the simulated statistics lie. If the historical value falls within the box, one can infer that the statistic is reproduced well by the model. A schematic box plot is presented in Fig. 2.

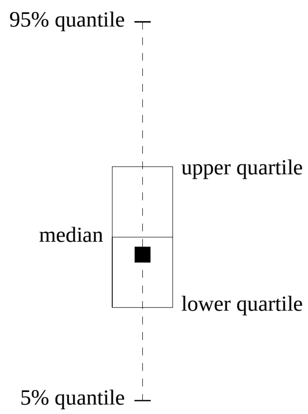

Fig. 2. Boxplot (the square represents the historical value)

Box plots of selected monthly and annual basic statistics are shown in Fig. 3. As seen, the mean flows and the standard deviations of the proposed method and AR(1) simulations match well those of the historical time series. The box plots of the coefficient of skewness show that the proposed method generates less biased values compared with the AR(1) model. Both models reproduce monthly lag 1 correlations well. However, the AR(1) model has some bias.

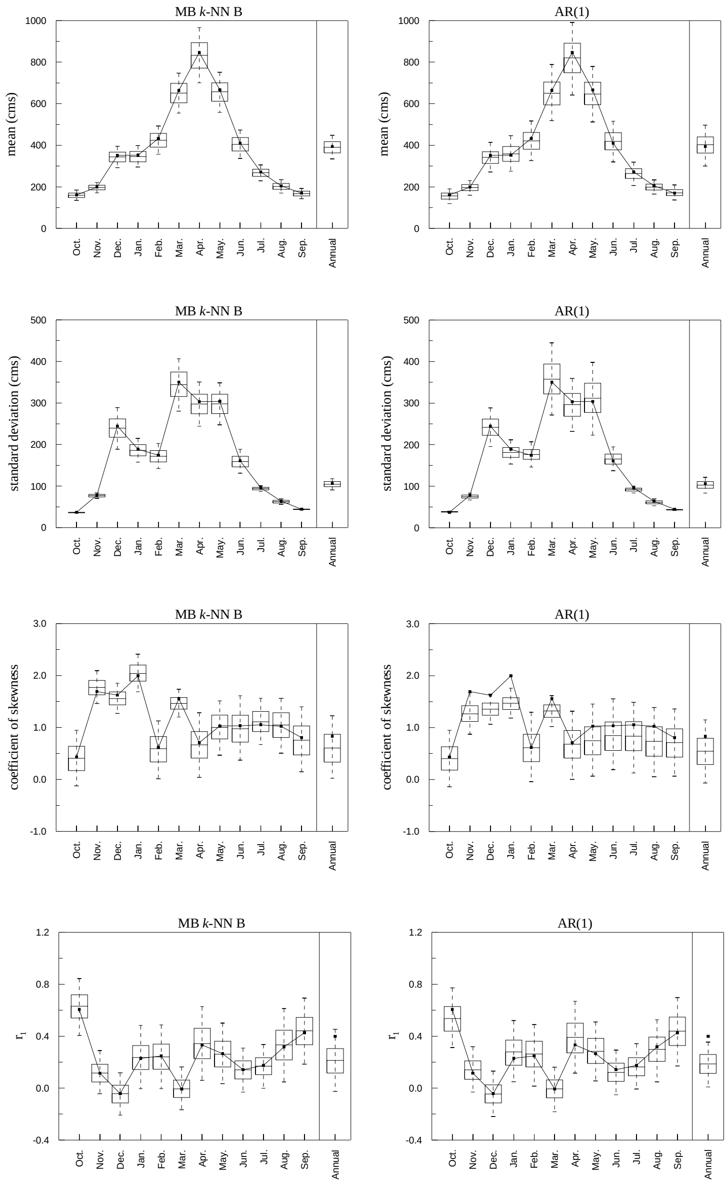

Fig. 3. Comparison of monthly and annual basic statistics (mean, standard deviation, coefficient of skewness, and lag 1 correlation) of simulated and historical flows

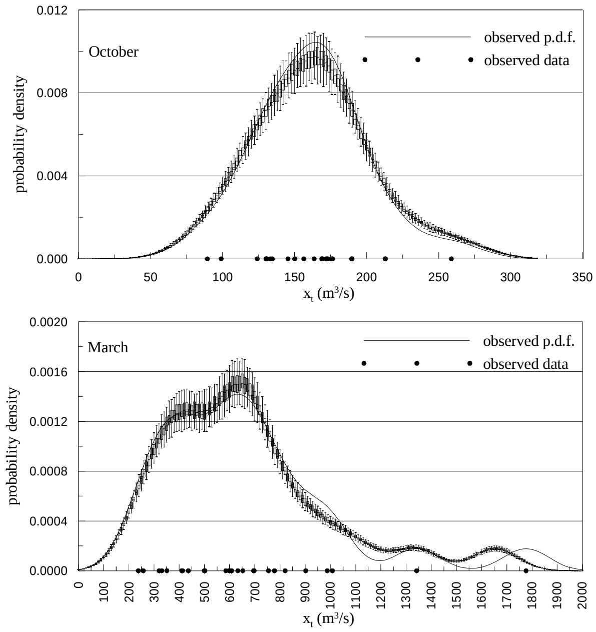

Fig. 4. Probability density function (PDF) estimates of selected months for the proposed method simulations

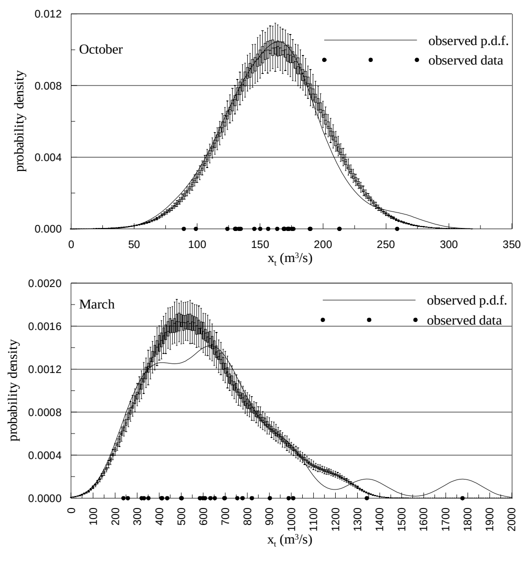

Fig. 5. Probability density function (PDF) estimates of selected months for the AR(1) simulations

The probability density functions (PDFs) for each month were also computed, using the univariate Gaussian kernel density estimator:

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n}\frac{1}{(2\pi)^{1/2}}\exp\left[-\frac{(x-x_i)^2}{2h^2}\right] \tag{3}$$

where h is a parameter called the bandwidth that defines the locale over which the empirical frequency distribution is averaged and can be estimated using the least square cross validation (LSCV) method [5]. Box plots of the PDFs for selected months are shown in Figs. 4 and 5.

As seen in Fig. 4, PDFs of the historical time series is preserved well by the simulations. In the other hand Fig. 5 shows that the AR1 model is not capable to reproduce the non Gaussian structures.

4 Conclusions

In this paper a new nonparametric approach for the simulation of seasonal streamflows is introduced. The proposed method is based on developing MLP networks and applying the *k*-nearest neighbor resampling algorithm to the residuals of the developed networks. The basic statistics and the PDF of historical time series can be modeled by the method. The proposed method also overcomes the usual shortcoming of the bootstrap in reproducing only historical sample values.

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Analysis of Rainfall Data of Gdańsk Meteorological Station

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Abstract. The aim of this paper is to examine local changes in the precipitation pattern: annual and seasonal sums as well as daily maximum rainfalls, under the global climate changes at the meteorological station of Gdansk, during the period of 1951 to 2008 (58 years).
The study examines the annual and seasonal sums of precipitation – for cold period (month XI-IV) and for warm season (V-X) and evaluates the changes of these amounts for each year during the period of investigation. The largest total daily precipitation amounts were examined on monthly basis. The study evaluates the annual course of the daily maximum rainfalls and analyses the changes of these values during the 58 years, for each month.

Keywords: Rainfall, rainfall measurements, rainfall data, maximum sums, daily rainfalls, statistics

1 Introduction

Changes in climate involve factors both external to and internal - within the climate system. External ones include solar variability, astronomical effects of the earth's orbit and volcanic activity. Internal factors include variability within the atmosphere and ocean, and their feedbacks.

Climatic changes on geological time-scales involve continental drift, volcanic activity and possible changes in solar output. Within the last few million years glacial-interglacial cycles appear to be strongly controlled by astronomical variations in the earth's orbit; atmosphere-ocean-cryosphere feedbacks must also be involved.

Shorter-term fluctuations appear to result from changes in atmospheric circulation regimes, but it is uncertain whether specific factors such as solar variability and atmospheric composition are the primary causes of such changing regimes. During the last century, man-induced local and global climatic changes have become a new reality, primarily through changes in atmospheric composition and earth surface properties.

A warming trend in the northern hemisphere up to the 1940s and slight subsequent cooling is well documented. Although not yet fully understood, changes in the atmospheric composition (increase of greenhouse gas concentrations) are suspected to be responsible for these trends.

It is very interesting and complicated problem how these climate changes influence the precipitation regime? The distribution of the precipitation over time, as well as over the distance is very complex and irregular. Such irregularity is especially pronounced with respect to the occurrence of the exceptionally heavy storm events.

The scope of this paper is to examine the local changes of the precipitation pattern at the meteorological station of Gdansk during the past 58 years, under the global climate changes. The years under investigation, 1951–2008, was a period of the pronounced warming in Poland [1], [2]. In contrast, some climate models predict the climate cooling for the next 50 years. For the year 2025 the solar activity will decrease and result in the smaller solar energy output. During the period 1951–2008 the average annual temperature in Poland increased about 0.6ºC. The rise of mean temperature was higher during the winter seasons – about 1.1ºC, and smaller during summer period – about 0.1ºC (at several regions summer temperatures were actually cooler).

2 The Effects of the Climate Changes on the Annual and Monthly Precipitation

Many world studies [1], [2], [3], [5] showed that during the 100 years, 1880–1980, the precipitation have undergone the different changes, depending on the region. For example, in the arid area annual precipitations have generally decreased.

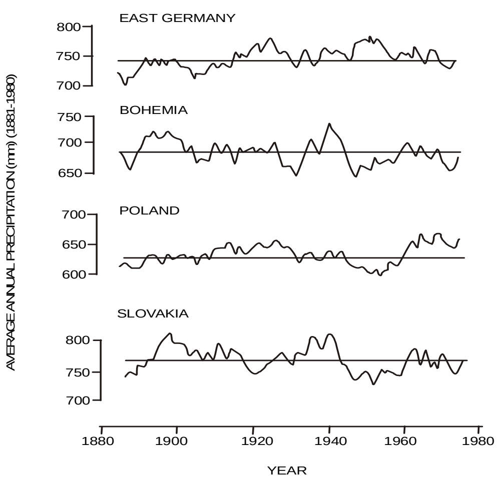

Fig. 1. Area-averaged annual precipitation data, smoothed by 11-year running means for central Europe, 1881–1980 [3]

These changes for Central Europe for the years 1880–1980 – the distribution of area – averaged annual precipitation data are presented in the Fig. 1, [3]. The series for Poland and Slovakia made double use of weighted arithmetic means station data, for station altitude as well as for geographical area.

To compare this distribution with the data for our station in Gdansk the annual precipitation for years 1951–2008 as well as a 10 – year running means are presented in Fig. 2.

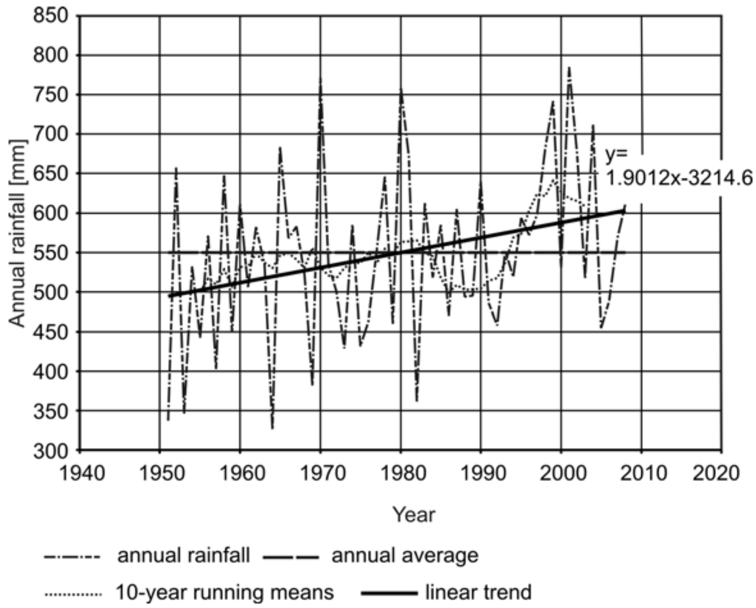

Fig. 2. The annual precipitation for years 1951 – 2008, 10 – years running means and annual average of Gdansk meteorological station

The increase of the total annual precipitation is well pronounced (linear trend). During period of the investigation the trend of this augmentation in average was about 100 mm (18%).

3 Analysis of the Seasonal Precipitation

The analysis concerned also the annual precipitation for the selected periods of years as well as the rainfall for the cold months: XI –IV (winter), and warm: V – X (summer) season. The average values for these seasons and for the selected periods of years are presented in Table 1 and in Fig. 3.

In Gdansk area the precipitation during the warm season were about 63–70% of the sum of annual rainfall, in average 347 mm, with minimum equal 167 mm in 1964 and maximum equal 552 mm in 1980. The rising trend for this season was well pronounced – the increase of the precipitation during the years 1951–2008 was about 56 mm.

The precipitation in the cold period (XI – IV) was in general smaller than in the warm season (in average 203mm), and was 28–30% of the annual values. Maximum was in 2001 – amount 286mm and minimum in 1996 – only 67.2mm. For the cold season the rising tendency was also observed – the increase of rainfall sum was about 35mm during the years of investigation, however the large differences for particular years were observed.

Table 1. Average annual and seasonal precipitation for selected periods of years, Gdansk meteorological station, 1951–2008

No	Period of years	Average precipitation		
		Annual [mm]	Winter XI–IV [mm]	Summer V–X [mm]
1	1951–1960	500	176	325
2	1961–1970	546	209	326
3	1971–1980	536	201	343
4	1981–1990	545	201	344
5	1991–2000	573	208	369
6	2001–2008	602	224	377
Average	1951–2008	550	203	347

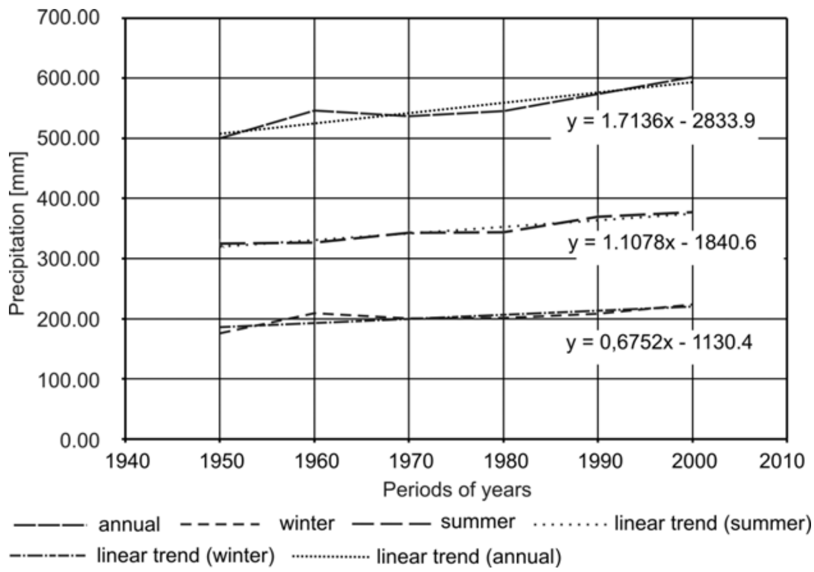

Fig. 3. Average annual and seasonal precipitation for the selected periods of years and its linear trends, Gdansk 1951–2008

4 Analyses of Daily Maximum Rainfalls

This analysis is very important for the field of urban hydrology [2], [4], [6], [7], [8], [9]. The changes in the storm regime are expected to modify the rainfall pattern and will influence designing and modeling of sewer systems. The results of different studies have already indicated great vulnerability of sewer systems to the results of climate changes [1], [3].

4.1 Annual Distribution of Monthly Average of the Daily Maximum Rainfalls

The first step of analysis concerned the daily maximum rainfalls for each month of the year. The average value of the daily maximum rainfalls for each month for the period 1951–2008 was calculated and was compared with the average sum of precipitation for this month. The results are presented as the annual distribution of the daily maximum rainfalls as well as its percentage of monthly mean values in the Tables 2 and 3, and in the Fig. 4. The percentage of average daily maximum rainfalls in monthly sum of precipitation varied slightly from ~20% to 24% for October to January, to ~30–40% for period March to September.

Table 2. Average of the daily maximum sum of rainfalls in Gdansk (1951–2008) and its percentage of monthly mean value of precipitation

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Mean daily maximum (mm)	8.0	6.5	7.0	9.9	15.7	19.7	24.1	20.2	16.5	12.2	11.4	8.6
Mean monthly value (mm)	32.8	25.2	26.1	31.9	48.7	57.5	70.0	63.3	57.9	48.3	47.1	40.4
Percentage of monthly mean sum (%)]	24.1	32.3	32.5	31.0	28.1	26.4	39.2	42.0	33.2	18.9	24.4	24.2

The amount of averaged daily maximum rainfalls for period 1951–2008 during the course of year varied from 6.5 mm in February to 24.1 mm in July. During the winter season it was less then 10 mm and in the summer 15 to 25 mm. There were no large differences for the different selected time intervals (Table 3), with one exception for the years 2001–2008 – when average of maximum daily rainfall in July was 37.8 mm due very high value of rainfall observed in 9 July 2001 – 123.5 mm.

The maximum and minimum values of daily maximum rainfalls for period of investigation for each month are presented in the Table 4 and in the Fig. 5. The differences for these extreme values were very large but it depends of the month. For example for July the maximal value was 123.5 mm in 2001, and minimum 4.2 mm in 1964, while for February maximum 14.7 mm in 1961 and minimum 0.7 mm in 1982.

The percentage calculated for each month’s individual values were also very different. The maximum and minimum of these percentages are presented in Table 5.

The maximum value varied from 55 to 99% and minimum about 10 - 15%. During July and August the maximum attained was 97- 99%, due the big convective thunderstorms.

Table 3. Average of maximum daily rainfalls for the selected periods of years, Gdansk 1951–2008

Month	Average of maximum daily rainfalls [mm]											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1951–1960	8.4	7.6	5.9	10.4	16.3	21.3	17.5	29.3	16.9	10.3	18.0	9.3
1961–1970	6.0	6.2	5.7	10.7	8.7	20.4	21.7	22.4	15.7	11.8	8.1	11.6
1971–1980	8.7	6.3	6.5	10.2	15.3	16.3	23.8	16.4	11.3	12.8	12.9	7.5
1981–1990	7.0	5.8	7.0	9.3	16.2	24.1	25.5	16.7	14.3	13.5	11.0	8.1
1991–2000	7.1	6.2	7.5	10.0	19.9	21.1	21.5	17.6	23.3	14.6	8.0	4.4
2001–2008	10.8	6.6	10.0	9.1	15.4	13.0	37.8	19.2	17.4	9.0	8.3	8.6
1951–2008	8.0	6.5	7.0	9.9	15.7	19.7	24.1	20.2	16.5	12.2	11.4	8.6

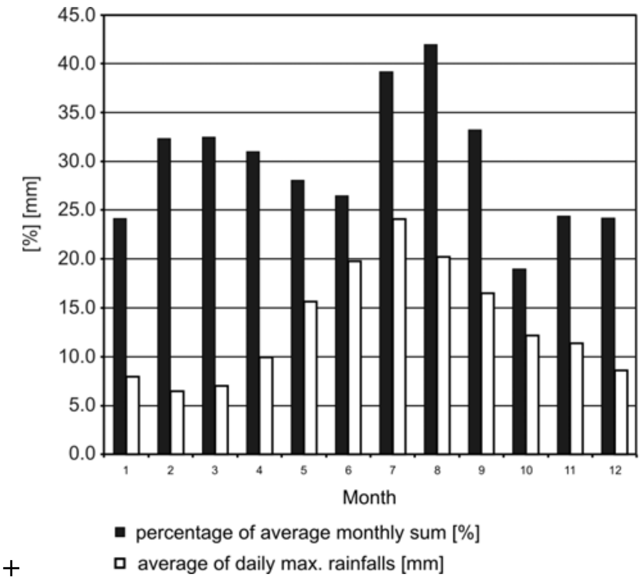

Fig. 4. Annual course of monthly average of daily maximum rainfalls and its percentage of monthly mean sum of precipitation, Gdansk 1951–2008

Table 4. Maximum and minimum values of daily maximum rainfalls, Gdansk 1951–2008

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Max (mm)	19.0	14.7	29.5	30.0	42.8	48.6	123.5	57.7	41.1	33.2	31.4	20.0
Year	2007	1961	2001	1980	1967	1965	2001	1970	1997	1998	1968	1958
Min (mm)	1.5	0.7	1.2	1.3	3.5	3.6	4.2	2.7	2.0	0.9	2.4	1.9
Year	1972	1982	1969	2005	1964	1969	1964	1984	1984	1984	1997	1972

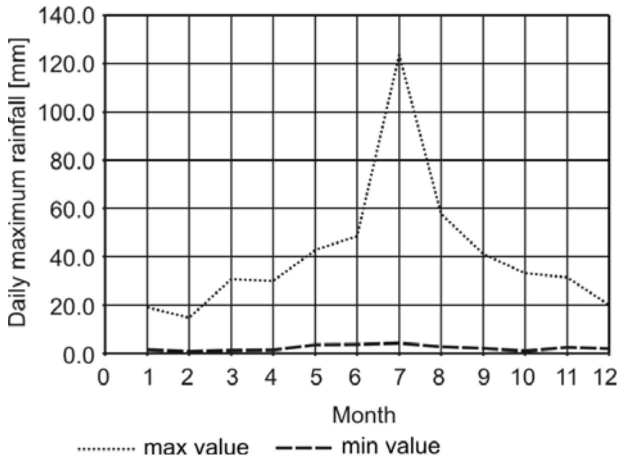

Fig. 5. Maximum and minimum values of daily maximum rainfalls, Gdansk 1951–2008

Table 5. Daily maximum rainfalls as maximum and minimum percentage of monthly sum of precipitation; Gdansk (1951– 2008)

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Percentage maximum (%)	66.1	83.3	55.1	60.5	71.5	72.0	97.0	99.1	76.1	59.4	75.2	67.9
Percentage minimum (%)	12.6	10.5	13.0	14.3	10.4	14.3	12.5	15.2	10.8	6.9	10.3	5.9

4.2 Frequency of Percentage of the Daily Maximum Rainfalls in Mean Monthly Sum of the Precipitation, Gdansk 1951–2008

Frequency of the percentage of the daily maximum rainfalls in mean monthly sum of the precipitation during selected periods of the years and for the each month during the course of the year for the intervals: <25%, 26–50%, 51–75%, 76–100% and >100% are presented in Tables 6 and 7.

Table 6. Maximum daily rainfalls divided into percentage of mean monthly sum of precipitation for the selected periods of years, Gdansk

Period	Interval of percentage (number of cases)				
	< 25%	26–50%	51–75%	76–100%	>100%
1951–1960	66	48	5	1	0
1961–1970	48	55	12	5	0
1971–1980	71	40	7	1	1
1981–1990	61	46	12	0	1
1991–2000	58	47	13	2	0
2001–2008	46	45	3	0	2
1951–2008	350	281	52	9	4
(%) cases	50.0	40.31	7.72	1.36	0.61

In 90% of the observed cases the daily maximum rainfalls values were less or equal of 50% of mean monthly sum of the precipitation: in 50% of cases less than 25%. In only 2% of cases (13 events) daily maximum values were higher than 75% of monthly sum and in 4 cases (0.61%) were higher than mean monthly sum of precipitation; These events occurred in period 1971–1990 and 2001–2008 – three cases in July and one in March.

Table 7. Frequency of percentage of the daily maximum rainfalls in mean monthly sum of the precipitation during the year, Gdansk 1951–2008

Interval of percentage	Month (number of cases) I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
<25%	37	30	34	28	27	17	24	23	24	35	37	34
26–50	18	25	20	21	20	29	29	28	29	20	18	24
51–75	3	3	3	8	9	10	2	3	5	3	3	0
76–100	0	0	0	1	2	2	0	4	0	0	0	0
>100	0	0	1	0	0	0	3	0	0	0	0	0

4.3 Classification of the Daily Maximum Rainfalls, Gdansk 1951–2008

The classification of the daily maximum rainfalls in Gdansk for the years 1951–2008

Table 8. Classification of the daily maximum rainfalls in the selected periods of years, Gdansk 1951–2008

Period	Interval of the amount of daily maximum rainfalls (mm) (number of cases)							
	$\leq 1,0$	1.1–5.0	5.1–10.0	10.1–20	20.1–30	30.1–50	50.1–100	>100
1951–60	2	26	42	36	8	6	0	0
1961–70	0	25	21	52	12	7	3	0
1971–80	0	20	39	41	17	2	1	0
1981–90	2	17	41	39	13	7	1	0
1991–00	0	20	36	40	15	9	0	0
2001–08	0	10	32	40	11	2	0	1
1951–2008	4	118	211	248	76	33	5	1
(%) cases	0.60	17.0	30.3	35.65	10.9	4.70	0.70	0.15

was based on the amounts of the daily maximum rainfall for eight intervals of values: less than 1.0 mm, 1.1–5.0 mm, 5.1–10.0, 10.1–20.0 mm, 20.1–30.0, 30.1–50.0, 50.1–100.0 mm, and >100 mm. Table 8 presents this classification in the selected periods of years, and Table 9 over the year, for each month. The majority of daily maximum rainfalls were between 10.1–20 mm (35.65%, 248 events) and 5.1–10.0 mm (30.3%, 211 events). Only one case was higher than 100 mm – 0.15% and 5 (0.70%) between 50.1–100 mm. All these heavy rainfalls were in July and August during the warm season. In general the events higher than 20 mm occurred always in warm season April–November, only once in March.

Table 9. Classification of the daily maximum rainfalls during course of the year, Gdansk 1951–2008

Interval of daily maximum rainfall [mm]	Month (number of cases)											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
≤ 1.0 Very small	0	1	1	0	0	0	0	0	0	1	0	1
1.1 – 5.0 Small	20	23	21	14	4	4	1	1	6	6	6	12
5.1–10.0 Moderate	20	27	22	20	17	11	5	9	7	23	2	23
10.1 – 20.0 Temperate	18	7	13	21	22	2	26	24	33	21	19	22
20.1 – 30.0 Heavy	0	0	1	3	10	10	17	17	7	6	5	0
30.1 – 50.0 Very heavy	0	0	0	0	5	11	6	4	5	1	1	0
50.1 – 100.0 Extremly heavy	0	0	0	0	0	0	2	3	0	0	0	0
> 100.0 Catastrophic	0	0	0	0	0	0	1	0	0	0	0	0

5 Conclusions

1. During the period of investigation (1951–2008) in Gdansk area, the rising trend of the annual and seasonal sum of precipitation was observed. The increase of the total annual precipitation was well pronounced (linear trend). This augmentation during the period of 58 years was about 18% (100 mm) in average while the mean annual value of precipitation was 550 mm.
2. The precipitations during the warm season (V – X) were about 63–70% of the sum of annual rainfalls. The total sum was in average 347 mm, with minimum equal 167 mm in1964 and maximum equal 552 mm in 1980. The increase of the precipitation during the years 1951–2008 was 17–20% (about 56 mm).
3. The precipitation in the cold period (XI–IV) were in general smaller than in the warm season (in average 203 mm), and were 28–30% of the annual values. Maximum was in 2001 – 286 mm and minimum in 1996 – only 67.2 mm. The increase of rainfalls sum was about 18% (35 mm) during the years of investigation, however the large differences for particular years were observed.
4. The smallest sums of daily maximum rainfalls appeared in the cold period December-March, the largest one in July and August; the same was true for its percentage of the monthly sums of precipitation.
5. During the years of investigation (1951–2008) the largest percentage of daily maximum rainfalls in monthly sum was the 99.1% in August, 97% in July and one exceptional case in February (83%).
6. More than 90% of observed cases of the daily maximum rainfall were smaller than half of monthly sum of precipitation.
7. The daily maximum rainfalls in the cold period of the year generally were the moderate rainfall, smaller than 20 mm; while in the warm period there were heavy and very heavy rainfall, sometimes higher than 30 mm (4.7%) and 50 mm (0.7%) and of convective type of precipitation. In the summer the exceptionally heavy storm, higher

than 100 mm, was observed only once - on 9 July 2001 – 123.5 mm total sum, which caused catastrophic flood in Gdansk.

8. The analysis of the daily maximum rainfalls did not confirm this rising tendency observed in total annual and seasonal sum of precipitation. The results presented in Table 8 showed that there were not the augmentations of the values of the daily maximum rainfalls during the course of 58 years of investigation, however the biggest storm was observed in July in 2001, after 50 years of observation.
9. This limited investigation did not find a clear tendency of the changes in the rainfall regime in the Gdansk area over 58 years period of recent postulated climate change. It appears that it would be necessary to further investigate the sums of rainfalls for the consecutives days as well as rainfall duration and intensity to detect more trends over time and to gain more insight into implications of current possible climate changes.

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Spectral Analysis of Flood Waves in Open Watercourse

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Abstract. The Sava river is one of three longest rivers in Croatia, and therefore very important for water resources management in the Republic of Croatia. The length of the Sava River is 945 km, and its catchment area is 95,720 sq. km. Because of its importance, the Sava is the subject of continuous hydrological research. This paper contributes to this body of research by outlining the application of spectral analyses. Generally, large floods do not result from a single flood wave, but from a number of successive flood waves. This paper is based on the study whose aim was to carry out spectral analysis of successive flood waves on the basis of measured water levels. By Fourier transformation, spectral density functions were developed from measured water levels. They reflect the hydrological character of the studied watercourse and its catchment area. From stable water wave spectra it is possible to derive synthetic level graphs, which, in turn provide the basis for hydraulic analyses of propagation of successive synthetic water waves.

Keywords: Spectral analysis, water levels, flood, synthetic flood wave

1 Introduction

Hydrological regime of a river is a part of complex hydrological processes and systems in the nature. This paper deals with the hydrological regime of water levels in the Sava River by describing the dominant periods by spectral analysis. Unlike the traditional analyses in the time domain, application of spectral analysis in hydrological practice is infrequent. Moreover, relevant literature tends to provide only theoretical accounts, and lacks reviews of how particular methods are applied [3]. This paper presents an example of application of spectral analysis on hydrological data. The first part briefly describes how the hydrological series was selected and formed. It is followed by a short theoretical background, and it finishes with the discussion related to the obtained results. Our central analyses dealt with power spectral density (PSD) obtained by the periodogram method based on FFT algorithm (Fast Fourier Transformation). The periodogram method was used, which gave satisfactory results. FFT algorithm is currently the most widespread in available computer programs, from generally accepted MS Excel to more advanced mathematical programs such as Matlab (MathWorks).

2 Data

The analysis involved hydrological data in the form of measured water level graphs from six gauging stations on the Sava River. These are, going upstream, the gauging stations (GS): Slavonski Kobaš, Davor pumping station, Mačkovac weir, Stara Gradiška, Jasenovac, and Crnac. The average distance between the six selected stations is 37 km, on the Sava river reach of 184.5 km. While selecting the gauging stations we were governed by the idea to make the distance between the first and the last GS not too long, assuming that it would be easier to notice similarities on a shorter river reach, and in the part of the course with approximately similar conditions of sediment discharge and channel behavior. The analysis covered the middle reaches of the Sava River, and therefore the comparison did not include gauging stations upstream from GS Rugvica.

The spectral analysis of water levels has been conducted on the data from the past 25 years. However, due to the war in the nineties, the process of recording water levels in the gauging stations was interrupted, which left us with incomplete records. GS Kobaš has continuous records for the entire period 1982-2007. The largest problem was GS Stara Gradiška where the gauging records are incomplete in the period from 1991 to 1999 (Table 1).

Table 1. List of gauging stations on the Sava, their mutual distances and distance from the river mouth, and the years of missing data (due to war)

Gauging station (GS)	Years of missing data	Distance from river mouth	Distance from previous GS
		[1]	[1]
Slavonski Kobaš	-	390.5	
Davor pumping station	1995-1998	418	27.5
Mačkovac weir	1990-1993	439	21
Stara Gradiška	1991-2000	453.4	14.4
Jasenovac	1990-1995	500.5	47.1
Crnac	1993	575	74.5
		Average	36.9

Hydrological data of GS are given as daily water level observations at 14.00 hours over the period from 1982 to 2007. The data are segmented in the series of 1048 days (i.e. 1048 observations, because observations were taken once a day), each series starting on January 1 of the initial year of the series. Hourly observations were taken because our intention was to analyze the actual state of the watercourse, i.e. the idea was not to analyze the data which had already been statistically processed and/or analyzed. We made sure to make the total number of observations as a power of number 2 (2^{11}=2048) because this is the precondition for maximum efficiency of the Fourier transformation in the form of FFT algorithm [2]. In addition to the above condition related to the number of observations, it was also necessary that the number of daily observations (length of the series) describes seasonal and annual behavior of the Sava River. The total length of the analyzed data covers the period of 25 years (1982-2007), which is statistically significant, and the sub-series of 5.6 years (2048 days) within the record cover both seasonal and annual behaviors of the Sava River.

3 Method

Algorithms for transformation of discrete data from the time domain into the frequency domain, and vice versa, belong to the group of DFT (Discrete Fourier Transform) algorithms. Several authors have independently worked out fast DFT algorithms, and contributed a great deal to their further development. The work by Tukey and Cooley from 1965 [2] is considered the starting point of modern use of FFT (Fast Fourier Transform), and is nowadays a conventional method widely used in electrical engineering, biomedicine, geophysics, astrology, oceanography, etc. [1] , [4],[5], [6].

The forward Fourier transform takes a time-domain signal *g(t)* (i.e. the observed hydrological time series) and transforms it into a frequency-domain signal, *G (f)*, where *f* is frequency, and *t* time (i.e., the time elapsed from the start of the data record analysed). The forward Fourier transform is generally defined as

$$G(f) = \int_{-\infty}^{\infty} g(t)e^{-2\pi i f t}dt \tag{1}$$

where $i = \sqrt{-1}$, and all other values as previously defined. Also, Fourier transform may be explained as decomposition of time series into sine waves of varying amplitudes, phases and periods. Summing up_sine waves of the mentioned characteristics by Fourier analysis, results in the original time series (signal). This physical interpretation by decomposition into sine waves is complicated by the fact that Fourier transform gives complex values. It is necessary to mention that, unlike the simpler Fourier series, the Fourier transform can be efficiently applied to non-periodic functions. Inverse Fourier transform, which transforms the frequency-domain signal back to the time domain, is defined as:

$$g(t) = \int_{-\infty}^{\infty} G(f)e^{2\pi i f t}df \tag{2}$$

From among many equivalent expressions for the above forward-inverse Fourier transform pair, equations (1) and (2) were chosen in the given form as the most practical for hydrological applications. The reason is that frequency units are equal to the inversed value of time units of the input signal, *g(t),* thus, if t is expressed in days, *f* is in days^{-1} The equations for Fourier transform pair, generally prevailing in literature, are the following:

$$G(\omega) = \int_{-\infty}^{\infty} g(t)e^{-i\omega t}dt \tag{3}$$

and

$$g(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} G(\omega)e^{i\omega t}d\omega \tag{4}$$

where

$$e^{-i\omega t} = \cos\omega t - i\sin\omega t \tag{5}$$

and ω is angular frequency in radians per unit of time.

In this analysis, only the one-dimensional form of Fourier transform was used, which is appropriate for hydrological time series because input and output signals are each function of only one independent variable, i.e. time.

For the input signal *g(t)* which assumes real values (as in our case), Fourier transform *G(t)* is complexly-conjugated symmetrical, and these values can be presented either in complex notation:

$$G(f) = R(f) + iI(f) \tag{6}$$

wherein *R(f)* and *I(f)* are real (or cosine) and imaginary (or sine) parts of *G(f),* respectively, or in polar notation:

$$G(f) = A(f)e^{i\Phi(f)} \tag{7}$$

wherein *A(f)* and *Φ(f)* are the amplitude and phase of the signal spectrum, respectively. These two notations are related by the following equations:

$$A(f) = \sqrt{R(f)^2 + I(f)^2} \tag{8}$$

and

$$\Phi(f) = \tan^{-1}\left(\frac{I(f)}{R(f)}\right) \tag{9}$$

Graphic presentation of the distribution of Fourier coefficients (given in the forms *R(f)* and *I(f)* in the complex plane is difficult to interpret, and there is a need for other presentations, such as periodogram [3]. Periodogram method belongs to non-parametric methods where PSD is determined directly from the signal. The fact that the periodogram is directly proportional to the square of the spectrum amplitude of the process enables easy calculation of the periodogram in any mathematical program (e.g. Matlab or MathCAD).

Identification of frequency components in the data requires only the first half of the frequency range (from 0 to Nyquist frequency) because the other half is only the reflection of the first. Nyquist critical frequency (f_c) is the highest frequency that can be detected in the data by Fourier transform. If there are frequencies higher than Nyquist's, overlapping occurs and a portion of the signal-related data is lost, and the basic signal can no more be recovered from the sampled signal [3].

4 Spectral Analyses of Flood Waves

The number of signal data is N=2048 which means that the minimum frequency interval is 1/2048= 0,000489 day^{-1}; the time interval is Δt=1 day, and Nyquist frequency is 0,5 day^{-1}. Almost all dominant frequencies (peaks) are in the narrow frequency range between 0 and 0,02 day^{-1} (which corresponds to the period of 50 days). The graphic presentation is given for this range (Figs. 1 and 2). Frequencies higher than 0,1 day^{-1}(10 days) do not contain any more information about periods.

The fundamental idea of spectral analysis of water level graphs was to examine time and spatial stability of the spectrum in 6 GS for the entire period of 25 years. For each day of the analyzed 2048, the signal was obtained by calculating the deviation from the hourly water level at 14.00 hours from the mean value for the observed series (signal). Thus, the mean value becomes zero around which the water level varies, and we obtain a cyclic phenomenon for which spectral density of power is determined. Time stability was tested by forming first 11 signals for GS Kobaš with time shift of 2 years, taking the first datum with the beginning of the calendar year (e.g. January 1, 1982). These signals form a particular "time window" of 2048 days, which shifts through the series of 25 years. By overlapping of 11 spectra, two expressedly predominating frequencies are noted: one of 0,0034 day^{-1}(293 days) and 0,0059 day^{-1}(171 days). It should be noted that for the time period 1982-1987, the predominant frequency 0,0030 day^{-1} (341 day) also occurs. The same dominant frequencies were noticed also on the remaining 5 GS *(Fig. 1)*, where the analyses involved from 6 in GS Stara Gradiška (where formation of more spectra was not possible due to the longest pause in measurements), to 10 signals in GS Davor, Mačkovac and Jasenovac (Fig. 1). The same dominant frequencies serve as evidence of the time stability of the spectrum, and physically these dominant periods would represent annual (341 and 293 days) and seasonal (171 days) fluctuations of extreme water levels in the Sava. Somewhat higher spectrum instability was noticed in GS Crnac, which may be explained by the influence of the Kupa River backwater. In spite of that, the same dominant periods may be noticed in this GS as well.

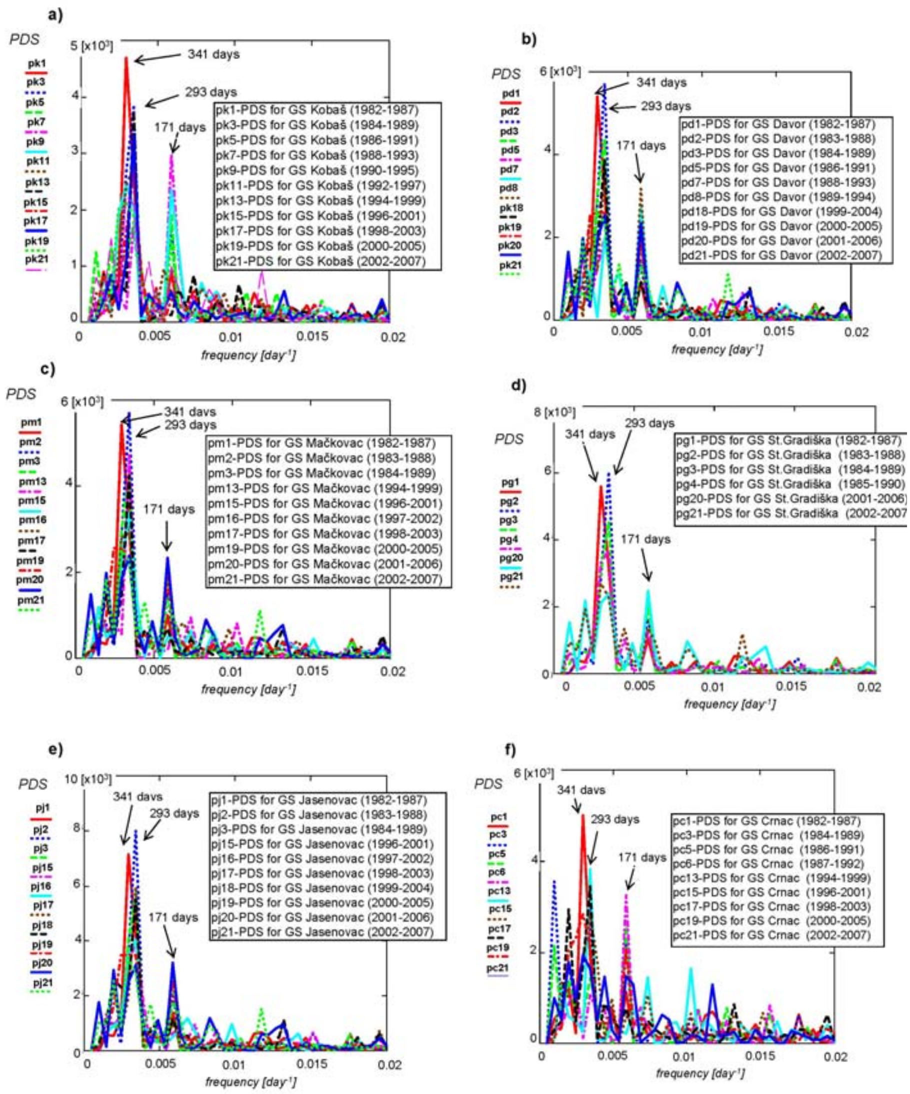

Fig. 1. Analysis of time stability of spectra in GS Kobaš (a), Davor (b); Mačkovac (c), St.Gradiška (d), Jasenovac (e) and Crnac (f)

Spatial stability of the spectrum is proved by comparison of signals in all 6 GS for the same time periods. The comparison was conducted for only 4 time signals, but even this analysis confirmed the same dominant frequencies. A deviation is noticed for GS Crnac for the time sequence 1984-1989, which may also be explained by the influence of the Kupa River backwater, whereas for other spectra a good overlapping may be seen in the shape of spectra. This makes sense in physical terms because the same flood wave passes through all GS in a few days (i.e. very short time period for our analysis *(Fig. 2)*). GS Stara Gradiška was omitted from analysis for time sequence 2000-2005 because of a lack of measured water level data in first 45 days of the year 2000.

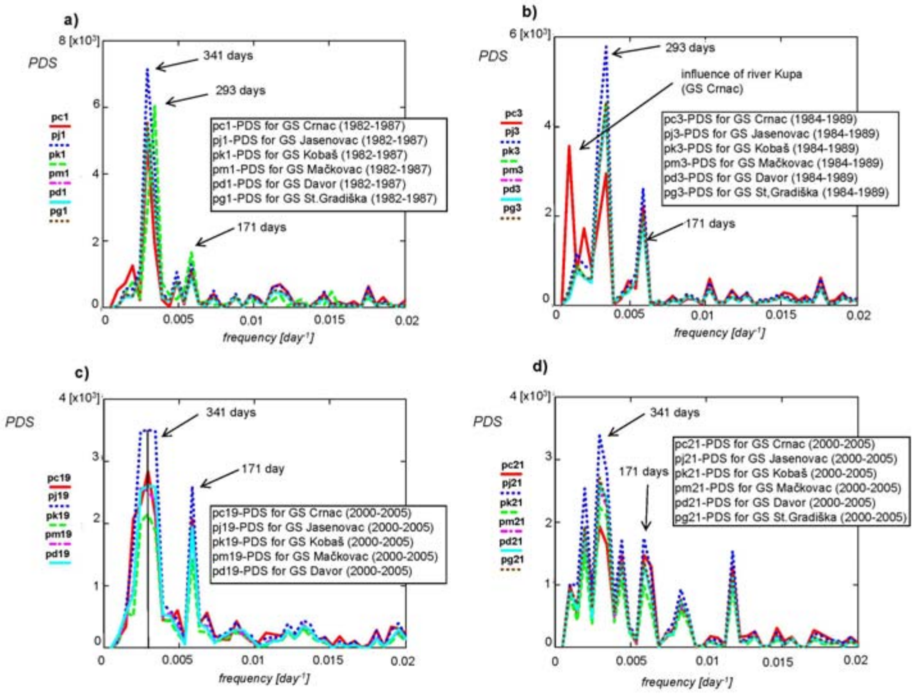

Fig. 2. Analysis of spatial stability of spectrum for time sequences 1982-1987 (a), 1984-1989 (b), 2000-2005 (c), and 2002-2007 (d)

5 Conclusions

This paper delineates, in a descriptive manner and with the help of spectral analysis, the behavior of water levels in the Sava River. The analysis proves spatial and time stability of flood wave spectra on a 184.5 km stretch in the middle reaches of the Sava River. This opens the possibility for further research of these spectra towards, which may lead to developing a single synthetic spectrum, as well as forming appropriate synthetic water level graphs.

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Paper: **A72**

Experience from Irrigation and Environmental Protection in Croatia

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Abstract. The strategic and planning documents related to the National Plan of Irrigation and Land and Water Management were used for assessing the current status of water and impact on the environment and water, and for forecasting the future status and future environmental impacts in relation to the current and planned irrigation-related activities. In this connection, special attention will be paid to the quality of water used, or which might be used, for irrigation. The paper was prepared based on the irrigation experience from the national irrigation plan, county irrigation plans, design documents, and experience from the country and abroad.

Keywords: Irrigation, quality of irrigation water, environmental impact assessment, environmental impact indicators

1 Introduction

Irrigation is a measure which helps provide sufficient quantities of water for agricultural production at times of water deficit or drought. Since at present there are no irrigation water quality standards in Croatia, physical, chemical, biological, and microbiological properties of water are controlled according to the FAO guidelines on the basis of the type of agricultural crop which is or will be cultivated on irrigated surfaces.

According to the Central Bureau of Statistics, in the late 1990s only 9,264 ha or 0.86% of agricultural areas in use was irrigated. Irrigation was most widespread on the areas within family-owned agricultural farms in Split-Dalmatia and Dubrovnik-Neretva Counties, while in Osijek-Baranja County areas irrigated the most were those cultivated by business entities.

According to available data on water resources in Croatia, there is enough irrigation water, but it is necessary to establish an organizational structure and repair and extend irrigation infrastructure. An irrigation system is complex infrastructure and a large water consumer, which requires regular abstraction and distribution of water to agricultural land with as few losses as possible and without environmental risks.

2 National Irrigation Projectin in Croatia

In contemporary conditions of agricultural production, irrigation is a measure which enables the most intensive use of production areas. In the moderate climate zone, irrigation is most often an additional measure for providing the optimal content of soil moisture. In other words, irrigation compensates for the deficit of moisture from precipitation during the periods when that is necessary. It has to be stressed that each irrigation system is a major consumer of water. In order to irrigate approximately 1.000 ha of agricultural areas in the mainland Croatia it is necessary to ensure around 3.000.000 m^3 of water per year, a quantity which represents the annual consumption from a water supply system of a small town. The main tasks of the water engineering part of the irrigation system are: abstraction of sufficient quantity of water from a water abstraction site for irrigation needs, delivery of the required quantity of water to a plot on the basis of an irrigation plan, and distribution of water on the plot.

Having in mind high-quality agricultural soils, abundance of water resources, and favourable weather conditions in Croatia, and in order to achieve more efficient and more economical agricultural production, the National Project of Irrigation and Land and Water Management in the Republic of Croatia (NAPNAV) was adopted at the end of 2005. The National Irrigation Project represents a highly important strategic national program whose implementation is extremely sensitive due to the fact that it in its major part encroaches upon natural resources - water and soil.

In order for irrigation to be carried out as successfully as possible:

- It is necessary to protect agricultural land from external and proper waters by implementing hydrotechnical and agrotechnical amelioration measures.
- It is necessary to regulate the irrigation activity through appropriate regulations and ordinances which would regulate the way irrigation is established, the right to use water, the costs, and a number of details related to irrigation.
- It is necessary to encourage and co-finance irrigation projects which are based on the application of professional knowledge and legislation.

Soil suitable for irrigation has to be rendered fit from the aspect of agrotechnical and hydrotechnical measures, which suggests that the irrigation system is the final part of hydrotechnical interventions in a soil amelioration area, as part of creating conditions for a balanced and persistent water-air regime in the soil.

A method of irrigation and an irrigation system are selected on the basis of the following basic criteria: climatic and pedologic conditions, the type of cultivated crop, the size and shape of the production area, source of irrigation water, quality of irrigation water, configuration of terrain, and goals of agricultural production.

All irrigation systems and methods can today be classified into the following irrigation methods: surface irrigation, subsurface irrigation, sprinkler irrigation, and drip irrigation.

When it comes to the quality of irrigation water, chemical properties (concentration of salts, etc.) and physical properties (water temperature and the quantity of solid particles, etc.) of water must be tested before planning irrigation of an area.

3 Positive and Negative Impacts of Irrigation

There are various irrigation methods, and which of them will be selected depends primarily on the user of the system and the irrigated agricultural crop. It is important to stress that if irrigation is used properly, it brings numerous benefits. However, irregular and incompetent use of irrigation can have negative consequences for plants, soil, and water. The irrigation method nearest to the natural conditions of supplying agricultural land with moisture, and hence generally the most environmentally friendly method, is the drip irrigation method.

3.1 Positive Impacts of Irrigation

Positive impacts of irrigation are reduced damage to agricultural crops from drought, modified structure of sowing on behalf of crops that generate more income, potential for after stubble sowing, which eventually results in positive economic impacts which justify the preparation of the project and development of new irrigation systems.

Irrigation benefits derive from water’s role as a vegetation factor. Water has the following meaning for plants and soil: it is integral part of a plant; it regulates the plant feeding regime by producing nutrients in the soil, which it delivers to the plant via root hairs; it regulates the plant’s thermal regime; it mediates in the process of photosynthesis; and it helps in the development of micro flora.

As a soil improvement measure, irrigation brings the following benefits: it impacts the microclimate of the ground-level layer of the atmosphere; it impacts the temperature of soil and plant; it impacts physical, chemical, and biological processes in the soil; it enables several sowings (potential for sowing after stubble crops); and it improves the social status of the population by opening employment possibilities. All of these benefits generated by irrigation have an impact on the height and quality of cultivated crops.

3.2 Problems which Can Occur Due to Inexpertly Implemented Irrigation

Croatia has witnessed problems which can occur due to inexpertly implemented irrigation. These can be classified into the following four groups: leaching of nutrients and depletion of the arable layer; degradation of physical properties and erosion of the soil; water-logging of the soil; and soil salinization.

If water is not dosed properly, and if heed is not taken of defining water requirement per each irrigation cycle, more water can be added than necessary, nutrients can leach, and arable soil can be depleted. In order to prevent such problems from happening, particular care has to be taken of the balance of nutrients in the soil, regular portions of water for irrigation, and of timely application of adequate agrotechnical measures (tillage, fertilization, etc.).

Excessive wetting of the soil can cause poorer soil porosity and weaker filtration capacity, which leads to the degradation of physical properties of the soil, because of which the soil erodes more easily (irrigation erosion). This phenomenon is particularly marked on sloping terrains and during surface irrigation. The degradation of physical properties of the soil and irrigation erosion are reduced by expert determination of the quantity of irrigation water, selection of the most favourable irrigation method, as well as proper application of agrotechnical measures.

Water-logging of the soil occurs when the level of groundwater rises towards the surface and enters into a space where it adversely affects the cultivation of agricultural crops. Increase in groundwater level leads to air being pushed out of soil pores, i.e. to the lack of oxygen, and hence to changes in biochemical processes and mineralization of organic matter. Because of that nutrient elements in the soil transform into forms which can be harmful to crops. The presence of groundwater above the tolerance limit causes degradation of physical, chemical, and microbiological properties of the soil, which also limit the potential for the cultivation of agricultural crops. Elimination of water-logging on the areas where this problem has occurred requires the application of hydrotechnical (drainage) and agrotechnical (tillage, fertilization, etc.) measures.

Salinization is a phenomenon of an excess amount of salt in the arable layer. This problem occurs as a result of irrigation in two ways. It can occur with increase in groundwater level due to irrigation with more quantities of water than necessary, because “good water” is also a source of salt. If the level of water in the ground becomes high enough (if it reaches the so called “critical depth”), water rises (capillary) up to the root of the plant or even to the surface of the terrain. The water rises in that way is used by plants, or it evaporates, while salts are retained in the soil. If such a process happens to last for a longer time, the quantity of salt keeps increasing, eventually leading to saline soil. This problem is more severe than water-logging because it makes the cultivation of agricultural crops more difficult. Soil salinization can also occur if irrigation is performed with salt water. The added water leaves the soil by transpiration and evaporation, while salts are left in the soil. When the amount of salt reaches certain concentration, the soil becomes saline and conditions for the cultivation of agricultural crops are rendered difficult or even impossible.

On the basis of the above-mentioned problems which may occur due to inexpertly implemented irrigation, it has to be stressed once again that irrigation system management starts at the source of water by analysing its quality. Any water contains microelements and heavy metals in varying concentrations. The issue of heavy metals, particularly when wastewater is used for irrigation, can be very severe, which calls for an analysis of heavy metal concentrations in such cases.

4 Irrigation and Enviromental Protection

Along with all of the above-mentioned positive impacts of irrigation and problems which can occur due to inexpertly implemented irrigation, there are also **negative environmental impacts** which have to be assessed and taken into account already during the process of planning and designing new irrigation systems, in order to minimize environmental impact to an acceptable level through adequate water and soil protection measures. Application of such an approach provides for the achievement of sustainable development goals through sustainable use of water and soil resources.

Irrigation can cause increased erosion, decrease in biodiversity, water and soil pollution, which can all put the biological balance at risk. The environmental impact of irrigation must be identified, foreseen and prevented through environmental protection measures.

4.1 Impact of Irrigation on Enviromental Pollution

Introduction of irrigation systems has a direct impact on the changes related to water (hydrosphere) and soil (pedosphere), and indirect, but not less significant impact on biosphere (the living world). Therefore, the impact of irrigation has to be identified, foreseen and fully prevented. During implementation of large irrigation projects, environmental impact assessment has to be made in order to identify potential changes in the environment and the system's sustainability.

Impact on water (hydrosphere). Irrigation impacts both surface water and groundwater. Demands for producing greater quantities of food lead to expansion of irrigated areas, thereby increasing the quantity of water used for that purpose, and abstraction of huge quantities of water contribute to the lowering of groundwater level.

Impact on water balance. Any abstraction of water impacts the water balance. Uncontrolled water abstraction at times of low water level can disrupt the biological minimum of watercourses. The hydrological regime of surface water is closely related to groundwater level. Groundwater recharges a watercourse at times of low water, while at times of high water groundwater is recharged from the watercourse. Impacts of water abstraction beyond the framework of renewable resources can occur after a longer abstraction period, resulting in the lowering of groundwater level on a very wide area. One of the solutions for providing sufficient quantities of irrigation water is to construct storage reservoirs. Such structures are considered as highly complex hydrotechnical projects, in particular in the case of storage reservoirs of a larger volume and a larger area. Their construction changes the intended land use. Land is converted into aquatic surfaces, which changes the biological structure.

Areas particularly sensitive to the change in the water balance are protected ecosystems whose survival depends on sufficient quantities of water, water abstraction sites, watercourses with marked downward trend in characteristic flows, and coastal areas. The basic characteristic of the spatial distribution of surface- and groundwater resources in Croatia is their heterogeneity dependent on the specific qualities of terrain, climate and geology. Surface water use is based on large rivers of the glacial water regime and multi-purpose storage reservoirs. Other watercourses in Croatia cannot be a reliable source of water for irrigation without building hydrotechnical structures. Groundwater resources should be taken into account in the Adriatic agricultural region, as well as within alluvial aquifers of the Drava, Danube, and Sava river basins. Groundwater use is intended primarily for water supply.

Measures for protecting against impact on water and water balance are:

- Controlled surface water abstraction with preservation of the biological minimum and other requirements (water supply, navigation, fish-farming),
- Controlled groundwater abstraction within the limits of renewable resources,
- Ensuring the biological minimum in watercourses on which storage reservoirs have been built,
- Priority is given to smaller storage reservoirs ahead of large storage reservoirs,
- Discharge of sediment from a storage reservoir in order to preserve the balance in the watercourse,
- Monitoring of groundwater levels on the wider project area,
- Monitoring of low water trends,
- Defining vulnerable and protected areas where irrigation cannot be developed.

If irrigation is implemented on the areas protected under the Nature Protection Act (strict reserve, national park, special reserve, nature park, regional park, nature monument, important landscape, forest park, and park architecture monument), or vulnerable areas which still haven't been defined in Croatia, environmental impact assessment has to be carried out and environmental protection measures have to be defined.

In order to assess environmental impacts in such areas, it is necessary to monitor the status of water and the status of soil. Environmental protection measures will be carried out on the basis of monitoring results. Since irrigation-related activities were initiated by the adoption of the NAPNAV in 2005, intensive execution of all of the above-mentioned tasks is expected, as well as definition of vulnerable areas and areas on which irrigation is allowed, areas on which irrigation is allowed if environmental protection measures are taken, and supplementing county irrigation plans.

In the Republic of Croatia numerous acts have been adopted which regulate environmental protection, nature protection, and preservation of biodiversity and landscape diversity. Their main goals are the following: constant preservation of the authenticity of biodiversity of natural communities and preservation of ecologic stability; preserving the quality of living and non-living nature and rational use of natural resources; preservation and restoration of cultural and aesthetic landscape values; and improving environmental status and providing better living conditions. On the territory of the Republic of Croatia around 28% of the mainland area is covered by by various degrees and means of protection (Water Management Master Plan of the Republic of Croatia, 2004).

Protected areas. Under the Nature Protection Act (OG 70/2005), protected areas in Croatia are classified into nine categories. The Croatian legislation deals with eight protection categories, among which the national park and the nature park, as the highest categories, are protected by law on the national level, while the protection of other areas (strict reserve, special reserve, nature monument, protected landscape, forest park, and horticultural monument) is under the responsibility of a county.

Around 2.200 km^2 of land within the protected areas is used for agricultural production of various types and intensity of use. Within the protected areas, the surfaces of some soils are highly suitable for irrigation. However, the protected areas are excluded from irrigation planning because there are enough areas on which irrigation can be developed. If a plan for using the surfaces within the protected areas for agriculture and potential construction of irrigation systems is justified, an environmental impact study has to be prepared.

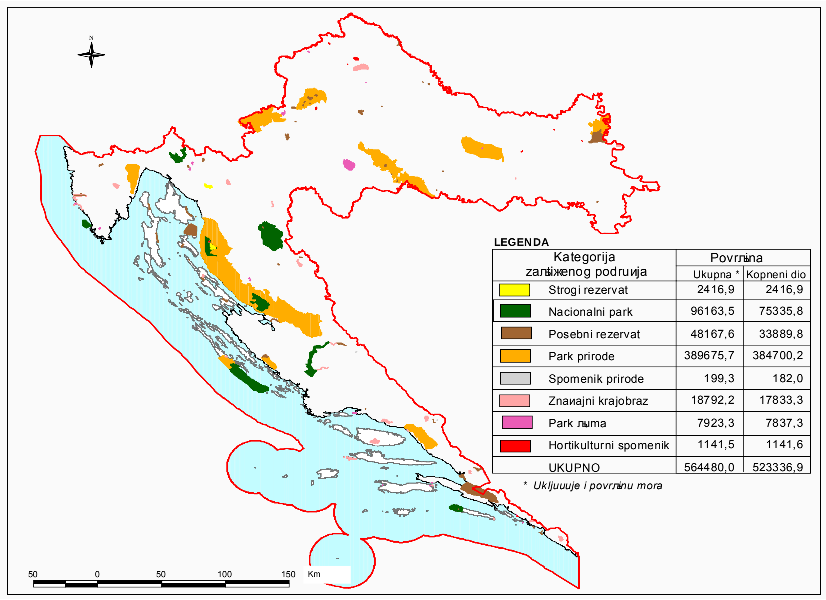

Fig.1. Map of protected areas in the Republic of Croatia

*Drinking water protected areas***.** Protection of water from pollution is regulated under the Water Act (OG 107/1995). Protection of sources of surface water and groundwater used for public water supply is regulated through establishment of water protection areas or sanitary water source protection zones (Ordinance on the identification of sanitary water source protection zones, OG 55/2002). The said regulations restrict agricultural production in sanitary protection zones I and II, while in zones III and IV there are no restrictions.

Drinking water protected areas in Croatia account for 19% of the mainland. The development of irrigation systems shouldn't have to be a priority on water protection areas particularly because of the protection of water sources intended for water supply. Use of water from natural lakes for irrigation is not recommended. Some of the lakes in Croatia are already under protection, and there's an initiative that all natural lakes be protected, thereby preserving the values of these ecosystems.

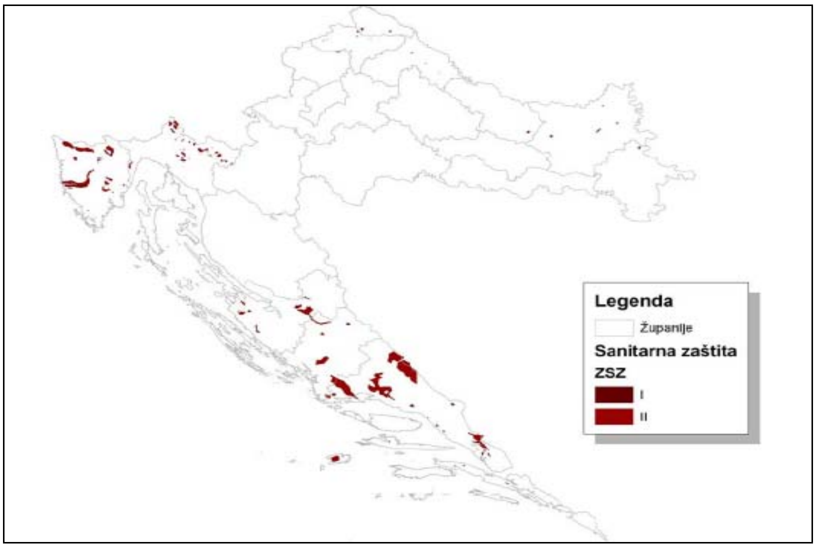

Fig. 2. Areas of sanitary protection zones I and II on which no irrigation will be implemented

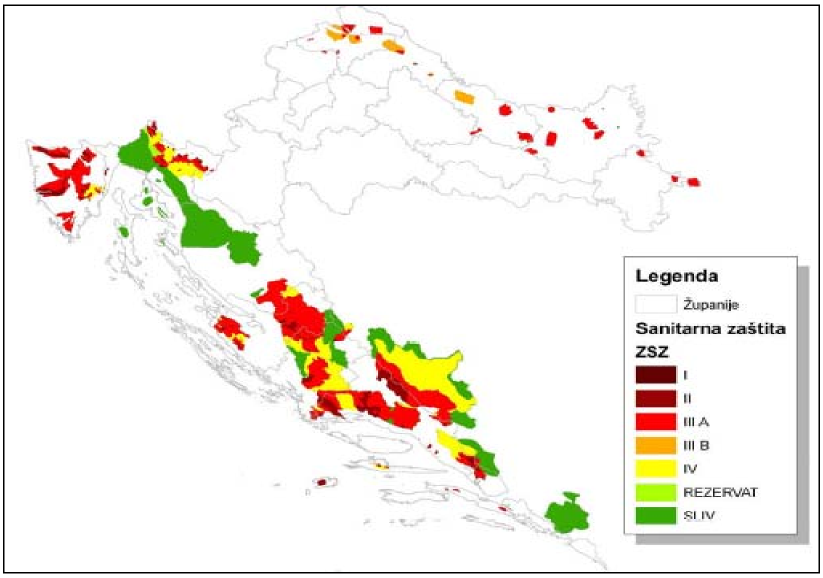

Fig. 3. Proclaimed and proposed drinking water protection areas in the Republic of Croatia

Water quality impacts. Agriculture is considered to be one of the largest diffuse sources of water pollution. Such sources are hard to identify, measure, and control. Irrigation is a measure which can have an impact on the change of the water regime in the soil, and consequently on the transport of potentially harmful substances to groundwater and surface water. Herbal nutrients, remnants of pesticides in the conditions of a modified water balance due to irrigation, can be subject to soil leaching, and as such can threat to pollute water. The areas most sensitive to pollution are karst areas and alluvial areas with a relatively shallow top layer. Nitrogen fertilizers are used nowadays in agriculture in order to speed up the growth of plants. This results in the global increase in nitrogen circulation in the environment. Water quality is affected by an increased nitrate concentration. This prompted the adoption of the Nitrates Directive (91/676/EEC), and Codes of Good Agricultural Practice and designation of "nitrate vulnerable zones" with specified management rules. Codes of Good Agricultural Practice and areas particularly sensitive to the pollution of water by nitrates haven't been clearly defined in Croatia. Such regulations and documents in Croatia are yet to be drafted and harmonized. According to general water classification in Croatia, all sources of irrigation water - groundwater, open channels, natural lakes, and storage reservoirs - potentially meet the quality criteria for irrigation water.

Protective measures in relation to impacts on water quality:

- harmonization of the existing regulations with international standards, i.e. regulating those issues which so far haven't been covered by law;
- establishment of a monitoring system, particularly during irrigation;
- establishment of an effective supervision system.

Impact on soil (pedosphere). Soil damage which occurs during irrigation is most often the result of inadequate selection or inadequate management of the system. It can be divided into physical and chemical damage, i.e. physical modifications lead to chemical modifications through physico-chemical processes. The major adverse impact and problem of chemical damage of soils during irrigation is salinization and alkalization. Soil salinization is a process in which salts accumulate in the rhizosphere up to the concentrations which have an adverse impact on the growth and development of crop plants. Chemical degradation of the soil is also caused by the accumulation of harmful substances, and this process is connected with irrigation practice in which wastewater or polluted water is used as the source of water. The problems related to chemical pollution of the soil must be dealt with at the source of irrigation water.

Protective measures in relation to impacts on the soil:

- Legally regulate the quality and suitability of irrigation water;
- Classify soils according to the criteria of suitability for irrigation, and in line with that define adequate management system and measures;
- Monitor the status of soils under irrigation;
- Regulate the conditions for using alterative sources of irrigation water (industrial and urban waste water, liquid manure, etc.).

Impact on the living world (biosphere). Change of land use of and change of ecosystems for the needs of agriculture, accompanied by irrigation, have a direct impact on biosphere. Secondary or indirect impacts on biosphere as a result of irrigation can occur in case of marked lowering of the groundwater level, which disrupts biological conditions in the ecosystem, and other changes related to moisture and temperature of air and soil have to be taken into account as well. Pursuant to the Environmental Protection Act (OG 82/94), the basic goals are constant preservation of the authenticity of biodiversity of natural communities and preservation of ecologic stability; preserving the quality of living and non-living nature and rational use of natural resources; preservation and restoration of cultural and aesthetic landscape values; and improving environmental status and providing better living conditions.

Vulnerable areas haven't been precisely defined in Croatia or abroad; their designation is rather a matter of national decisions. The Nitrates Directive most often represents a legal framework, just like other regulations on environmental protection. When defining the method of management on vulnerable and protected areas, all cultivation measures have to be taken into account, including irrigation. An irrigation project, its planning, execution and management, and maintenance, have to be harmonized with legislation and physical plans. One of the important goals in designing irrigation systems is to propose measures which will prevent or minimize negative impacts.

4 Environmental Monitoring on Irrigated Areas

After overlapping the soil suitability map with the map of water protection areas, the map of drinking water protection zones I and II, and the map of protected areas, monitoring should be established on the areas obtained by overlapping. Monitoring is related to the environment and protective measures. With certain protective measures and adequate monitoring, irrigation can be implemented on vulnerable areas as well.

4.1 Water

Various water quality parameters are today monitored on over 500 monitoring stations, and water quality tests are performed on around 290 monitoring stations (data from 2002.2.), including transboundary, national, and local monitoring. Following construction of irrigation systems, the number of water quantity and quality monitoring stations will increase in relation to the needs of using water for irrigation. The quantity of irrigation water will be defined by the size of irrigated area and demand of cultivated crops, and water quality will be regulated by an ordinance which will define the quality of water from the aspect of irrigation. Groundwater monitoring on the areas under irrigation and on the wider area of impact will also have to be strengthened.

4.2 Soil

The soil monitoring system needs to be organized on the basis of the specific qualities of the irrigated area (the size of the catchment area, the size of irrigated surfaces, representation and characteristics of soil types, etc.). Compared to water monitoring, monitoring of the status of soils and impacts of agriculture on water pollution is much more complex and demanding.

5 Concluding Remarks and Recommendations for the Development of Methodology

Background data used for the drafting of this paper was systematized data from the NAPNAV and county irrigation plans. Analysis of data from county irrigation plans has lead to the conclusion that data is incomplete in terms of obtaining a clear idea about agricultural areas on which irrigation can be implemented. This particularly refers to the identification of protected areas, and implementation of irrigation with environmental impact assessment, monitoring of the status of water and soil, and special environmental protection measures. These need to be supplemented in order to define measures on protected areas.

Overlapping the map of suitability of soils for irrigation with the map of water protection areas, map of sanitary zones I and II, and map of protected areas would result in a map of areas suitable for irrigation with adherence to environmental protection restrictions. The soil suitability map should also be overlapped with a map of vulnerable zones (under the Nitrates Directive 91/676/EEC), which is in the process of development. In this way the areas with soils for irrigation would be reduced, and the definition of conditions for irrigation in the protected zones could be initiated. On the basis of the above, it is suggested to develop methodology for establishing a map of available areas with adherence to environmental protection restrictions.

The map of available areas with adherence to environmental protection restrictions should be overlapped with the map of soils suitable for irrigation in order to eventually obtain the area on which irrigation is allowed without additional environmental protection measures.

As for the remaining areas of soils suitable for irrigation, they should be micro-zoned, ranked in terms of environmental impacts, impacts and the status of water and soils should be monitored, and required environmental protection measures should be identified. It is necessary to establish research areas - pilot projects for the said characteristic area.

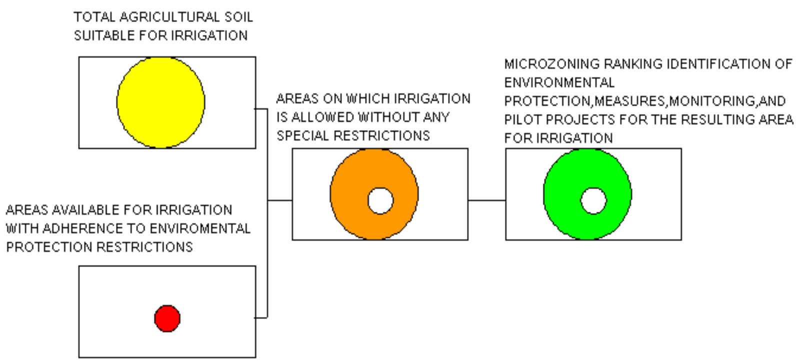

Fig. 4. Schematic presentation of the procedure for identifying the available and “sustainable” irrigation areas

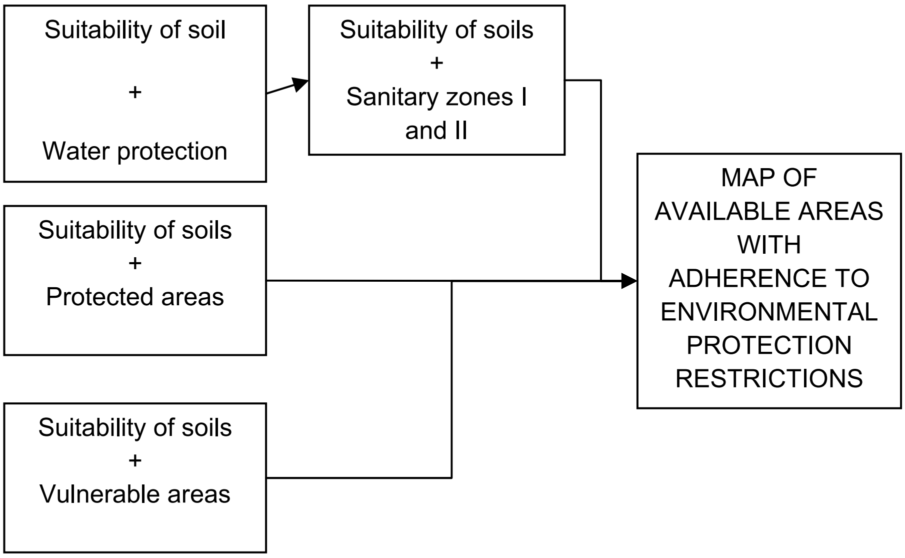

Fig. 5. Proposal of the methodology for the preparation of cartographic presentations of agricultural areas available for irrigation with adherence to environmental protection restrictions

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Paper: **A74**

Best Management Practices for Irrigation as a Function of Groundwater Quality

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Abstract. Sustainable development implies that the needs of the present generation should be met without compromising the ability of future generations to meet their own needs. This includes both the quantitative problems of water availability for the needs of society and the problems of water quality. Protection of groundwater reserves is a key issue that has gained considerable public attention in recent years. Water table management is a drainage practice in which a system of tile drains is used to keep the water table at an optimal level for a selected crop. As a part of CPSP (Country Policy Support Program), a Basin Wide Holistic integrated Water Assessment (BHIWA) model was developed. Best management practices are recommended methods, and/or activities designed to prevent or reduce water pollution while maintaining producer profits.

Keywords: Modernization of agro, food and water economy, management practices, environmental awareness, groundwater

1 Water Management

Arable agriculture land in the Republic of Macedonia is estimated at 612,000 ha. With development of more reservoirs, it is possible to secure irrigation of realistically 370,000 ha. To date, a total of 106 reservoirs of various sizes have been built, and they cover 163,693 ha of fertile arable land, i.e. 24.5% of the arable land. Out of the total land for irrigation (163,693 ha), 100,000 ha (61%) can be irrigated by sprinklers, and 63,300 ha (39%) simply by gravitation. Because of underdevelopment irrigation systems, land given for other purposes etc, it is realistic to expect irrigation of 126,617 ha (77.35% of the irrigation-covered land for which there exists a technical documentation), or 19% of total arable land due to under developed irrigation systems and other land given permanently for other purposes. Exploitation level varies greatly, and it ranges from 40 to 70%. By completing the rehabilitation project for the system HMS Bregalnica, Tikves, and Polog, a significant increase of exploitation level is expected.

The largest irrigation systems are the following: Bregalnica (28,298 ha), Strezevo (20,200 ha), Tikves (19,225 ha), Strumica (16,717 ha) and Kumanovo (10,000 ha). Water supply for population and industrial facilities is usually performed by (separate) local water supply systems. Annual population demand for water is approximately 440 milion m^3 of water, and annual industrial demand is 534 million m^3 of water. Eightly four (84%) of the whole water capacity in Macedonia originates domestically, while are, or flowing in from the neighboring countries. There are three natural lakes in Macedonia: Ohrid Lake-total area 348,8 km^2 , out of which 229,9 km^2 in the Republic of Macedonia, Prespa Lake-total area 274 km^2 , out of which 176.8 km^2 in the Republic of Macedonia, Dojran Lake – total area 43 km^2 , out of which 27.4 km^2 in the Republic of Macedonia. There are 19 big and over 100 small water dams built for utilization of the 4,414 registrated springs and the hydro potential of the rivers. Their total volume is 1,854 km^3 of water. Also there are facilities (green house, spas, pools) in the Republic of Macedonia where geothermal water is used for heating.

2 Environmental Protections and Improvement

2.1 Water Protection

The Cadastre of Pollutants of Vardar River was elaborated in two phases: in the first phase, a poll was conducted through all the inhabited places and industrial facilities which are a constituent part of the urban areas along the Vardar river course, and in the second phase, based on the conducted poll, a selection of industrial capacities classified as pollutants and potential pollutants was made and complete technical documentation on the state of their waste waters was prepared. According to the knowledge acquired during the visit to the populated area and industrial capacities presented in the Cadastre of Pollutants of Vardar River it may be concluded that the state regarding the waste waters related in this recipient is critical to the extent of a catastrophe due to the following: central waste waters filtering stations do not exist in any of mentioned populated areas, the industrial capacities release their unfiltered waste waters partially in the urban sewerage systems and partially directly into the recipient, there are systems for filtering of waste waters at the level pre-treatment or complete treatment in a small number of industrial capacities (however, these systems are pretty old and non-efficient and some of them are even non-usable so that the waste waters are mainly released through the existing by-passes), in the inhabited places and industrial capacities there is a partially constructed sewerage infrastructure mainly of a mixed type through which the complete amount of fecal. Technological and atmospheric waters are released directly into the river, and the depositing of the communal and industrial waste materials in the towns is inappropriate and not well organized (it is performed in places which do not satisfy the health department regulations so that they add to the pollution of the total environment, especially air, soil and ground water).

After the accomplishment of the Cadastre of Pollutants of the Vardar River, there exist, possibilities for realization of the second phase of the Programme of Measures and Activities for Protection of the Waters of Vardar River and its tributaries against pollution which involves elaboration of conceptual solutions for filtering of the total amount of waste waters from the inhabited places. For purpose of obtaining of the most favourable economic-technical solutions, it is necessary to elaborate several variant solutions of central filtering stations with an emphasis on measures to be taken for industrial waters.

2.2 Best Management Practices for Nutrient and Irrigation Management

Best Management Practices (BMP) are recommended methods, structures, and/or activities designed to prevent or reduce water pollution while maintaining producer profits. The goal of BMPs is to protect Vardar river valley water resources from degradation, while maintaining the economic viability of agriculture and related industries. Ideally, these practices will improve producer profitability at the same time soil and water is protected from contamination. Success with voluntary BMPs will depend upon how many farmers and agricultural chemical applicators actually use and promote them.

Having in mind these recommendations of BMPs and one may say the following about The Best Management Practices:

INTEGRATED CROPLAND CULTURAL PRACTICE (Crop Relation BMPs, Soil Management BMPs, General Nutrient Management BMPs), NITROGEN FERTILIZER MANAGEMENT, BEST MANAGEMENT PRACTICES FOR NITROGEN FERTILIZATION (Nitrogen Application BMPs, Fertilizer Handing and Storage BMPs), PHOSPHORUS MANAGEMENT (BMPs for Phosphorus Fertilization), MANURE AND ORGANIC WASTE UTILIZATION (BMPs for Manure Utilization, Manure Storage BMPs), IRRIGATION MANAGEMENT (BMPs for Irrigation Management, Flood or Furrow Irrigation BMPs, Sprinkler Irrigation BMPs, Chemigation BMPs).

3 The Main Strategic and Reform Objectives

It is necessary to design and create a modern, stable and dynamic agricultural sector, integration of the Macedonian agriculture into the global development processes, development of the rural areas and establishment of favourable economic conditions for the Macedonian farmers, improve the marketing of the agricultural commodities, development of the regional cooperation, and implementation of the action plan for execution of the Agreement for Stabilization and Association with the European Union. Significant improvement is achieved by carrying out the activities for reform and harmonization of the legislative to the one of the EU, as follows: private farmers are allowed to have access to public land by distributing 27,5000 ha of arable land to new users, denationalization of land previously, nationalized from original owners, privatization of companies and transformation of agricultural cooperatives are in their phases, newly passed regulations now regulate usage of goods/assets of public interest, such as water, forests, pastures, agricultural land, fish farms and wildlife, veterinary and plant protection regulations are getting approximated with those of the EU. Border cross veterinary and sanitary inspection teams are trained and appropriately equipped. Institutional and financial support has been obtained for opening of 37 new veterinary facilities, with an aim to improve the quality of service and enhancing the competitiveness, a national system for identification and registration of livestock is getting introduced, structural changes have been made in the National Extension service, after the technical equipment process will be finished, permanent training of 78 agronomists will continue, as well as implementation of the state project for their (Extension service) subsequent privatization and self-financing by providing services on farms, support and encouragement to the formation of farmer associations, a total of 178 local associations have been formed by 2002, 14 regional unions and 9 national unions, all of these are united into a Federation of Macedonian Farmers, representing approximately 25, 000 farmers, the process of liberalization of the agricultural commodities market goes on, in accordance to the Agreement for Stabilization and Association with the WTO, free trade agreements have been signed with several countries in the region, the system for preferred crediting has been abandoned, and all subsidies, as well as stimulations that have been in place since 1996 have been terminated, after the subsidies have been abandoned, financial support to the agriculture continued through programs by which, during the period 1997-2001, a cumulative amount of 25 million EUR has been invested, in order to support the agricultural development, a Fund for agriculture has been founded, and a special Fund for water resources for the water management.

4 Water Table Management and Migration of Phosphorus

Agricultural practices have become far more aggressive and demanding for the environment. Intensive use of fertilizers (natural and chemical) has led to high nutrient concentrations in the fields. Transport of nutrients has also been discovered, as many water streams and lake became contaminated from agricultural sources. Among these, phosphorous has become a concern in past years, for its active role in water bodies. Water table management has obvious agronomical advantages, since if provides the crop the right conditions of soil moisture and of water input needs. However, its environmental impacts have yet to be fully evaluated.

5 Basin Wide Holistic Integrated Water Assessment Model

As a part of CPSP (Country Policy Support Program), a Basin Wide Holistic integrated Water Assessment (BHIWA) model was developed. The model has seven computation modules:

1. Actual evapotranspiration, quick runoff and natural recharge
2. Irrigation withdrawal
3. Irrigation returns
4. Evapotranspiration (ET) by sector
5. Domestic and industrial withdrawals
6. River water balance
7. Groundwater balance

In addition to these modules, there are worksheets to facilitate data inputs, and generation of aggregated results in the form of tables and charts.

6 Conclusions

People in the Vardar valley have a strong interest and extraordinary knowledge of their surface and groundwater resource. Agricultural producers are leading the effort to protect and wisely utilize the water that makes life possible for people, crops and wildlife ecosystems within the valley. The goal of this paper is also to prepare a review of Best Management Practices (BMPs) containing nutrient and irrigation guidelines and recommendations. It is also presented water management, environmental protection and improvement, the main strategic and reform objectives, water table management and migration of phosphorus and basin wide holistic integrated water assessment model.

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Seasonality Analysis of the Occurrence of Low Flows in Slovakia

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Abstract. The aim of the study was to examine seasonality indices for their potential in the regionalization of low flows in Slovakia. The minimum discharges from the summer and winter periods were collected from 198 small and mid-sized catchments for this purpose from the whole territory of Slovakia. The seasonality analysis was based on the Burn methodology, and the seasonality indices as a mean day of the occurrence of low flows and the seasonal concentration index were calculated. The results of the seasonality analysis were mapped and pooling groups with similar seasonality indices were derived. The pooling schemes achieved could be applied for following indirect regional estimation of design low flows in Slovakia.

Keywords: Seasonality, minimum discharge, regionalisation

1 Introduction

In recent decades seasonality has attracted a lot of scientific attention. Seasonality appears to be a useful indicator of the catchment similarity in terms of hydrological processes. Burn [3] suggested a method that uses the seasonality of flood response as the basis for a similarity measure within the region of influence approach. The regionalization technique was applied to a set of catchments in Canada and was shown to be effective in estimating extreme flow quantiles. Merz, et al. [11] and [12] have demonstrated that the seasonality approach is indeed useful in the context of extreme flood regionalization in Austria. They used a cluster analysis based on circular statistics of flood occurrences within the year and plotted vector maps to visualize the spatial patterns of the seasonalities of hydrological variables. The interpretation of these seasonality patterns led to an assessment of the main climate-driven flood-producing processes in Austria.

Studies on seasonality analyses in the context of low flow regionalization are, however, rare. Young [17] applied a low flow seasonality index for an estimation of low flow seasonality in the UK. Laaha, *et al*. [9] and [8] compared various seasonality measures for low flows monitored at stream gauges in Austria. They found that seasonality measures were able to classify catchments into summer and winter low-flow-dominated sub regions. Schreiber and Demuth [13] analysed the seasonality of the mean annual 10-day minimum of total discharges measured in 169 catchments in southwest Germany. The results indicated typical low flow occurrences from September to October for large parts of the area studied, apart from the Pre-Alps, which are dominated by winter low flows. Aschwander and Kan [2] investigated the long-term characteristic of seasonal distribution of Q_{95} for representative gauges from 143 headwater catchments in Switzerland. They found two different typical seasonal distributions of low flows, again depending on the catchment's altitude. Some examples of low flow statistics can also be found in [1] and [16].

Many small low-flow studies led to the following development of national low flow estimation procedures, e.g., for the UK [7] or Switzerland [2].

In Slovakia, studies on low flows were published by, e.g., Straka and Dub [5] and Szolgay [15]. Majerčáková, Lešková, Šedík [10] and Demeterová [4] analysed the low flows of various duration periods for catchments from all over Slovakia and mapped their regional and seasonal distributions. Some interesting studies were published by Fendeková and Némethy [6] dealing with low flow analyses in the Starohorský River basin.

2 Seasonality Analysis

In this study the seasonality analysis of low flows was analysed using directional statistics methods. According to Burn [3], directional statistics form a useful basis for defining similarity measures derived from the timing of events. A seasonality index is based on two parameters, Θ and r, which are calculated from the Julian dates of all days in the observation period when discharges are equal to or below Q_{95}, by means of circular statistics. The first parameter Θ is the mean day of the occurrence, is measured in radians and is a measure of the average seasonality of any low flows. Parameter Θ takes values between 0 to 2π, 0 relating to January 1st, π/2 relating to April 1st, π relating to July 1st and 3π/2 relating to October 1st. The second parameter r is the mean resultant of the days of the occurrence, which is a dimensionless measure of the variability of low flow seasonality. The possible values of r range from zero to unity, with r = 1 corresponding to strong seasonality and 0 corresponding to no seasonality (low flow events are uniformly distributed over the year) [8].

For each catchment the days on which a low flow was smaller than Q_{95} were extracted from the period of record and transformed into Julian Dates *Dj* (the day of the year ranging from 1 to 365 in ordinary years and 1 to 366 in leap years). *Dj* represents a cyclic variable, which can be displayed as a vector on a unit circle. Its directional angle in radians is given by:

$$\Theta j = \frac{Dj.2\pi}{365} \tag{1}$$

The arithmetic mean of the Cartesian coordinates x_Θ and y_Θ of the total of n single days j is defined as:

$$x_\Theta = \frac{1}{n}\sum_j \cos(\Theta_j) \tag{2}$$

$$y_\Theta = \frac{1}{n}\sum_j \sin(\Theta_j) \tag{3}$$

From this, the directional angle of the mean vector was derived by:

$$\Theta = \arctan\left(\frac{y_\Theta}{x_\Theta}\right) \text{1st and 4th quadrant: } x\rangle 0 \tag{4}$$

$$\Theta = \arctan\left(\frac{y_\Theta}{x_\Theta}\right) + \pi \text{ .2nd and 3rd quadrant: } x\langle 0 \tag{5}$$

The mean day of occurrence is obtained by back-transforming the mean angle to a Julian Date:

$$D = \Theta\frac{365}{2\pi} \tag{6}$$

The length r of the mean vector is a measure of the variability of low flow days, which is also called the seasonal concentration index:

$$r = \sqrt{x_\Theta^2 + y_\Theta^2} \tag{7}$$

3 Data

The seasonality analysis in this study was based on data from 198 small and medium-sized catchments selected from the whole territory of Slovakia, with catchment areas ranging from 4 to 500 km^2 and with observation periods longer than 20 years. Figure 1 illustrates the spatial distribution of the selected catchments in Slovakia.

The seasonal low flow discharges were analysed in the selected catchments. Two separate seasons were chosen: the summer season (May-October) and the winter season (November-April). The following characteristics of the low flows were derived from the discharge observations in the selected catchments for both seasons:

- Q_{95} low flow quantile [m^3.s^{-1}] discharge, which is exceeded on 95% of all the days of the measurement period, estimated from the period 1961 - 2000,
- dates of low flow occurrence lower than Q_{95} from the entire observation period.

Fig. 1. Spatial distribution of the analysed catchments in Slovakia

4 Results of the Low Flows Seasonality Analysis

4.1 Summer season

Table 1. Grouping catchments according to the mean day of low flow occurrence and the value of the seasonal concentration index in summer season

Group	Month	Value of seasonal concentration index	Number of Catchments
1	August	0.0-0.6	1
		0.6-0.8	18
		0.8-0.85	17
		0.85-0.9	38
		0.9-1.0	14
2	September	0.6-0.8	11
		0.8-0.85	28
		0.85-0.9	37
		0.9-1.0	27
3	October	0.8-0.85	1
		0.85-0.9	1
		0.9-1.0	5

The summer season was set from May to October. Table 1 shows the seasonal concentration of summer low flows lower than Q_{95} in the separate summer months and the number of catchments belonging to a certain range of the value of the Burn seasonal concentration index. It is evident that for most of them i.e., 103 of the catchments analysed, September was the month with the highest occurrence of low flows lower than Q_{95}. For 88 catchments the low flows were observed in August. October was represented by only 7 catchments. In the other summer months, no low flows lower than Q_{95} were observed. The seasonal concentration index was very high in the three summer months; for 84% of the catchments it reached a value of between 0.80-0.95.

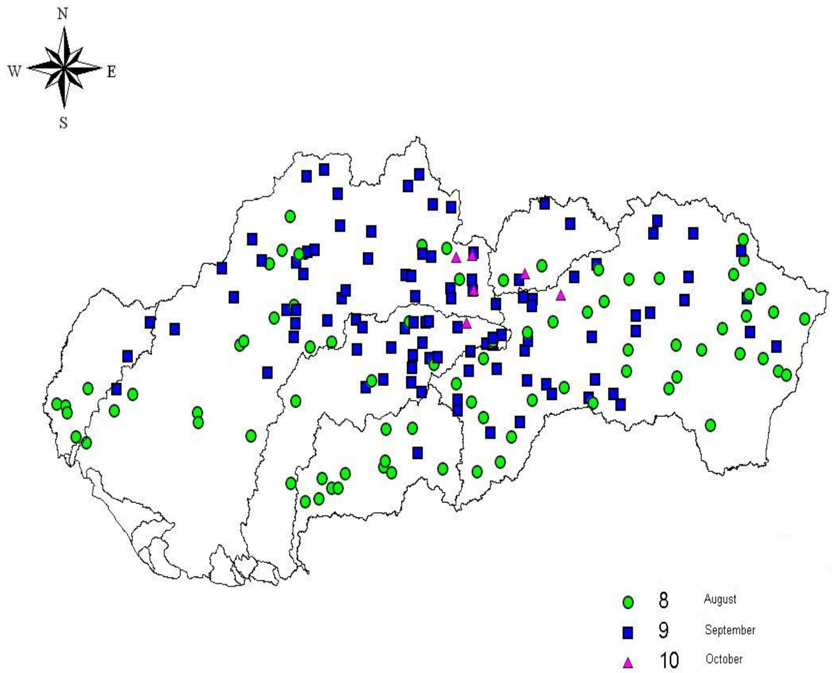

Fig. 2. Seasonality of summer low flows expressed by the month with the highest occurrence of low flows lower than Q_{95}

Based on the previous analysis, the seasonality of summer low flows lower that Q_{95} as expressed by the mean day of the occurrence and by the index of seasonal concentration (r) was visualised by mapping in Figs. 2 and 3.

From the results visualised in Fig. 2, we can see that September is a typical month with a low flow occurrence for catchments located in the western, southern and eastern parts of Slovakia, also including the lowlands. August is a typical month with a low flow in the mountainous regions of Slovakia, mainly in the central and northwestern parts. Finally, October is a typical month for the occurrence of low flows at the end of the summer season in the eastern part of the High Tatra Mountains.

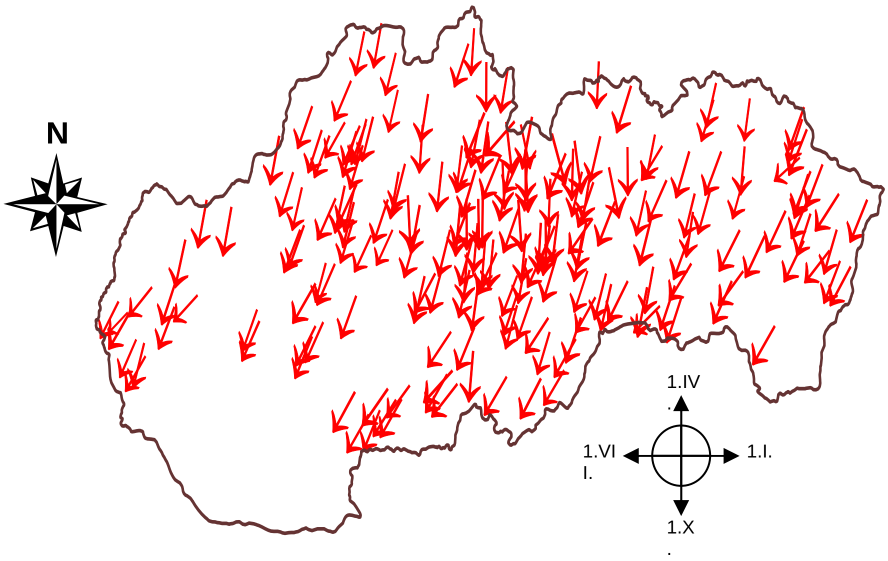

Fig. 3. Seasonality of summer low flows lower than Q_{95} as expressed by the seasonal concentration index

4.2 Winter season

A similar seasonal analysis was also made for low flows in winter months. The winter season was set from November to March. Based on the Burn methodology [3], the occurrence of low flows lower than Q_{95} was analysed

Table 2 shows the seasonal concentration of the winter low flows in all winter months with the number of catchments belonging to a certain range of the Burn seasonal concentration index value. The highest occurrence of low flows was detected in January for 105 catchments. In December it was for 51 catchments, in February for 25, 10 in November and only for 2 catchments in March.

Table 2 also shows that the seasonal concentration index ranges between 0.8 – 0.9 for 101 catchments and between 0.7–0.8 for less than 50% of the catchments. The lowest value of the seasonal concentration index of 0–0.7 was observed in seven catchments. The visualisation of these results is in Figs. 4 and 5.

Based on the previous analysis the seasonality of winter low flows lower than Q_{95} expressed by the mean day of the occurrence and by the seasonal concentration index was mapped. The results are presented in Fig. 5.

Table 2. Grouping catchments according to the mean day of the occurrence of low flows and the value of the seasonal concentration index in the summer season

Group	Month	Value of seasonal concentration index	Number of Catchments
2	December	0.0-0.5	1
		0.6-0.7	3
		0.7-0.8	15
		0.8-0.9	19
		0.9-1.0	13
3	January	0.0-0.5	1
		0.6-0.7	1
		0.7-0.8	26
		0.8-0.9	66
		0.9-1.0	11
4	February	0.6-0.7	1
		0.7-0.8	2
		0.8-0.9	15
		0.9-1.0	7
5	March	0.8-0.9	1
		0.9-1.0	1

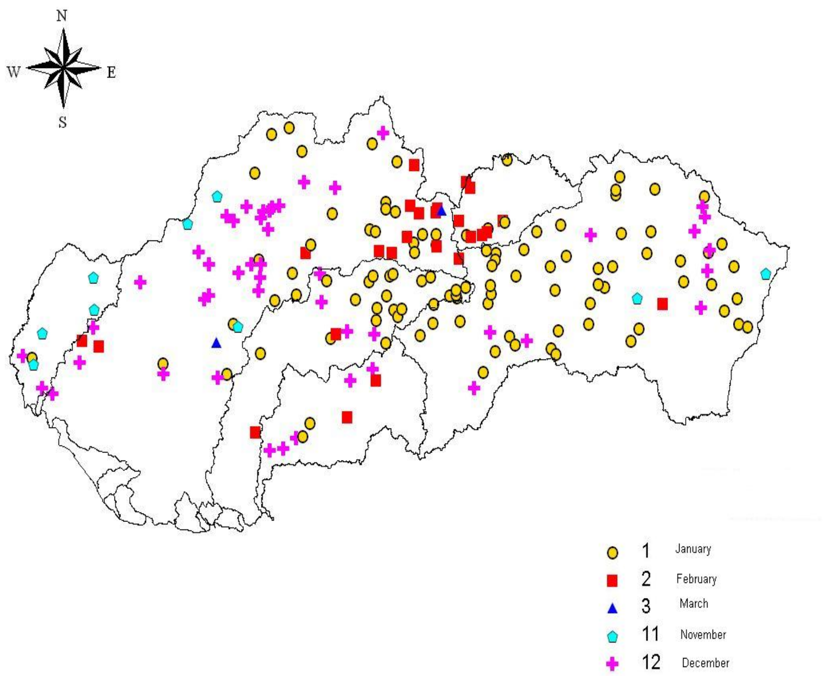

Fig. 4. Seasonality of winter low flows expressed by the month with the highest occurrence of low flows lower than Q_{95}

From the results visualised in Figs. 4 and 5, we can conclude that January is a typical month with a low flow occurrence for catchments located in the middle and eastern parts of Slovakia. February is typical of the High and Low Tatra regions. December prevailed for catchments in the western part of the Flysh region and the eastern part of the Laborec Highlands. November is a month of low flow occurrences in winter for catchments in the Záhorská Lowland and the Chvojnická Highlands.

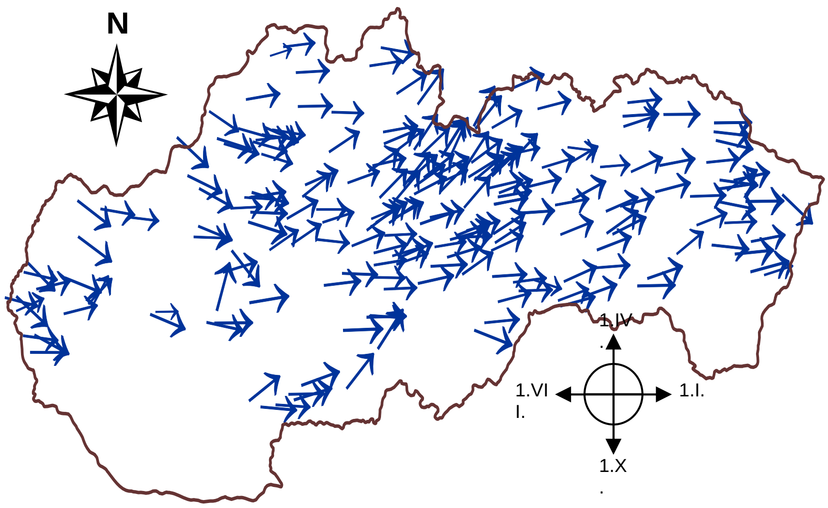

Fig. 5. Seasonality of winter low flows lower than Q_{95} expressed by the seasonal concentration index

5 Conclusions

The aim of the study was to examine seasonality indices for their potential in the pooling of low flows in Slovakia. For this purpose the minimum discharges from the summer and winter periods were collected in 198 small and mid-sized catchments from the whole territory of Slovakia. The seasonality analysis was based on the Burn methodology [3], and the seasonality indices as the mean day of the occurrence of low flow and the seasonal concentration index were calculated. The results of the seasonality analysis were finally mapped, and pooling groups with similar seasonality indices in Slovakia were determined. From the results of the seasonality analysis in the winter period, we can conclude that January was a typical month with low flow occurrences for catchments located in the middle and eastern parts of Slovakia, February was typical of the High and Low Tatra regions. December prevailed for catchments in the western part of the Flysh region and the eastern part of the Laborec Highlands. November was the month of low flow occurrences for catchments in the

Záhorská Lowland and the Chvojnická Highlands. We can see from the visualised results of the seasonality indices in the summer months that September is a typical month with low flow occurrences for catchments located in the western, southern and eastern parts of Slovakia, also including the lowlands. August was a typical month with a low flow in the mountainous regions of Slovakia, mainly in the central and northwestern parts. Finally, October was a typical month for low flows in the summer in the eastern part of the High Tatra Mountains.
The pooling schemes achieved could be applied for following undirect regional estimation of design low flows in Slovakia.

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Ground Water Resources of Lijevce Field as a Potential for Irrigation in Agriculture

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Abstract. Lijevce field is placed in the north-west part of Bosnia and Herzegovina. By great part, this field represents agricultural area, under intensive cultivation. Lijevce field is bordered with the rivers, Sava and Vrbas. Beside surface water, Lijevce field abounds in ground water resources. According to the hydrogeologic parametars, ground water potential in Lijevce field belongs to the richest potentials in Bosnia and Herzegovina. Dominant soils in this area are eutric cambisols, fluvisols, gleysols and pseudogleys. Previous research showed that ground water drains toward the Sava and Vrbas rivers. The contribution of the ground water was estimated on about 15 $m^3 \cdot s^{-1}$. Currently, about 5% of total Lijevce field area is irrigated. This percentage is too low having in mind agricultural and water potentials. The possibility of the ground water utilisation for irrigation in agriculture is very high. The quality of the ground water is more than acceptable for the agricultural uses. In the southern part of the Lijevce field inter-granular aquifer was formed with free level of water table, which oscillates on the depth from 4-6 m under soil surface. The northern part of Lijevce field has specific geologic structure in which clay cover dominates making possible subartesian and periodically artesian pressure inside intergranular aquifer. The irrigation system was bilt on 2027 ha untill 1991 in the Lijevce field. According to estimation with the ground water resources of Lijevce field represent the potential for the 28500 ha of agricultural fields irrigation.

Key words: Ground water, resources, irrigation, agriculture

1 Introduction

Taking in consideration its natural wealth, Bosnia and Herzegovina finds its place among countries abound in natural resources. Economy crisis caused bad natural resource management, in the broader meaning. Lack of good integral natural resources managment resulted development of one causing damage in the other branch of the economy. Lijevce Field is good example of possible integral management in agricultural production and its intensification. With its southern exsposure, fertile soils and considerable quantity of ground water, Lijevce Field represents till now not enough used capacity. Latest analysis shows that there are actual possibilities for irrigation of 28500 ha in Lijevce Field, taking in consideration existing ground water resources. Intensification of agricultural production will be possible if ground water, as an renewable natural resource, is used in optimal manner. It is important to emphasize that till 1991, in this area, only 2027 ha were covered by irrigation systems. These systems were primarily using ground water as water supply resources. Irrigation systems were mainly based on drill wells, sometimes with compensational pools for artificial possibility of increasing well capacity. Dominant soils in Lijevce Field are cambisols, fluvisols, gleysols and pseudogleys.

2 Geographical Location and Hydrography of Lijevce Field

Lijevce Field is placed in the north-west part of Republic of Srpska (Fig. 1), between 17°15` and 17°30` eastern longitude, and 44°55` and 45°10` northern latitude. Field covers around 300 km^2. Sava River borders Lijevce Field from the north and Vrbas River borders it from the east and southeast. Kozara Mountain represents its west and south-west border. Through its central part there is motorway between city Banja Luka and town Gradiska and conects western part of Republic of Srpska and Bosnia and Herzegovina with highway Belgrade – Zagreb. Diagonal through the Field there are canals that regulate water torrent streams from the Kozara. Besides its role in torrent stream control these canals have function as well as drainage control in period of the year when high water is present and also as irrigation canals during dry season. There are defensive embankments in the east and north part of the Field that protect it from high water of Sava and Vrbas rivers. The Field is placed on the junction of three municipalities: Laktasi, Gradiska and Srbac.

3 Hydrogeological Research History of Lijevce Field

During the last 50 years water was very important subject of research in Lijevce Field. Main part of the Field was under influence of high water of two rivers, Sava and Vrbas, so research work was focused on protection from water surplus in the beginning phase. Regarding this the research methodology was focused to define hydrological investigations after which are accepted solutions like building defensive embankment, paralel to mentioned two rivers, for flood control and open canals that had primarly role to drainage soils in wet season as well as to collect water from Kozara mountain. After land-reclamation systems were built, agricultural production suffers extrem development in Lijevce Field. Big farms were formed, that have huge field parts under intensive agricultural production. Society development of this area increased water supply demand which led to new hydrogeological research in order to define hydrogeological characteristics of ground water resources and possibility to use great water quantities. These investigations were detailed and dealt with ground water and its interaction with surface water. More than 200 piesometers were drilled and ground water levels were monitored for more than 15 months. River level on 6 profiles on the both Vrbas and Sava River were monitored as well. The result of all mentioned investigations was defining several locations for ground water scoop with 1000 l/s capacity. Concept like this could have fulfill regional area water supply demand. Unfortunately, after the big earthquake, this concept of ground water exploatation didn't find its place among new ideas. Beside that all good ground water scoop locations are partially damaged, so now there is problem to meet demand of certain local area.

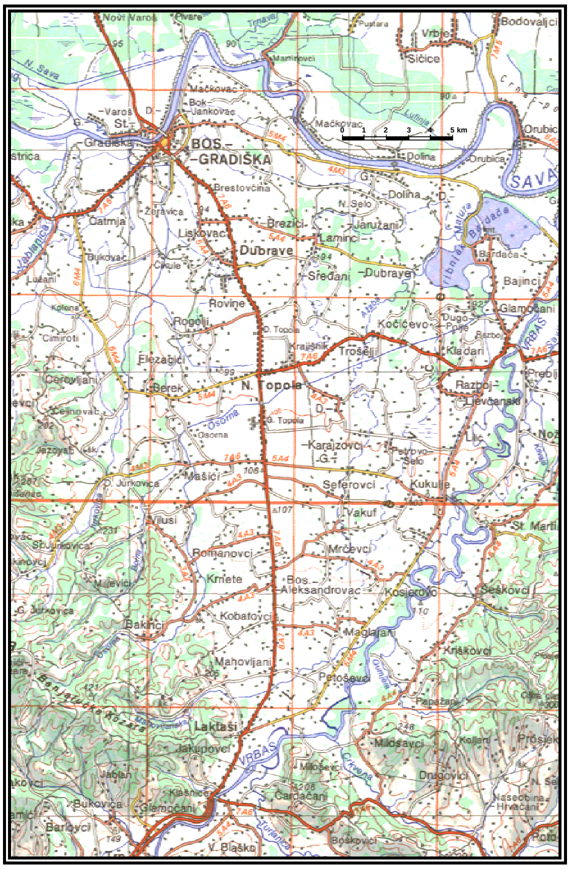

Fig. 1. Topographic map of Lijevce Field

After Land Reform was finished and big state agricultural estates were formed in order to increase agricultural production some new hydrogeological research were conducted. There were two goals: land-reclamation systems regarding drainage and fertile soil irrigation in order to increase yield. All research works were directed to Lijevce Field and three municipalities Laktasi, Gradiska and Srbac. It is necessary to emphasize next research works:

- land-reclamation of Lijevce Field and Milova Podgradci – ground water in river basins;
- land-reclamation of Lijevce Field and Milova Podgradci – drainage of valley areas;
- land-reclamation of Lijevce Field and Milova Podgradci – area Masici-Razboj-Laktasi – irrigation using ground water.

Besides above mentioned measures some flood control projects were conducted – defensive embankment parallel to river Sava and Vrbas courses. By dike building the problem of flood and so called long water stagnation, in northern and north-west area of Lijevce Field was solved. Open canals, in the eastern and north-east part of the Field, drained waters coming from the Kozara Mountain. Water surplus problem was solved by building of these canals in wet season and water from them could be used for irrigation in dry season. Land-reclamation measures enabled more intensive agricultural production. Taking in consideration possible area for agricultural production the conclusion was that there will be lack of water for irrigation. Possible solution was exploitation of ground water. Research for ground water exploitation was conducted first for the human water supply demand and later on for irrigation in agriculture. Between 1971 and 1975 new detailed hydrogeological research were again conducted in three phases. First phase was dealing with gathering the information from abundant geological and hydrological documentation. Some geophysical research works on measuring profiles Klasnice-Bosanski Aleksandrovac were made [1]. Second phase asumed drilling of three experimental wells with piesometric net and experimental water-pumps, monitoring of the regime in natural condition as well as during exploatation [15]. This level of research work defined scoop conditions and reserves of ground water. Third phase assumed hydrodynamic and sanitary conditions and ground water resources protection. Besides research for Banja Luka water supply demand also Bosanska Gradiska was involved. Above mentioned research gave precise data of ground water reserves in quantity of 2 m^3/s and high quality. Ground water exploatation conditions for the next 30 years were given.

As a base of hydrogeological research besides basic geological research also geoelectrical testing of Bosanska Gradiska were conducted [2]. The whole Lijevce Field was covered by these research works. In order to find out some new and better solutions for Gradiska water supply demand few researches were made to confirm abundant of "Bosanska Gradiska" ground water resource on model of ground water flow in Lijevce Filed aquifer [13]. Flow model is adjusted for diferent exploitation conditions. All results showed stationary condition. On hydrogeological characteristics basis of northern part of Lijevce Field and Bosanska Gradiska that are dealt with in feasibility study [12] and showed on hydrogeological map (Fig. 2) with its profiles, some compressed ground water resource could be noticed in plan and profile. Spread alluvial sediment and brim, neogenic complex could be seen also.

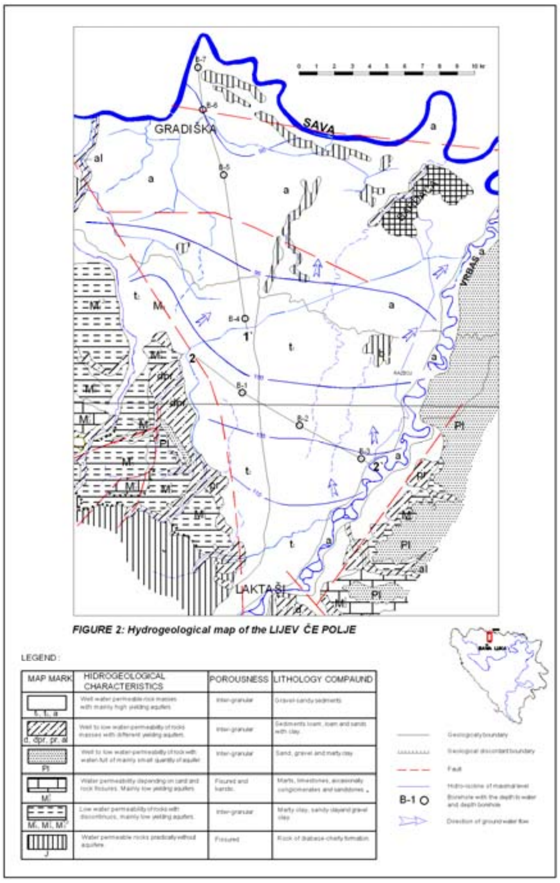

Fig. 2. Hydrogeological map of the Lijevce Field

4 Ground Water Potential of Lijevce Field

Earlier research defined ground water resource in plan and profile that also considers feeding zone, diffusion and ground water flow out. During research, hydrogeological parameters, neccessary for plan and design of future ground water resources, were defined.

Lijevce Filed is built from terrace layers with intergranular porosity. These layers acumulate ground water. Ground water resources is bordered from the north by the Sava river and from the south-east, east and partially north-east by theVrbas river while the edge part of Kozara mountain makes the western border. Ground water resource feeds itself from surface waters, dominantly water from Vrbas river. Feeding zone is defined from Klasnice to Razboj. In this part Vrbas river loses its water constantly but from Razboj to river mouth to Sava, Vrbas stream takes the ground water and increases. Besides mentioned, all Sava river flow course through Lijevce Field takes with it ground water and increases its flow to hydrological maximum of 15 m^3/s. Observing from terrain surface down by the depth of subject space, there are two lithostarthygrafical units that should have characteristics of hydrogeological collectors. High water permeable rocks formed hydrogeological collector presents coarse to medium gravel with sand (8.40 m layer) and petit and medium gravel (12.40 m layer) - rocks with intergranular porosity. Compressed type of ground water is formed here. Its level oscillates on about 6 meter.

Gained water pump data on abandoned well B-1 are basic indicators of these layers [1]. Filtration characteristics of these water permeable layers, intergranular porosity have below shown average values:

- filtration coefficient	$K=1 \times 10^{-3}$ m/s
- water conduit coefficient	$T=KM=1.4 \times 10^{-1}$ m^2/s
- water strain coefficient	$\mu= 0.21$
- piesometric conduit coefficient	$a=6.67 \times 10^{-1}$ m^2/s

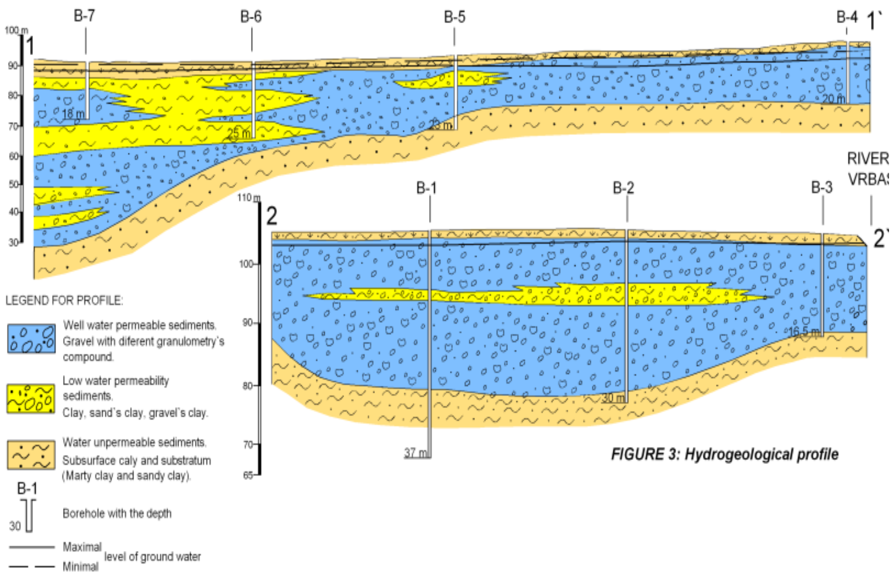

Fig. 3. Hydrogeological profile

Weak water permeable rocks or rocks with hydrogeological function as isolation ward on the research terrain, have humus layer, sand clay and loam, that makes waterproof roof of alluvial layers. Adopted filtration coefficient value from earlier investigation [1] of these layers is about $K>1x10^{-6}$ m/s. These layers make certain kind of barrier to water from precipitation that brings to weak infiltration. Hydrogeological structure of this kind is good from the aspect of aquifer protection from surface pollution. Beside this surface layer there is also one weak water permeable layer (depth 10 to 14 m) represented by sand clay and clayed gravel (Figs. 3 and 4).

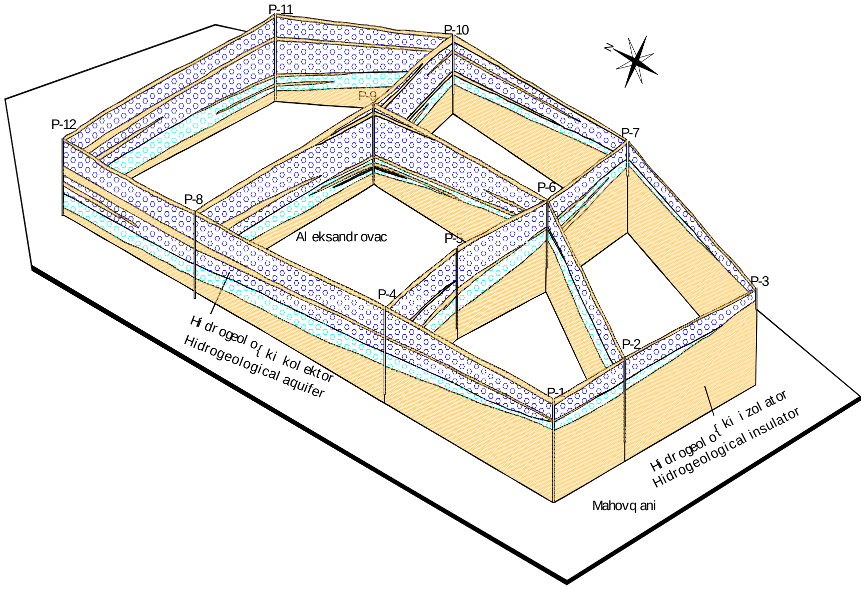

Fig. 4. Block-diagram of the south part of Lijevce Field

These layers cause ground water resources have sub-artesian character, in certain period of the year. Northern part of Lijevce Field (Fig. 2) has dominant clay overlayer layer that causes ground water with subartesian and artesian pressure during certain period of the year (hydrological maximum). Bearing in mind that surface part of Lijevce Field, is more or less, covered by weak water permeable clay cover, quality of ground water is high and surely acceptable from irrigation aspect. In the southern part of Lijevce Field there is natural phenomena of thermal water flow. It flows under pressure. There are two such wells that are exploited even now. Researches confirmed that mentioned thermal water mix with free ground water in alluvial layers. During terrain inspection it is confirmed that in village wells, in wider surrounding, this water has temperature higher than annual average. This water could be used for greenhouses warming and for irrigation.

Prospective agricultural area is in accordance with spread of compressed ground water resources, which is favourable from the ground water scooping aspect for irrigation purposes.

5 Conclusions

Lijevce Filed has considerable quantities of ground water, which could be directly scooped, exploited for irrigation of agricultural land. Curently by irrigation covered part of Lijevce Field represents less than 10% of total 28500 ha, planned for irrigation. Hydrogeological structure as well as hydrogeological rock function that builts Lijevce Field make possible several solutions for ground water scooping. Estimated surface and ground water potential that could be used for irrigation of Lijevce Filed is about 15 m^3/s. Thermal water occurence gives solution for heating of greenhouses and also for irrigation that additionally could improve agricultural production. By its area and soil quality Lijevce Field represents great potential for agricultural production in Republic of Srpska and Bosnia and Herzegovina. Together with scooping of considerable quantity of ground water, agricultural production shall get intensive character with possibility for fast refund of investment in irrigation systems.

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EIS–Monitoring Method of the Earthen Dikes of Water Reservoirs

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Abstract. Electrical impedance spectrometry is an indirect measuring method, which enables on the basis of the measurement of electrical impedance (or admittance) to monitor selected processes running in soils when being loaded with water. Through the solution of the international project E!3838 of the programme EUREKA, a unique measuring device was developed, being currently applied in water management in the Czech Republic, e.g., to monitor the state of protective earthen dikes of hydraulic structures (pond dikes) and its changes. The paper gives examples of achieved results.

Keywords: Indirect monitoring method, electrical impedance spectrometry, dike, soil, moisture, free water level, EUREKA Program

1 Introduction

Due to the current development and prognoses signalling a higher frequency of extreme meteorological situations, flood protection becomes an important component of life. From the given aspect it is also necessary to pay increased attention to one of the protection elements most used – the state of protective dikes.

It is usually earth-fill dikes, both diversion dikes (reservoir, pond and dry dikes), and protective dikes. These dikes are exposed for a short time to an extraordinary load, during which they may be broken. As compared with reservoir dikes permanently impounding water and creating reservoirs, protective dikes have a number of specifics connected especially with an irregular, short-term and often extreme load with water. It can generally be stated that protective dikes are in comparison with, for example, reservoir dikes loaded with greater uncertainties as regards the state of the basement, materials used and technological construction. It is linear constructions of not only local, but also worldwide significance, the length of which ranges in hundreds to thousands of kilometres. Due to the great variability of the natural environment, its geologic structure, geotechnical diversity, rugged morphology, hydrogeology and wide typology of individual constructions, it is necessary to regard each protective dike as well as their partial sections as an original and unrepeatable work. Many of the given constructions are loaded due to their high agedness with the uncertainty of geological and geotechnical conditions of the environment. In these installations there is mostly no documentation describing their composition or technology of construction. Moreover, these works were heightened, repaired or reinforced in the past, and thus they are again confronted with a serious question of how they can resist extreme hydrodynamic stress at flood flow rates. From the above-given facts it is evident that the spectrum of factors entering into the process of assessment of the state of protective dikes is very wide.

To secure the long-lasting stability of the dike structure, and thus its safety under all assumed situations, is the primary condition of its design, construction and operation. Protective dikes have been built mainly of local materials. From the statistical point of view it shows that most failures and disasters of protective dikes were caused by either their spillover or seepage. It is necessary to re-emphasise that both the phenomena, and above all the matter of seepage (through the dike body and its basement - underflow of the dike body), are closely connected with the great variability of dike construction and the adequate uncertainty of their real parameters. The causes of the given failures then closely relate to the already-mentioned specifics of these works, the most striking of which is the effect of their irregular hydrodynamic stress.

The flow of liquids in the porous soil is generally a very complicated non-stationary flow, which has a spatial character. The problems which occur in connection with it are very frequent in the engineering practice (pumping of groundwater, oil or natural gas, water losses from reservoirs, water filtration, grouting activities, and others). The flow is characterised by its direction and velocity and, as a consequence of hydraulic resistivity of soil, by the loss in the piezometric head (the sum of geodetic and hydrostatic pressure heads), with three values (velocity of flow, direction of flow, and pressure head) being the function of position and time.

The axes of pore tubes, through which water flows, are spatial curves with marked torsion, with a random spatial orientation, with a randomly changing cross section, density and mutual intersection. The ratio of the sizes of the components of the flow velocity vector is then a value random in space and time and very difficult to determine. It is, therefore, possible to appropriately describe the porous soil only by its average properties (e.g., the average resistance of soil to the flow), with respect to both its characteristics and the flowing liquid. When solving the problems of flow through the porous environment, all available means which can provide information on a monitored phenomenon are thus combined (modelling, measurement on real objects); very often first assessing a possibility of simplification of a solution by a procedure that sufficiently accurately approximates the real regime of flow. For example, the flow is often assessed as stationary and the spatial character is replaced with the planar one.

In the Laboratory of Water Management Research of the Department of Water Structures, we have managed to develop quite a unique measuring device thanks to the solution of the international project E!3838 of the programme EUREKA directed into the sphere of applied research and research for industry. It enables through electrical impedance to monitor certain changes running in soil when being loaded with water. The project is presented on the web pages www.eureka.be of the programme EUREKA; more detailed information on the achieved results and activities connected with the solution of the project can be obtained through the special web pages of the project www.eureka3838.com.

2 The Monitoring Method of Electrical Impedance Spectrometry

The method of electrical impedance spectrometry (EIS) has become a popular analytical method for its information capability and has taken the front place in the study of physical and chemical properties of materials and living tissues. It was applied, e.g., in detecting the chemical purity of material, the content of water, the concentration of solutions, the corrosion of material, pathological changes of cells, etc.

The basic principle of the method is the measurement of the frequency characteristic of impedance of the measured object or material. The frequency characteristic of impedance Z can generally be expressed as a function of a complex variable in the form:

$$Z = R + jX \tag{1}$$

where: R is resistance forming the real part of impedance independent of frequency, X is reactance, the imaginary component of impedance and the magnitude of which changes with frequency.

Impedance measurement by developed impedance spectrometers uses a comparative method which consists in the comparison of the measured impedance with the normal resistance R_n, with its known value of electrical resistance, and its reactance is negligible in the considered frequency band, or the electric current is divided between two orthogonal components, the real I_R, flowing through the real component of the substitute impedance R, and the imaginary I_C, flowing through the substitute capacity C.

Then in a vector diagram, the reference vector is the vector of voltage U, with which the real component of the current I_R is in phase, and the imaginary component is perpendicular to it.

The measured data received in a PC represent the values of impedance of the equivalent circuit formed by the parallel combination of the resistance R and the reactance X formed by the capacity C and the inductance L (in soils, it is generally applied so indistinctly that it is neglected), where (ω is angular velocity)

$$X = j\omega L - \frac{1}{j\omega C} \tag{2}$$

We must emphasise that in case of the parallel combination of the elements R and X, the calculation of the total measured impedance Z arises from the individual admittances Y of these elements, and it holds true that:

$$Y = \frac{1}{Z} = \frac{1}{R + jX} \tag{3}$$

In Eq. (1) $R = 1/G$ represents the real part of admittance, where G is conductance and the imaginary part of admittance can be written as $X = 1/B$, where B is susceptance. By transposing the Eq. (3) by means of the given symbols, we can obtain an analogy of the relation (1):

$$Y = \frac{1}{Z} = G + jB \tag{4}$$

The total impedance in a complex form is then expressed by the formula:

$$Z = \frac{1}{Y} = \frac{RX^2}{R^2 + X^2} + j\frac{XR^2}{R^2 + X^2} \tag{5}$$

3 The Developed Device

To measure the electrical impedance Z of soils and its changes due to the loading of soils with water, a unique measuring device Z-meter has been developed, enabling monitoring in laboratory and real environments (Fig. 1). With the matrix configuration of measuring electrodes, it is possible to read data from 128 points. The important parameters of the device are given in Table 1. With respect to the sensitivity of the measuring device to the monitored changes Z, it is possible to apply two different principles of the connection of two measuring probes (two- and four-terminal measurement). If constant conditions are found during measurement, when especially the contact of the sensor of the probe with the monitored soil is one of the determining factors, it is possible to eliminate the effects of parasite resistance (the length of conductors, transition resistance, and the like).

The apparatus meets high demands for accuracy and reproducibility of measurement. The Z-meter is controlled by a PC, which performs the function of an intelligent console serving for visual contact of the operator with the measuring system. The main tasks of the PC before measurement are to arrange the setting of the type of an experiment (frequency characteristic, measurement at one frequency), parameters of an experiment (frequency of the measuring signal or frequency range of measurement, interval of the rise of frequency, level of the measuring signal), the method of interpretation of results, archiving of results, control of basic functions of the Z-meter as the actual meter of impedance, and activation of an experiment. During measurement, it receives data from the Z-meter, displays them and archives them, if possible. After the end of an experiment, results can be unpacked and further processed by a spreadsheet, e.g. MS EXCEL. A speedy communication interface Universal Serial Bus (USB) serves for data transfer between the Z-meter and the PC.

Table 1. Basic parameters of the Z-meter

Z-meter	Parameters
Range of impedances	10 Ω – 1 MΩ
Frequency range	100 Hz – 20 kHz
Accuracy of modulus of impedance	+/- 2 % of the range
Accuracy of phase	+/- 2°
Level of measuring voltage	500 mV – 5 V with an interval of 500 mV
Communication with a PC bus	USB (COM port), LAN, GSM, CF card
Integrated electronic switcher	128 measuring points, each with 4 terminals (alternative of 2 or 4 terminals measurement)

Fig. 1. Z-meter device with control PC and the probes installation

The software of the device Z-meter is made up of two program blocks. It is a utility program of the device control by means of the parent PC, which is designated as Z-Scan va.b, where the sign va.b represents a certain phase of development of the given utility software (Fig. 2). The second block represents a program of the built-in signal processor ADSP 2181, which is set in the “service” modulus by pressing the push button “HW Version”. The program of the signal processor is marked as DSP va.b, where the sign va.b has the same meaning as in the preceding case.

3.1 Measuring Probes

Measurement on the dike of the Koberice water reservoir was instigated by the observed increased leakage on the downstream side of the dike. In the dike crest on the edge of the upstream face, 7 vertically divided rod electrodes were mounted at a mutual distance of 2 m. The system monitored approximately a half of the dike in profiles designated as 0_1 to 5_6. The electrodes in pairs form the measuring probe with 12 vertical monitoring profiles. The total length of each installed rod electrode is 3.5 m and the electrodes are mounted 0.15 m below the dike crest; thus, they are not noticeable on the crest or on the upstream face of the dike (Fig. 3).

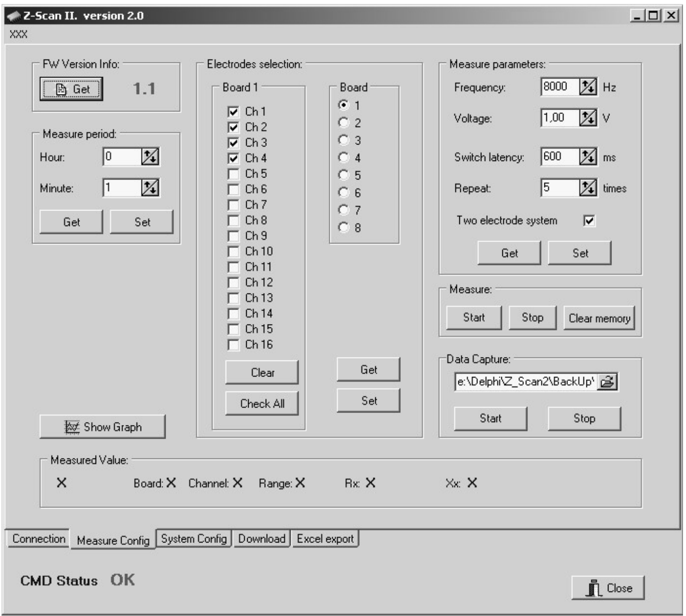

Fig. 2. Dialogue window of the utility program Z-Scan v.2.0

To monitor the movement of the free groundwater table and the effect of water infiltrated into soil by the change in electrical conductivity, a simpler two-electrode system of connection of vertically divided measuring electrodes was applied. In them, an electrically conductive part (a 0.15 m long stainless tube with 0.002 m thick walls) interchanges with a nonconductive one (a 0.15 m long polyamide tube with 0.005 m thick walls).

Fig. 3. Compositive system of stable measuring electrodes and their installation

The number of the measuring profiles is limited by the number of the measuring channels of the device Z-meter, i.e. 128. The electrodes were installed in soil by hand, which required the development of special procedures and technical elements.

The evaluation of the measured change in electrical impedance Z (or electrical conductivity G of soil) in the monitored profile is always made in the so-called virtual point, which lies in the middle of the horizontally as well as vertically divided measured profile.

4 Characteristics of the Monitored Area

In 1979, in the forest area Knezak – Bezedrak (southeast of the municipality of Koberice) on a nameless left-side tributary of the Kobericky potok (brook) at km 0.850 at an altitude of about 250 m a.s.l., two small water reservoirs were built. They were later supplemented with a third one. The area of interest is located in a narrow floodplain (Fig. 4), where soil was heavily waterlogged due to a high level of groundwater. The quality of the meadow vegetation was low by both its species composition and the yield and indicated the low land value. By having built water reservoirs, a landscape enhancement element and a source of water for forest animals have been formed.

Fig. 4. Situation of the area of interest and view to upstream face of the earth dike of water reservoir Koberice, which is called Bezednik III (the name means without the bottom)

After having filled the lower reservoir in 1980, dike leakage began to appear outside the outlet pipe. It obviously occurred due to a defect in the sealing core [1]. Based on a geological appraisal, the defect was remedied by an additional watertight layer of clayey soil on the upstream side of the dike. Over time, however, the defect re-appeared, and therefore, in 1998, a permit for the works "Restoration of the Water Reservoir Koberice" in the cadastral territory Koberice, Vyskov District, was issued. The solution consisted in the treatment of the water reservoir Bezednik III for the purpose of water retention in the landscape and for the aesthetic purpose. At the water structure, there are an emergency spillway, an outlet device, and a sedimentation area in front of the outlet object. The earth dike of the reservoir was built of local materi-als. The dike of the water structure will be protected when diverting water to the discharge Q100. The bench mark is on the protective frame of the outlet device and has an elevation of 300.67 m. horizontally; all measurements were made in the local coordinate system. The basic parameters of the reservoir are given in Table 2.

Table 2. Basic parameters of the water reservoir Koberice

Basic parameters	Data
Hydrological arrangement	4-15-03-084
Basin area	2.12 km^2
Backwater area	3 586 m^2
Dike width in crest	3.5 m
Dike length	72.5 m
Maximum depth of reservoir	2.0 m
Volume of inactive storage	4 792 m^3
Volume of non-controllable flood storage	2 558 m^3
Total volume of reservoir	7 350 m^3
Outflow of design amount Q_{100}	6.5 m^3/s
Annual mean discharge Q_a	0.005 m^3/s
Minimum clearance discharge in the profile below the reservoir	Q_m = 0.001 m^3/s
Elevation of inactive storage level	300.20 m of relative height (not connected horizontally to state levelling)
Capacity of emergency spillway	Safe diversion Q100
Capacity of lower output Q_v	0.126 m^3/s
Slope and inner diameter of outlet	I = 2%, DN 300
Upstream facing of dike	Concrete panels
Downstream facing of dike	Vegetative, by grassing
Upstream slope of dike	1:3
Downstream slope of dike	1:2 – 2.5
Method of sealing of upstream face of dike	Dikep-proof sheet

5 Achieved Results

The complex processing of measurements and the evaluation of the state of the earth dike of the water reservoir Koberice calls for greater attention. The measurement has been conducted since 8/2006 regularly once a month; changes in the electrical conductivity of soil in the monitored profiles are evaluated. In Fig. 5 and 6, an example of evaluation of measured profile 2_3 is displayed (the distance of the imaginary centre of the given profile is 11.65 m from the edge of the crest of the emergency spillway) at all measured depths in the individual months, or at one depth in all measured profiles, and at one depth, 3.5 m, in all profiles in relation to time. In Fig. 7, the results of the present monitoring are processed in summary for all measured profiles and all depths.

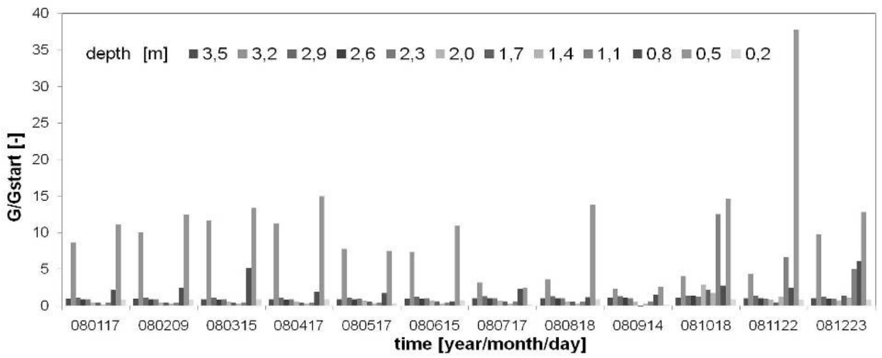

Fig. 5. Time development of the relative change in electrical conductivity *G* of the soil at depths of profile 2_3 such one example of earth dike monitoring in section 2_3, where it is possible to see climatic influences. The highest changes are in the level 0.5 m below the surface of the dike crest.

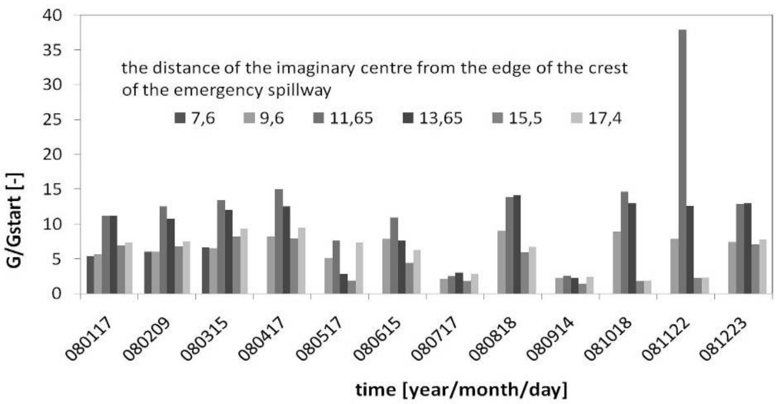

Fig. 6. Time development of the relative change in electrical conductivity *G* of the soil at depths of 0.5 m such one example of evaluation of earth dike monitoring at one depth for different distance of the crest of the emergency spillway.

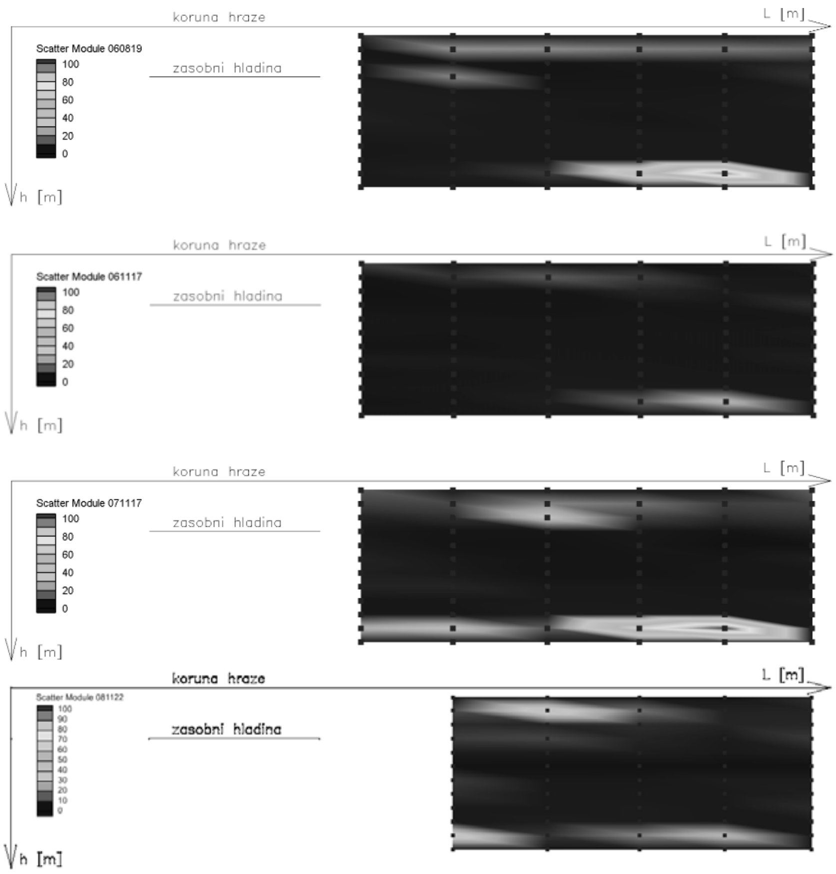

Fig. 7. The examples of the results of monitoring in summary for all measured profiles and all depths are shown. The results are from the August 2006, when the measurement started. This status of the dike body was taken as basic. In the November 2006 was carried out the reconstruction of the downstream face of this dike and at the other figures are shown results from the November 2007, 2008. In the figures are calculated relative changes of electrical conductivity. The black squares are monitoring points.

6 Evaluation

Electromagnetic methods, in which we can also include the method of electrical impedance spectrometry, are among wide-spread geoelectrical methods and are applied in various fields of human activity. For example, in archaeology, they were probably used together with resistivity methods around 1946; in medicine, the EIS method is often applied for the identification of malignant cells in tumour diseases. The principle of the given methods is the measurement and evaluation of the distribution of the electric potential or the gradient of the potential of the electric current. The EIS method can principally be classified as active, i.e. with its own source generating the pulsating field similarly as transient sounding or dipole electromagnetic profiling.

It can be stated that the measuring device Z-meter, including the designed measuring probes, has satisfied the expected requirements during the performed experiments. The rod probes did not affect the measured medium much by their dimensions and the suitable geometry of the experiment, which was an advantage in laboratory experiments. For measurements on real objects, it would be necessary to install different probes of a more rugged construction. Due to the fact that the vertically divided measuring probes longer than 1 m remain in soil even after the end of the experiment, it can be stated that they are non-invasive to the measured medium. The probes 1 m long or shorter can be removed from the measured medium after the end of monitoring. Because their diameter is 0.025 m, it is mostly not a problem to plug up the created hole (with mud of local material, bentonite, and the like), if necessary.

It can be stated that when respecting the above-given uncertainties of measurement and the phenomena taking place in the boundary layer at the contact of soil grains with the surface of the probe sensor – flowing water (with the different content and composition of dissolved substances, especially salts), choices of the measuring connection resulting from the character of measurement and other facts – the method provides very good results and findings on the phenomena running in soils when loaded with water.

Acknowledgements

The development of the EIS method and the measuring device in the application sphere is facilitated by addressing the international project E!3838 of the programme EUREKA. We would like to thank MEYS of the Czech Republic and the company GEOtest Brno, a.s. for their financial support provided for the solution of the project E!3838, without which the solution would be impossible.

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Appendix: The E!3838 Project

The international project E!3838 [9] was announced as an individual project in the euroenviron section in June 2006. Partners in the project are from Switzerland, Cyprus and the Slovak Republic and as contact members are GEOtest Brno, a.s. and the Faculty of Civil Engineering of Brno University of Technology from the Czech Republic. A new project partner has been Italy since 2008.

The project is based on the research, design and development of the automated system of the observation of soil moisture changes. To reach this goal – that non-electrical quantity progress investigation, an indirect non-invasive method taking advantage of the correlation between the observed quantity and the electrical quantities has been selected. The determination of electrical impedance changes of soil takes advantage of the method of electrical impedance spectrometry (EIS). These changes are caused by the loading of soil with water. The changes of soil moisture produced by the absorption of soil and (bank, induced, rainfall) water infiltration will be focused on. The complexity of the problem consists especially in the non-stationary flow of water through the unsaturated soil environment. The results of soil moisture changes and the monitoring of free water level movement will be applicable in the calibration of mathematical models and in the verification and localisation of soil cohesiveness defects, and possibly of other changes (application for agriculture, irrigation of sports areal, pollution transport, laboratory education and others).

The research, design, development and production of the automated system of the soil moisture changes are the main business of the Czech upholder – the project coordinator. The solution assumes the development of an instrument for impedance measurement, which is a multi-channel, fully digital Z-meter device with the software for the system control and evaluation of results and a system of wireless data transmission. This system is tested in SK, IT and is prepared for CH. The suitable localities for monitoring were also selected, three of them in the Czech Republic, one in Slovakia, one in Switzerland and one in Italy. The colleagues from Cyprus are still included in the parties interested in the project. Their cooperation in the solution of the given issue develops in the theoretical field of the creation of processing software for a particular task being solved in the Cyprian conditions.

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Hydrologic Inputs Related to the Irrigation in Vojvodina Province

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Abstract. Vojvodina Province is characterized of a continental climate with pronounced annual variability of air temperatures, as well as the others climatic elements on which depends the soil water regime. The main reason why irrigation should be developed in this region is the phenomenon of the climate is coming increasingly arid. Records of lower precipitation as well as higher air temperatures and evapotranspiration support this fact in recent years. Analysis of basic climatic data revealed that the dry years were more common for the period after 1981. Calculated water balance indicates that the total water amount using by evapotranspiration during growing season is bigger than total amount of precipitation in this region. These results point to fact that, in agroecological condition of Vojvodina region, quantity of precipitation without irrigation is not sufficient for water requirements of crops.

Keywords: Irrigation, precipitation, evapotranspiration, droughts, water balance

1 Introduction

The Vojvodina Province is northern part of the Serbia, which covers the area of 21.533 km^2. It is predominantly agricultural region with approximately 1.780.000 ha arable land. Agriculture is a basic section of economy. In respect of natural conditions the Vojvodina Province is the most productive agricultural region in Serbia. Vojvodina Province is characterized of a continental climate with pronounced annual variability of air temperatures, as well as the others climatic elements on which depends the soil water regime. The paper deals with the role and the state of meteorological and hydrologic inputs required for the planning and conducting of irrigation in Vojvodina Province. The attention is directed towards the fact that there is a lack of water in periods of droughts and low waters. Due to favourable natural conditions the region of Vojvodina Province has great possibilities for agriculture with irrigation. The main reason why irrigation should be developed in this region is the phenomenon of the climate is coming increasingly arid. Records of lower precipitation as well as higher air temperatures and evapotranspiration support this fact in recent years. Drought is one of the most harmful events, which in many parts of the world endangers the existence of people and causes enormous damages to various branches of economy. The droughts that have occurred in Vojvodina Province in recent years were of dimensions of an elemental catastrophe in respect of agricultural production. They were mainly a consequence of the shortage in rainfalls and/or their unfavourable time distribution. Drought is manifested as a shortage of moisture in the soil, especially in the summer months, when evapotranspiration is most intensive. The amounts of water needed by a crop it will mostly depend on the regional climate, nature of the crop species, and the stage of its growth. The fact is that in agroecological condition of Vojvodina region, quantity of precipitation without irrigation is not sufficient for water requirements of crops. This naturally leads to crisis in traditional farming, solution of which involves the application of irrigation. The central challenge facing irrigated agriculture today and in the foreseeable future, not only in our country but in world too is how to produce more food with less water. Water is essential for irrigation purpose, but its indiscriminate use can lead not only to shortages, but also to the deterioration of crop yields and soils. It is hence vital to ensure that it is applied as effectively as possible in order to reach sustainable. Irrigation system management should be careful organized because of rational exploitation of water-air regime of agricultural soil according to requirements of optimal crop development. It is necessary to apply only such amount of water that the crops need.

2 Droughts in Vojvodina Province

Drought with its characteristics is the phenomenon of very complex properties. Either single component or a number of components can describe it. Drought analyses in Vojvodina Province were investigated by many authors. Some of them deal only with precipitation, but the others investigate water balance. The results of complete analysis of the stochastic process of extreme dry weather intervals during growing season at 22 meteorological stations in Vojvodina Province show that the part of the growing season with the highest probability of having the longest extreme rainless period refer to the period of the second half of August and September. Periods of no rainfalls have tendency of increasing from south-west to north-east. The analysis included all available data on extreme dry weather intervals, which are defined as the upper extremes of intervals of no rainfall longer than 15 days [1], [2], [3], [4]. An analysis of probability of occurrence of minimal precipitation on the territory of Vojvodina found that all precipitation below the Vojvodina average which occur once in five years or rare, causing a drought in hydrologic year or in its seasons [5]. In the period of 41 years taken for the analysis, even in 90% of them there was smaller or greater water shortage, i.e. a drought of the different degree was observed [6]. Also, 32% drought years are obtained by analysing annual precipitation sum in Vojvodina during multiyear period and 53% by analysing precipitation sum during growing period [7]. Amount and distribution of precipitation were analysed and it found that hydrological 1992 year was extremely dry and because of that the yield of field and vegetable crops were reduced [8]. Drought is manifested as a shortage of moisture in the soil, especially in the summer months, when evapotranspiration is most intensive. At the basis of calculated water balance for maize, sugar beet and soybean, for 11 meteorological stations, it was concluded that total water amount using by evapotranspiration during growing season is bigger than total amount of precipitation in Vojvodina. All these are pointing out to the fact that under present climatic conditions in Vojvodina an effective and stable agricultural production is possible only by applying crop irrigation [9]. Three dry years are separated during period of 39 years for the meteorological station of Rimski Sancevi, according to ratio between precipitation and evapotranspiration for whole year. In this years their ratio are extremely unsuitable, it means that there ratio were less than 0.5. According to ratio between precipitation and evapotranspiration for the growing period 15 years are separated. In these years their ratio was unsuitable for agriculture production. Increasing of the ratio between precipitation and evapotranspiration for whole year as well for the growing period is obtained according to linear trend function. There were 15, 23 and 14 dry years according to index of aridity by De Martone, rain factor by Lang and hydrotermic coefficient by Seljaninov. These analysis and analysis of precipitation and other climatic elements showed more frequency of dry years after 1981 [10].

3 Analysis of Climatic Data

Table 1. Average monthly precipitation, P (mm), air temperatures, t (^{o}C), sunshine hours, n (hour), relative air humidity, RH (%), wind speed, u (m/s) for Meteorological station Rimski Sancevi, Vojvodina Province

Periods	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
P (mm)	35.2	32.2	37.1	51.2	58.9	87.4	69.2	57.3	44.9	54.4	49.9	46.2
T (^{o}C)	-0.3	2.0	6.4	11.3	16.9	19.7	21.4	21.0	16.7	11.5	5.8	1.4
N (hour)	66.8	99.7	154	181	234	259	287	276	202	164	86.1	59.7
RH (%)	86	79	71	68	67	70	68	69	73	76	83	86
U (m/s)	2.9	3.2	3.5	3.1	2.6	2.2	2.1	2.0	2.1	2.6	2.9	2.9

The climatic conditions of Vojvodina Province display the features of moderate continental climate [11]. Amount of precipitation (Table 1) often varies, especially during growing period. Coefficient of variation (C_v) ranges from 49.1% for June to 80.1% for October. June is usually month with the highest amount of precipitation in this area. Air temperature is stable climatic element whose coefficient of variation is higher during the winter due to low temperatures. It is important to consider that it ranges during growing period from only 5.6% in July to 14.4% in April. Mean sum of sunshine hours during year is 2069.3 hours and vary from 1711.4 hours to 2529.3 hours. During growing period average sum is 1438.9 hours and vary from 1170.1

hours to 1791.3 hours. Coefficient of variation (C_v) is the smallest for the August (12.9%). The values of relative air humidity are relative stable during analyzing period. Coefficient of variation (C_v) ranges from 3.3% for December to 11.1% for August. Relative air humidity is the climatic element with the smallest values of coefficient of variation. The highest values of wind speed are in March and the smallest during the summer. Coefficient of variation (C_v) ranges from 16.5% for April to 31.7% for January. Analysis of basic climatic data revealed that the dry years were more common for the period after 1981. All criteria that have been used for determination of dry years proved that. Also, after that period climatic changes are caused with reduced precipitation, relative air humidity, higher air temperature and sum of sunshine hours [10].

4 Reference Crop Evapotranspiration

Water has always been essential to man's life. One of the largest consumers of water is agriculture. In order the irrigation measures could give the expected results it is necessary to determine, as exactly as possible, the necessary amounts of water ensuring a normal crop growth. Smaller amounts than the necessary ones do not give the expected results, whereas the excessive water may cause certain problems and undesirable consequences (overmoistured soil, secondary salinization). There are several irrigation factors that can result in significant improvements in the use of agricultural water. The determination of crop water requirements (potential evapotranspiration) is of major importance in providing desirable irrigation management in arid and semiarid climates. Estimating crop water requirements can be achieved by several procedures. The most reliable of these procedures are based upon the use of climatic data, since it is difficult to obtain accurate field measurements. All this is pointing out to the importance of choosing the right procedure for establishing the crop water requirements, as well as the amounts of water to be used for irrigation. Prediction methods for crop water requirements are used owing to the difficulty of obtaining accurate field measurements. Potential evapotranspiration from different crops can be estimated from reference crop evapotranspiration, ETo and established crop coefficient [12]. There are numerous equations that require meteorological data for estimating ETo. The most reliable procedure for estimating ETo should provide consistent and reliable results and require a minimum amount of data and computation. The comparison of two modified Penman's methods for estimating ETo using climatic data from Rimski Sancevi is carried out. Estimates of ETo determined by these methods were compared to the Pan Evaporation method. The reference crop evapotranspiration was calculated by the appropriate computer program CRIWAR 2.0 [13]. CRIWAR 2.0 calculates the crop irrigation water requirements of cropping pattern in an irrigated area. Calculation of the reference crop evapotranspiration, ETo by two alternative methods: the FAO Modified Penman Method and the Penman-Monteith Method is part of this simulation program. The analysis was carried out on the basis of the available monthly values of meteorological elements for the series of 36 years. Investigated area was at Rimski Sancevi in South Backa region, Vojvodina Province, located on latitude of 45.2 degrees north and altitude of 86.0 m above sea level. In this condition growing season is April 1 - September 30. The long-term and regular observations of average air temperature, precipitation, sunshine hours, relative air humidity and wind speed are used. Obtained results were compared to the Pan Evaporation method [12] as a standard for evaluating the reliability of the different equations (Fig. 1). The evaporation on the evaporator of Class A is not being measured all over the year, but only from April to October, so that all comparisons were done for these months as well as for growing period. The values of reference crop evapotranspiration are very changeable from year to year. It is concluded on the basis of calculated values for every year during observation period. The maximum values of reference crop evapotranspiration are approximately 30% bigger than corresponding minimum values for each method. Average values of reference crop evapotranspiration during growing season are approximately 80% of corresponding yearly value.

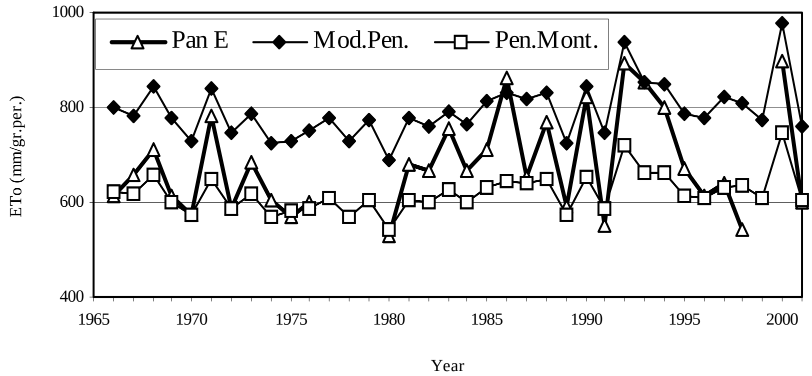

Fig. 1. Reference crop evapotranspiration ETo (mm) during growing period for Meteorological station Rimski Sancevi, Vojvodina Province

The mean monthly values of the ETo during the analyzed period are given in Table 1. Obtained results of reference crop evapotranspiration indicate to maximum value in July and minimum in September for all methods during growing season. The values of reference crop evapotranspiration increase from the beginning of growing season to July and decrease from July to September (Fig. 2). It is confirmed for all methods on the average of 36 years.

Table 2. The average month values of reference crop evapotranspiration ETo (mm), for Meteorological station Rimski Sancevi, Vojvodina Province

Month Method	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	IV-IX
Modify Penman	15.6	27.4	61.6	96.0	141.2	155.5	168.2	144.8	86.9	50.8	22.0	13.6	792.7
Penman-Monteith	12.1	21.3	47.4	73.8	108.9	120.9	131.6	114.2	69.9	40.4	17.5	10.6	619.2
Pan-Evapo.	-	-	-	77.7	109.5	117.6	139.0	137.8	93.4	52.8	-	-	616.7

The results of the above analysis indicate best agreement between Penman-Monteith. Method and results obtained on the evaporator of Class A for the growing period. The deviation of predicted ETo values from the pan values (Fig. 1) was dependent on year and the respective equations. Also, it can be concluded that higher values of ETo obtained on the evaporator of Class A are closer to the FAO Modified Penman Method, whereas, a small values signifies drastic disagreement. Compared to Penman-Monteith Method there was evidence that the FAO Modified Penman Method over-predicted the reference crop evapotranspiration. The monthly estimates of ETo have been plotted versus the pan method (Figure 2) to provide a visual comparison of the two different methods. This analysis showed close agreement between Penman-Monteith Method and results obtained on the evaporator of Class A from the beginning of the growing period to July. From August to October better agreement with the FAO Modified Penman Method are found [14].

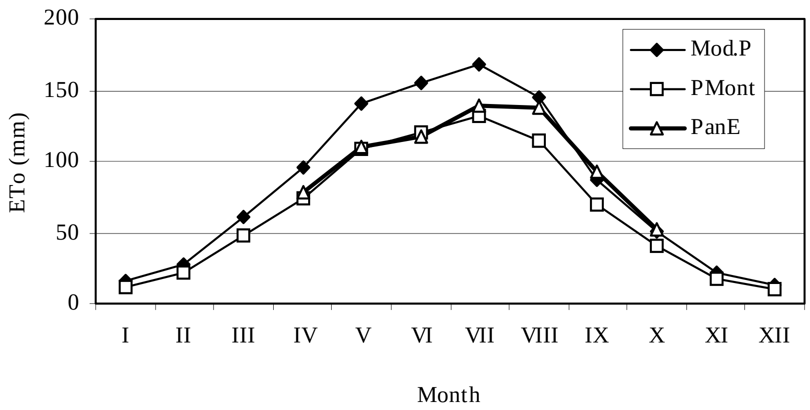

Fig. 2. Average month values of reference crop evapotranspiration ETo (mm), for Meteorological station Rimski Sancevi, Vojvodina Province

5 Crop Irrigation Water Requirements

Table 1. The mean month values of crop evapotranspiration, ETc, and total crop irrigation water requirements, ETc-Pe, for Meteorological station Rimski Sancevi, Vojvodina Province

Months	ETc(mm)								ETc-Pe
Crops	IV	V	VI	VII	VIII	IX	X	Sum	(mm)
Maize	-	85	131	183	151	41	-	591	371
Sugar beet	39	95	151	184	156	78	10	713	448
Soybean	-	87	146	177	142	26	-	578	362

The crop irrigation water requirements consist of two components: potential evapotranspiration (crop water requirements), ETc, minus the effective precipitation, Pe. Effective precipitation as used in CRIWAR is the part of the total precipitation that replaces, or potentially reduced, a corresponding net quantity of required irrigation water. Calculation of the water amounts needed for irrigation was carried out for three field crops - maize, sugar beet and soybeans. Investigated area was at Rimski Sancevi, Vojvodina Province [9]. In this condition growing season are 140 days for maize, 180 days for sugar beet and 135 days for soybeans. The mean month values of potential evapotranspiration, ETc, and total crop irrigation water requirements, ETc-Pe, for maize, sugar beet and soybeans during their growing period are presented in Table 3.

6 Conclusions

Under the present climatic conditions in Vojvodina Province an effective and stable agricultural production is possible only by applying crop irrigation. The main reason why irrigation should be developed in this region is the phenomenon of the climate is coming increasingly arid. Records of lower precipitation as well as higher air temperatures and evapotranspiration, support this fact in recent years. Analysis of basic climatic data revealed that the dry years were more common for the period after 1981. Calculated water balance indicates that the total water amount using by evapotranspiration during growing season is bigger than total amount of precipitation in this region. The values of water deficit are very changeable during years. These results point to fact that, in agroecological condition of Vojvodina region, quantity of precipitation without irrigation is not sufficient for water requirements of crops. This naturally leads to crisis in traditional farming, solution of which involves the application of irrigation. The central challenge facing irrigated agriculture today and in the foreseeable future, not only in our country but in world too, is how to produce more food with less water. Water is essential for irrigation purpose, but its indiscriminate use can lead not only to shortages, but also to the deterioration of crop yields and soils. It is hence vital to ensure that it is applied as effectively as possible in order to reach sustainable. Irrigation system management should be careful organized because of rational exploitation of water-air regime of agricultural soil according to requirements of optimal crop development. It is necessary to apply only such amount of water that the crops need.

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100-year Flood Event Scenario and Flood Risk Assessment for Uh River at Lekarovce (Slovakia)

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Abstract. In this paper the analysis of the flood regime of the Uh River at Lekarovce station was done. In the first part we reconstructed the series of annual maximum discharges Qmax of the Uh River at Lekarovce station based on water levels of the Uh River in stations Lekarovce (Slovakia) and Uzgorod (Ukraine). The reconstructed series was used for assessment of the N-year design discharges. Using the reconstructed shape of the November 1992 flood we created the 100-year flood scenario for the Uh River at Lekarovce station. The last part of the paper deals with the flood risk assessment of the Uh River at Lekarovce. The result of this study shows the decrease of water accumulation in the Uh River basin and increase of the catastrophic flood risk in this area. By treaty with Hungary, the Bodrog flows at its outlet on the border are limited. To cope with this restriction under real flood conditions, additional storage is necessary on the Ukrainian part of the basin. Rising or reconstructing the protective bunds is not a definite solution.

Keywords: Uh River, flood regime, 100-year flood scenario, flood risk assessment

1 Introduction

The catastrophic July 2008 flood in Ukraine (Dniester River basin) attracted our attention also to the Uh River basin, even that it was only marginally exposed to the rainfall activity.

Although the development and operational use of non-structural measures, such as flood forecasting and warning systems, represents one of the effective flood protection measures, the structural means (flood protection, levees, flood control reservoirs) are of great importance, too [14]. Particularly in the upper parts of basins or smaller basins, where the elapsed time between detection of the flood cause (heavy precipitation), and its consequence (flooding) is short and not sufficient for effective protection activities (evacuation, etc.).

In the Bodrog basin (Fig. 1), in both its parts (Slovakia, Ukraine), so far no rainfall-runoff forecasting model is in operational use. As to the structural flood protection measures, considerable differences between these two parts exist. In Slovakia, the lowland river sections are protected by levees (bunds) with elevation mostly lower or equal to 100-year water level. On rivers Ondava and Laborec reservoirs are constructed with storages for substantial reduction of the flood peaks.

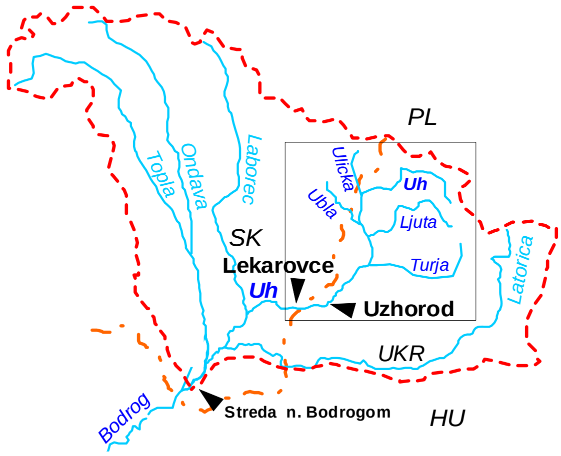

Fig. 1. Scheme of the Bodrog River basin

In addition to these, two smaller storages exist as polders (dry reservoirs) in the lowland part, which can be utilized in case of extreme emergency.

On the other hand, neither such storages nor reservoirs exist in the Ukrainian part of the basin. Protection of the basin lower parts is comparable with that in Slovakia.

Such system does not provide a safe protection against the extreme flood events. Already in 1985 Dzubak [4] pointed out that by damming of the riverbed on the Ukrainian and on the Slovak territory the Uh River flood threat increases. This has been documented during several historical events (summer flood on the Uh River in 1998 the last) when on several spots the protection bund had to be breached intentionally in order to eliminate flood hazards downstream.

Aims of this contribution are following:

1. Reconstruction of the Uh Qmax series at Lekarovce gauging station, on the base of the Lekarovce and Uzhgorod water stages;
2. Determination of the N-years design discharges and determination of the 100-year flood hydrograph scenario, for the Uh at Lekarovce;
3. Flood risk assessment of Uh River at Lekarovce.

2 Uh River Basin and Data Description

The Uh River basin is one of the five large basins forming the Bodrog River basin (Topla, Ondava, Laborec, Uh and Latorica).

The Uh River springs in Ukraine under the Uh Pass. The basin area of Uh is 2790.9 km^2 at the confluence with Laborec River. The length of the river is 132.4 km, out of which 19.6 km are on the territory of Slovakia. The major part of the basin is in Ukraine. Upper parts of the rivers are of a pronounced mountainous character (slopes of the river channels 15–20 m/km), their lower parts belong to the lowland with slopes 2–0.3 m/km, or even less ([18]; [21]). The hydrological conditions of the Eastern Slovakia were studied e.g. by [20]; [9]; and [1].

2.1 Data

For the analysis of the flood regime of the Uh River at the station Lekarovce (river km 16.6; area 1989.41 km^2): maximum annual discharge (Qmax) of individual water years during Nov 1930–Oct 2006 was used.

The Uh water level observations at Lekarovce started in 1930. During the World War II between 1939 and 1945 Lekarovce belonged to Hungary, and the observations 1941–1950 are missing. The extreme discharges Qmax of this period (derived according to Uzhgorod station) were published by Dzubak [4].

2.2 From the Uh Flood History

Conditions of the flood wave creation in the Uh River basin are highly unfavourable. A flood comes very fast as well as changes of water levels (over 7 m in the course of 3 hours). The main Uh tributaries in Ukraine (Turya and Lyuta, Fig. 1) have similar travel time as the Uh River, and the coincidence of the flood waves of individual tributaries occurs very often.

The formation of the flood wave on the Latorica River in the past had different character (longer travel time). The flood wave on Uh usually overtook the flood wave on Latorica by several days. But later, especially due to the Latorica River embankment, the flood waves become faster and are coinciding with flood wave of the Uh River on Slovak territory ([15], [7], [13], [6], [10], [16], [11], [8]). According to historical records, among the most famous floods in the whole Bodrog basin belong those August floods in 1813, 1893, and 1913 [11]. Sutor *et al.* [21] refers that the highest evaluated Uh flood is the one from the end of October 1926. At that flood the peak discharge in Uzhgorod was 1580 m^{3}s^{-1}, and the estimated one in Lekarovce 1200 m^{3}s^{-1}. The decade 1974–1983 was rich with floods over 1000 m^{3}s^{-1}; they occurred in 1974, 1979, 1980, and 1982 (Fig. 2).

The Uh at Lekarovce flood distribution since 1950 indicates a prevailing winter flood regime (Fig. 3). Floods occur mostly in the winter season (November – April), 82% in the average of the highest flows. They occur mostly in the months of March and December. However, such peak flows distribution throughout the year does not mean that the highest flood must occur in month of the highest flood frequency. In contrary, the highest historical floods often occur during the summer season. To such belong highest floods of the years 1813, 1893, and 1913, which influenced the whole Bodrog River basin simultaneously. By chance, it happened in August, the month with lowest frequency of the flood occurrence.

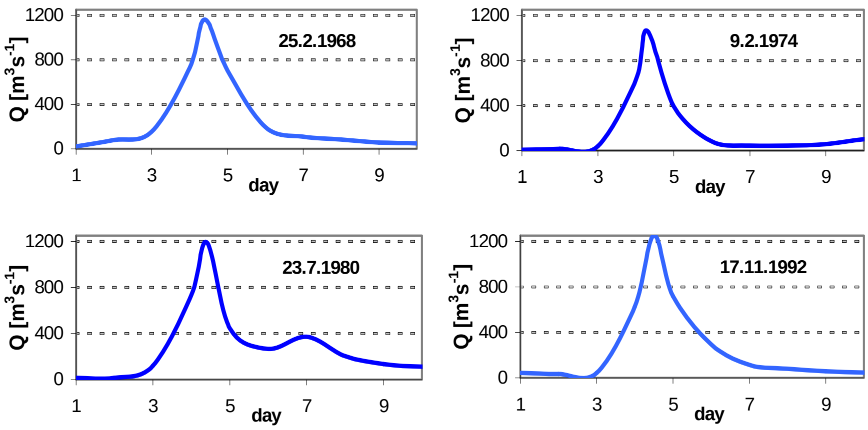

Fig. 2. Recorded flood hydrographs of the Uh River at Lekarovce

The highest recorded Uh flood at Lekarovce over last twenty years was the one of 17 November 1992 (Figs. 4 and 5). It was a typical heavy rainfall flood. The precipitation amount over the Uh basin was app. 100 mm within 24 hours. This caused the highest so far observed water level at Lekarovce gauge 1090 cm [21]. At such water level in Lekarovce in today conditions, already the discharge of 960 m^{3}s^{-1} overtopped the protective embankment (bund). This indicates an insufficient riverbed capacity. Peak flow at Uzhgorod reached 1280 m^{3}s^{-1}. The peak at Lekarovce reached 870 m^{3}s^{-1}. The flood wave volume passing through the Lekarovce cross section reached the volume 114 million m^3 that overtopped the bund was 18 million m^3. Without the bund overtopping, the estimated flood peak at Lekarovce would reach 1250 m^{3}s^{-1}.

After the July 1998 floods in the Torysa and Mala Svinka basins, another flood situation developed over the territory of eastern Slovakia at the beginning of November 1998. On the Uh River at Lekarovce water level has risen by 8 meters within 18 hours, to a water stage of 1057 cm, corresponding to discharge of 820 m^{3}s^{-1}. Water started to overtop the embankments at the road bridge in Lekarovce, as well as the protective bund on the state frontier with Ukraine.

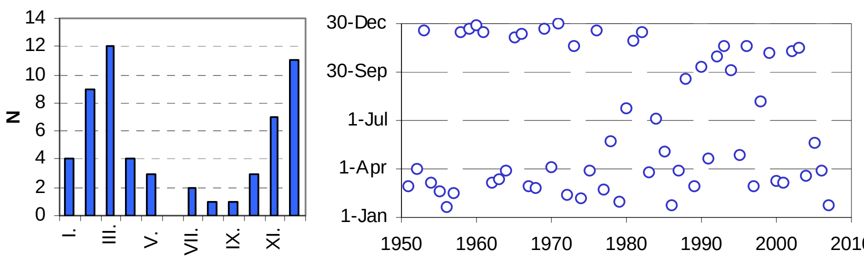

Fig. 3. Number of the flood N in a given month (left), and the day of the flood occurrence (right), Uh at Lekarovce within 1951–2007

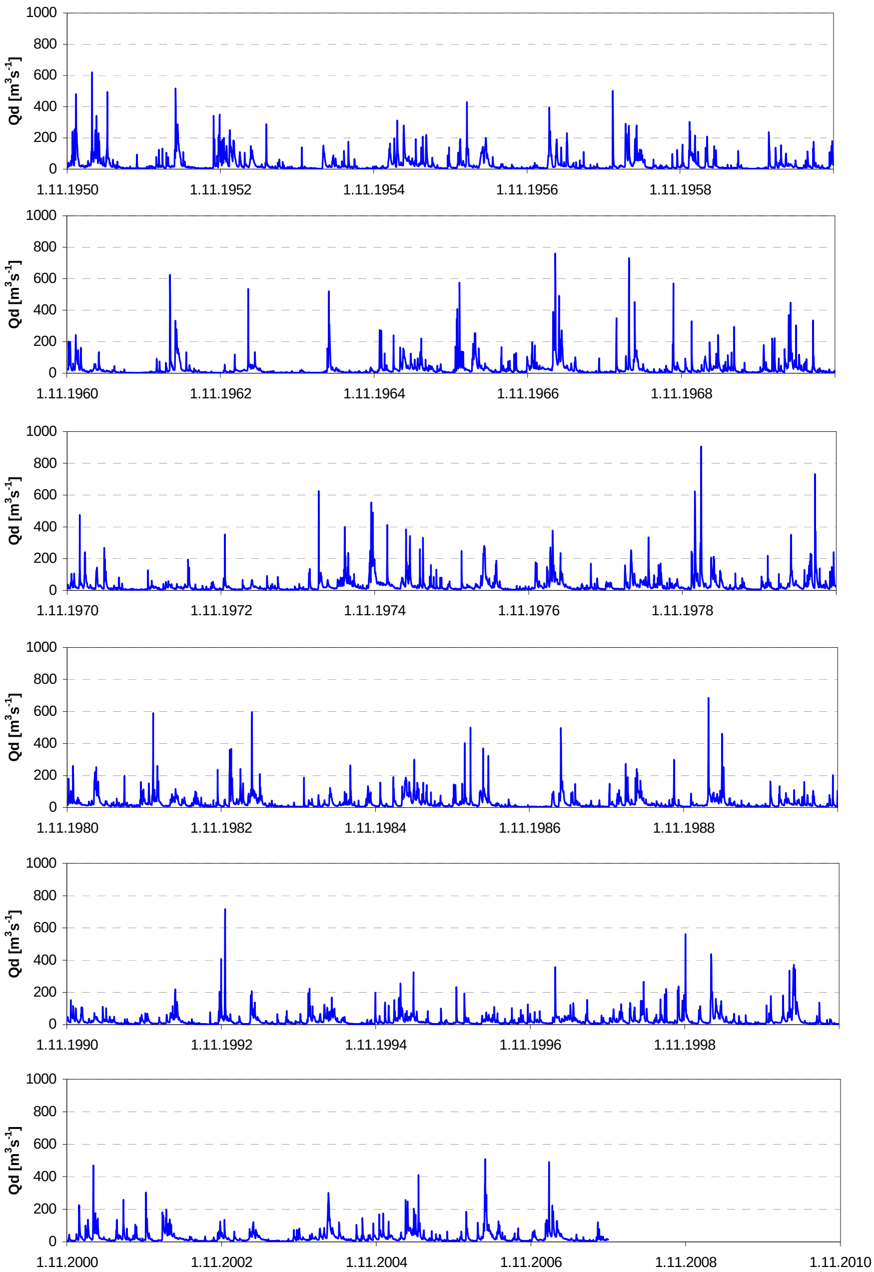

Fig. 4. Observed daily discharge (Q_d) in Uh River at Lekarovce gauging during November 1950–October 2007

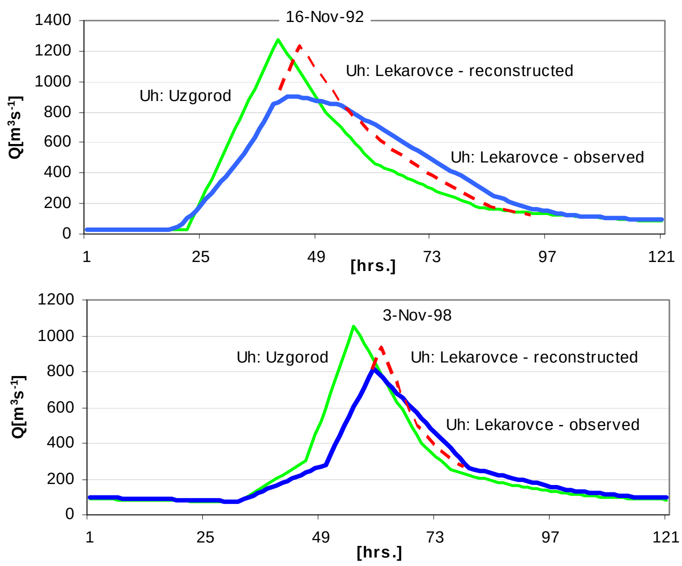

Fig. 5. Uh River hourly flood hydrographs in 1992 and 1998, Uh: Uzhgorod (grey line), Uh: Lekarovce- observed flows (black line), and Lekarovce- reconstructed flows (dotted line)

This situation called for an intentional bund breaching. By blasting the bund, two breach openings were created in the left hand protection bund, through which the Uh water was released into a drainage canal system to the Cicarovce pumping station. This protected neighboring communities against flooding. The reconstructed flood peak was of about 920 m^3s^{-1}. The low Uh River channel discharge capacity called for its later reconstruction in the river section between Lekarovce and Pinkovce.

After a heavy storm rainfall in July 2008, a catastrophic flood occurred in a nearby Dniester basin, to the north of the Uh River basin. According to the preliminary estimates, it was the heaviest flood in the region in the last 100 years. Fortunately, the Uh basin was not hit fully by the rains and no important flood occurred on the Uh River.

3 Frequency Analysis and Design Values

Frequency analysis provides information about the magnitude and frequency of selected discharges. Frequency commonly is expressed in terms of exceedance probability p or as a recurrence interval T in years.

Kasparek [12] recommends using the longest available measured data series for calculation of the extreme discharge, despite of the possible runoff formation changes. In case of the mean annual discharge he recommends the appropriate reduction of the time series used for calculation of the design values.

Flood-frequency information is important for defining flood-hazard areas; for managing floodplains; and for designing bridges, culverts, dams, levees, and other structures. Flood-frequency analysis commonly is performed on records of annual maximum peak discharges Q_{max} collected systematically at streamflow gauging stations, (Bulletin, 1982).

In this work we tested 11 types of distribution, e.g.: Log-normal distribution, Log-Pearson III type distribution, Erlang distribution, Gamma distribution, Logistic distribution, Weibull distribution, etc for estimation of distribution of Qmax time series. To verify whether specified distribution types could adequately represent the observed data, the χ^2 test, Kolmogorovov-Smirnov test (K-S test) and Anderson-Darling test (A-D) can be used. The best results were obtained for Log-Pearson III type distribution (Fig. 5). Therefore, it is recommended to use Log-Pearson III type distribution.

The probability P of the individual empirical mean annual discharge Q_{max} was estimated according to:

$$P=m/(n+1) \quad (1)$$

where: m is serial number of the element in decreasing order, and n is number of elements.

For the probability of Q_{max}, the following formula is used historically in Slovakia ([20], [16], [17]):

$$P = 1 - e^{-1/T} \quad (2)$$

which is based on peak over threshold (POT) method.

Return period T for Q_a is calculated according to formula:

$$T = 1/P \quad (3)$$

and for Q_{max}

$$T = -1/(\ln(1-P)) \quad (4)$$

Because of frequent breaks of the flood protection levees between stations of Uzhgorod and Lekarovce, the Lekarovce Qmax discharges cannot be used for indirect determination of the extreme flows. For this reason, we used the reconstructed Lekarovce time series (according to Uzhgorod Q_{max} time series) for determination of the T-years flow estimates (Fig. 6).

Table 1. T-year discharge of the Uh River at Lekarovce - reconstructed according to Uzgorod [$m^3.s^{-1}$], 1947–2005, log-Pearson III theoretical distribution

P	0.5	0.2	0.10	0.02	0.01	0.005	0.002	0.001
T-year	1.4	4.5	9.5	49.5	100	200	500	1000
	596	895	1089	1496	**1660**	1820	2026	2179
5% CI	534	794	953	1271	**1396**	1516	1667	1778
95% CI	667	1030	1282	1842	**2077**	2310	2615	2845

Therefore we can conclude that the 100-year discharge of Uh is about 1660 (in interval 1396–2077) m^3s^{-1}, the 200-year discharge is about 1820 (1516–2310) m^3s^{-1}, and 1000-year about 2179 (1778–2845) m^3s^{-1}, respectively (Table 1).

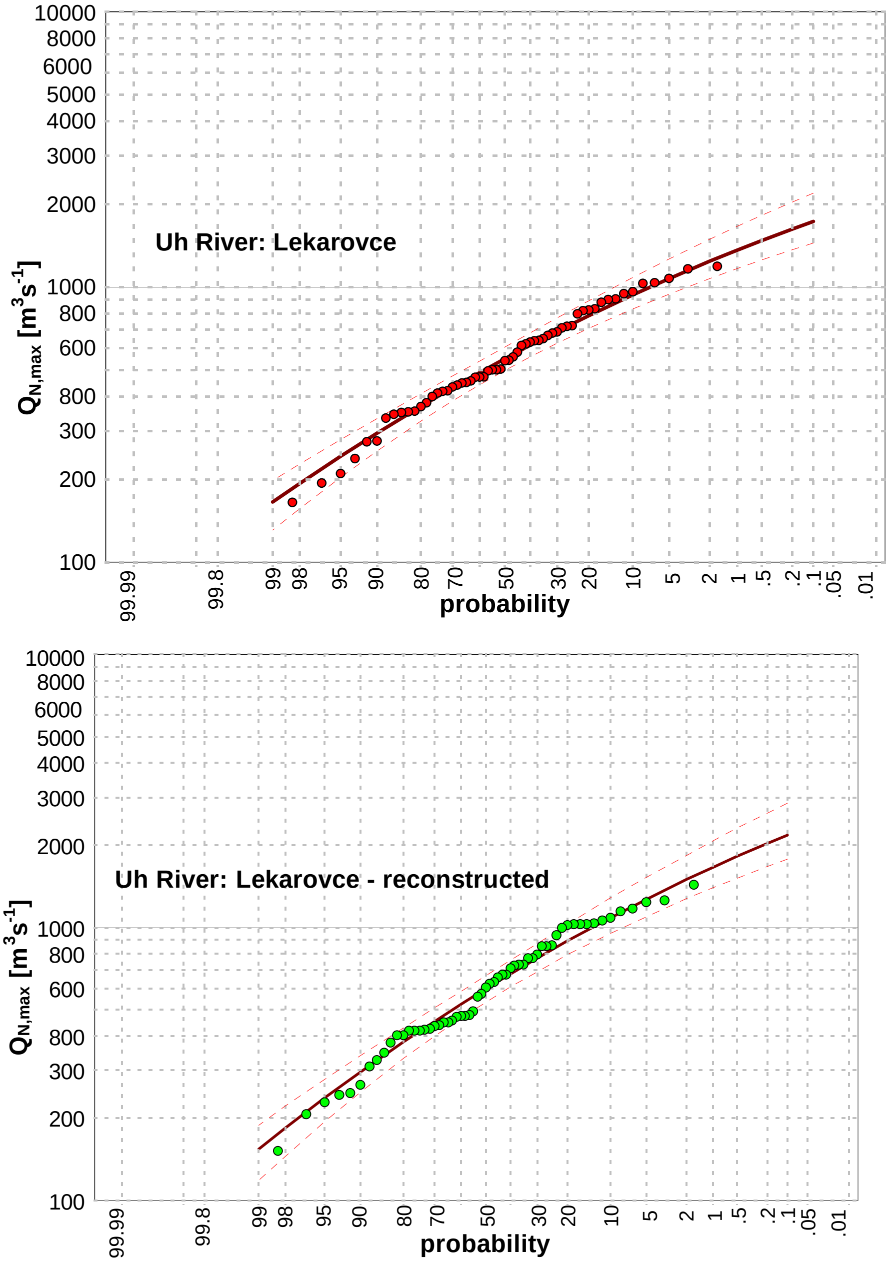

Fig. 6. Comparison of empirical and theoretical log-Pearson type III distribution curve of the annual maximum discharge Q_{max}, period 1947–2005, for Uh River: Lekarovce observed and reconstructed Q_{max} series (1947–2005), 5% and 95% confidence limits.

3.1 Scenario (Design) 100-year Flood

Scenario of the 100-year flood hydrograph we determined on base of the reconstructed most extreme flood of the last 20 years, - the one of November 1992 (Fig. 7). The observed hourly flows of the November 1992 flood were adjusted so that its peak equals to the 100-year discharge.

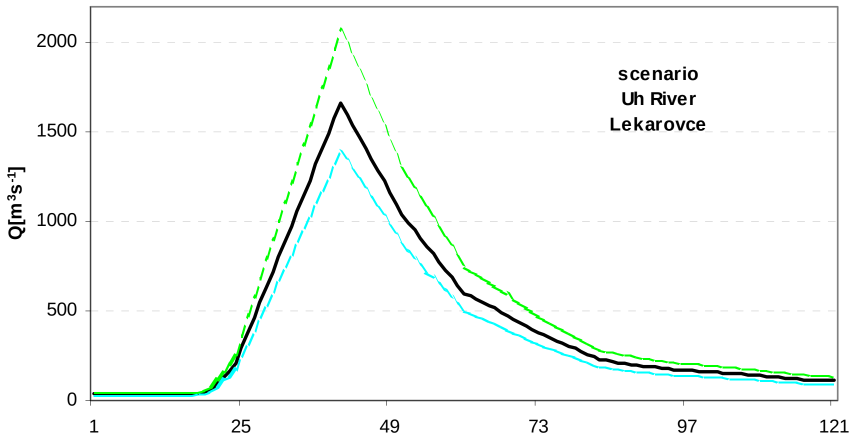

Fig. 7. Scenario of the 100-year flood: Uh River at Lekarovce, 5 and 95 % confidence intervals, hourly data

4 Flood Risk Assessment

Flood risk R is defined as the probability that one or more events will exceed a given flood magnitude within a specified period of N-years. Accepting the flow frequency curve to be accurately representing the flood exceedance probability, an estimate of the risk may be computed for any chosen time period (Bulletin 17b, 1982). Two basic approaches may be used to compute the risk: nonparametric and parametric methods. Parametric methods which use the binomial distribution require that the annual exceedance frequency be exactly known.

The binomial expression for risk estimation is:

$$R_I = \frac{N!}{I!(N-I)!} . p^I (1-p)^{N-I} \tag{5}$$

where: R_I is the estimate of the risk in N years with the exact I number of flood events exceeding a flood magnitude with annual exceedance probability p.

When I equals 0, equation (5) reduces to:

$$R_0 = (1-p)^N \tag{6}$$

where R_0 is the estimated probability of non-exceedance of the chosen flood magnitude in N years. From this, the risk R of one or more exceedance becomes:

$$R_{(1\,\text{or more})} = 1-(1-p)^N \tag{7}$$

For a 1-year period the probability p of exceedance (which is the reciprocal of the recurrence interval (return period) T for T>10), expresses the risk.

There is a 1 percent chance that the 100-year flood will be exceeded in a given year. This statement, however, ignores the considerable risk that a rare event will occur during the lifetime of a structure.

The frequency curve in Fig. 6 can also be used to estimate the probability of a Uh flood exceedance during a specified time period N. For instance, there is a 45.3% chance that the flood with annual exceedance probability of P=1% (e.g. P=0.01) discharge 1700 m^3s^{-1} will be exceeded one or more times in the next 60 years at Lekarovce gage.

5 Conclusions

In this paper the analysis of the flood regime of the Uh River at Lekarovce station was done. In the first part we reconstructed the series of annual maximum discharges Qmax of the Uh River at Lekarovce station based on water levels of the Uh River in stations Lekarovce (Slovakia) and Uzhgorod (Ukraine). The reconstructed series was used for assessment of the N-year design discharges. Using the reconstructed shape of the November 1992 flood we created the 100-year flood scenario for the Uh River at Lekarovce station. The last part of the paper deals with the flood risk assessment of the Uh River at Lekarovce. The result of this study shows the decrease of water accumulation in the Uh River basin and increase of the catastrophic flood risk in this area. The July flood of 2008, in the Uh neighbouring Dniester basin give a scenario what high daily precipitation can be in this region. At the Jeremca gauging station (Ukraine) during this flood, between 22 to 26 July 2008, following daily rainfall amounts were observed: 44, 47, 129, 47, and 84 mm, together 351 mm ([19], personal communication, 2008). Would this rainfall event move a little to the south, it would hit fully the Uh River basin.

By treaty with Hungary, the Bodrog flows at its outlet on the border are limited. To cope with this restriction under real flood conditions, additional storage is necessary on the Ukrainian basin part. Rising or reconstructing the protective bunds is not a definite solution. To determine the extent and location of this flood control storage, there is a need to simulate several critical rainfall-runoff flood scenarios by a suitable mathematical basin model [5]. Final results of such study might be a proposal of the system of reservoirs (storages) on the uncontrolled basin part for the optimum control of flood flows of the river flowing in its lower reach through densely populated land with intensive agriculture. At the same time, the rainfall-runoff model would be also a solid base for a coherent flood forecasting system of Bodrog on the Slovak and Ukrainian territory.

Acknowledgement

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Impact of the Municipal Landfill in Gdańsk-Szadółki on the Groundwater in Complicated Hydrogeological Conditions

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Abstract: The paper presents observations of groundwater quality in the surroundings of the municipal landfill in Gdańsk – Szadółki. Because of complex hydrogeological conditions, the landfill impact was assessed for every of the three indicated aquifers in reference to the groundwater flow direction. The most important are the observation results for the third aquifer which is locally used in this region. There are some symptoms of the landfill impact. The main useful aquifer for the Gdańsk region, separated from the three upper aquifers by a thick layer of impermeable deposits is not vulnerable for contamination from the landfill.

Keywords: Municipal landfills, groundwater protection, groundwater monitoring

1 Introduction

The municipal landfill in Gdańsk-Szadółki has worked since 1973. The wastes have been stored in the zone of former gravel-pit, situated a few kilometers from the town (Fig. 1). In the course of time the landfill developed extending to the area of 57 ha and becoming a well-managed landfill. Currently a new program of further landfill modernization and enlargement has started - new section of 12 ha will be added and some modernizing investments e.g. waste sorting station, composting plant will be introduced. Such a great storage yard is a potential source of groundwater pollution. This is why complex investigations concerning groundwater pollution hazard have been led in the zone of the landfill. There are 27 piezometers monitoring groundwater quality and groundwater level and also 2 points on Kozacki Stream flowing through the landfill area.
The aim of the research presented in the article is assessment of the landfill impact on groundwater and verification of existing monitoring system. The investigations were

based on rich geological and hydrogeological data and also in the part concerning groundwater quality - on numerous physical – chemical groundwater analyses. The data and investigation results are included in different documentations and reports. The number of studies and their range prove, that the influence of the landfill on the environment has been considered for many years. Dozens of boreholes were drilled on the landfill, some of them reaching even 70 m b.g.l. area, and hundreds of samples were taken for wide range of physical-chemical analysis.
Gathered data allow to assess current state of landfill influence on groundwater and to indicate probable course of processes in the future allowing to plan their control.

Fig.1. Location of the landfill

However, some important problems haven't been solved yet, owing to very complicated geological structure and hydrogeological conditions in the zone of the landfill and also due to complex nature of pollution migration in groundwater.

2 Hydrogeological Conditions

The area of the municipal landfill in Gdańsk - Szadółki is situated in the edge zone of the Kashubian Lake District. The folded surface of the terrain lowers from about 130 m.a.s.l. in the Otomin vicinity to 90–100 m a.s.l. in Kowale and Szadółki area. The landfill itself is elevated 100 – 115 m a.s.l. The hydrogeological conditions and geological structure were recognized by numerous drillings and were presented in different documentations. The studies show, that hydrogeological conditions in this

area are very complicated. It is the result of both: complex sedimentation conditions in Pleistocene and glacitectonic disturbance occurring in the edge zone of the upland. The observed complication degree of the upper part of the Quaternary deposits is unique even as for geological strata of the same age.
This hydrogeological complexity manifest itself by variable extends of aquifers and aquifuges.
Schematic view of the aquifers occurring beneath the landfill and in the landfill surroundings are shown in the cross-sections (Fig. 2)
Schematization of hydrogeological conditions in Quaternary deposits allow to indicate 3 upper horizons, and beneath them, under thick layer of aquifuge, the main usable aquifer for Gdańsk, continuing also on the area of Vistula River Delta [1], [2].

First aquifer (1). The aquifer occurs beneath almost the whole area of the lanfdill on the depth from 2 to 12 m. It is built of fine grained and silty sands. The thickness is variable and changes from less than 1 m to 6 m and in some places the horizon disappears. Groundwater table occurs 1,5 to 8,5 m b.g.l. And the flow direction is east-word. High values of hydraulic gradient suggest discontinuous nature of the aquifer or in some places indicate limited filtration parameters. The (1) horizon is recharged by direct precipitation. A part of groundwater from aquifer (1) recharges the horizon (2) percolating through boulder clays and in some places by direct contact of the aquifers.
The horizon (1) is the first link of the leachate contact with groundwater.

Second aquifer (2). It occurs 10 – 25 m b.g.l., beneath boulder clay series. It is composed of silty sands, fine- and middle-grained sands and it spreads beneath almost the whole area of the landfill. The thickness varies from 2 to over a dozen m and in some places is reduced to 0 m. The horizon is drilled in Otomin surroundings, but disappears to the East direction, in Kowale area. (Fig. 2) The aquifer is confined and the potentiometric surface is slightly lower than groundwater table from the horizon (1). Small differences between groundwater stabilization in the aquifers (1) and (2) indicate that the horizons are in hydraulic contact. So the aquifer (2) is under the influence of the landfill and the intensity of the contact depends on extension of inter-bedding aquitards and also on hydraulic conditions. Groundwater levels show, that the Kozacki Stream flowing through the landfill is a gaining stream and it drains both water bearing strata (1) and (2).

Third aquifer (3). The aquifer's depth varies from 30 to 70 m. It is separated from the upper aquifers by boulder clay and silts deposits of thickness from several to 40 m. An important fact is that the layer's thickness may be reduced to 0 in places, and thus the aquifer (3) could be in contact with the upper two. The thickness of the water bearing strata (3) varies from 20 to 40 m. Symptomatic fact about the aquifer is that hydrostatic pressure is very low and there are also zones were groundwater table, under atmospheric pressure, occurs. It's a proof of good groundwater flow conditions which was confirmed by well discharge tests and hydraulic coefficient investigations. The potentiometric surface indicates East-word direction of groundwater flow.
The aquifer (3) is a usable horizon – there are wells in Kowale capturing water from this aquifer. It is underlain by boulder clay series of the thickness reaching 50 m. The layer separates the water bearing strata (3) from the main usable aquifer for the

Gdańsk region (Fig.2). The cross-section shows that the aquifer is in places in contact with Miocene sandy series.

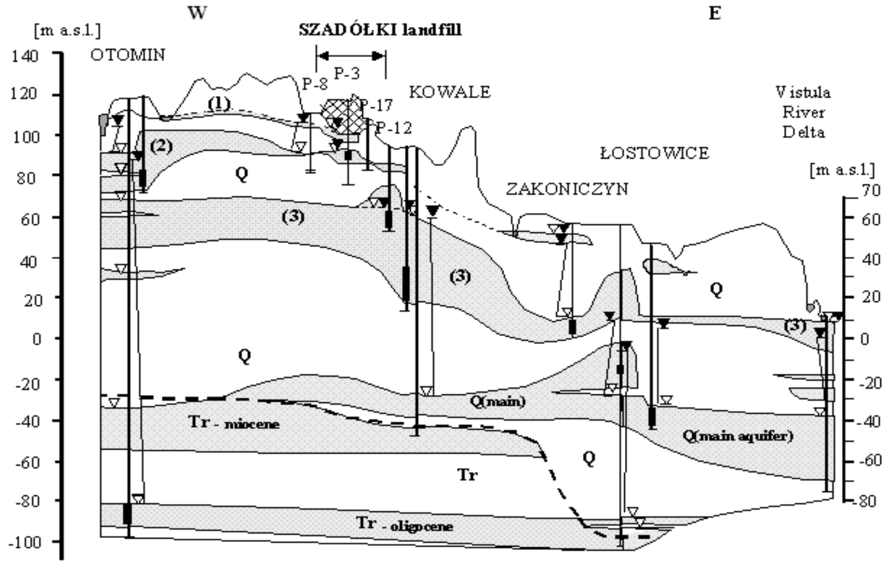

Fig.2. Schematic cross-section through the landfill from Otomin (Kashubian Lake District) to the edge of Vistula River Delta -on the basis of [2]

The variability of hydrogeological conditions in the zone of the landfill was also confirmed by electric resistance investigations led by geophysics specialists in 2007 [5].

3 Observations

Before the year 2002 observations of the landfill influence on groundwater were not systematic. However, during the geological and hydrogeological investigations many measurements and analysis were done and they make up a good point of reference for currently led systematic investigations in 27 piezometers.

The observation wells reach all the three aquifers: (1) – 14 piezometers, (2) - 7 piezometers, (3) – 5 piezometers. The piezometers are marked on the hydroizohypse map (Fig. 3).

From October 2003, the groundwater level has been measured four times a year and the same frequency concerned taking samples for physical – chemical analysis. The range of analysis has been diverse though. Every three months pH, electrolytical conductivity, Pb, Cd, Cu, Zn, Cr, Hg, TOC and sum of PAH were measureded; and every six months analysis were wider including also: hardness, alkalinity, oxidability, ammonia, nitrate and nitrite nitrogen, chlorides, sulphates, phenols, sodium, and potassium .

The observations of groundwater level indicate that in (1) and (2) aquifers the level shows only slight fluctuations - between 20 and 60 cm. In the third aquifer the groundwater level is very stable.

On the basis of systematic measurements it was possible to elaborate groundwater contour line maps for the aquifers (1), (2) and (3) [1]. The map for the (3) horizon is presented above (Fig. 3). The arrows indicate an approximate eastward direction of groundwater flow. Almost the same direction takes place in the upper aquifers. The groundwater level in (1) and (2) aquifers is similar and changes from about 110 m a.s.l. in the NW part of the landfill to about 90 m a.s.l. in the eastern part. In the aquifer (3) it is much lower and elevates about 64 – 65 m.a.s.l. which is visible in the presented map (Fig. 3).

4 Groundwater Quality Changes

The data concerning chemical composition of groundwater are very rich. Their range and frequency of sampling are described above. In order to assess the groundwater quality, the most significant pollution indicators were chosen, that is: electrolytical conductivity and chloride, sodium, potassium, ammonia ions. The choice was mainly based on study of the leachate composition and also on bibliography [3], [6]. The values of chosen indicators were analyzed in every aquifer separately, also with relation to groundwater flow direction. The piezometers were divided into 2 groups – located on the inflow direction and on the outflow side, so as to compare groundwater quality on both sides of the landfill. The quality assessment will also refer to hydrogeochemical background determined for the Kashubian Lake District [4] and for natural groundwater in Poland [7].

An exemplary table with chosen data for one piezometer is presented below (Table 1). Other tables with data wouldn't be quoted in the paper.

Table 1. Pollution indicators values in piezometer P-19C - aquifer (3)

determ	unit	04.11.04	30.03.05	22.06.05	12.09.05	24.11.05	22.03.06	12.06.06	13.09.06	22.11.06	13.03.07	12.06.07	11.09.07
conduct	μS/cm	370	345	1440	248	459	448	466	467	489	471	308	466
Cl	mg/dm^3	13,4	30,8		5,3		5		0,03		5,4		6,77
Na	mg/dm^3	9	12		20		9,7		8,88		8,56		7,96
K	mg/dm^3	2,12	9,2		11,2		2,9		2,45		2,68		3,08
N/NH4	mg/dm^3	0,51	0,82		0,14		0,29		5,8		0,35		0,32
PAH	μg/dm3	0,051	0,01	<0,01	<0,01	<0,01	0,02	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
TOC	mg/dm^3	7,8	16,34	7,53	<1	1,02	<1	48	6	4,6	<1	6,6	3,4

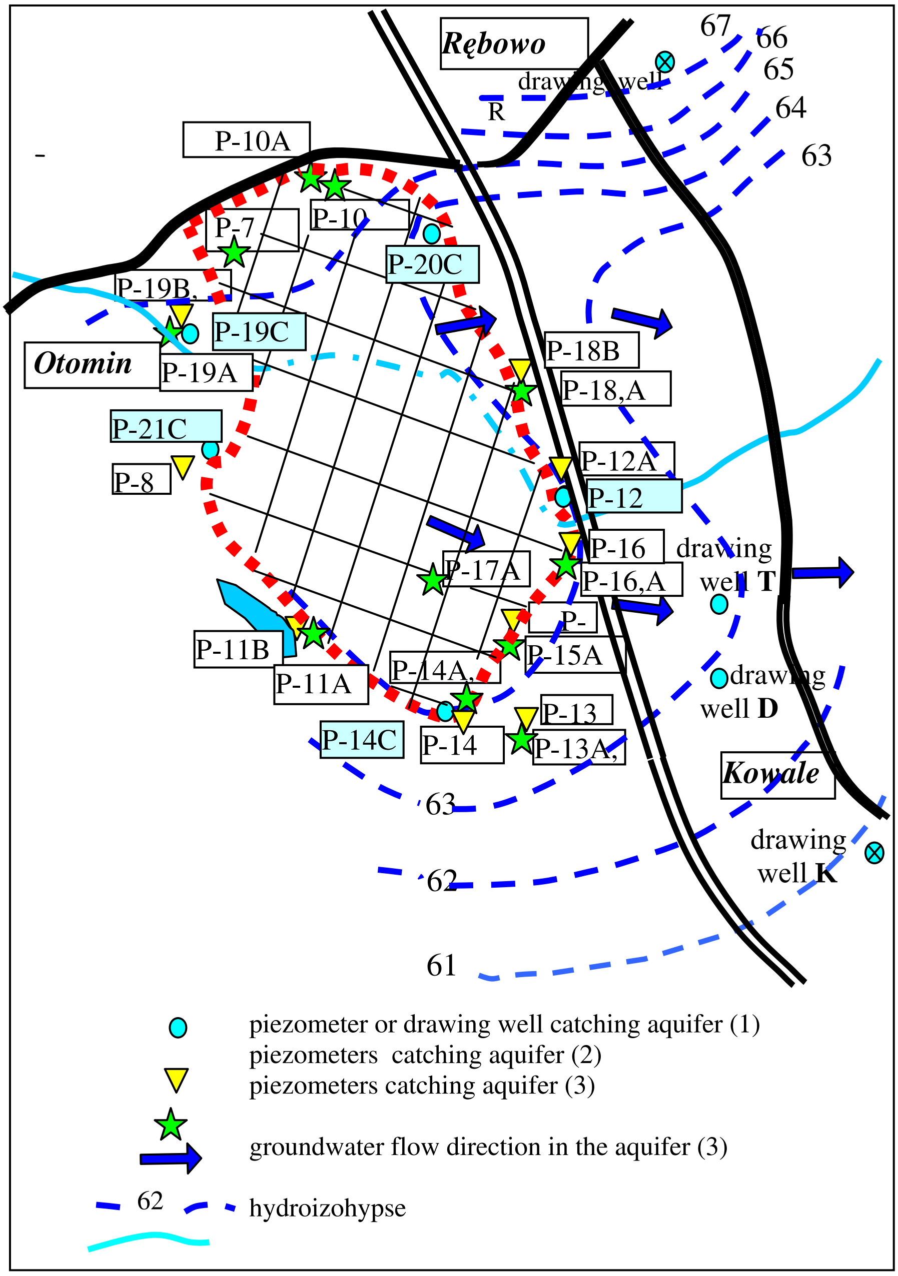

Fig. 3. Location of observation wells on the landfill area and map of hydroizohypse for aquifer (3,)- according to B. Kozerski

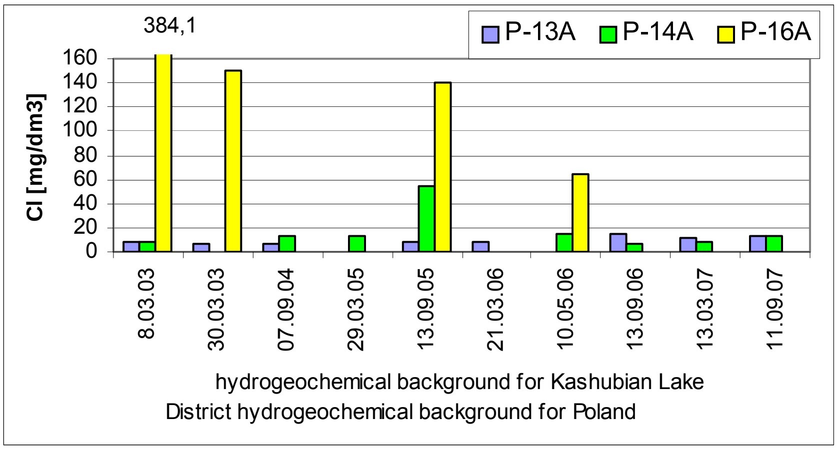

Fig. 4. Concentrations of chlorine ion in aquifer (1) on the outflow side of the landfill

Aquifer (1)

Investigation show that on the inflow side there is practically no influence of the leachate. But on the outflow side (P-13, P-14A, P-16A) contamination is evident, but rather slight. In piezometer P-16A values of all the indicators, except of PAH are elevated, e.g. conductivity value is: 1860 – 2216 µS/cm.

Chlorine ion concentrations are shown in the chart (Fig. 4). The maximum value was 384,1 mg/dm^3 in 2003.

Aquifer (2)

The most visible changes on the inflow side were observed in the piezometer P-11B. In 2004 electrical conductivity was 2465 µS/cm, and 1142 µS/cm, but in the following years – decreased to around 500 µS/cm. Other observation wells don't show any influence of the landfill. However on the outflow side the influence is evident. In observation well P-16 the concentrations of Cl^- Na^+, electrolytical conductivity exceeded the upper limit of hydrogeochemical background and show increasing tendency. In 2007 Cl^- concentration was 937 mg/dm^3, electrolytical conductivity 4987 µS/cm and TOC: 112 mg/dm^3.

Changes of chloride concentrations located on the outflow side of the landfill are presented in the Fig. 5.

Aquifer (3)

This aquifer will be characterized without reference to the groundwater flow direction. Small differences in groundwater level make it difficult to indicate the direction of flow on the landfill area. Outside the landfill the outflow is in direction E and ES.

Groundwater composition in (3) horizon differs from hydrogeochemical background of the Kashubian Lake District. In piezometers P-20C and P-21C chlorine ion concentration reach 668 and 227 mg/dm^3. Increased amounts of Cl^- were also stated in 2004, when the borehole was drilled. Such anomalies in Cl^- concentrations should be connected with the landfill influence. It was already said, that the impermeable layer separating aquifer (2) from (3) is probably discontinuous.

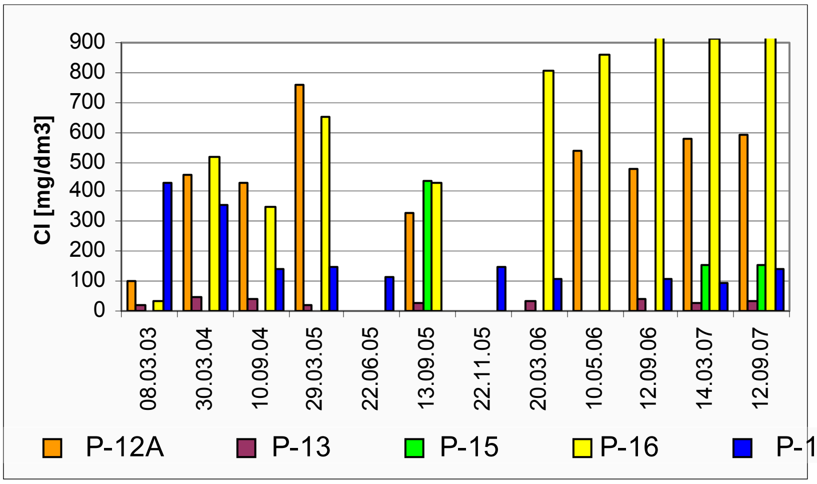

Fig. 5. Concentrations of chlorine ion in aquifer (2) on the outflow side of the landfill.

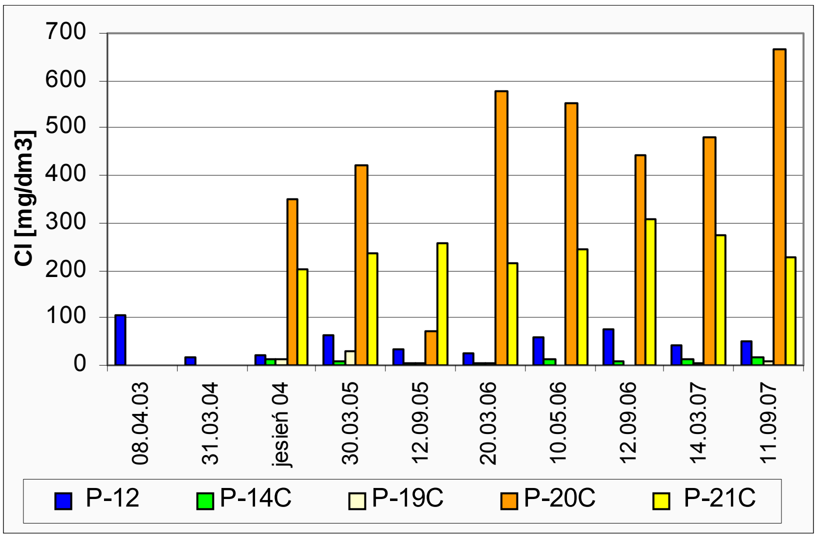

Fig. 6. Concentrations of chlorine ion in aquifer (3)

The problem of increased Cl^-concentration in the aquifer (3) seems to be the most important in the assessment of the landfill impact on the groundwater. It should be underlined that in the piezometers P-14C and P-19 the Cl^- amount doesn't exceed the range of hydrogeochemical background.
Additional facts that should be taken into consideration in are:

In 1966 (before the landfill existence) Cl^- concentration in a well in Rębowo ("R drilling well" in the Fig.2) was 113,6 mg/dm^3. In 1996 it was 106,5 mg/dm^3

In the "drilling well T " in Kowale Cl^- concentration was 27,73 mg/dm^3 in 2005, but in 2006 increased to 198,6 and 166,6 mg/dm^3. Similar values concern "drilling well D "in Kowale: 19,98 mgCl^-/dm^3 in 2002 and 81,5 mgCl^-/dm^3 (2006), 90,8 5 mgCl^-/dm^3 (2008)

Archive analysis from the "drilling well K" in Kowale indicate increased Cl^- concentration (92,19 mg/dm^3) in 1968.

5 Conclusions

In the light of presented data, it can be stated, that the groundwater is under the influence of the landfill, but the impact degree is differentiated. The contamination of (1) and (2) aquifers is limited to the landfill area and thus it is not dangerous for the groundwater use. It can only influence the Kozacki Stream water quality because of the gaining character of the stream. The recorded contamination of the (3) aquifer is the most important because it can result in limited use of the horizon in the future. Additional complication in explanation of the increased concentrations of chlorides are elevated values of the ion recorded before the landfill existence.

It is worth emphasising that despite of rather short time of observations their results allow to assess the landfill impact on the groundwater in the surroundings of the landfill. However, it is necessary to widen the monitoring system in order to determine the way and the rate of the pollution migration. New observation wells should be drilled on the outflow part of the landfill so as to widen the monitoring system of the aquifer (3).

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International Symposium on Water Management and Hydraulic Engineering

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Paper: **A112**

Stream Water Temperature and Climate Change-An Ecological Perspective

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Abstract. Rivers and streams are complex environments where physical, biological and chemical processes take place simultaneously and jointly determine water quality. Freshwater must be well managed and protected because it shelters an enormous number of aquatic species. In this context, stream water temperature is a crucial water quality parameter, for it determines the fitness and life of all aquatic organisms. This work reviews the thermal tolerance of such organisms, summarizes their behavioral and physiological responses to temperature, and outlines the major factors determining water temperature. To predict the influence of both air temperature and climate change on streams, Mohseni's nonlinear model is reviewed and applied to several monitored watersheds in Ontario. A detailed case study involving Wilmot creek shows both the suitability of Mohseni's model for existing temperature regimes, and predicts that an increase of 5°C in air temperature will will likely result in an increase in average weekly stream temperatures of between 2.6°C and 3.3°C.

Keywords: Stream water temperature, thermal tolerance, aquatic behavioural response, climate change

1 Introduction

Rivers and streams are sites of great environmental concern; therefore the United Nations General Assembly proclaimed the year 2003 as the International Year of Freshwater. The purpose was to increase the public and governmental awareness throughout the world of the significance of sustainable freshwater use, management and protection. Since the entire earth depends on a daily basis of freshwater, this challenges one of the most important issues facing our life.

On a global basis, only 2.5% of all water is fresh, and 70% of this is frozen. Freshwater that is found in rivers, streams and lakes forms a complex system where simultaneously various physical, chemical and biological processes take place; all have a considerable impact on the water quality.

Freshwater, even though it comprises only 0.65% of the earth's water and has an uneven distribution in both space and time, plays a dominant role in global water and energy budgets. Running waters (streams and rivers) are shelters of enormous variety of organisms, which life depends on a certain biotic and abiotic surrounding factors. One key factor in this group is the stream water temperature. From this vast array of process and actions, the current research is narrowed to running waters, including streams and rivers. Although the preliminary idea of this research was to deal with streams, because of the similarity of their processes, rivers are discussed as well.

Three major goals are considered in this research: the factors determining stream water temperature, the influence of climate change on this set of interactions, and the question of developing a suitable model of stream water temperature under new climatic conditions.

The entire life in the stream depends on a specific thermal tolerance range, specifically that range that provides a near-optimum fitness for a range of organisms. If the streamwater temperature changes the aquatic organisms will either disappear or shift to other regions where more comfortable and suitable conditions can be found. This leads to physiological stress in organisms and species loss in the stream; therefore a comprehensive understanding of the significance of streamwater temperature and the factors that define it, as well as an improved the knowledge of life that exists in the running waters, is essential.

At the same time the rivers and streams as part of the natural systems are exposed to some indirect effects as a result of climate change. Since climate change on a river or stream can in turn affect the aquatic biota, an estimation of the stream's response to increased stream temperature is desirable and valuable. Therefore a model becomes a useful tool for a better representation of the expected changes. The model is based on a nonlinear relationship that exists between the air and stream water temperature nowadays, with anticipated changes in climate conditions in the future.

Finally, to the authors' knowledge, this work outlines the first official attempt in Canada to make such comprehensive study covering all of the above-mentioned subjects. Also for the first time in Canada, Mohseni's model is used for prediction of impact on climate change on stream water temperature and aquatic organisms' life. The Mohseni model is widely used in USA (Mohseni et al., 1999) and the quality of the model to accurately represent stream temperature is well recognized. Moreover this is the first model that is based on a non-linear relationship between air and water temperature and therefore it is more realistic than the previously used linear model.

2 Stream Water Temperatures

Streamwater temperature has a significant importance for water quality. It influences all physical, chemical and biological parameters of the water. If the natural equilibrium in the system is destroyed, as result of changes in stream water temperature, some species under stress may migrate to other favorable streams or rivers or, even worse, may die. All organisms have limited stream temperature tolerance range and if these ranges are exceeded different behavioral and physiological responses are expected. Higher water temperature causes a lack of dissolved oxygen, which makes aquatic life more sensitive to any toxic wastes, parasites and diseases. These basic tendencies set the context of the current study.

Water temperature is one of the paramount water quality indexes. It influences directly the physical, biological and chemical characteristics of the river. For the physical and biological characteristics, water temperature affects the ability of water to hold dissolved oxygen; the metabolic rate of aquatic organisms; the rate of photosynthesis and aquatic plant growth; the fish and other stream inhabitants' resistance to parasites, diseases and pollution. The chemical reaction rates vary with different water temperatures and this affects the self-purification capacity of streams and their sanitary qualities (Webb, 2001).

Water quality control is based on the possibility of fish survival in the entire water. Since aquatic organisms have limited temperature tolerances, they can live normally only in a specific temperature range. Exceeding these ranges influences the behavioral and physiological responses of the aquatic creatures. The higher water temperature causes a lack of dissolved oxygen, which makes the aquatic life sensitive to any toxic wastes, parasites and diseases. Often some species die or migrate to other favorable streams.

The accurate prediction of water temperature is a complex issue. Therefore a sound understanding of the ongoing processes related to the river temperature and a comprehensive analyzes of the different stream temperature factors and the ongoing physical process is an invaluable task. This could create the basis for stream water temperature modeling and so the temperature changes can be predicted. All of this can have a beneficial impact on water quality and to help protect threatened and endangered ecosystems.

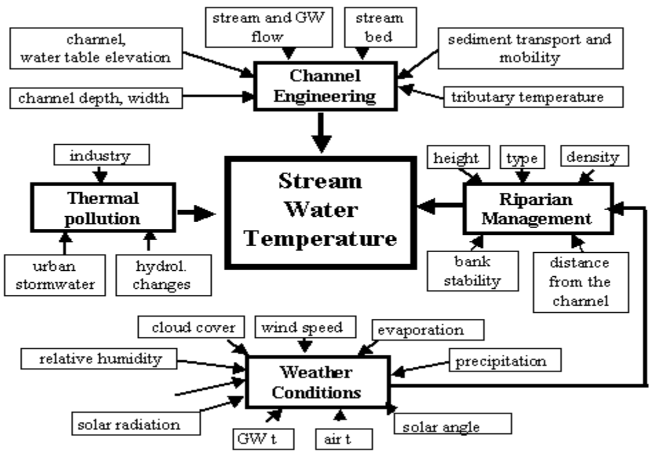

Fig. 1. Factors, affecting stream water temperature

Over the years, researchers have extensively studied increasing water temperature in order to protect threatened or endangered ecosystems. The initial concerns were stream temperature increases caused by logging of riparian forests, urbanization and especially cooling water discharges from the electric power industry. Recently, a renewed interest has been caused by the threat of global climate change (Sinokrot, Stefan 1993).

Figure 1 summarizes the factors effecting the water temperature – directly or indirectly. The factors can be divided to 3 major groups: Riparian vegetation (which is influenced from the Weather Conditions), Channel Engineering and Thermal Pollution.

3 Climate Change Effect on Ecology

The second goal of this research is to study the possible impact of the climate change on the running waters and on the dynamic responses of different elements of the hydrological system. Climate changes become a major environmental concern and understanding the complex connection between all elements within the natural hydrological system could help to predict the extent of the potential changes and the consequences that are likely to appear. For example, there is a sense that the global warming will make the rivers and streams more vulnerable, thus directly affecting existing ecosystem processes. In addition, changes in greenhouse gas concentrations, radiation, temperature, sea level and water quality all can influence the life in an ecosystem, the hydrological cycle and the catchment's land use. In fact, a major focus in this research is given to the increasing of the stream temperature as result of the air temperature increase (McCarthy *et al*., 2001). The latter, as a result of the climate change or urban development, directly affects the stream water temperature; moreover the air temperature increase is considered as a good "predictor" for changes in water temperature. Global warming, through increased precipitation and altered stream flow amounts, timing and variability, will lead to a wide variety of changes in the frequency of floods and droughts. Such changes may have severe impacts on freshwater. Although climate change impacts are difficult to predict in detail, it is likely that rivers and stream will become more vulnerable and it is expected that this will affect the entire ecosystem. One of the most significant changes will be elevated stream water temperature, which will have direct and indirect effects on the aquatic organisms. The latter is related often to various modifications with irreversible effects.

4 Stream Water Temperature Modeling

Modeling is not only a powerful approach to predict the changes that are likely to occur one system, but also is an instrument to improve the quality of analysis that engineers, planners and operators will make. In general, it is difficult to find an appropriate and accurate model that will represent the real situation and will predict the potential changes because of the dynamic processes that occur simultaneously in the running water. Therefore using an appropriate model for the particular situation is a significant challenge.

An attempt is made to consolidate the understanding of the stream problems associated with water temperature, and to predict the potential ecological response within the system under the new climate change conditions. Simulations with an appropriate and accurate streamwater temperature model for an environmental system permit an estimate of the possible impact of climate change on stream water temperature and consequently on the aquatic biota. In addition with the aid of sensitivity analysis, quantative estimation can be performed of the changes of streamwater temperature with increasing air temperature.

In this research, Mohseni's stream water temperature model (Mohseni *et al*., 1998) is applied. It is one of the first non-linear models connecting air and stream water temperature. It considers that an S-relationship exists between the air and stream water temperature. It has been already tested and been shown to be successful for USA, but no similar attempt has thus far been done in Canada. Therefore the authors of this research began this process through an analysis of Wilmot Creek, ON, Canada.

The analyses are performed based on the average weekly streamwater temperatures, because there is a sense that those analyses are the most representative with respect to fish. Overall, the results of the modeling are encouraging with regard to identifying the impact of climate change on stream water temperature. One significant aspect is an excellent fit that has been derived between the observed and the predicted stream temperatures (Fig. 2).

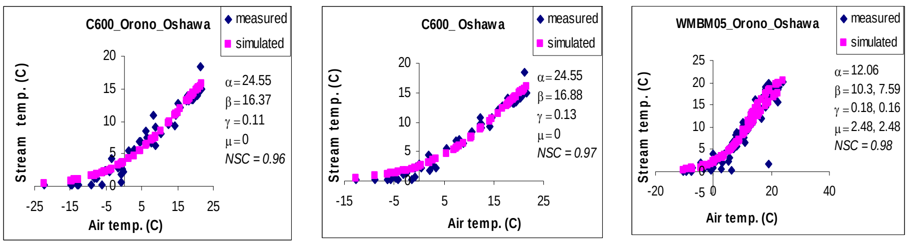

Fig. 2. Weekly observed and simulated stream water temperatures versus air temperatures

The model was verified with the help of two statistical parameters NSC (Nash and Sutcliff Coefficient) and RMSE (root mean square error). The NSC values range from 0.91-0.98 with an average of 0.95, which is pretty close to the best value of 1, and describes an almost perfect fit between the observed and the predicted stream temperatures. RMSE did not prove to be a completely satisfactory tool for fit estimation. Despite that, based on the great results given by the NSC parameter, it can be concluded that the model is applicable and appropriately chosen for the particular watershed. Moreover this is important to make correct analysis.

To estimate the changes of the stream water temperature with increasing air temperature, sensitivity analyses were used (Fig. 3). The air temperature is the modified parameter and the values ranges between 2°C and 5°C, values that are predicted with the help of GCMs and are generally believed to be reasonable for Ontario.

The result shows that air temperature increase by 1°C reflects the average weekly stream water temperature with an increase of 0-0.5°C. For air temperature increase 2°C the changes in the stream temperature changes within the pilot section fluctuates between 0.2°C and 1.6°C. An increase of air temperature with 5°C will result in a stream water temperature increase of 2.6°C and 3.3°C respectively (Table 1). As result of global warming (with $2CO_2$ increase), this will tend to increase the stream water temperature up to 3.3°C. In general a daily temperature increase in range 2-5°C is tolerated, but speaking about an average weekly increase that probably will lead to some shifting in the location of species.

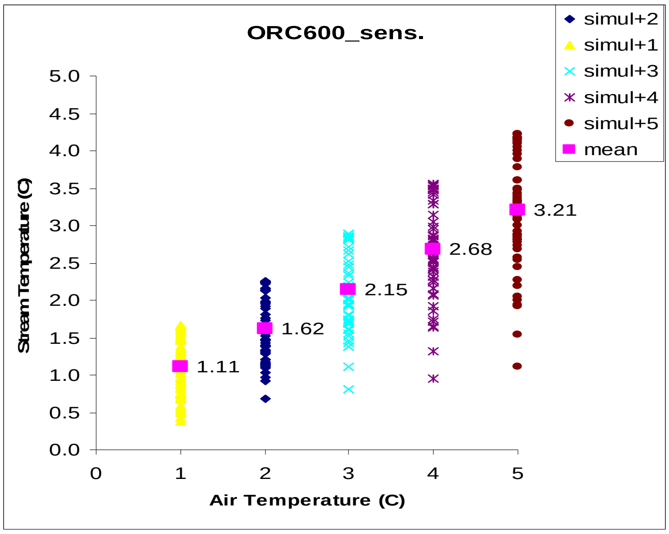

Fig. 3. Sensitivity analysis performed for ORC_600

Table 1. Impact on Air Temperature Change Scenarios on Stream Water Temperature

	Increase in mean stream water temperature				
Scenario (air t increase)	+ 1°C	+ 2°C	+ 3°C	+ 4°C	+ 5°C
WBM05	-0.1	0.2	0.4	0.7	0.9
WMINC5	0.6	1.2	1. 9	2. 6	1.3
ORBM01	0.5	0.9	1.4	1.9	2.4
ORC600	1.1	1.6	2.2	2.7	3.3
WMWEIR	0	0.7	2.7	2.0	2.6

5 Conclusions

The result of this research is a comprehensive overview of work related to stream water temperature along with the analysis of the potential impact of climate change on streams and stream ecology. A solid understanding is required of the factors that influence stream water temperature and also to appreciate the significant changes that may occur in an ecosystem as result of the climate change. In addition, the non-linear temperature model, implemented in this study provides a qualitative and quantitative description of the dynamic mechanisms that currently exists and is to be expected in the observed stream under a new climate scenario.

Understanding of the hydrological processes and prediction of the potential changes may offer a new scientific insight into the freshwater management under the new climate conditions. It is increasingly apparent that the climatic changes are coming with a complex mix of impacts on all aspects of the water resources, which in turn affects water quality. Some of these impacts are so far not predictable, but with the help of an additional research lot of uncertainties can be resolved. Moreover some opportunities for adaptation to these changes may be expanded.

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Topic 4

Water Bodies Protection and Ecohydrology

International Symposium on Water Management and Hydraulic Engineering
Ohrid/Macedonia, 1-5 September 2009
Paper: **A02**

Karst Landscape Ecohydrology

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Abstract. Karst represents a specific area consisting of surface-relief and surface-underground hydrographic networks resulting from water circulation and its aggressive chemical and physical action in conduits, joints, fractures, bedding plains and cracks along the layers of soluble rocks. It is a highly vulnerable and variable water and ecological system in both time and space. Karst systems have great significance for biodiversity conservation and very often they represent important cultural heritage. Karst ecosystems have been indicated as priority parts of biological and landscape diversity protection, which requires a specific approach. The objective of this paper was to analyse anthropogenic influences on the karst environment using concepts of karstology and karst ecohydrology. The paper describes some special issues on which karstology and karst ecohydrology should focus their interests: caves, karst landscape, dry stonewalls, stone clearing and wildfires in karst regions.

Keywords: Karst ecohydrology, karstology, anthropogenic influence, caves, dry stonewall

1 Introduction

One billion people in about 40 countries live in areas characterized by karst formation. Karstification is a geological process which creates especially vulnerable landscapes requiring extremely careful management. Common environmental problems to these fragile landscapes are: desertification, fast and massive groundwater pollution, the collapse of land, wildfire, and flooding and droughts. There is a close relationship between processes of soil formation and karstification. The karstification process occurs in fissured limestones and dolomites as a consequence of dissolution and weathering. Soils develop along these fissures, cracks and bedding planes where water accumulates, further enhancing weathering and soil formation. With the progress of karstification the movement of soil through a karst system occurs through the enlargement of karst fissures.

The karst environment has very different characteristics than all other environments. Water circulation in karst areas is different than in non-karst areas, which is the main reason for the strongly different characteristics of karst and non-karst hydrology as well as of karst ecology. Because the appearance, storage and circulation of water in karst is significantly different than in other more homogenous and isotropic terrains, karst ecohydrologists need to develop different methods and approaches. Water availability and its great variability in time and space are often key controlling factors in the biodiversity of natural karst ecosystems.

Karst terrains are characterised particularly by steeply sloping small to large depressions, subsurface drainage and strongly connected surface water to groundwater flow. The various actions and appearance of water in karst result in numerous variations of surface and subsurface karst forms, which serve as promising habitats for many karst species.

The decisive components of ecology in any physical setting, including karst, are: (1) Species; (2) Population; (3) Community; (4) Environment; (5) Ecosystem. Species are organisms that can interbreed and produce fertile offspring. A population is a collection of individuals, all members of the same species. A community is a collection of populations living together in an environment. The environment represents abiotic and biotic surroundings. The ecosystem creates communities and the abiotic environment. An ecosystem has three biotic components (producers, consumers and decomposers) and three abiotic components (organic matter, inorganic matter and climate).

Ecohydrology as a concept is in a very early phase of formation. Because of this it offers many scientific challenges and possibilities for exciting, hardly foreseen and dynamic development. Ecohydrology has the potential to provide scientists with environmentally friendly and sustainable solutions to several problems related to water quantity, flooding and pollution. Karst as a specific landscape and environment, to insure its sustainable development and protection, definitely needs new achievements in ecohydrology. It needs specific approaches to ecohydrology, i.e. it needs karst ecohydrology. A framework for this new and promising concept is given in [4].

2 Karst Ecohydrology and Karstology

Due to the specificity of the karst environment and especially due to the particularity of water circulation and storage in karst areas (on the surface as well as underground), few species are able to develop and survive in such difficult conditions. For the sustainable functioning of any ecosystem, of crucial importance are: (1) Levels of organization of individuals, population, community and the ecosystem; (2) Energy flow through ecosystem; (3) Food chains and food webs involving the primarily energy flow; (4) Material cycling through ecosystems and the conservation of matter. All these processes exist in karst media. Because karst presents a much more challenging environment than other physical settings it results in the existence of specific, mostly endemic species with a small number of individuals in populations. Karst species often are extremely endangered because of the extreme vulnerability of karst terrains and due to fact that populations are small.

The coupling of thermal, chemical, mechanical, ecological, and hydraulic processes in karst fluid-rock interaction is extremely complex and subjected to multiple feedback loops that often cannot be adequately understand or properly addressed in models.

The first problem is that science does not know enough about these feedback loops especially between water and biota. The next generation of hydrologic-hydrogeologic-ecological models for karst areas must involve a development of grid-scale parameterizations from sound scientific principles at the atomistic level, a test of such parameterization over time and space-scales that are beyond and/or below the usual grid scale of the computational model [3],[18]. Karstology can be defined as the science of integrating hydrological, geomorphological, hydrogeological, ecological, environmental, biological, speleological, socio-economics, cultural, political and all other processes over varied spatial and temporal scales in specific karst regions. It is an integrated scientific system composed of individual branches that take up complex studies of karst systems. The domain of karstological interest is a karst landscape, all its abiotic, biotic and socio-economic elements and components, as well as their internal mutual interactions and the external relations of the karst itself with adjoining landscapes and with other factors [15].

Conducting basic research in karstology is a key for understanding the nature of karst and its processes. The main goal is to understand the complex phenomena of karst; the evolution of its surface and subsurface, the evolution and function of karst aquifers and karst ecosystems, the origins of karst terminology and the history of karst science. This research will provide knowledge for the efficient protection of vulnerable karst environments and for the planning of human activities on karst.

Until now karstology has generally been part of the geosciences community, but in the near future it should connect the geosciences with social and humanitarian scientific and practical disciplines. Karst as a specific landscape and environment needs new achievements in karstology in order to find answers to further challenges. Karstology can be understood as the logical and effective holistic integration of many different approaches. The role of hydrology (or water and its changes in time and space) in karstology is of crucial importance.

The development of karstology as a real interdisciplinary and holistic scientific and practical discipline can help in achieving this goal. In should be stressed that expanding existing capacity is not adequate to help karstology in the achievement of real interdisciplinarity along with theoretical and practical efficiency. Karstology should become the basis for karst ecohydrology.

The crucial, often precarious "balancing act" involves some highly complex issues that cut across the physical, natural and social sciences [10]. Ecohydrology has the potential not only to unlock elements of this complexity but also provide a foundation for the sustainable management of water resources [20]. If ecohydrology wishes to solve complex problems between hydrology and ecology, a truly interdisciplinary approach of ecohydrology should be developed. It is a prerequisite for understanding complex hydrological and ecological interactions and processes, to ensure sustainable development and for solving practical problems [10].

3 Particularity of Karst Environment in the Croatian Karst

The Dinaric karst covers about 60,000 km^2. It stretches the length of the eastern coast of the Adriatic Sea, from the Bay of Trieste in the north, to the Drim River basin in the south and the Western Morava valley in the east. This karst structure is some 600 km in length, and up to 200 km in width, falling within the borders of seven countries: Italy, Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and Albania. The first detailed karst studies as well as the first theories on water circulation and storage in karst were developed as part of the investigations of the Dinaric karst. The Dinaric karst region is an area of dramatic variety of species, habitats, landscapes and peoples.

In the Dinaric karst region are found some cases of concordance of species distribution areas with possible hydrographical situations in the past [16]. If the distribution area of a species recently bound to a subterranean habitat, terrestrial or aquatic, is in opposition with actual drainage system area, two conditions had to coincide in its history: (1) The population must have been isolated in a drainage system with a different flow direction; (2) The ecological mechanisms, most probably interspecific competition, must prevent spreading of species along the actual subterranean streams [16].

Karst areas represent about 49% of the land area of Croatia, which consists of 27,683 km^2. In it approximately 7,000 caves and pits are known at present. It is expected that this number will increase considerably with new discoveries. The rang of geomorphology, climate, hydrogeology and hydrology cause a remarkable number of different karst groundwater environments in Croatia: (1) Inland and coastal caves; (2) Superficial and deep phreatic networks; (3) Interstitial-hyporheic substrates; (4) Epikarst and other infiltration zones [8].

The majority of subterranean species in Croatian karst are troglobionts. Some 299 terrestrial and 177 aquatic troglobites have been recorded, almost 70% of them endemic. Troglobiont is any creature having a cave-dwelling mode of life. In many Croatian caves, the main source of energy is the faecal materials of bats [8]. The karst region of Croatia enjoys an unusually rich biodiversity of global significance. Croatian karst ecosystems host about 3,500 species of flora (283 endemic), 12 species of amphibians, 36 species of reptiles, 200 species of resident birds, 79 species of mammals, and 64 species of freshwater fish (11 endemic). Subterranean karst habitats support an ever increasing list of newly discovered endemic troglodytic (eyeless and adapted for an entirely subterranean existence) species and families. These subterranean and terrestrial karst ecosystems are fragile, interconnected, and dependent upon the maintenance of a delicate balance between topographic relief, hydrology, climate and vegetation. This balance is currently under stress caused by anthropogenic influences as well as climate change and variability

Many subterranean taxa in Croatian karst regions are threatened by pesticides, storm-water discharge, microbiological pathogens and nutrient stress resulting from the remote transport of pollutants. Especially in recent times quarrying and intensive motorway building have destroyed many caves including their valuable habitats and species.

The strategic objective regarding the karst and underground ecosystems conservation in Croatia is to preserve the present values of the biological and landscape diversity of the karst as an area of global value, and secure a balanced management of all natural resources of the area.

4 Anthropogenic Influences on the Karst Environment

The construction of different large-scale hydrotechnical (dams, reservoirs, inter-basin water transfer, regulation and canalisation works, exploitation of surface water and groundwater, etc.) and civil engineering works (construction of motorways, quarries, mining, urbanisation, industrialization, etc.) as well as agricultural interventions during last 100 years in the karst regions have greatly influenced their surface and groundwater regime. The environmental effects exerted by hydrotechnical structures and civil engineering or agricultural works in karst are even more serious than the consequences related to the technical and hydrological aspects.

The importance of maintaining the morphological and ecological connections between surface and underground parts of the karst systems should be stressed. The connectivity of various habitats is important for fulfilling the needs of organisms to move within the landscape and karst underground and for sustaining a series of physical, biological and chemical processes that control the structure and functioning of the karst system.

The following threats to karst ecosystems have been identified: (1) Habitat changes, fragmentation and destruction; (2) Water and air pollution; (3) Extensive and uncontrolled exploitation of natural resources; (4) Introduction of foreign species; (5) Generally unsustainable development, especially unsustainable water resources management. As the demand for water continues to increase, it is clear that balancing the needs of people against the needs of terrestrial and aquatic ecosystems becomes a premier environmental issue [14].

The removal of rock by quarrying results in either the modification or the destruction of specific and beautiful karst landforms in the quarried area together with the total destruction of the existing ecosystems as a result of the stripping of soil, grassland and woodland [9]. The problem is that although limestone quarrying represents the most visually obvious and the most dramatic anthropogenic impact on karst terrain it has received little attention from karst geomorphologists or karst ecologists. Quarrying definitely has a strong negative influence on karst water circulation and causes the pollution of groundwater. Many karst freshwater organisms have a restricted geographical distribution. Because of that they are extremely vulnerable to habitat destruction and other anthropogenic modifications to karst water circulation.

Dams and large-scale impoundments have caused severe population declines in or the extinction of many karst aquatic species worldwide [21]. The adverse impact of dams and impoundments on river systems have been recognized as the most important cause of fragmentation and habitat loss in running water [17]. In open water courses below dams the changes of physical as well as chemical conditions, include great modification of natural hydrological and water temperature regimes so that few native species can survive. Problems regarding the karst environment do not start after dam construction is finished and its reservoir is full of water. Instead, they appear during the civil engineering works, especially due to massif excavation, transport with heavy lorries, the work of civil engineering machines, blasting and the construction of grouting curtains.

The injection of materials into karst groundwater, i.e. the construction of grouting curtains, definitely could be the cause of unpredictable negative consequences on karst groundwater environments. The building of dams in karst areas always includes the construction of grouting curtains. Grouting is a procedure by means of which grout is injected into karst voids, fissures, crevices, conduits and caves. The ingredients for the preparation of mortars and grouting suspensions are: (1) Cement; (2) Bentonite; (3) Clay; (4) Sand and fillers; (5) Additives for stability; (6) Water [13]. During construction millions of tons of injection mass is injected in the underground. Physically as well as chemically this mass voraciously and quickly destroys underground habitats and kills an enormous number of endangered and endemic species. The great problem is that until now neither engineers nor ecologists took care of this great and massive negative influence on underground karst environments.

The dams have made an important and significant contribution to human development, but the social and environmental costs have, in too many cases, been unacceptable and often unnecessary [19]. There cannot be one, single, dogmatic a priori answer to the questions of dams or no dams, in terms of optional water and environment resources management, which will suit all the different conditions of all the countries of the world, either at present, or for the decades to come [1].

4.1 Caves

Water caves are one of the most characteristics features of a mature karst landscape. As a system of connected voids, conduits and large halls, they transmit and store a great quantity of underground water. Karst massive is continuously changing by the processes of rock dissolution. The great majority of caves have been created principally by the dissolution of bedrock by water circulating through initial karst openings. The role of bedding planes is especial important in this process.

A cave is a natural subsurface void in rocks (predominantly in carbonate rocks) that is large enough for human access. It can be filled by air and/or water, and often is partially occupied by sediment. Caves are conspicuous and interesting features of relatively mature karst terrains. From the karst ecohydrological point of view it is very important to incorporate numerous pieces of cave information into site-specific environmental characterizations [12]. From the hydrological point of view caves represent a pattern of connected conduits which drain water through a karst aquifer. At the scale of the karst catchment, caves generally display patterns that correlate with flow and recharge characteristics of their karst aquifers. The most interesting pieces of cave information are: (1) Cave types associated with various carbonate aquifer systems; (2) Understanding the hydrological significance of cave locations on the catchment scale; (3) Complementary information from inventories of sinkholes, sinking streams, and karst springs; (4) Implications of nearby caves for distinguishing diffuse versus conduit flow; (5) Dye tracer methods for vadose versus phreatic conduits; (6) Inferring flow directions from trends of cave passages, joints, faults, etc.; (7) Role of caves in food chains and food webs; (8) Role of caves in habitat and niches existence.

In fact all of the caves are ecologically heterogeneous, and have diverse fauna. A high ecological diversity means a great variety of habitats. Cave habitats are strongly zonal. The following five terrestrial zones are recognized: (1) Entrance; (2) Twilight; (3) Transition; (4) Deep; (5) Stagnant air [11]. This classification emphasises the transition between surface and subsurface. The surface and underground environments meet in the entrance zone. The twilight zone extends from the boundary of plant life to the limit of light. The transition zone is in total darkness but is subjected to nocturnal desiccating winds caused by cold air sinking into the cave. The deep zone, which called the dark zone [6], is characterised by total darkness and the long-term presence of moisture and a saturated atmosphere. The stagnant air zone lies beyond the deep zone and only slowly exchanges air with the surface.

The absence of light in the karst underground, particularly in caves, makes photosynthesis impossible. Plants, which are the major food source on the Earth's surface, are absent [6]. For food, cave animals generally depend on what enters haphazardly from outside. In caves, there are the following two sources of organic matter vertically percolating water from epikarst and sinking streams. It has been estimated that between 20,000 and 100,000 species of animals worldwide live exclusively in caves [7]. Many of those species are limited to a single cave, or to a handful of caves in one highly circumscribed area.

4.2 Karst Landscape

The present-day karst landscape is the result of natural and human interactions over thousands of years. Human societies have been so closely intermingled with their environment that a complex co-evolution has been claimed to shape the interactions between ecosystem components and humans. The components and dynamics of current geomorphological variability as well as biodiversity and ecosystem functioning in karst region cannot be understood without taking into account the history of human interventions. Various and ingenious systems of land use and resource management provided a framework for the development of civilizations living on this region [2].

A high degree of division into parcels, physically delimited by a very developed network of dry stonewalls, represents the most important feature of the whole Mediterranean karst region landscape. Fig. 1 refers to the landscape of the island of Hvar (Croatia). Dry stonewalls are of fundamental importance as a habitat for a very diverse flora and fauna. They keep the moisture during the hot summer period, create shade and serve as the shelter for many species. Hand-built dry stonewall terraces permitted agricultural production on slopes up to 70%. Terracing by dry stonewalls prevents overland flow and serves as a very effective measure against erosion.

Massive stone clearings mean the entire disappearance of stonewalls. This process could be very dangerous from ecological and hydrogeological points of view. The carbonate formation of the Murgia (Southern Italy) represents a huge karst aquifer, holding the main groundwater resource of the region. Up to the 1980s, agriculture consisted in typical extensive fields of olive and almond trees, and grapes. A high degree of division into parcels, physically delimited by a very developed network of dry stonewalls, represented an important feature of this region. By the massive stone clearing at the end of 2003, 40% of the Murgia territory had been transformed [5].

Current studies indicate that the agricultural activities in the Murgia have important consequences on groundwater quality, variable with the season and the trend of precipitation. Direct observation of the stone cleared surfaces evidences a net loss of the fine soil component, so farmers are obliged to add new soil. A great part of the lost soil finally reaches the sea during the frequent floods. The soil loss is the closest precursor of the desertification of the concerned areas [5].

Fig. 1. Characteristic karst landscape with dry stonewalls (Island of Hvar, Croatia)

The hazard of wildfires has increased over last decades throughout the whole Mediterranean region. Wildfires can have a significant effect on some hydrological and ecological parameters. The destruction of the forested ecosystem of a basin has direct and serious consequences for its behavior. At the same time wildfires can affect ecohydrological processes indirectly, but profoundly, by altering the physical and chemical properties of the soil, converting organic ground cover to soluble ash, modifying the microclimate, etc.

Recently the wildfires have been especially frequent, with devastating consequences, on the coastal, Mediterranean part of karst. A Mediterranean biome's climate has a mild, rainy season that coincides with winter. Hot, dry periods influence this biome's plant type which is characteristically made up of woody shrubs adapted to withstand drought. Mostly these shrubs are evergreen and typically have small, thick, waxy leaves designed to retain moisture. Many of these plants develop on thin, rocky degraded soils and contain highly flammable oils.

Key fire-related negative impacts on epigean and subterranean ecosystems are: (1) Reduced proportion of animals involved in mineralization and humidification; (2) Decreased density of most invertebrate groups; (3) Changed species composition; (4) Changed soil and stonewall humidity; (5) Changed pH; (6) Destruction of food resources for both surface and subterranean invertebrates. The wildfire affects soils and carbon storage in soil and vegetation. The short-term consequences of wildfires are very different from long-term consequences. Wildfires have devastating effects on animals with limited mobility. The main reasons for this are: (1) Their poor dispersal ability; (2) Their habitats on vegetation and in litter; (3) Their sensitivity to low humidity and lack of shade. Changes of the biotic and abiotic factors above the ground lead to changes down through the superficial to deep karstic aquatic and terrestrial habitats.

5 Conclusions

Water is a crucial natural factor on which the sustainable development of both human beings and their environment depend. Water links the biosphere and social systems, and in this way directly and strongly influences the future of our planet. Hydrological processes involve flows of matter and energy (water, nutrients, sediments, species, seeds, heat, etc.) between different karst landscape components. This is why hydrology is fundamental for karst water resources management but recently it is not sufficient to find adequate answers to the challenges of the future. For these challenges modern holistic science should use new interdisciplinary concepts, approaches, methods and technologies. The development of comprehensive knowledge generated by the integration of various branches of science and development in ecological engineering are increasing the opportunities to develop more sustainable, economically viable karst environments.

Karst ecosystems have been resilient and resistant to the long-lasting but slow human pressure, especially land use changes, whose main activity was “primitive stone clearing”. This kind of coexistence between human beings and nature resulted in a sustainable functioning and balance of vulnerable karst ecosystems. It seems that present-day pressure on the karst ecosystems (urbanization, industrialization, motorways construction, dams and reservoir construction, massive stonewall clearing, tourism, new aggressive agricultural and land use practice, etc.) does not ensure sustainable development as well as biological diversity.

The assessment of climate change and/or variability as well as human influence on these processes is one of the greatest concerns for modern science, especially karst ecohydrology. Karst ecohydrology in close co-operation with karstology should give new directions to managing the relationships between water and development in karst regions using the very latest as well as established classical concepts.

The necessity of identifying a karst system in a holistic way is becoming more significant, due to the fact that karst terrains have been recently more densely populated. Humanity has not only learned a great deal from its successful achievements, but also from its errors.

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Water Management in the Razim-Sinoie Lacustrine Complex

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Abstract. The lakeshore complex Razim-Sinoie is the largest surface of water from our country (in natural system) being situated in the south of Danube Delta. In the XX-th century, the anthropic intervention determined important modifications of the hydrochemicals characteristics with effects on the ichthyofauna, on the regime of variations of the levels and the hydric evaluation, causing some problems bound with pollution, the clogging of the lakes and the acceleration of the erosion of banks. After the year 1970 the plans of reconditioning the Razim-Sinoie complex have been resumed, this time the accent fell on the transformation of the lakes in a hidrotechnic system with a main function regarding the irrigations and a secondary function regarding pisciculture. In this hidrotechnic system the lakes in the north compartment of the lacuster complex measuring a surface of approximately 520 km^2 from which about 120.000 ha were to be irrigated. Although the lake Sinoie was not a part of this hidrotechnic system, the modifications brought to this hidric system as well as the circulation of water, namely the salinity had direct and immediate effects upon the hidrobiological characteristics of the underwater ecosystem.

Keywords: Water management, lake, Razim-Sinoie

1 Introduction

The Razim-Sinoie lake complex is situated in northeastern Dobrogea, south of the Danube Delta and on the coast of the Black Sea (44°47' and 45°01' northern latitude and 28º30' and 29°08' eastern longitude), constituting the largest water surface in our country. It appeared and evolved in a former branched marine gulf, Halmyris, at the basis of a fossilized marine cliff (in the west), being connected to Sfântu Gheorghe branch (in the north) by means of several canals and backwaters and separated from the sea by several alignments of low and weakly consolidated marine bank-ridges, all these characteristics conferring it numerous particularities reflected in the hydrological, thermo, dynamical and hydrochemical regime of the lakes' water [9], [10],[17], [20], [21].

The great diversity of the aquatic ecosystems and their accentuated vulnerability in relation to the anthropic intervention requires that their management and their economic valorization must have as a major desideratum the conservation and the protection of the biodiversity, in order to obtain an ecological balance. In order to attain these desiderata, by means of the Law no. 82 of November 20, 1993/ HG no. 248 of May 27, 1994 concerning the creation of the "Danube Delta" Biosphere Reserve, three types of areas were established within it, namely: strictly-protected areas (with integral protection), namely 18 (50600 ha, out of which in the Razim-Sinoie complex, 6 such areas add up to a total surface of 9123 ha), buffer-zones (223300 ha) and economic zones (306100 ha) where people currently practice traditional economic activities and which include all the rural and urban localities (Sulina) [23].

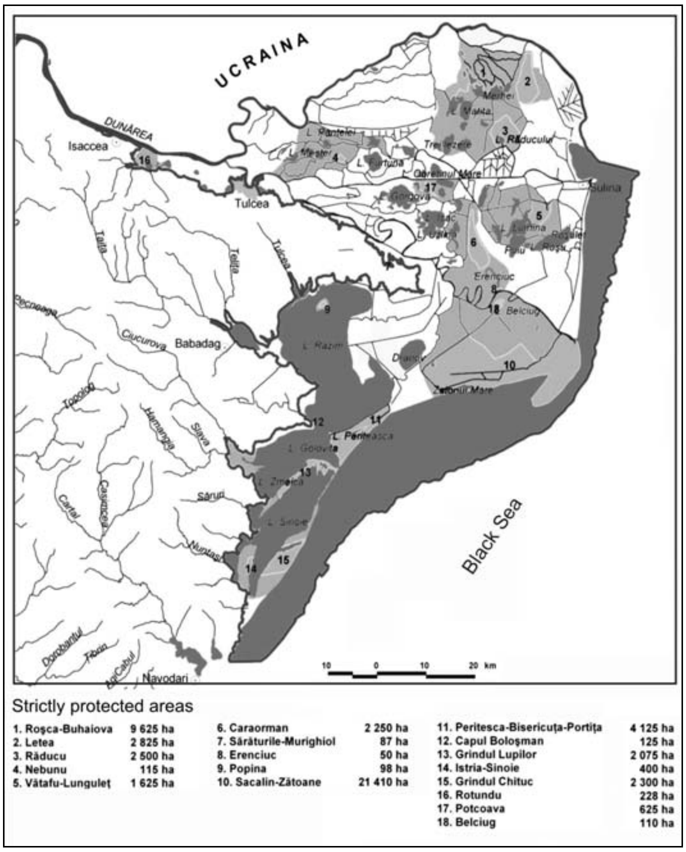

Fig. 1 . The Danube Delta Biosphere Reserve - strictly protected areas

2 Evolution of the Legislative Framework

In time, even since the period between the two World Wars, there has been a series of researchers who, through the studies they made, tried to promote these principles, maintaining a balance between the valorization of the significant natural resources and the protection of this so valuable and yet so fragile area. One of these remarkable researchers of this area was **Grigore Antipa**. Following the propositions made during the first decennia of the 20th century and the works carried out by the Direction of the State-Run Fisheries (Directia Pescariilor Statului), an efficient hydro connection was achieved between Sfântu Gheorghe branch and the Razim-Sinoie complex [2]. During the period 1930-1950, the efforts made by some researchers led to the declaration of certain areas of the Danube Delta and of the Razim-Sinoie complex as *natural reserves,* some of them being introduced later on in the world list of the biosphere reserves - as part of UNESCO's "*The Man and the Biosphere*" (MAB) international program. In 1938, in the Razim-Sinoie lacuster complex, by means of the Decision of the Board of Ministers HCM no. 645, the Popina Island and Periteaşca-Gura Portitei-Bisericuta area were declared as reserves.

During the period that followed, after 1950, as a consequence of the creation of the Commission for Natural Monuments (Comisia Monumentelor Naturii) of the Romanian Academy, the number and surface of the reserves in the Danube Delta and in the Razim-Sinoie complex grew (HCM no. 891/1961; HCM no. 528/1970), amounting to six: three ornithological reserves, a forest reserve and two complex reserves, occupying a total area of 41046 ha [23].

In the Razim-Sinoie complex were reconfirmed the two reserves declared previously, and to them were added the ***protected nesting areas*****.**

The **Periteasca – Leahova – Portiţa** reserve, covering 3900 ha, situated in the Razim-Sinoie lagoon complex, was made up of a proportion of up to 50% lakes, offering optimal conditions for the lacuster birds and winter guests. In this reserve there were both biocenoses developed on dry sands from the tops of the bank ridges or on sands bathed by the sea waters or by the water of the Razim lake, and also biocenoses adapted to the lakes with significant variations of salinity.

The **Popina Island** reserve, 98 ha, situated north of Razim Lake, is the nesting place of the *Tadorna ferruginea* and of other migratory birds, especially during the autumn migration.

Beside the *protected natural reserves*, a series of *resting places or refuges* have been created, which represent the permanent nesting areas of the migratory birds.

In the area of and near the Razim-Sinoie complex have been created four such refuges, seeing that through this area pass most of the itineraries of the Southeastern Europe migratory birds: the **Saraturile** refuge, situated south of Murighiol locality is a nesting place for *Himantopus himantopus* and *Recurvirostra avosetta*; the **Fundul Golovitei (Ceamurlia)** refuge shelters colonies of *Egretta alba* and *Platalea leucorodia*; the **Istria-Sinoie** refuge occupies the gulf situated near the homonymous localities and constitutes a significant area for the nesting of *Tadorna tadorna*; **Grindul Lupilor**, during the period that precedes the autumn migrations, becomes one of the places of maximum avifauna density, while during the summer the most encountered avifauna here is the crane.

Seeing that in these natural reserves and resting places for nesting have been encountered rare species of animals and birds and that there is a special scientific interest about them, some of them have been decreed natural monuments or protected by the law, as for instance: *Platalea leucorodia*, *Egretta alba*, *Pelecanus onocrotalus*, *Pelecanus crispus*, *Tadorna tadorna*, *Tadorna ferruginea*, *Himantopus himantopus*, *Recurvirostra avosetta*, *Otis turda*, *Cygnus olor*, *Cygnus cygnus* etc.

However, the period before 1989 was generally characterized by massive anthropic interventions in the Danube Delta and in the Razim-Sinoie complex, determined by the **Program of total arrangement and exploitation of the natural resources of the Danube Delta (Programul de amenajare si exploatare integrala a resurselor naturale din Delta Dunarii)**, elaborated and coming into force through a decree of the State Council of 1983, according to which a significant part of the delta, including Razim-Sinoie lacuster complex, was to be arranged for agriculture.

After 1989, following the political changes and given the new vision on the natural patrimony conservation and protection, through the **Decree of the Romanian Government no. 983/1990** concerning the organization and functioning of the Ministry of the Environment, published in the Official Gazette (Monitorul Oficial) no. 105/ September 14, 1990, was created the Danube Delta Biosphere Reserve. So, in the article 5 point 1, this law mentions that: „*For the guidance and the control of the entire scientific, tourist and leisure activity of the Danube Delta, is created the "Danube Delta" – biosphere reserve – an institution with juridical personality subordinated to the Department of the environment.*"

The 3rd point of the same article delimits the surface of this reserve, amounting to 580000 ha, stating that it includes: "*the Danube Delta, the **Razim Sinoie lagoon complex**, the Danube's waterside between Isaccea and Tulcea, the seacoast between Chilia branch and Midia Cape up to the 20 m isoheight, and the maritime Danube – up to Cotul Pisicii"*.

The new structure's general objectives established by the law (art. 5 point 4) were: *to ecologically redress the Danube Delta and to conserve the genofund (biodiversity) of the ecofund; to know the productive capacity and to establish the dimensions of the exploitation of the Danube Delta resources, within the admissible ecological limits.* The provisions of the HCM no. 983/1990 came into force through the Law no. **82/ November 20, 1993** concerning the creation of the **Danube Delta Biosphere Reserve.** According to this law, the Danube Delta Biosphere Reserve is structured as follows: **strictly protected areas** (with integral protection), namely 18 (50600 ha), **buffer zones** (223300 ha), surrounding the strictly-protected areas, in order to gradually reduce the anthropic pressure and **economic zones** (306100 ha) where people currently practice traditional economic activity and which include all the rural and urban localities (Sulina).

On the basis of this legal framework, The Scientific Council of the Danube Delta Biosphere Reserve approved, for the period 1995-1999, the ***Management Plan*** containing 35 objectives and 87 projects, grouped into four categories, namely: general objectives to redress the ecological condition of the Danube Delta Biosphere Reserve, the legislative framework and forms of cooperation and promotion concerning the reserve; objectives concerning the durable economic use of the Danube Delta Biosphere Reserve area and the use of natural fertilizers (agriculture without chemical fertilizers and pesticides, use of natural resources – common reed, mace reed, wood, fish, bird and mammal fauna, ecotourism); objectives and activities in the buffer zone which are to contribute to the reduction of the anthropic pressure on the strictly protected areas and to the rehabilitation of the previously degraded habitats; objectives concerning the strictly-protected areas, like the improvement of the water quality, research and monitoring of the biodiversity, for its conservation and protection (*Management Objectives for Biodiversity Conservation and Durable Development in the Danube Delta Biosphere Reserve, Romania / Obiectivele de management pentru conservarea biodiversităţii şi dezvoltarea durabilă în Rezervaţia Biosferei Delta Dunării din România*, 1995) [19].

Since 2006, for at least 10 years, the complex problems of the Danube Delta Biosphere Reserve will constitute the objectives of the MASTER PLAN for the Danube Delta Biosphere Reserve, which has been presented and developed in a workshop during the **14th "Deltas and Wetlands" International Symposium, September 2005**. The Master Plan project comprises 6 chapters. In each chapter are included numerous objectives of which we mention: the promotion of the economic growth and social development concerning the water and sewage systems in the localities of the Danube Delta, the transport on water and on land in-between the localities, the protection against floods, ecotourism, fish resources, education, culture and health, all these in relation to the biodiversity conservation and protection, ecological reconstruction, integrated monitoring and management [23].

3 Modifications of the Maximum and Minimum Water Level Regime

Knowing the rules that determine the modification of the levels of these lakes was a priority during the period prior to 1970 because, based on the knowledge gathered on this topic, it was possible to design and decide the location of the hydrotechnical constructions (protective dams, pumping stations, water gates, water feed pipes etc.).

The most important role, concerning the water alimentation of Razim-Sinoie lake complex and consequently in the evolution of their levels, goes to the canals connecting it to Sf. Gheorghe, one of Danube's branches. For this reason, the lake level regime is characterized by two specific elements, namely: a periodical variation determined by the water level regime on Sf. Gheorghe branch and a non-periodical variation, superposed on the periodical one, determined by the wind direction and intensity.

This is how we can make a correlation between the levels from the hydrometric stations situated on Razim-Sinoie lake complex and the levels of Sf. Gheorghe branch.

The correlation between the water level on Sf. Gheorghe branch and the average water level in the northern area of Razim hydrotechnical system, for the period between 1962 and 2006, convincingly highlights the influence of the Danube's flow regime on the level of the lakes' water, these level variations obviously determining a variation of the water volumes accumulated or lost [11], [12].

Another element that influences the water level in Razim-Sinoie lake complex is the wind. Given its large surface, its border configuration and the lack of natural barriers, the lake water-bearing structures have to stand a tangential friction that triggers first of all a displacement of a superficial water layer [16]. If the wind speed grows and remains at a high level for a long period of time, the movement is also transmitted to the following water layers, which leads to a superficial water leak, actually a horizontal displacement in the direction of the wind [17], [20].

Because of the specific climatic peculiarities, generally the highest frequency goes to the north and north-east winds, which often push large water quantities from the north of Razim to the south, which determines an increase of the levels at Jurilovca or Canal V and a level decrease at Sarichioi or Sarinasuf.

Level modifications in the northern compartment (Razim-Goloviţa lakes) because of the intensification of the wind in the direction north or north-east occurred as well after 1974, the immediate effects being a level decrease in Razim lake (ph. Sarichioi) and a level increase in Goloviţa (ph. Jurilovca). This thing can be noticed only by means of a comparative analysis of the monthly minimum and maximum levels from the two stations. So, for instance in 1980 (December) and 1981 (January) on the background of high average water levels (December 1980 $H_{med\ Sarichioi}$ =122 cm; $H_{med\ Jurilovca}$=116 cm and January 1981 $H_{med\ Sarichioi}$ = 124 cm; $H_{med\ Jurilovca}$ =122 cm) and of the intensification of the wind speed, the ***maximum monthly level at Jurilovca station*** occurred on **January 9, 1981** - ***130 cm*** and on the same day the ***minimum monthly level was recorded at Sarichioi station (January 9, 1981 – 104 cm)***, the same phenomenon having been encountered during the previous month (**December 9, 1980** – maximum monthly level ***Jurilovca – 125 cm***; minimum monthly level ***Sarichioi – 104 cm***) [11], [12].

3.1 Maximum Levels

The general morphometric characteristics of the lakes and the climatic particularities (strong winds from the north and north-east during the winter) favor the increase of the maximum levels recorded at the hydrometric stations situated in Razim-Sinoie lake complex [18, 21].

The absolute maximum values recorded in the data series changed in time because of the general increase of the average values after 1974. Prior to 1974, the absolute maximum level was recorded in Goloviţa lake (Jurilovca) on March 11, 1970 (+106 cm) and in Babadag lake on January 18-22, 1961 (+86 cm) [9]. On the general background of the increase of the average monthly and yearly levels in the northern compartment after 1974, the maximum levels reached were of 153 cm in Razim Lake (Sarichioi) on June 2, 1988 because of the high water level in the Danube, and of 130 cm in Golovita lake on January 9, 1981, the determining factor being the wind.

These values go beyond the estimated certainty value of 1% that different authors calculated before 1974. The extension of the series of data and the completion of the previous period led to much higher maximum value levels with a certainty of 1%, namely of over 140 cm for Canal V and over 100 cm at Dunavat [16]. These values were surpassed after 1974, and the analysis of the hydrometric materials recorded afterwards it was possible to draw a new certainty curve for the maximum level.

The new maximum annual values obtained based on it, with a certainty of 1% are of over 160 cm in Razim lake and of over 140 cm in Golovita lake, with a lower variation between the absolute values than in the previous evaluations. The increase of the values with a certainty of 1% for the southern area is caused by the wind influence, as the exposed surface is larger and involves in its oscillation a larger mass of water, while for Razim lake the increase is caused by the water coming from Sf. Gheorghe branch, which led to the inversion of the maximum levels with a certainty of 1% (after 1974, they were larger in Razim lake than in Golovita lake).

The influence of the sources that contribute to the attainment of the yearly maximums can be noticed very well if we compare the months when these values occur in Razim and Golovita lake. For Razim lake, given the direct discharge of the water from Dunavat and Dranov canal, the most frequent annual maximums occur in March-April (65%), months that correspond to the periods of high water on the Danube, while in Golovița lake, yearly maximums occur frequently during the cold season (30%) especially in December, but also in January and February in a context of intense winds and storms [11], [12].

3.2 Minimum Levels

The minimum monthly and annual levels recorded an increase of their absolute values, because of the gradual increase of the average level of the lake water. If before 1970, the absolute minimum values recorded at the stations situated on the lakes of Razim-Sinoie complex were negative (-16 cm on Babadag Lake on 8-11.11.1969) or near zero (+9 cm at Jurilovca 26.10.1959) and were caused by the decrease of the volume of water coming from the Danube, which is a characteristic of the autumn and winter waters, after 1974, frequent minimal monthly values of over 100 cm (104 cm at Sarichioi on December 9, 1980 or the same value on January 9, 1981 and 112 cm at Jurilovca on January 31, 1981) are recorded.

The absolute minimum values recorded at the stations situated on Razim and Golovita lakes are positive, near zero and below those recorded previously: Sarichioi, +3 cm on December 26, 1986 and Jurilovca, +8 cm on March 1, 1978.

The most frequent minimum monthly values belong to the interval 50-70 cm representing together 35%, the rest being attributed to the intervals situated in the immediate vicinity, either superior or inferior.

The maximum yearly values occur especially during the winter and in the autumn, based on the general water level decrease. For the period under analysis, such values have never been recorded during the months of April, May, and June.

Because of the big differences between the absolute maximums and minimums recorded in Razim and Golovita lakes, the interval of variation increased significantly by comparison to the previous period, the maximum amplitude recorded recently being of 150 cm (the previous values calculated by Breier Ariadna [9] were of 106 cm) while the maximum annual amplitude is of 120 cm in 1988 (the maximum annual level was of 153 cm at Sarichioi and the minimum annual level was of 33 cm at the same station).

4 Hydrochemical Characteristics

From a hydrochemical viewpoint, until 1974, extremely important was the existence of the communication with the sea, as well as the sense of this communication. The normal drainage process in Razim-Sinoie complex is from the lake to the sea, because the levels of the lakes' waters were generally above 0, and through this drainage process is eliminated a certain quantity of water with a mineralization of 1-2 up to about 10 g/l. The accidental penetration of the seawater during strong storms brings a water input with a higher mineralization (13-15 mg/l).

During the period that preceded the execution of the canals ensuring the connection with Dunavat and Dranov rivulets, the water of Razim Lake used to have a salinity that was close to that of the Black Sea and even higher during certain periods [2], then it was variable during the period 1924-1925 (2.6 g/l in June 1924 and 7.8 g/l in October 1925 [8]), after that, in 1937 it reached the level of 0.5 g/l in Razim and 1.5 g/l in Goloviţa [5], [24], [28]. In Sinoie Lake, the salinity of the water also differed in time: in June 1912 its value was of 16.7 gr/l [2], during the period 1924-1925 it recorded higher values than those of the Black Sea, respectively of 27.8 g/l (October 1925, [8]) and afterwards in 1937, it decreased to 8.7 g/l. These great differences between the values recorded during relatively short time intervals (1924-1925) are explained by the differences of alimentation with water from the Danube and by the temperatures regime.

In 1951, the water salinity in Razim Lake varied between 1.14-2.15 g/l in Holbina Gulf, 2.95 in Fundea Gulf, 3.77 g/l in Dunavăţ-Coşburun area and in the rest of the areas it ranged between the limits of 4.0-13.5 g/l. In Sinoie Lake, the values varied a lot, ranging between 26.56 and 38.70 g/l [28].

After the completion of the hydrotechnic works of the period 1956-1959 [4] when Fundea-Lipoveni canals were dredged (1960) and the underwater threshold from the opening Gura Portiţa was built, the water salinity decreased in the north of the lacuster complex in the year 1961, reaching the value of 0.5-0.7 g/l [6], [7].

The salinity in Razim-Sinoie complex is distributed non-homogeneously and increases from north to south gradually as we go further from the sweet water source.

Starting from these observations, we can say that the salinity of the lakes' waters in Razim-Sinoie lacuster complex has recorded a continual decrease during the period of 1950-1970, the lowest values being registered in the north of Razim Lake and at the mouths of the canals ensuring the connection with Sfântu Gheorghe branch. The variation limits of the values for this interval were narrow for Razim and Golovita lakes, the existing fluctuations of the respective period being triggered by the hydrological regime of the Danube and by temperatures. For Sinoie Lake, the decrease in salinity was continual and serious, and in an interval of 20 years the final values became 10 times lower than the initial salinity values, from 20 g/l in 1950 to almost 2 g/l in 1970.

After 1970, through the closure of the mouth Gura Portiţa and the arrangement of the canals, the sweet water input coming from the Danube increased, the water salinity and the total salts concentration being stabilized in the northern compartment (Razim-Golovita) in the interval of 0.4-0.6 g/l (up to 0.2 g/l NaCl) with a slight increase from north to south (in 1969 water mineralization varied between 6.53 g/l in Razim near Sarichioi commune and 5.2 g/l in Sinoie [9].

At present, in Sinoie lake, the total salts content is normally situated in the interval 0.5-1.5 g/l, but it is not stabilized yet, being dependent on the regime of the Danube waters and on the functioning regime of the harbour locks from the canals II and V. During certain years, the content of total salts can exceptionally reach much higher values. In parallel with the gradual salinity reduction and salts content decrease occurred the modification of the water's hydrochemical type. In all the old analyses, regardless of the mineralization, the NaCl type is dominant. Beginning with 1961, the influence of the Danube water gradually becomes more and more visible, and the mixed hydrochemical type becomes more frequent and finally extends up to Dolosman Cape.

5 Hydrobiological Characteristics

After the drag workings of the channels Dunavat (1905) and Dranov, which had at their bases the results of the made researches by Grigore Antipa (1984) it was produced an improving of the hydro-biological characteristics of the lakes a thing proved by the further evolution of the complex. At the beginning of the '50 of the last century the salinity system's problem represented the object of some systematic researches, in order to increase the fish-culture's productivity and in order to guide the fauna's structure to valuables species from the economic point of view [13].

From 1980 to 1983, the submersed macro-pits are also present but as small parts, isolated and they could rarely be met in Golovita and rarely in the north of the Razim Lake.

In the Sinoie Lake the process of water sweetness determined the regress of typical slamantric species and the installation of some abundant association of *Potamogeton pectinatus, Ceratophillum Demersus, C. Submersum* but only till the deep of 1.5 m.

During the time with a saltish system, the phyto–plankton of the Razim Lake was weak developed but it could be establish an increase of its density and in general of the plankton productivity in the times and areas when the salinity was reduced.

They were registered "blossoms" of the waters produced by Ditalomeae in spring and Cianoficeae in autumn. From 1979 to 1991, in the same time with the increase of ph phyto - plankton productivity, it was registered a decrease of the number of species from a number of 140 species to 75 species [15].

For the smaller lakes, as Babadag, the studies made by Liliana Torok in 1995 [29] put in evidence the oscillated evolution of vernal dynamic and summer dynamic of the plankton Ditalomeae. For the analyzed time (Mars- June 1995) the author conclusion that it exists two times of algal blossom of water and one with intense modification quantitative and qualitative.

The analyze of the structure and dynamic of the zoo- plankton association must have in view the aquatic characteristics and dynamic influence at which this is exposed the presence of the tropic levels in this ecosystem under the form of a chain or of a pyramid must have in its view the diversity of the existent species and the way of walking and their life time.

Starting from these considerate the made studies in the time with a saltish system of the complex Razim-Sinoie put in evidence a dominating structure of rotifer with a number of almost 60 species [28], the salinity system influence the composition of species even if the rotifers maintained the numeric domination.

The eutrofisation process that was generated at the beginning of 1980 and 1990 in Danube Delta and in the complex Razim-Sinoie determined the decrease of the species numbers with more than 53% in the same time with the increase of species numbers (4.7 times), of biomass (6.9 times) and the productivity (4.8 times) [30].

Also the density and the phyto - plankton biomass evolutes progressive in the same time with the increase of temperature, high values were registered in July and August and in the case that the water temperature stays high they can be registered high concentration until October (eg. the Sinoie Lake, October 1993 [1]). The studies made by the mentioned authors put in evidence for the Razim Lake a byodiversity reduced with 18 species in September and 16 in October 1995. Dominating are the crustacles species, from the copepode can be meet *Paracyclops affinis, Macrocyclops albidus* (in September) şi *Cyclops vicinis, Macrocyclops fuscus* (in October). Due to the sweet water and the nutrition factors from the connection channels with Sf. Gheorghe channels (channel Muscata in the present study) at their river mouth in the lake Razim can be observed an explosion of zooplankton a thing that determines law values of the solved oxygen, so a maximum deficit [26].

In the lake Golovita the physic properties and chemical properties of water and also the hydrologic and biologic parameters determine the distribution and the abundance of organisms [27]. The biodiversity is weak and they exists small differences about the number and the type of species in the west, center and east of the lake.

In the actual hydrographic system of the complex in which the water salinity doesn't represent an important factor it is maintained the rotifere domination that can go over 80% from the zoo plankton number, while 70-90% from biomass are parts of small cladocere from the type *Moina, Chidorus and Chidorus and Copepodelor* [3].

The benthonic fauna is well developed and it's made from elements with a big nutritive values, the researches made in the lakes of the complex Razim- Sinoie between 1950 and 1960 when the salinity had different systems and uncontrolled putting in evidence an increase of the biologic productivity once with the salinity decrease. The comparative researches upon the benthonic fauna made between 1951 and 1952 and 1955- 1956 where they were registered different systems of salinity, it was evidenced that the salinity decrease has as result the increase of productivity but also the decrease of the species number.

Between 1980's, the epiphytic fauna represented a quantitative domination of 50% from the benthonic fauna from the complex Razim, after 1980, in the same time with the increase and the disappearing of the submerse macro-phyts, this important tropic level has lost step by step the importance in the structure and the function of the ecosystem [3]. The effects of the process of eutrophization is reflected also in the simplification of the structure on fauna's species where they can be met only 1-2 species of chironomide but which realize a bio-mass level quite high. Ephy- fauna which registered in the past important densities and qualities at the interface sediment- water registered an important regress.

For the lake Sinoie, as in Lake Razim's case, the changes that appeared in the fauna evolution of benthic non-vertebrates are closed by the changes of general conditions of the ecosystem, especially of the salinity system. The salinity decrease, the close of the connection with the Black Sea and the acceleration of the pollution and eutrophisation had as result a continue decrease of the biodiversity [25].

Under the circumstances of the high salinity level that varies between 17-20 g NaCl/l, the bio-mass of the benthonic fauna had high levels, being advantaged by the absence of some important costumers, the fish species from Sinoie are especially sea species of small dimensions, with the exception of some years when the grey mullet migration were more intense.

After 1974, the Sinoie Lake evolute in a low saltish level system, the biocenoza is made from species dominating of sweet waters. The average total annual of benthonic kept in 1977- 1979 increase, registering values close to the ones from the complex Razim, to 300 kg/ha, from which the shellfish are excluded, 64.5 kg/ha. This time it was registered an increase of the species diversity till 49 of taxonomies from which 55% sea species, 39% salty and sweet water species and 6% sweet waters species, this thing is possible due to the ionic reserves from the sediments placed on the lake bottom which substitute partially the osmotic equilibrium at the interface water-sediment [25].

If at the beginning of the salinity decrease it could be observed an increase of the species diversity, an increase that continued to the end of the years 1980 (from 49 taxonomies in the previous time to 79 taxonomies from which 48% sea species, 44% salty water species and 8% sweet water species), step by step it appeared the situation that an entire series of species and groups of organisms to disappear so, beginning with 1982 the majority of the sea species were replaced with the sweet water species and in 1988 they were identified just 14 species salty water and no sea form. The quantitative analyses put in evidence the fact that the benthic fauna is continue simplified through the decrease of bio-diversity, the only group that makes an exception is the one of chironomidelors, the time with the biggest special bio-diversity being met in 1978-1988 when the Laguna had a saltish hydro-chemical system.

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Protection of Lake Ohrid from Wastewater

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Abstract. Thanks to the natural characteristics, Lake Ohrid is declared as a natural monument, put under special protection, enforced with Law, and included in the list of world natural treasures of UNESCO. In order to provide global protection of Lake Ohrid and conservation of its sensitive ecosystem, measures have been undertaken for construction of regional sewage system for protection of the Lake from wastewater. The construction rate of the facilities of the regional sewage system provides collection, discharge and treatment of approximately 75% of the wastewater, produced in the region. Efforts for Protection of Ohrid Lake resulted with: preparing of Feasibility Study for Protection of Lake Ohrid from Macedonian side in 1979 year, preparing Study for Integral Protection of Lake Ohrid from Macedonian and Albanian in 1995 year.

Keywords: Ohrid Lake, protection, sewage system, development

1 Introduction

There are no many places in the world as region of Ohrid Lake. Main characteristic of the region is given from the shining Lake's water that splash the shore and unique ecosystem with many endemic species of flora and fauna. The mountains that surround the Lake are above 2000m giving magnificent views on the Lake blueness and living settlements around the Lake. Nature was really generous to this region. Probably that is basic reason for huge human interest for this region and urban expansion at the same time. Thanks to the natural characteristics, Lake Ohrid is pronounced as a natural monument, put under special protection, enforced with Law, and included in the list of world natural treasures in UNESCO. Rapid development of Ohrid/Struga region made big influence to the region, resulting with negative changes to the ecosystem of the Lake.

In order to provide global protection of Lake Ohrid and conservation of its sensitive ecosystem, measures have been undertaken for construction of regional sewage system for protection of Macedonian part of the Lake from wastewater.

2 Regional Sewage System for Ohrid Lake Protection

Basic concept for regional sewage system for Protection of Ohrid Lake is prepared in 1979 year. Its realization was developed accordingly financial possibilities. Regional sewage system is designed to receive, evacuate and treat all wastewater in the Lake region. Treated water from the treatment plant is sent into the river Crn Drim that's mean away from the Lake

3 Facilities of the Regional Sewage System

Regional sewage system for protection of Lake Ohrid facilities are described as follows. Secondary sewage network in Ohrid: total length 108 km, mixed sewage network 54km, separated fecal sewage system 43km, atmosphere sewage 15km, 6 pumping stations, pipes profile Ø200mm- Ø600mm, material asbestos-concrete, PVC, PE, concrete. Secondary sewage network in Struga: total length 59 km, 7 pumping stations, pipes profiles ∅200mm-∅600mm, material asbestos-concrete, PVC, PE, concrete.

Table 1. Detailed data about the Primary Collector

Section			Pipe lines			
No	From pumping station	To pumping station	L (m)	D (mm)	J (%)	material
1	Elesec	Metropol	1.852	600	0.20	PVC
2	Metropol	Granit	1.400	600	0.15	PVC
3	Granit	O.Nikolov	1.550	800	0.15	concrete
4	O.Nikolov	Ohrid 1	3.000	800	0.15	concrete
5	Ohrid 1	Ohrid 2	1.045	1.000	0.10	concrete
6	Ohrid 2	Daljani	3.337	1.200	0.15	concrete
7	Daljani	Podmolje	5.006	1.200	0.08	concrete
8	Podmolje	Sateska	2.404	1.200	0.17	concrete
9	Sateska	Struga 3	4.264	1.200	0.10	concrete
10	E.Kamen	Struga 3	9.102	150-600	-	PE
11	Struga 3	TP Vranista	3.934	1.200	0.08	concrete
	Total:		36.894			

Treatment plant for the waste water: capacity 120.000 living inhabitants, average daily hydraulic charge Qcp/day=40.000 m^3/day, biological daily charge 7.300 kg BIOD 5/day, waste water treatment mechanical and biological (aerobe process), quality of treated water $\leq$ 25mg BIOD 5/l, suspend materials S$\leq$30mg/l, PH 6.5-8.5, collected and treated waste water is discharged in the river Crn Drim away from the lake. The construction rate of the facilities of the regional sewage system provides collection, discharge and treatment of approximately 75% of the wastewater, produced in the region.

Table 2. Installed capacities at the pumping stations of the primary collector

	Pumping station	Number of pumps	Capacity of one pump (l/s)
1	Metropol	2	85
2	Granit	2	130
3	Orce Nikolov	2	170
4	Ohrid 1	3	315
5	Ohrid 2	3	425
6	Daljani	4	400
7	Podmolje	4	410
8	Sateska	4	410
9	Struga 3	4+3	412/225
10	Vranista	4	560
11	Industrial zone	2	200
12	Kalista	2	24,4
13	Elen Kamen	2	24,4

4 Financial Aspects of Construction and Maintenance

Financial assets are often restrictive factor for realization of predicated dynamic for construction of the Regional sewage system. From our resent experience we will mentioned couple sources of financial assets used in construction of the system.

Financial sources assets for financing the construction: budget of the Republic of Macedonia, budget of Ohrid and Struga Municipalities, Ohrid and Struga citizens' contribution, Proaqua's own participation, donations from German Government Donation » 11 million Euro and Swiss Governmental Donation » 2 million Chf.

Financial sources assets from current work: users of the services for evacuation and treatment of the wastewater.

5 Sewage System Functioning Effects on Lake Ohrid Protection

The contribution of the sewage system functioning in Lake Ohrid region in the global protection of the Lake is obvious. More than half of Macedonian Lake shore is equipped with technical possibilities for acceptance, transport and treatment of the wastewater. Such enabled technical possibilities result with treatment of more than 15.000.000.00 m^3 urban waste water in the treatment plant and treated water is sent in the river Crn Drim.

Effect of Regional system for Protection of Lake Ohrid functioning can be presented with following parameters: efficient and sanitary correct management with waste water in city of Ohrid and Struga where high level of connection is achieved, for city of Ohrid 92% and for city of Struga 90,1% that means approximately 15 million m^3 urban waste water annually is transported from the lake shore to the treatment plant "Vranista"; process of building sewage networks is initiated for receiving and treatment of the waste water in rural areas especially within the Lake shore; outflow of the treated water out of Lake Ohrid; correct work of the treatment plant is assured in compliance with EU directives for waste water; MJP Proaqua personnel is educated to manage the process of receiving, transporting and treatment of urban wastewater giving 20 years contribution in keeping the Ohrid Lake glow; general conclusion of institutions in charge for monitoring of Lake Ohrid: " Due to the construction and functioning of the sewage system in the region , water from the Lake is with high quality on the places where the sewage system is established".

6 Concept for Development of the Regional Sewage System

Middle -Term Development till 2010 Year: Phase 1 (till 2005): Realization of the Priority Measures according to the Project for Environmental Protection of Ohrid Lake financed by German Government (donation). Phase 2: Concluding the Primary Collector Elesec-Pestani, Elen Kamen-Radozda.
Long - Term Development till 2025 Year: Planning of the long term development of Regional sewage system of Ohrid and Struga from one side, planning for discharge and treatment of the urban waste water from other settlements in the river basin of river Crn Drim will be prepared accordingly the articles of the Law for waters (Official gazette of Republic of Macedonia No. 87/2008) that will enter into the force from 01.01.2010 year.

7 Conclusions

In order to provide global protection of Lake Ohrid and conservation of its sensitive ecosystem, measures have been undertaken for construction of regional sewage system for protection of the Lake from wastewater. The construction rate of the facilities of the regional sewage system provides collection, discharge and treatment of approximately 75% of the wastewater, produced in the region. Efforts for Protection of Ohrid Lake resulted with: (a) preparing of Feasibility Study for Protection of Lake Ohrid from Macedonian side in 1979 year; (b) preparing Study for Integral Protection of Lake Ohrid from Macedonian and Albanian in 1995 year.

In 2000/2001, a General Plan for development of the regional system till the year 2025 was prepared. In the first phase of the middle term development of the system (2000-2005), the priority measures contained in the Project for Environmental Protection of Lake Ohrid had been realized. The objective of the priority measures were to contribute to the protection of the lake, by reducing the input of wastewater into the lake, reaching the collection rate of wastewater of over 80% for the both cities Ohrid and Struga. The contribution of the sewage system functioning in Lake Ohrid region in the global protection of the lake is obvious. The general conclusion of the institutions, responsible for monitoring realization is the following: "on the locations where the sewage system is constructed and is in function, the water in the lake is with good quality, thanks to the construction and functionality of the sewage system".

Additional efforts for extending the Regional sewage system are made that are predicated in phase 2 from the middle term development that have to be done till 2010. Long term planning till 2025 will be made in common with the articles from the Law for water (Official gazette of Republic of Macedonia No. 87/2008) that will enter into the force from January 2010.

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Changes of Ecological Status of the Keres River

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Abstract. The aim of the paper is to present the long-lasting problem of pollution of the small river Keres, which has its source in Hungary and in its lower course flows into the Tisa River in Vojvodina. The results of analyses conducted on a monthly basis from 2003 have shown that the water of the Keres is highly polluted, i.e. it falls in the category of sewage water. High COD values, significantly above the maximal allowed concentration for the Serbian 4th class evaluation (40 mg/l) were recorded since the end of 2004, even up to 164 mg/l. Along the entire watercourse the Keres is loaded with As, Cr and Cu above the allowed MAC. The accumulation of As, Ba, Cu and Sr in plants Plantago major, Sas carex and Phragmites australis at locations 100 m upstream from the Ludos Lake and at Adorjan village is particularly significant.

Keywords: River Keres, pollution, heavy metals, COD

1 Introduction

The small river Keres flows from Hungary to Serbia, where after a short course flows into Ludos lake, and further towards the Tisa. The water quality of the Keres river is in category II, according to current regulations [1]. The flow of water in our country, upstream from Ludos lake, depends mostly on the amount of water discharged in Hungary.

The sewage waters from Subotica flow through the roundabout channel around Palic lake into the Keres, and further into the Tisa river. The repairing of sewage waters purifier from Subotica, which started in 2004, resulted in severe aggravation of the Keres water quality, and its low capacity water current has the characteristics of sewage waters.

2 Material and Methods

Quality investigations of the Keres River in Serbia, as well as the sampling, were performed according to literature references [2]

HPK was determined by Kubel method, with acidic $KMNO_4$.

The concentration of nitrites was determined with α–naphtylamine, after diamination.

The chemical parameters were analyzed according to literature reference [3],[4]

The spectrophotometric measurements were performed at 543 nm. The Spectrophotometer KONTRON, type Uvikon 930 S/N 27-1872, was used in experimental analyses.

The concentration of heavy metals in the Keres river water was determined at different locations: A – 1,000 m upstream from Ludos lake, B – at the dam below Ludos lake, C- at the border of SO Kanjiza, D– 200 m after the fishpond in Kapetanski rit, E– at Adorjan.

The concentration of heavy metals and metalloides in water was determined by the Atomic absorption spectroscopy method, with graphitic cuvette, according to Hungarian standard [5]

The concentration of heavy metals and other elements in plants *Plantago major,* Sas *carex, Phragmites australa* was determined at the localities 1,000 m upstream from Ludos lake and at Adorjan, where Keres entersTisa.

The determination of content of chemical elements in the plants was performed by the Atomic absorption spectroscopy with graphitic cuvettes, according to Hungarian standard [6] (GFAAS-Varian Spectra AA800).

The analyses of chemical elements in water and plants were performed at the Corvinus University in Budapest.

3 Results and Discussion

The pollution detected in the Keres Kiver can be the organic load and the load with heavy metals.

The organic load detected in the Keres starts at Ludos Lake. The highest HPK values were ranging from 120 to 160 mg/l. The change of HPK values from 2003 (before the Keres degradation) till August 2007 is presented in Fig. 1. The latest results show that the Keres River is, and was in previous years, in the category of sewage water.

The pollution detected since autumn 2004 reflected on the increase of nitrite and nitrate ions in water.

The concentrations of nitrite ions during 2003, 2005, 2006 and 2007 are presented in Fig. 2.

During 2003, the values for nitrite ions were in the range prescribed for quality clases 1 and 2. In the following two years the values increased about 10 times, on the average. The highest nitrite concentration, 0.81 mg/l, was measured at the end of August, 2005. In 2006 and 2007 the concentration of nutrites in the Keres water was beyond the limits of normatives for class 4.

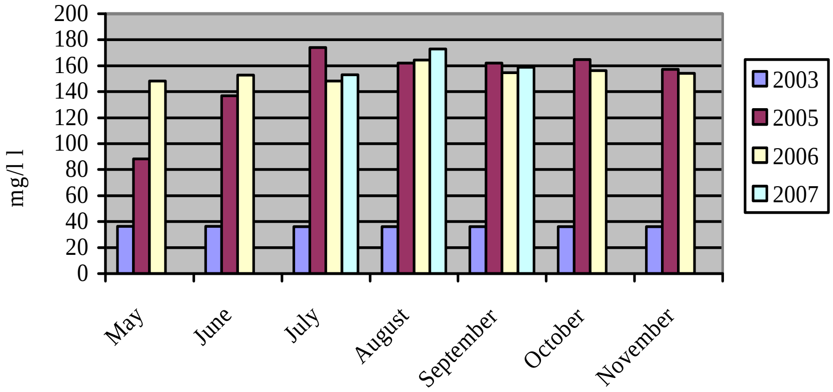

Fig 1. COD values in Keres River in 2003, 2005, 2006 and 2007

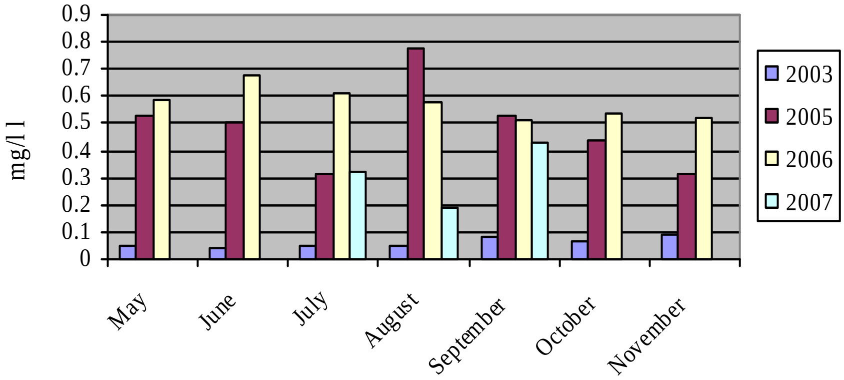

Fig 2. Concentration of nitrites in Keres River in 2003, 2005, 2006 and 2007

The values for nitrate ions in 2003, 2005, 2006 and 2007 are presented in Fig. 3. In 2005, 2006 and 2007 the nitrates concentration is in the range for 3 and 4 quality class, whereas the values are several times higher compared to 2003, the year which can be considered as the referent one.

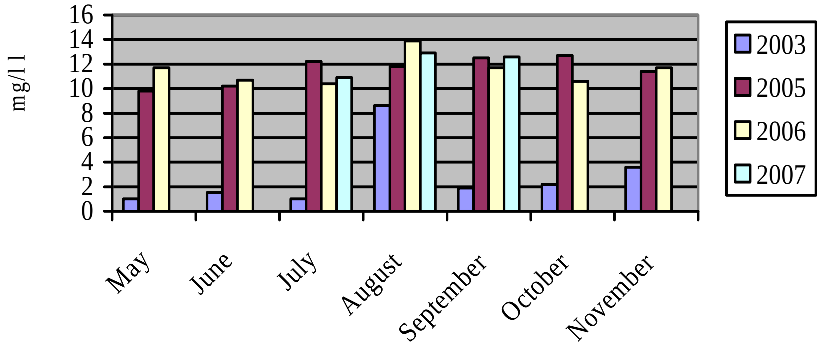

Fig 3. Concetration of nitrates in Keres River in 2003, 2005, 2006 and 2007

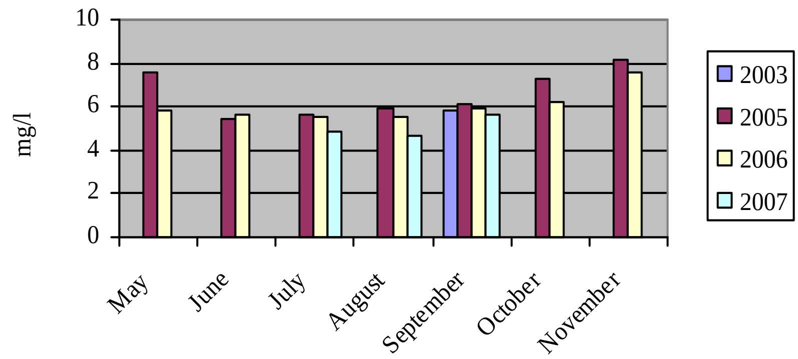

Fig 4. Concentration of dissolved O_2 in Keres River in 2003, 2005, 2006 and 2007

During the whole period of investigation, the concentrations of dissolved O_2 were from 4.7 to 9.1 mg/l.These values are within the range of usual seasonal deviation of this parameter in the function of water temperature change.

In the entire investigated period pH value of Keres river was in the range 6 – 9. The neutral, i.e. salt-basic medium remained **,** apart from the presence of high organic load. Figure 5 presents pH values in the Keres River.

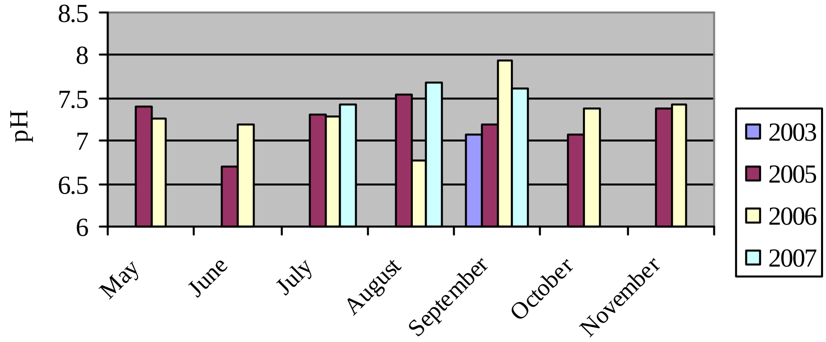

Fig 5. pH values of River Keres

The concentration of heavy metals in the Keres River water was determined at different locations : A– 1,000 m upstream from Ludos lake, B– at the dam below Ludos lake, C– at the border of SO Kanjiza, D– 200 m after the fishpond in Kapetanski rit, E– at Adorjan. The obtained results are presented in Fig. 6.

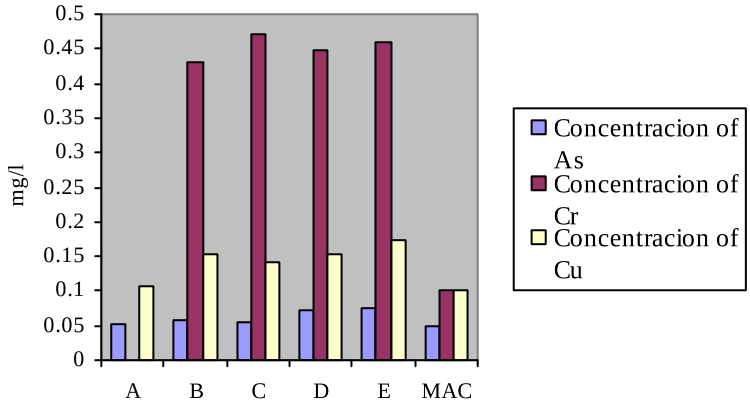

Fig 6. Concentration of As, Cr and Cu in Keres River, MAC - maximum accepted concentrations

Along the entire watercourse the Keres is loaded with As, Cr and Cu above the allowed MDK. The piling-up of As, Ba, Cu and Sr in plants *Plantago major, Sas carex* and *Phragmite*s *australis* at locations 1,000 m upstream from Ludos lake and at Adorjan is particularly significant. In addition, at Adorjan, Cr was also detected in plants. The results stating the piling of heavy metals in water plants are presented in Table 1.

Table 1. Concentration of metals, metalloides and nonmetals in water plants (in μg/g)

Metals	Plants					
	Plantago major		Sas carex		Phragmites australis	
	A	B	A	B	A	B
Al	92.23	260.2	140.7	41.4	90.29	107.16
As	3.74	3.91	2.70	4.89	3.30	3.4
B	16.7	19.5	6.04	12.61	9.15	10.25
Ba	31.37	30.59	23.44	20.97	30.26	22.05
Ca	17,180	23,778	4,532	5,163	3,170	3,861
Cd	< 0. 5	< 0. 5	< 0. 5	< 0. 5	< 0. 5	< 0. 5
Co	< 0. 5	< 0. 5	< 0. 5	< 0. 5	< 0. 5	< 0. 5
Cr	< 0.5	1.12	< 0.5	1.48	< 0.5	0.96
Cu	11.66	10.97	9.6	6.7	6.6	6
Fe	346.1	416.8	152.2	635.5	71.64	73.83
Ga	0.91	0.97	1.71	2.27	1.77	2.36
K	41,802	38,745	20,507	14,699	20,415	19,997
Li	0.79	0.81	0.42	0.83	0.31	0.31
Mg	4,374	4,873	2,021	2,410	1,548	1,851
Mn	27.92	33.92	121.5	193.8	91.11	99.25
Mo	< 0. 5	< 0. 5	< 0. 5	< 0. 5	< 0. 5	< 0. 5
Na	1,401	870	1,744	1,328	1,110	747.6
Ni	0.77	1.12	0.57	0.76	0.928	1.73
P	2,795	2,808	1,550	1,408	1,800	1,403
Pb	<0. 5	<0. 5	<0. 5	<0. 5	<0. 5	<0. 5
Se	<0. 5	<0. 5	<0. 5	<0. 5	<0. 5	<0. 5
Si	384	329.4	693.2	324.6	720.5	413.5
Sr	74.43	105.8	17.4	25.59	41.52	49.53
Ti	1.03	5.597	2.261	10.79	0.8933	1.7019
V	<0. 5	<0. 5	<0. 5	<0. 5	<0. 5	<0. 5
Yn	25.41	30.41	15.04	26.25	13.35	14.35

According to the first (non-reported) results, lymphocytoses was found in several kinds of small art of carp fish, pointing to stress in fish from Kapetanski rit. due to organic pollution. The planctone composition of the Keres favors the fact that water quality is in category IV i.e. in the class of sewage waters

4 Conclusions

Contrary to official categorization. during the investigation period. from 2004 to 2007. the quality of the Keres River was found to be in the category of sewage waters since the reconstruction of city sewage water purifier in Subotica started [7],[8],[9].

Sewage waters from Subotica affected directly quality of the Keres, degradating it to the level of collector of pollutants. The problem is that the water of Keres River was used during draft periods for irrigation of this distinct agricultural region in Serbia. For this reason, the monitoring of Keres, as the tributary of Tisa River , in the scope of the project "Continuous investigation of Tisa river from Martonos to Senta". is of great importance for the local population of this region.

The pollution. which can be of public and industrial type, appears mainly as an organic load – presented through very high HPK values. The latest results, obtained in September 2007,show HPK was 160 mg/l in the Keres. This value being four times higher compared to the situation before the repair of the sewage water purifier in the city of Subotica .[10]

The pollution with some heavy metals and metalloides (As) over the limit values for the 4^{th} class (according to JUS categorization) was also registered at almost all monitored locations in the Keres. Besides, the toxic elements are already piling in water macrophytes [11]. The origin of these pollutants corresponds to pollutants of industrial waste waters of Subotica. except As. There is no reliable proof, however. It seems that this pollutant comes from Hungary.

During 2006 and 2007. mud was removed and the Keres riverbed was revitalized. In this period. activities were performed on 7 km and 15 km long sections. respectively. A total of 75.000 m^3 of earth was removed from the Keres riverbed. The mud from the Keres is located in the form of embankment on agricultural land. Having in mind that the leveling of the embankment is planned. the incorporation of mud into the cultivable soil and the contamination with heavy metals is a reasonable danger.

Acknowledgements

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Paper: **A37**

Delving Deeper into the Hydrodynamics of Karstic Lakes: one more Step to Improve Environmental Management and Ecohydrology

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Abstract. Hydrodynamics determine mass and heat fluxes and should therefore be included in either management or ecohydrological models. That is especially true in the case of karstic lakes where, apart from wind and surface heat flux forcings, baroclinic and convective instabilities due to the underground inflow must be considered. These forcings may dominate the general circulation and affect the stratification and general mixing of the lake which can vary depending of the area of the lake. The case of Lake Banyoles, in Catalonia (Spain), is being presented as an example. This lake has the particularity that the small particles coming from the aquifers which are dragged away from the sources can be used as tracers to study its dynamic.

Keywords: Karstic Lake, hydrodynamics, mixing, geothermal plume, baroclinic current, internal seiches

1 Introduction

Lake Banyoles is the largest of a series of five lakes (some intermittent) located in the same hydrographic karstic basin in Catalonia (northeastern Spain), and the second largest natural lake in Spain. The area is very instable and last lake was only formed in 1978. Lake Banyoles has a surface area of 1.2 km^2, a mean depth of 14.8 m and about 95% of its total inflow enters the lake through twelve warm underground springs. All outflows from the lake are located along its eastern shore at the surface. The main aquifer, a limestone layer under gypsiferous rocks, is corroded and small particles remain in suspension and form fluidized beds in the conic-like sub-basins (dolines) where springs are located [1]. Because of the high number of dolines forming the lake, it is highly heterogeneous, and based on the thermal stratification down to the bottom it can be considered as formed by six different sub-basins (Figure 1). Basins B-I and B-II are located in the southern lobe of the lake with a mean depth of 18.2 m. The northern lobe, where the majority of the sources are located, has a mean depth of 9.7 m and it is connected to the southern lobe through a narrow neck with a maximum depth of 10 m. The lake is holomictic so, once a year there is a physical mixing of the surface and the deep waters, with exception of basin BIII, the bathymetry of which favors meromictic behavior.

In the first part of the paper (sections 2-5) previous studies on the lake are reviewed and in section 6 new data are presented to illustrate the importance of the 3D structures.

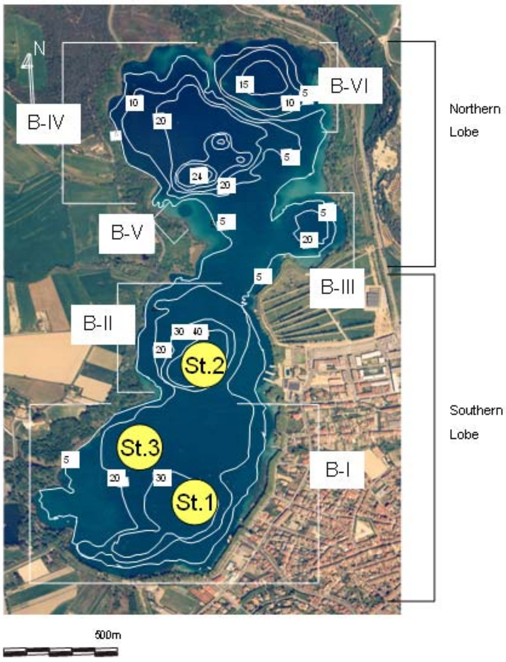

Fig. 1. Bathymetric map of Lake Banyoles with indications of the sub-basins (from B-I to B-VI) forming the lake, which from the surface appears to be formed by two main lobes, the northern and southern lobes. The location of the sampling stations (St.1, St.2 and St.3) mentioned in section 6 is also shown

2 The Fluidized Beds

A great majority of particles within the fluidized beds mentioned in section 1 have a diameter between 1 and 20 μm [2] and in suspension behave like a monodispersive system [3]. Under stationary conditions, the particle sedimentation velocity, a decreasing function of particle concentration, is counterbalanced by the velocity of water advection. When the water inflow increases, the fluidized bed expands, and its upper localized interface—the lutocline—rises sometimes nearly 20 m over ten months [1].

In Figure 2(a) echo sounder profiles of some of the underground sources are presented. Note the sharp and stable lutocline at the upper part of the fluidized beds across which the sediment concentration decreases from about 200 mg/l to 5 mg/l [4]. The mean extension of the lutocline measured during different campaigns is shown in Figure 2(b) The formation of the lutocline was well predicted by a k-eps model and the results showed a severe damping of the turbulent kinetic energy at the lutocline level [5].

3 Underwater Mass and Heat Inflow

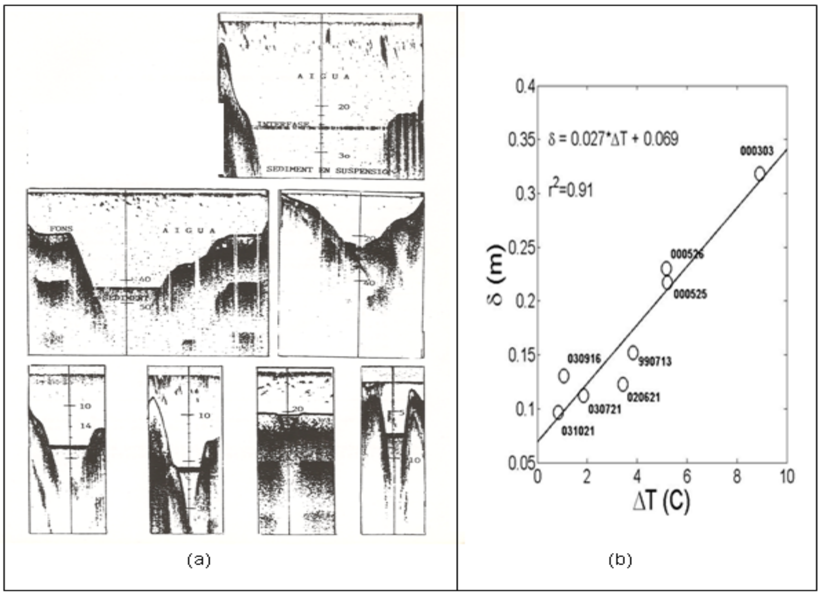

Fig. 2. (a) Echo sounder profiles of the seven larger underground sources recorded on 22nd of May 1986; (b) Mean thickness of the lutocline measured during several campaigns carried out from 13th of July 1999 (990713) to 21st of October 2003 (031021) together with the difference of temperature across it.

In Figure 2(a) the stability of the upper interface of the fluidized bed can be observed within the entire spring basin (up to 200 m of diameter), which supports the idea of a laminar regime below the lutocline in accordance with the results of the k-eps simulations mentioned in section 2. The lutocline in fact is located at the level where the upward inflow velocity equals the settling velocity of the particles within the fluidized bed. Settling velocities can be obtained by withdrawing water samples from discrete levels and immediately measuring the settling rates. Accordingly, under stationary conditions, the underground inflow through every individual spring can be obtained by knowing the cross-sectional area of the basin at the sampling depth, the porosity of the suspension, and the settling velocity of the particles below the lutocline [3]. Doing so reveals that, in many situations, about 90% of the total underground inflow enters the lake through basin B-I, located in the southern lobe, and that the underground inflow into the northern lobe is less than 5% of the total inflow to the lake.

Fluidized beds are warmer than the hypolimnetic water and in winter their temperature can be as much as 10°C higher. Thermal interface at the upper surface of the fluidized bed coincides with the lutocline and has the same vertical extension. Based on the temperature profile across the interface, an alternative method to obtain the inflow velocity has been proposed when high resolution thermal profiles are available [6]. In this case, $U=-K_t(dT/dz)_{MG}/(T_0-T_1)$, where MG is the depth of the inflexion point of the thermal profile within the lutocline and T_0 and T_1 are the temperature of the fluidized bed immediately below the lutocline and the temperature at the thermal inflexion depth, respectively.

Knowledge of U allows computation of the thermal flux through the lutocline $F_Q=\rho C_v U(T_0-T_2)$, where T_2 is the hypolimnetic temperature immediately above the lutocline and T_0 immediately below, as already stated. Net phreatic heat flux into the lake in winter can be as high as 25 MW [7]. It has been found that phreatic heat inflow follows Newton's law of convection $F_Q=h\Delta T$, where h is the convective heat transfer coefficient [8]. In the case of B-I when considering $\Delta T=T_0-T_1$, the approach is very good and h was found to be (73±6) W/m^2K [6]. Relatively low values of the coefficient—in the order of fewer than 100—are usually found in natural convection [8]. Also if $\Delta T=T_0-T_2$, Newton's law approach is still good with h = 20±11 W/m^2K. In fact, this result indicates that within an error of 55% for the heat flux, we could consider a constant velocity inflow for basin B-I of U=5x10^{-6} m/s. This is in accordance with the data used for this parameterization: the mean values and standard deviation of U and ΔT, which were, respectively, (5±1) x10^{-6} m/s and (4±3) ºC. Note that the relative variability of U with respect to the mean is only 20% and that of ΔT is 75%.

Nonetheless, heat flux into the lake is sometimes found to happen under a diffusive layer convection regime. At the upper interface of the fluidized bed, particle concentration and salinity (decreasing upwards) have the opposite effect of temperature (also decreasing upwards) on the vertical density distribution and the corresponding density ratio may sometimes allow this regime to develop [9]. A multidiffusive step-like structure within basin B-II, with diffusive interfaces located at depths of 34.7, 35.2 and 35.4 m was measured at that time a second thermocline (different from the seasonal one) existed in the area, coinciding with the bottom of the lake around the depression area, at a depth of about 20 m. This second thermocline greatly isolates the conic region from the rest of the lake. Upward advective velocity was at least two orders of magnitude lower than the convective velocities within the convective layers.

On that occasion measured microstructure data allowed the resolution of the turbulent scales so that turbulent fluxes could be obtained experimentally [10].Experimental heat fluxes supported Fernando's model for low-stability regime [11] for double-diffusive convection, $Nu=4.7 \times 10^{-4} (Ra_D Pr)^{1/2}$, where Pr is the Prandtl number and Ra_D is the layer Rayleigh number, but also the Grossmann and Lohse unifying theory of thermal convection [12]. In this case data were in agreement with either regime IV_1, which keeps the classical 4/3 law [13], or with regime IV_U, which presents a dependence $Nu \sim Ra^{1/2}$, like Fernando's law. This coincidence suggests that data were in a transitional state between regimes IV_1 and IV_U. Kelly's approach usually applied in oceanographic studies [14] greatly diverges from our data which present a stability ratio of $R_\rho=1.1$.

4 Internal Waves and Baroclinic Circulation

Using a 1D model with Lagrangian layers, the thermal stratification for three main basins were modeled separately [15]. In the model the treatment of ground water inflow was introduced so that (daily) underground volume inflow was added to the lowest computational layer. If the resulting layer density was lower than that of the overlaying layers, the layers were successively amalgamated (from the bottom upward) until a gravitationally stable vertical profile was obtained. As a result, the seasonal thermocline was found to be considerably smoother than when the underflow did not exist.

Because of the absence of sharp thermoclines, the second highest vertical mode of internal seiches—stationary waves—is active during more than two-thirds of the whole stratified period [16],[17]. Some numerical results of the internal seiches in Lake Banyoles are presented in Fig. 3. Figure 3(a) shows the vertical structure of the horizontal and vertical velocity components for the second vertical mode and Fig. 3(b) the corresponding horizontal structure of the amplitude of the first longitudinal and transversal modes. Higher vertical modes (up to the 4^{th}) were later observed in reservoirs [18], where sharp thermoclines do not develop because of water withdrawal.

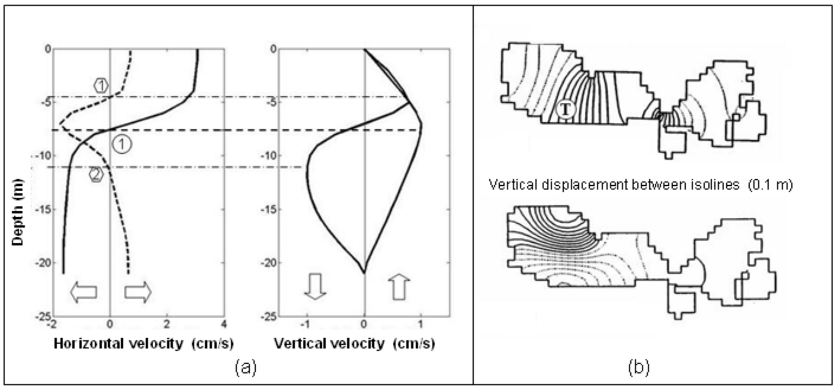

Fig. 3. (a) Vertical structures of the vertical and horizontal component of the velocity for a second vertical mode; (b) 2D horizontal structure of the vertical displacements of the first longitudinal and transversal horizontal modes.

Different cooling rates between the two lobes of the lake are important due to their different depths (section 1) and to the fact that about 90% of the phreatic inflow enters the lake through sources located in the southern lobe (section 3) which, being deeper, presents a higher thermal inertia. Accordingly, in winter a baroclinic flow develops carrying cooler water from the northern to the southern lobe; a counterpart surface flow carries warmer water from south to north [7].

In Figure 4 a scheme of characteristic winter heat fluxes in and out of the lake at the two lobes and the corresponding magnitude of the baroclinic flow is presented. As can be observed, the baroclinic current (20000 l/s) is found to be about 40 times greater than the highest inflow. This baroclinic flow induces the mass circulation of water in the entire lake about every five days and must therefore play an important role in lake-wide circulation and water quality. Residence time of the northern lobe would change from almost one year (if the baroclinic current did not exist) to a few days.

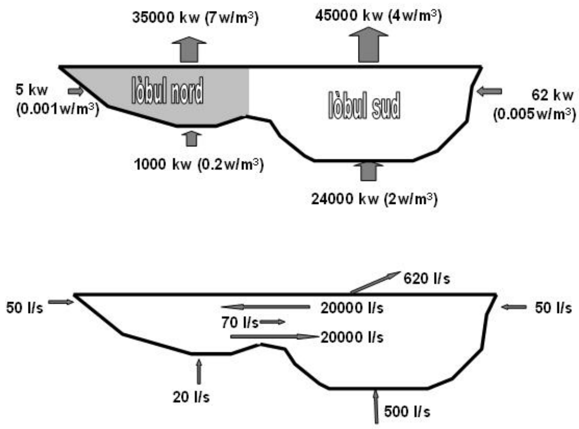

Fig. 4. Scheme of heat and mass fluxes in Lake Banyoles at the beginning of the winter season

Baroclinic flow is affected by the wind so that the higher the velocity of the southern wind components, the higher the velocity of the current, which can be found to be close to 10 cm/s. In this case the turbulent viscous diffusivity, which drives the exchange between water masses at the neck connecting the two lobes, is in a range between $2x10^{-2}$ to $7x10^{-2}$ m^2/s [19]. This result is in accordance with Alavian's parameterization of the entrainment coefficient with the Richardson number [20].

5 Hydrothermal Plumes

The dynamics above the hot lutocline is dominated by a convective plume up to the depth where the plume reaches its neutral buoyancy level. The existence of these plumes was first documented in 2001 when a hydrothermal plume with a vertical scale of about 18 m was presented based on microstructure and particle concentration data [21]. The plumes develop to a maximum height (h_{max}) from the lutocline, limited by the temperature gradient at the seasonal thermocline, if it exists, at the time it spreads laterally at the equilibrium height (h_{eq}), as shown in Fig. 5(a). Measurements were in accordance with the parameterizations $h_{max}=3.7(B_oD)^{1/3}/N$, where B_0 is the buoyancy flux, D the characteristic size of the hot plate (the lutocline in this case) and N the Brunt-Väisälä frequency [22].

Small particles (5-10 μm in diameter) are entrained from the lutocline and dragged upwards, modifying the clarity of the water column. Particle volume concentration, which ranges from 5-10 μm, affects not only the water quality of the lake. The ecology of the lake also depends on the plume dynamics as turbidity affects the photosynthetic activity of phytoplankton and constrains fish habitats [23].

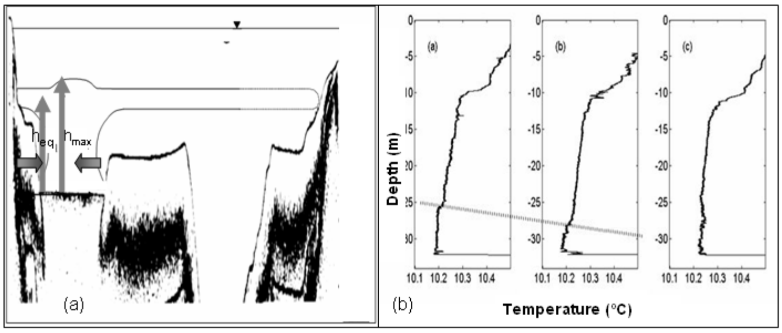

Fig. 5. (a) Scheme of a plume in Lake Banyoles reaching a maxim altitude h_{max} and intruding at altitude h_{eq}. Horizontal arrows show lateral intrusions into the plume. (b) Temperature profiles taken at three different stations within a radial section in basin B-I above the region covered by the fluidized bed.

As a result of the plume generation, surrounding (colder) water is entrained into the base of the plume. This can be observed in Fig. 5(b) where three different profiles obtained at three different stations located in a radial direction within B-I are presented. The first profile was taken at the most external station and the last one at the most internal. As observed, the thickness of the intruded colder layer decreases towards the interior of the source and it is not observed in the most interior region. As a result, this intrusion limits the base where the plume develops. In fact, lateral intrusions trigger high variability within the plume, which is only fully developed at a small central zone of the whole lutocline area. The forced convective regime within the intrusive layer presents high intermittency of the mixing process [24].

6 Spatial Heterogeneity during a Large Phreatic Inflow Episode

The interactions between the multiple processes present in the lake (summarized in the previous sections) becomes more complex during episodic events in which the phreatic inflow suddenly increases and until a stationary state is reached. In the following, we present the data from a campaign performed in February 2009 recorded at Stations St.1 and St.2 in basin B-I, and at Station St.3 in basin B-II. Stations St.1 and St.2 were located in zones where different subterranean springs keep the fluidized bed in suspension and Station St.3 was located far from the underground springs in an area where a fluidized bed doesn't exist. See Fig. 1 for the location of the stations in more detail. The campaign was carried out when, after a period of heavy precipitation at the percolation area of the aquifer, fluidized beds were expanding (section 2). During the campaign wind conditions were rather calm.

Data were collected by a microstructure profiler free sinking at a speed of ~ 0.85 m s^{-1} and sampling at a high frequency (1024 Hz). Dissipation rates of the turbulent kinetic energy were estimated by fitting the Panchev-Kesich shear spectra [25].

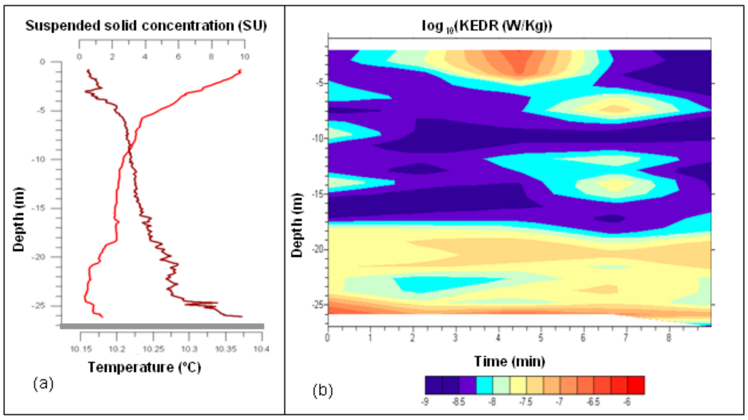

Fig. 6. (a) Characteristic temperature and suspended solids concentration profiles at station St.1. (b) Dissipation rate of turbulent kinetic energy, in logarithmic scale, computed from small scale shear profiles recorded in St.1 at times 0, 2.67 ,4.45, 7.05 and 8.98 min.

Figure 6(a) shows single profiles of temperature and turbidity, characteristic of the water column at St.1. Because of the huge increase of both variables in the fluidized bed, data from a few tens of centimeters immediately above the lutocline level—at 27.05 m—are not shown so that the structure of the water column for these variables can be visualized. More precisely, temperature in the fluidized bed increases up to 19.25°C and turbidity reaches the saturation level of the sensor. The fluidized bed is represented in Figure 6(a) with a grey rectangle. In this fugure, a colder layer is observed below 19.5 m depth which intrudes into the subsidence where the spring is located. Note that the depth of the plane bottom at the southern lobe is 20 m. Coinciding with this intrusion is a slight increase in turbidity. In general, turbidity decreases from about 8-10 SU at a few tens of centimeters above the lutocline to less than 1SU at 4 m depth. Towards the surface, turbidity increases again up to 2SU because of phytoplankton (identified with the chlorophyll sensor; data not shown). Temperature from about 19 m to 10 m is about 10.2 ºC, and then it increases smoothly up to the surface, at 10.4 ºC.

In Figure 6(b) the dissipation rate of the turbulent kinetic energy is represented for 6 profiles recorded at St.1 about every two minutes. High values of dissipation are observed within an area 1-2 m above the lutocline leve. The median value of dissipation above this region and within the intruded layer is still rather high, about ~10^{-7} W/kg, and then decreases in the rest of the water column down to the noise level of the sensor (10^{-9} W/kg), although some intermittent events with higher dissipation rates can be observed in the interior of the water column. Also near the surface directly affected by the wind, the dissipation rate increases in some of the recorded profiles.

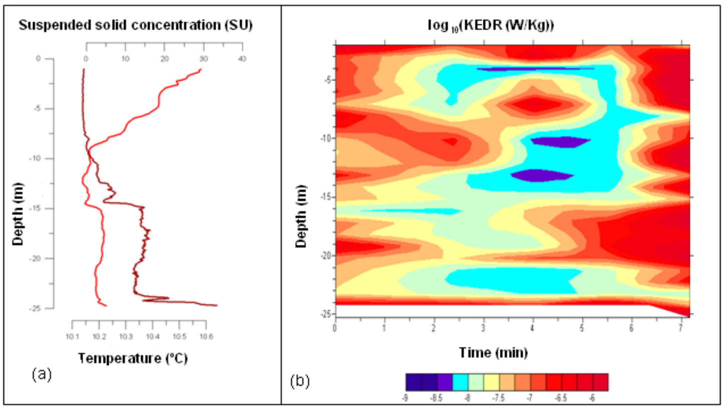

Fig. 7. (a) Characteristic temperature and suspended solids concentration profiles at station St.2. (b) Dissipation rate of turbulent kinetic energy, in logarithmic scale, computed from small scale shear profiles recorded in St.1 at times 0, 2.62, 4.12, 5.65 and 7.17 min.

In Figure 7(a) characteristic temperature and turbidity profiles are shown for St.2. In this case, temperature at the lutocline level increases up to 11.8°C and was located at a depth of 25.2 m. A colder intrusion is also observed at the base of the water column extending from above the lutocline to about 21 m depth. In this case, however, the turbidity of the intruded water is lower than that of the water column immediately above it. Note also that both turbidity and temperature remain rather constant from about 20 m to 15 m as a consequence of the high phreatic inflow which has raised the lutocline level to a depth of about 25 m, although it is normally below 35 m. Above this level and up to 10 m, the temperature of the water column is about 10.5°C, 0.3°C cooler than in St.1 for the same depths.

Finally, temperature increases progressively from about 10 m in depth to the surface. Between about 3 and 5 m a thermal homogenous layer is observed where the turbidity is very low, indicating that these depths are not affected by the dynamics of the underground spring. Note that this was not the case at St.1 where this homogenous layer does not exist and the effect of the underground source reaches up to 3 m from the surface. At St.2, absolute concentrations of suspended particles are higher than those observed in St.1, ranging from values of ~40 SU a few tens of centimeters above the lutocline and decreasing upward to ~15 SU at 15 m and 5 SU at about 10 m. Values above 10 m decrease quickly to 1-2 SU.

Dissipation rates for the six profiles recorded at St. 2 are represented in Fig. 7(b). As in the case of St. 1, high values of dissipation—in the order of ~10^{-6} W/kg—are observed immediately above the lutocline. In this station, turbulent activity is found to be higher in the entire water column, with most of the dissipation rates being above $10^{-8.25}$ W/kg. Note that high dissipation rates are also observed on the surface due to wind activity which, because of the very small stratification of the water column, can easily affect the whole column.

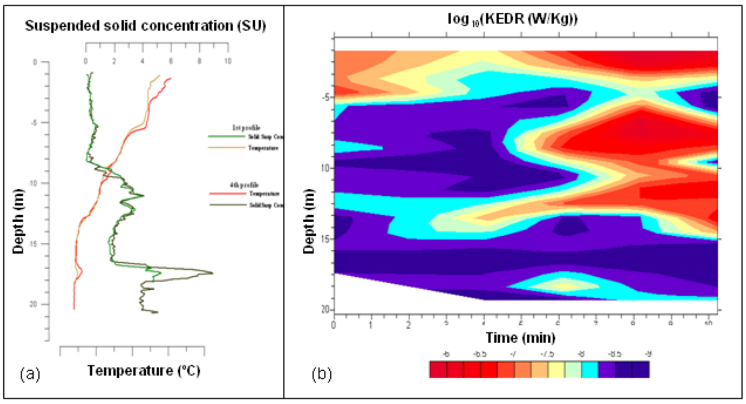

Fig. 8. (a) Characteristic temperature and suspended solids concentration profiles at station St.3. (b) Dissipation rate of turbulent kinetic energy, in logarithmic scale, computed from small scale shear profiles recorded in St.1 at times 0, 4.71, 6.28, 7.44, 9.01 and 10.24 min.

Finally, Figures 8 refer to St. 3 and are analogous to those discussed for the other two stations. In Figure 8(a) two different temperature and turbidity profiles, recorded at the beginning and at the end of the recording period, are presented. From these temperature profiles it can be seen that, as in the case of St. 2, a rather homogeneous layer appears between 3 and 5 m of depth from where temperature keeps decreasing down to a depth of 13 m (and not to 10 m as was the case for St. 2), coinciding with an increase in turbidity between 13 and 9 m.

The turbidity layer observed in Fig. 8(a) between 13 and 9 m could come from source BI where St.1 was located. In the lower part of the column, where the level of turbidity is higher, temperature profiles clearly exhibit a horizontal intrusion at depths between 16.5 and 18 m which correlates with a peak in turbidity of up to 8 SU. This intrusion is identified at the same level in all the profiles recorded at this station.

Figure 8(b) shows that in this case, dissipation rates at the bottom of the basin are low and show no turbulence activity, as was the case in the previous station. As already commented, St. 3 was not located above an underground spring and no fluidized bed existed in the area. First casts at this station showed a high dissipation rate only at the surface layer, which was directly affected by the mild wind present during the campaign. On the last profiles represented in Figure 13 some mixing events are identified as affecting the whole water column, down to 15 m depth, and coinciding with the intrusions observed in Fig. 8(a). A detailed look at Fig. 8(a) reveals that the main features for both casts are similar, although the small scale variability on the second cast is higher, coinciding with high dissipation rates at the surface that show the influence of the wind through the entire water column.

7 Conclusions

In summary, the data presented in this paper show the complexity of the system and the important impact that episodic events in which underground inflow greatly increases can have on the dynamics of the lake. So far, no 3D hydrodynamic simulations have been carried out to capture how different processes interact in Lake Banyoles, but it appears to be the next step in acquiring a better understanding of the dynamics of Lake Banyoles in particular and of karstic lakes in general.

Acknowledgement

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Analysis of Monthly Discharge and Precipitation Time Series for Selected Wetlands in Slovakia

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Abstract. This study deals with the modeling and forecasting of discharge and rainfall time series in the areas of three selected wetlands in Slovakia. First, an analysis of the systematic components (trends, seasonality, periodicity and residual components) was performed. Subsequently, prediction models for the mean monthly discharges and the mean monthly precipitation totals were derived. The models tested were the linear ARMA models, the nonlinear TAR models, TAR with exogenous component and TAR combined with Long Memory models. The Monte Carlo method was applied for prediction of mean monthly discharges and precipitation. The results obtained could help ecologists in making decisions on wetland management, improving the ecological conditions in the analyzed wetlands as also in planning of future eco-technical measures.

Keywords: Wetland, precipitation, monthly discharges, forecasting modelling, ARMA models, TAR models

1 Introduction

The National Report on the Status and Protection of Biodiversity in Slovakia emphasizes the importance of wetlands and inland water ecosystems as some of the most diverse ecosystems in the country. Slovakia has identified 12 peatland habitats from a total of 16, and amongst these, five are high priority and they are protected at the European level. Three types of peatlands are distinguishable in Slovakia: a) raised bogs, b) poor fens and c) rich fens. In relation to other types of peatlands, rich fens possess the highest level of species diversity due to the unique calcareous water chemistry created by high amounts of minerals in the water. In particular, bogs and fens are described as important refuges for relic species of arctic flora and fauna from the Ice Age. Despite of their relatively small areas, wetlands belong among one of the most important and valuable ecosystems of the Slovak Republic. Wetlands are important for the biodiversity conservation but they are very sensitive to natural and anthropogenic changes in their environments.

The aim of recent ecological studies in Slovakia is to acquire a better understanding of changes in selected wetlands in Slovakia and to build a methodological basis for future improving of their ecological conditions, which will include recommendations for changes in land use in farm areas, as well as proposals for the creation of buffer zones and land purchases.

For this purpose, in our study, a time series analysis was applied as a valuable tool to get information about analyzed data structures and their components, and provides a good basis for their successful future predictions.

Autoregressive modeling in hydrology can be found in studies of Jones and Smart [12] as well as Worrall and Burt [28]. Tesfaye, et al. [21] used seasonal ARMA models for the identification of mean annual discharges. The seasonal models were analyzed in [28], [19], [23], [5], [25], [26], [20], and [21]. The formation of predictive linear models for time series of discharges in Slovakia can be found e.g. Pekárová, et al. [17], [18] and Komorníková and Szökeová [14] who analyzed mean monthly and annual discharges on the Kysuca River. The testing of mean monthly discharge time series with Long Memory models was performed by Komorníková and Szökeová [15]. Állóová [1] tested time series of mean monthly precipitation totals data in the regions of the Belianske Lúky, Abrod and Kláštorské Lúky wetlands. Amendola [2] dealt with the prediction of mean rainfall data using regime switching models. These models are suitable for time series analysis of extreme events.

There is less evidence of the application of Threshold AutoRegressive (TAR) models in hydrology. Initial studies with possible switching between two models according to previous rainfall can be found in the studies of Amendola and Sorti [3] or Tong [22]. The use of second-generation nonlinear models such as TAR-ARCH and TAR-BL was proposed by Amendola *et al*. [3], [4]. Subsequent studies in nonlinear modeling led to good reliability in expressing processes [11]. Construction of prediction models using nonlinear models is quite difficult, and if the length of the predicted data is longer than one period, it is much more complex.

In this study mean monthly discharges and rainfall time series of the selected wetlands in Slovakia were analyzed.

2 Time Series Modelling

Series of random variables ordered in time is called a stochastic process. By this we mean that observation x_t, t = 1, 2, … is presumed to be a realized value of some random variable X_t.

If the time series $\{x_1, \ldots, x_t, \ldots\}$ are a discrete equidistant univariate series of consecutive observations (real data observed at one place) then x_t is the observed value of the time series at time t. So this series are single realization of a stochastic process

$\{X_1, \ldots, X_t, \ldots\}$. We will use the term "time series" to refer both to the observed data and the stochastic process. The length n of the time series is the total number of observations.

It is natural to assume that the generating mechanism is probabilistic and to model the time series as stochastic processes. In order to make any kind of statistical inference from single realization as a random process, the stationarity of the process is often assumed. Intuitively a process $\{X_t\}$ is stationary if its statistical properties do not change over time.

Stochastic process $\{X_t\}$ is called Gaussian white noise process when each random variable X_t has normal distribution with mean value $E(X_t) = \mu = 0$, constant variance $D(X_t) = \sigma^2$ for all t and $corr(X_t, X_s) = 0$ for $t \neq s$.

The time series can be viewed as realization of a stochastic process. Many problems related to water resources and environmental systems deal with temporal data that need to be analyzed by means of time series analysis, which became a major tool in hydrology. It is used for building mathematical models to describe hydrological data, forecast hydrologic events, detect trends, provide missing data, etc.

2.1 The Time Series Decomposition

The time series often exhibit trends, sometimes shifts (jumps), seasonality and periodicity. These attributes are referred to as components.

1. *Trend (T)*: In general, natural, human, economical and other processes produce gradual trends. It is a long-term component that represents a growth or a decline of the time series over an extended period of time.

2. *Seasonal component (S)*: The term of seasonality is used for time series defined at time intervals which are fractions of a year. It's a pattern of change that repeats itself from year to year.

3. *Cyclical component (C)*: The changes in time series do sometimes wave-like fluctuation around the trend which shows the possible existence of periodicity with longer intervals.

4. *Irregular component (e)*: That is a part of time series represented by residuals, after the above mentioned components have been removed.

Following additive model of these components was applied:

$$X_t = T_t + S_t + C_t + e_t \quad (1)$$

2.2 Autoregressive Moving Average Models (ARMA)

By time series modeling the basic assumption is that the value of the time series at time t, X_t, depends only on its previous values (deterministic part) and on a random disturbance (stochastic part). Furthermore, if this dependence of X_t on the previous *p* values is assumed to be linear, we can write:

$$X_t = \phi_1 X_{t-1} + \phi_2 X_{t-2} + \ldots + \phi_p X_{t-p} + D_t \quad (2)$$

where $\{\phi_1, \phi_2, ..., \phi_p\}$ are real coefficients, D_t is the disturbance at the time t, and it is usually modeled as a linear combination of the zero mean, uncorrelated random variables or a the zero-mean white noise process $\{Z_t\}$:

$$D_t = Z_t + \theta_1 Z_{t-1} + \theta_2 Z_{t-2} + ..., \theta_q Z_{t-q} \quad (3)$$

($\{Z_t\}$ is a white noise process with the mean 0 and the variance σ^2 and only if $E(Z_t) = 0$, $E(Z_t^2) = \sigma^2$ for all t, and $E(Z_s, Z_t) = 0$ if $s \neq t$, where E denotes the expectation). Z_t is often referred to as a random error or a noise at time t. The constants $\{\phi_1, \phi_2, ..., \phi_p\}$ and $\{\theta_1, \theta_2, ..., \theta_q\}$ are called autoregressive (AR) coefficients and moving average (MA) coefficients, respectively, for the obvious reason that (1) resembles a regression model and (2) a moving average. Combining the Eq. (1) and (2), we get:

$$X_t - \phi_1 X_{t-1} - \phi_2 X_{t-2} - ... - \phi_p X_{t-p} = Z_t + \theta_1 Z_{t-1} + \theta_2 Z_{t-2} + ... + \theta_q Z_{t-q} \quad (4)$$

This defines a zero-mean autoregressive moving average (ARMA) process of p and q orders, or ARMA(p, q) [6].

The order of an AR or ARMA model can be selected using various approaches. One of them is based on the so-called information criteria. The idea is to balance the risks of underfitting (selecting order smaller than the true order) and overfitting (selecting order larger than the true order). The order is chosen by minimizing a penalty function. The two commonly used functions are:

1. The Akaike's information criterion:

$$AIC(p, q) = \ln \hat{\sigma}^2 + \frac{2(p+q)}{n} \quad (5)$$

2. The Bayesian information criterion:

$$BIC(p, q) = \ln \hat{\sigma}^2 + \frac{(p+q)\ln(n)}{n} \quad (6)$$

where ($\hat{\sigma}^2$ is a sample covariance function).

The most commonly used approach to check the model adequacy is to examine the residuals calculated from the estimated model. If the fitted model is the "true" model, the residuals should behave like a white noise process with a zero mean and constant variance.

We used the Portmanteau test which is based on the following statistic:

$$Q_h = n(n+2)\sum_{k=1}^{h} \frac{\hat{\rho}_z(k)}{n-k} \quad (7)$$

which has an asymptotic χ^2 distribution with h – p – q degrees of freedom. If $Q_h > \chi^2_{1-\alpha}(h-p-q)$, the adequacy of the model is rejected at level α.

2.3 Long Memory Models

In natural sciences often time series generated by non-stationary stochastic processes are analyzed. The non-stationarity can be caused either by in time changing mean value or in time changing variance [7].

Process y_t is called integrated of order d, I(d), if:

$$(1-B)^d y_t = a_t \quad (8)$$

where: d is integer, B is backward operator (B $y_t = y_{t-1}$), and a_t is stationary and ergodic process with positive limited spectrum. Process y_t, which verifies (8) for 0 < d < 1 is called fractional integrated process of order d [9].
Time series with long memory are modeled with AutoRegressive Fractional Integrated Moving Average (p, d, q) models (ARFIMA), which is a combination of fractional differentiation and linear ARMA(p, q) process. An important attribute is that the effect of parameter d on outlying variables falls hyperbolically but influence of AR and MA process falls exponentially. Correlation structure for big time-lags is characterized by d and all other parameters characterize correlation structure in small time-lags. Even though ARFIMA (p, d, q) for 0.5 < d < 1 is non-stationary process, generated time series are tightened to the process mean value [7].
By testing time series for long memory it is tested the null hypothesis H0: process is with short memory. Next the Hurst coefficient H containing parameter d is estimated to standardize the time series. At first the series is adapted to 12×N matrix (N is number of years) with elements Y_{ij}, i=1,...12, j=1,...N. After accounting for the mean value $\overline{X}_i$ and standard deviation $\hat{S}_i$ for each month, the normalized values of the standardized series are calculated as

$$M_{ij} = \frac{Y_{ij} - \overline{X}_i}{\hat{S}_i} \quad (9)$$

Hurst coefficient H is the slope of regression curve

$$\ln[E(R_T / s_T)] \approx \ln c + H \ln(T) \quad (10)$$

where the left side of the equation presents the observed data, and right side the regression curve. From estimation of H we get the estimation of fractionalization parameter $\hat{d} = \hat{H} - 0{,}5$. If d is in interval (0, 0.5), the standardized time series are generated by stationary and invertible long memory processes. Next, the time series is differenced and modeled with linear ARMA.

2.4 Regime-Switching Models (Nonlinear Models)

In recent years several time series models have been proposed which formalize the idea of the existence of different regimes generated by a stochastic process (mainly in economy and finance). Our attention was restricting here to models assuming that in each of the regimes, a linear AR model can describe the dynamic behavior of the time series adequately.

TAR (Threshold Autoregressive)
The idea of multi-regime forecasting models is not new. Tong (1978) initially proposed the Threshold Autoregressive (TAR) model, which assumes that the regime

that occurs at a time t can be determined by an observable threshold variable q_t relative to a threshold value, which we denote as c.

Suppose that the observed data are (y_1, …, y_n), where n is the total number of observations in a time series and it is called the *length* of the time series. Let $x_{t,i} = (1, y_{t-1}, ..., y_{t-p_i})'$ *and* $\phi_i = (\phi_{0i}, \phi_{1i}, ..., \phi_{p_i i})'$ *for* $i = 1,2,..$ I[A] is an indicator function with I[A] = 1 if the event A occurs and I[A] = 0 otherwise, q_t is the transition variable e_t is i.i.d.(0, s^2).

TAR model is linear within a regime, but liable to move between regimes as the process crosses the threshold. The two-regime Threshold Autoregressive (TAR) model with regimes AR(p_1) and AR(p_2) takes the form:

$$y_t = x_{t,1}^{'}\phi_1 \, I[q_t \geq \text{c}] + x_{t,2}^{'}\phi_2 \, I[q_t < c] + e_t \tag{11}$$

Identification of the appropriate model orders p_1, p_2 and estimation of the threshold c and of the AR coefficients in both regimes can be done with help of information criteria, e. g., the:

Akaike information criterion:

$$AIC(p_1, p_2) = \ln \hat{\sigma}^2 + \frac{2(p_1 + p_2)}{n} \tag{12}$$

Schwarz information criterion:

$$SIC(p_1, p_2) = \ln \hat{\sigma}^2 + \frac{2(p_1 + p_2)\ln n}{n} \tag{13}$$

Hannan-Quinn information criterion:

$$HQIC(p_1, p_2) = \ln \hat{\sigma}^2 + \frac{2(p_1 + p_2)\ln(\ln n)}{n} \tag{14}$$

which are to be minimized. We used the above mentioned AIC and BIC.

SETAR (Self-Exciting Autoregressive)

SETAR is a special case of the TAR models, when the threshold variable q_t is taken to be a lagged value of the time series: $q_t = y_{t-d}$ for a certain integer d > 0. For example, in the two-regime case with AR(p_1) and AR(p_2), the model is

$$\begin{aligned} y_t &= \left(f_{0,1} + f_{1,1}\, y_{t-1} + ... + \phi_{p_1,1}\, y_{t-p_1}\right)[y_{t-d} \leq c] + \\ &\left(f_{0,2} + f_{1,2}\, y_{t-2} + ... + \phi_{p_2,2}\, y_{t-p2}\right)[y_{t-d} > c] + e_t \end{aligned} \tag{15}$$

The least squares estimate of *c* can be obtained by minimization of:

$$\hat{c} = \arg \min_{c \in C} \hat{\sigma}^2(c) \tag{16}$$

where: $\hat{\sigma}^2(c) = \frac{1}{n}\sum_{t=1}^{n}\hat{\varepsilon}_t(c)^2$ is the residual variance, and C denotes the set of all allowed threshold values. A popular choice for C is $C = \left\{ c \middle| y_{([\pi_0(n-1)])} \le c \le y_{([(1-\pi_0)(n-1)])} \right\}$ where $y_{(0)}, \ldots, y_{(n-1)}$ denote the order statistics of threshold variable y_{t-d}, $y_{(0)} \le \ldots \le y_{(n-1)}$, and [.] denotes the integer part. A safe choice for p_0 appears to be 0.15.

STAR (Smooth Transition Autoregressive)
A more gradual transition between the different regimes can be obtained by replacing the indicator function I in (14) by a continuous function G, which changes smoothly from 0 to 1 as q_t increases (so-called transition function).

LSTAR (Logistic Smooth Transition Autoregressive)
As already mentioned, STAR models can pass from one regime to another continuously. If the transitions function is a logistic one:

$$G(y_{t-d};\gamma,c) = \frac{1}{1+\exp(-\gamma[y_{t-d}-c])} \quad (17)$$

The model is called LSTAR.

Nonlinear TAR with exogenous factor
Additional time series which enter to the model are called exogenous. In this study the rainfall data were selected as the exogenous time series and were chosen to define the threshold variable too. Using this approach got very good results were achieved.

2.5 Monte Carlo Forecasting Method

In this paper the Monte Carlo forecasting method was applied. The one-step forecast was calculated as a mean of k values:

$$y_T(h) = \frac{1}{k}\sum_{i=1}^{k} F\left(y_T(h-1) + \varepsilon_i^{v}, \hat{\delta} \right) \quad (18)$$

where the nonlinear function F represents the selected model.
For comparison of the forecasting performance of alternative models the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE) were calculated:

$$RMSE = \sqrt{\frac{1}{P}\sum_{T=1}^{P}(\hat{y}_T - y_T)^2} \quad (19)$$

$$MAE = \frac{1}{P}\sum_{T=1}^{P}\left|\hat{y}_T - y_T\right| \quad (20)$$

where: P is the number of the forecasted periods, and $\hat{y}_T$ is the predicted value for y_T.

3 Data Analysis

The selected wetlands represent three main types of ecosystem with different topographical, geological and ecological situations. Abrod is a typical representative of a lowland spring fen system, Kláštorské Lúky is a spring fen system located in hollows and Belianske Lúky is a spring fen system located in the foothills of the highest part of the Carpathian Mountains, Fig.1. Abrod and Belianske Lúky were selected as the most appropriate for the implementation of project restoration measures, as they have very high diversity, are only moderately degraded and therefore have the high restoration potential. The locality of Kláštorké Lúky is significantly more degraded, though the restoration potential is also very high - its restoration is very urgent.

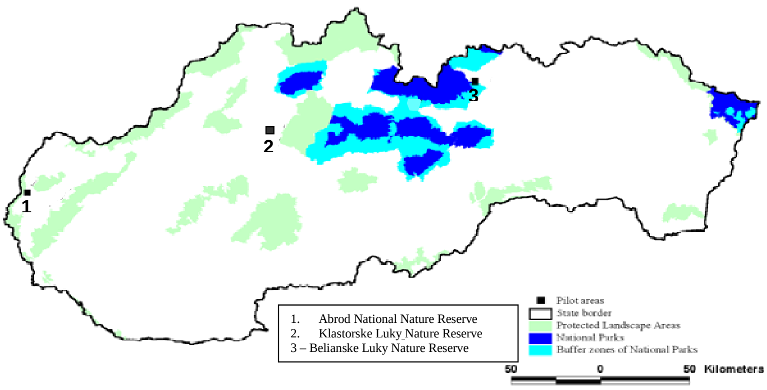

Fig.1. Location map of the analysed wetlands

3.1 Kláštorské Lúky Wetland

The Kláštorské Lúky National Nature Reserve wetland is situated in the north-west of Slovakia in region of the Strážovské Mountains, close to the towns Kláštor pod Znievom, Príbovce and Valča. The Kláštorské Lúky wetland is a part of the Turiec wetlands, which was designated as the Ramsar site of the international importance in 1998 with a total area of 467 ha. In 1974, 86 ha were designated as a National Nature Reserve (NNR), the category of strictest protection for national sites of special scientific interest. Kláštorské Lúky is a complex of wetlands; native plant communities are distributed over large areas. Altogether 223 taxons of vascular plants were recorded within the site; of these, 28 are listed as threatened at the national scale. A total of 90 species of spiders were identified on the site.

For the discharge time series analysis in the Vríca catchment, following gauging stations were selected: Kláštor pod Znievom/Vríca, Kláštor pod Znievom/Znievsky Creek and Slovany/Vríca, (Table 1). For an analysis of the mean monthly precipitation totals, the stations Kláštor pod Znievom and Príbovce were chosen (Table 2), due to the longest period of observation (104 years).

Table 1. The selected precipitation stations in the area of the Kláštorské Lúky wetland

Station	Id of gauging station	Observation period	Number of years of observation
Kláštor pod Znievom	24180	1.01.1901 - 31.12.2004	104
Príbovce	24220	1.01.1901 - 31.12.2004	104

Table 2. The selected gauging stations in the area of the Kláštorské Lúky wetland

Station	Id of gauging station	Observation period	Number of years of observation
Kláštor pod Znievom/Vrica	5995	1.01.1984 – 31.12. 2004	21
Kláštor pod Znievom/Znievsky creek	6000	1.01.1969 – 31.12. 1986	18
Slovany/Vrica	6010	1.01.1969 – 31.12. 1985	17

3.2 Belianske Lúky Wetland

The National Park - wetland Belianske Lúky (892 500 m^2) is situated in the north – east part of Slovakia, near villages Spišská Belá, Strážky and Ždiar in the basin of the Biela River. The area forms the biggest spring-fed fen system in Slovakia with an extraordinarily high value of biodiversity. 51 different threatened taxa of higher plants have been recorded from a total number of 220 species in the locality thus far. Selected gauging stations and precipitation stations are in Tables 3 and 4.

Table 3. The selected precipitation stations in the area of the Belianske Lúky wetland

Station	Id of gauging station	Observation period	Number of years of observation
Tatranská Lomnica	12140	1.01.1981 - 31.12.2004	24
Kežmarok	12180	1.01.1981 - 31.12.2004	24

Table 4. The selected gauging stations in the area of the Belianske Lúky wetland

Station	Id of gauging station	Observation period	Number of years of observation
Spišská Belá-Strážky/ Čierna voda	8200	1.01.1976 - 31.10.1985	10
Spišská Belá/ Beliansky potok	8210	1.01.1976 - 31.10.1985	10

3.3 Abrod Wetland

Abrod - is a National Nature Reserve of 92 hectares, which was designated in 1964 for rich fen protection. Situated in the Borská lowlands, it has been recognized as a unique botanical and zoological location since 1923. The wetland is located in natural depression in altitude 153 to 149 m a.s.l.. Currently, 480 taxa of vascular plants have been recorded, including 104 threatened species, of which 3 occur only in this area of Slovakia. The Porec Creek is draining the Abrod wetland. The analyzed gauging stations and precipitation stations are presented in Tables 5 and 6.

Table 5. The selected precipitation stations in the area of the Abrod wetland

Station	Id of gauging station	Observation period	Number of years of observation
Malackya	16160	1.1.1981 – 31.12.2004	24
Šaštín/Stráže	15200	1.1.1981 – 31.12.2004	24

Table 6. The selected gauging stations in the area of the Abrod wetland

Station	Id of gauging station	Observation period	Number of years of observation
Veľké Leváre/Rudava	5072	1.1.1961 - 31.12.2004	44
Studienka/Rudava	5070	1.1.1971 - 31.12.2004	34

4 Results

For the modeling of the rainfall and discharge time series the Mathematica 5.2 software was applied. Mathematica 5.2 belongs to the "Computer Algebra Systems" program group with other softwares, e.g., MAPLE, DERIVE and MACSYMA. Mathematica 5.2 not only allows classical numerical calculations, but also symbolic calculations, which are not limited to simple events, but can be used for elementary algebra, integral and differential calculus. In this study, the Time Series Analysis Package of Mathematica 5.2 was applied for the time series modeling.

In the first step the identification of the model type and the determination of the model order using the Hannan-Rissannen procedure were performed. The suitability of each model was then tested using the Portmanteau test.

According to the statistical tests, for all precipitation stations, the best selected models were AR(1), ARMA(1,1) and MA(1), (Table 7). Despite the good results according to the statistical tests, we recommend to test also another models as ARCH or GARCH. In Table 7 also the best selected prediction models with the values of statistical tests for all discharge station are presented.

The best selected forecasting models for discharge time series are presented in Figures 2 to 4. We can see that best model for time series was the nonlinear TAR model combined with long memory model accept the station Kláštor pod Znievom/Znievsky Creek and the Spišská Belá/Beliansky Creek where the best model was linear AR(1). For the station Spišská Belá/Strážky the ARFIMA(1,1) long memory model was selected. For the station Studienka/Rudava was the best selected model AR(1) and for the Veľké Leváre long memory model ARFIMA(1,2) d=1.

Table 7. Prediction errors MAE and RMSE and selected best models for analysed gauging stations

Wetland Kláštorské Lúky			
Station	Best model	MAE	RMSE
Kláštor pod Znievom/Vríca	TAR_LM SETAR (1,1) d=1	0.086	0.107
Kláštor pod Znievom/Znievsky Creek	MA(1)	0.128	0.202
Slovany/ Vríca	TAR_LM SETAR (1,1) d=1	0.087	0.113
Kláštor pod Znievom	AR(1)	23.123	19.272
Príbovce	AR(1)	22.309	18.973
Wetland Belianske Lúky			
Spišská Belá/ Beliansky Creek	AR(1)	0.074	0.092
Spišská Belá Strážky/ Čierna voda	ARFIMA(1,1) d=1	0.120	0.139
Tatranská Lomnica	AR(1)	22.158	18.985
Kežmarok	AR(1)	16.458	14.532
Wetland Abrod			
Studienka/ Rudava	AR(1)	0.452	0.555
Veľké Leváre	ARFIMA(1,2) d=1	0.242	0.339
Šaštín Stráže	AR(1)	25.265	30.584
Malacky	AR(1)	22.704	28.972

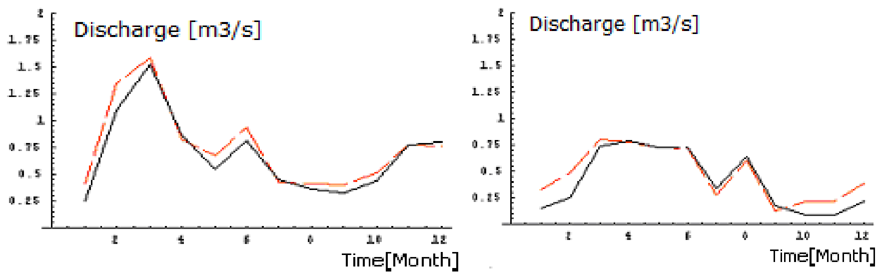

Fig. 2. Comparison of observed (solid line) and forecasted mean monthly discharges (dashed line) using TAR_LM (SETAR [1,1] d=1) model at the Kláštor pod Znievom/Vríca station – Kláštorské Lúky wetland (right); Comparison of observed (solid line) and forecasted mean monthly discharges (dashed line) using TAR_LM (LM_SETAR [1,1] d=1) at the Slovany/Vríca station – Kláštorské Lúky wetland (left).

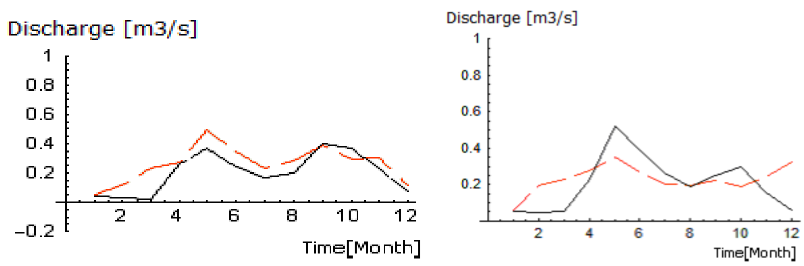

Fig. 3. Comparison of observed (solid line) and forecasted mean monthly discharges (dashed line) using AR(1) model, the Spiš. Belá/Beliansky potok - Belianske Lúky wetland (right); Comparison of observed (solid line) and forecasted mean monthly discharges (dashed line) using ARFIMA (1,1) d=1 model, the Spiš. Belá/Strážky –Belianske Lúky wetland (left).

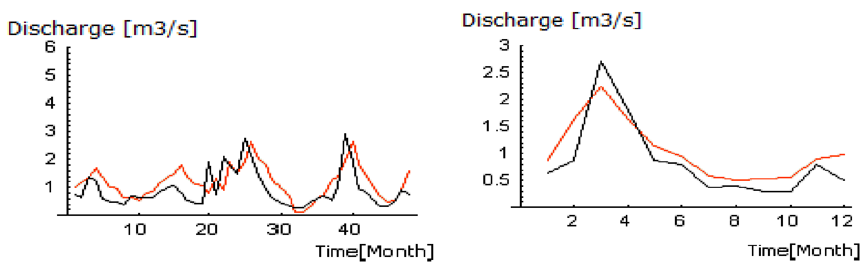

Fig. 4. Comparison of observed (solid line) and forecasted mean monthly discharges (dashed line) using AR (1) model, the Studienka/Rudava AR (1) –Abrod wetland (right); Comparison of observed (solid line) and forecasted mean monthly discharges (dashed line) using ARFIMA(1,2) d=1 model, the Veľké Leváre/Rudava –Abrod wetland (left).

5 Conclusions

In this paper the modeling and forecasting of the mean monthly discharges and the mean monthly precipitation time series in the area of wetlands Kláštorské Lúky, Belianske Lúky and Abrod was presented. The models tested were the linear ARMA, ARFIMA models with a long memory and the nonlinear TAR models and the TAR models combined with the long memory model.

For discharge predicting the most suitable models were the linear AR models, long memory models or combined model TAR and long memory model, which provided the best results.

Only the linear ARMA models were suitable for the time series of the mean monthly precipitation totals, but the results were useless for further practical modeling or forecasting. Modeling and forecasting the mean monthly precipitation totals was not satisfying, therefore for future studies the use of models like ARCH (Autoregressive Conditional Heteroscedasticity) and GARCH (Generalized ARCH) or MSW

(Markov-Switching) can be recommended for testing. Also better results may be reached using TAR models with various aggregation operators.

The derived predicting models could help ecologists in decision-making concerning wetland management, in improving the ecological conditions in the wetlands and in planning future eco-technical measures for improving the hydrological cycle (e.g., an increase in the ground water level) in the analysed wetlands Kláštorské Lúky, Belianske Lúky and Abrod.

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Ecological Quality Assessment of the Drietomica Stream by Bioindication

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Abstract. During the years 1995-2007, research on the impact of river regulation on the aquatic zone of the Drietomica stream was implemented. Drietomica is a typical representative of streams in the Slovak flysch area, and it is located in north-western Slovakia in the region of White Carpathians.
In this article the results of modeling a microhabitat by means of Instream Flow Incremental Methodology (IFIM) are presented. For the one-dimensional modeling, the Riverine Habitat Simulation System (RHABSIM) and for the two-dimensional modeling, River2D software, both of which are used to analyze the interaction between water flows, the morphology of a riverbed and the biological components of the environment, were used. After a hydraulic calibration was performed, the available fish habitat in the shape of a weighed usable area was simulated using both models.
The current stage of the research represents the testing of the differences between the various types of models and a comparison of the impact of the non-biotic parameters on the development of the criteria curves, which define fish hiding-places as a microhabitat of a stream.

Keywords: IFIM, habitat, bioindication, abundance, ichthyomass

1 Introduction

The ecological state of a stream is affected by many factors, the most important of which are the habitat of fauna and flora in the aquatic part of the stream. The configuration of a habitat significantly affects the organization and structure of a biological community. Understanding the impact of human activity on a habitat's structure remains one of the most neglected research fields in water management. The loss of dead arms and reduction of the inundation area and natural riverbed segmentation is one of the primary reasons for negative changes in the aquatic part of a stream [3]. Many biologists consider habitat loss, habitat degradation, and habitat fragmentation the primary threats to species survival. Habitat loss occurs when habitat is converted to other uses, such as when a wetland is filled or a prairie is covered by housing developments. Habitat degradation occurs when the habitat is so diminished in quality that species are no longer able to survive. Water development projects include dams, dredging, stream channelization, flood control structures, and canals. These projects adversely affect species in a number of ways. The natural flow of rivers and streams may be disrupted and riparian (stream bank) habitat may be destroyed, fragmented, or degraded [8]. Some examples of improper engineering in the Pilica River in Vistula drainage basin in Poland are shown by Penczak [6], [7]. Engineering, which consists here in protecting eroded banks by reveting them with fascine or limestone boulders, is unfavorable for fish mainly in the initial phase and more in small than in large rivers [6].

The entry of Slovakia into the European Union (EU) has determined the orientation concerning standard techniques used within the bounds of the EU. It is necessary to achieve compatible results which are usable during the process of the transposition, implementation and legal application of European frameworks in water management. Within the bounds of monitoring and assessing the ecological quality of water, the European framework directive 2000/60/ES requires the determination of the characteristic parameters of unaffected water bodies which correspond to a very good ecological quality. These conditions are declared as reference conditions of a given type of water body. If the stream lacks unaffected reaches, modeling of the biological conditions in the stream is required. "Type-specific biological reference conditions based on modelling may be derived using either predictive models or hindcasting methods. The methods shall use historical, palaeological and other available data and shall provide a sufficient level of confidence about the values for the reference conditions to ensure that the conditions so derived are consistent and valid for each surface water body type." [10].

2 Methods

The hydroecological quality of three reference reaches of the Drietomica rivulet was evaluated using the RHABSIM 1-dimensional model. One of those reaches was also evaluated using the River2D 2-dimensional model.

The characterization of the reference reaches.

The first reference reach with a length of 100 m lies in the village of Drietoma. The riverbed has been modified into a simple trapezoid-shaped profile with slopes of 1:1.5. The slopes are stabilized by concrete feet and prefabricated components. The bottom of the riverbed is flat with an average width of 12 m. Riverbank vegetation is occasionally present. According to a granulometric analysis, the mean grain gauge is d_{50} =17.5 mm.

The second reach with a length of 119 m lies above the village of Drietoma and is 1800 m away from the first reach. The character of the riverbed is natural with a segmented bottom. The riverbanks are stabilized by a root system of willow and alder vegetation, the crowns of which shade most of the stream. The average riverbed width is 7 m with 1.2 m deep local potholes. The mean grain gauge is d_{50} =26 mm.

The third reach, which was modeled using both 1D and 2D models, is 240 m long. It has a natural character and is connected to the second reach upstream. That reach was chosen because it incorporates various types of habitat including fish covers. Distribution of various types of microhabitat in this reach is shown in Fig. 1. The relevant codes of all types of the microhabitat are classified into the cover suitability curve presented in Fig. 2.

The water of Drietomica falls into the I class of cleanness according to the oxygen regime factor, according to other factors, it falls into the II class.

Assessment of the habitat quality of the aquatic part of the Drietomica stream.

The models that we used in this study work according to the principle of the IFIM method (Instream Flow Incremental Methodology) [4], [5]. It is an interdisciplinary decision-making system, which has arisen as a result of the knowledge that most fish species prefer certain combinations of water depths, flow velocities, hiding places and materials of a riverbed. If these values are known in a given stream reference reach, it is possible to forecast the impact of changes to the biological environment of a stream.

The following procedure was used for modeling the quality of the Drietomica habitat:

- delineation of certain stream reference reaches;
- measurements of the topographical parameters of the reference reach;
- hydrometric measurements during 3 various water levels of each reference reach;
- conducting an ichthyological and hydraulic survey aimed at assessing the quality of the habitat for various fish species (determination of the criteria curves);
- processing data that characterizes individual types of habitat and criteria curves; and the quantification of the hydraulic and morphological characteristics of the stream using the fish as a bioindicator.

Table 1. The diversity of species of the ichthyofauna in the reference reaches of the Drietomica stream during the years 1995-2006 (N – Natural stream, R – River regulation)

Family – *Species*	N	R	Family – *Species*	N	R
CYPRINIDAE			SALMONIDAE		
Common minnow – *Phoxinus phoxinus*	+	+	Rainbow trout – *Oncorhynchus mykiss*	+	-
Gudgeon – *Gobio gobio*	-	+	Brown trout - *Salmo labrax* m. *fario*	+	+
Dace – *Leuciscus leuciscus*	-	+	Brook trout - *Salvelinus fontinalis*	+	-
Chub – *Leuciscus cephalus*	-	+	THYMALLIDAE		
COTTIDAE			Grayling - *Thymallus thymallus*	+	+
Bullhead - *Cottus gobio*	+	+	BALITORIDAE		
Alpine bullhead - *Cottus poecilopus*	+	+	Stone loach – *Barbatula barbatula*	+	+
Hybrid (*C.gobio* x *C. poecilopus)*	+	-	Number of species (without hybrid)	8	9

The ichthyologic measurements were implemented in cooperation with the Zoological Institute of the Slovak Academy of Science in Bratislava and the Department of Poultry Farming and Small Farm Animals of the Slovak Agricultural University in Nitra.

Table 2. Basic data of the abundance ($pcs.ha^{-1}$) and ichthyomass ($kg.ha^{-1}$) in the reference reaches of Drietomica during the years 1995 – 2006. The Italicized data are from fishing out in the summer

Year	Abundance ($pcs.ha^{-1}$)				Ichthyomass ($kg.ha^{-1}$)			
	Natural stream – reference reach 2		Regulated stream – reference reach 1		Natural stream – reference reach 2		Regulated stream – reference reach 1	
	spring (1a)	autumn (1b)	spring (2a)	autumn (2b)	spring (1a)	autumn (1b)	spring (2a)	autumn (2b)
1995	-	2606	-	17425	-	64,1	-	152,3
1996	993	1374	1975	4258	16,1	35,8	31,9	51,3
1997	-	4822	-	6625	-	111,5	-	88,2
1998	1333	*3097*	5433	*6398*	32,3	*42,4*	79,1	*71,6*
1999	-	-	-	-	-	-	-	-
2000	5987	6391	3292	8300	191,9	123,2	39,9	46,0
2001	-	*10582*	-	*7144*	-	*100,0*	-	*41,7*
2002	7148	*9837*	8098	*26749*	108,6	*92,6*	81,7	*287,7*
2003	6361	-	22253	-	203,5	-	278,6	-
2004	-	*2507*	-	*34017*	-	*54,5*	-	*271,6*
2005	4886	-	14036	-	55.3	-	149.3	-
2006	-	3704	-	10915	-	84.2	-	131.4

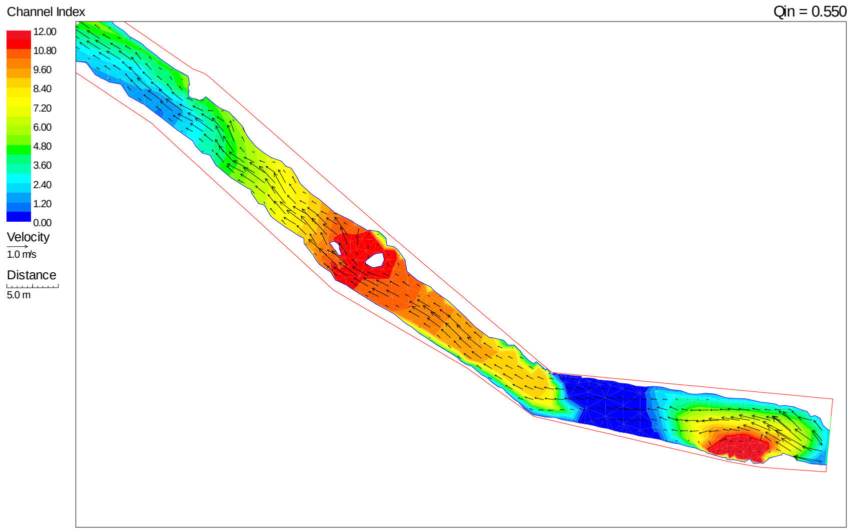

Fig. 1. Distribution of various types of cover in the third natural reference reach (see Fig. 2 for the microhabitat codes). The velocity vectors during the discharge Q=0.550 $m^3.s^{-1}$ are also presented.

Ichthyologic characteristics of the reference reaches. There is a significantly higher abundance of fish in the lower stream reach than in the upper stream reach. The seasonal changes in the abundance are related to fluctuations in biodiversity as a result of migration during the time of reproduction and increases in the frequency of growth. Regarding the ichthyomass, the changes in the first and second reaches are tiny and statistically inconclusive. Under normal conditions the ichthyomass of the lower reach should also be significantly higher. The cause of a contrary state is the river regulation of a certain reach and, as a consequence, the lack of suitable life conditions for some fish species.
The diversity of species of the ichthyofauna in the Drietomica rivulet is listed in Table 1, the basic data for abundance and ichthyomass are given in Table 2.

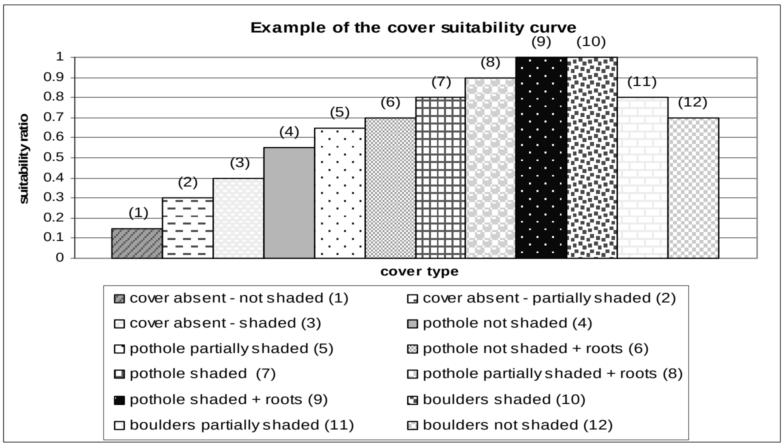

Fig. 2. The cover suitability curves in the third natural reference reach

3 Results

Quantification of the quality of a habitat in the IFIM methodology is represented by the weighed usable area (WUA), which is a direct function of discharges and represents the suitability of the entire modeled reach divided into microhabitat levels. These outcomes are the proper basis for future decision-making and water-management planning.

After the hydraulic calibration of both models, we simulated a suitable habitat in the form of a WUA during various discharges (Fig. 4). There is an obvious difference between the results obtained by the 1D and 2D models (Table 3 and Fig. 3) which is due to the greater accuracy and larger detail of the 2-dimensional hydraulic module of River2D following from the 2D modeling principle. Unlike 1D modeling it also considers the spatial direction of a stream (a certain model can simulate flow intensity in various directions) and the input topography of the riverbed is more detailed in the 2D model. The effect of the implementation of the cover criteria curves into the model is also obvious from the table given of the comparison of the WUA share on the total water surface area. However, the decrease of this share as a result of the implementation of the cover criteria curves is a logical consequence of the embedment of the other parameter (cover) into the model, which follows from the WUA calculation method (a multiple reduction of the WUA by the mutual multiplication of the suitability rate of the individual parameters).

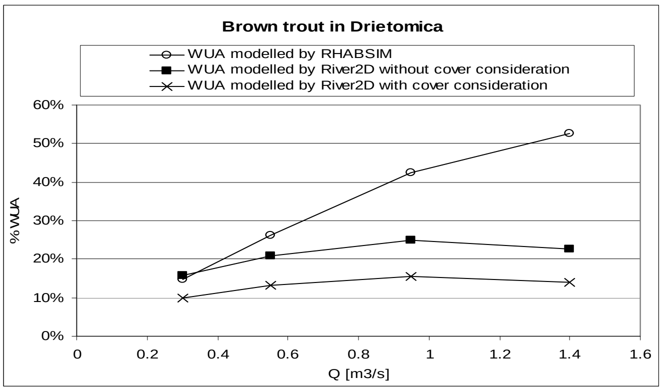

Fig. 3. Comparison of the weighed usable area (WUA) share on the total water surface area in the natural part of Drietomica during various discharges simulated by 1D and 2D models, considering and not considering the fish cover places in determination of criteria curves

Table 3. Comparison of the weighed usable area (WUA) share on the total water surface area in the natural part of Drietomica during various discharges simulated by the 1D and 2D models, considering and not considering the fish cover places in determination of criteria curves (WCFC - without considering fish covers, CFC - considering fish covers)

		model	River2D			RHABSIM		
Q (m^3/s)	bioindicator *(Latin name)*	method	WUA (m^2)	Total surface area (m^2)	(%)	WUA (m^2)	Total surface area (m^2)	(%)
0.3	Alpine bullhead	WCFC	289	1235	23.40	263	1118	23.52
	(Cottus gobio)	CFC	181	1235	14.66			
	Brown trout	WCFC	194	1235	15.71	166	1118	14.85
	(Salmo trutta m. fario)	CFC	124	1235	10.04			
0.55	Alpine bullhead	WCFC	348	1385	25.13	449	1271	35.32
	(Cottus gobio)	CFC	218	1385	15.74			
	Brown trout	WCFC	287	1385	20.72	334	1271	26.27
	(Salmo trutta m. fario)	CFC	184	1385	13.29			
0.95	Alpine bullhead	WCFC	390	1520	25.66	665	1380	48.19
	(Cottus gobio)	CFC	233	1520	15.33			
	Brown trout	WCFC	379	1520	24.93	587	1380	42.54
	(Salmo trutta m. fario)	CFC	236	1520	15.53			
1.4	Alpine bullhead	WCFC	318	1605	19.81	717	1446	49.59
	(Cottus gobio)	CFC	186	1605	11.59			
	Brown trout	WCFC	364	1605	22.68	762	1446	52.70
	(Salmo trutta m. fario)	CFC	225	1605	14.02			

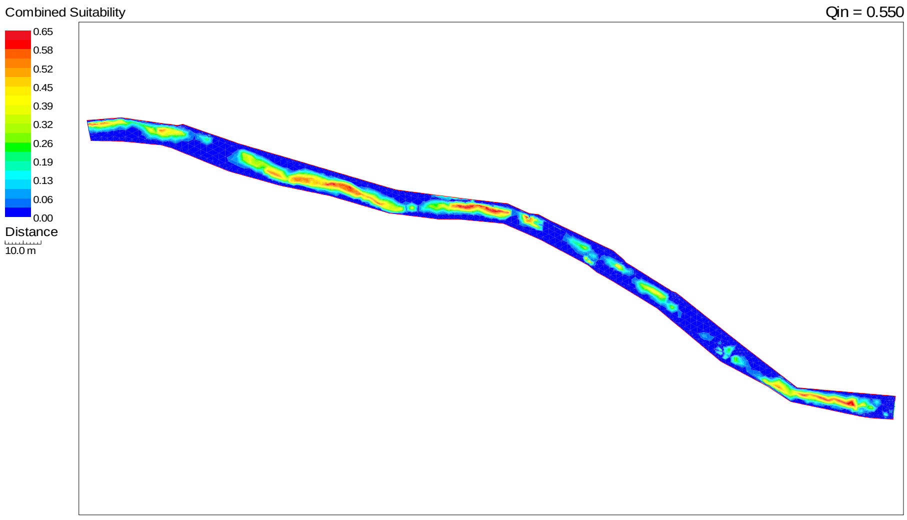

Fig. 4. Progress of combined suitability for Brown trout considering fish-covers in the natural reach of Drietomica during the 0.55 m^3/s discharge

4 Discussion

From the existing results of our stream habitat modeling research [4], [5], it follows that the relationship between a fish population and the characteristics of its habitat as modeled by the IFIM methodology gives a true picture of the changes evoked by discharges and riverbed topography interference (for example, river regulation). A lot of various habitat models exist that are related to the stream biota, but their outcomes are incompatible. A greater uniformity aimed at a better compatibility of individual results would be more useful.

In the next developments in modeling stream biological conditions in Slovakia, attention should be directed to models using the IFIM methodology, and considering the greater accuracy of the 2D models, their use is especially recommended. Initiate method also fulfils all conditions for standardizing the determination of the unaffected natural state of a stream by modeling, which is directly required by European Water Framework Directive 2000/60/ES. This method also allows the utilization of hydrological drought data in [1], [2], [9] for setting the certain values of discharge or water level, during which the phenomenon of hydrological drought is lasting.

5 Conclusions

During the years 1995-2007, the research on the impact of river regulation on the aquatic zone of the Drietomica brook was implemented. In this article the results of modeling of the microhabitat by means of the IFIM methodology are presented. For the one-dimensional modeling RHABSIM and for the two-dimensional modeling River2D software were used. The current stage of the research represents testing the differences between the various types of models and a comparison of the impact of the non-biotic parameters on the development of criteria curves concerning fish hiding-places as a special microhabitat.

Acknowledgements

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Topic 5

River Basin Restoration Strategies and Practices

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Paper: **A01**

Methods of Roughness Coefficient Determination in Natural Riverbeds

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Abstract. The roughness coefficient determination in natural river beds is based on the analysis of boundary layer development along the canal walls. The structure of the open canal can be very complex and changeable which results in different evaluation methods of determining the roughness coefficient *n*. A considerable number of measured valued for similar surface canal characteristics are analyzed in order to determine the roughness coefficient for the observed natural canal. The paper offers parameters which affect the roughness coefficient variability in beds. The roughness coefficient variability along the flow which depends on water level changes has been additionally described and graphically presented. The paper presents the vertical velocity profiles which are result of the aquatic vegetation. The paper offers review of the most represented methods of roughness coefficient evaluation used in practice, as well as numerous empiric methods based on the grading structure of the slopes and the bottom of the canal as well as methods based on measuring data.

Keywords: Roughness coefficient, boundary layer, evaluation methods, vertical velocity profile

1 Introduction

Determination of the roughness coefficient presents a provocative and a creative task of the contemporary hydraulics of open flows. An initially simple determination of the roughness coefficient *n* becomes a very complex problem because the coefficient has been changing in time and space depending on geometric, geomorphological and hydraulic parameters of water current beds. It is an interdisciplinary task because it includes the knowledge of hydrology, statistical data processing, hydromechanics, hydraulics, geology and mechanics.

All more pronounced appearances of the large watery waves in water currents, to which regulated water currents are no exception, are a consequence of both noted climatic changes and inappropriate water-managing solutions. Although regular conceptions of water-managing solutions have the crucial influence on the efficiency of flood protection system, the inappropriate functioning of sewage systems is also to be found at conceptually well set solutions, but with inappropriate hydraulic dimensioned systems [1]. Most often it is the result of negligence during the design phase when the conditions of bed state were idealized during the exploitation phase. The designed state which was mostly constructed by the design is liable to changes in bed geometry and bottom fall. The plant cover state often significantly varies from the designed conditions [2].

The surface roughness n of natural beds varies along the wetted canal scope. In the drain trench, for example, rocky bottom with concrete slopes for erosion protection can be found. In that case the coefficient n will be different for low waters in respect to larger depths at the flowing. Similar to this, the river bed can have one value of the roughness coefficients n appropriate for its normal flow and another value of the coefficient n for flood periods when the flow also occurs in flood retention areas.

A canal covered in ice often has different values of the roughness coefficient n for the considerably reduced water level [2], [3]. Such a canal is not an “open” canal, although the analysis of such flowing has often been based on equations for flow in open canals. This is acceptable as long as the icy cover is thin enough to make the firm border in the conditions of shear stress resistance. For a more accurate determination of the roughness coefficient the bed can be divided into more subareas. By doing so a separate roughness coefficient n is then determined for each subarea. This kind of calculation is more accurate in relation to methods by using of which the coefficient n is obtained based on the total surface of the bed cross section [2], [4].

2 Roughness Coefficient of Natural River Beds in General

Unlike the constructed canals, the natural river beds (lowland and mountain watercourses, rivers and streams) have irregular shapes of cross sections, changes of the bottom slopes and numerous curves along their flow. The changes of hydraulic parameters along the flow, the presence of shallow waters and hydrodynamic forces which influence the changes along the length and the depth of the flow (Figure 1) are very frequent. The natural regime of river flows can be abruptly changed due to construction of dams, water-storage facilities and other hydropower structures in river beds. Thus the dams provoke the reducing of the flow which sometimes extends also to several dozen of kilometers upstream from the dam [1].

The roughness coefficient of natural beds depends on many factors, the most significant of those being the corresponding basic bed roughness, the irregularity of cross section shapes, the occurrence of gullies in the bed, the wearing away of the alluviums and other. Experience has shown that the roughness coefficient changes not only along the bed [5], [6], but also when the water level changes occur (Figure 2).

This is the reason why the roughness coefficient n is usually determined according to hydrometric data of the observed river bed.

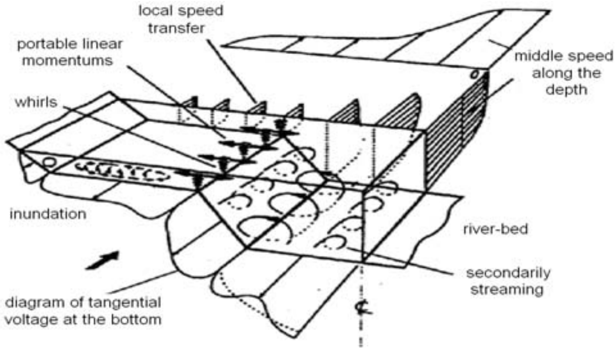


Fig. 1. The conceptual model of flow structure on the borderline between the main canal and inundations, [1]

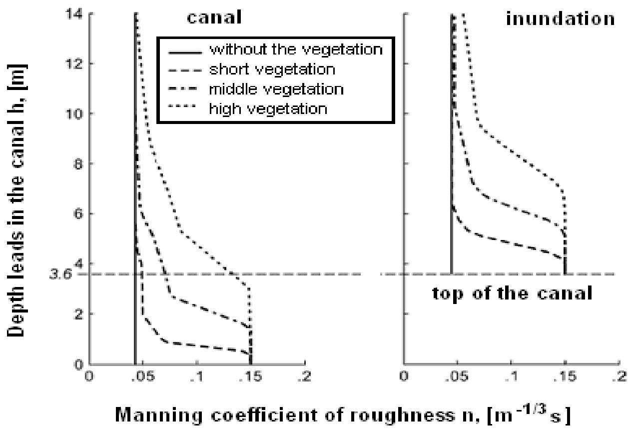


Fig. 2. Change of the roughness coefficient n depending on the water level height in the main canal and inundation, [6]

Figure 3 shows the way by which the roughness coefficient n can be varied depending on the vegetation at two different locations within the same bed. In case of very tall vegetation on canal walls, the roughness coefficient is approximately constant while in the case of a middle and short vegetation on canal walls prominent roughness coefficient changes occur at the bed walls through time (Figure 3).

The canal roughness and flow conditions are significantly determined by the flood wave velocity (Fisher and Reeve, 1994, Kouwen and Fathi-Moghadam, 2000), [6]. The influence of roughness is more prominent at smaller flood waves in relation to greater flood waves. At numerous water currents the roughness coefficient diminishes with the enlargement of water level, but then sharply increases as soon as the inundations are included in the live section (Fig. 2). Due to lack of hydrometric data which could make the basis for determining the roughness coefficient *n,* the data collected from water currents or beds similar to the analyzed river are often used in practice, [2], [7].

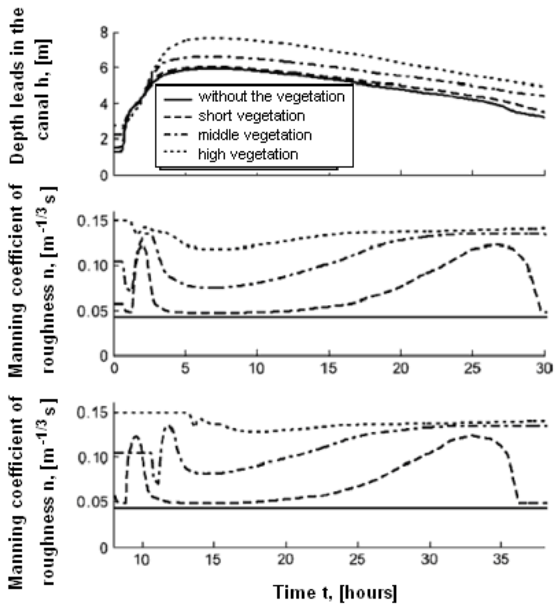


Fig. 3. Roughness coefficient *n* change depending on time at two different locations within the measuring canal, [6]

3 Formation of Boundary Layer in Natural River Beds

In case of a complete roughness development at flowing in the open beds, the vertical velocity profile in the wall area follows the logarithmic law which can be described mathematically in accordance to the Prandtl logarithmic law modified by Nikuradse (1933), [8]. Different methods of velocity profile adjustment through the vegetation for the sunken flowing as the modification Prandtl logarithmic law and calculations of crucial parameters (roughness heights and zero surfaces moving) are presented in Table 1. Single marks in equations characterize: n_{ras} – roughness coefficient for vegetation, (m), R - the hydraulic radius, (m), v_{yP} – velocity inside the vegetation at the determined height y, (m/s), κ_o – the modified Karman constant, the absolute roughness ε, (mm), the integration constant C, while A and B are empiric constants.

In case of flexing vegetation with a small relative underwater part, the surface roughness behaves differently when compared to the static roughness [9], [10]. The influence of a pebbly bottom with a small relative underwater part on the velocity profile is not same as for the on the surface covered bottom (Fig. 4).

Table 1. Methods for describing the velocity profile across the vegetation, [8]

Author	Velocity distribution across the vegetation
1. Plate and Quraishi, (1965)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln\frac{y-h_p}{n_{ras}}$
2. Kouwen and coworkers, (1969)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln\frac{y}{n_{ras}}+C$
3. Nnaji and Wu, (1973)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln\frac{R}{n_{ras}}$
4. Haber, (1982)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln\frac{y}{n_{ras}}+\frac{v_{yP}}{v_*}$
5. Murota and coworkers, (1984)	Slow sway: $\frac{v}{v_*}=\frac{1}{\kappa_o}\ln(y-(h_P-h'))+C$ Rapid sway: $\frac{v}{v_*}=\frac{1}{\kappa_o}\ln y+C$
6. Christensen, (1985)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln\left(\frac{y-(h_P-\varepsilon/29{,}7)}{\varepsilon}\right)+8{,}5$
7. Temple, (1986)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln(y-\alpha_{yP})+C$
8. Watanabe and Kondo, (1990)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln\left(\frac{y-(h_P-h')}{n_{ras}}\right)$
9. El-Hakim and Salama, (1992)	$\frac{v}{v_*}=A+\frac{1}{B}\ln\left(\frac{y}{h_P}\right)$
10. Klopstra and coworkers, (1997)	$\frac{v}{v_*}=\frac{1}{\kappa}\ln\left(\frac{y-(h_P-h')}{n_{ras}}\right)$

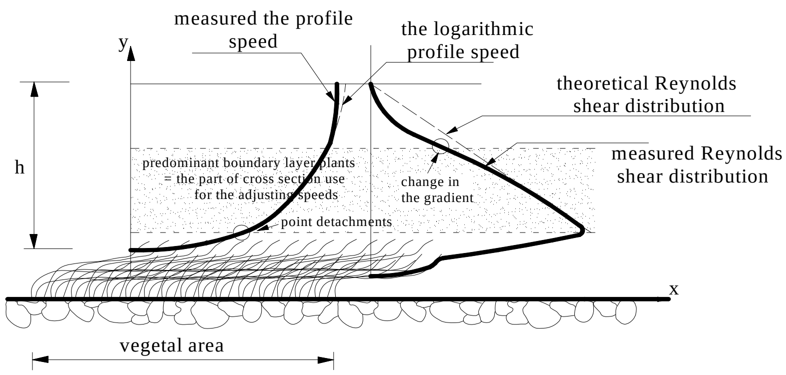


Fig. 4. Presentation of predominant vegetation boundary layer spreading, [8]

4 Methods for Determining Roughness Coefficient in Natural Beds

The surface roughness of the wetted scope of the canal enables the evaluation of the roughness coefficient *n*. If the grain diameters are smaller and more even, the roughness coefficient *n* value is smaller and does not change when the flow depth changes occur. If the material on bed walls is gravel or pebble, the roughness coefficient becomes larger and can significantly vary with the flow depth [10]. When evaluating the coefficient *n* the influence of vegetation in slow and accelerated flow must be also taken into consideration. The relative importance of vegetation for the coefficient *n* can also be observed functioning as the flow depth, density, velocity distribution and the very type of vegetation [11].

The canal irregularity additionally influences the roughness coefficient changes by changing the cross section of the canal and the wetted scope along the longitudinal axes. In natural river beds the consequences of irregularity occur due to elimination process or rinsing of the canal material. Gradual changes have an insignificant influence on the coefficient *n*, while an unexpected change can result in high coefficient *n* values [4], [7]. Existence of obstructions in the canal (the felling of high and low trees, landslides in the flow, appearance of large trunks and stumps at the bottom of the canal) significantly influence the change of roughness coefficient values. The disturbance level of such obstacles depends on their number and size. While the distortions of the canal of large radii with frequent changes in the flow direction give a relatively small resistance, the strong meanders with curves of a smaller radius will significantly influence the growth of the roughness coefficient *n.* Distortions having large radii influence the formation of the main current and sedimentation in specific parts of the bed [8].

In numerous open canals the value of the roughness coefficient *n* diminishes with the growth of the flow. This is a result of the irregularity which has the crucial influence on the roughness coefficient value at lower water levels. The coefficient *n* value can be increased by the flow increase if the slopes of natural river beds are rough, that is, grassy and covered in bushes. On inundations, the coefficient *n* value varies with the depth of the submerging.

Considering the above mentioned remarks and possible factors which influence the roughness coefficient *n* changes, several methods for determining the roughness coefficient value can be discussed at a considerable level of certainty.

4.1 Storage Methods (SCS Method)

The storage method (Soil Conservation Service method) which is used for roughness coefficient *n* evaluation includes the division of base values for an uniform, straight and regulated bed situated in the original material and then modifies this value with the correction factor determined by the critical observation. SCS method proposes usage of turbulences in the flowing as a measure or indicators of the retardation degree [4]. These factors encourage the larger degree of turbulence which results in the increase of the roughness coefficient *n*.

4.2 Ven Te Chow Method

Ven Te Chow method (1959) is used for the coefficient roughness *n* evaluation in open canals and natural beds. It using table values for the roughness coefficients obtained from measuring the specific canals/beds, [2]. The table quotes the minimal, normal and maximum rates of the roughness coefficient *n* for every single type of open canals. The table values of the roughness coefficient *n* can be found in every book which deals determination of roughness coefficient in natural beds.

4.3 The Photographic Method of Roughness Coefficient Evaluation

Geometry of beds together with hydraulic parameters which specify the bed flow can be used for calculation the surface resistance coefficient [7]. The American geologic society (AGU) uses in its own work the program which enables the hydro technicians to evaluate the resistance coefficient at flowing through the canal with the estimated accuracy of up to ±15 % under different flow conditions. The method provides photos showing all the necessary kinematic and geometric characteristics of the observed bed part (Figure 5).

Calculated Manning roughness coefficient: $n=0{,}038\ m^{-1/3}s$ ($Q=17{,}202\ m^3/s$)
Date of watery wave: 22nd February 2006
Date of shootings: 23rd February 2006
Depth of flow in the main bed: 2,63 m
Depth of flow in inundations: 0,0 m
Description of the main bed and inundations: strongly expressed erosions on the right bed shore; scattered appearance of gullies, short vegetation of 5 cm in diameter, climbing grass.

Fig. 5. Application of photographic method in the canal Butoniga, Istrian Peninsula, (Post 05+700 km)

Based on the provided photos the following parameters can be characterized:
- position (the place) at which flood line in the bed ca be noticed;
- the peak flow in the canal which was measured by the specific hidrometric wing;
- the marks of high water levels which can be used for determining the surface profile at peak flows;
- the peak flow which is limited in relation to the shores of the canal.

The roughness coefficient is estimated based on measured flows, shapes of water surfaces and characteristics which are observed on more than two transversal sections within the bed [5].

4.4 Empirical Methods and Formulas for Roughness Coefficient Determination

Today there are numerous empiric methods in the world which are used for the roughness coefficient *n* determination. One from them which was suggested by Strickler (1923) determines the roughness coefficient based on the following reference [3]:

$$n=0{,}047 \cdot d^{1/6} \tag{1}$$

The mark *d* presents the grain diameter (in millimetres) of a uniform sandy slope revetment and the canal bottom. Simons and Senturk (1976), [3] state that due to experimental calculations used by Stickler; the Eq. (2) can not be applied on flows with the movable bottom. Henderson (1966) claims that Strickler's experiments were based on water currents with pebbly bottom and also that the value *d* represents the mean value of the bottom material. The equation for the evaluation of the roughness coefficient *n* provided by Henderson (1966) can be written in the following way [3]:

$$n=0{,}034 \cdot d^{1/6} \tag{2}$$

Raudkivi (1976) came to the modified calculation of Strickler equation and offered the following formula for the evaluation of roughness coefficient *n* calculation:

$$n=0{,}042 \cdot d^{1/6} \tag{3}$$

where the value *d* is measured in (m). The Eq. (4) can be widened as following:

$$n = 0{,}013 \cdot d_{65}^{1/6} \tag{4}$$

where d_{65} presents the grain diameter of the bottom material (in millimeters) taken as 65% of material share. Raudkivi additionally quotes that the equations (3) and (4) can be used for the choosing the roughness height in the fixed ground at hydraulic models.

The later research of Garde and Raju (1978) establish that the Strickler analysis of data was based on different streams in Switzerland which have bottoms of rough material and no waves [3]. According to the research of the two quoted authors the roughness coefficients is determined based on the following formula:

$$n = 0{,}039 \cdot d_{50}^{1/6} \tag{5}$$

where d_{50} represents the grain diameter of the bottom material taken as 50% of weight material. Subramanya (1982) gives a more complete equation for the roughness coefficient evaluation [3] which is the following:

$$n = 0{,}047 \cdot d_{50}^{1/6} \tag{6}$$

Petryk and Bosmajian (1975) developed the method for analyzing the vegetation density when determining the roughness coefficient for very thin layers on inundations [2], [5]. By favoring the forces in the longitudinal direction which can be reached and by substituting the Manning formula the following equation for the evaluating the roughness coefficient was obtained:

$$n = n_o \sqrt{1 + \left(\frac{C_* \sum A_i}{2gAL}\right)\left(\frac{1}{n_o}\right)^2 R^{\frac{4}{3}}} \tag{7}$$

where n_o is Manning border coefficient of roughness, including the influence of vegetation, ($m^{-1/3}s$), C_* the real coefficient of friction for the vegetation in the flow direction, ΣA_i the total frontal vegetation surface which interrupts the flow in (m^2), g gravity constant in (m/s^2), A cross section of the bed in (m^2), L length of the canal which was reached in the calculation in (m), and R the hydraulic radius in (m).

Limerinos (1970) gives the empiric formula for determining the roughness coefficient based on the calculation of the hydraulic radius R and grain diameter size d_{84} which corresponds the 84% of weight material share in the bed (the values range from 1.5 to 250 mm) [4], [7]. The formula was obtained based on measurements on 11 water currents with changeable structure of bed materials, those ranging from tiny gravel to middle size stone pebbles:

$$n = \frac{0{,}8204 \cdot R^{\frac{1}{6}}}{1{,}16 + 2{,}0 \cdot \log\left(\frac{R}{d_{84}}\right)} \tag{8}$$

Burkham and Dawdy (1976) proved that Limerinos formulation for the evaluation of the roughness coefficient can be used for the upper flow regime in streams with sandy roughness [3]. In Strickler formulas for evaluating the roughness coefficient of stiff beds [2], the absolute height of surface roughness ε is correlated with d_{50} percent of bed sediment:

$$n = C \cdot \varepsilon^{\frac{1}{6}} \tag{9}$$

Chezy coefficient C has in the process the following values C=0,034 for riprap revetment at $\varepsilon=d_{90}$, C=0,038 for the flow capacity of canal riprap at $\varepsilon=d_{90}$, respectively C=0,034 for the natural sediment at $\varepsilon=d_{50}$.

Apart from the above mentioned methods for evaluating the roughness coefficient in complex beds, there are some methods in practice which are relatively close to the former. The General Los Angeles method [10] and Colbatch method [11], [3], [4] must be undoubtedly mentioned in this context:

$$\bar{n} = \frac{(A_1 n_1 + A_2 n_2 + A_3 n_3 + \ldots + A_N n_N)}{A} \tag{10}$$

$$\bar{n} = \frac{(A_1 n_1^{1,5} + A_2 n_2^{1,5} + A_3 n_3^{1,5} + \ldots + A_N n_N^{1,5})^{\frac{2}{3}}}{A^{\frac{2}{3}}} \tag{11}$$

where: $A_{1\ \ldots}\ A_N$ present the partial surfaces of live canal sections in (m^2), and A is the total surface of cross section in (m^2).

The roughness coefficient *n* value of the main bed and inundations can also be determined by Force sum method. This method has been suggested by Pavlovski, Muhlhofer, Einstein and Banks [2], and is the following:

$$\bar{n} = \frac{\sqrt{O_1 n_1^2 + O_2 n_2^2 + O_3 n_3^2 + ... + O_N n_N^2}}{O^{\frac{1}{2}}} \tag{12}$$

where O_i is the wetted scope when dividing surfaces in groups in (m), n_N the roughness coefficient *n* when dividing surfaces in groups in ($m^{-1/3}s$), and *O* the total wetted scope of cross section in (m).

4.5 Methods of Roughness Coefficient Evaluation Based on Measurement Data

Besides empiric formulas for determining the roughness coefficient *n* which were stated in the previous item, there are approximate formulas in practice which enable a swift and reliable estimation of roughness coefficient *n*. The final forms of these formulas are obtained by solving the basic kinematic characteristics and measuring the geometric characteristics of the natural bed [12].

The first way of roughness coefficient *n* determination requires determination of the mean value if power line decrease $\bar{I}_E$, in order to positively determine the average total loss ΔH on the defined bed section ΔL based on this value. It must be stated that the Chezy coefficient *C* is calculated based on Manning formula and that the Manning roughness coefficient for two characteristic cross sections *i* and *i-1* is accepted to be approximately the same ($n_1 \cong n_2 \cong n$):

$$\bar{I}_E = \frac{\Delta H}{\Delta L} = \frac{\bar{I}_E \cdot \Delta L}{\Delta L} = \frac{I_{E,i} + I_{E,i-1}}{2} \Rightarrow n = 2^{1/2} \cdot \frac{(R_i \cdot R_{i-1})^{2/3}}{(v_i R_{i-1}^{4/3} + v_{i-1} R_i^{4/3})^{1/2}} \cdot \bar{I}_E^{1/2} \tag{13}$$

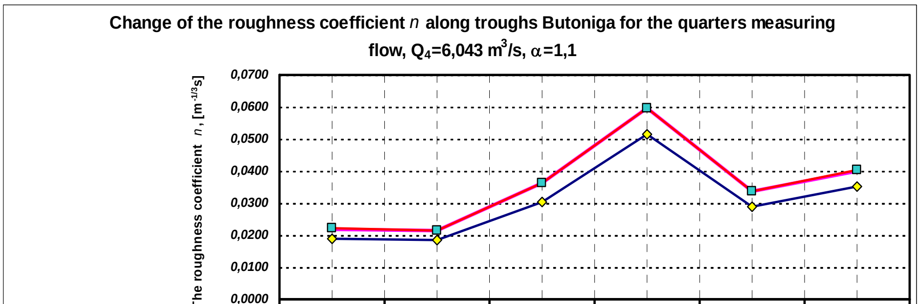
where: R_i, R_{i-1} represents hydraulic radii on *i* and *i-1* cross section in (m), while v_i, v_{i-1} are mean flow velocities on *i* and *i-1* cross section in (mps). The other way for roughly estimating the roughness coefficient *n* focuses on determining of mean velocity $\bar{v}$ and mean hydraulic radius $\bar{R}$ on the interrogated bed section ΔL:

$$I_E = \frac{\Delta H}{\Delta L} = \frac{n^2 \bar{v}^2}{\bar{R}^{4/3}} = \frac{n^2 \left(\frac{v_i + v_{i-1}}{2}\right)^2}{\left(\frac{R_i + R_{i-1}}{2}\right)^{4/3}} \Rightarrow n = 2^{1/3} \cdot \frac{(R_i + R_{i-1})^{2/3}}{v_i + v_{i-1}} \cdot I_E^{1/2} \tag{14}$$

The third way of determining the roughness coefficients *n* is based on calculation the roughness coefficients n_1 and n_2 on specific profiles, where by moderating these values the required roughness coefficient *n* value of the required observed section ΔL is obtained:

$$n = \frac{n_i + n_{i-1}}{2} = \frac{\left(\frac{R_i^{2/3}}{\nu_i} \cdot I_E^{1/2}\right) + \left(\frac{R_{i-1}^{2/3}}{\nu_{i-1}} \cdot I_E^{1/2}\right)}{2} \tag{15}$$

For identical geometric and kinematic parameters of the interrogated bed sections, the roughness coefficients *n* differ considerably when the first and the second way of determination are applied, while in the third case they almost coincide with the second way of determination (Fig. 6).



	Share between 1. and 2. the measuring profile	Share between 2. and 3. the measuring profile	Share between 3. and 4. the measuring profile	Share between 4. and 5. the measuring profile	Share between 5. and 6. the measuring profile	Share between 6. and 7. the measuring profile
The roughness coefficient n on the given share (1. way calculates)	0,0190	0,0185	0,0305	0,0515	0,0290	0,0351
The roughness coefficient n on the given share (2. way calculates)	0,0220	0,0215	0,0362	0,0598	0,0337	0,0399
The roughness coefficient n on the given share (3. way calculates)	0,0221	0,0216	0,0362	0,0597	0,0337	0,0402

Fig. 6. Change of roughness coefficient *n* on the interrogated section of Butoniga bed (Istrian Peninsula) in three characteristic cases of roughness coefficient determination, [12]

5 Conclusions

In everyday practice of designing the expertness in roughness coefficient *n,* that is, the knowledge of a real range of changes of its values for specific types of canal development and level of its maintenance during the calendar year is of outmost significance. The roughness coefficient *n* for different bed and revetment types is usually chosen from the literature. The descriptions, based on such choices, usually provide the designer a large possibility of subjective concluding. In the world literature the roughness coefficient of different revetments is well described and defined, whereas its determination depends on many parameters which can change within the short or the longer period of exploitation, especially for earth beds and inundations. These changes of bed state happen due to the change of water level in the bed, when the full range of hydraulic parameters changes due to change of bed geometry through time (the instability of embankment slope) and change of bed vegetation thickness.

The contemporary model approaches to the problem solving from the domain of open canal hydraulics whose usage at planning the water-managing solutions ensures better or more rational dimensioning of particular regulation structures and beds, emphasizes the need of a more reliable defining of bed roughness to even larger extent. In this sense it is necessary to conduct field research of particular hydraulic characteristics, as well as their analysis. Apart from the intentionally conducted field research and analyses, the interpretation must be also based on the whole row of other information and data primarily tied to the bed maintenance regime, the observed appearances of large waters as well as to the previously conducted hydrometric measurements.

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Classification and Estimation of Flood Losses

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Abstract. Floods represent one of the greatest hazards in the sphere of natural disasters. As a result of flood events, losses and extensive damage arise. Flood losses can generally be divided into the direct and indirect. Their estimation is an essential part of flood risk analysis and management. Direct losses coincide predominantly with material damage and loss of human life. There exist more or less accurate routine procedures for the estimation of direct material losses which are used in flood protection and risk analysis studies. Indirect damage is difficult to classify and estimate. It includes e.g. lost profit due to the economic failure of entrepreneurial subjects, flood-induced socio-psychological problems (e.g. unemployment, suffering, shock), health problems, complications affecting transport, water and energy supply, etc. Further issues are of environmental, ecological or hygienic character. In general, indirect losses are linked to the direct ones and they can be usually expressed in terms of a percentage of the latter. In this paper flood losses are listed and classified. The methods used for flood loss estimation as a function of hydrologic and hydraulic characteristics are described in brief completed with few practical examples.

Keywords: Floods, flood loss, direct loss, indirect loss, and fatality

1 Introduction

Flooding constitutes one of the greatest dangers in the area of natural disasters. In the Czech Republic floods arise from heavy rainfall or alternatively from spring snowmelt combined with rain (so-called natural floods), or are caused by anthropogenic activities (e.g. dam break floods). Owing to such flooding, extensive damage and losses can arise, the height of which depends on many factors. Some of the most important factors are land use and the vulnerability of particular objects in the floodplain, the warning system, the preparedness of inhabitants and the quality of the emergency rescue system. Another significant factor is the flood hazard expressed by characteristics of the flood such as water depth and velocity, its temperature and quality, etc.

Flood losses depend on the flood damage [4] and can be divided into those that are direct and indirect [5]. Furthermore, it is possible to sub-divide both of them into economic and non-economic losses (Table 1). The direct economic losses include material losses (in residential developments, industry, agriculture) and environmental losses; the direct non-economic losses are damage to health and loss of human life. Indirect losses are difficult to classify, quantify and include into analyses. Indirect losses are both economic losses connected with necessary financial aid (from the state, municipality or private subjects) or forms of endowment, and indirect non-economic losses like hygiene problems, the threat of disease, losses of a socio-psychological character induced by shock due to losses in terms of property or human lives, job losses, etc. Some other classifications can be found at [4] and [5].

Naturally, losses in individual parts of a flooded area will be assessed differently according to the character of the territory. In this text we will deal with options for and methods of assessment (resp. estimation) of flood losses.

Table 1. General division of flood losses

FLOOD LOSSES	DIRECT	ECONOMIC	MATERIAL LOSSES
			ENVIRONMENTAL LOSSES
		NON-ECONOMIC	DAMAGE TO HEALTH, LOSS OF HUMAN LIFE
	INDIRECT	ECONOMIC	INDUCED LOSSES
		NON-ECONOMIC	SOCIO - PSYCHOLOGICAL LOSSES
			LOSSES OF HYGIENIC CHARACTER

According to the Czech civil code the losses are defined as detriment to property, which can be expressed via a financial equivalent. From the viewpoint of flood losses the definition is not accurate and complete since some losses are financially hard to express.

2 Direct Losses

Direct flood losses are all losses that arise directly due to the impact of flood water. These losses are of a material nature and impact the environment, life and health of the affected population. The extent of such losses is possible to estimate quite reliably after a flood event. In the case of the estimation of future potential direct flood losses, calculation is mostly done on the basis of known past flood losses, experience and professional estimates.

Direct flood losses can generally be divided into economic and non-economic losses. Economic losses are mainly of a material character, and the most important non-economic loss is the loss of human life.

The height of flood losses is dependent on flood characteristics, especially on water depth in the floodplain, flow velocity and the velocity at which the water level rises, on the duration of area inundation, on water quality and on other factors.

2.1 Direct Economic Losses

Direct economic losses are formed mainly by material losses and in general it is possible to classify them into the loss of property, losses to the infrastructure and also to the environment.

First of all, direct material losses are connected with damage to residential buildings, cottages, other civic facilities, industrial areas, recreational and sports facilities, shopping areas, gas stations, and also to the infrastructure (waterworks, water and gas supply, sewerage, roads, etc). The damages and losses affecting water structures and water courses, including dam failures, are of great importance too. Losses to agriculture and forest management due to the washing away of fertile agricultural land together with the crop growing on it also belong to this group.

The extent of the damage to civil structures is influenced by their vulnerability, which is determined by their technical parameters, e.g. building materials, age of the structures, geotechnical and hydrogeological characteristics of the sub-base (bearing capacity, groundwater flow regime) and other factors. The height of losses is also influenced by the flooding hazard quantified by flood characteristics such as water depth and flow velocity, the duration of flooding and rate of water level increase, the temperature of the water and its quality, sediment transport and some other factors. Climatic factors such as wind velocity, air temperature and humidity, ice development, etc. are also of importance. In risk analysis, only a few of the above-mentioned factors are usually taken into account, namely water depth and velocity, and the type and foundation of the structure.

For the estimation of agricultural, environmental and other direct economical losses special techniques are used [2]. The plants could die or suffer from necrosis due to an extensive period of flooding even with a relatively small water depth. If waste water treatment plants are flooded they are not usually able to operate properly, which can cause contamination of both surface and subsurface waters. The environment can be contaminated by spills from chemical and industrial factories in case of their flooding.

Estimation of material losses. For the determination of material losses the methodology described in e.g. [2] can be used. The basis for such estimates is a comprehensive database of representative property types and their vulnerability in the case of flooding. Furthermore, it is necessary to define factors influencing the extent of damage to representative properties. For the further solution, aggregated objects can be used, e.g. according to Table 2.

In practical applications it is important to restrict the number of factors influencing the consequences of floods on objects. The three following factors have a decisive influence on flood damage: water depth (factor A), duration of inundation (factor B) and subsoil bearing capacity (factor C). Combinations of these factors were assumed when determining percentage flood damage using so called "damage curves" (examples of selected structures are presented in Figs.1 and 2). In our case the flow velocity was assumed to be lower than 1.0 m/s for each type of object/facility. This corresponds with conditions at lowland areas. For all combinations of the above-mentioned factors the extent of damage was determined by expert assessment (structural designers, civil engineers and authorized experts) for individual representative properties (Table 2).

Table 2. Database of representative properties [2]

1	Offices, housing in closed blocks in central cities, "watertight" yards
2	Panel houses, blocks of flats
3	Semi-closed blocks of dwelling-houses, grassed inside-blocks
4	Terrace houses in continuous arrangement, urban, suburban and village developments
5	Terrace houses free-standing in gardens, cottages
6	Unoccupied objects – barns, warehouses
7	Cottage colonies – cabins, appurtenances
8	Recreational structures, cottages
9	Greenhouses
10	Halls made of bricks (industrial, sports, etc.)
11	Prefabricated halls
12	Football grounds
13	Bathing pools (swimming-pools)
14	Tennis courts
15	Volleyball and other courts

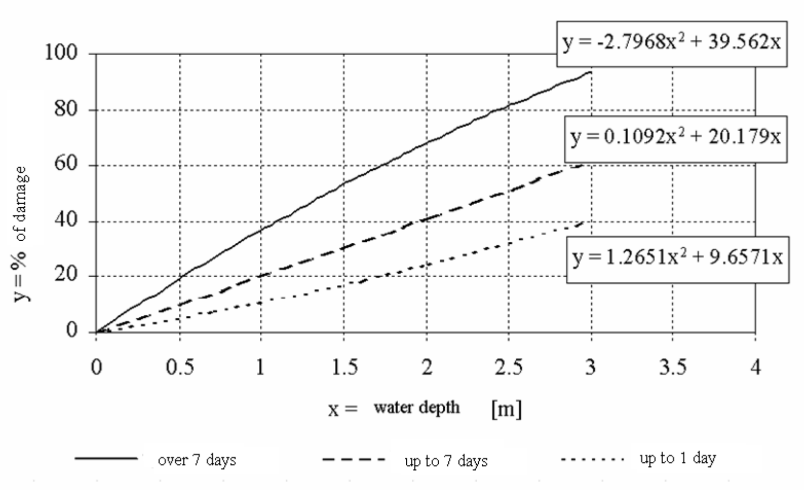

Fig. 1. Damage curves for various periods of flooding - terrace houses in continuous arrangement, subsoil with high bearing capacity – item 4 in Table 2

In practical applications it is convenient to develop Geographic Information Systems (GIS) applications. They enable the compilation of an input database to analyse the results of hydraulic calculations in the form of inundation, water depth and velocity maps. GIS applications also serve for the generation of maps of real estate, urban developments and property in a given area (provided by the statistical bureau). With the help of a digital model of the terrain, hydraulic calculations, built-in damage curves and property maps, the total direct material flood losses can be calculated in the defined area of interest [1].

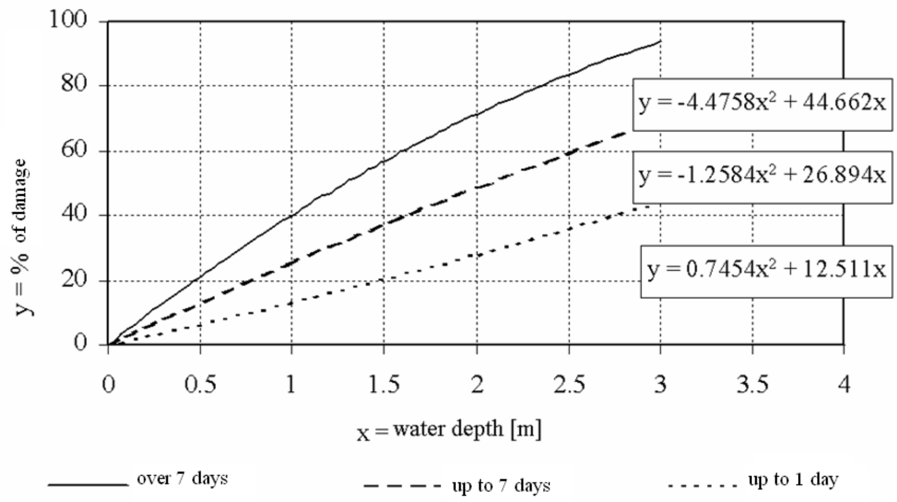

Fig. 2. Damage curves for various periods of flooding - terrace houses in continuous arrangement, subsoil with low bearing capacity – item 4 in Table 2

2.2 Direct Non-Economic Losses

Non-economic losses are difficult to evaluate in monetary units. Normally, one lost life is used as the “loss unit”; serious injury is assumed to be equivalent to a life lost. The number of fatalities depend on the population in the area, the form and speed of the flood, the timing of the flood warning in advance of the event, the parameters of the flood (water depth, velocity, water temperature, etc.) and also on the momentary activity of people in the area.

Estimation of loss of life. In the references and available literature, the estimation of loss of human life is focused dominantly on dam break floods. For hydrological floods only data from real past floods are available. In the Czech Republic five significant floods have occurred during the last 12 years, namely in the years 1997, 1998, 2000, 2002 and 2006. The data concerning direct material losses were related to the numbers of fatalities (Table 3). This enables the comparison of the ratio between direct material losses and fatalities during floods in relation to the nature of the flood, and the warning system. The conditions during the flood situation were classified as follows (see also [3]):

- amount of advance warning time – limited, medium, high;
- understanding of flood severity - vague, medium, precise.

Table 3 gives an idea about the ratio between direct material losses and fatalities in various flood scenarios. It can be assumed that the ratio corresponds to the amount of advance warning time and the understanding of flood severity.

It is known that the understanding of flood severity and the preparedness of society was relatively small until 1997, and has been much better since the year 2000. The July 1997 and August 2002 floods originated due to regional precipitation events of high intensity, therefore long warning times were available. At the same time the spring 2006 flood came slowly and was well forecasted. The other floods were of a local character and similar to "flash floods" with limited forecasting and very limited warning.

Table 3. Comparison of direct economic losses and numbers of fatalities

Flood situation	Number of fatalities	Direct economic losses in EUR	Number of fatalities per billion EUR	Warning time in minutes	Understanding of flood severity
July 1997	60	2,200 million	27	long	vague
July 1998	10	64.3 million	159	limited	vague
March 2000	3	139.3 million	22	limited	medium
July 2002	2	3.6 million	556	medium	precise
August 2002	19	2,610 million	6	long	precise
Spring 2006	9	214.96 million	42	long	precise

Comment: 1 EUR = 28.0 CZK

The data in Table 3 can be the basis for the estimation of the number of fatalities when direct material losses have been estimated (e.g. by the technique mentioned in section 2.2).

3 Indirect Losses

The term 'indirect losses' does not refer to the damage arising as a direct effect of an inundation by water but rather to that which comes into existence subsequently as result of direct losses. These losses can be of a long-term character and regional importance, and they can destabilise the economy and the market. The assessment of indirect losses is still quite complicated and is accompanied by a number of uncertainties. In the same way as in the case of direct losses, indirect ones can be divided into economic and non-economic losses.

3.1 Indirect Economic Losses

During flood events, situations occur which necessitate the use of considerable financial resources for removal of the flood's consequences. These expenditures can be on crisis management, the rescue services, evacuation, the guarding of property, the ensuring of temporary lodging, the participation of the army, etc. In the case of damaged infrastructure (roads, railroads, bridges, sewerage, gas and water supply systems, electricity lines, telecommunication and data cables, etc.) it is necessary to ensure alternative connections and supplies. This leads to additional costly activities including the establishment of new temporary lines and bypasses, standby transport facilities and other initiatives causing time delays and further expense. Affected companies and enterprises suffer from production restrictions due to flooding and potentially also due to the non-delivery of components from flooded subcontractors. Other indirect economic losses arise in the agricultural sector where the value of the land can drop and consequently agricultural production can stagnate. In the case of long-term flooding the vegetation suffers from illness, decay and may possibly wither and die.

All of the losses mentioned can be expressed in monetary units, though with a good deal of difficulty and a lack of reliable data.

An example of indirect economic loss estimation. In the following text only partial indirect economic losses induced by the damage to a bridge are expressed. The bridge, which is over the Litava River, is located on the main road in the town of Bucovice in southern Moravia, Czech Republic. During a flood the bridge is expected to be seriously damaged, which will necessitate the diversion of traffic to the town of Zdanice along an alternative route according to the flood management plan (see Fig. 3). In such an event the elongated route will induce indirect economic losses due to additional travel expenses and time delay.

Fig. 3. Marked routes from the town of Bucovice to the town of Zdanice – a dashed line marks the original route; the solid line marks the diverted route

The direct economic losses arising from the bridge damage are estimated at 840 thousand EUR. The partial indirect economic losses are calculated in Table 4.

The distance between Bucovice and Zdanice along the original route is 10.5 km, the diverted route is about 31.7 km long and the difference between both lengths is 21.2 km. The prolonged alternative road creates additional cost both for the inhabitants of the local neighbourhood and for the community (public transport, supply, etc.).

Table 4. Evaluation of indirect losses due to bridge damage

Costs	Number	Price in EUR
Daily number of cars crossing the bridge	1500	
Original length between Bucovice and Zdanice	10.5 km	
Length of diverted route from Bucovice to Zdanice	31.7 km	
Difference in lengths	21.2 km	
Cost of 1 litre of fuel		1.0
Expenses per 1 km		0.5
Expenses per 1 day		530.0
Estimated time for bridge repair	4 months	
Total indirect economic loss		63 600

From the proportion of the indirect to the direct economic loss the percentage 7.6% is obtained. When generally evaluating extra travel expenses due to damaged roads and bridges during floods, the indirect economic loss can be estimated at from 5% to 10% of the direct economic losses for the infrastructure

3.2 Indirect Non-Economic Losses

These losses involve induced socio-psychological losses, hygiene problems and the menace of infections and epidemics. Similarly to the direct non-economic losses, it is hardly possible to specify these losses in terms of financial value.

In general the most endangered are old, handicapped and disabled people and the socially vulnerable. Most inhabitants are able to adapt to the situation which has arisen. However, some weaker individuals may suffer and need medical help. For old people the exposure to such problems increases in effect due to the difficulty the aged find in accommodating themselves to the loss of property, changes and stress. For socially vulnerable individuals floods can lead to the loss of their homes and their joining the homeless community.

Even if the flood situation itself is highly stressful, the stressful situation that comes after the flood is more significant, as this is when the losses are discovered in their full extent. Remedial measures are long term, time consuming and mentally demanding. Mental impairment can take even several years to manifest itself.

Presented in the following text is an attempt to quantify socio-psychological losses by financial means via expenses to the medical services and in terms of needed pharmaceuticals.

Example of determination of indirect non-economic losses. From the viewpoint of ethics and morality, loss of life and losses of a socio-psychological nature are very difficult to evaluate in monetary units. An attempt was made to deal with these losses via the price of applied medicaments (antidepressant drugs). After the flood in the Morava River catchment in July 1997 a precautionary development programme of post-traumatic stress treatment was carried out [2]. The sample was taken from a population at risk of 10 000 inhabitants, from which about 25% (2500 inhabitants) were struck by mental problems. Antidepressant treatment was applied to 614 patients. A more detailed analysis was carried out for 78 patients (66 women and 12 men from the age of 20 to 90 years with an average age of 43.5 years). The statistics show that the females were more vulnerable than the males. The treatment continued for 3 months and was successful in 82% of cases. Of course, the analysis did not pertain to the people who refused help or who were ill for more than 3 months. In the following cost estimate (Table 4) it is assumed that 25% of the population at risk will be affected, and only the specified drug (Seropram - citalopram) and dosage will be applied at an average cost. The cost only represents the price of the prescribed drugs, medical services are not included. The following tables show the average prices of medicaments in the year 2003. In Table 5 the cost of psychiatric ambulatory care during the first 6 months is estimated using prices from the year 2003.

Table 4. Assessment of costs of pharmaceuticals (antidepressant drugs) [2]

Duration of treatment	Average cost/patient in EUR	Assumed number of patients	Total cost of drugs in EUR
1st month	38	2 500	95 000
2nd.+ 3rd months	76	2 500	190 000
4th + 5th + 6th months	113	1 250	141 250
Final costs			426 250

Table 5. Assessment of costs of psychiatric ambulatory care during the first 6 months of treatment [2]

1st month	32	2 500	80 000
2nd.+ 3rd months	38	2 500	95 000
4th + 5th + 6th months	26 + 76	1 250	127 500
Final costs			3 025 000

The rough estimates result in a unit cost about of 43 EUR for pharmaceuticals (antidepressant drugs), and of about 303 EUR for psychiatric ambulatory care during the first 6 months of treatment. The unit cost represents expenses per one individual living in the flooded area (population at risk).

It must be stated that the calculation presented above involves only partial expenses for the treatment of mental problems covered by health insurance companies. The expenses are always site specific and can differ for various flood scenarios. The description of real losses will need more detailed and complex research, even if experience from our research shows that data acquisition is very arduous due to the reluctance of physicians to provide data about medical treatment, and legal restrictions governing the provision of such data. Usually only general statistical data are available.

4 Conclusions

In this paper flood losses are classified. The methodology of estimation of direct economic losses using damage curves and GIS techniques is briefly described. A possible method of evaluation of fatalities using data about direct economic losses is outlined and some relevant data from past flood situations in the Czech Republic are presented.
In the case of indirect losses only single partial solutions are mentioned, namely the expenses connected with damage to traffic infrastructure, and the losses induced by medical treatment of mental illness as a consequence of stressful situations are discussed. It is true that recently indirect losses have not been included in routine loss analysis. However, in total they can represent tens of percent of direct economic losses and can significantly influence the results of cost-benefit analyses and the assessment of the profitability of flood protection measures.

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Rječina River Basin Restoration (Croatia)

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Abstract. The city of Rijeka (Croatia) developed from the old Tarsatica on the right and the newer Sušak on the left side of the River Rječina right on the river's mouth in the Adriatic Sea. The Rječina was the driver of the city; it moved mills, supplied the city with drinking water (and still does) and along its flow the first manufacture, and later industrial plants of this city in development, and was raised. Today these areas and industrial buildings along the Rječina mostly do not fulfil their primary function and are waiting for their conversion and re-integration in the life of the city. This paper will show plans as well as already undertaken regulation, restoration and revitalisation works in the riverbed and the riversides of the Rječina. These solutions try to connect the city and its citizens with "their" river and the natural environment, valorise the areas along the river as well as the industrial and architectural heritage.

Keywords: Rječina River, river basin, restoration, revitalization, industrial-architectural heritage

1 Introduction

The city of Rijeka (Croatia) developed from the old Tarsatica on the right and the newer Sušak on the left side of the Rječina River right on the river's mouth in the Adriatic Sea (Fig. 1). The Rječina was the driver of the city, it moved mills, supplied the city with drinking water (and still does) and along its flow the first manufacture, and later industrial plants of this city in development, were raised (leather factory, pasta factory, paper mill, butchery, hydropower electric plant, …). Today these areas and industrial buildings along the Rječina mostly do not fulfil their primary function and are mostly waiting for their conversion and re-integration in the life of the city. Although in the recent past the Rječina was more of an obstacle that had to be bridged so the city could function in the accelerated rhythm of modern life, than an integral part of Rijeka's life, today significant steps have been undertaken in order to revitalise the River Rječina and the areas along its flow.

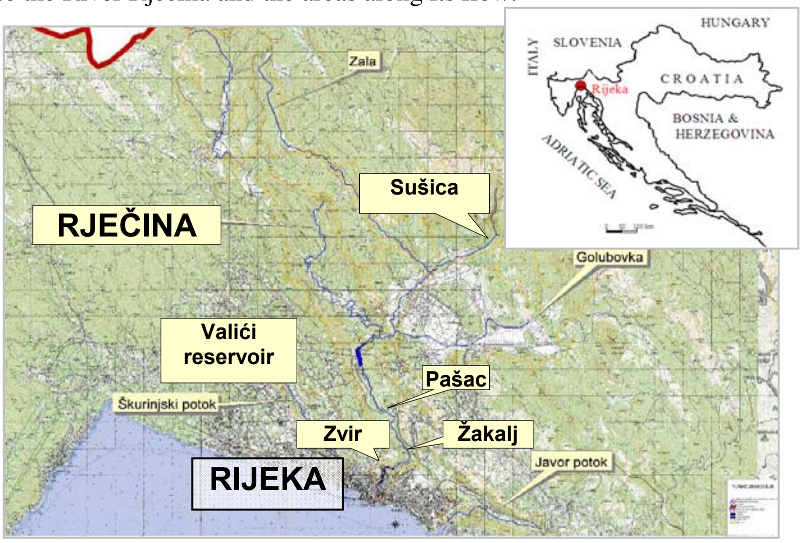

Fig. 1. Map of Rječina River and the city of Rijeka

This paper will show plans as well as already undertaken regulation, restoration and revitalisation works in the riverbed and riversides of the Rječina. Some of the important ones related to the regulation of Rječina were done in the beginning of the last century to control the strength of the river in order to protect the city of Rijeka and the port from flooding and backfilling with materials eroded from the upper parts of the catchment. Also new projects for restoration and revitalization of structures in the riverbed and buildings in the surrounding areas will be presented. These new projects are trying to achieve social benefits. These new solutions try to re-connect the city of Rijeka and its citizens with "their" river. They try to connect the centre of the city with the natural environment, valorise the areas along the river as well as the industrial and architectural heritage directly by finding new purposes for existing buildings that are not in use any more, organizing walkways along the river etc. In this way the expansion of city life all along the river can be enabled

2 Rječina through the Past

RJEČINA (Rečina, Ričina), also called in the past Eneo, Oeneus, Tarsia, Flumen, Pflamm, Fiume, Reka, is the major watercourse in the area of Rijeka [7].

It is a karst river with the catchment area that represents a space historically related to the earliest signs of human existence in the region.

The advantages of the geographic position and natural conditions, with the abundance of drinking water, were the major factors for positioning and for the growth of the city at the Rječina river mouth in the Adriatic Sea and also smaller settlements along the river banks all the way up to the source.

After Liburnian settlements in the Roman times the municipium Tarsatica developed from the former military castrum. The medieval Rijeka Sv. Vida developed on the foundations of the Roman town. In the same time on the left bank the settlement Trsat developed with municipal organization. In the 11th century the Croats lost Merania – the area between Plomin and the Rječina, which continued to be the border for several centuries. In the Middle Ages, the Rječina catchment area was divided between the municipalities of Rijeka, Trsat, Grobnik and Kastav. The major area was cultivated and the feudal economy resulted in construction of flour-mills, saw-mills and stumping-mills that led to the development of settlements in the middle and upper reaches. Things changed in the 18th century when Rijeka received the status of the free port which led to the development of commerce and industry. The port was situated in the mouth of the Rječina River so manufactures and industry facilities were established in the lower and upper catchment areas (paper mill, leather processing, slaughterhouse, large industrial flour-mills and pasta factory). The city developed very rapidly due to social and political circumstances and also the construction of the railway. Both banks were industrialized and urbanised with further industrial, municipal and residential construction. The city promenade developed along the river. With time under the pressure of commercial interest the former green oasis almost completely disappeared. The harbour in the river mouth was substituted with the large port developed in front of the city by systematic filling. Interventions into the natural environment started already in the Middle Ages – by construction of water driven facilities, development of the harbour and banks and cleaning the river channel from sediment. Due to flood hazards, the new river channel was excavated in the 19th century, the delta was formed and the old channel was transformed into Mrtvi kanal (Dead Channel). But this was not enough to eliminate the food hazard, it was only reduced, so at the end of the 19th and beginning of the 20th century regulation works on the middle and upper reaches were accomplished. Finally the river was harnessed. Part of these projects will be presented in this paper. The Rječina remained a border until the end of World War Two; however in particular instances, the natural conditions dictated join action by sometimes opposed political parties, because the Rječina was always perceived as the common concern and the common benefit.

3 Hydrographic-Hydrologic Characteristics of the Rječina River

The Rječina is a typical karst river that starts as a very strong karst source in the hinterland of Rijeka 352 m a.s.l. After the course of 18.63 km the Rječina enters the Adriatic Sea in the centre of the urban area of Rijeka (Fig. 1). The area of the direct river catchment is about 70 km^2, but the catchment area of all sources that nourish Rječina and its tributaries is much larger, about 300 km^2 [3].

The upper horizon represents the zone of periodical discharge caused by the source of the Rječina which has the average annual flow of 7.8 m^{3}s^{-1}, but also some regular annual drought periods lasting from 1 to 4 months and usually occurring during summer and occasionally during winter periods (Figs. 2 and 3) [4]. Since 1915 the source has represented the most important water resource for the water supply system of Rijeka. In recent times around 20 mil.m^3 of water per year have been used for water supply purpose. The source is used until its abundance decreases to 0.2 m^3s^{-1}. This quantity is the biological minimum for fish stock protection.

Fig. 2. The source of the Rječina River

Fig. 3. The surroundig area of the source

Zones of permanent discharge are located near the coastline in the centre of Rijeka. Those are the spring Zvir, situated very closely to the Rječina riverbed and also the Martinšćica area, a few kilometres away from the Rječina riverbed. The spring Zvir rises 2.5 m a.s.l. with the average annual flow of 4.4 m^3s^{-1}. About 7 mil.m^3 of water per year is pumped form the spring Zvir in the water supply system mostly during drought periods when the Rječina source dries out or its abundance decreases to the biological minimum.

Along the river there are some morphologically very interesting and different areas. The upper and the middle part of the Rječina course is formed within impermeable paleogene flysch rocks. In its lower part it narrows to a canyon formed by cretaceous and paleogene limestone rocks [1]. Through this canyon the river enters the city of Rijeka. In the past the Rječina River was entering a glacial lake (today the area of Grobničko polje) and then went under the surface. With time the river broke through the flysch layers creating the canyon. Because of this geomorphologic development both slopes of the Rječina valley between the reservoir Valići and the settlement Pašac are on the verge of stability. Landslides occurred many times during the 20th century. The last major landslide occurred on 5th December 1996. This area is considered one of the most active landslide areas in Croatia.

The upper part of the Rječina is a nicely shaped natural flow in a wide valley area. The middle part, that is the canyon part, starts with the inflow of the tributary Sušica, 8.8 km upstream of the Rječina mouth. This part ends almost in the centre of Rijeka, about 2 km upstream of the Rječina mouth. The flow regime in the middle and in the lower reaches has changed a lot after the construction of the 35 meter high concrete gravity dam Valići and formation of the reservoir of 0.47 mil.m^3 near the settlement Grohovo in 1968 (Fig. 4). The water from the reservoir was and is still used for electrical energy production in the hydropower plant located in the centre of Rijeka near the spring Zvir. The annual production of electrical energy is about 100 GWh.

Downstream of the Valići reservoir the river bed is dry most of the time, except in high water periods when the spillway is overflown. The average annual flow is about 1.6 m^3s^{-1}. Before the construction of the dam on the measuring station Grohovo, just downstream of the dam (Fig. 5), the average annual flow was 9.1 m^3s^{-1}.

Fig. 4. Valići reservoir with the concrete dam

Fig. 5. Grohovo landslide

The causes of this are mostly the construction of the dam but also, to a smaller extent, the global changes of the water regime. These changes in the Rječina canyon part water regime are shown in Fig. 6.

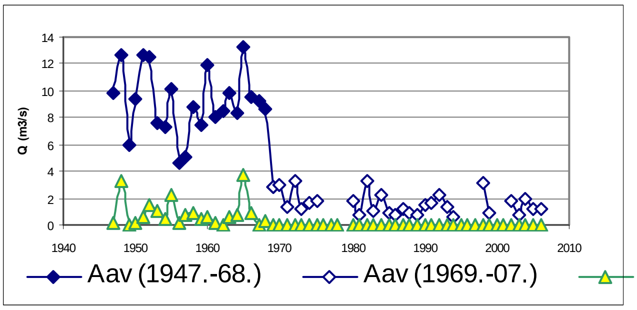

Fig. 6. Changes in the water regime at the Grohovo measuring station (average annual and minimal average monthly flow in the period 1947-2007)

The Rječina canyon part downstream of the reservoir Valići is very attractive and interesting from the aspect of natural characteristics and cultural-architectural heritage, but since the riverbed is mostly without water a great damage has been done to the ambient characteristics of this area (Fig. 7). In this very area there are 23 consolidation steps (barriers) constructed between 1898 and 1908. These steps are a very valuable architectural heritage and are still in function today (Fig. 8).

The lower part of the Rječina course, after the canyon part, has again a permanent water surface level, partly because of the Adriatic Sea influence and partly due to the water discharge from the hydropower plant and from the spring Zvir.

Fig. 7. The canyon-part of the Rječina

Fig. 8. Consolidation steps (barriers)

The mouth of the Rječina in the sea is right in the centre of Rijeka. This being so-caused many floods in the centre of the city and also the backfilling of the old port area during the past. This is the reason why in the 19th century the excavation of a new river channel and the formation of the delta with transformation of the old river bed into Mrtvi kanal (Dead Channel) was performed. After that the planning and then the regulation of the Rječina with previously mentioned consolidation steps were done. Most of the regulation works were done in the middle and in the lower part of the river course, especially in the area of the Grohovo landslide (Fig. 5).

4 Plans and Projects Related to the Regulation of the Rječina Through the Past

Since the beginning of the urban area development, the city of Rijeka and the Rječina River have always been interconnected in both the functional and the ambient sense.

The flow course and the Rječina canyon carved into the steep terrain configuration, were Rijeka's connection with the hinterland, as well as Rijeka's open gate to the Adriatic Sea .

Today the flow course and the Rječina canyon have lost the character of the industrial centre of the city of Rijeka and have become the area where the city and the nature are very close to each other, but unfortunately without a proper communication.

In the past, the development of urban areas alongside the lower part of the Rječina influenced the approach to the regulation of this river. The solutions had to take into account the protection from high waters, protection from bringing large quantities of sediment materials in the estuary and in the old port area and also find ways to exploit the hydropower potential of the river.

The first works in the riverbed were related to solving local problems such as water diversion towards the mills in the middle and lower reaches of the Rječina and the periodical removal of the sediments from the estuary.

Due to the constant backfilling of the old port areas with river sediment in 1820 the initial idea about the river flow translation out of the port areas was developed [7]. This was accomplished in 1855 according to the project of Karlo Keckes from 1847.

The new riverbed was excavated more eastward and the Delta was formed (Fig. 9). The old riverbed became the Mrtvi kanal (Dead Channel). Through this new riverbed Rječina waters are entering the sea even today.

Fig. 9. The Rječina mouth (the old riverbed Dead Channel and the new riverbed)

In those times there were often high water appearances that endangered the city centre areas. High waters were registered in 1849, 1852, 1853, 1870, 1879, 1883, 1884 and 1898. These high waters caused the activation of a very large landslide Grohovo in 1885, 1887, 1892 and 1893. That is today, as already mentioned, the largest active landslide area in Croatia (Fig. 5). All this resulted in the decision to start serious regulation works in the middle part of the Rječina course. The project was ordered by the Hungarian Royal Cultural-Engineering Office of the 1st County. The project for "Regulation of the middle course of the Rječina" was completed in 1905, and the project leaders were Bèla Pèch and Pál Holfeld (Figs. 10 and 11) [8].

The project was a very advanced one in many aspects, even in comparison with today's modern engineering approaches. Beside the hydrographical description of the Rječina, the project included analyses and results from precipitation and hydrological monitoring on which the dimensioning of the hydraulic structures was made. Also the last catastrophic flood (in 1898) and damages caused by it were also presented. This flood was caused by heavy rain on 19th October 1898 when 222 mm of rain during 3.5 hours formed a catastrophic flood wave with the estimated flow of 439 m^3s^{-1}, that is, more than 100-year return period high water for the Rječina River. Besides the technical solution for the regulation of the river, the use of water power for production of electricity was also considered. It must be pointed out that all solutions were carefully evaluated. The project included the construction of barriers (consolidation steps) in the Rječina riverbed upstream of the Žakalj mill, the riveting part of the riverbed, especially to assure the stabilization in the Grohovo landslide area (Fig. 12).

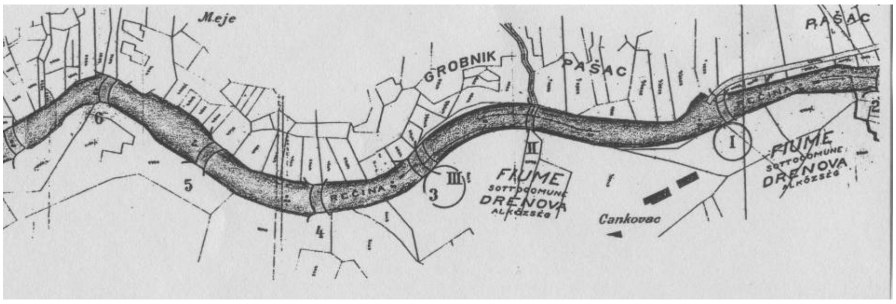

Fig. 10. Layout from the project “Regulation of the middle course of the Rječina” (barriers 1 to 7)

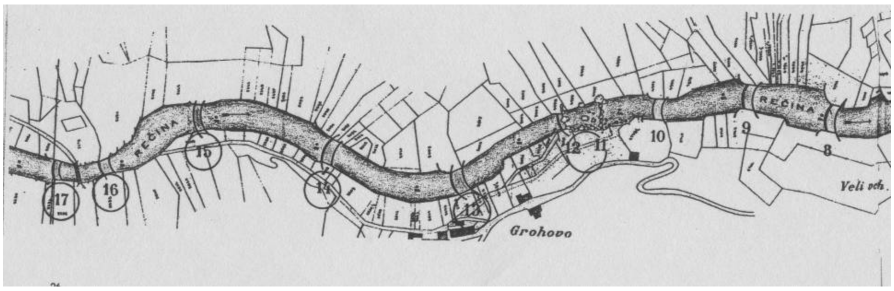

Fig. 11. Layout from the project “Regulation of the middle course of the Rječina” (barriers 8 to 17)

A part of regulation works started even before the completion of the project itself. The work on the regulation of the Rječina was finished in 1908. 23 stone-concrete barriers (steps) were built altogether. With small reparations and adequate maintenance they still serve their purpose. Due to their peculiar appearance they represent a part of the valuable historical and hydro-technical heritage of these areas.

Numerous other projects dealt with the hydropower potential of the Rječina and possibilities of its use starting with the Pál Holfeld’s project from 1903. This first project, as well as the two following projects (by Giordano in 1912 and the National Company for Electrical development from Milan in 1921), suggested the construction of a dam and a reservoir in Grohovo [7]. The concrete dam was finally built in 1966. Actually it is a small reservoir with the volume of 0.47 million m^3 which is used for daily regulation of the flow to the hydropower plant in Rijeka. The hydropower plant, located at the bottom of the Rječina canyon behind the spring Zvir, was completed two years later. The capacity of the tunnel which leads the water to the hydropower plant is 21 m^3s^{-1}. The construction of the dam caused changes in the hydraulic flow regime of the Rječina and does not assure the biological minimum flow in the river downstream of the dam. There are periods of time when the only water in the Rječina River are the small quantities contained in stilling basins of the barriers

Fig. 12. Barriers built according to the project "Regulation of the middle course of the Rječina"

The lower part of the Rječina course regulation, as it is still today, was performed according to the project "Regulation of the lower course of the Rječina" designed by the civil engineer Nikola Čulinović [6].

With the disappearance of the industrial facilities along the Rječina, first of all, the paper factory, the possibility of a new revitalization of Rječina, which would correspond to the needs of the modern city and modern times, was created. The revitalization should create the communication space between the city and the nature in the hinterland, no more than a step away from the very centre of the city. These ideas were elaborated in the works of the city planner Zdenko Sila and architects Olga Magaš and Nana Palinić in order to bring the city of Rijeka to its river, by which the city gained its name.

5 Revitalisation of the River Rječina - Interactions in the Context of Interrelationships between the Natural Environment and the Revitalisation of Industrial-Architectural Heritage

For the purpose of showing the natural beauty of the Rječina and the beauty of the regulated section of barriers (consolidation steps) and stilling basins, several projects for constructing a walkway along the Rječina as well as for revitalisation of the area surrounding the river and its tributaries have been made. Manufacture plants along the river that were once initiators of the urban development of the city are nowadays difficult to reach or even completely inaccessible, so the revitalisation of the area around the lower Rječina, the part next to the centre of Rijeka, has become more than imperative.

Due to the signing of the European convention on water preservation, works on the access to the middle Rječina bed have been started only after a landslide by the village Grohovo was activated again in 1997, at which occasion the material buried the river bed and the very centre of the city were about to be flooded. The situation was used for planning a multipurpose access to the Rječina water flow. The critical area of the middle and lower flow was first elaborated in designs for areas of the middle flow, and a walk with a recreation zone was designed on the given sections. Following this, the area of the lower river flow, up to the former paper factory, was elaborated next. The design of the education park - Eco Park Žakalj comprised a revitalisation of the once important economic centre for manufactured production in the river canyon with a group of mills, under the town of Orehovica [2]. The rebuilding of two demolished bridges up to the biggest mill Žakalj and the construction of a smaller dam and a storage lake have been planned, as well as the renewal of the doorway and the dilapidated entrance building into the info-centre (Figs. 13 and 14).

Fig. 13. The bridge leading to the Žakalj Mill: once and today

After the factory suddenly stopped working and went bankrupt, the access to the canyon part of the river was opened wide through a new "city within a city", destroyed to death, but holding a big potential in need of renovation (Fig. 15). By revitalising the abandoned plant, fixing the streets, renovating the structures and changing their original purposes, it is possible to open the doors to all the natural beauties of the Rječina. The preliminary design done by Olga Magaš, "The Rječina Walk – Arranging the Rječina Bank on the Section from the Paper Factory to Pašac Bridge" plans a conversion of existing industrial buildings of the former paper factory into structures of housing-business purposes with a walk through the "new city" and the canyon bank to the Eco Park [5]. The walk is planned on two levels, on the terrain and within the bed of the factory's aqueduct on a higher level up to the canyon way and the factory dam as a potential museum exponent in the open (Fig. 15).

Revitalisation of the lower river area, of industrial plants in the Školjić zone, of the former city park walk "Passegiata dello Scoglietto", and especially of the former paper factory, as a logical continuation of the city centre, has been analysed in many studies, zoning plans (two Executive Zoning Plans) and architectural designs which are partially included in Rijeka's new Master Zoning Plan.

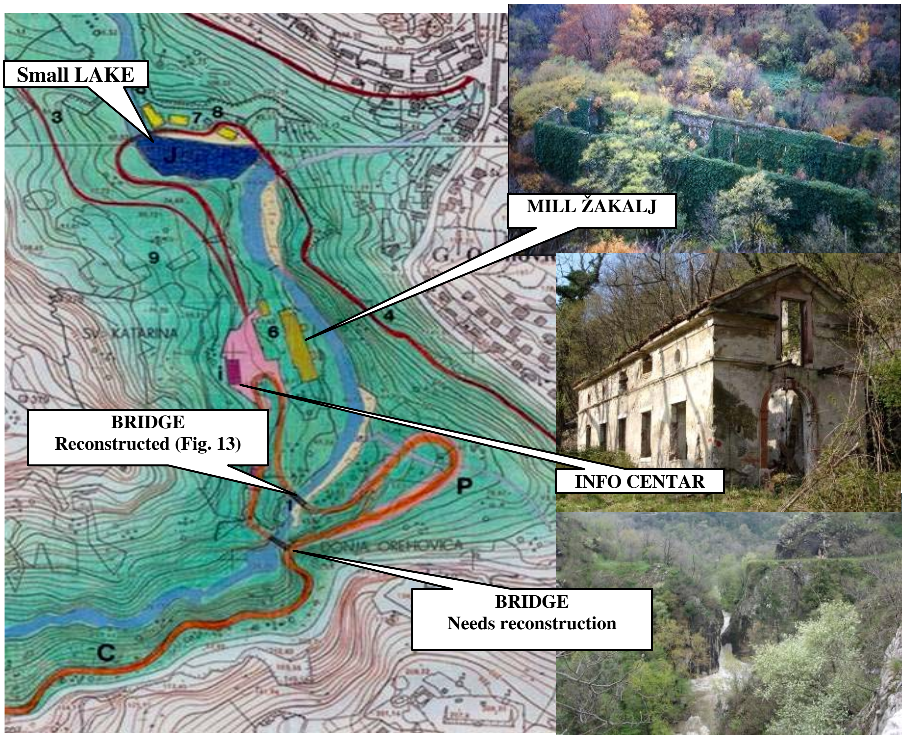

Fig. 14. Eco Park Žakalj

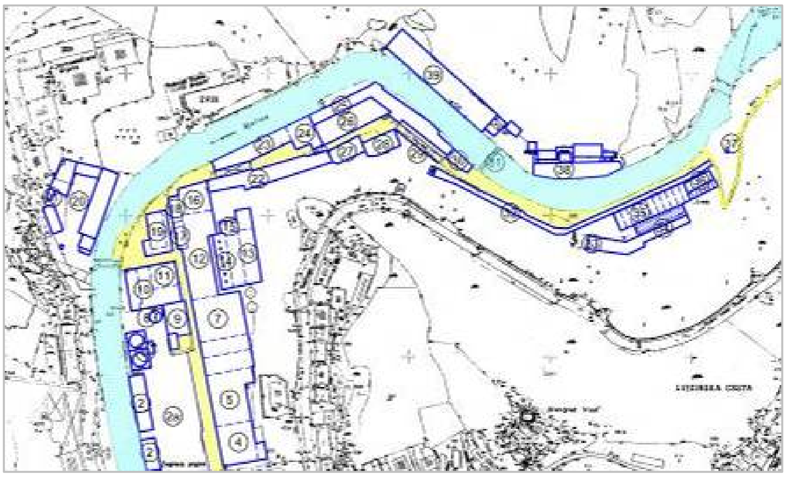

Fig. 14. Existing buildings with old functions that should be reassigned to new purposes (buldings were mostly related to the production of paper e.g. warehouses and workshops (2,4,22,24,28,29,30), administration building (9), printing house (25) etc., but also for other purposes like the factory for match production (39), bridge (31), stable (36) etc.)

6 Conclusions

This paper presents an example of a possible approach to restoration and revitalization of rivers in urban areas is especially if the water of those rivers was the foundation for the development of the surrounding area.

The revitalization and restoration of the Rječina river basin starting from the city centre can open the possibility of extending the centre and inhabitants activities to a more natural environment.

In this way the city will gain a wide green area for long walks away from the urban rapid way of life. All generations of city inhabitants and tourists that enter this new revitalized area will have the possibility to be educated about the history of Rijeka and also to appreciate the industrial and architectural heritage of this town.

Aknowledgement

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Water and Protection of Building Pit

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Abstract. The more buildings go under the surface of the ground, the more demanding their construction gets. Adverse foundation soil characteristics and water presence make realization of construction works even worse. Potential problems have to be observed by previous researches, which lead to a better realization quality as well as to a more substantial final structure. Its ground and climate characteristics make Slavonia interesting to observe the problems of building pit protection.

Different construction examples of building pit protection in Slavonia are illustrated in this paper. Important problems of this part of construction work can be observed here. This paper describes construction of anchored reinforced concrete diaphragm wall, numerous examples of steel sheet piling, as well as the use of wellpoint system for underground water level reducing.

Since these constructions are quite often, it is valuable to point out gained experiences and avoid possible damages and humans tragedies.

Keywords: Hydro Power Plants (HPP), construction, development, integrated management

1 Introduction

Slavonia (including Baranja) is geographical region with mainly lowlands areas, which defines north-eastern Croatia. It is bordered by three big rivers: the Drava in the north, the Sava in the south and the Danube in the east. The existence of these rivers points to development of the ground under the influences of water and its detritus of gravel, sand and clay. Many surface layers were developed in swamp conditions. Water bearing layer, where medium till fine-grained sands prevail, is heterogeneous and isotropic. Its thickness is over 150 m and it is covered by dusty and clay layer (mostly > 10 m, in places even to 50 m, but also < 1 m) [1], [2].

Being in the moderate climatic zone, Slavonia has favourable climate conditions with regular exchange of seasons and without too big temperature extremes. The average precipitation a year (663 mm/year – Osijek, 1969-98) is in agricultural sense not enough, and occasional problems occur due to disproportional distribution of humidity during the vegetation period. These problems (droughts and floods) are emphasized during the last decade which confirms climate changes in this area. Observing toward the west (uplands area of Papuk and Krndija) the amount of precipitation a year grows considerably. River basin areas and drainage regime have been undergone to changes by water management, which have long tradition there [3], [4], [5].

Nearness of river courses (maximum distance from a big river is about 50 km) is emphasized here as well as significant permeability of basic layers, which reflects on the underground water condition. Construction of significant canal net and the others water resources objects (accumulation, pumping station, barrage and similar) also influence very much the underground waters changing the drainage conditions of its own and outside (mountainous) waters across this area. Since the building of various objects has here been done near (on the bank and/or in the very bed) the rivers, the problems of construction works protection under the ground level are much expressed and they have their specific qualities [6].

Basic protection of excavation has been done due to many reasons: in order to limit the excessive amount of excavation by constructing milder slopes and at the same time to increase useful space, so that the workers, who work inside and around the excavation, can be protected, as well as to insure less influence of the excavation on the nearby objects. The dependence on the neighbouring objects and on ground characteristic has been observed. Protection problem is more complicated when building site encroaches upon the underground waters, and the works in water are the most demanding. For all that the pieces of information about underground water level and its variations are very important. There is always small amount of these figures. When we take into the consideration the stochastic character of hydrological cycle elements, it can be concluded that it is a question of the most demanding building works. Therefore the acquired experiences should be shared [7].

The examples from practical work of Slavonian builders show mastered and effective usage of some technologies for building pit protection. The following will emphasise reliable ways of excavation protection, the examples of using the steel sheet piling will be given, the construction of deep protective reinforced-concrete diaphragm will be described, the application of the well point system for decreasing underground water will be pointed out and it suggests the specific qualities of construction works at bridge priers in the bed of watercourse. Finally the important acquired experiences, which could be used by new construction undertaking, are being summarized.

2 The Excavation Protection

All excavations in coherent grounds and lacking spaces must be insured. Those sorts of supports can be simply made of handy materials at the building site, boards and beams, braced or held. There are nowdays different types of supporting systems on the market, of different producers, which can be installed very fast and effective.

In installation trenches (very elongated excavations) protection from excavation caving in is mostly turned to protection of people who are in the trenches. Supports in these trenches are insured by bracing because they are narrow enough.

Bracings are used when it is possible to get two parts of sheet-pile wall in the way to install the support between them. They can be installed vertically on parallel walls, if these are near enough or diagonally in corners, when sheet-pile walls are so shaped to have corners. They are dimensioned as axially-pressed building parts, and in most cases bracings are steel I profile or heavy tube scaffolding.

The systems of made formworks, shown in Fig. 1, are rammed by excavation machine on the building site ("spoon" of the excavator). For deeper trenches, till 6m depth, steel planks are used instead of formworks.

The works in installations trenches have been underestimated, especially considering the safety of workers despite laws and regulations for their safety.

Fig. 1. Krings Verbau formwork system and steel planks driving make main sewer excavation protection

Fig. 2. After caving situation on the building site of sewer collector when two workers of the firm Vodovod tragically died (Vjesnik, 01.09.2001.)

Due to such risky behaviour, the insurance of trenches can be rarely seen and the workers often work in trenches which are not insured in any way. Since it is a question of works on long parts, while designing, very often we do not have enough facts about ground characteristic changes along the marked route. Therefore, while constructing, the previously mentioned should be taken into consideration and where the characteristics are worse, we should apply more adequate protection from caving in. We should also pay attention to stability changes of excavated materials in conditions of intensive and long-lasting precipitation. Unfortunately, negligence in that sense happens and can be disastrous. Caving in of the 5 m trench, which was not insured (Fig. 2), in area of town Osijek, ended with two tragic deaths when connecting sewer collector was built in 2001. The reasons were heavy rains and the presence of scud of non-coherent materials.

3 Sheet Piling

Excavation protection by sheet piling started with usage of wooden planks in different varieties, and some of them, in smaller proportion, are still used today. The application of steel sheet piling became significant during the steel industry development at the beginning of the 20th century. The majority of today`s sheet pilings are produced by the rolling procedure, and joints are so designed to insure the minimal flow through of water and ground fragments.

Considering the purpose and using duration ("captureness") of the sheet piling we differ: supports or temporary buildings and permanent supports or sheet-pile walls. Considering the sort of loading on sheet piling there are: supports which accept only ground and do not have to be watertight (it is the case when the bottom dimension of the excavation is above the underground water level); the sheet piling which accepts loading made by hydrostatic pressure – watertight (the bottom dimension of excavation is under the underground water level) and sheet-pile walls - buildings always loaded by hydrostatic pressure, which at the same time can and cannot be loaded by ground.

The way of holding, in other words supporting of vertical excavation is in practice very various. Among many possibilities the basic ones are: bracings - by channels with parallel walls and suitable closed plan-viewed areas , supports (diagonal bracing)- by supporting the object of wide plan-viewed areas and anchors – geotechnical anchors, IBO anchors, tie rods and anchorage blocks (steel or concrete).

Supports or diagonal bracings are used in building pit if they do not disturb working area. It is necessary to insure stable support on sheet-pile walls and on the ground. They are constructed for smaller heights of supporting buildings, since for bigger heights they are not economically justified and when static anchor holding is not possible due to bad surrounding materials (some clay and sands etc.).

Anchors are used to connect sheet-pile walls to the natural ground (its support). Geotechnical anchors transfer loading from the layer on sheet-pile wall in deeper ground through anchor part and they are regulary prestressed, which means that one part of the power is introduced into them before they take over the full loading. Technology of drilling and implanting of anchor has gone so far that we can only rarely see supports supported by diagonal bracing. Anchor supports stay in the ground although they lose their basic purpose when the building ends [7].

Necessary mechanization for driving of the sheet piling consists of crawler excavator, hydraulic hammer and power generator. Since the weight of hydraulic crawler excavator is big, there is a condition for machine arrival which demands the insurance of working corridor - hard working base for sheet piling driver and free access to all working positions.

The sheet piling is driven before starting of excavation of building pit in the way that it plan-viewed closes the excavation surface given in the project. Before starting the driving work it is necessary to get the plan of existing underground installations in direction of driving corridor that is insured. The investor has the responsibility for their protection. Sheet piling is very favourable to use in very mild clays with little shear strength. When soil mechanics characteristics of ground layers are not favourable, predrilling with geotechnical drills is usually done immediately before the driving of the sheet piling.

The usage of sheet piling has its point with small temporary excavations (for example, for construction of single foundation) because they are easy to install and pull out.

Sheet piling is often used at potential danger for rising of the building pit bottom. So it is rammed into deeper, stiffer and more impermeable layers or it is constructed long enough to prevent the bottom instability caused by vertical up going water course.

Sheet piling protection is also used in excavation protection on open watercourses, for example at bridge prier construction in a river or bank supporting constructions, and they can be constructed as temporary or permanent (Fig. 3).

Fig. 3. Construction of building pit protection at bridge prier in the bed of the river Bosut in Vinkovci: phase of dike construction in the bed and driving of steel planks (left), example of permanent support at quay construction in Vukovar port for putting to shore of small vessels (right)

At excavations of deep building pits the steel sheet piling has been accepted as one adequate solution. In the Fig. 4 the steel planks construction is shown for building pit protection with usage of anchors as supporting system.

The example of an office-residential building, in the picture 5, shows that steel sheet piling insures the safety of building pit and at the same time supports the city traffic route which goes close by the building site. The object is constructed along the bank of the river Drava but above the river level. The sheet piling system is supported by diagonal bracings of steel I profile, reinforced in the foundation plate of the object.

According to long time offering calculations the firm Vodogradnja Osijek d.d. gives financial justification of steel sheet piling in relation to reinforced-concrete diaphragm from relations of financial coefficient which is for diaphragm 1.80 and for steel sheet piling with anchors 0.80 [8].

Fig. 4. Construction of steel sheet piling supporting by anchoring (trade center Interspar in Osijek): (left) drilling of anchor layer by special machine, (right) installation of main beam

Fig. 5. Building pit protection by steel sheet piling of Esseker center in Osijek: (left) ground excavation in protected building pit, (right) supporting of steel sheet piling by diagonal bracing

4 Reinforced Concrete Diaphragm

Development of reinforced concrete technology in construction of sheet-pile walls made the development of reinforced concrete diaphragms possible. It is a question of permanent buildings which are represented by unbroken, timbering made, wall in the ground. Except that, it is possible to construct diaphragm from pre-finished reinforced-concrete elements or by the pile by pile method. They are recommended in situations, when it is necessary to insure water resistance till the more significant depth (till 30 m), although the construction of much bigger depth (120 m) has already been realized. Due to high prices the usage of diaphragms as permanent solution is restricted only to water bearing grounds which are difficult for drilling (cohesionless soil). It is possible to anchor the diaphragm and increase in that way its stability [7].

On the object Eurodom Osijek the diaphragm was constructed for protection of very deep building pit, 17 m depth. Its task was to protect deep excavation so that building pit had vertical walls but without bringing the neighbouring, big city objects in danger. The characteristics of this diaphragm were that it could not be leaned on a firm ground layer (usually clay) but it was “floating”. It is rarity and it has been proved here that it can be, even so big, constructed in the sand. Reinforced-concrete diaphragm of the mentioned object has the width of 80 cm and the depth of 28 m, anchored by geotechnical anchors about 25 m long (1600 pieces), made in sandy-clay ground. Reinforced-concrete foundation plate has thickness of 1.50 meters, total volume of about 10.000m^3. Building works of foundation included about 200.000 m^3 of excavations and about 80.000 m^3 of placed concrete. The value of the whole investment comes to about 120 million Euros [9].

During the excavation works very wet and long lasting period occurred and it comes to the increasing of the underground water level due to underground drainage of its own river-basin waters towards the bed of the river Drava. During construction there were two water levels of the river Drava which were the highest in the last century. Underground water varied on the upper limit of generally expected values (on about 3 m). In these circumstances by intensive pumping of seepage water from building pit (by system of drains and percolation wells), the smaller fragments of neighbouring ground were washed out, which made the anchoring works difficult and warned on neighbouring settlement. Very unfavourable circumstances (caused by long lasting bigger amount of precipitation) brought the changes of the original project idea. The shallower excavation was made and the underground part of this multipurpose object became shorter for a half of a floor.

Two parallel walls, lightly reinforced, 80 to 100 cm high make introduction channel (Fig. 6). Its width is always about 10 cm wider than the width of the machine which does the excavation. Introduction channel is created on the whole plan-view of future diaphragm, and since the part of drilling mud is lost by the building, it is necessary to supplement it and therefore the machine with the basin for finished drilling mud is placed near the introduction channel. During the excavation the drilling mud is poured into the trench and when concreting it is pushed by placed concrete. Drilling mud level must be significantly higher than underground water level. Pushed drilling mud goes back to the introduction channel and flows to the excavation place of new tunnel liner of the trench. For optimal performance it is necessary to harmonize the phases of excavation and concrete in order to maintain approximately constant amount of drilling mud in the introduction channel.

Fig. 6. Construction of diaphragm wall on multipurpose object Eurodom in Osijek: (left) construction of introduction channel, (right) trench excavation for diaphragm by special equipment

The edge of the primary part of the wall is done with recess so that the convex part of the secondary wall goes into it, which provides better water impermeability.

In trench of the demanded depth the reinforcing cage is placed (Fig. 7). The basic element of the cage is stiffener - horizontal reinforcement of higher profile, distributed approximately every 3 m along the height of the cage, which the main reinforcement is weld on. Some rods of the main reinforcement are made with hooks on the upper ends which are used to hang the cage while concreting. This is the way to insure the proper elevated position of the cage. At reinforced-concrete buildings, which are constructed on the ground, the protection layer is thicker than usual and it is recommended for diaphragms to be approximately 10 cm. Cages must be like that to be safe while lifting from the ground and placing. For that purpose it is necessary to weld at least 2/3 joints.

Diaphragm concreting is done by contractor procedure. Due to its consistency concrete is conically spilt on the bottom of the trench and it is not recommended that excavation construction of single tunnel liner is longer than 7 m. While placing, contractor pipe is slightly turned and pulled out but it is necessary for the pipe to be submerged all the time at least 1m into concrete. It is necessary to insure the constant transport of concrete so that the procedure can be done without interruptions and damages because the repair is very expensive and complicated. Since the concrete in the top of trench is mixed with drilling mud and has worse characteristics, it is necessarily to remove the final part, 50-80 cm height.

Fig. 7. Eurodom Osijek: (left) reinforcing cage for building of diaphragm wall, (right) concreting of diaphragm by contractor procedure

5 Wellpoint (Pipe Wells)

When decreasing the underground water level by system of open building pit, in the way of water pumping from peripheral part of building pit, the method of well point or pipe well gave effective results. This method in the area of eastern Slavonia has not been used enough because of low level of information and shortage of equipment. In the last few years its application has found its place in building firms, especially at construction of installation trenches, which are, in this way, protected from caving in by formwork, and from underground waters by system of wellpoint.

The equipment consists of: pump, flexible and rigid pipes, fittings, latches, pipe filters and special pipe head. Removable centrifugal pump with the supplement of vacuum machine works in two ways: it presses water under pressure of 3 to 30 bars in wellpoint, and it in that way makes their driving into the ground easier or it pumps water from wellpoint when they are placed on the required depth.

Needle probes - wellpoints on their end (head), due to double effect of pump, have a latch which regulates entrance and exit of water, which is shown in picture 8. They are driven along the periphery of building pit, depending on ground type, at intervals of 1 to 4 meters, and they are horizontally connected by pipes. When it is a question of more compact layers, it is necessary, immediately before filter placing, to drill the holes in the ground by hydraulic drill. The pump and pipes for water drainage are placed in the central part.

Fig. 8. Application of wellpoint in the area of old bed of the Drava near Osijek: (up) head of the pipe filter (PVC), (down) parts of wellpoint machine on the building site of sewer pumping station Bilje

Fig. 9. Application of wellpoint system on one level near Donji Miholjac (left), decreasing of underground water level on bigger depths on more levels (right)

Pump enables, at the same time, pumping from every probe, which insures constant level of underground water and enables its decreasing for 4-5m. Where the underground water should be decreased to bigger depths, it is possible to place to system of wellpoint on two or three different levels and decrease the level on underground water in that way (Fig. 9).

The great advantage of this system is that its component pipe wells can be pulled out after one application and used again on the other place, which is not case with classic wells.

6 Works in Watercourse Bed

The works in the river bed belong among the most demanding building works. Sometimes it is enough to neutralize the water flowing, but for many works the operative area must be drained off. To new experiences of Slavonian region belong the constructions of central bridge prier of two bridges on Drava (near Osijek, 2005. and near Belišće, 2003). Construction technology was somewhat different.

At bridge Osijek (Fig. 10) foundation protection was made by surrounding driving of reciprocally braced steel planks, concreting demersal horizontal level surface and pumping of seepage water.

Fig. 10. Building pit in the river bed: it shows the protection by closed series of planks reciprocally braced, pumping of seepage water and some building works

At Belišće bridge (Fig. 11) metal formwork was used, whose lower part was permanently placed, and upper part was removed when the works were finished. To be more precise, prier foundation in the watercourse was solved with a group of 10 reinforced-concrete piles, diameter 150 cm, length 20,0 m. Piles were connected by reinforced- concrete head construction, thickness 2.5 m. It is plan-view shaped so that it creates as little as possible resistance while water flowing. The width of head panel was 7.0 m, a length 22.0 m. Piles were conducted from the vessel, after that the sand around piles was digged to the depth which protects head beam from underwashing. The lowering of two-part form trunk followed and underground concreting inside and outside of the trunk. Supported concrete, thickness 1.0 m was used as the stopper for space protection inside of form trunk, while the water was pumped from it.

Concrete from the outside was protected by crashed stones so that it could not be washed out by water after placing. After pumping of water from the form trunk, the following was done: cutting off formworks of piles'columns, arrangement of piles head, arranging of reinforcement of head block and its concreting. The reinforcement for joints with columns was built into the head block. Final phase of these works was construction of columns to designed dimension and the separation of upper part of form trunk from lower part, which stays as integral part of the foundation [10].

Fig. 11. Steel formwork application for making the works possible on dry when constructing the bridge prier in the river bed (Drava near Belišće)

6 Conclusions

This paper shows the review of used methods for building pit protection in the area of Slavonia with the purpose to protect from caving in and water filtering. Buildings foundation work is especially demanding if the works are done on non coherent ground and with presence of water. Specific quality of this area is that water, in all its appearances (precipitation, surface courses, underground waters), influences the works in the ground.

From the economical point of view, all types of protection of building pit are actually great expense. It grows according to demanding technologies, special equipment and obligatory preliminary researches.

Considering the actual experiences from regional foundation works the following elements can be pointed out:

1) Caution with deeper excavation; bracing is used for strip works, and if not, it is very important to pay attention to influences of inhomogeneous materials and humidity (inflows, rains) on caving in, protection by vertical walls differently but adequately supported is used for wider excavations.

2) The advantages of sheet piling are practically proved through multiple uses and acquired routine in application and through increasing of reliable protection from land-sliding and water filtering.
3) Although the concrete diaphragms are not competitive at lower depths, they are proved at higher depths and adequate materials; the caution for water influences is necessary – reliability of data about underground water levels, their regime in rainy period.
4) Wellpoint is proved as reliable way of decreasing of underground water level in the region; Mobility and repeated application of equipment as well as experiences about effectiveness on local grounds (which should be more studied) are the ace-card for future mass application.
5) When working in the running water, depending on hydrological-hydraulic regime, it is possible to fill up the part of the bed and to protect the building site by planks driving; It is also possible to create still water by the trunk made of heavy formwork (or caisson); the aim is to create reliable excavation and placing of material (concrete, dike) and to create the conditions for pumping and safe drying of pit for the further work on foundation; it is very important to take into consideration the water level changes and the use of low water periods during a year as well as to harmonize the works with the upstream systems for water managing

At the end, the mentioned death cases should be permanent warning that none financial aspect can shade a life as the only priceless item in building works.

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Restoration Measures and Practices in Prespa Region

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Abstract. The Prespa region, situated in the Balkan Peninsula and encompassing parts of Albania, Macedonia and Greece, is a high altitude basin that includes the interlinked Macro Prespa and Micro Prespa Lakes and their surrounding mountains. Prespa Lakes system is the largest international water body in the Balkans and is of particular importance for the wider region. The unique values of this ecosystem are being progressively eroded because of either changes in or intensification of specific human activities including unsustainable patterns of exploitation of natural resources, and inappropriate land-use practices that result in progressive soil and water contamination, loss of forest cover, erosion and wildlife loss.The threats to the ecosystem functions are further exacerbated by the dramatic decline of the water level of Prespa Lake. The present water level of Macro Prespa Lake is 9 m lower than the average long-term observed water level. A comparison of Landsat images shows that the decline in water level caused a loss of lake surface of over 10 km^2, which is most evident at the shallow parts. Therefore, steps in improving the present state have been undertaken by international support. The development and implementation of an integrated approach to the region's conservation and management is of paramount importance.

Keywords: Ecosystem, key stresses, restoration measures, integrated management

1 Introduction

The Prespa region is situated in the Balkan Peninsula and is shared among the three neighbouring countries Albania, Macedonia and Greece. It is considered to be an ecosystem of global significance and has been identified as one of Europe's major trans-boundary “ecological bricks”. The entire Prespa Region hosts unique habitats that are important from both European and global conservation perspective.

However, unsustainable agricultural, fisheries, water and forest management practices as well as use of non-timber forest products is causing stresses on the ecosystem health of the Prespa Basin. The awareness of local communities and beneficiaries on the values of the natural resources and the importance of sustainable use of the resources is very low. Also there is limited knowledge on environmental protection/conservation issues among the decision makers and the general population, and lack of streamlined information available for the interested parties.

The international ecological significance of the area, and especially the need for sustainable natural resources and water management for the benefit of both nature and the inhabitants, led to increased international interest for supporting the restoration and preservation of the natural values of the area.

The purpose of this paper is to present a summary of key stresses in the Prespa Lakes ecosystem, their impacts and significance, and to provide an overview of the ongoing activities aiming at integrated ecosystem management in the lake’s basin, while focusing on the restoration efforts in the river basin of Golema Reka, which is the largest sub-basin within the wider Prespa basin.

2 Prespa Region Description

Prespa Basin Area, Hydrology and Water Quality: The total area of the Lake Prespa basin is app. 1,600 km^2, of which 62% falls within Macedonia (1,000 km^2), 17% in Albania (263 km^2) and 21% in Greece (330 km^2). Approximately 28,900 people live in this area, with the largest town being Resen with a population of 7,000. The Macedonian part of Prespa has experienced a decline in inhabitants by roughly 20% over the past thirty years, but population density is still over 28 persons/km^2.

The Prespa basin area includes the two interlinked lakes: Micro and Macro Prespa, and permanent or seasonal streams, which discharge into the two lakes. The major Contributing waters to Macro Prespa Lake are Golema Reka, Brajcinska Reka and Kranska Reka in Macedonia and Aghios Germanos River in Greece. There is no major source of surface water input from Albania to Mikri Prespa.

Specifics of Macro Prespa Lake are that water from this lake runs into Ohrid Lake (some 200 m lower altitude) through underground flows and appears at Ohrid Lake coast and bottom of the lake. There were average oscillations of the water level of Macro Prespa Lake in the period 1961-1986, from when the water level started drastically to drop-down. For Prespa Lake, analyses of registered water levels for the period 1951-2000 show negative trends.

The present water level of Macro Prespa is approximately 9 m lower than the average long-term observed water level. A comparison of Landsat images shows a low of over 10 km^2 surface area due to decline of water level, which is the most evident at the shallow parts of the lake.

The lake water quality is deteriorating and showing signs of eutrophication expressed by oxygen depletion in lower layers of the lake. This phenomenon is related to a number of natural and anthropogenic factors that affect the lake water quality.

Among the factors that affect the lake most important is the presence of nutrients (nitrogen and phosphorous), which trigger a sequence of biological growth in the lake. The organisms consume oxygen that, in limited quantities, is brought into the lake by atmospheric exchange.

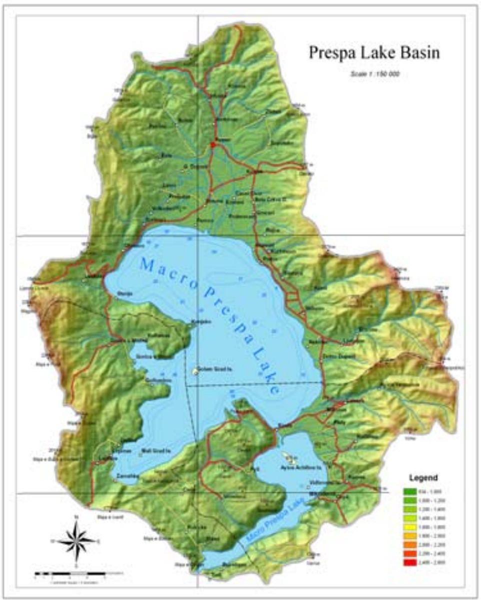

Fig. 1. Prespa Lake basin

Biodiversity: The Prespa basin area accommodates a number of unique species of flora and fauna. This is primarily the result of adaptation to the different rock and soil types, the range in altitude (850-2641 m a.s.l), the influence of both Mediterranean and Continental climates, the relative isolation of the high altitude area and low population levels. These factors have resulted in a flora and fauna that is globally unique and places the area among the top ten most diverse protected areas in the world of similar size. By way of example Galicica National Park has more than 1,300 species, or approximately 37% of the flora, of Macedonia.

In addition, the Prespa basin has 50 animal species and 19 plant species that are endemic to the area. The global importance of the area has been recognized by the designation of two Ramsar sites, or wetlands of international importance, one for Lake Prespa and one for the Greek part of Micro Prespa.

3 Key Stresses on Ecosystems Health

The following section provides an overview of the anthropogenic sources of stress on the Prespa Lakes ecosystem, their sources and the underlying causes/barriers organized by the following key sectors: 1) Land-use management, 2) Water management, 3) Agriculture, 4) Fisheries, 5) Forest management, 6) Solid Waste management, and 7) Wastewater management.

Land-use Management: The significant loss of lakeside shoreline, wetland and forest habitats, and the sediment transport to the lake, has occurred with the conversion to agricultural land and buildings, partly attributable to ineffective land-use planning and the development controls, as well as the insufficient level of integration of the ecosystem management objectives and practices into the planning processes.

Water Management: The key stresses in the water management sector are related to the insufficient water quantity, the eutrophication processes, degraded aquatic habitats and increased seasonal temperatures in aquatic habitats. The sources of these stresses are mainly attributed to the: lack of integrated water management and planning of water resources, pollution from organic waste from untreated wastewaters and fertilizer runoff (increased level of nutrients causing eutrophication), the seasonal irrigation (reducing natural flow regime in streams and increasing temperature), pollution from pesticides and industrial compounds.

Agriculture: The uncontrolled use of pesticides and fertilizers, as well as poor solid waste disposal and a low level of environmental awareness have disturbed aquatic, animal and plant habitats. Significant impacts to the ecosystem are generated by the inappropriate agricultural waste management practices (organic waste and pesticide packaging)

Fisheries Practices: The reduced populations of native and endemic fish species and the inter-specific competition from exotic species and the potential dilution of genetic diversity have been recognized as the key stresses in the fisheries sector. These stresses are related to the over-fishing (fish harvest exceeding sustainable levels), harvesting of fish during spawning season and introduction of exotic species of fish fauna for commercial purposes.

Forest Management: There has been poor management of forested areas together with the excessive harvesting of non-timber products, over-grazing in forested areas and an unsustainable level of firewood collection. Forest management has emphasised timber production rather than sustainable use and conservation (focus on commercial aspects vs. ‘ecosystem oriented’ approach).

Solid Waste Management: The inconsistency of the current solid waste management system in the region causes significant quantities of various types of solid waste to be disposed of in an uncontrolled manner. This inappropriately disposed waste has considerable negative impact on the environment.

Wastewater Management: Pollution from organic waste, from untreated household and industrial wastewater, as well as fertiliser run-off from farming areas have resulted in eutrophication processes.

4 Efforts for Integrated Ecosystem Management in the Prespa Lakes Basin

The aim of the ongoing initiative supported by the UNDP in the Prespa region is to contribute to the improvement of the overall health of the Prespa Basin ecosystem, through effective transboundary action based on previous in-depth analysis of the fundamental causes of the priority stresses of the ecosystem, identification of priorities for the environmental concerns and designing realistic and feasible measures to avoid, prevent, mitigate or compensate ecosystem impacts by meeting, to the largest extent possible, development and environmental objectives.

This programme is providing support in catalysing the adoption and implementation of ecosystem management interventions in the Prespa Lakes Basin of Albania, Macedonia, and Greece that integrate ecological, economic, and social goals with the aim of conserving globally significant biodiversity and reducing pollution of the trans-boundary lakes and their contributing waters.

The strategy is to mainstream ecosystem management objectives and priorities into productive sector practices and policies and to strengthen capacity for restoring ecosystem health and conserving biodiversity first at the national level in Albania and Macedonian Prespa by piloting ecosystem-oriented approaches to spatial planning, water use management, agriculture, forest and fishery management, and conservation and protected area management. Building on this strengthened national-level foundation in the Prespa Basin, the programme is designed to strengthen ongoing trans-boundary cooperation in resource management and conservation by empowering the existing trans-boundary institution and piloting trans-boundary management and conservation activities.

The following section provides an overview of the key ecosystem restoration principles and priority measures currently underway in the Prespa region through the UNDP programme and other contributing parties[1]. Generally, the activities are may be categorized as follows:

1. Strengthening legal and regulatory environment and establishing land and water use management basis for maintaining and restoring ecosystem health in the Prespa Lakes basin.
2. Modifying productive sector resource management practices to reduce pesticide inputs, increase habitat heterogeneity and improve status of target species and communities within the Prespa Basin.
3. Conserving priority biological diversity across the Prespa basin and making key protected areas fully operational
4. Strengthening the ongoing transboundary cooperation in the Prespa Basin by strengthening the transboundary coordination mechanisms and piloting transboundary conservation and water management.

The activities under the *First category* are designed to lay the ground work at the national level in the Prespa Basin for ecosystem management – for achieving meaningful sustainable development and conservation results on the ground in each national sector of Prespa. The key interventions include: preparation of integrated land-use/spatial plan for the Prespa region, development of ecosystem oriented water management plan at local scale.

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[1] NOTE: The activities presented here are mainly those under implementation in the Macedonian part of the Prespa region, although complementary activities are underway in the two other neighboring countries. The Macedonian part of the basin is the largest and as such provides the most significant contribution to the overall status of the Prespa ecosystem health.

The activities under the *Second category* deal with demonstrating practical ecosystem oriented approaches to managing resources in the productive sector, including agriculture, forestry, fisheries and wastewater management. The focus of the activities of this component is on: reducing environmental impacts of agriculture, introducing ecosystem oriented forest management, demonstrating decentralized wastewater management for small communities (natural wastewater treatment systems), and etc.

The focus of the work under the *Third category* of activities is on establishing mechanisms for protection of the priority habitats and biological diversity by operationalizing the protected areas system in the Prespa region. This component also focuses on formulation of management and restoration plan for the Golema Reka sub-basin which will be presented in more detail in the next chapter.

And finally the *Fourth category* of activities involves activities related to strengthening the transboundary cooperation and coordination mechanisms for integrated management of transboundary resources, including water and priority species and habitats of transboundary importance.

5 River Restoration Measures and Practices in Golema Reka Basin

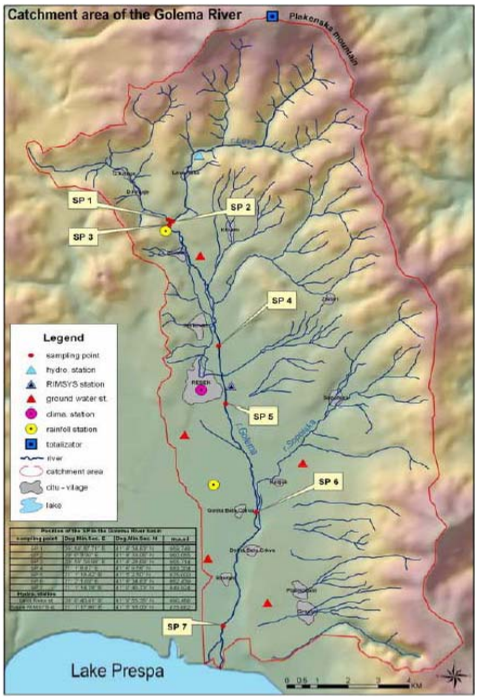

Fig. 2. Catchment area of Golema Reka

Description of the Basin and the Key Pressures to the River Ecosystem: Attempts for applying an integrated approach to restoring the ecosystem functions based on the previous analysis of the key impacts and their underlying causes are being undertaken in the largest sub-basin of the Prespa Lakes basin.

With a total area of 182.9 km^2, and perimeter of approximately 58 km, Golema Reka basin forms the largest and most important sub-basin of the Prespa Lake. Maximum altitude of Golema Reka is 1989 m a.s.l, the minimum is 849.5 m a.s.l and the average is 1361 m a.s.l. The river has its spring in the village of Krusje, flows through several villages and reaches the Prespa Lake at the village of Ezerani. The city of Resen is situated on the central part of the river. Tributaries of Golema Reka are Leva Reka, Krivenska Reka, and Cesinska Reka. Maximum slope of the watershed terrain is about 31%, and the average slope is 15.3%. The Golema Reka watershed is characterized by 14% of agricultural areas which mainly consist of apple orchards. Hydrographic network of Golema Reka basin is presented in Fig. 2.

About 67% belong to forest cover, mainly oak and pine. Other natural vegetation like shrubs covers app. 15%. Wetlands cover about 2%.

The entire river corridor can be divided in three sections: upper, central and lower part. The *upper part* includes the springs of the river and its spans roughly to the Jankovec village. The springs of the river are located in the region of the Krusje village, where a water tap structure for a water supply system of Resen and several neighboring villages has been built. Due to absence of significant sources of pollution, the water quality in the upper part of the river is not extensively deteriorated; however, problems such as sedimentation of the river channel, for example, exist due to surface erosion. The *central part* of the river includes the section from Jankovec to downstream of Resen town. In the central part of the river the environmental problems are more significant as a result of more densely populated areas, and as well higher density of agricultural production. The *lower part* of the river corridor is the section that is extending downstream of Resen to the inflow into the Prespa Lake. This is the most polluted section of the river. The quantities of both communal and industrial wastewaters inflowing into the river are excessive, but as well significant amounts of various types of solid waste can be noticed in the riverbed. Due to erosion processes, human activities, and virtually inexistent maintenance the riverbed is also seriously damaged at several sections, which results in flooding of agricultural land on both sides of the river in the case of heavy rainfall. The river inflow (delta) into Prespa Lake is located in the strict nature reserve/wetland Ezerani.

A number of problems related to the status of the river basin have been identified during the assessment stage. These problems actually coincide with the previously described environmental problems of the Prespa region and are summarized as follows: a) decline of the river flow, b) deterioration of water quality, c) reduction of biological diversity, d) surface erosion and sediment transport, e) flooding of agricultural lands. Examples of pressures to the ecosystem of Golema Reka are presented in Fig. 3.

Fig. 3. Examples of pressures to the ecosystem of Golema Reka

These problems of the river and its basin are caused by the following main factors: intensive agricultural development in the river basin, inappropriate management of industrial and municipal solid waste, direct inflow of both industrial and domestic wastewaters in the river, uncontrolled exploitation of natural resources within the river basin, insufficient monitoring of hydrological, water quality and other environmental parameters, low public awareness, weak enforcement of the water resource management regulations, and low maintenance of the river channel.

Basic restoration principles and practices: The main design of the restoration and protection measures is based on preliminary assessment of the overall status of Golema Reka and the contributing human activities in its basin [2], [3]. Priority is given not only to the restoration measures of the river corridor and the riverbed itself, but also to developing basin-wide programme of measures extending across the key productive sectors contributing to the quantity and quality of the flow of Golema Reka. The design preparation exercise consisted of comprehensive review of all existing data and related projects, establishment of the river restoration objectives and actual development of river restoration measures. Special attention during the selection of measures has been given to the objective of achieving environmental improvement, but also to their cost-effectiveness with respect to the local conditions.

Since the general goal of the planned interventions is restoring, to the extent possible, the natural functions of the river, the design of the river restoration and protection measures considers the dynamics and the natural balance of the river ecosystem as a whole. Therefore, during the design development process, the following basic river restoration guiding principles were followed: a) preservation and protection of aquatic resources, b) restoration of ecological integrity, c) restoration of natural structure and function, d) work within the watershed landscape context, e) address ongoing causes of degradation, f) focus on feasibility, g) involve the skills and insights of multi-disciplinary team, h) design of self-sustainability, i) restore native species and avoid non-native species, g) use natural fixes and bioengineering techniques.

Having considered the previous aspects of the integrated, basin-wide approach, the design of the restoration and protection measures, was structured to incorporate the following interrelated components which actually respond to the previously analyzed anthropogenic pressures: a) restoration of the riverbed and the riparian corridor, b) mitigation of the solid waste and wastewater impacts, c) improvement of the condition of wetlands, d) improvement of the forest cover and mitigation of the erosion processes, e) mitigation of the problems related to the land-use practices, f) improvement of the river monitoring, g) public awareness raising.

The implementation of the restoration measures development under each of the above components is not only important for the environmental status of Golema Reka, but also for the overall stability of the Prespa Lakes ecosystem, since the basin of Golema Reka covers approximately 40% of the Prespa Lake basin area, has over 70% of the total population of Prespa and represents an area with the most intensive economic activity.

The first component of the project: Restoration of the riverbed and the riparian cover is actually related to development of a detailed design for restoration of the riverbed in priority sections defined during the preliminary site investigation. Two priority sections were selected, one of which extends along the urban area and the other one is located in the village of Ezerani, in the vicinity of the river delta where the most considerable and frequent flood events occur. For that purposes of reducing the urban pollutant pulses in the urban section, a wastewater collection system was integrated in the river restoration design, to provide for evacuation of wastewaters generated along this river section, and their transport to the existing central wastewater treatment in the village of Ezerani. For the needs of selecting the most appropriate solution for restoration of the riverbed in its urban section, a few alternatives were compared and evaluated against a wide range of economic, financial, environmental and structural criteria. During this analysis, a significant number of *constraints* for designing a full-scale river restoration plan were identified. Some of them include: need for removal of existing structures and facilities (even factories built in the vicinity of river), hydraulic and flood control requirements in the urban area (minimum width of river channel), need for adequate architectural design because of the urbanization requirements, limitations imposed by the existing planning documentation (General and Detailed Urban Plans), need for expropriation of large area of private land along the riverbed, size of investment and availability of funds, requirements for stability of the structure because of the existing buildings along the river and etc. The photos in Fig. 4 show the existing status of the urban river section subject to physical interventions, as well as the future appearance after the finalization of the construction works.

Fig. 4. Current and future appearance of the urban river section in Resen

The technical solution in the other priority river section (Ezerani) however sets higher ecosystem restoration objectives, which in this particular case are more feasible. The design of the restoration works in Ezerani is prepared to follow the natural flow of the river to the largest extend possible, with minimum interventions in the riverbed geometry, and with preservation of the existing riparian vegetation. The design foresees construction of earth embankments of local material with height which will ensure adequate control of the designed flood events. The flood control requirement was one of the most important criteria for selection of the optimal solution, since the area is prone to frequent floods causing significant damage to agricultural land and existing structures in the village. The major constraint for implementation of the proposed technical solution is the high costs for compensating the private owners for the expropriated land extending along this river section.

Since the full restoration of the river seemed impossible only with physical interventions in the riverbed, given the number, size and complexity of the existing barriers, which are mainly related to the inadequate planning of the human activities in the river's natural flood plain from the past, significant attention was given to developing a comprehensive, basin-wide programme for mitigating the key previously identified adverse impacts to the river ecosystem as a whole.

Since *solid waste* and *wastewaters*, were recognized as the key pressure sources to the river ecosystem, set of measures was designed to improve their management in the river basin of Golema Reka. Based on previous analysis of the categories, diversity and quantities solid waste affecting the river ecosystem, a comprehensive solid waste management programme comprising of short and long-term measures was proposed. The proposed measures vary from conducting clean-up campaigns, to establishment of complete management system for the organic waste (central composting facility and/or waste-to-energy facility) generated at the river basin level.

The list of identified interventions for mitigation of the adverse impact associated with the current wastewater management focuses on resolving the problems related to:

direct discharge of wastewater from the industry into the river, incomplete separation of sewerage and storm water drainage system, incomplete connection to the existing collection network of villages in the river basin and inexistence of collection and treatment systems in other villages. For the villages which cannot be connected to the existing municipal wastewater treatment plant by gravity flow, decentralized wastewater treatment system has been recommended.

Given the importance of the *wetlands* in maintaining the overall balance of the river ecosystem, and the range of beneficial functions they perform (for example: flood mitigation, shoreline stabilization and erosion control, water purification through retention of nutrients, sediments and pollutants and etc.), their restoration was considered as one of the priorities of the project. For that purpose wetlands on Golema Reka were evaluated with the U.S. Army Corps of Engineers Wetland Evaluation Technique (WET), which is a predictive computer model which provides output based upon collected statistical, historical and field data. Subject to evaluation were the wetlands at the Krusje spring (karstic source for Golema Reka) and Ezerani (natural lacustrine fringe wetland), already designated as 'Strictly Protected Natural Reserve', according to national legislation. Based on the evaluation of the current status of the both wetlands, a set of restoration measures has been proposed. These measures involve: closing the existing artificial fish ponds (at the spring in Krusje), restoration of the river corridor with natural vegetation, restriction of irrigation water use in dry periods, prohibition/limitation of sand excavation activities, creation of wetlands in former fish ponds (by diverting high discharges of Golema Reka and the effluent from central municipal WWTP in Ezerani in the former fish ponds to provide advanced/tertiary treatment). The implementation of such measures would be undoubtedly associated with risks and constraints mainly related to opposition by the affected local farmers to change irrigation practices, sand excavation habits, need for compensation for privately owned land (for example existing fish ponds at the river delta etc.), and for shutting down the work of the existing fish farms at the spring in Krusje and etc. Unfortunately, because of the insufficient care of the river status in the past many of the other landscape elements important for water retention and purification (meanders, wetlands, riparian corridors and ponds) have been completely lost. Their restoration will be associated with strong barriers caused by the unplanned land-use patterns and usurpation of land inside the river's flood plain.

Considering the importance of the status of the *forest* for the balance of the river ecosystem, particularly related to the erosion and sediment transport processes, as well as the hydrological regime of the basin, measures for improvement of the forest cover have been designed. The design of measures is based on previous assessment of the status of forest cover and the erosion zones (superficial and in-depth erosion). Following the development of erosion control measures, afforestation actions were organized to improve the status of the forest cover in the basin.

Besides the forest sector, critical impact to the river ecosystem is caused by the agricultural activities. The measures aiming at reducing the impacts of agriculture in the river basin were developed through the *land-use* component. Based on the assessment of the land-use patterns in the basin and the associated impacts, mainly related to pesticide and fertilizer use, as well as irrigation practices, a variety of mitigation measures have been proposed. These measures include: long-term institutional and capacity building activities aiming at adopting the principles of Good

Agricultural Practices (GAP), measures for controlled application of fertilizers and pesticides, and water use for irrigation purposes.

And finally, given the importance of the monitoring of water quantity and quality parameters for undertaking management actions aiming at maintaining the natural balance of the river ecosystem, a comprehensive *monitoring* programme for the river basin of Golema Reka was proposed. The measures for improvement of the river monitoring are based on previous definition of the priority monitoring parameters, and the capacities within the existing responsible institutions.

6 Conclusions

The major environmental impacts of ecosystem stress in the Prespa Basin include ineffective land-use controls, unsustainable water management, damaging agricultural practices, unsustainable fishing and forest management, pollution from untreated wastewater and inadequately handled solid waste from various sources. These impacts have significant negative effect on biodiversity and important ecological areas. They are additionally intensified by the rapid decline of the water level of Prespa Lake and the loss of significant quantities of fresh lake water. Therefore series of ecosystem restoration and management measures have been developed and are under implementation. Although diverse in nature and complexity these measures are organically interrelated. They involve interventions in the legal, regulatory and planning instruments by mainstreaming ecosystem priorities, and also practical demonstration of ecosystem oriented concepts for resource management in the productive sector and the protected areas management.

Specific restoration activities have been designed for the river basin of Golema Reka which is the main tributary of the Prespa Lake. The river restoration efforts are considering the key principles of integrated river basin management, which set the basis for integrated water and land use management, which is an essential prerequisite for maintaining and restoring ecosystem functions and services.

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Verification of a Simplified Flood Routing Method Based on Field Observation

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Abstract. Different numerical schemes have been proposed for computing the reference discharge in Muskingum-Cunge based flood routing methods. In this paper the field application of these schemes has been investigated by using a number of observed flood hydrographs of Karoon River, Iran. Also, the results of these simplified methods have been compared with that of a full hydrodynamic model. The results indicated that the studied schemes generally provided reasonable output in comparison with the observed hydrographs. Also, the discrepancies among the results of these schemes were not significant. Furthermore, the computed results of the studied simplified methods reasonably concur with that of hydrodynamic model which indicate that the application of these methods is justified especially in situations where the required intensive data for the hydrodynamic models are not easily available.

Keywords: Flood routing, unsteady flow, Muskingum-Cunge method, variable parameters

1 Introduction

In spite of the vast advances in software and hardware computing facilities improved simplified flood routing methods have still been published in the literature regularly. One of the most important issues in choosing the proper flood routing method is the availability of the required data for using a specific method. There are numerous field situations which lack sufficient and reliable data for employing sophisticated data intensive models. In such cases using complicated models with relatively uncertain data would not grant reliable result for the user. Instead the simplified methods which usually do not require massive data could provide reasonable output.

The Muskingum-Cunge flood routing method is a simplified method that yield reasonable results in such circumstances. Many researchers have proposed different computational schemes for evaluating the reference discharge which is employed in determining the parameter of the method [1], [2], [4], [5], [6], [7], [8], [9], [10], [11], and [12]. However, published materials concerning the application of the method and the effect of the proposed schemes on the computed hydrographs for field conditions are very few. This paper presents the results of applying constant and different variable parameter Muskingum-Cunge methods to the observed flood hydrographs of Karoon, located in Khozestan, Iran. The results of these methods were also compared with that of a hydrodynamic model in order to assess the methods capability in providing reliable output.

2 Constant Parameter Muskingum-Cunge Method

It has been shown that conventional Muskingum method is an approximation of the Convection-Diffusion equation and it yields the same results as the kinematic wave equation does [2]. By differentiating kinematic wave equation and matching the numerical and physical diffusion, Cunge [2] modified the conventional Muskingum method and presented the later so called Muskingum-Cunge model. The model determines the routed hydrograph by applying Equation 1 to each computational cell.

$$Q_{i+1}^{n+1} = C_1 Q_i^{n+1} + C_2 Q_i^n + C_3 Q_{i+1}^n \tag{1}$$

where: Q is discharge at the nodes of the computational cell (Fig. 1); C_1, C_2 and C_3 are routing coefficients calculated based on the routing parameters, K and X, as shown by Equations (2) to (6):

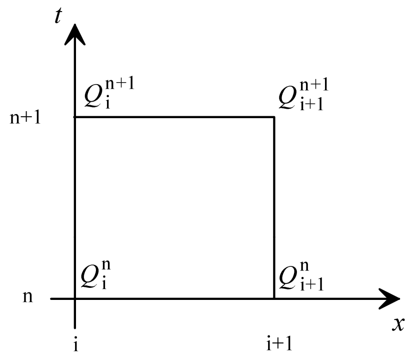

Fig .1. Computational cell

$$K = \Delta x / c_r \tag{2}$$

$$X = \frac{1}{2}\left(1 - \frac{Q_r}{BSc_r\Delta x}\right) \tag{3}$$

$$C_1 = \frac{KX + 0.5\Delta t}{K(1-X) + 0.5\Delta t} \tag{4}$$

$$C_2 = \frac{-KX + 0.5\Delta t}{K(1-X) + 0.5\Delta t} \tag{5}$$

$$C_3 = \frac{K(1-X) - 0.5\Delta t}{K(1-X) + 0.5\Delta t} \tag{6}$$

where: c_r is wave celerity; Q_r is reference discharge; B is top width of the cross section at the water surface; S is longitudinal bed slope; Δx and Δt are spatial and temporal steps, respectively. The Eq. (2) and (3) indicate that the routing parameters K and X, are determined based on geometric and hydraulic properties of the channel. However, they are kept unchanged during the entire computation when using constant parameter Muskingum-Cunge method (CPMC). In other words they were computed based on a constant "reference discharge". Ponce and Chaganti [8] proposed Eq. (7) for evaluating the reference discharge.

$$Q_r = \left(Q_b - Q_{pi}\right)/2 \tag{7}$$

where: Q_b and Q_{pi} are base flow and maximum inflow discharges, respectively.

3 Variable Parameters Muskingum-Cunge Method

Ponce and Yevjevich [7] claimed that variable routing parameters could more properly reflect the nonlinear nature of flood wave than the constant parameters do. However, the variable parameter schemes induce volume loss during the computation [7]. Ponce and Chaganti [8] argued that the volume loss is the price that should be paid to model the nonlinear characteristic of flood wave.

In the variable parameters Muskingum-Cunge method (VPMC), the computation of routing parameters is based on a reference discharge that is determined within each computational cell. Therefore, the routing parameters will vary from a time step to another according to the nonlinear variations of the discharge. The reference discharge is determined by averaging the discharge of the nodes of each computational cell.

Basically, two schemes were proposed for determining the reference discharge in each computational cell. The first scheme uses known discharge values of three nodes of the cell, which is referred to three points averaging scheme. The second one includes the unknown discharge value of the forth node, that is (i+1, n+1), in the computation of the reference discharge. This scheme is usually referred to as four points averaging scheme and clearly requires trial and error procedures to determine the reference discharge. Each of the averaging schemes encompasses three computational techniques which were presented as follows [12]:

3.1 VPMC3-1

$$Q_r = \sum_{i=1}^{3} Q_i \Big/ 3 \tag{8}$$

$$c_r = \sum_{i=1}^{3} c_i \Big/ 3 = \sum_{i=1}^{3} f(Q_i) \Big/ 3 \tag{9}$$

3.2 VPMC3-2

$$Q_r = \sum_{i=1}^{3} Q_i \Big/ 3 \tag{10}$$

$$c_r = f(Q_r) \tag{11}$$

3.3 VPMC3-3

$$c_r = \sum_{i=1}^{3} c_i \Big/ 3 = \sum_{i=1}^{3} f(Q_i) \Big/ 3 \quad for \quad K \tag{12}$$

$$\left(\frac{Q}{c}\right)_r = \sum_{i=1}^{3} \left(\frac{Q_i}{c_i}\right) \Big/ 3 \qquad for \quad X \tag{13}$$

3.4 VPMC4-1

$$Q_r = \sum_{i=1}^{4} Q_i \Big/ 4 \tag{14}$$

$$c_r = \sum_{i=1}^{4} c_i \Big/ 4 = \sum_{i=1}^{4} f(Q_i) \Big/ 4 \tag{15}$$

3.5 VPMC4-2

$$Q_r = \sum_{i=1}^{4} Q_i \Big/ 4 \tag{16}$$

$$c_r = f(Q_r) \tag{17}$$

3.6 VPMC4-3

$$c_r = \sum_{i=1}^{4} c_i \Big/ 4 = \sum_{i=1}^{4} f(Q_i) \Big/ 4 \qquad for \ K \tag{18}$$

$$\left(\frac{Q}{c}\right)_r = \sum_{i=1}^{4} \left(\frac{Q_i}{c_i}\right) \Big/ 4 \qquad for \ X \tag{19}$$

3.7 VPMC4-4

Tang *et al*. [12] suggested Eq. 20 for determining the correction factor, cor, proposed by Cappelaere [1], in order to consider the longitudinal hydrostatic pressure gradient term which he believed would improve the volume conservation in diffusion wave flood routing model [1].

$$cor = \sqrt{1 - \mu \frac{2D}{cQ_r} \frac{\partial Q}{\partial x}} \tag{20}$$

where μ is adjustment factor which takes into account the effect of the $\partial^2 y/\partial x^2$ term and depends on the size and shape of the channel. In the VPMC4-4 scheme, the effect of the longitudinal hydrostatic pressure gradient is considered by modifying the wave celerity and the diffusion coefficient in the following way [12]:

$$c' = c \cdot cor \tag{21}$$

$$D' = \frac{D}{cor} \tag{22}$$

where c' and D' are modified forms of the wave celerity and the diffusion coefficient.

4 Field Application

To evaluate the applicability and accuracy of the proposed schemes and techniques six flood hydrographs of Karoon have been routed using computer programs written in Visual FORTRAN 6.5. The routing results were also compared with the results obtained by applying the well known hydrodynamic model HEC-RAS [13]. Karoon is located in south west of Iran which has relatively proper condition for routing tests. The routing reach is about 61.4 kilometer long with a longitudinal slope of 0.00015. The geometric data are available only for two sections nearly17 kilometers apart from each other and located at the downstream side of the reach. An equivalent rectangular channel 312.5-meter wide was considered. The bankfull discharge of this section is reported 2500 cms which is considered in this study [3].

Two approaches for determining the flow depth are used. In the first approach Manning's formula was used and the rating curve of the downstream section was employed in the second approach. Table 1 shows the observed and computed peak discharges and the peak time for each scheme, which are of most importance in flood management studies. The computations were achieved based on 1hr and 1km time and space intervals (Δt and Δx), respectively. Figs. 2, 3 and 4 show the computed and the observed outflow hydrographs for the different schemes examined herein. In these figures the depth of flow, which is required for computing the routing parameters, is determined by using Manning's formula.

It is obvious from these figures that the VPMC schemes (three or four point schemes) reveal better results, of peak discharge and time to peak, than the constant parameter scheme. There is no significant difference between the routed hydrographs, using different techniques of each scheme.

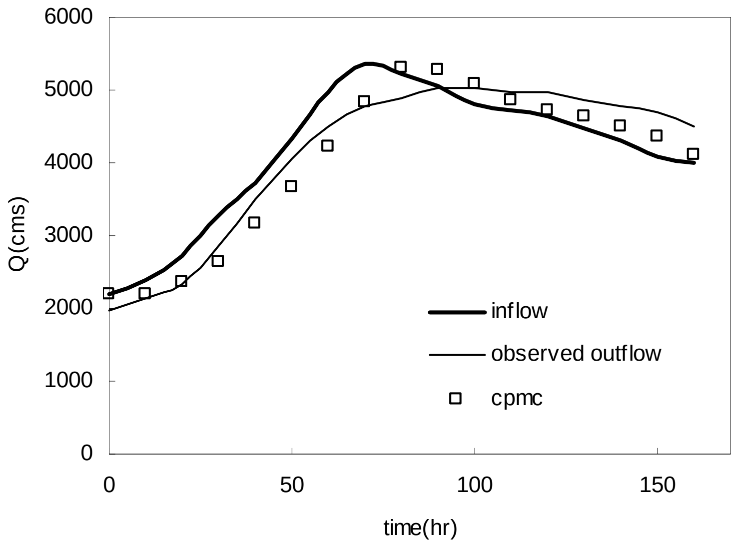

Fig. 2. Observed hydrographs against computed one based on CPMC method for 1994 flood event

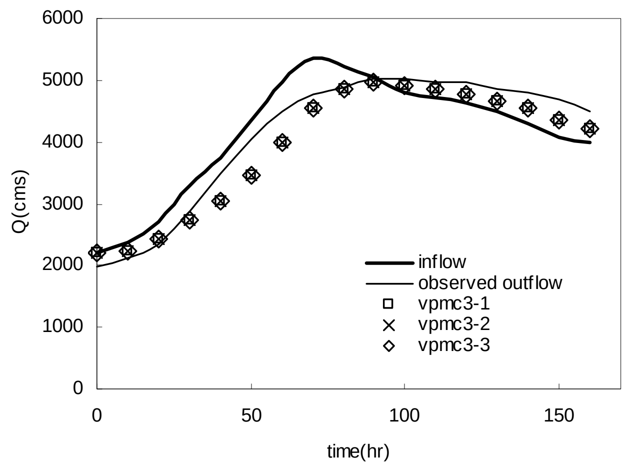

Fig. 3. Observed against computed hydrographs using three point schemes for the 1994 flood event

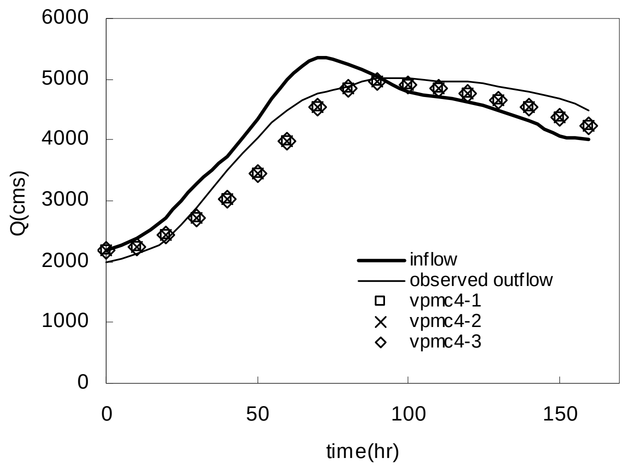

Fig. 4. Observed against computed hydrographs using four point schemes for the 1994 flood event

Figure 5 shows the computed and the observed outflow hydrographs for the four point schemes examined herein. In this figure the depth of flow, which is required for computing the routing parameters, is determined by using the reported rating curve of the cross section [3]. Comparing Figures 4 and 5 shows that using the rating curve of the actual cross section for the equivalent cross section decreased the accuracy of the results. Therefore, in such circumstances it is recommended that a resistance equation (such as Manning's equation) is used for determining the flow depth when the actual cross section is approximated by an equivalent one.

Table 1. The computed peak discharge and the time to peak for each scheme for studied flood events

method of computing water depth	year	inflow		observed outflow		CPMC		VPMC3-1		VPMC3-2		VPMC3-3	
		Qp (cms)	tp (hr)	Qp (cms)	tp (hr)	Qp (cms)	tp (hr)	Qp (cms)	tp (hr)	Qp (cms)	tp (hr)	Qp (cms)	tp (hr)
Manning Eq.	1973	4538	88	4038	104	4510	103	4289	113	4289	113	4289	113
	1987	3726	40	3694	48	3692	47	3021	47	3021	47	3021	47
	1988	4238	112	4357	120	4218	126	4074	127	4074	127	4074	127
	1990	2877	43	2697	48	2847	52	2474	46	2474	46	2474	46
	1992	2294	144	2119	152	2291	156	2283	155	2283	155	2283	155
	1994	5385	72	5058	96	5324	84	4972	90	4972	90	4972	90
Rating curve	1973	4538	88	4038	104	4516	95	4520	94	4488	99	4520	94
	1987	3726	40	3694	48	3676	44	3682	43	3577	46	3682	43
	1988	4238	112	4357	120	4225	119	4227	118	4206	122	4227	118
	1990	2877	43	2697	48	2825	49	2829	48	2671	50	2829	48
	1992	2294	144	2119	152	2289	153	2288	153	2278	155	2288	153
	1994	5385	72	5058	96	5350	76	5356	75	5291	78	5356	75

Table 1 (continued). Computed peak discharge and the time to peak for each scheme for studied flood events

method of computing water depth	year	VPMC4-1 Qp (cms)	VPMC4-1 tp (hr)	MVPMC4-2 Qp (cms)	MVPMC4-2 tp (hr)	VPMC4-3 Qp (cms)	VPMC4-3 tp (hr)
Manning Eq.	1973	4288	113	4288	113	4288	113
	1987	3021	47	3021	47	3021	47
	1988	4072	126	4072	126	4072	126
	1990	2475	46	2475	46	2475	46
	1992	2283	155	2283	155	2283	155
	1994	4972	90	4972	90	4972	90
Rating curve	1973	4520	94	4488	99	4520	94
	1987	3682	43	3577	46	3682	43
	1988	4226	118	4206	122	4226	118
	1990	2829	48	2671	50	2829	48
	1992	2288	153	2278	155	2288	153
	1994	5356	76	5290	78	5356	76

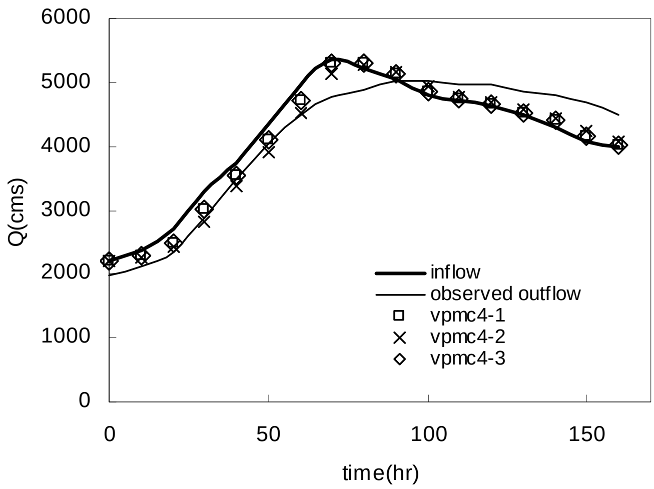

Fig. 5. Observed against computed hydrographs using four point schemes and rating curve for the 1994 flood event

Figure 6 presents the computed outflow hydrographs of HEC-RAS full dynamic model and VPMC4-3 scheme. It should be emphasized that the Manning's equation was used to determine the depth of flow and accordingly the routing parameters in VPMC4-3 scheme. Equivalent cross section is used in both models.

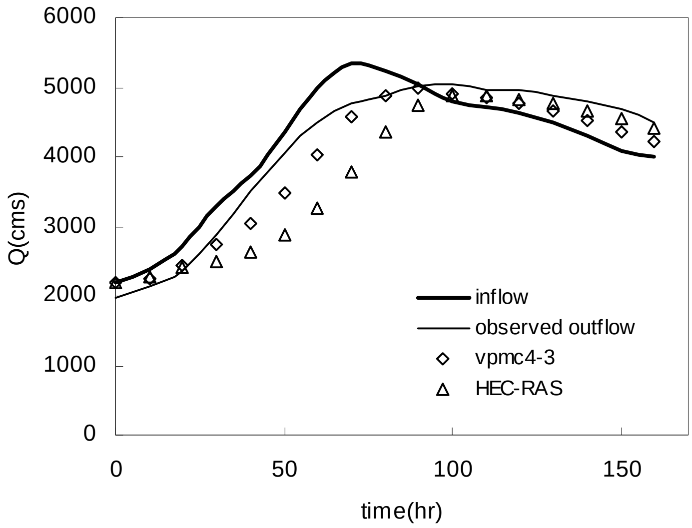

Fig. 6. Observed hydrographs against computed ones based on VPMC4-3 scheme and HEC-RAS for the 1994 flood event.

Figure 6 shows that Muskingum-Cunge based methods reproduced the output hydrographs with higher accuracy than HEC-RAS does. The equivalent cross section which is an approximation of the actual cross section is used in both. It seems that the full hydrodynamic model is much more sensitive to the accuracy of the input data.

5 Sensitivity to Grid Size

One of the most important steps in simulation of unsteady flow with full dynamic models is to determine the proper grid size to avoid the instability. In order to examine the sensitivity of Muskingum-Cunge different schemes to the size of temporal and spatial intervals, inflow hydrographs had been routed with different time and space steps. For this reason the routing reach as well as the duration time of inflow hydrograph has been divided to different intervals.

Figs. 7 and 8 show the routing results according to different amounts of space and time increments. Fig. 7 indicates that changing the amount of space interval will produce no significant change in the results. In Fig. 8 decreasing the time interval down to a specific amount increase the accuracy of results, but beyond this limit changing of time increment does not show significant change in the routing results. It can be concluded that it is preferable to avoid usage of relatively large time step.

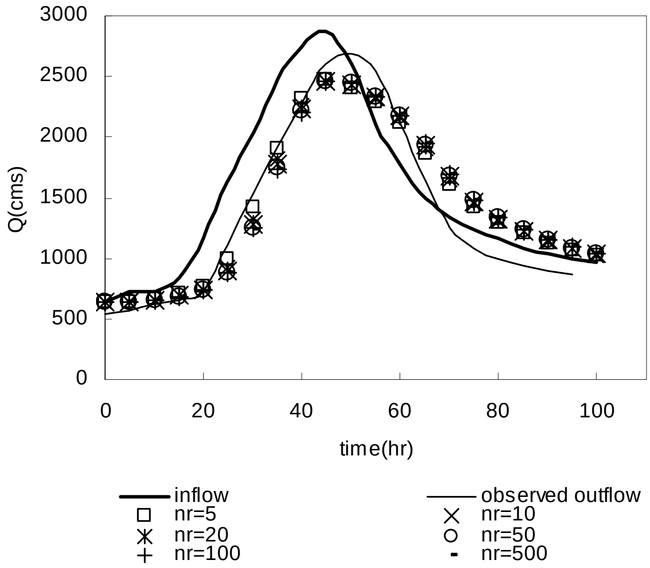

Fig.7. Observed against computed hydrographs using VPMC3-3 scheme and different space steps for the 1990 flood event. (nr = number of intervals)

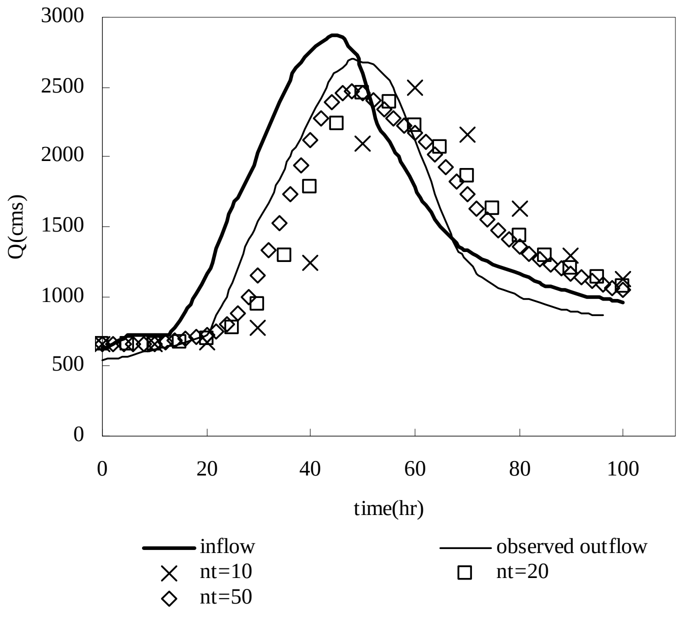

Fig. 8. Observed against computed hydrographs using VPMC3-3 scheme and different time steps for the 1990 flood event (nt = number of time reaches)

6 Conclusions

In this paper the applicability of different Muskingum-Cunge based methods were examined for evaluating flood events occurred in Karoon. The proposed schemes were able to simulate flood events with proper accuracy. This indicates the applicability of the simplified methods especially when the accuracy of the required data for the hydrodynamic models is questionable. The computed outflow peak of the VPMC schemes which was determined by using the reported rating curve are somewhat higher than the same parameter computed by using Manning's equation to estimate the flow depth.

The results indicate no significant difference among the computed outflows using the different averaging schemes and techniques. However, four points scheme slightly improve the volume conservation of the routed hydrograph; but VPMC4-4 technique did not improve the volume conservation significantly compared to other techniques of the scheme. Maximum difference computed between observed and routed time to peak is 21 hours detected in 1994 flood when the rating curve is used to determine the water depth. The average of differences between observed and routed time to peak, when the Manning's equation is used to determine the water depth, is less than 5 hours. This indicates that more attention should be paid when the river's rating curve of real cross section is used for approximate equivalent channel cross section. Also proposed methods should not be used in situations where the time to peak plays an important role.

There is no significant difference among results of routing with different space steps; though decreasing the time steps up to a definite limit increases the accuracy of results.

Acknowledgment

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Paper: **A86**

Optimization of the Operation on Polder System in Bardejov Region

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Abstract. The thesis contains the analysis of present situation of two polders system, which is situated in the Bardejov territory above the Sveržovka village. The solution consists of hydraulic assessment of polder function, their capacity as well as capacity of effluent river-basin, mathematical simulation and optimization of operation against overflowing of river banks and general improvement of flood protection situation during the flood. The thesis offers also the best possible result in hydraulic and economic point of view.

Keywords: Polder system, flood simulation, HEC-RAS

1 Introduction

There is no area in the East Slovakia, which should not sense the power of storm rainfall and local floods. Over the past decade there are many of villages that were affected by this appearance. The engineers and others interested are breaking up in point of view how to prevent these effects. Since 1997 the floods cause damages for 50 millions EUR and this number is still not definitive, but only one fifth of this payment has been invested in the prevention.

Protection of settlement near the big rivers such the Danube River is sufficient but there are also projects how to increase this protection. Worse situation is on smaller rivers like Kamenec or Sveržovka Rivers because of their very problematic location in relation to the settlements and surrounding nature landscape.

2 Existing Technical Arrangements

Bardejov territory is typical for its very fast development of floods which are affected by high level of longitudinal slope of rivers and the terrain, rainfall intensity, river basin practically without flood plain area and very close located settlements.

Two main rivers should be found in the aggrieved area. The Kamenec River, which is tributary river and flows into the Sveržovka River. There are five smaller villages and two polders located in this territory.

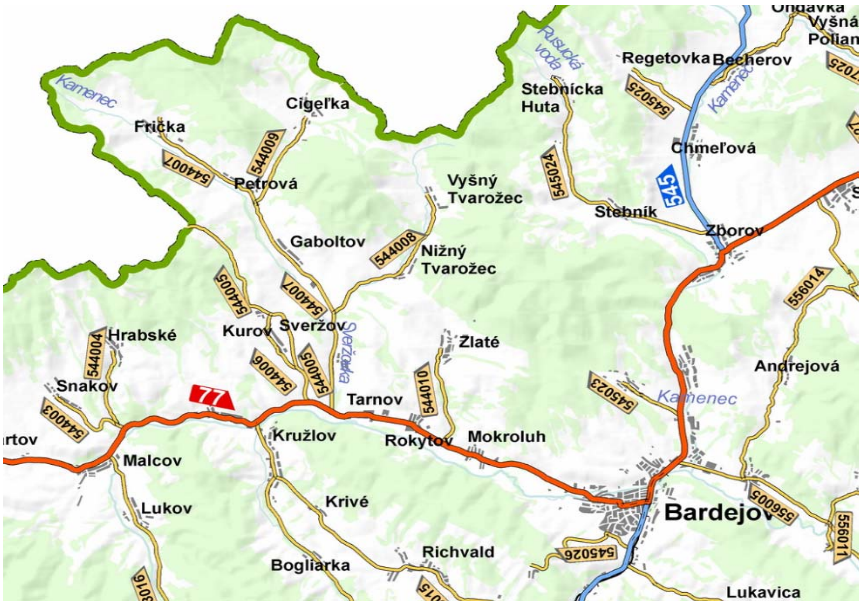

Fig. 1. Bardejov territory

3 Polder (General Characteristics)

A polder is a low-lying tract of land enclosed by embankments known as dikes that forms an artificial hydrological entity, meaning it has no connection with outside water other than through manually-operated devices (Fig. 3).

There are three types of polders:

- -Land reclaimed from a body of water, such as a lake or the sea bed;
- -Flood plains separated from the sea or river by a dike;
- -Marshes separated from the surrounding water by a dike and consequently drained.

The ground level in drained marshes subsides over time and thus all polders will eventually be below the surrounding water level some or all of the time. Water enters the low-lying polder through ground swell due to water pressure on ground water or rain fall and transportation of water by rivers and canals. This usually means that the polder has an excess of water that needs to be pumped out or drained by opening sluices at low tide. However, care must be taken in not setting the internal water level too low. Polder land made up of peat (former marshland) will show accelerated compression due to the peat decomposing in dry conditions.

Polders are at risk from flooding at all times and care must be taken to protect the surrounding dikes. Dikes are mostly built using locally available materials and each has its own risk factor: sand is prone to collapse due to over-saturation by water while dry peat is lighter than water, making the barrier potentially unstable in very dry seasons.

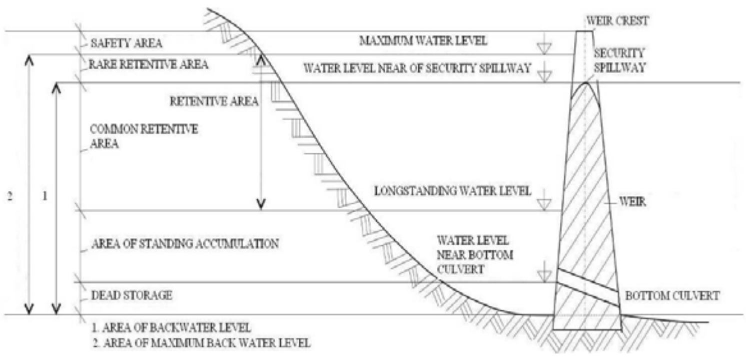

Fig. 2. Scheme of polder

3.1 Division of Polders

Polder should be divided in to few groups by various points of view
Division by control valve:
a) None regulated. Bottom culverts has persistent cross-section without any regulation components.
b) Regulated. Bottom culverts are available for regulation.
Division by method of building-up:
a) Dam type polder; Applicable in areas with good topography.
b) Flat polder; Wide area polder with low backwater level intervention.
c) Lateral; Polder located in parallel with river [2].

4 Polder Vyšný Tvarožec

Design discharge: $Q_n = 11.00\ m^3.s^{-1}$
Polder bottom level: 500.7 m a.s.l.
Bottom culvert level: 499.66 m a.s.l.
Spillway crest level: 509.80 m a.s.l.
Weir crest level: 511.00 m a.s.l.

Capacity of polder up to spillway crest level: 68 900 m^3
Volume of flood wave: W = 230 400 m^3
Duration of flood wave increasing: t_{inc} = 1.0 h
Duration of flood wave decreasing: t_{dec} = 3.0 h
Total duration of passing of flood wave: t_c = 4.0 h

Table 1.Volume curve of polder co-ordinates

Water level [m a.s.l.]	499.66	502.00	506.00	510.40
Volume [m^3]	0	126	5715	68900

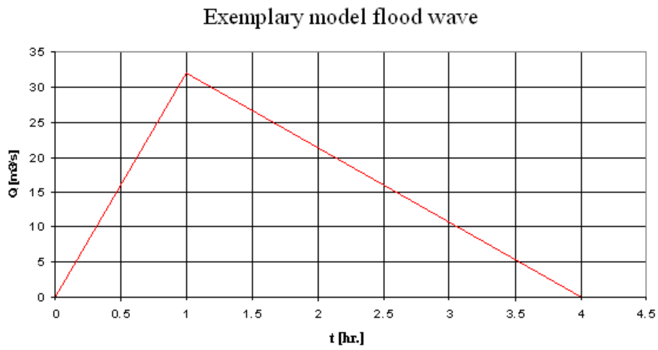

Fig. 3. Exemplary model flood wave

5 Polder Frička

Design discharge: Q_n = 8.00 $m^3.s^{-1}$
Polder bottom level: 519.24 m a.s.l.
Bottom culvert level: 518.90 m a.s.l.
Spillway crest level: 527.10 m a.s.l.
Weir crest level: 528.30 m a.s.l.
Capacity of polder up to spillway crest level: Wp=78 700 m^3
Volume of flood wave: W = 216 000 m^3
Duration of flood wave increasing: t_{inc} = 1.0 h
Duration of flood wave decreasing: t_{dec} = 3.0 h
Total duration of passing of flood wave: t_c = 4.0 h

Table2. Volume curve of polder co-ordinates

Water level [m a.s.l.]	518.90	522.00	525.00	527.70
Volume [m^3]	0	6438	32 304	78 700

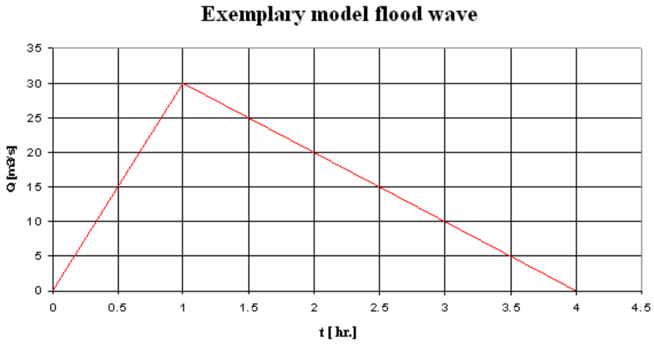

Fig. 4. Exemplary model flood wave

6 Modelling

Whole area was simulated in HEC-RAS software which is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities.

The HEC-RAS system will ultimately contain three one-dimensional hydraulic analysis components for: steady flow water surface profile computations; unsteady flow simulation; and movable boundary sediment transport computations. A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

The current version of HEC-RAS supports steady and unsteady flow water surface profile calculations. New features and additional capabilities will be added in future releases.

6.1 HEC-RAS overview

At the top of the HEC-RAS main window is a Menu bar with the following options:

File: This option is used for file management. Options available under the File menu include: New Project; Open Project; Save Project; Save Project As; Rename Project: Delete Project; Project Summary; Import HEC-2 Data; Import HEC-RAS data; Generate Report; Export GIS Data; Export to HEC-DSS; Restore Data; and Exit. In addition, the most recently opened projects will be listed at the bottom of the File menu, which allows the user to quickly open a project that was recently worked on.

Edit: This option is used for entering and editing data. Data are categorized into four types: Geometric Data; Steady Flow Data; Unsteady Flow Data; and Sediment Data. In the current version, Sediment Data is not active.

Run: This option is used to perform the hydraulic calculations. The options under this menu item include: Steady Flow Analysis; Unsteady Flow Analysis; Sediment Analysis; and Hydraulic Design Functions. In the current version, Sediment Analysis is not available.

View: This option contains a set of tools that provide for graphical and tabular displays of the model output. The View menu item currently includes: Cross Sections; Water Surface Profiles; General Profile Plot; Rating Curves; X-Y-Z Perspective Plots; Stage and Flow Hydrographs; Hydraulic Properties Plots; Detailed Output Tables; Profile Summary Tables; and Summary Err, Warn, Notes.

Options: This menu item allows the user to change Program Setup options; set Default Parameters; establish the Default Units System (U.S. Customary or Metric); and Convert Project Units (U.S. Customary to Metric, or Metric to U.S. Customary).

Help: This option allows the user to get on-line help, as well as display the current version information about HEC-RAS.
Also on the HEC-RAS main window is a Button bar. The Button bar provides quick access to the most frequently used options under the HEC-RAS menu bar [7].

7 Additional Options

Taking into account relatively narrow valley with number of residential areas there is not enough space to form extensive hydraulic structures therefore I proceed to less invasive solutions [3].

Alternative solution taken into account:

- Emplacement of bottom outlets closings;
- Increasing of river basin retention capacity;
- Increasing of river basin retention capacity in combination with emplacement of bottom outlets closings;
- Building the polders with lateral spillway.

8 Emplacement of Bottom Outlets Closings

This alternative is taking under consideration emplacement of bottom outlets closings onto each polder with combination of timely warning system. The bottom outlets should by manipulated separately in depending upon the actual hydrological and hydraulic parameters on each sub-basin [1], [5].

8.1 Appraisal

HEC-RAS proved that this solution rapidly improved water level regime along the river and also the backwater level on each lateral inflow was set on more consensual level. There is a divergence between the travel time of flood waves therefore the junction of the rivers is not stressed by backwatering, as well [2], [4].

9 Increasing of River Basin Retention Capacity

To increase the retention capacity of river basin barrages should be used. Barrage is a small overflow-type weir commonly used to raise the level of a river or stream. Water flows over the top of a barrage, although some barrages have sluice openings which release water at a level below the top of the weir. Barrages are frequently used on upper parts of rivers or in mountain streams to reduce erosive ability of stream [6].

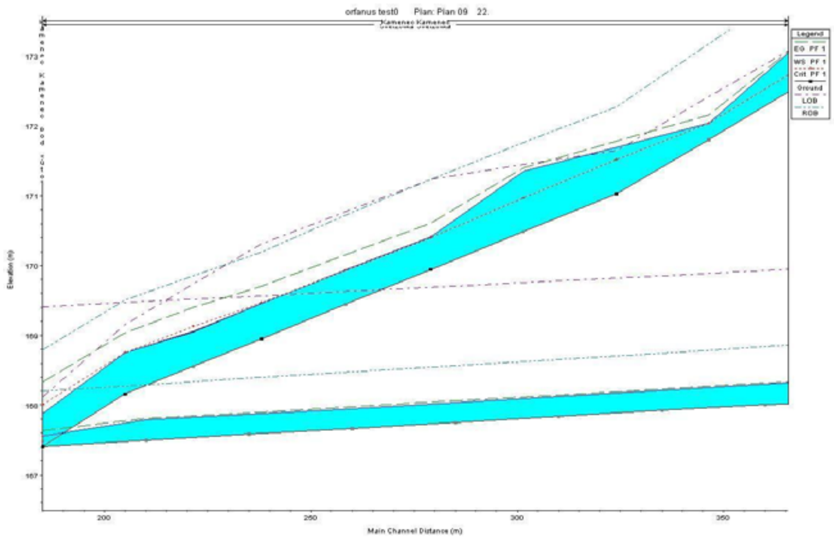

Fig. 5. Junction point

9.1 Appraisal

There is rapid degradation of water velocity along both rivers but time travel for each sub-basin is almost same and this fact may cause problems in junction.

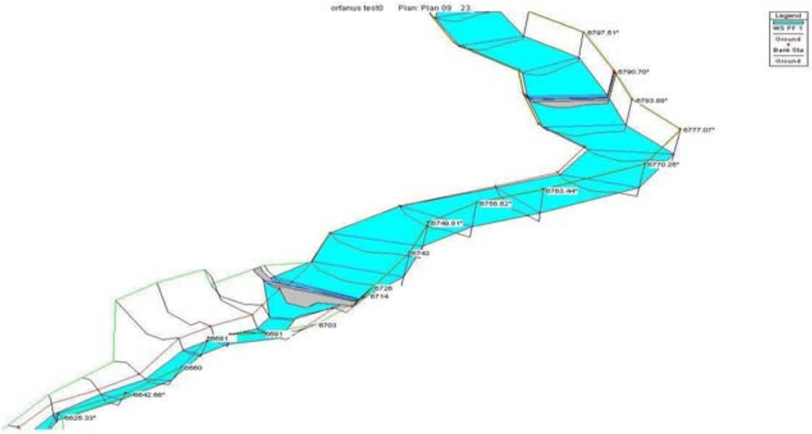

Fig. 6. Increasing of river basin retention capacity

Table 3. Potential locations of barrages:

River	Number of barrage	Chainage (rkm)	Barrage height (m)	Level of spillway crest (m a.s.l.)
Kamenec	1	7.945	1.20	200.80
	2	7.025	1.00	199.82
	3	6.260	1.50	193.85
	4	5.825	1.20	185.80
	5	5.155	1.20	180.00
	6	1.540	0.90	171.80
Sveržovka	1	6.860	1.20	181.20
	2	6.785	0.80	180.10
	3	6.715	2.00	180.00
	4	6.492	0.60	173.90
Junction	1	0.134	0.60	167.80

10 Increasing of River Basin Retention Capacity in Combination with Emplacement of Bottom Outlets Closings

This is a combination of both upper described alternatives.

10.1 Appraisal

It is the most effective method how to reduce the risk of overflowing the river basin during the flood.

11 Building the Polders with Lateral Spillway

This solution takes into the consideration to build up two polders with lateral spillways, one on each river. The polders were pre-named as Nižný Tvarožec polder and Petrová polder [4].

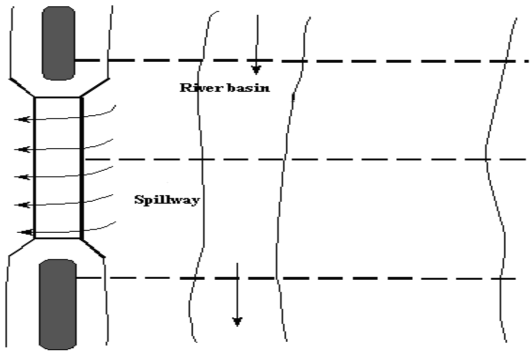

Fig. 7. Lateral spillway

11.1 Basic parameters

Nižný Tvarožec Polder
Volume of polder up to the crest of lateral spillway: Wp=21 158 m^3
Design discharge: Q=5 $m^3 .s^{-1}$
Chainage: 6.670 rkm
Level of lateral spillway crest: 374.60 m a.s.l.

Petrová Polder
Volume of polder up to the crest of lateral spillway: Wp=13 888 m^3
Design discharge: Q=5 $m^3 .s^{-1}$
Chainage: 5.685 rkm
Level of lateral spillway crest: 383.25 m a.s.l.

11.2 Appraisal

For this solution, looks like the Petrová polder is non-effective because of its small retention volume. But modelling has shown that the Nižný Tvarožec polder should affect the flood, above all, in the middle parts of river Sveržovka.

12 Conclusions

The task of the thesis: Optimization of the Operation on Polder System in Bardejov Region was to analyze present conditions and hint an alternative to increase the resistibility of river basin.

Table 4. Comparison of alternatives and its effects

Parameters	Rivers	Alternatives			
		1	2	3	4
Average discharge Q ($m^3.s^{-1}$)	Kamenec	6.67	42.41	6.52	5.90
	Sveržovka	4.13	22.30	3.89	5.88
Average velocity v ($m.s^{-1}$)	Kamenec	0.93	1.78	0.86	0.99
	Sveržovka	1.00	1.87	0.81	1.19
Travel time to junction t_j (h)	Kamenec	1.58	3.00	3.26	2.05
	Sveržovka	1.29	2.02	2.49	2.36
Delta t (h)	Junction	0.29	0.98	0.77	0.31

- Emplacement of bottom outlets closings,
- Increasing of river basin retention capacity,
- Increasing of river basin retentive capacity in combination with emplacement of bottom outlets closings,
- Building the polders with lateral spillway.

Depending upon these results I would recommend the alternative: Increasing of river basin retentive capacity in combination with emplacement of bottom outlets closings. This alternative appears as most effective and steady for this area.

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Sources of Groundwater Pollution of Danube Allivial Plain

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Abstract. The conditions necessary for the Danube alluvial plain formation, as well as natural characteristics of the groundwater reservoir were analysed as part of the research for the Novi Sad municipality. Definition of the hydrogeological aquifer parameters based on existing investigations was necessary as a basis for the analysis of pollution sources, infiltration direction and depth, as well as of the pollutant type.

Keywords: Danube alluvial, pollutants, groundwater

1 Introduction

This work is part of the research cofinanced by the city of Novi Sad within the framework of the Novi Sad Ecogeochemical Aspects Programme. It is also part of the scientific project: Sustainable Reclamation as a Basis of Soil and Water Management in Vojvodina, funded by the Republic Ministry of Science and Environmental Protection.

The broader research field covers the administrative area of the Municipality of Novi Sad. The geomorphological terrain belongs both to the South Backa (Varoska) loess terrace at the confluence of the Danube-Tisa-Danube canal and the Danube and to the Danube alluvial plain. Morphological forms are either weakly pronounced or masked by urbanization. Meanders of different ages are found in the broader research area in the Danube alluvial plain. The oldest ones have great oval arches, which are cut across by younger meanders that are almost parallel to the course of the Danube, and a pronounced structure. Fish ponds are constructed on them. Apart from the meanders of different ages, in different parts of the shore, there are river islands formed, such as the Mackov Sprud sandbank near Beocin, the Kamenica and Petrovaradin River Islands and the Ratno ostrvo (War Island) near Novi Sad [1].

2 Lithological Characteristics of the Danube Alluvial Plain

The alluvial sediment depth at some research locations in Novi Sad varied from 17.0 m to 38.0 m, depending on the erosion by the river and the development of the riverbed, stagnant tributary or flood facies. The most representative profiles of the lithological composition of the alluvion with hydrogeological parameters of the gravelly/sandy environment have been obtained during the hydrogeological research over the last thirty years aimed at the formation of source areas of the Novi Sad water supply system (Fig. 1, 2, 3, 4). Suggest the existence of three environments with different hydrogeological function: aquitard, aquifer and the underlying stratum.

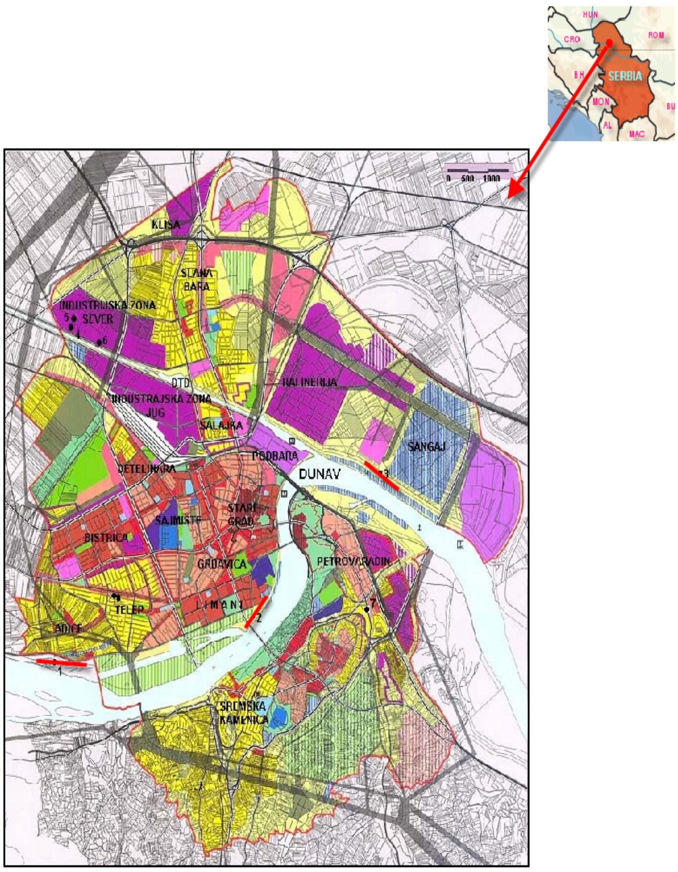

Fig. 1. General geographic map with ground water source area sites in the City of Novi Sad Legend: 1. ADICE source, 2. STRAND source, 3. RATNO OSTRVO source area, 1-6 locations electromagnetic prospection

The aquitard sediments are low permeable, their thickness ranging from 3.0 m to 6.0 m. They are composed of diverse alevrite and loessoid varieties deposited on the ground, in the aqueous environment or overdeposited.

The aquifer comprises grey-greenish silty to small-grained occasionally gravelly sands of 10.0 m to 20.0 m thickness, vertically gradated and interstratified here and there with lenses and interbeds of the alevrite-clayey sediments. The sands are quartz, poor in mica, but rich in coloured minerals, well rounded and sorted. The granulometric composition and the hydrogeological function of the aquifer is dependent on the facies type (riverbed, stagnant tributary, river island or flood).

The third lithological member is the impermeable underlying stratum composed of Older Quaternary or Pliocene grey-blue lean carbonaceous clays.

In Veternik (west of Novi Sad), at the Pasnjak site, the caprock thickness is half a meter, the sand-gravelly stratum being 21.50 m. The gravels are medium- to coarse-grained, well rounded, and bound with sandy cement. They are made up of quartz, sandstone, cherk, limestone and green schist. The underlying layer is composed of impermeable dark green lean clays with carbonaceous concretions and interbeds of low-coal clays, at a depth of 22.0 m.

The caprock at the Rimski Sancevi (northeast of Novi Sad) site is of 6.0 m thickness, made of the flood facies yellow-brown clays, and the water-borne sand-gravelly sediments of the Danube bed facies are of 25.0 m thickness. The underlying stratum is at a 31.0 m depth.

The yellow silty loessoid and loam caprock at the Sajlovo (northwest of Novi Sad) site is of 11.0 m thickness. The sandy-gravelly alluvion is of 27.0 m thickness. Grey-and-green lean clays are registered at a depth of 38.0 m.

At Klisa, the Rit site, the underlying stratum of the alluvial sands is at a 37.0 m depth, the caprock thickness being 4.0 m and composed of yellowish silty sandy mica clays. The quartz sands are well rounded and sorted, composed of mica and occasionally of gravel. The last aquifer stratum, of 4.0 m thickness, comprises well rounded cemented gravels. The approximate filtration coefficients of the aquifer, as suggested by the granulometric analyses, vary from 6 to 9 x 10^{-5} m/s [2], [4], [5].

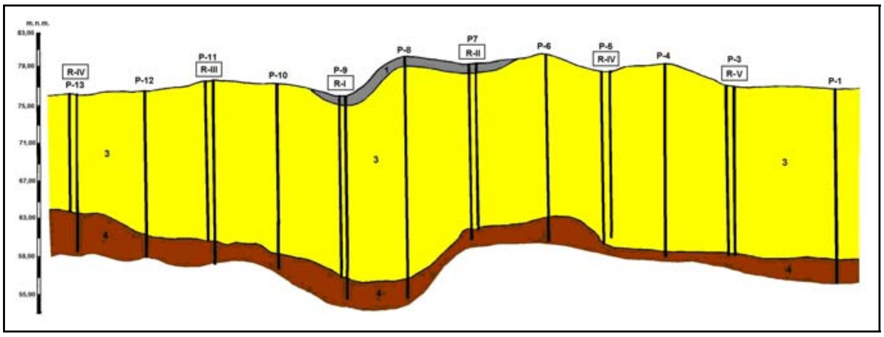

Fig. 2. Longitudinal hydrogeological profile at the STRAND source area site (Legend: 1-embankment, 3- sand, 4-soft clay)

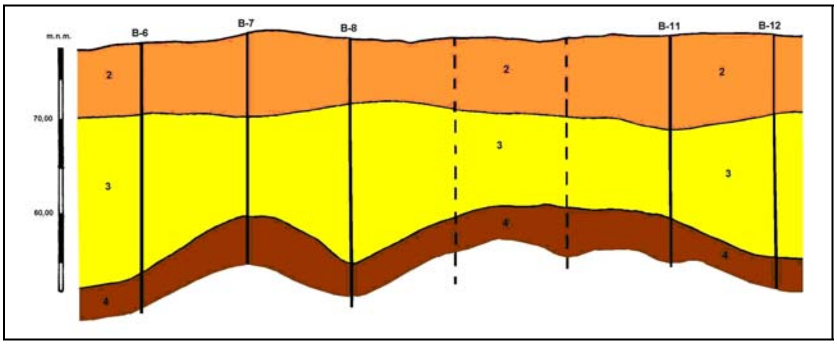

Fig. 3. Longitudinal hydrogeological profile at the ADICE source area site (Legend: 2-yellow sandy clay, 3- sand, 4-soft clay)

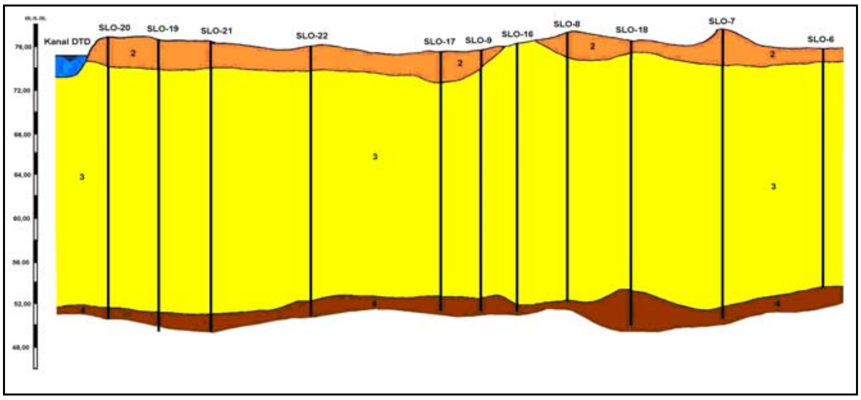

Fig. 4. Longitudinal hydrogeological profile at the RATNO OSTRVO source area site (Legend: 2- yellow sandy clay, 3- sand, 4- soft clay)

3 Research Method

A new electromagnetic method, based on the physical fields of elements and compounds, has been used in the area of Novi Sad. It can be classified into electromagnetic geophysical or alternative methods. The method has been invented by Zvonimir Janković, a Belgrade electrical engineer. The apparatus includes a portable emitter of low frequency electromagnetic waves equipped with an emission beam width regulator and an emission beam receiver.

The emitter of low frequency electromagnetic waves equipped with the emission beam regulator is used in such a way as to direct the emission beam being emitted by the emission arrow as desired, and adjust the beam width by the beam regulator for the purpose of detecting the object – chemical element. The author has determined the frequencies of all the chemical elements of Mendeleev's Periodic System and of the compounds most commonly identified as groundwater and soil pollutants. A low-frequency field (ranging from 2 to 20 Hz) can help detect the overall dimensions of ore bodies, humans and other living things or underground infrastructure. It can therefore be used in mining, archaeology, in the detection of people buried alive in the wreckage of natural disasters, and also in environmental protection: in detecting damaged underground facilities containing hazardous substances likely to contaminate the environment, illegal dumpsites, animal graveyards etc. The detection range is up to 3 km with both horizontal and vertical prospection. In the industrial zone of Novi Sad, this method has been used to identify underground settling tanks and waste water drainage pipes, both intact and damaged ones, depth distribution and spatial distribution of certain pollutants in the infrastructure zone, pollution direction, lithological composition and the occurrence of underground waters.

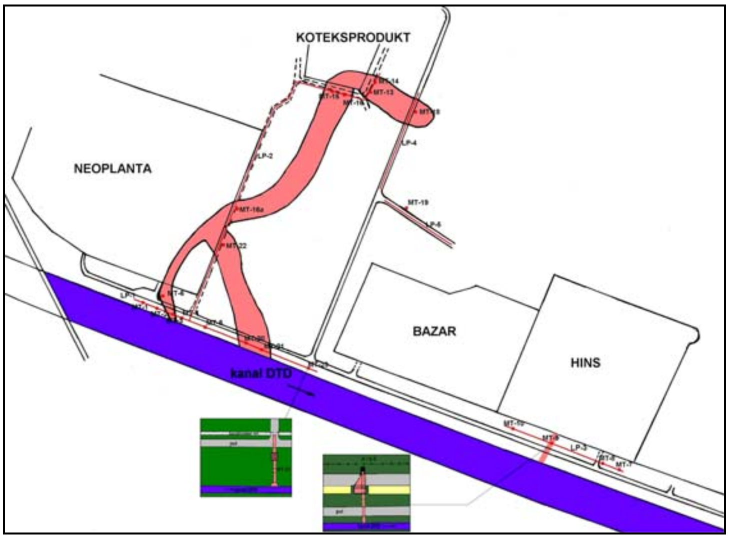

Fig. 5. The industrial zone of Novi Sad with the locations of profile lines and horizontal pollutant prospection (Legend: “Neoplanta” Meat Industry, “Cotexproduct” Fur Processing; “Bazar” Warehouses, “HINS” Chemical Industry , MT-4 measurement point

Pollution

4 The Results on Electromagnetic Prospection in the Industrial Zone

The results on horizontal and vertical prospection in the industrial North zone near Neoplanta are given in great detail and attached to Figs. 5 and 6.

In the “Sever” industrial zone, at 4 profiles, horizontal electromagnetic prospection has been first performed at measurement points 50 m apart. It has determined the presence of all the pollutants detectable by this method. The major ones detected include ammonia, nitrates and arsenic. As shown in Fig. 3, the separation of the polluted underground course into two directions is induced by the depth and inclination of the underlying stratum along which the pollutant moves. The underlying stratum comprising grey impermeable clays is located very high between the two directions of the underground course. Morphologically, it is a river lake which separated the Danube branch from the riverbed. The pollutant occurrence in the second water-bearing stratum suggests the association of the first and second strata through a deeper intake structure in the area of Neoplanta and the Cotexproduct. In the geochemical longitudinal profile (Fig. 6), the pollutants have been recorded only at measurement points. No polluted zones have been found between the points, as pollutants infiltrate vertically until they reach the watertight underlying stratum, remain at the lowest levels above the watertight underlying stratum and then horizontally move in the direction of the underlying stratum slope and of the most intense groundwater flow. It is only at the longitudinal profiles through alluvial sediments, which are vertical to the DTD canal, and parallel to the modern course of the Danube, that the electromagnetically detected zone is completely polluted.

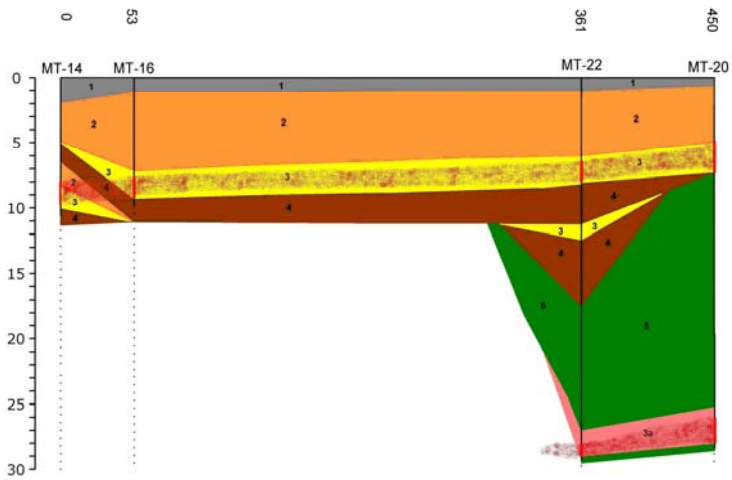

Fig. 6. The industrial zone (SEVER) of Novi Sad- vertical pollutant prospection (Legend: MT-16 measurement point, 1- embankment, 2- yellow sandy clay, 3- sand, 4- soft clay, 5- clay)

Pollution

Vertical prospection at 24 measurement points has detected at a 3-4 m depth a wastewater outlet of constant width from the Neoplanta plant to the DTD canal. Groundwater and soil pollution underneath the drainage pipe and the settling tank near HINS has been detected and pollution with arsenic coming from the wastewater settlling tank registered in the COTEXPRODUCT Fir Industry [3].

5 The Results on Geochemical Prospection in the Citi Area

First, pollutants have been detected by horizontal geochemical prospection at differently spaced measurement points distributed along the profiles. It is only at these measurement points that vertical geochemical prospection has been made coupled with the determination of the lithological profile down to the first impermeable underlying stratum, water occurrence, pollutant direction, depth pollution and pollutant frequency intensity. The fundamental criterion in determining the microlocations for the vertical geochemical prospection has been the following: to set up the profiles near the potential pollution source such as petrol stations, power transformer stations, industrial plants, underground infrastructure, bus and railway stations, water supply source areas, cemeteries, etc.

The **Fertiliser Plant location,** measurement point MP– 4. It is vertical to the pyralene polluted groundwater flow direction. Down to the impermeable underlying stratum, at a 26.00 m depth, the following has been detected: nitrates and nitrites (30 units), ammonia (40-50 units), pyralene (15-20), iron (about 10), arsenic (10-15), managenese (5 units) and boron (up to 5 units). The lithological profile has been defined down to 30.0 m, and the occurrence of water registered at 11.10 m.

The Dairy location, measurement point MP– 5. The pollution in the vertical profile has been detected at a 6.00 – 18.00 m depth, where clay has first appeared, being continually measured down to 20.00 m. The groundwater level has been registered at 6.00 m. The following pollutants have been detected in the vertical profile: ammonia (40 units), mercury (30 units), along nitrates and nitrites, lead and manganese (20 units each), arsenic (10 units), iron (5 units) and pyralene (trace amounts).

The **ALBUS location,** measurement point MP – 7. Prospecting has determined the contents of ammonia, nitrates and nitrites to be 30-35 units in 9.00– 23.00 m interval. The waters also contain manganese, arsenic, pyralene and iron. The course width having 60 units and pyralene 30–40 units. The following pollutants have been detected in the 7.00 m to 20.00 m sands: mercury (60 units), arsenic (35 units), ammonia, nitrates and nitrites (60 units each), manganese (40 units), iron (5 units) and lead (15 units). The polluted groundwater flow is in a northwest-southeast direction, the course having a great width.

The **Spens location,** measurement point MP-9: Pollution has been detected in the clay stratum in 3.00–8.30 m interval with phenols (50 units), iron (40 units), petroleum (40 units), pyralene, nitrates and nitrites (40 units each) and lead (25 units). In the 8.30–21.00 m water-saturated sand interval, ammonia (50 units), pyralene (20 units), arsenic (30 units), boron, manganese, mercury, phenols, nitrates and nitrites (10 units each) have been registered to be the highest.

The **Limanski Park location,** measurement point MP-11: In the 8.70-24.50 m water-bearing horizon detection has been made of ammonia (30 units), arsenic (20 units), mercury (15 units), manganese (10 units), boron and iron (3-5 units), phenols and pyralene in trace amounts.

The **petrol station location near the railway station,** measurement point MP-12: Vertical prospection down to 20.00 m has registered the following: petroleum and pyralene (60 units) in 2.00– 5.00 m water-free sand interval and nitrites, nitrates and pyralene in clays. In 6.20 m – 18.80 m sands the following pollutants have been detected: mercury (60 units), arsenic (55), pyralene (20 units), ammonia (15 units), nitrates and nitrites (10 units), manganese (2-3 units), phenols in trace amounts and lead (up to 5 units). The polluted groundwater flow is in a west-east direction, the course width ranging from 0.5 m to 3.00 m.

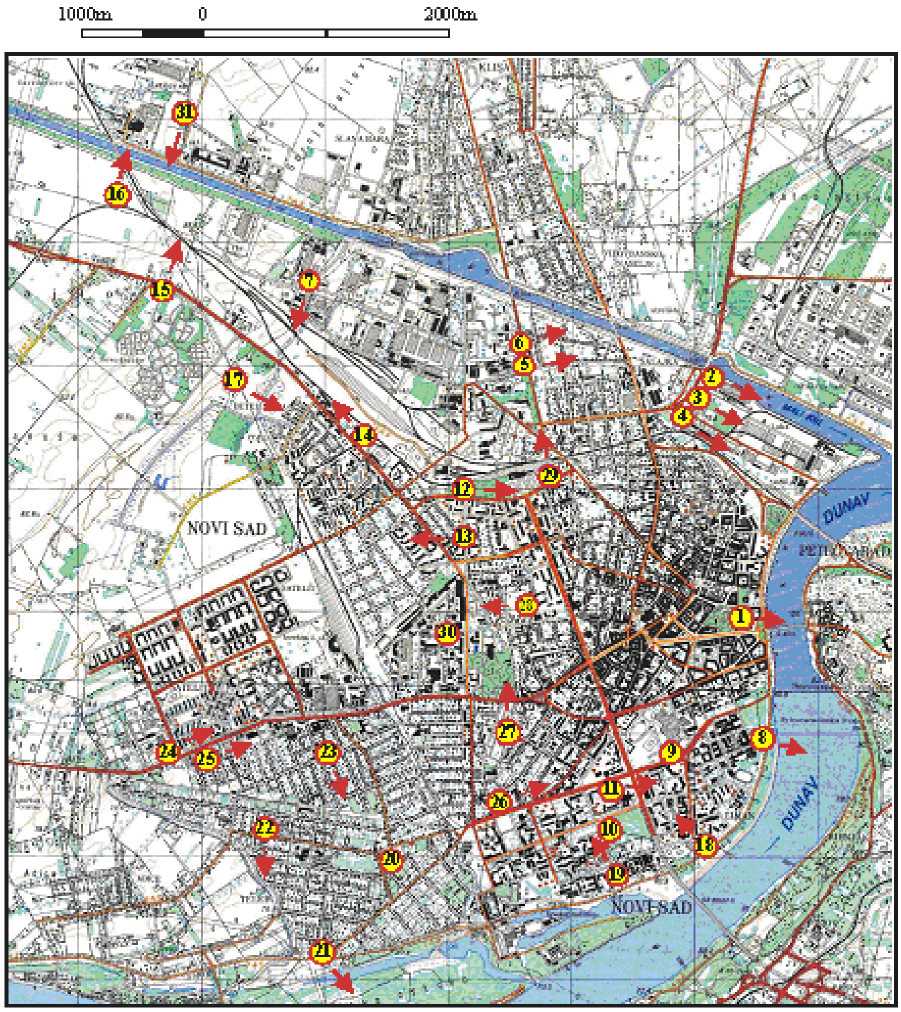

Fig. 7. General map of Novi Sad with previous and current research locations (Legend: 15 - measurement points, ➡ pollution direction)

The **Matijevic Meat Industry location**, measurement point MP-16: The vertical prospection down to 50.50 m has identified the following: petroleum (30 units) in the 1.00 m-25.00 m sand interval and nitrites, nitrates (30 units), arsenic (10) and lead (20 units) in clays. The following pollutants have been detected in the 44.00 m – 50.50 m sands: mercury (15 units), arsenic (20-30 units), ammonia (50 units), nitrates and nitrites (45 units), manganese (trace amounts), phenols (20 units). The polluted groundwater flows in a south-north direction, the course width being great towards the DTD canal. The pollutant occurrence in deeper alluvion portions is most likely due to a leaking septic tank or other underground treatment facilities or wastewaters technically badly being exported. The wastewaters have reached the aquifer through the technical water or water supply well. It should be checked whether the meat processing plant is using the municipal water supply system for the manufacture of its processed products.

The **Rumenacki Put petrol station location,** the measurement point MP-17. The vertical prospection down to 25.00 m has detected the following: petroleum (50 units) in 4.50 m-7.00 m clays and nitrites, nitrates (30 units), arsenic (20 units), ammonia (45 units) and manganese.

The **Limanski park**, the measurement point MP – 18. Vertical prospection down to 26.00 m has detected the following: nitrites, nitrates (50 u nits) down to 6.00 m, followed by arsenic (55 units), ammonia (20 units), manganese (50 units), mercury (40 units), iron (70 units) and lead (30 units) in the 6.00 m – 25.00 m sand interval. The polluted groundwater flow is in a southeast-northwest direction, the course having a great width from the Danube towards Liman 2. This is where the city bus stop is located [3].

6 Conclusions

Preliminary geochemical prospection by RADIAN-2001SF, a new non-invasive electromagnetic method, has been used to qualitatively detect soil and water pollutants.

A total of 30 points have been distributed in the horizontal prospection at locations of potential pollutants. Two locations have been set up at existing artesian wells, for method checking purposes, as the chemical composition and the lithological profile have been known. Detection has been made of 14 pollutants. Different nitrogen triad concentrations have been determined at all locations, and arsenic, manganese and iron at 22. **Mercury, lead and petroleum** have been detected at 15 locations. **Pyralene** has been detected in trace amounts or at high concentrations at 12 locations, **phenols** at 10, and boron at 8. Different iodine concentrations have been measured at the artesian well at the Clinical Centre in all sand intervals, and sulphur has been detected in Sremski Karlovci.

The use of this method does not induce mechanical ecosystem disturbance, since standard monitoring facilities represent potential pollutant movement paths. The method results in positive financial effects, as standard monitoring requires intake monitoring facilities and water sampling for chemical analysis.

The new method, RADIAN-2001SF, is a cheaper, rapid, environmental field method that can be used in pollutant cadastral registering and that can increase the environmental inspection efficacy in the water and soil quality control in the city area.

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