CONTEMPORARY ISSUES OF ADAPTIVE WATER MANAGEMENT

31.10.2012.

Belgrade, Serbia

Water for Sustainable Development and Adaptation to Climate Change

PROGRAMME OF THE CONFERENCE
CONTEMPORARY ISSUES OF ADAPTIVE WATER MANAGEMENT

8:30-9:00	**Registration of attendees**
9:00-10:30	**Opening ceremony** *Introductory notes:* SANU - Academician Nikola Hajdin Minister of Education and Science - Prof. Dr. Žarko Obradović Prof. Dr Milan Dimkić - Significance of UNESCO Category II Water Centers in Transition Countries: the Belgrade Center *Welcome addresses:* UNESCO Paris - Assistant Director General Africa - Mme Lalla Aïcha Ben Barka* IWA - Mr. Vasile Ciomos Dr Omar Salem IHP National Committee for Serbia - Prof. Dr Jovan Despotović IAWD - Mr. Vladimir Taušanović
10:30-11:00	**Coffee break**
11:00-13:00	**Morning session** Academician Fedor Mesinger - Climate Change and Mediterranean Water Resources: What do we Know at Present? Prof. Dr Soontak Lee - Global Water Challenges in UNESCO IHP Intergovernmental Council and 7th World Water Forum Preparation Processes Prof. Dr Milan Dimkić - Importance of the Aerobic State of Alluvial Aquifers for Groundwater Use Mr Philip Weller - Contemporary Issues of Adaptive Water Management - Experiences in the Danube River Basin
13:00-14:30	**Lunch break**
14:30-17:30	**Afternoon session** Dr Hans-Jürgen Brauch - Importance of Groundwater Quality Investigations of Bank Filtration Waters of Rhine and Danube for GW Management in Large River Basins Prof. Dr. Branislav Petruševski - Adsorptive Treatment: An Innovative Approach for Drinking Water Production from Groundwater Dr Neno Kukurić - Groundwater and Climate Variability - IGRAC's Experience and Activities Dr Salvatore D'Angelo - Groundwater Management Coping with Global Change Prof. Dr Olusanjo Bambgboye - UNESCO Regional Centre on Integrated River Basin Management (RC-IRBM) and Africa HELP Basin Coordinating Unit at National Water Resources Institute, Kaduna, Nigeria Dr Biljana Radojević - Impact of Climate Change on Flood Regimes Mr Dejan Dimkić - Climate Change in Serbia and Impact on Water Resources Prof. Dr Stevan Prohaska - Stochastic Structure of the Forming Process of the River Runoff on Rivers with Longest Time Series in the World
17:30-18:00	**Cocktail**

* The Assistant Director General, Africa, Mme Lalla Aïcha Ben Barka will be accompanies by Dr Shamila Nair-Bedouelle (Senior Programme Specialist, Science and Technology)

Publisher: Institute for the Development of Water Resources “Jaroslav Černi”
For the Publisher: Prof Milan Dimkić, Ph.D.C.E. Director

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Preface

With a GDP of some 7000 US$ per capita and moderately abundant water resources, Serbia belongs to the group of countries that are undergoing economic transition and also modifying their approach to water management.

Serbia's water management tradition is very strong. Despite a protracted period of economic and political crisis brought about by economic sanctions and political changes, today's capacities (universities, experts, etc.) are quite respectable. However, there is a clear need to enhance the networking of domestic and international educational and scientific institutions. Additionally, while striving towards sustainable water management, it is essential to adaptively integrate the constraints and requirements resulting from both rapid transition changes and the challenges of climate change. All of this has occasioned the need for establishing a Category II Center for Sustainable Development and Adaptation to Climate Change.

On 11 October 2012, responding to a request of the Serbian Government and based on resolutions of the UNESCO General Conference and the IHP Intergovernmental Council, the Executive Board of UNESCO approved the establishment of the Center.

The Center is expected to support efforts aimed at capacity building, the advancement of knowledge, and the networking of institutions engaged in water management, particularly in circumstances involving climate change and rapid socioeconomic transformation.

The Center will be of great significance to the host country, Serbia, as well as to the region of Southeast Europe (SEE), facilitating and advancing North-South cooperation and supporting UNESCO's comprehensive efforts aimed at developing and implementing the International Hydrological Program (IHP).

The Center is being established at the Jaroslav Černi Institute for the Development of Water Resources (JCI), as JCI has sizeable scientific and professional capacities and the ability to substantially support the work of the Center.

Presented hereafter is an overview of the frameworks, reasons and assumptions underlying the function of the Center within the IHP program, relating to water management issues in challenging circumstances occasioned by impending socioeconomic transformation and climate change in the host country, the region, and beyond.

Significance of UNESCO Category II Water Centers in Transition Countries: The Belgrade Center

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Introduction

Many countries around the world are facing the challenge of meeting increasing water demands resulting from population growth, industrialization and urbanization, while their water resources are dwindling due to pollution and, in some cases, over-exploitation.

Management of water resources needs to be addressed at various levels (global, regional, and local), because each level has its own particular characteristics.

It is the local level where water management is most specifically implemented, conducted and controlled.

The ultimate goal of regional water management is the establishment of a legal and institutional framework for sustainable water management within a certain area (river basin, groundwater basin).

At the global level, water management seeks to enable and facilitate:

a) A more explicit approach to water-related issues throughout the world;
b) Scientific and professional capacity building in all regions and equating of education levels;
c) More effective funding of the water sector; and
d) Enhanced networking and exchange of knowledge and technologies.

The objectives of the UNESCO network of category II centers are largely aimed at b and d above, seeking to allow for water management coordination and enhancement at the regional and local levels.

Phases of water management

Phase 1: Abundance

Water management has generally evolved through several phases. Initially, there was a phase of *abundance*, where the availability of water resources exceeded the levels of water use, while water pollution was insignificant.

Phase 2: Depletion

Next came the phase of *depletion*, during which the levels of water use and water pollution were considerable relative to available water resources, leading to a gradual depletion of these resources. In the late 1960's, the accumulated consequences of intensified industrial development resulted in increased concerns for the general state of the environment.

Phase 3: Sustainable water management

The 1987 Report of the World Commission on Environment and Development: Our Common Future, better known as the Brutland Report, set out the most frequently quoted definition of sustainable development: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Water, being a vital element of the environment, followed this concept and provisions addressing sustainability were gradually incorporated into the foundations of the international water law. The UNECE Water Convention (1992), Article 3, states: “To prevent, control and reduce transboundary impact, the Parties shall develop, adopt, implement and, as far as possible, render compatible relevant legal, administrative, economic, financial and technical measures, in order to ensure, inter alia, that: i) Sustainable water-resources management, including the application of the ecosystems approach, is promoted...”.

Today, throughout the world, major efforts are being made to achieve sustainable management of water resources. Still, considerable differences exist between various parts of the world, and between various countries, in the level of effort expended to institute an appropriate level of water management.

Adaptive water management

There are many definitions of adaptive water management. However, despite the diverse ways in which this term is used, adaptive water management is mostly considered to be a structured, iterative process of optimal decision making in the face of uncertainty, aimed at reducing uncertainty over time through appropriate monitoring. This uncertainty is generally attributed to climate change. However, increasing consideration is being given to the uncertainties attached to socioeconomic drivers. Sudden socioeconomic changes in a country can produce a strong impact on water sector capacities, management approaches and spending. This is especially true of transition countries.

Water management indicators

The question of the capacities needed for robust water management is closely related to two very important parameters/indicators: one is the natural abundance of water resources and the other is the economic power of the country under consideration - Fig. 1.

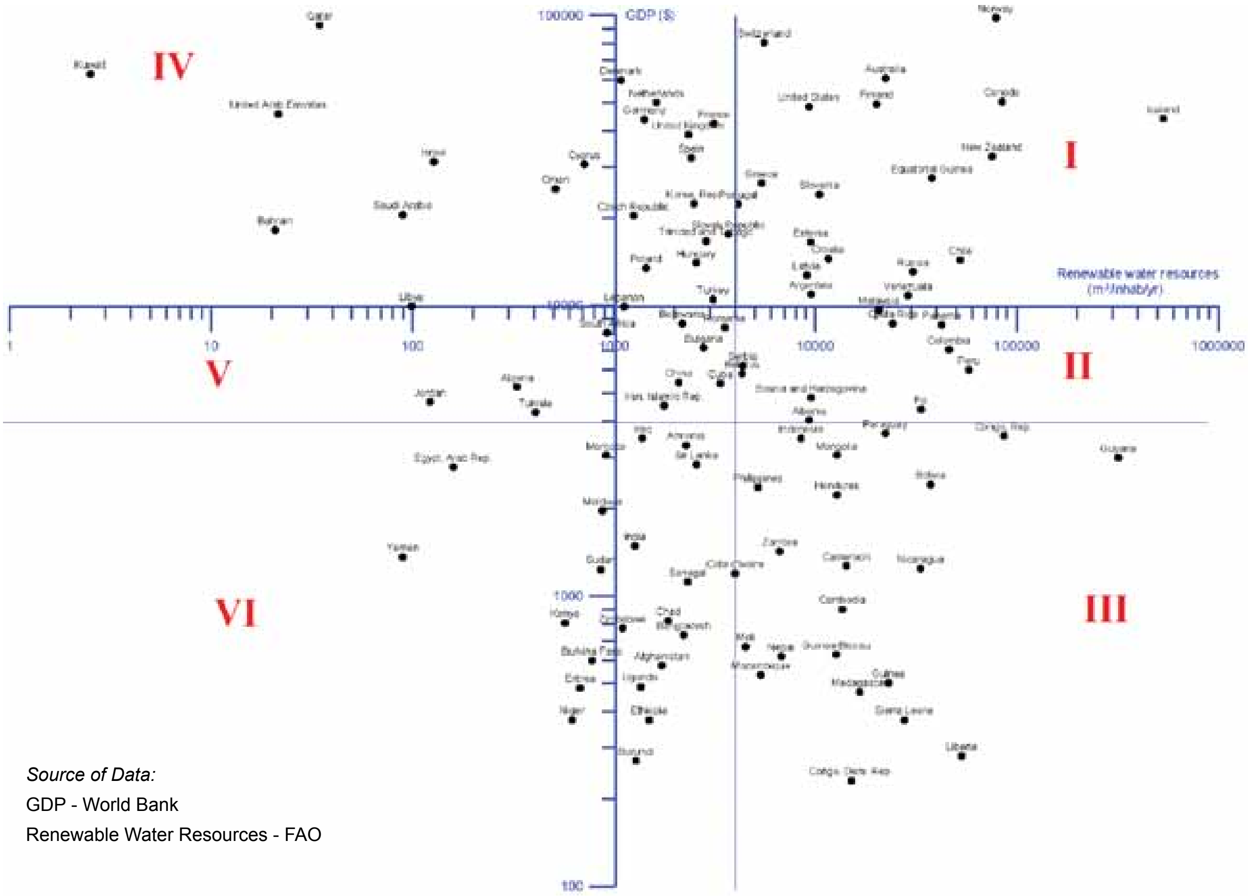

Fig. 1. Economic power and water abundance as indicators of the status of water management.(Dimkić, Milovanović)

In this regard, countries can generally be divided into six groups:

I. GDP in excess of 10K US$ per capita and modest-to-abundant water resources (more than 1000 m^3 per capita per year). These countries have largely resolved the numerous water sector issues. Countries not yet rich (10-20K US$ per capita) have already undertaken substantial activities to enter the stage of sustainable water management. Rich countries (more than 20K US$ per capita), but with modest water resources, need to save water and accelerate their transition to sustainable water management.

II. GDP 3-10K US$ per capita and modest-to-abundant water resources (more than 1000 m^3 per capita per year). These countries are generally preparing for economic progress and the transition from the water depletion phase to the sustainable water management phase. Additionally, a considerable number of such countries are politically undergoing systemic adjustments. This paper refers to them as transition countries.

III. GDP less than 3K US$ per capita and modest-to-abundant water resources (more than 1000 m^3 per capita per year). These countries are generally seeking to improve their economic circumstances and the status of water management. Most of them, along with Group V and VI countries, are facing major water sector issues (Fig. 2,3).

IV. GDP in excess of 10K US$ per capita, arid and desert conditions (less than 1000 m^3 per capita per year). These countries need to adopt cutting-edge technologies to provide water and develop water management.

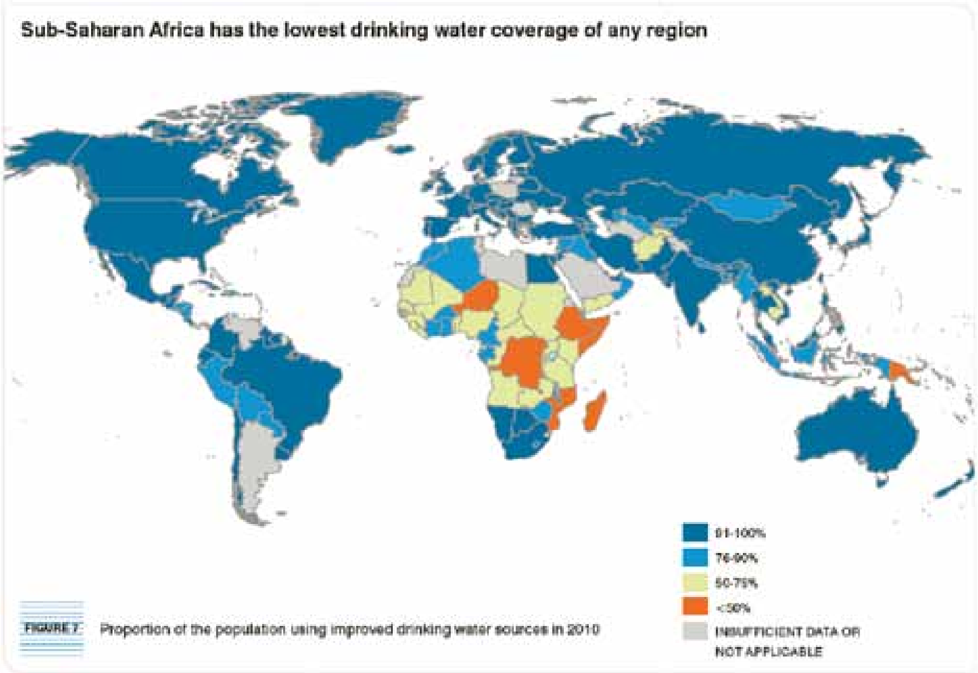

Fig. 2. Proportion of population using improved drinking water sources in 2010. (Progress on Drinking Water and Sanitation, 2012 Update, UNICEF)

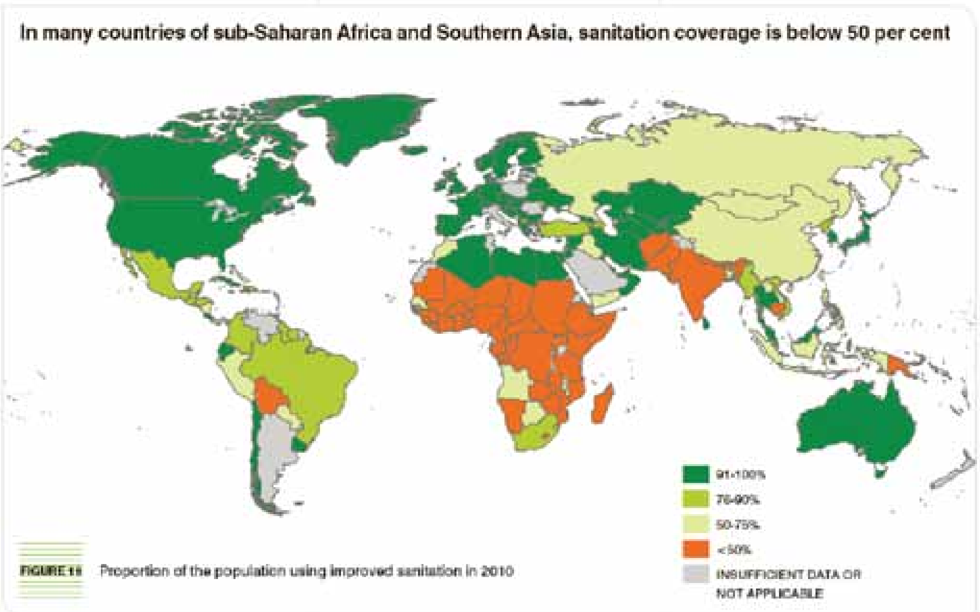

Fig. 3. Proportion of the population using improved sanitation in 2010. (Progress on Drinking Water and Sanitation, 2012 Update, UNICEF)

V. GDP 3-10K US$ per capita, arid and desert conditions (less than 1000 m^3 per capita per year). The countries that belong to this group are faced with major issues and need to make a considerable effort to implement adequate water management.

VI. GDP less than 3K US$ per capita, arid and desert conditions (less than 1000 m^3 per capita per year). The water sector problems of these countries are enormous.

The procedures and processes related to the development of water sector management need to reflect the specific features of the type of country in question and to be adapted to each group, recognizing the circumstances of each country.

The socioeconomic drivers that impose the need for adaptive water management include:

- the need to meet the basic demands of the population in poor countries,
- the challenges brought about in countries transitioning from one group to another (e.g. from Group II to Group I, or from Group III to Group II),
- the challenges stemming from rapid changes and lagging adaption, or insufficient knowledge of such changes,
- the challenges caused by population concentrating in a single area,
- the challenges resulting from disasters and similar events.

Climate change as a driver

A number of global and regional climate and hydrological models have been developed to assess future temperature, precipitation and runoff levels for different climate scenarios (IPPC 2007, SINTA 2008, SEECOF 2010, CC-WATERS 2011). Some of the forecasts are depicted in Figures 4, 5 and 6.

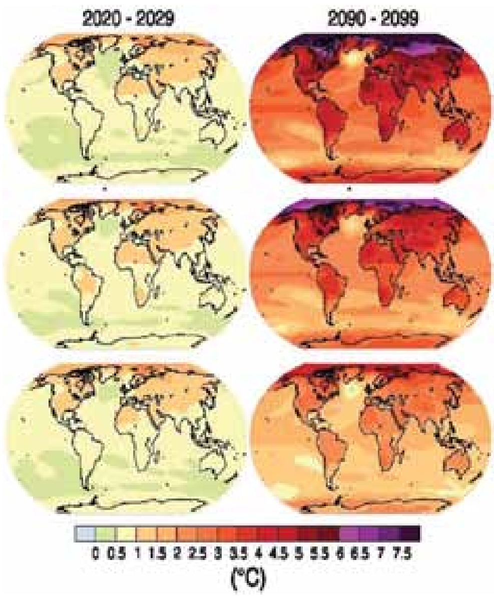

Fig. 4. Variations relative to average temperatures during the period from 1980 to 1999, Scenarios A2, A1B and B1 (respectively) (IPCC 2007.)

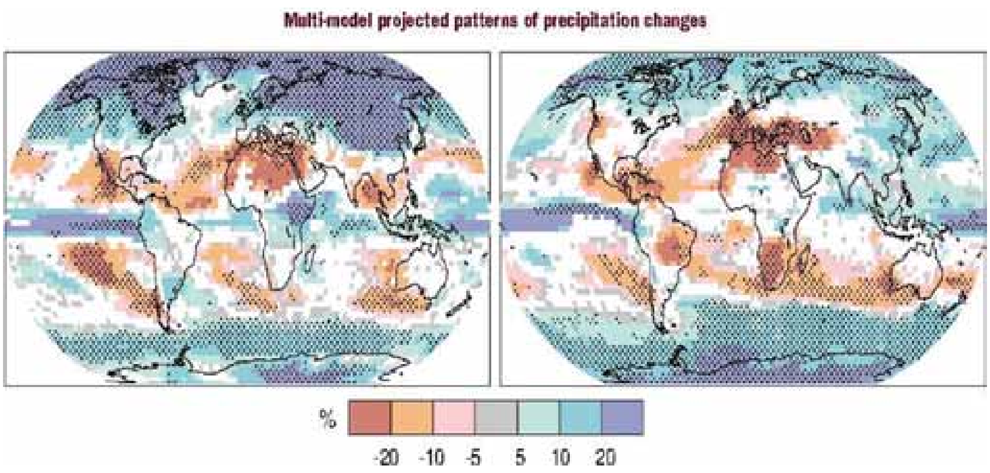

Fig. 5. Relative precipitation changes (2090-2099 vs 1980-1999); values represent multi-model averages based on Scenario A1B for December-February (left) and June-August (right). (IPCC 2007.)

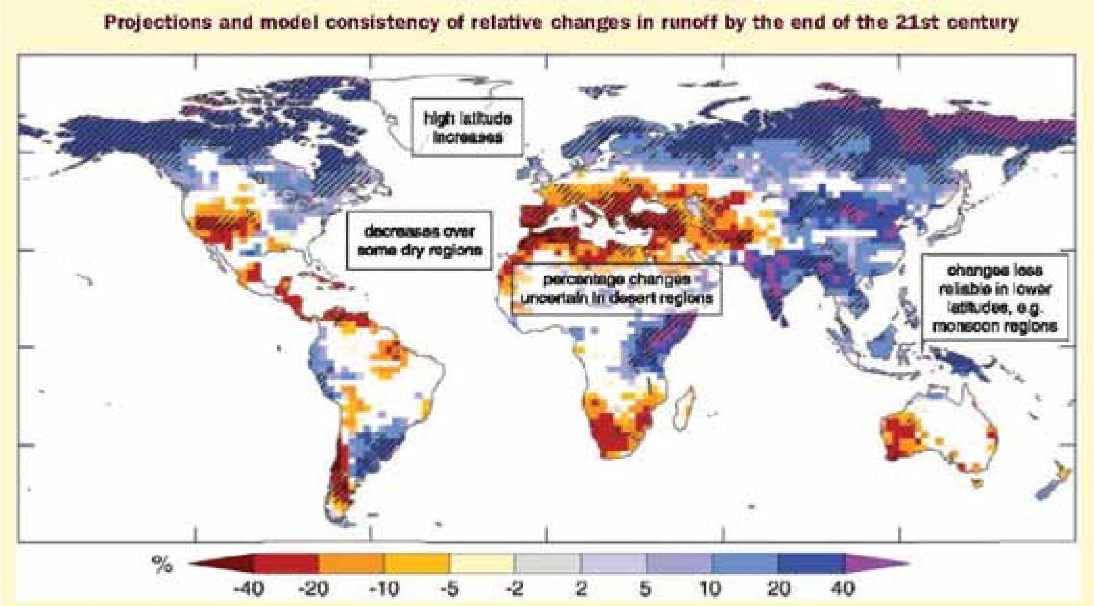

Fig. 6. Large-scale relative changes in annual runoff (water availability, %) at the end of the 21st century relative to 1980-1999. Values represent the median of 12 climate models using the SRES Scenario A1B. (IPCC 2007.)

Not enough light has yet been shed on the mechanisms leading to climate change as global and regional forecast methods have not been sufficiently tested. Still, there are indicators that precipitation will decrease in a significant number of mid-latitude regions (the Mediterranean, southern Africa, Australia, etc.). The frequency and severity of extreme events – floods and droughts – are also expected to increase.

Given that unfavorable outcomes of climate change are expected in this part of Southeast Europe, Serbia is developing several institutions to specifically address this issue, including:

- the Milutin Milanković Regional Center for Climate Change,
- the Milutin Milanković Citizens' Association; and now
- the UNESCO Category II Center for Sustainable Development and Adaptation to Climate Change.

Over the past several years, a number of international and national projects addressing climate change and its impact on water resources in Serbia and the region have either been completed or initiated, such as:

- Research into climate change and environmental impacts: impact monitoring, adaptation and mitigation,
- Assessment of climate change impact on Serbia's water resources,
- Climate change impact on river regimes in Serbia,
- Climate Change and Impacts on Water Supply (CC-Waters), etc.

The prognosis for Serbia is a warning of sorts: Serbia can expect average annual temperatures to increase and river discharges to decline. Current investigations of climate change in Serbia are based on 26 temperature stations and 34 precipitation stations. The annual average temperature trend in Serbia was found to be about 0.6°C/100 years, while the precipitation trend was around zero (or very slightly negative).

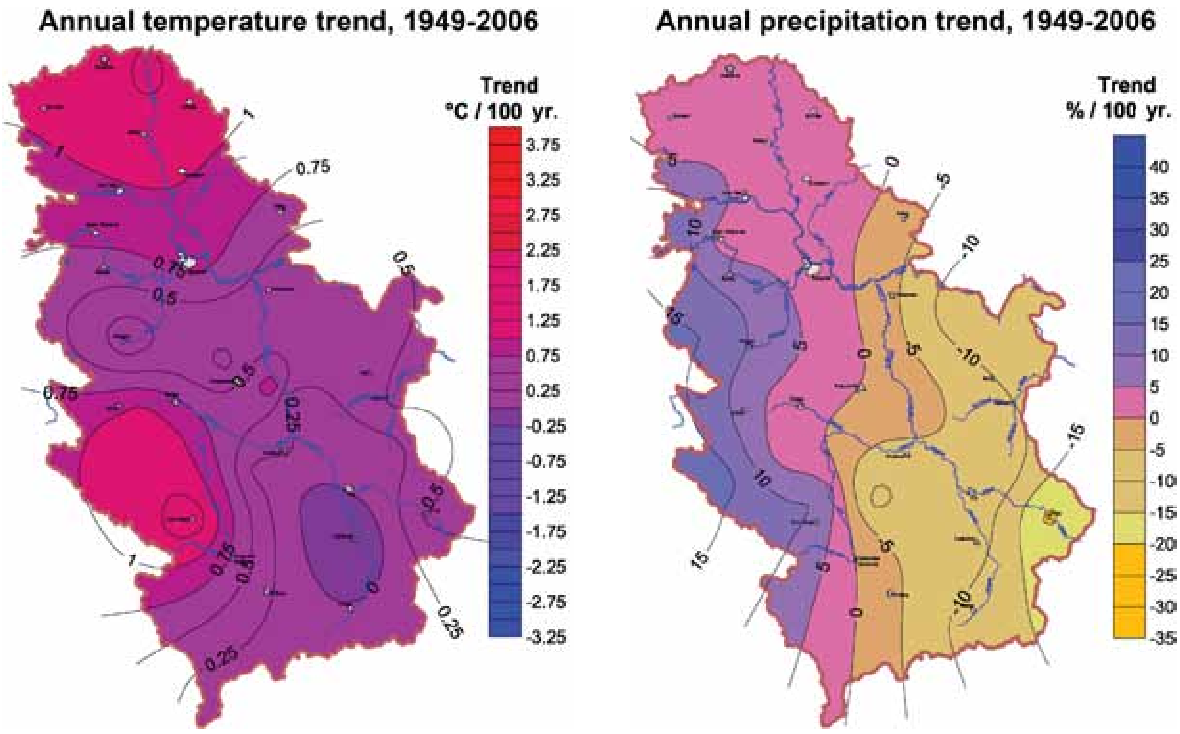

Fig. 7. Recorded annual temperature and precipitation trends in Serbia (1949-2006). (Sustainable and Adaptive Water Management: Case Study of Water Management in Serbia, M.Dimkić, M.Milovanović, D.Dimkić)

According to the investigations of the effects of the climate change, Serbia is experiencing a downward river discharge trend. To give precise answers to the questions that arise, current trends of the governing parameters need to be assessed, and then potential developments reviewed under three scenarios: optimistic, moderate and pessimistic (from a water resources availability perspective). Research generally shows the capacity trend of existing sources of drinking water supply, as well as the additional volumes of water and capital projects needed.

Although climate change needs to be seriously considered even in the near term, particularly in the central and eastern parts of Serbia, the main link of the sustainable and adaptive water resources development chain lies in the economic sphere.

State of the water sector in Southeast Europe: the Danube River Basin

There are a number of big and medium river basins in SEE Europe (Fig. 8). The largest among them is the Danube River Basin.

Regional cooperation in the Danube River Basin

Occupying more than 800,000 square kilometers or 10 percent of Continental Europe, the Danube River Basin extends into the territories of 19 countries. It is considered to be the “most international” river basin in the world. The 14 countries (8 EU and 6 non-EU at present) that share more than 2000 square kilometers of the basin each are, along with the European Union, the contracting parties of the ICPDR.

The ICPDR was created to implement the Danube River Protection Convention (DRPC). It is both a forum that allows its contracting parties to coordinate the implementation of the DRPC and a platform to review the progress made. The key objectives of the ICPDR include the following:

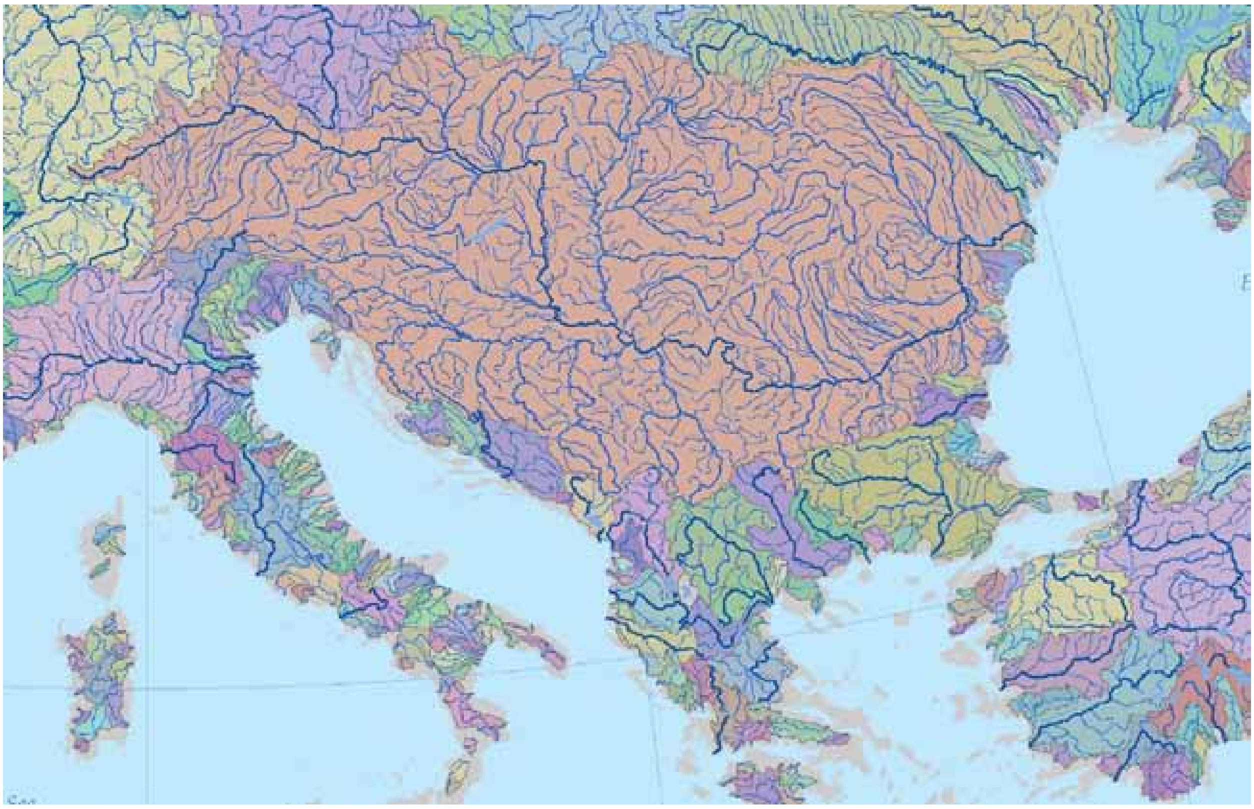

Fig. 8. River basins in SEE (JRC website)

- To ensure sustainable water management;
- To ensure the conservation, improvement and efficient use of surface water and groundwater;
- To control pollution and reduce inputs of nutrients and hazardous substances; and
- To control floods and ice hazards.

The ICPDR is an international organization composed of representatives from each contracting party. All key decisions are prepared by relevant expert groups and taken by the delegations of the contracting parties. The expert groups discuss issues related to their mandate, produce reports and make recommendations for coordinated action.

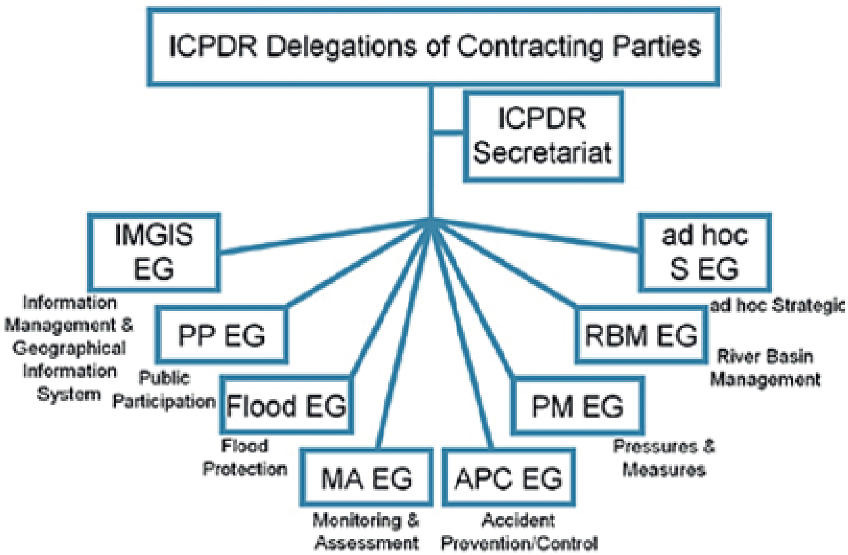

Fig. 9. Structure of the ICPDR. (ICPDR website)

The ICPDR has a Permanent Secretariat to support its work, supervised by the Executive Secretary. The Secretariat has its headquarters in Vienna, from where it administers, manages and supports the work of the ICPDR.

When the EU Water Framework Directive (WFD, formally Directive 2000/60/EC) was adopted in October 2000, all countries cooperating under the DRPC (which include, at present, 8 EU and 6 non-EU member states) agreed to make every effort to implement the WFD throughout the Danube River Basin. In this regard, the ICPDR has developed two key documents: the 2004 Danube River Basin Analysis and the 2009 River Basin Management Plan along with a Program of Measures.

Apart from regional coordination of the Danube River Basin within the ICPDR, relations between the Danube countries are governed by bilateral agreements implemented by various commissions, as well as supported by several regional organizations (such as the IAWD). Still, most of the water management effort is undertaken by the countries themselves.

Mis-alignment of socioeconomic drivers of water management in the Danube River Basins

There is a large disparity between the economic circumstances of the Danube countries; for example, Austria and Germany report a GDP in excess of 40K US$ per capita, while Moldova's GDP is less than 3K US$ per capita. Additionally, there are considerable differences between renewable water resources (in Germany an average of some 1500 m^3 and in Croatia as much as 10,000 m^3 per capita per year).

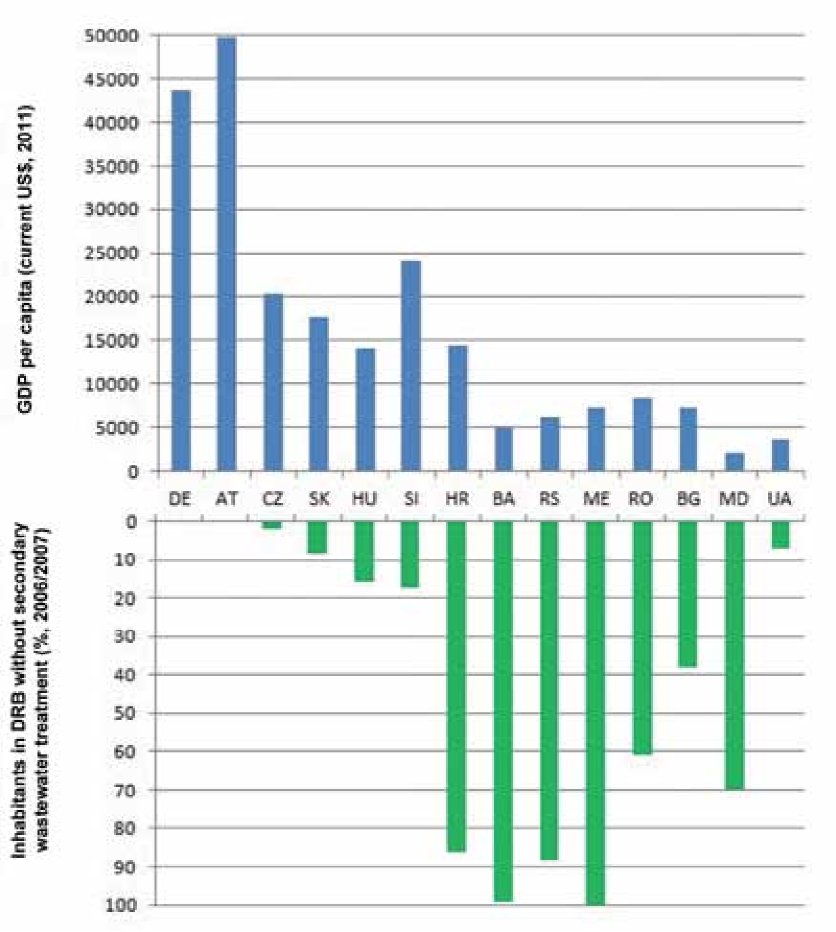

Fig. 10. Parallel representation of GDP and percentage of missing urban wastewater treatment plants.

Figure 10 shows that the most developed countries in the Danube River Basin have generally resolved the issue of urban wastewater treatment. However, the countries with a relatively modest GDP per capita are still faced with considerable spending on both wastewater treatment plants and other hydraulic infrastructures.

Of course, the differences in economic power result in disparities in the availability of hydraulic infrastructures and water management in general. Low-GDP countries need considerable time to build the required infrastructures, set up the necessary institutions, and improve the overall water sector. These enhancements need to be implemented with clearly identified priorities and sources of financing.

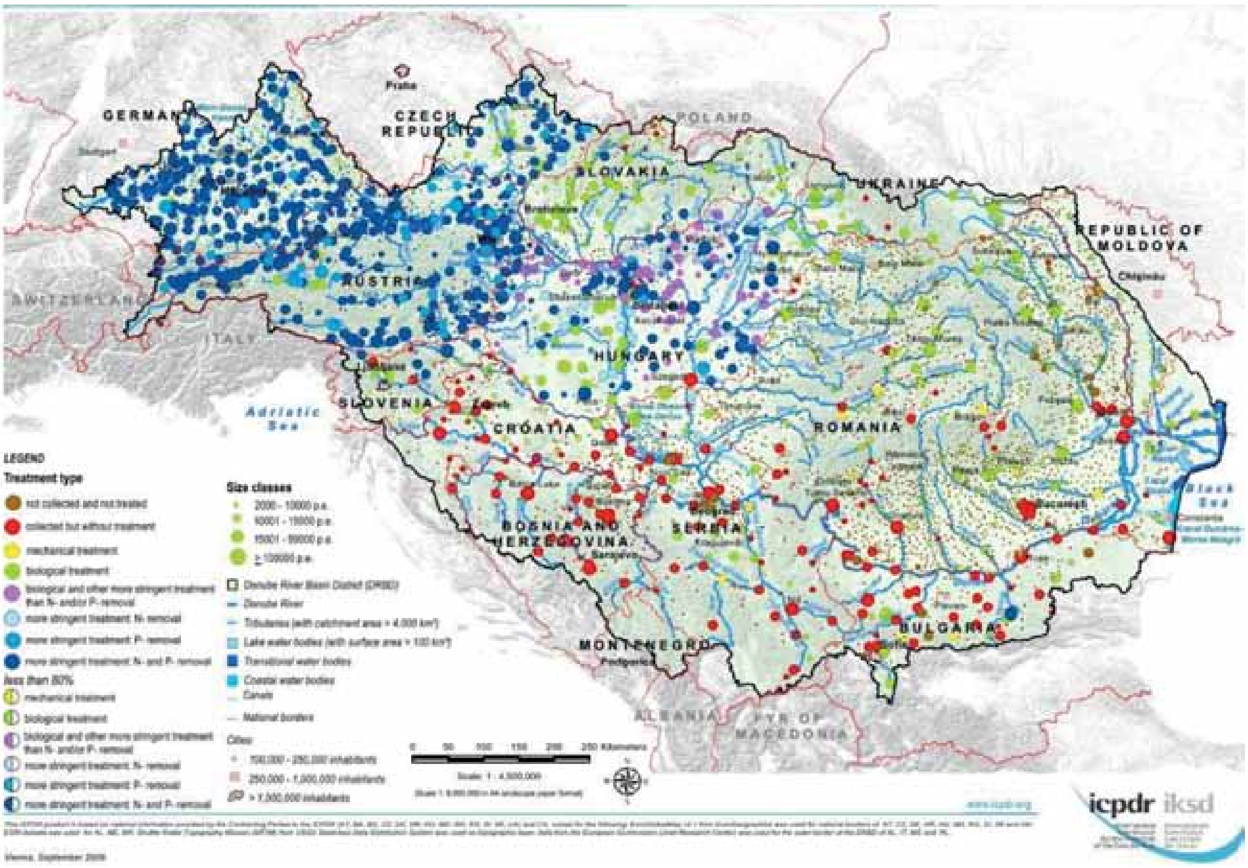

Fig. 11. Danube River Basin District – Urban Wastewater Discharges – Reference Situation.(Danube River Basin Management Plan, ICPDR)

Some Notes about Water Management in Serbia

Serbia is a country that possesses considerable water resources, most of which belong to international river basins. In Serbia, some 9M people live in an area of 88,361 km^2. About 92% of available water resources originate outside of Serbia – some 162.5 billion m^3 annually. Serbia's national water resources contribute approximately 16 billion m^3 annually (roughly 8% of the total). The country's largest rivers are international: the Danube, the Tisa, the Sava, and the Drina. The largest national river is the Velika Morava.

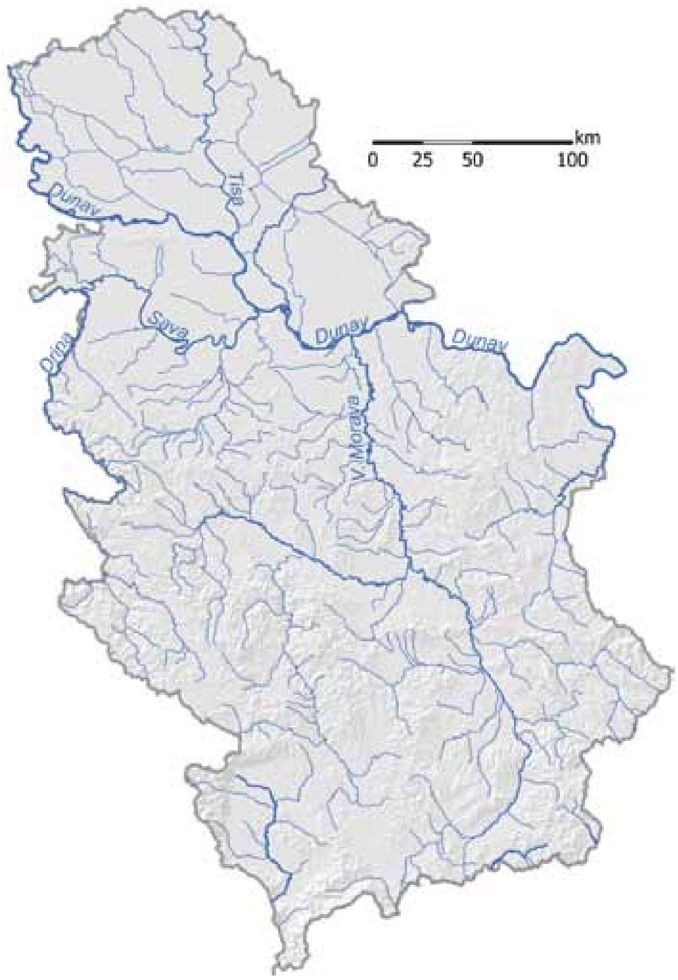

Fig. 12. Watercourses in Serbia

Annual precipitation in Serbia ranges from 550 to 650 mm in the plains, and from 800 to 1,200 mm in the mountainous regions, with an average of about 785 mm. Basic hydrological indicators of Serbia's largest rivers (from 1946 to 2006) are shown in Table 1.

Table 1: Basic hydrological indicators of Serbia's largest rivers (low, medium, and high flows)

River	Monitoring station	F (km²)	Discharge (m³/s)		
			Q_{av}	$Q_{min\ 95\%}$	$Q_{max\ 1\%}$
Danube	Bezdan	210,250	2,267	952	7,017
	Pančevo	525,009	5,264	1,976	15,311
Tisa	Senta	141,715	794	134	3,914
Sava	Sremska Mitrovica	87,996	1,535	272	6,379
Velika Morava	Ljubičevski Most	37,320	234	35	2,396
Drina	Radalj	17,490	362	69	4,940

All rivers belong to three sea basins: the Black Sea, the Adriatic Sea, and the Aegean Sea. Most of the waters flow toward the Black Sea, on average about 176 billion m^3/year, with about 2 billion m^3/year reaching the Adriatic Sea and the remaining 0.5 billion m^3/year the Aegean Sea.

More than 70% of Serbia's population and industry use groundwater for their water supply. According to the Water Master Plan of Serbia, the total yield of groundwater sources is roughly 23 m^3/s, but the total volume currently being extracted is slightly lower and amounts to some 19-20 million m^3/year. More than half of the abstracted water is groundwater from alluvial aquifers, 80-90% of which originates from infiltrated river water.

Legal and organizational aspects of water management in Serbia

Serbia has a long tradition of water management – in some parts of the country (the Province of Vojvodina) going back 250 years. Public water supply, however, traces back to the end of the 19th century, first in the capital Belgrade. Significant development was documented in the 1950's and 1960's, when many major towns began to acquire modern water supply systems.

The main piece of legislation which addresses water is the new Water Law, passed in May 2010. However, certain aspects of water management are also regulated by a set of environmental laws.

The focal water management institution in Serbia is the Ministry of Agriculture, Forestry and Water Management/Water Directorate. The main implementation bodies are the public water enterprises: "Serbia Waters" for the river basins south of the Sava/Danube, "Vojvodina Waters" for areas to the north, and "Belgrade Waters" for the territory of Belgrade. These enterprises are primarily responsible for flood protection, drainage, irrigation, and the like.

Certain aspects of water protection, as well as drinking water supply and sanitation services, are the responsibility of some other ministries.

Status of Serbia's water sector

The status of most of Serbia's water sector was generally deemed to be acceptable between the mid-1960's and mid-1980's. However, during the subsequent two decades (major socio-economic crisis, war in the region, economic sanctions), there was a marked drop in water sector spending, with respect to both maintenance of existing infrastructures and development of new infrastructures.

The 1991 Water Law called for water sector reform which was largely not implemented. Economic sanctions and the war in the region additionally aggravated the situation. A new Water Law was passed in 2010; however, this law can only be fully enforced after a large number of related bylaws have been enacted.

Current economic assessments of the water sector suggest that available funds are significantly lower than required. Water tariffs and water management charges have been extremely low.

The consequences of the funding shortfall are evident across all water management segments, and are quite serious in some cases:

- Although not everywhere complete, public water supply functions relatively well in a number of cities. Some 75% of the population has access to modern water supply systems. However, in some regions of Serbia the quality of the supplied water is not adequate. A number of Serbian cities experience water shortages during the summer months. A significant portion of the Province of Vojvodina is supplied by over-exploitation of groundwater from deep aquifers.
- Water protection leaves a lot to be desired. Wastewater evacuation coverage lags behind drinking water supply, such that only slightly more than 50% of the population has access to public sewers. Wastewater is generally discharged untreated into watercourses. Only a few percent of the pollution sources (less than 10%) are equipped

with functioning wastewater treatment facilities. However, a significant decline in industrial activity, resulting from the socioeconomic crisis and a transition process, allowed for the water quality of major rivers to be maintained at acceptable levels. For example, the water quality of the Danube River at its point of exit from Serbia is equal to or better than that at the point of entry. Nevertheless, economic revival and growth will necessitate considerable water protection improvements. This segment will, therefore, require the greatest attention and the highest level of spending.

- The condition of flood control systems is fair but maintenance has been lackluster for many years and these systems require additional funding.
- Drainage is rather well developed and encompasses some 2 million hectares. However, these systems have not been seamlessly maintained and are in need of rehabilitation.
- Irrigation coverage is low (about 30,000 ha). However, this is more of an agricultural than a water management issue, and should primarily be addressed within the scope of the national agricultural policy.

The water quality of the Danube and its three major tributaries (the Sava, the Tisa, and the Velika Morava) is graphically represented via the typical parameter (BOD_5), which best reflects current water quality trends.

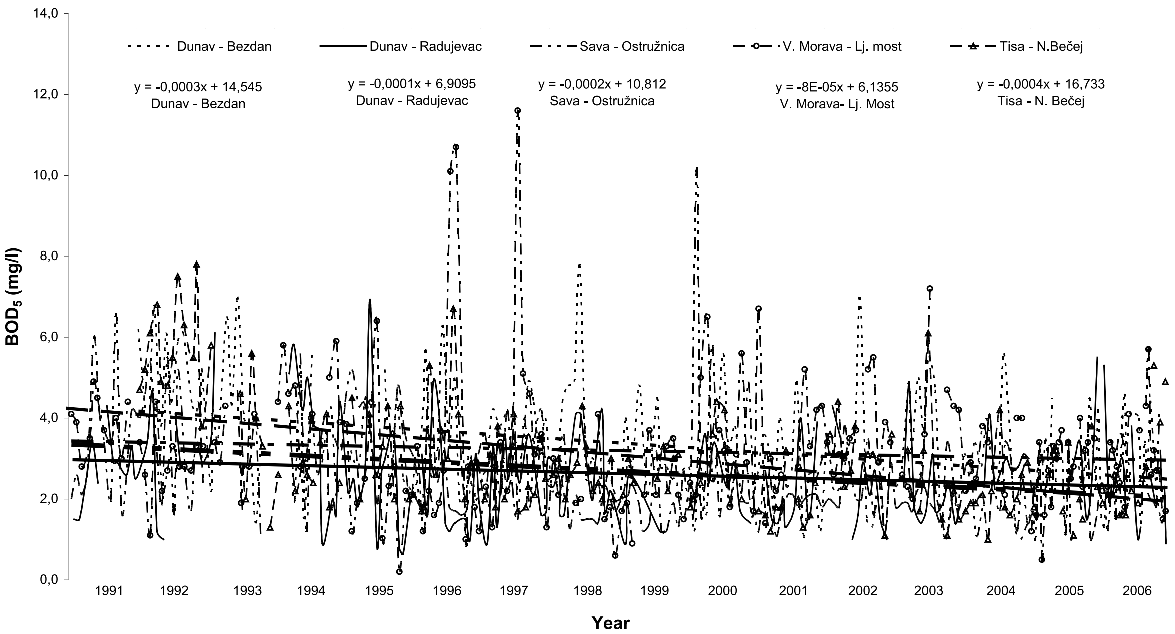

Figure 13: BOD_5 of large rivers in Serbia (1991-2006). (Sustainable and Adaptive Water Management: Case Study of Water Management in Serbia, M.Dimkić, M.Milovanović, D.Dimkić)

In general, all large rivers exhibit a downward trend of organic matter content. This trend is especially apparent in the Danube's entry profile at Bezdan, as a result of protection measures implemented in upstream EU countries (mostly construction of wastewater treatment plants). The average level for the period from 1991 to 2006 was about 3.2 mg/l. During the same time, downstream monitoring stations also reported a decline in organic matter content (BOD5); the average level recorded at Zemun (near Belgrade, upstream of the mouth of the Sava River) was 2.7 mg/l.

At the time of writing, some 50% of human settlements in Serbia have access to public wastewater collection systems, meaning that a large number of communities (more than 100 with a population of more than 2000 PE) do not have access to such systems. Additionally, of the communities that have access to public wastewater collection only some 12% have wastewater treatment plants in place.

Spending needed in the water sector

Studies prepared to date suggest that Serbia needs to spend 8-10 billion € on basic water sector infrastructures to support sustainable water management consistent with the standards required by relevant European Union directives. The country will not be able to allocate such a large sum over a period of a few years and, as a result, it will need 20-30 years to achieve the required standards. On average, Serbia will have to spend 400-500 million € each year. The current drinking water tariff is low (about 0.5 € per cubic meter for households). Estimates indicate that the economic price of water should be 1.1-1.5 € per cubic meter (drinking water + evacuation and treatment of wastewater).

When this tariff is translated into what an average Serbian family of four would need to pay on a monthly basis for their water service, the cost is some 20 €. This is about 3% of the current income of an average Serbian family. Consequently, water tariffs will have to be increased to cost-recovery levels gradually (over several years). Additionally, some consumers will need to be sheltered (subsidized). By necessity, investments in capital projects must be gradual and prioritized.

Because it has fallen behind to some extent with respect to drinking water supply, Serbia's first priority now needs to be to ensure access to healthy drinking water for its population. To accomplish this, Serbia needs to build a number of new local water supply systems, reconstruct and upgrade various water treatment plants, and build new regional water supply systems.

Water protection is Serbia's next important goal, including the construction of wastewater treatment plants. Settlements in sensitive and protected areas, and large communities along low-discharge streams, should be given top priority. This segment requires the largest amount of investments, or 3-4 billion €, depending on the necessary level of treatment.

The water sector needs to implement capital projects in other segments as well, primarily irrigation systems (as part of overall agricultural development) and the upgrading of flood defenses and erosion and flash-flood control works.

Educational and professional resources

Prior to the crisis in the former Yugoslavia (before 1990), the water sector boasted a number of strong water sector institutions and companies. Following the break-up of the country, the resources of some of these organizations shrank. However, there are still highly regarded technical, scientific and educational capacities comparable to those of countries more economically powerful than Serbia at this time. Additionally, Serbia still has a considerable number of highly-experienced professional human resources.

Universities

Today, formal water-related education is offered by the following institutions:

- University of Belgrade, Faculty of Civil Engineering, Institute of Hydraulic and Environmental Engineering;
- University of Novi Sad, Department of Environmental Protection;
- University of Belgrade, Faculty of Forestry, Department of Torrential Streams and Erosion/ courses in environmental engineering and protection of soil and water resources;
- University of Novi Sad, Faculty of Civil Engineering (based in Subotica), Department of Hydraulic and Environmental Engineering;

- University of Nis, Faculty of Civil Engineering and Architecture, Department of Hydraulic Engineering;
- University of Novi Sad, Faculty of Science and Mathematics, Department of Chemistry and Department of Biology and Ecology;
- University of Belgrade, Faculty of Mechanical Engineering, Department of Hydropower and Department of Process Technologies;
- University of Belgrade, Faculty of Mining and Geology, Department of Hydrogeology;
- University of Novi Sad, Faculty of Agriculture, Department of Water Resources Development;
- University of Belgrade, Faculty of Agriculture;
- University of Belgrade, Faculty of Technology;
- University of Novi Sad, Faculty of Technology, Department of Environmental Protection;
- University of Belgrade, Faculty of Electrical Engineering;
- University of Kragujevac, Faculty of Mechanical Engineering;
- University of Belgrade, Faculty of Biology; and
- University of Belgrade, Faculty of Chemistry.

Institutes

- Jaroslav Černi Institute for the Development of Water Resources, Belgrade;
- Siniša Stanković Institute of Biology, Department of Hydroecology and Water Protection, Belgrade;
- Institute of Biology and Ecology, Water Laboratory, Kragujevac;
- Serbian Institute of Geology, Belgrade;
- Soil Institute, Belgrade, etc.

Demand for professional human resources

The figure 14 shows the distribution of hydraulic engineers/members of the Serbian Chamber of Engineers by municipality.

It is apparent that the distribution shown above is quite uneven and that there are many municipalities with no hydraulic engineers/members of the Serbian Chamber of Engineers.

Given that spending in the water sector is expected to increase considerably and that there is an evident shortage of engineers in certain parts of Serbia, it is necessary to intensify the production of experts needed by the water sector. Additionally, in view of the nature of the transition changes in Southeast Europe, coordination and an exchange of experiences are needed between communities in similar transition circumstances (in technical and economic terms), as well as those that have made greater strides towards economic prosperity and sustainable water sector management.

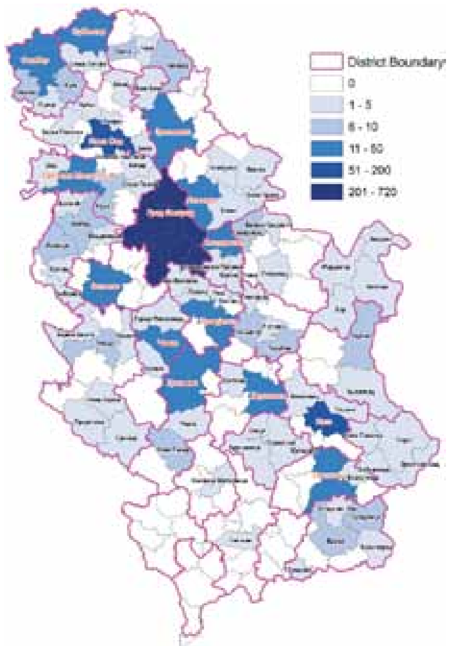

Figure 14. Distribution of hydraulic engineers/members of the Serbian Chamber of Engineers. (Role of Science and Education in Water Management in Republic of Serbia, M.Dimkić, N.Dragović, M.Milovanović)

There are considerable opportunities for intensifying the participation of existing educational, scientific and professional capacities from Serbia and several other SEE countries in North-South capacity building.

Jaroslav Černi Institute for the Development of Water Resources and its support to the UNESCO Regional Category II Center for Sustainable Development and Adaptation to Climate Change

Jaroslav Černi Institute for the Development of Water Resources (JCI) was founded more than sixty years ago. Its successful engagement in numerous projects and activities related to water use, water protection and protection from the adverse effects of water in Serbia, the former Yugoslavia and more than 20 countries worldwide attests to the importance of JCI not only locally, but on a much wider scale as well.

JCI's professional human resources generally hold degrees in: civil engineering (hydraulic and structural), hydrogeology, technology, mechanical engineering, biology, chemistry, geotechnical engineering, geophysics, geomechanical engineering, geodesy, architecture, electrical engineering, economics, and law. JCI currently employs about 20 doctors of science, about 10 masters of science, and more than 140 university graduates. It is especially noteworthy that JCI hired about 100 young engineers over the past decade and is currently supporting master's and doctoral studies of about 20 employees.

JCI devotes considerable attention to the development of instrumentation and laboratory equipment, allowing for both efficiency and independence in performing a large number of functions, while keeping in step with state-of-the art achievements in analytical methods, techniques and the like.

JCI has four laboratories for hydraulic, soil science, water, geotechnical, and geophysical testing.

The Water Testing Laboratory continually strives to procure and maintain cutting-edge analytical equipment (carbon (TOC) analyzer, nitrogen (TN) analyzer, gas chromatography-mass spectrometry (GCMS) analyzer, oxygen and nitrogen isotope analyzer, atomic absorption analyzer, BART tests, high-performance microscopes, and the like).

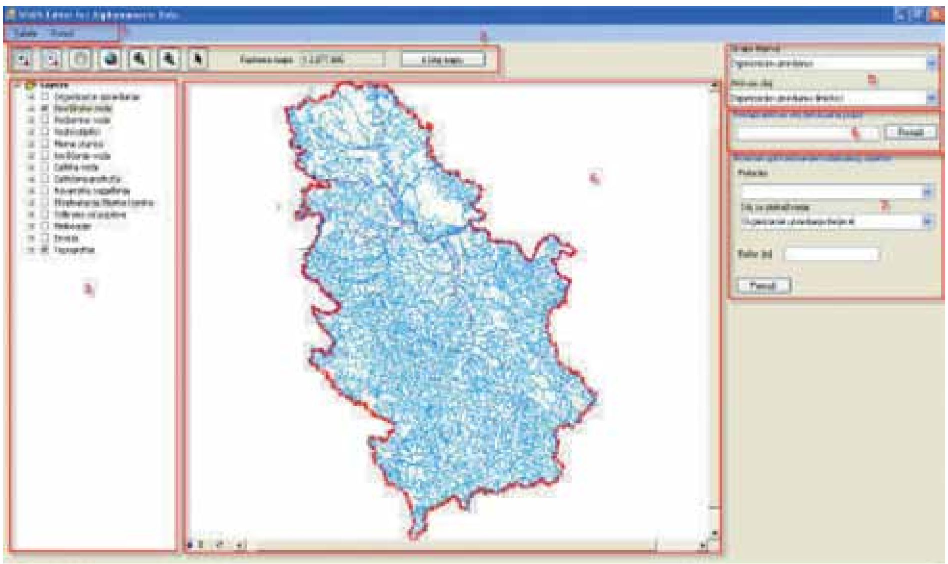

Fig 15. Water Information System of Serbia

JCI's Hydraulics Laboratory, the largest of its kind in the region, is fully equipped to perform cutting-edge tests and measure pressures and discharge; it features an open-channel flow measuring weir, a sensor probe for depths in excess of 1000 meters, a current-meter calibration channel, and similar equipment

JCI also keeps abreast of the latest advances in software technologies. It operates an information system that allows it to network with all researchers and link-up with external systems such as the Water Information System of Serbia (currently at an experimental stage), the DANUBIS (ICPDR), and similar facilities.

In its day-to-day activities, JCI relies heavily on cutting-edge software (primarily water-related but also in the areas of construction, geotechnical engineering, and the like):

- River hydraulics (MIKE 11, HEC RAS…)
- Groundwater (FEFLOW; MODFLOW...)
- Structural (TOWER, ROCKSCIENCE applications...)
- Sewage (MOUSE, MIKE URBAN, CANALIS)
- Wastewater treatment plants (AQUA DESIGNER)
- Water supply systems (VESNET, EPANET)
- GIS technologies (ESRI ArcGIS, HEC GeoRAS)
- Other (AutoCad, Civil 3D...)

Given that JCI provides considerable water management support to government bodies, special consideration is given to the implementation of the leading principles of water management:

- EU water directives,
- Water management programs,
- Implementation of water management plans, both nationwide and at a large system scale,
- Planning and other documents of the Republic of Serbia.

Another important JCI activity is the transfer (and implementation) of imported technologies, either independently or in collaboration with other Serbian institutions:

- Analytical technologies (e.g. micropollutants – TZW (Karlsruhe, Germany), University of Belgrade/Faculty of Technology, University of Novi Sad/Faculty of Engineering, etc.);
- Water treatment technologies (e.g. membrane technology applied in the City of Donji Milanovac);
- Software technologies;
- Measurement technologies (structural displacement, surveys at great depths, measurements of sudden water pressure changes, etc.)

In addition to the transfer and implementation of imported software, JCI actively develops its own applications (such as the LIZZA 3D groundwater model).

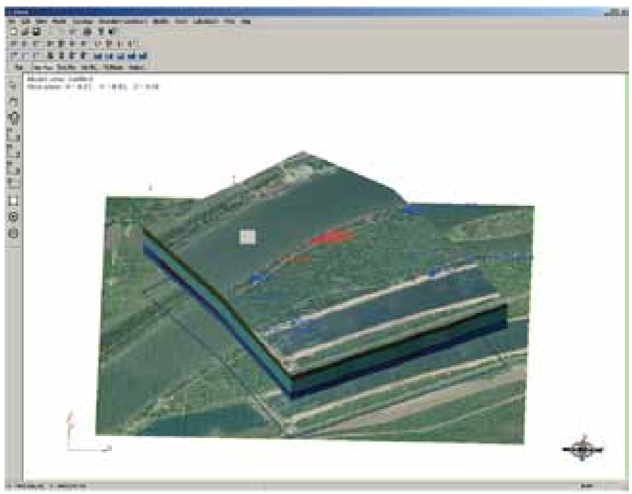

Fig. 16. LIZZA software for groundwater flow calculations.

JCI actively monitors the developments in the international arena and has established close ties with a number of international institutions. Special emphasis is placed on the following activities:

- Collaboration with international associations (e.g. IWA, IAWD);
- Cooperation with international commissions (e.g. ICPDR, the Sava Commission);
- Participation in international projects (FP, SEE, etc.)
- Organization and hosting of international conferences:
  - Groundwater Management in Large River Basins (2007)
  - Planning and Management of Water Resources Systems (2008)
  - Balkans Regional Young Water Professionals Conference (2010)
  - IWA Specialist Groundwater Conference (2011)
- Participation in national and international professional gatherings;
- Work abroad.

JCI has made and continues to make significant scientific contributions. For example, it is actively involved in long-term research of the ageing of wells and other groundwater abstraction facilities, in relation to the aerobic state of the aquifer.

Fig. 17. Belgrade IWA Specialist Groundwater Conference 2011

Some of the capabilities and underlying assumptions of the Center

Activities

- Networking in water management knowledge dissemination, capacity building and problem solving in economic transition countries, taking into account climate change and socioeconomic transformation;
- Highly-specialized human resources capacity building;

- Management capacity building;
- Assistance in the development of baseline studies and water management plans.

Who is expected to benefit from the outcomes of the Center's activities?

Serbia

- Management capacity building at institutions in charge of water management (both centralized and municipal);
- Establishment of closer ties with scientific and professional organizations from countries in the region and beyond;
- Integration and enhancement of water management capacities and knowledge;
- Assistance in the development of studies and master plans.

The region

- Networking of institutions and all resources involved in water management development and climate change programs;
- Study and awareness raising of the impact of economic transition and climate change on water management;
- Capacity building.

UNESCO IHP

- Capacity building and networking advances;
- Activities aimed at identifying the impact of climate change on water resources;
- Raising awareness of the issues of transition countries and the impact of such issues on water management;
- Activities aimed at improving North-South water management cooperation in circumstances involving socioeconomic and climate changes.

North-South cooperation

- Capacity building through joint efforts;
- Benefiting from economic transition experiences gained by Group 2 countries in countries belonging to Groups III, V and VI;
- Use of the Center's capacities to develop water management in countries belonging to Groups II, III, V and VI.

Networking of the Center to date

The organizations that have supported the establishment of the Center include:

- the International Commission for the Protection of the Danube River (ICPDR)
- the International Association of Water Supply Companies in the Danube Catchment Area (IAWD)
- the International Sava River Basin Commission (the Sava Commission)

- the Serbian Water Directorate within the Ministry of Agriculture, Forestry and Water Management
- the Slovak National Committee for the UNESCO International Hydrological Program
- the Bulgarian National Committee for the UNESCO International Hydrological Program
- the Water Institute of the Republic of Slovenia
- the University of Banjaluka/Faculty of Architecture and Civil Engineering, Bosnia and Herzegovina
- the Hydrometeorological Institute of Montenegro
- the University of Skopje/Faculty of Civil Engineering, Macedonia
- the University of Skopje/Faculty of Forestry, Macedonia
- the University of Skopje/Faculty of Natural Sciences and Mathematics, Institute of Biology, Macedonia
- the University of Skopje/Faculty of Agricultural Sciences and Food, Macedonia
- the University of Belgrade/Faculty of Mining and Geology, Serbia
- the University of Belgrade/Faculty of Civil Engineering, Serbia
- the University of Belgrade/Sinisa Stankovic Institute of Biological Research, Serbia
- the University of Novi Sad/Faculty of Technical Sciences, Serbia
- the University of Nis/Faculty of Civil Engineering and Architecture, Serbia

UNESCO centers with whom a working relationship has been established to date include:

- the Regional Centre on Integrated River Basin Management (RC-IRBM), Kaduna, Nigeria
- the UNESCO Chair in Hydroinformatics, Capital Normal University, Beijing, China

Climate Change and Mediterranean Water Resources: What do we Know at Present?

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Humankind is well aware, since quite some time ago, that the Earth has experienced very large climate changes during its history. But arriving at the present knowledge of the chronology of these changes, and even more to the most likely reasons for these changes, was a slow process with many surprises along the way. It is an area of keen interest today, because of the expectation that the ongoing increase of the carbon dioxide (CO_2) content of the atmosphere could eventually lead to dramatic changes of the conditions on our planet as we know it.

It is now a little more than 150 years since John Tyndall published a paper on his measurements of the absorption efficiency of gases in the infrared region finding, to his surprise, that water vapor and carbon dioxide have absorption efficiency in the infrared very much higher than in the visible region. He immediately understood that this property might be related to the past climate changes geologists of the time talked about. The idea has been further advanced by Svante Arrhenius, and then by Guy Callendar. Measurements by Charles Keeling, and the end of the fifties, in the Antarctic and on the volcanic mountain Mauna Loa of Hawaii, showed that even in the short time span od two years considerable increase in the atmospheric content of CO_2 took place.

Keeling measurements on Mauna Loa have continued and today the “Keeling curve” is carefully watched. The atmospheric content of CO_2 that in the preindustrial time was about 270 ppm (parts per million, by volume) today is more than 390 ppm, and is regularly increasing by about 2 ppm per year. There is little room for doubt that the human activities, primarily burning of fossil fuels, is the main driver of this increase. At the same time, since the seventies, the average global near-surface temperature while oscillating considerably year to year is rather systematically increasing, so that today it is about 0.8°C greater than its average of the 30 year period 1951-1980. It is well understood that the CO_2 because of its “greenhouse gas” properties of being transparent in the visible domain but an efficient absorber in the infrared should tend to increase the near-surface temperature. But there are many other factors that affect the Earth's near-surface temperature; thus, is the increased content of CO_2 the primary cause of the observed global warming?

In spite of the very assertive affirmative answer by the latest report of the International Panel on Climate Change (IPCC), arguments challenging this explanation abound. Maybe the most convincing argument in favor of the CO_2 being the primary driver of the fast temperature increase in progress is that of Hansen and Sato (2012). They start with the summary of the estimated deep ocean temperature record of the Cenozoic Era, comprising the last 65.5 million years. During the first 20 or so million of years of this period the Earth was very warm compared to present. Temperature was generally rising until about 50 or so million year ago (Mya), with a maximum during the so-called Paleocene-Eocene Thermal Maximum (PETM), at about 55 Mya, about 11°C higher than today. The Earth at about 50 Mya entered a general cooling trend, with permanent ice sheets forming in Antarctic 35-40 Mya, and eventually also in the Northern Hemisphere, about 5 Mya. During the sequence of ice ages of the most recent half Mya at several times deep ocean temperatures were attained of about 3°C less than today, the last time during the Last Glacial Maximum (LGM) at about 20,000 years ago.

There are no even nearly credible candidates other than CO_2 that could explain most of the general cooling of the Earth's deep ocean temperature by an amount as large as about 14°C. There exists fairly reliable paleoclimate information on the content of CO_2 of the atmosphere, as well as the knowledge on how much warming one could expect for doubled CO_2, showing that changes of this magnitude are possible. One should underscore that these changes are not just due to the radiative effects; equilibrium response to doubling of CO_2 compared to preindustrial values is only about 1.2°C. Various feedbacks increase this response to 5-6°C. They include increased amount of atmospheric water vapor, changes in the ice coverage, clouds, etc. etc. As an example, it suffices to recall the recent minimum ice coverage of the Arctic, September 16 of this year, at almost only a half of what is the median value for the last two decades of the previous century.

There is little hope that the production of CO_2 is going to be significantly reduced during the next decade or two. Namely, except nuclear power plants that many countries today consider most unwelcome, no energy source is available that in the foreseeable future can generate the amounts of energy that can match the amounts generated by coal power plants. Thus, if the amount of CO_2 continues to increase at the present pace for some decades, what is in store for the Earth, for the Mediterranean region, and specifically, Serbia? Water resources clearly are a crucial component of the changes to be expected, and our main objective here.

Integration of coupled atmosphere-ocean-ice-vegetation climate models is the only way we have to deduce some answers valid for decades into the future, and the rest of the century. These are reported upon in IPCC reports, with the last one published in 2007, and the next one expected in 2013; and in various papers regularly appearing in scientific literature and reports on projects completed. In my presentation I will summarize the results of a four-year multinational E6 project “Regional Assessment of Climate Change in the Mediterranean” (Navarra and Tubiana 2013) where an ensemble of models has been used; and will supplement this by results of a single model to a nonnegligible degree developed in Serbia (Ђурђевић and Рајковић 2009; Djurdjevic and Rajkovic 2010). For a single number information here, let me add that that the former of these, Navarra and Tubiana (2013), as precipitation trends over Serbia for the first half of this century, foresee a reduction for summer months of about 1.5 (mm/month)/decade; and some reduction, albeit less so, in winter months as well.

References

Ђурђевић, В., and Б. Рајковић, 2009: Неки резултати из SINTA пројекта: Промене климе према IPCC сценарију A1B и њихово динамичко скалирање за медитерански регион. In: Стваралаштво Милутина Миланковића, Српска академија наука и уметности, Београд, (Serbian Academy of Sciences and Arts, Belgrade), 99–106.

Djurdjevic, V., and B. Rajkovic, 2010: Development of the EBU-POM coupled regional climate model and results from climate change experiments. Advances in Environmental Modeling and Measurements, D.T. Mihailović and B. Lalić, Eds., Nova Science Publishers Inc, 23-32.

Hansen, J. E., and M. Sato, 2012: Paleoclimate implications for human-made climate change. In: Climate Change: Inferences from Paleoclimate and Regional Aspects, Eds. A. Berger, F. Mesinger, and Dj. Šijački, Springer, 21-47 (doi:10.1007/978-3-7091-0973-1_2).

Navarra, A., and Tubiana, L. (Eds), 2013: Regional Assessment of Climate Change in the Mediterranean. Vol. 1: Air, Sea and Precipitation and Water. Springer, x+310 pp., in press.

Global Water Challenge in UNESCO IHP Intergovernmental Council and 7th World Water Forum Preparation Processes

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President, International Hydrologic Environmental Society (IHES)
Vice President, UNESCO IHP Intergovernmental Council

Abstract

Life on this planet has evolved around the availability, movement, and quality of water. Like every other living being on this planet, water is essential for human survval. However, this fatal element has now been challenged and found to be untenable. In recent years the availability of and access to freshwater have been highlighted as the most critical natural resource issues facing the world. It is generally believed that global water shortage represent a full-scale emergency, where the global water cycle seems unlikely to be able to adapt to the demands that will be made of it in the coming decades. Therefore, over the next 25 years, one-third of the worlds population will experience sevee water scarcity as well as water-related disasters by extreme hydrologic events, and then water resources become a limiting factor and its management increasingly complex task.

To cope with these global water challenges, the International Hydrological Programme(IHP) was established in 1975 as the UNESCO intergovernmental programme of the UN system devoted to scientific study of the hydrological cycle and to formulating strategies and policy for the sustainable management of water resources. The programme is implemented in phases of six years, in order to remain prompt in identifying new, emerging problems, alerting decision makers, raising public awareness and providing the necessary resources to respond with action. This IHP is a multidisciplinary programme at the forefront of a assuming all global water challenges and governed by its Intergovernmental Council with strong support and participation of IHP National Committees, UNESCO water-related centres and chairs.

Another multi-stakeholder platform to discuss important global water issues is the World Water Forum which was initiated and organized by the World Water Council (WWC) and became the world's largest water-related event holding every three years as a joint venture between the WWC and the government of the host country. Following the previous six Fora, Daegu Gyeongbuk of the Republic of Korea was selected as th venue of the 7th World Water Forum (7th WWF) in 2015 and all global water challenge issues will be brought and discussed to find the ways of implementation under the main theme of "For Future Water Together" by vrture of solutions for water suggested in the 6th WW in 2012 in Marseille, France.

Importance of the Aerobic State of Alluvial Aquifers for Groundwater Use

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Abstract

Introduction

Groundwater represents the largest accumulation of fresh water on the planet Earth and accounts for more than 97% of all fresh water. Groundwater recharges rivers during periods of low surface water flow and feeds springs, oases and wetlands.

Groundwater is a traditional and favored drinking water supply resource. This resource is used because of both its proximity to the point of consumption and the self-purification processes that strive to reach the baseline quality of aquifer water. In addition to drinking water supply, groundwater is used extensively for irrigation.

Alluvial aquifers are the most frequently used sources of groundwater. Most of the abstracted groundwater traces to alluvial aquifers. This presentation highlights the importance of the oxic state of the alluvium and its effect on the self-purification processes of groundwater and well screen clogging with trivalent iron. The presentation is an overview of the subject-matter addressed, including some interesting results of research conducted over the past several years by the Jaroslav Černi Institute for the Development of Water Resources. The research correlates the increase in local hydraulic losses at the well screen with the oxic state and iron concentrations of groundwater.

Figure 1 is a typical section of an alluvial aquifer along a river course. Coarse material is generally deposited along the upper course of the river, such that the degree of oxicity of such aquifers is high. As a rule, fine material, often consisting of clay and silt, is deposited along the lower course, consistent with the lower flow velocity.

Such material often carries minerals containing low-valence (2+) iron and manganese metals. The oxygen dissolved in the river water is primarily used for the oxidation of organic substances and low-valence iron compounds. High aerobic conditions allow for a greater effectiveness of purification during bank filtration. Also, as a rule, aerobic conditions contribute to well longevity. If the conditions of an alluvial aquifer are anaerobic, the presence of iron in the water often leads to biochemical clogging of the well with iron.

Baseline quality of groundwater

One of the significant benefits of bank filtration is the improvement of the initial quality of water loaded with man-made products. This change in water quality (for example on the way from the river to a riverside well) always tends to achieve the baseline quality of groundwater. The baseline quality is natural groundwater quality (free from artificial substances). It depends on the mineral composition, hydrology, oxic state, etc. The baseline quality may vary considerably between aquifers, as it depends to a considerable extent on the oxic state and the mineral composition of the aquifer matrix. The baseline quality of river water is much more uniform (between different rivers) and, as a rule, quite different from the baseline quality of groundwater.

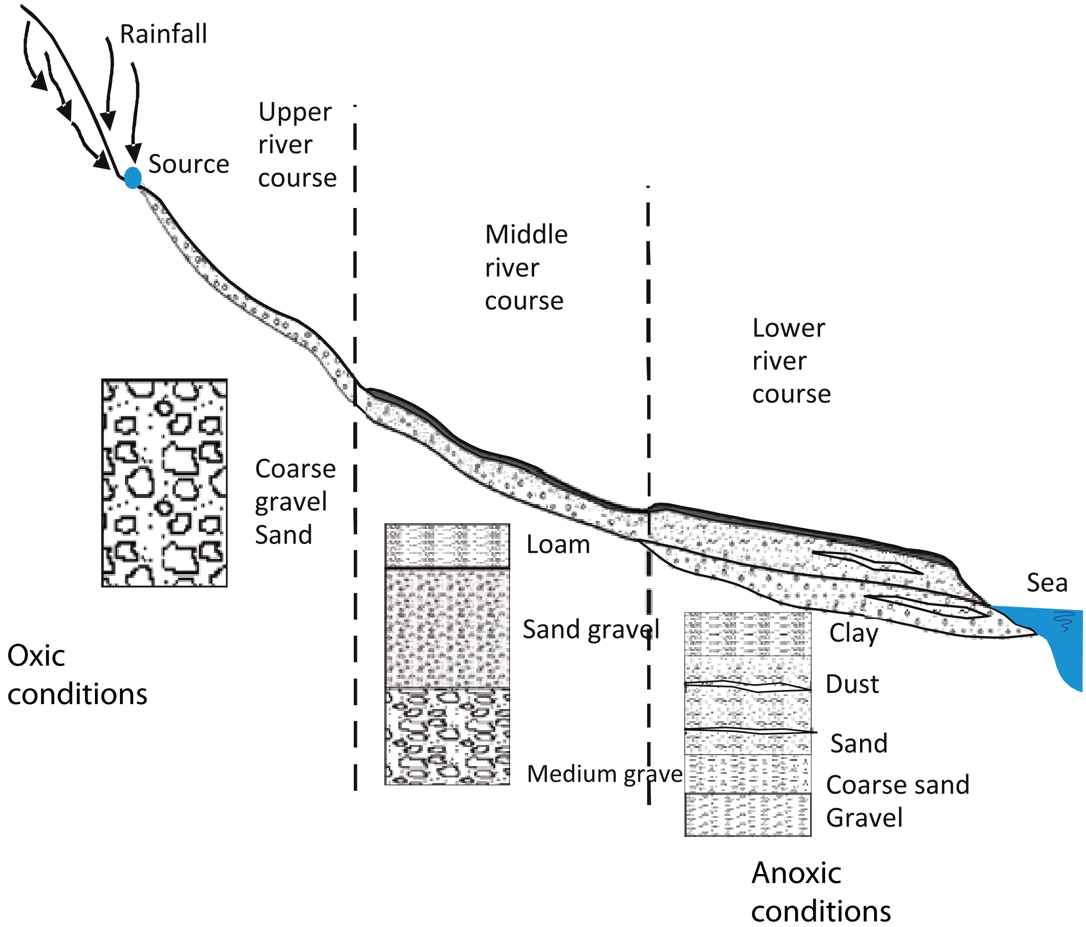


Figure 1. Variation in grain size distribution of an alluvial aquifer along a river course. (Dimkić et al., 2011c)

Table 1. Baseline quality: characteristic substances in surface water and oxic/anoxic groundwater.

Parameter	**Surface water**	**Groundwater**	
		Oxic groundwater	**Anoxic groundwater**
Total organic substances (COD, TOC, BOD and $KMnO_4$ demand)	Occurrence frequently due to anthropogenic contribution	Usually lower concentrations that in surface water; occur in natural, baseline concentrations; if increased by human activity, self-purification mechanisms strive to achieve baseline concentrations. Degradation of organic pollutants generally better in aerobic than in anaerobic conditions.	
Iron and manganese	Generally very low concentrations, except in eutrophic waters	Low concentrations possible, usually of dissolved Fe^{3+}	Frequent occurrence in concentrations higher than in surface water or aerobic groundwater. Iron occurs as insoluble Fe^{2+}
Dissolved oxygen	Frequently close to saturation (8-9 mg/l)	Present in concentrations lower than the concentration of saturation	Virtually absent O_2< 0.2-0.5 mg/l
Nitrates	Generally low concentrations (5-10 mg/l), except in polluted waters	Generally low concentrations; elevated concentrations are caused by anthropogenic impact	Generally absent
H_2S	Generally absent	Generally absent	Temporary present

Self-purification processes

There are numerous natural self-purification processes that lead to the baseline quality of groundwater. They can be classified into three main groups: processes associated with transport in the liquid phase, exchange of substance between the liquid phase and the solid phase, and loss of certain substances from the system due to various processes (Table 2).

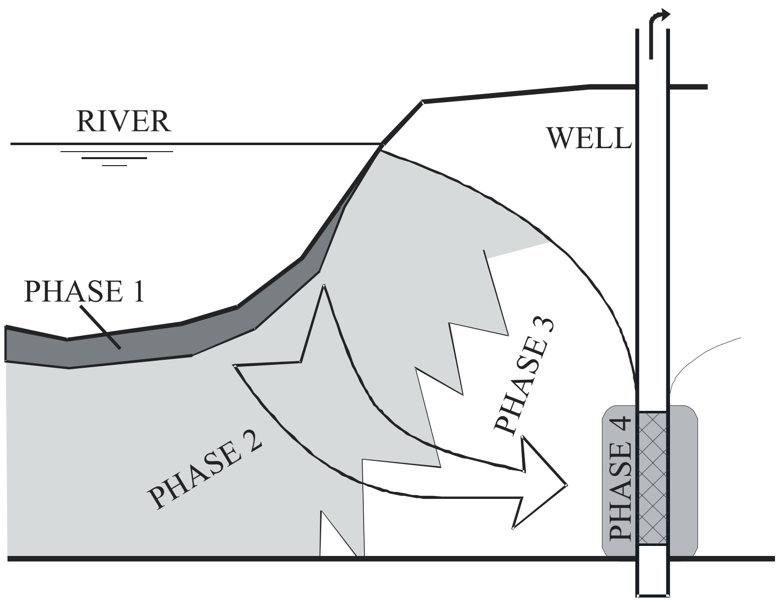
Table 2. Natural processes that lead to the baseline quality of groundwater

1. Transport via liquid phase	1.a Convective transport of solute	1.1 Convection
	1.b Dispersion/diffusion of solute	1.2 Diffusion
		1.3 Dispersion
2. Transfer from liquid to solid phase	2.a Transfer of solute from solid phase into solution	2.1 Desorption
		2.2 Rock dissolution
		2.3 Transfer of solid into solution
	2.b Transfer of substance from solution to solid phase	2.4 Physical sorption
		2.5 Chemical sorption
		2.6 Sedimentation
3. Loss of substance from the aquifer	3.a Degradation processes	3.1 Biodegradation
		3.2 Chemical oxidation-reduction processes
	3.b Other processes	3.3 Radioactive decay
		3.4 Evaporation

Effects of bank filtration

Drinking water sources that rely on alluvial aquifers may generally be divided into three types: bank filtration sources, artificial groundwater sources, and alluvial sources beyond river influence. For each of these types, it is of vital importance for both the development of a water supply source and the establishment of its safeguard zones, to properly determine the role of the self-purification potential and the baseline quality of the groundwater within the aquifer.

Figure 2 is a schematic representation of bank filtration. Depending on the oxic state and the nature of the processes involved, bank filtration can be divided into four phases:



Phase 1: Intensive sorption and high biochemical activity during filtration through riverbed sediments

Phase 2: Filtration occurring in predominantly oxic conditions and related physico-chemical and biochemical processes

Phase 3: Filtration occurring under diminishing oxygen concentrations, or under anoxic conditions

Phase 4: Filtration within the zone of influence of and to the well screen. Well screen clogging processes.

Figure 2. Phases of bank filtration. (Dimkić et al., 2011c)

Examples of self-purification during bank filtration are shown in Figure 3 (groundwater source of the City of Belgrade, Serbia) and Figure 4 (application of this method in the alluvium of the Rhine River, Germany).

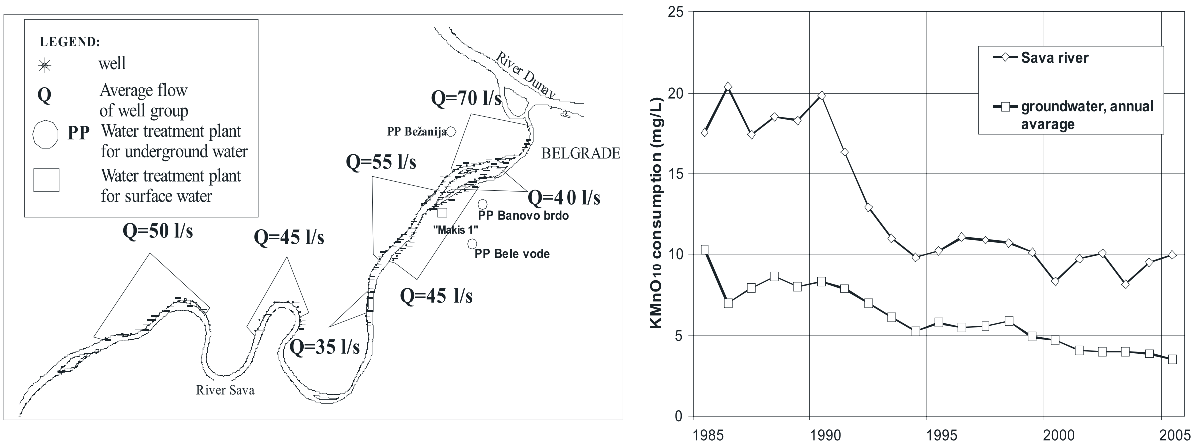


Figure 3. Belgrade groundwater source: radial wells along the Sava River and estimated average monthly $KMnO_4$ demand of the Sava river water and of composite groundwater at the source (Dimkić et al., 2011c)

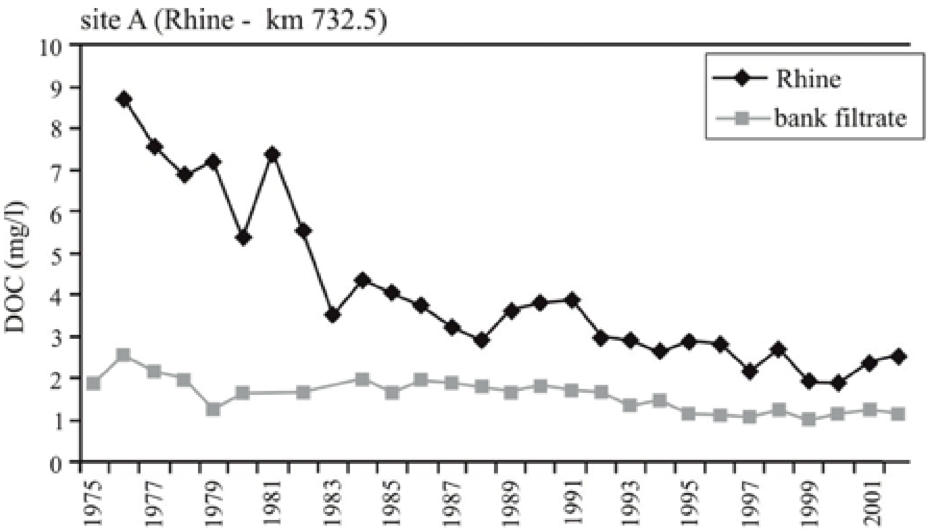


Figure 4. Average annual DOC concentrations in the Rhine river water and extracted raw water at a bank filtration site. (Dimkić M., Brauch H.J., Kavanaugh M. (2008b))

In addition to these examples, the effectiveness of self-purification can be shown with regard to numerous other substances. For example, the study of the effect of self-purification on diverse micropollutants (for example pharmaceuticals) is quite topical today.

Well ageing caused by iron

Well ageing due to well clogging with iron occurs when, under conditions of a relatively reduced redox potential, a sufficient quantity of dissolved iron reaches the well screen. More favourable redox conditions in the well should exist (more oxygen and/or a higher Eh value than in groundwater) to produce the following reaction:

$$Fe^{2+} - e^{-} => Fe^{3+}$$

These reactions occur with the catalytic effect of bacteria which use energy from the reaction and/or its products for their needs. Iron bacteria can be primarily anaerobic, optionally anaerobic or, rarely, slightly aerobic.

The transformation of Fe^{2+} into Fe^{3+} hardly ever occurs under extremely oxic conditions (Eh > 300 mV) and is of low intensity in low oxic environments (150 mV < Eh < 300 mV), but it occurs in anoxic environments. Besides oxicity, the grain-size distribution of the aquifer, screen quality and velocity of groundwater flow to the well are also important for the intensity and kinetics of the process. A well ageing study of the Belgrade Groundwater Source conducted in recent years, as well as a research project financed by the Ministry of Science of the Republic of Serbia (JCI, 2010), and a project of the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia (JCI, 2011), all address the well aging problem at approximately 150 water supply and drainage wells, which operate under aerobic and anaerobic conditions.

Clogging of the well screen tends to occur through physical, chemical and biochemical processes. Based on extensive research conducted in Germany, Houben (2003a) reported that more than 80% of the studied wells were clogged with iron compounds. Detailed research on some 150 alluvial wells in Serbia has also shown that trivalent iron was the dominant cause of well clogging. Chemical corrosion is manifested by corrosion and destruction of the screen material and the well structure as a whole, while the consequence of chemical clogging is a deposit formed on the screen and around the well screen zone. Groundwater contact with air and the dissolution of gasses, especially oxygen, enhance the formation of deposits.

Establishing a correlation between the kinetics of the formation of local hydraulic losses at the well screen and some indicators of oxic groundwater conditions is in fact a new engineering approach to the study of well clogging (ageing) under a given set of oxic conditions. This work is partly based on the results of many years of monitoring of the behaviour and processes in approximately 150 wells at several alluvial aquifers in Serbia. At locations with a high redox potential, no well clogging with iron deposits was observed. In relatively low oxic environments (150 mV < Eh < 300 mV, 0.2 mg/L < O_2 < 1 mg/L), iron clogging was found to be of low intensity. Under low or medium anaerobic conditions, iron clogging is frequently present. The most intensive and beneficial research of the clogging rate was possible at five radial wells of the Belgrade Groundwater Source with new (replaced) lateral screens. Changes in hydraulic resistance at the well screen were correlated with certain clogging indicators (Eh, Fe, bacterial count).

The clogging of a radial well lateral directly results in increased local hydraulic losses at the entrance to the lateral. The hydraulic parameter which can be used to quantify the extent of well clogging is Local Hydraulic Resistance (LHR), expressed as the quotient ΔS/v, where ΔS is the local well drawdown (i.e., the difference in water levels between the well and a nearby piezometer), and v is the entrance velocity of groundwater into the well screen (discharge per surface unit) (Dimkić and Pušić, 2008c, Dimkić et al., 2011b).

$$LHR = \frac{\Delta S}{v}$$

LHR variation over time may be expressed as

$$KLHR \approx \frac{\Delta(LHR)}{\Delta t}$$

where KLHR is the rate of change of local hydraulic resistance. The KLHR value is an indicator of the rate of LHR variation, i.e. the rate of well ageing.

Local hydraulic resistance at the wells of the Belgrade Groundwater Source was quantified based on the results of periodically performed pumping tests. This groundwater source is comprised of radial wells, located along the banks of the Sava River. The groundwater source has 99 radial wells and about 50 tube wells. The wells were built from 1953 to 1998.

A constant decline in well yield has been noted at most of the wells since the beginning of their operation. Over time, this has become a serious problem for the entire groundwater source. The problem was addressed in three ways: construction of new wells (today there is virtually no suitable location for the construction of a new well within the present groundwater source), replacement of laterals, and repeated regeneration of laterals.

During the 2005-2008 period, old laterals were replaced at five wells (hereafter: new wells), through the application of a more modern technology and the installation of screen pipes made of superior material (Cr-Ni steel alloy), compared to the previous period. At the same time, comprehensive research was carried out at the groundwater source in order to establish a correlation between well yield and certain indicators of well ageing. The new wells were the focus of this research.

Plots of LHR variation over time are shown in Figure 5. Only the period of well operation with new laterals was analysed. The origin of the X-axis represents the time of installation of new laterals at each well.

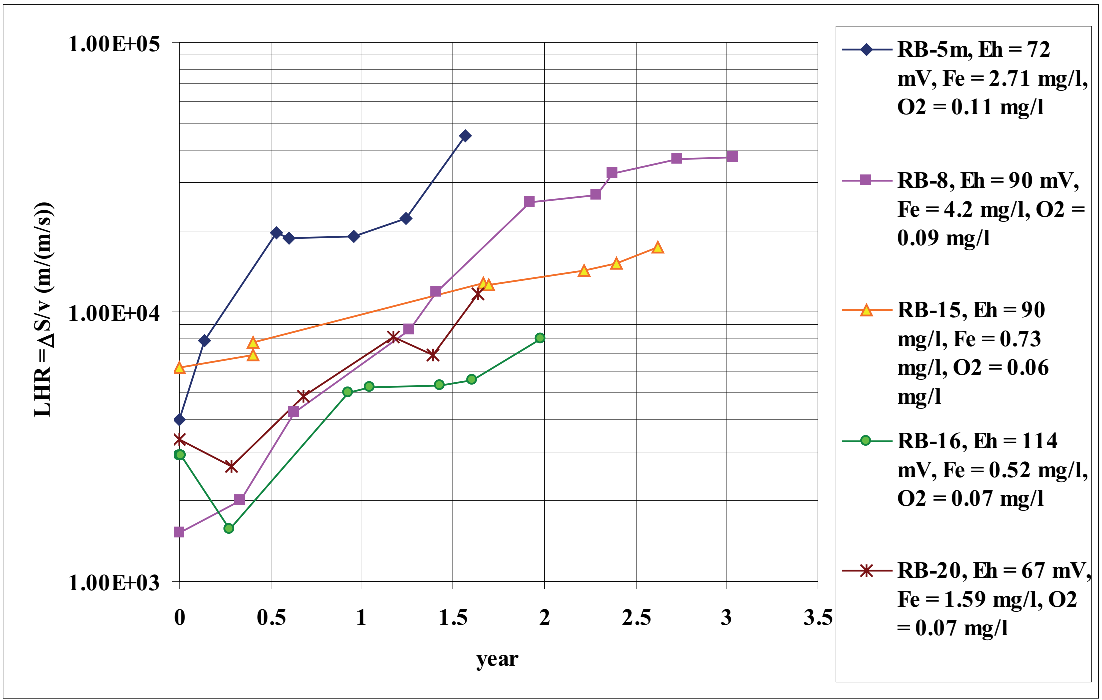


Figure 5. Change in LHR following installation of new laterals (Dimkić et al., 2011b).

Based on research of radial wells of the Belgrade Groundwater Source, as well as of a great number of tube wells in several large alluvial aquifers in Serbia, a correlation between KLHR and clogging indicators (*v*, Fe, Eh, B, Γ) was established

$$KLHR = KLHR(v, Fe, Eh, B, \Gamma)$$

where: *v* - well entrance velocity, Fe – iron concentration in the well water, Eh - measured redox potential, B – a quantity which describes the intensity of bacterial growth in the well, Γ – a quantity which depends on several parameters – well screen installation method, gravel pack and aquifer grain-size distribution.

In the above context, the clogging rate of a well also depended on the discharge during abstraction. There is the practical question of LHR estimation, which in a given time period should not exceed a (likewise) given value. For example, the annual increase in LHR should not exceed a certain value (allowed value - AV), in order to ensure well longevity. The following empirical expression is proposed:

$$\Delta S_{year} = v_{perm} \cdot KLHR_{year} \leq AV \text{ (m)}$$

where ΔS_{year} is the proposed maximum permissible hydraulic resistance at the lateral as the annual average (m), and vperm is the permissible entrance velocity into the well (m/s).

Based on the above, the permissible entrance velocity of groundwater flow into the well (or lateral, in radial wells), taking the annual parameter change (i.e. the degree of oxicity) as a criterion, may be calculated as follows:

$$v_{perm} = \frac{\Delta S_{year}}{KLHR_{year}}$$

The concept of critical, maximum permissible entrance velocities into the well screen (v_{perm}), has in practice until now been linked exclusively to the occurrence of seepage instability of the aquifer around the well screen zone (e.g., Sichardt, 1928, Abramov, 1952, Kovacs, 1983).

Here, however, an additional criterion is introduced, namely the concept of the permissible rate of well clogging, KLHR, i.e. the permissible drawdown, ΔS_{year}. It is assumed that both criteria should be fulfilled. Determining the vperm value and setting the dimensions of the well screen in order to meet the condition that the entrance velocity (v_{en}) should not exceed the permissible velocity ($v_{en} < v_{perm}$), does not ensure complete cessation of clogging of the laterals. It only reduces the process to a level which allows the annual increase in hydraulic losses between the outer environment and the inside of the lateral, to be smaller than the given value ΔS_{year}.

Furthermore, a correlation may be established between vperm and the degree of oxicity of the groundwater, where the Eh level of groundwater is taken as an indicator. Figure 6 is a graphic representation of this approach in the form of plots of permissible velocities as a function of the increase in Eh, namely plots of permissible velocities based on the expressions proposed by different authors, where the occurrence of seepage instability (*v*) and vperm was taken into consideration as the sole criterion. It is assumed that the recommendation includes the laminar groundwater flow condition.

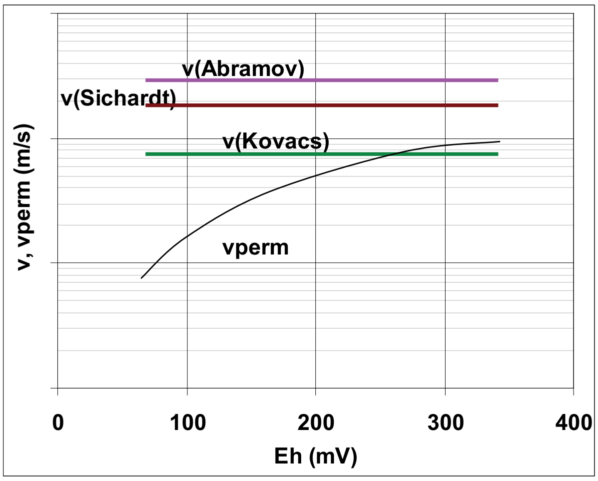


Figure 6: Graphic representation of the relation between the values of entrance velocity into the well screen, v (standard criteria) and v_{perm} depending on the degree of oxicity (expressed through the Eh of groundwater (Dimkić et al., 2011c)

Conclusion

Alluvial aquifers are extremely important for both human society and the environment. A large number of factors drive the oxic state of alluvial aquifers. It should be noted that the significance of mineral oxygen consumption is evident but has not yet been sufficiently investigated.

Oxic environments are generally more favourable for self-purification processes. However, some substances can also degrade in anoxic conditions. Knowledge of the effects that the degree of groundwater oxicity has on the baseline quality of groundwater and understanding of the process of purification of river water to the baseline quality level are fundamental for the design, use and protection of groundwater sources.

Well ageing due to screen clogging with iron deposits is a process of great economic significance. It predominantly occurs through the transformation of soluble Fe^{2+} into poorly soluble Fe^{3+}. In this paper, the correlation between the kinetics of local hydraulic resistance variation at the well and well clogging indicators is expressed as:

$$KLHR = KLHR(v, Fe, Eh, B, \Gamma)$$

With regard to groundwater source design, namely well discharge decline and well ageing, the oxic state in which biochemical processes become dominant is 50 mV ≤ Eh ≤ 200 mV. In this range of oxic conditions the critical well screen entrance velocity depends on biochemical parameters. In a highly oxic area, “standard” criteria - seepage stability and laminar flow of groundwater to the well - are the most significant criteria for well screen design and operation. It should be noted that wells where Eh < 50 mV were not studied.

Selected references

Abramov, S.K. (1952): Method of Calculation and Selection of Filters for Drilled Wells (in Russian). Works of Hydrogeology and Engineering Geology Section of The Federal Scientific Technical Mining Society, Vol. 1, Moscow

Alekseev, V.S. (1968): Well-screen Length and Diameter Selection Considering Load Nonuniformity. Power Technology and Engineering (formerly Hydrotechnical Construction), Vol.2, No. 8, August 1968 (translated from Giodrotekhnicheskoe Stroitel'stvo, No. 8, pp. 46-48, 1968), Springer-Verlag New York, LLC

Borch, M.A., S.A. Smith, and L.N. Noble. (1993): Evaluation, Maintenance, and Restoration of Water Supply Wells. American Water Works Association Research Foundation, Denver, CO. http://www.awwarf.com/research/topicsandprojects/execSum/401.aspx

Cullimore, R. (1999): Microbiology of Well Biofouling. CRC Press. Taylor & Francis Group. Boca Raton. London. New York.

Dimkić, M., Keckarević, D. (1990): Quantification of groundwater aquifer purifying potential as physical and biochemical reactor. X Counseling of the Yugoslav Society for hydraulic research. 9.-13. October 1990, Sarajevo, p. 467-479

Dimkić, M. (2007): Self-Purification Effects of Groundwater Seepage Potential, Monograph, pp.1- 252, The Andrejević Trust Fond, Belgrade, Serbia, ISBN: 978-86-7244-629-6 (in Serbian).

Dimkić, M., Pušić, M., Jordanovski, M. (2007b): In situ investigations to define the degradation of phenols in groundwater. Proceedings: Groundwater management in the Danube river basin and other large river basins, Regional IWA Conference, Belgrade, 7-9 June, 2007.

Dimkić, M., Đurić, D., Milovanović, M. (2008a): Relation of boundary values of groundwater quality parameters towards the protected zones for intergranular aquifers. Water and sanitary technics No. 3/2008. Belgrade, p.19-36

Dimkić M., Brauch H.J., Kavanaugh M. (2008b): Groundwater Management in Large River Basins. IWA Publishing, London, UK

Dimkić, M., Pušić, M., Vidović, D., Petković, A., Boreli-Zdravković, Dj. (2011a): Several natural indicators of radial well ageing at the Belgrade Groundwater Source. Part 1. Water Science and Technology. vol. 63.11, doi: 10.2166/wst.2011.590

Dimkić, M., Pušić, M., Obradović, V., Đurić, D. (2011b): Several natural indicators of radial well ageing at the Belgrade Groundwater Source. Part 2. Water Science and Technology. vol. 63.11, doi: 10.2166/wst.2011.564.

Dimkić M., Pušić M., Majkić-Dursun B., Obradović V. (2011c): Certain Implications of Oxic Conditions in Alluvial Groundwater, Journal of Serbian Water Pollution Control Society „Water Research and Management“, ISSN 2217-5237, Vol. 1, No. 2, p. 27-43, 2011.

Dimkić M., Pušić M., Obradović V., Kovačević S. (2012): The effect of certain biochemical factors on well clogging under suboxic and mildly anoxic conditions, Water Science & Technology, IWA Publishing, London, vol. 65, no. 12, p. 2206-2212, 2012. (doi: 10.2166/wst.2012.129)

Houben, G. (2003) Iron Oxide Incrustation in Wells: part 1 and 2. Applyed Geochemistry, Elsevier Science.

Houben, G., Treskatis CH. (2007) Water Well Rehabilitation and Reconstruction. McGraw Hill, New York. pp. 391. ISBN-13: 978-0-07-148651-4

JCI (2010) Defining the impact of aerobic degree onto the aquifer protection and usage in intergranular porous media in Serbia. TR 22014. Ministry of science and technological development, Ministry of agriculture, forestry and water management, The technological development project, 2008 – 2010

JCI (2011) Methodology of groundwater source evaluation, designing and maintaining in alluvial media, depending on the aerobic degree. TR 37014. Ministry of science and technological development, Ministry of agriculture, forestry and water management, The technological development project, 2011 – 2014

Kovacs, G. & Ujfaludi, L. (1983): Movement of Fine Grains In The Vicinity Of Well Screens. Hydrological Sciences – Journal – des Sciences Hydrologiques 28 (2), 6/1983. p. 247-260

Milovanović, D., Boev, B. (2001) The Earth, Plate Tectonic and Magnetism (in Serbian), Nauka, Belgrade

Nelson, D. (2002): Natural Variations in the Composition of Groundwater. Presented at Groundwater Foundation Annual Meeting. November 2002, USA

Schmidt, C.K, Lange, F.T, Brauch, H.J., Kühn, W. (2003) Experiences with riverbank filtration and infiltration in Germany, Proceedings International Symposium on Artificial Recharge of Groundwater, 14.11.2003, Daejon, Korea, 115-141

Sichardt, W. (1928): Method of Stabilization of Drilled Wells (in German). Springer. Berlin

Vuković M. and Soro A. (1990): Hydraulics Of Water Wells. Water Resources Publications, Littleton, Colorado, USA, p. 354

Contemporary Issues of Adaptive Water Management - Experiences in the Danube River Basin

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Executive Secretary of the ICPDR

Abstract

The **Danube River Basin** is the most international river in the world. Of the **19 countries** that have territories within this basin, 14 have more than 2000 square kilometers and have recognized their responsibility to align their efforts in ensuring adaptive management of water resources. On **29 June 1994**, the main Danube Basin countries signed the **"Danube River Protection Convention"** in Sofia, Bulgaria. The convention defines four main areas that require action: The protection of water and associated ecological resources; the sustainable use of water in the Danube Basin; the reduction of inputs of nutrients and hazardous substances; and the management of floods and ice hazards.

Today, the Danube River Protection Convention has 15 contracting parties: 14 countries and the European Union. Together, they form the **International Commission for the Protection of the Danube River**. The permanent secretariat of the ICPDR is based in Vienna and started its work in 1998.

Since the year 2000, the countries of the Danube have been using the methods and strategies for water management adopted in the **EU Water Framework Directive** (WFD). The WFD requires water management be carried out according to the outlines of natural river basins rather than national or other administrative borders. Alongside with the implementation of the **EU Flood Directive** (EFD) of 2007, the WFD enjoys highest priority for the ICPDR, as all its contracting parties, including the non-EU countries, agreed to its implementation.

Through the combined efforts of the countries a **Danube River Basin Management Plan**, based on the assessment of the environmental conditions in the basin and the actions needed to address them has been developed. The analysis led to the identification of four problem areas, so-called **"Significant Water Management Issues"** (SWMIs): organic pollution, nutrient pollution, hazardous substance pollution and hydromorphological alterations.

Responding to this analysis the Danube River Basin Management Plan and the **17 Flood Action Programs** list hundreds of measures to address these water management issues. The monitoring of these measures, which need to be implemented in the countries, and their effects is also coordinated by the ICPDR. This allows for continual adaptive management based upon new understandings and developments.

Central to the understanding that has developed is that water management strategies need to be aligned with other sectors which influence water. These are in particular inland **navigation, agriculture** and **hydropower**. Efforts to create dialogue and mutual understanding of the problems and possible solutions involving these sectors have been initiated. In addition, an extensive effort to create an adaption strategy to respond to **Climate change has begun**. Considerable progress in all of these areas has been achieved and this progress in adaptively managing water resources in the Danube River basin is being achieved.

Interactions Between River Water and Groundwater - Significance of Natural Attenuation Processes for Improving Water Quality

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Introduction

In Europe, groundwater is used for drinking water production wherever possible. Unlike surface water, groundwater is well protected against most types of pollution, is of good quality and relatively constant temperature and its abstraction can be easily adjusted to short-term fluctuations in consumption. However, exploitation of groundwater resources is restricted with regard to quantity. Surface water (rivers, lakes and reservoirs) is often exposed to risks of permanent and sudden pollution by wastewater effluents, non-point runoff from land use, transportation, power generation and traffic as well as by accident/ incidents or by increasing usage of chemicals. For drinking water preparation, well protected water resources are needed in order to secure good drinking water quality on a long-term basis and to reduce time and effort for water treatment according to the EU water frame directive. Today, approximately 65 % of the drinking water in Germany is produced from groundwater resources, whereas 13 % is from bank filtrate or infiltrate along major rivers. Direct abstraction and treatment of river water has declined only to 1 % due to various bacterial diseases in the past (Figure 1).

More than 300 waterworks in Germany use bank filtration and roughly 50 plants are based on artificial groundwater recharge. Major waterworks with river bank filtration can be found mainly along the river Rhine, in the Ruhr valley, along the rivers Elbe and Danube, and in the Berlin area.

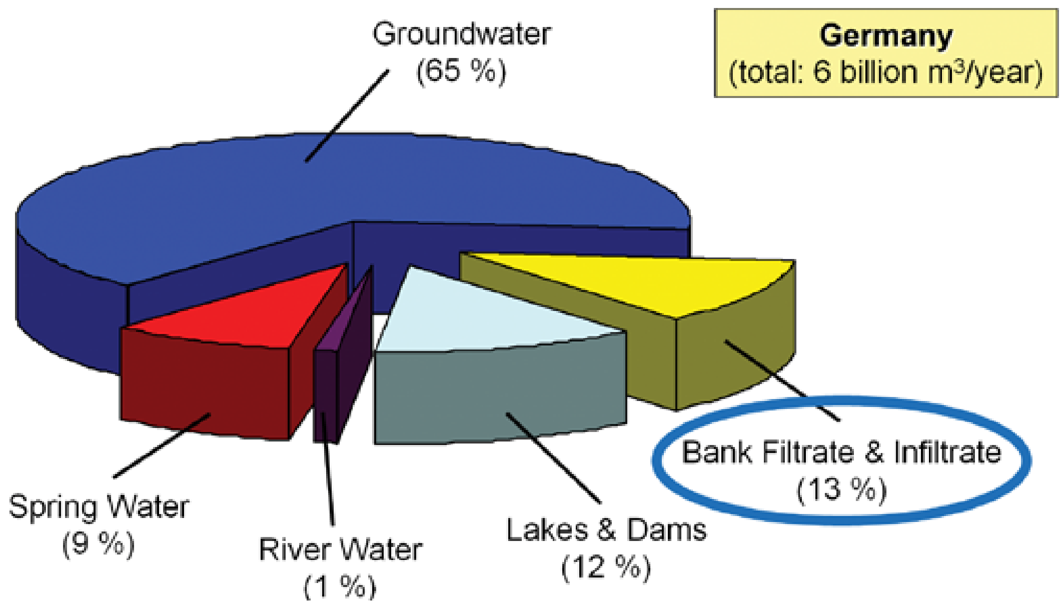

Figure 1: Water resources for public water supply in Germany

In the first half of the 20th century bank filtrate was possible to be used as drinking water without further treatment. But increasing chemical pollution – in the 60s and 70s of the last century – affected river water quality and subsequently bank filtrate and groundwater. High levels of ammonium, heavy metals and toxic elements, chloride, organic substances as well as micropollutants were discharged into surface water and necessitated supplementary water treatment steps to build up a multiple barrier system.

Effects of river bank filtration and artificial groundwater recharge

There are various benefits if using river bank filtration or artificial groundwater recharge as natural water treatment technology. Both techniques improve water quality and may cut down on other treatment costs. They combine the removal of particles, turbidity, pathogens, natural organic matter, organic and inorganic chemicals as well as peak smoothing in spills, temperature equalization, reductions in DBP formation, improvements in taste and order and the production of biologically more stable water (Schmidt, 1998; Kühn und Müller, 2000; Ray et al., 2002). As river water seeps through sediment and aquifer, it undergoes a diversity of natural attenuation processes, significantly improving water quality, without the need for processing chemicals, and resulting, in ideal cases, in a high quality of natural groundwater (Schmidt, 1988; Preuß & Schulte-Ebbert, 2000).

Over the last few decades there are numerous examples showing the improvement of river Rhine water quality and the effects on the adjacent groundwater and bank filtrate. The concentrations of basic water quality parameters like oxygen, ammonium, chloride, DOC and AOX were reduced significantly, both in river water and in bank filtrate, respectively.

The results of those investigations clearly show that restoration of the river Rhine caused a parallel and substantial quality improvement of the bank filtrate abstracted by water utilities along the river. Inorganic substances like ammonium and manganese, which had to be moved during subsequent water treatment, almost disappeared from the raw water. Further on, the amount of organic compounds in the bank filtrate, measured as DOC or as AOX, was substantially lowered. In general, these achievements provided several benefits for water utilities. In particular, the significant reduction in DOC-concentrations enabled the extension of the runtime of activated carbon filters and led to a reduction in the consumption of oxidation and disinfection chemicals.

Attenuation processes for removal of organic micropollutants

Numerous studies and long-lasting investigations have proven that river bank filtration and artificial groundwater recharge are excellent options to lower the concentrations of organic micropollutants (Schmidt und Brauch, 2006; Jekel und Grünheidt, 2006; Sontheimer, 1991). The fate of organic micropollutants is mainly determined by adsorption mechanisms and biological transformations. The biological processes are responsible for their elimination occur predominantly within the first meters of infiltration. That means the degradation of organic compounds is linked to both the presence of favorable redox conditions and sufficient residence times in the underground. In general, removal efficiency of the underground with respect to degradable substances may vary considerably, depending on a local geological and hydrochemical conditions as well as on the organic load of river waters and infiltration zones.

As redox conditions may have a significant impact on the removal of organic substances, some pharmaceuticals like carbamazepin and sulfamethoxazol and the x-ray contrast media iopamidol and amidotrizoic acid are found to be rather persistent under aerobic redox conditions, but tend to more readily removed under anoxic or strictly anaerobic conditions (Figure 2).

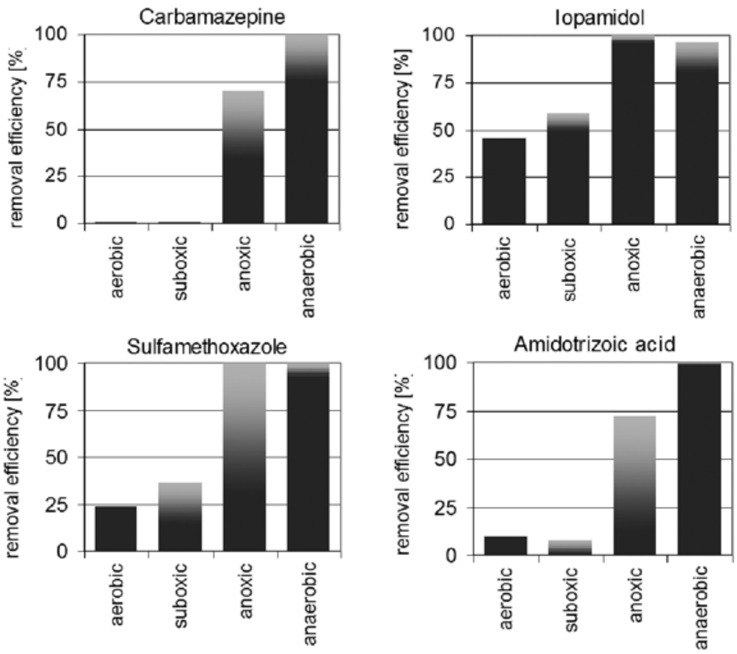

Figure 2: Removal efficiency of river bank filtration for carbamazepin, sulfamethoxazol, iopamidol and amidotrizoic acid in aquifers with different redox conditions

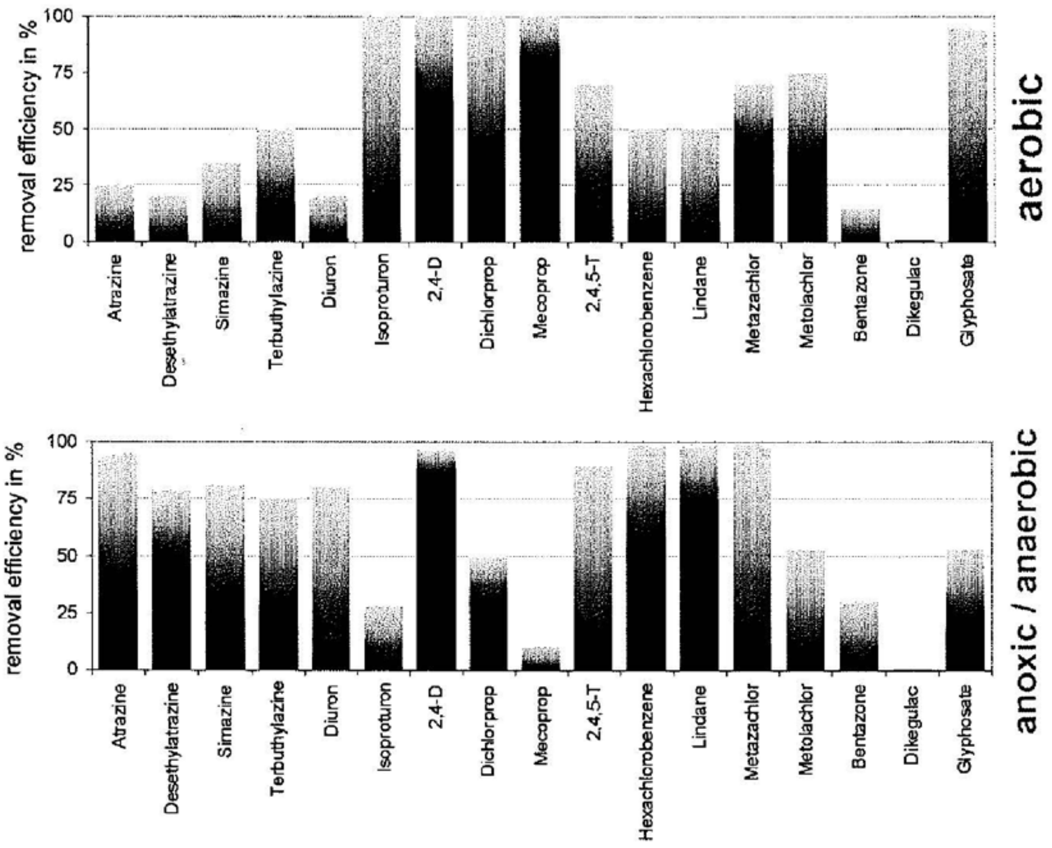

Figure 3: Removal efficiency of river bank filtration and artificial groundwater recharge for selected organo halogen compounds (Schmidt et. al, 2006)

Additionally Fig. 3 gives a comprehensive illustration of results reported in the literature, concerning the elimination behavior of organo halogen compounds during river bank filtration and artificial groundwater recharge. It is evident that anoxic and anaerobic aquifers provide higher removal efficiency for most organo halogen compounds than does river bank filtration under aerobic conditions.

The basic requirement for microbial degradation of organic substances is the existence of an adequate biocoenosis. Some trace substances can be depredated by multiple bacteria species, others only by specialist species (Schmidt, 1988). In addition, biodegradation of organic substances by microorganisms is usually temperature-depended. The relationship between temperature and degradation rate is in general that the rate of biochemical reaction increases with increasing temperature.

Today, a very interesting field of scientific research is the formation of metabolites and transformation products in underground processes. Organic micropollutants which are readily biodegradable can form rather persistent metabolites which are often more mobile and water soluble (Brauch and Sacher, 2011; Scheurer, Sacher and Brauch, 2012). Therefore, they can be found in the wells of water utilities. On the other hand, organic micropollutants like carbamazepine, EDTA, acesulfame and benzotriazole are not biodegraded under aerobic conditions and may pass the underground barrier unchanged. But most of micropollutants analyzed can be removed during underground by biodegradation/transformation or by adsorption onto soil.

Situation in the Danube basin area

Many studies and investigations are reported, concerning the occurrence and fate of organic micropollutants in the river Danube and the adjacent groundwater resources. Several findings showed that the concentrations found are comparably lower due to less industrial activities, lower population density and higher river water flow of the Danube. But the interactions between river water and groundwater concerning the fate of inorganic and organic substances, heavy metals and toxic elements as well as bulk parameters are often the same as reported for the Rhine basin. Investigations along major rivers in North America or Australia as well as in Korea confirmed the general approach that river bank filtration and artificial groundwater recharge are excellent options to reduce man-made pollution with natural treatment technology.

A second advantage is the strong need to preserve and protect water resources for drinking water preparation as it is claimed by the European water frame directive. More data and information will be delivered by the joint Danube survey (JDS 3) in 2013.

Adsorptive Treatment: An Innovative Approach for Drinking Water Production from Groundwater

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Keywords: groundwater treatment, water supply, adsorptive filtration, removal of metals.

Introduction

Groundwater is a predominant source of drinking water in large number of countries on all continents. Approximately half of the drinking used worldwide originates from groundwater (Sampat, 2000). Groundwater is extensively used as an important source of public water supply in Europe ranging from nearly 100% in Denmark, approx. 7% in Germany and in The Netherlands, 56% in France and 21% in the United Kingdom (EEA 1999). Groundwater is the only source of water supply is many cities in the world, and it is extensively used in many rural areas and small towns of developing countries in Asia and Africa.

Groundwater is generally a preferred source for water supplies because of its convenient availability close to where water is required, its constant and good natural, and relatively low capital and operational costs associated with drinking water production from groundwater. Against these common advantages, it should be noted that groundwater occasionally contains natural impurities, and is vulnerable to contamination by various anthropogenic activities.

Groundwater Quality Problems

In most cases groundwater is of very good microbiological quality and its chemical quality depends on hydrogeological conditions. Groundwater quality problems can be categorized as (i) naturally occurring (geogenic) and (ii) human induced (anthropogenic). Hence, generally some form of treatment will be required when groundwater is used for potable water supplies.

Most commonly occurring groundwater quality problems are elevated concentrations of iron, manganese, ammonium, arsenic, fluoride, and occasionally methane, hydrogen sulphide, and nitrate A high concentration of iron and manganese are by far the most common water quality problem associated with groundwater.

Treatment Methods

Conventional groundwater treatment

Conventional groundwater treatment involves aeration (to remove the volatile gases and to increase the oxygen concentration), followed by rapid sand filtration to remove the iron and manganese flocs formed after oxidation. In this process ammonium is biologically oxidised. Disinfection with chlorine is commonly the last treatment step to ensure microbial safety and to maintain disinfectant residuals in the distribution system. Alternatively, aeration is replaced by chemical oxidation using chlorine or ozone to speed up the rate of oxidation of iron, manganese, hydrogen sulphide or ammonium before filtration. When the groundwater is rich in colour or natural organic matter (NOM), or when iron and manganese are present in organically complexed form, coagulation (using aluminium or iron salts) and sedimentation is applied before rapid sand filtration.

Conventional groundwater treatment approach, however, has several limitations. Very often complete oxidation of contaminant is not achieved, whereas in others filterable flocs (precipitates) could not be formed. This approach also produces excessive volumes of backwash water and sludge, which must be properly disposed. Additionally, chemical oxidation and coagulation-based processes (specifically used for ammonia, arsenic, fluoride and other heavy metal removal), could result in formation of health hazardous by-products, and could create high residual coagulant (e.g. aluminium) level in treated water. Oxidation and coagulation processes need careful operation and require skilled manpower for proper O&M.

Adsorptive groundwater treatment

An attractive alternative approach for groundwater treatment is to employ the adsorption capacity of filter media to remove iron, manganese, arsenic, fluoride and other contaminants. Adsorptive iron and manganese removal involves limiting the oxygen concentration in groundwater, or limiting the contact time available for oxidation. Dissolved iron and manganese are under such conditions removed by adsorption onto the surface of the filter media. Subsequently, in the presence of oxygen, the adsorbed iron and manganese is oxidised forming a new adsorption surface on the filter media. In this way the process continues. The adsorption capacity of the filter media increases with the development of iron/manganese oxide coating on the surface (Sharma, 2001; Buamah, 2008). This approach results in better water quality and longer filter run in comparison to conventional groundwater treatment.

Similar process can be utilized for the removal of arsenic, chromium or other heavy metals from groundwater using iron oxide coated sand or other commercially available adsorptive media. After some time, the adsorption capacity of the filter media may be exhausted and the adsorptive media needs regeneration. Adsorption capacity of media can be restored by application of appropriate "regenerant", continuously during the filtration cycle or intermittently. Some iron(II), normally present in groundwater, or introduced during treatment will also help to regenerate the adsorption surface and to prolong the filter run time (Petrusevski et al., 2007). Adsorptive filtration process can also be applied for fluoride removal from groundwater using aluminium oxide coated filter media as adsorbent.

Adsorption followed by oxidation is also the dominant mechanism in sub-surface groundwater treatment that is increasingly applied for removal of iron, manganese and in some cases arsenic. Sub-surface groundwater treatment has been practised in many countries for the removal of iron, manganese, arsenic and nitrate. *Subsurface iron removal is a safe and sustainable small-scale drinking water treatment solution. The performance of this type of system is largely dependent on the groundwater quality and hydrogeological conditions at the site.*

Other innovative treatment approaches

High concentration of natural organic matter (NOM) in drinking water is undesirable from aesthetic reasons, and could also cause problems associated with formation of health hazardous oxidation by-products. Adsorptive removal of NOM with selective ion exchange resins is an innovative treatment approach recently developed and applied on several full scale drinking water treatment plants in The Netherlands. In addition to highly effective organics removal, formation of waste streams is strongly reduced in comparison to other treatment options for organics removal, and, overall treatment costs are very low.

Conclusions

- Groundwater is preferred source of water supply in many countries worldwide because of its relatively constant quality and low treatment requirements compared to surface water.
- Conventional groundwater treatment often involves aeration/oxidation followed by rapid sand filtration to remove common contaminants like iron, manganese and ammonium. Coagulation-sedimentation-rapid sand filtration is used for the treatment of groundwater with high colour, natural organic matter and complexes iron and manganese.
- Adsorptive filtration is an attractive alternative to conventional oxidation/ precipitation- based processes for groundwater treatment. This approach avoids or reduces the problems of colloid formation, rapid head loss development, and sludge treatment and disposal commonly associated with oxidation-based processes.
- Sub-surface treatment is other innovative approaches for groundwater treatment if the local hydrogeological conditions are suitable for their applications
- Adsorptive removal of natural organic matter with selective ion exchange resins is highly effective, environmentally friendly and relatively low costs approach for removal of organics from groundwater.

References

Appelo, C.A.J., Drijver, B., Hekkenberg, R. and de Jonge, M. (1999) Modelling in situ iron removal from ground water. Ground Water, 37 (6), 811-817.

Petrusevski, B., van der Meer, W., Baker, J., Kruis, F., Sharma, S.K. and Schippers, J.C. (2007) Innovative approach for treatment of arsenic contaminated groundwater in Central Europe. Water Science and Technology: Water Supply, 7 (3), 131-138.

Buamah, R. (2009) Adsorptive Removal of Manganese, Arsenic and Iron from Groundwater. PhD thesis, Wageningen University and IHE Delft, The Netherlands.

EEA (1999) Groundwater Quality and Quantity in Europe. June 1999, European Environmental Agency, Copenhagen, Denmark.

Braester, C. and Martinell, R. (1988) The Vyredox and Nitredox methods of in situ treatment of groundwater. Water Science and Technology, 20 (3), 149-163.

Sampat, P. (2000) Groundwater Shock. World Watch, January/February, 10-22.

Sharma, S.K. (2001) Adsorptive Iron Removal Groundwater. PhD Thesis, Wageningen University and IHE Delft, The Netherlands.

Sharma, S.K. and Amy, G. (2010) Chapter 15: Natural Treatment Systems. In: Water Quality and Treatment: A Handbook on Drinking Water. James K. Edzwald (ed.) Sixth Edition, AWWA and McGraw Hill Inc., USA.

UNICEF (1999) Fluoride in water: An overview. Water Front, Issue 13, December, pp 11-13.

Groundwater and Climate Variability - IGRAC's Experience and Activities

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Abstract

Groundwater is a key resource of global water supply, often the primary source for drinking, irrigation and industrial water supply, and extremely important for ecosystem sustainability. It is considered more reliable and generally less prone to contamination than surface water, rendering it the most viable source of water throughout many parts of the world. Strong regeneration and buffering characteristics of groundwater systems are of great importance in sustaining groundwater fed wetlands and vegetation and it is a baseflow to rivers. However, the global change, population growth and climate variability are increasing the pressure on groundwater resources.

The International Groundwater Resource Assessment Centre (IGRAC) is set up to facilitate and promote international sharing of information and knowledge required for sustainable groundwater resources development and management. Since 2003, IGRAC has been providing an independent content and process support, focusing particularly on transboundary aquifer assessment and groundwater monitoring. IGRAC is UNESCO Global Groundwater Centre, it also works under the auspices of WMO, has a MoU with International Association of Hydrogeologists (IAH) and it is financially supported by the Government of the Netherlands.

IGRAC's work primarily focuses on the global/regional assessment of groundwater resources and monitoring of their change, mainly through the development of the Global Groundwater Information System and activities related to transboundary aquifers (TBAs). The Global Groundwater Monitoring Network (GGMN) programme is set up to improve monitoring of the state of groundwater resources at the regional and global scale. The terrestrial data are basis for any kind of simulation and/or prediction of groundwater state due to climate variability. The mayor Transboundary Aquifers activities at IGRAC are carried out within the framework of the ISARM (Internationally Shared Aquifer Resources Management) programme, UNECE assessments and GEF (Global Environment Facility) projects. There are more than 400 transboundary aquifers in the world and their appropriate management is crucial for the water security in the changing world.

According to the Inter-governmental Panel on Climate Change (IPCC) in both their 3rd (2001) and 4th (2007) Assessment Reports: “groundwater is the major source of drinking water across much of the world… but there has been very little research on the potential effects of climate change”. Potential climate risks for groundwater include: reduced groundwater recharge, sea water intrusion to coastal aquifers, contraction of freshwater lenses on small islands and increased demand. Through improved data availability and assessment of large internationally shared aquifers, IGRAC is contributing efforts to mitigate the adverse impact of climate variability.

Groundwater Management coping with Global Change

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UNESCO Programme Specialist

Abstract

Groundwater is a valuable natural resource providing a primary source of water for agriculture, domestic and industrial purposes in many countries and accounts for 95% of readily accessible freshwater. On a global scale, one third of the population depends on groundwater for their drinking water, in urban as well as rural areas. Groundwater also plays a pivotal role in agriculture.

The importance of groundwater resources is highlighted in global environmental studies, including those of the IPCC (Intergovernmental Panel on Climate Change).

The last three reports of the IPCC emphasize a continuing need to assess the potential effects of CO_2-altered climates on aquifer recharge. The IPCC (2001, p. 200) concludes: "In general, there is a need to intensify research on modelling techniques, aquifer characteristics, recharge rates and seawater intrusion, as well as on monitoring of groundwater abstractions. This research will provide a sound basis for assessment of the impacts of climate change and sea-level rise on recharge and groundwater resources." Furthermore, the dynamics of groundwater systems in response to human and climatic stresses require further attention.

Adaptation to climate impacts on groundwater resources in developed and developing countries has not received adequate attention yet. This reflects the often poorly understood impacts of climate change, the hidden nature of groundwater and the general neglect of groundwater management.

The sense of urgency for climate change adaptation and the recognition of the centrality of water therein, have not yet permeated the political world and are not systematically reflected in national plans or international investment portfolios for adaptation.

Groundwater resources, that have been also proven safe to natural disasters, protected by geological features and with long residence times would provide populations with timely replacement of affected regular surface water supply systems and make rescue activities more rapid and effective. Such resources have to be investigated, evaluated and developed to substitute affected drinking water supplies.

Then the presentation will deal with different programmes and projects of UNESCO IHP about Groundwater Management coping with Global Change. In particular, it will be presented the Water Programme for Environmental Sustainability, Graphic, the Ground Water Governance programme and the Groundwater for Emergency Situation.

Unesco Regional Centre on Integrated River Basin Management (RC-IRBM) and Africa HELP Basin Coordinating Unit at National Water Resources Institute, Kaduna, Nigeria

Dr Olusanjo A. Bamgboye
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Abstract

The establishment of the Regional Centre for Integrated River Basin Management (RC-IRBM) started with a resolution that Sub-Sahara Africa is in dire need of knowledgeable and skilled personnel for sustainable development. UNESCO Leaders' Forum Background Document (36 C/INFO.15) estimated that 2.5 million engineers and technicians will be needed to improve access to clean water and sanitation alone in sub-Sahara Africa not to consider other sub-sectors of water resources development and management.

The Regional Centre for Integrated River Basin Management (RC-IRBM) established at National Water Resources Institute, Kaduna, Nigeria is envisaged to address the following components of UNESCO sustainable development promotions in the West African Region:

- Mobilizing and generating scientific knowledge;
- Paving the way for local knowledge through education and training;
- Addressing natural disasters and climate change adaptation;
- Improving access to and management of freshwater; and
- Ensuring sustainable and equitable use of biodiversity.

The countries in the sub-region have several decades of experience on river basin management with mixed results. There exist crucial river basin management problems in the sub-region which the proposed Regional Water Centre will address.

Water Governance Practitioners and River Basins Organizations within the sub-region require training and capacity building on Integrated River Basin Management (IRBM). There is the need for such organizations to come together to address issues relating to climate extremes, food and water scarcity in the region, environmental degradation, trans-boundary conflicts on water use and the likes.

The Regional Water Centre will no doubt further strengthen cooperation between UNESCO and its affiliates such as the Lake Chad Basin Commission (LCBC), Niger Basin Commission (NBC), West African Network for Capacity Building in IWRM (WA-NET), and other Trans-boundary Basin Commissions in the sub-region and other parts of the world.

The RC-IRBM is the Secretariat of the Africa HELP (Hydrology for Environment, Life and Policy) Basins Coordination Unit. This unit should be a challenge for more and qualitative hydrological science activities in the Continent.

Background

River Basins are dynamic systems over space and time, and any single management intervention has implications for the system as a whole, thus Integrated River Basin Management (IRBM) within the more encompassing context of Integrated Water Resource Management (IWRM) is one of the biggest challenges of the 21st century. Achieving sustainable development of water resources and river basins is a complex decision making process involving sector stakeholders and requiring an integrated and holistic approach to river basin management to offer solutions to critical river basin management problems related to water demand and supply, hydroclimatic disaster, conjunctive use of surface water and groundwater, inter-basin water transfer and international cooperation on shared basins and aquifers, echohydrology, and environment, as well as organizational and institutional aspects at different levels.

The Regional Centre for Integrated River Basin Management (RC-IRBM) was established at the National Water Resources Institute, Kaduna under the auspices of the UNESCO to serve as a training and research hub for the development of highly qualitative, technical, managerial human and institutional capacities required to achieve sustainable development of river basins at all levels within the West Africa sub-region. The RC-IRBM will also further strengthen cooperation between UNESCO, its affiliates, Lake Chad Basin Commission (LCBC), Niger River Basin Commission (NBC), West African Network (WA-Net), and other Trans- boundary Basin Commissions in the sub region. The RC-IRBM is also hosting the **Africa Co-ordination Unit of the Africa HELP Basins**. Launched in 1999, **Hydrology for the Environment, Life and Policy (HELP)** is a cross-cutting and **transdisciplinary** initiative of the United Nations Educational, Scientific and Cultural Organization **(UNESCO)** led by the International Hydrological Programme **(IHP)**.

Vision

To be the leading regional Institutions for capacity building in technical, and management areas of water resources having responsibility for planning and execution of training and research activities, acquisition, archiving and analysis of data and dissemination of information for sustainable integrated river basin management.

Mission

To provide education and training for water resources and related professionals in integrated water management with emphasis to build the capacity of sector organizations, knowledge centres and other institutions involved in management of water resources, the environment and agricultural infrastructure for effective delivery and resource stewardship for the benefit of the countries of the region.

Objectives and Functions

The Centre was established to pursue the following objectives and functions in close cooperation with IHP and other water-related centres under the auspices of UNESCO.

Objectives

a. Constitute a facilitator and synergetic structure providing the articulation of the different scientific and institutional stakeholders at local, national, regional and international levels, for the implementation of the IRBM particularly by facilitating interactions and providing support to River Basin Development Authorities or Organizations in the West African Region;
b. Conduct and promote hydroinformatics, integrated water resources management and socio-economic research;
c. Provide IRBM training and tertiary education facility for water professionals and practitioners in the West African region.

Functions

a. Coordinate the implementation of co-operative research projects and studies with regional, national and local authorities as well as the private sectors;
b. Build and run networking for information and knowledge exchange and capacity building in Member States of the West African Region;
c. Organize training courses, seminars, workshops and meetings;
d. Produce publications and other media for dissemination of information.

Structure of the Centre

The Centre was established by the Government of the Federal Republic of Nigeria as a category 2 centre under the auspices of UNESCO based on the document (36 C/Resolution 23) of the 36th session of the General Conference. The Agreement was signed on 12 March 2012 between the Government of the Federal Republic of Nigeria and the Director-General of UNESCO. The Centre is guided and supervised by a Governing Board renewed every six years and composed of:

a. a representative of the Director General of UNESCO;
b. a representative of the Government or his/her appointed representative;

c. three representatives of Member States of UNESCO from the Economic Community of West African States (ECOWAS) sub-region, which have sent to the Centre notification for membership and have expressed interest in being represented on the Board;
d. a representative of the New Partnership for Africa's Development (NEPAD) as a non-voting member;
e. the Executive Director of the National Water Resources Institute as non-voting member

Regional Coverage

The Regional Centre is to cater for the needs of the member nations in the West African Sub-Region.

RC-IRBM Focal Areas

The RC-IRBM is proactive in human capacities development through conduct of training and research in the major themes of IHP-VII and IHP-VIII plan with the following suggested focal areas:

1. Adapting to impacts of Global changes on River Basins and Aquifer systems.

a. Development of stress indicator in Hydrological system in different ecological zones of Region
   - Sahel and Sudan Sahel
   - Guinea Savannah and Derived Savannah
   - Forest Zones
b. Assessment of impact of Climate Change on Water Resources in Humid Areas of the Region.
   - Risk Assessment or failure in selected large and medium dams in the Region.
   - Mapping pollution hazards and trends to provide cause-effect relationships along major Rivers in the Region.
c. Managing saline water intrusion problem in selected aquifer in the Region.
d. Assessment of impact of climate variability on water Resources in Arid & Semi Arid Zones of the Region.

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2. Strengthening Water Governance for Sustainability.

a. Identification of potential causes of water disputes and strategies for their resolution.
b. Capacity Development for improved governance; enhanced legislation for wise steward ship of Water Resources.
c. Governance strategies that enhances affordability and assure financing.
d. Managing water as a shared responsibility across geographical and social boundaries (inventory and compilation of existing reports on shared water resources in the Region).
e. Development of integrated Water Resources Management Strategies in the Region in collaboration with GWP/Nigeria, GWP/West Africa and WRCC of ECOWAS.

3. Eco-hydrology for Sustainability.

a. Addressing knowledge gap in water-related environmental sustainability issues in estuaries, coastal, arid and semi-arid and heavily urbanized areas in the Region.
b. Investigating inter-relationship between the hydrological circle and biomass for cost effective and environmental friendly management.

4. Water and Life Support Systems.

a. Assessment of groundwater recharge and quality in selected aquifers in the Region.
b. Identification of national contaminants in surface and groundwater supply systems in urban and semi-urban areas in the Region and their effects on human health and impairment for other uses
c. Case study on rainwater harvesting for improved urban and rural water management in the Region.
d. Urban storm drainage and water management systems in urban cities in the Region.
e. Irrigation water Management &Waste reuse system for Agricultural Production.

5. Water Education for Sustainable Development

a. Organize specialised technical and professional development courses in water resources development and Management.
b. Establish Hydro-clubs in secondary schools.
c. Organize symposia for water resources media correspondents on sectoral reporting in diverse areas
d. Establish National Hydrology Essay Competition in Secondary Schools.
e. Organize symposia, workshops etc for water stakeholders.
f. Facilitate collaboration with other water related professional bodies in the sub region.

Impact of Climate Change on Flood Regimes

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Abstract

Climate change has not only an impact on the water cycle in general it also impacts the hydrological extremes. There is an indication that climate change affects the flood regime. The study aims to assess the impact of climate change on flood frequency and severity in a meso-scale catchment in France. The research was conducted on the catchment of the Yzeron River in western Lyon. The Yzeron catchment area is 130 m^2 and characterized by a rapidly expanding, scattered periurban development.

First statistical tests showed that both flood frequency and severity increased, between the two distinct periods in the 1970s and 1990s. During the same period an increase in rainfall frequency was detected. A more detailed analysis of the daily rainfall regime showed an increase of 10 to 20 mm in maximum rainfall in the 1990s, with a decrease in the number of rainfall events at the same time.

In order to assess the influence of climate change as result of a change in rainfall a diachronic approach was used with rainfall and land-use data from the two periods 1970s and 1990s. The data were used to calibrate a distributed hydrologic model and to simulate the urban, periurban, and rural hydrologic contributions.

The simulations showed the respective effect of both, climate change (through rainfall regime change) and urban development on flood frequency.

Keywords: climate change, simulation model, flood regime

1. Study area

This study relates to the Yzeron catchment. It is a mid-size catchment, located to the west of Lyon, France, where heterogeneous urbanization has been observed over a number of decades.

2. Preliminary data analysis

2.1 Discharge analysis

It was chosen the 1990s and 1970s as reference periods for comparing flood regimes because we know the state of land use during these periods from aerial surveys (see previous section). We used a stationary test to check the number of large floods that occurred during a given period. Accepting a confidence interval of 95%, the flood regime was declared to be non-stationary during the 1990s. Confronting this result with the magnitude of the floods during this period indicates that fewer but more intense floods took place. This could be the effect of both rainfall features and land use changes.

2.2 Rainfall analysis

The application of the same stationary test to a daily rainfall time series spanning the entire period indicates a slight decrease in the number of large daily rainfall amounts during the 1990s (Fig.1). Checking for intensity (daily amount per day) versus frequency distributions of the largest amounts, we observed the 1990s were statistically higher than the 1970s for a confident interval of 90%.

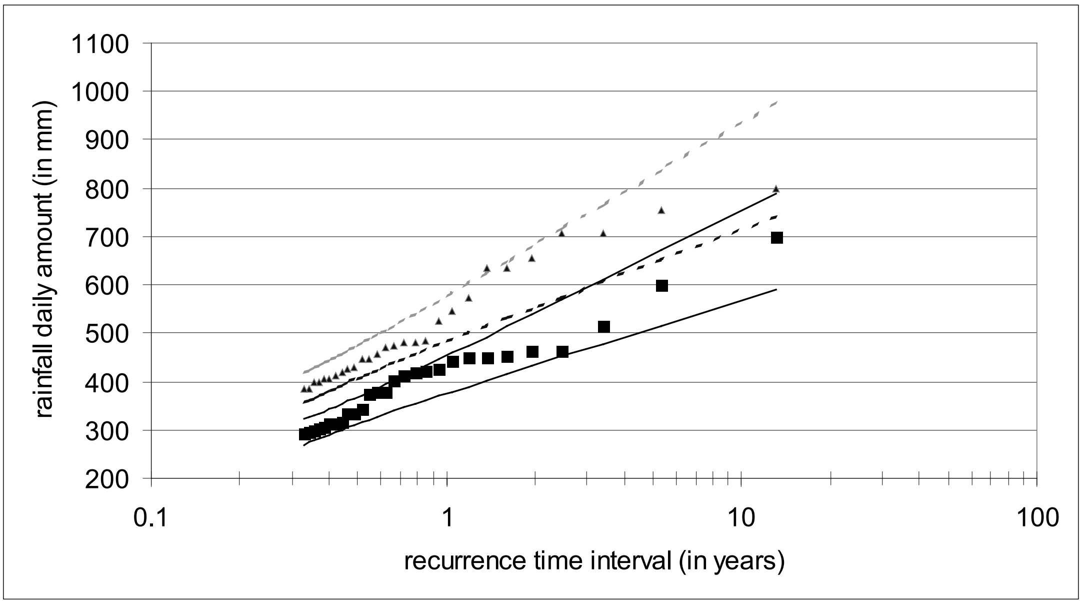

Figure 1: Distributions of maximum daily rainfall for the 1970s (black squares) and 1990s (grey triangles) with a 90% confident interval

2.3 Land uses

The aerial photographs from each period were assembled. Then it was used a transparent grid layer with a unit square cell size of 167 meters. Each cell was attributed a land use cover number corresponding to forest or grassland (including farming) or periurban or urban type. Periurban type was associated to any cell that contained artificial flowpaths like draining ditches and pipes and artificial runoff surfaces like impervious features such as roads, parking lots and houses, but for which the impervious rate was less than 20%. We can see that impervious cover cells grew, along the 1970s to the 1990s, from 6 to 19% of the total area. At the same time, we can observe a decrease of about 30% of grass and cultivated lands to the benefit of urban, periurban and forest areas respectively with a relative increase of 15, 12 and 5% for each.

3. Method

It was used a method based on a numerical simulation to assess the respective contributions of land use evolution and rainfall difference to flood increase. The method was implemented as follows:

- Build an hydrological distributed model, corresponding to the 1990s state of the basin, calibrate and validate this model;
- Build a second hydrological distributed model, corresponding to the 1970s state of the basin, assuming that the hydrological behavior of each type of surface (urban, sub-urban, grassland and forest) remained unchanged;

- Use in the two land-use state models the same 10 year-long time series of rainfall observed during the 1990s to simulate two series of hydrographs; this allowed removing the effect of the rainfall on the flood regimes response.
- Analyze and compare the statistical properties of two generated flood regimes, try to form conclusions on the influence of land use change.
- Asses the whole basin scale flood risk evolution

Hydrological model structure

To take into account the mixed land use evolution between the two periods, and to test the relative importance of an expected urban effect on the flood regime, it was used a semi-distributed hydrological model called CANOE. The architecture of the model allows consideration of three differing hydrological functions whose combination leads to three types of hydrological units whose categories are strictly urban, semi-urban, and strictly rural. The main steps of the construction of the distributed model are described below.

Sub-basins delineation

Three criteria were used to delineate sub basins: dominant land use, an outlet located on the perennial stream network, and finally, the number of basins should not exceed 30 so as to not alter the simulation process. The number of basins we finally retained was 23 with a mean size of 5 km^2. Imperviousness was estimated by the rate of the number of urban cells on the total number of cells in a sub-basin. Each sub-basin was then attributed a hydrological class according to the following rules: basins with less than 5% of imperviousness areas were declared as rural, basins with less than 25% as periurban, and basins over 25% as urban. For this purpose, forest and grassland covers were considered as rural hydrological units. We also used a statistical plot sampling method (Chocat and Seguin 1986) to assess the sub-basins imperviousness rate directly from maps in order to avoid any bias as a result of an arbitrary human cell codification. A good linear relationship was found between the imperviousness rates we calculated from these two methods. The correlation coefficient was 84% and only dominated rural basins exhibited different values.

Model calibration strategy

To calibrate the model, we chose 3 events for each season, it was used the Nash's classical criteria. Firstly, we calibrated the parameters of rural areas (initial losses and Horton's parameters) using flow data collected at the upstream stations. Afterward we calibrated the parameters of urban areas, using flow data collected at the downstream stations. We also used flow data from two experimental catchments of some squared kilometres to test the calibrations obtained with our larger basins (50 and 130 km^2).

Validation / Statistical tests

To assess the quality of the calibration, it was decided to use a method based on the analysis of the statistical properties of the distribution of some flood characteristics. Indeed, our aim was not to construct a model able to reproduce individually each flood, but to generate two series of virtual floods, presenting the same distribution as observed ones. We based our study on an holistic flood regime description, rather than on a selection of flood events characterized by their volume and peak. For the purpose we used the so-called peaks-over-threshold method (POT) to select a partial duration series (Stedinger et al., 1992) made of the ‘n’ greatest independent observed floods. In our case the description is completed by the analysis of discharge thresholds defined by durations during which a discharge threshold is continuously over-passed (Galéa & Prudhomme, 1997; Javelle et al. 1989, 2002). These flood characteristics are called ‘QCXd’ for discharge (Q) Continuously exceeded on a ‘d’ duration. Qcxd is expressed in cubic metre per second (c.m.s-1), as a discharge. Sampling the ‘n’ greatest QCXs for several durations that encompass the basin flood dynamics, results in different sets of data that are expected to follow probabilistic laws when plotted versus their experimental frequency (Javel et al. 1999, Javel et al. 2002). Flood regimes are then summarized in terms of expected maximum intensities for different given durations. Then, classical non-parametric tests like Wilcoxon-Mann and Withney or Kolmogorov-Smirnov can be used to compare the simulated flood regimes with the observed one, and then validate the model. The nul hypothesis we retained is ‘the two flood regimes belong to the same one’ Significance levels of 10, 5 and 1% were tested, to accept or reject the nul hypothesis.

It was used the same method to compare the series of simulated hydrographs corresponding to the 1970s and the 1990s, and to assess the real influence of land-use evolution on the flood regime.

Flood risk evolution

The flood risk can be defined as the crossing of the flood hazard and of the flooded area vulnerability. In our case the objective was to get a basin scale view of the cross effect of the imperviousness increase and of the land use evolution along the stream courses. We used for the purpose a simple metric of the vulnerability which corresponds to the acceptable flooding frequency that is acceptable for a given land use. Then mean recurrence interval of 0.5, 5.0 and 10.0 years were respectively attributed to grass-land and forest, periurban and urban land uses. We can then compare the frequencies (or the mean recurrence intervals) of the flood hazard and of the vulnerability.

Floodable area boundaries were determined from a digital elevation model (DEM) analysis considering at least all grid cells connected to a water course with no more than an arbitrary given height of one meter above a stream-cell elevation. Due to the 15 meters cell size definition, this was only an approximation but the objective was to compare the vulnerability evolution between the two observed periods. We calculated for the purpose the weighted amount of vulnerability at each period multiplying the land use type vulnerability by its area.

4. Results

Some orders of magnitude

A literature review (Pherson 1974, Hollis 1975, Galea et al. 1993) gives an idea of the order of magnitude of the effects of rural to urban change in land use on the flood regime (Fig.2). The ratio between post-urbanization and pre-urbanization peak floods can reach 10 to 20 for small or frequent floods (less than one-year return period). It can reach 2 for a 100 year return period flood. Other studies show that urban and rural flow peaks can remain in the same order of magnitude for a ten-years flood event. Turning a significant part of a basin area from crops to forest land use can, in some extent, smooth the flood regimes and compensate the effect of urban growth. In our case the forest compensation effect would only concern periurban sub-basins but nor the whole basin that only changed from 5% from crop to forest.

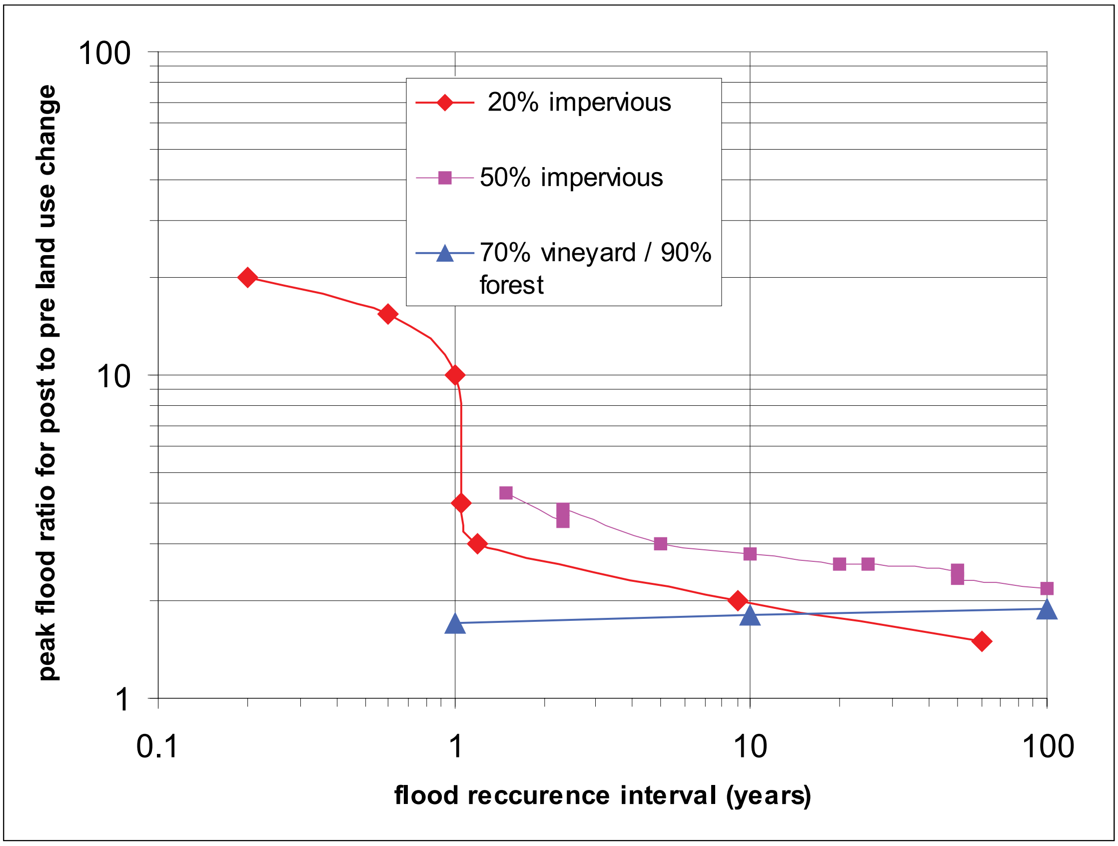

Figure 2: Some magnitude orders for flood peaks in relation to land cover change types (data collected from Hollis 1975)

Power of test analysis

To discriminate the flood regimes it was assessed the power of the statistical tests to detect independent differences between position (magnitude) and shape parameters (rate of increase with frequency) of the QCXd distribution. We observed that QCX distributions did not belong to the same flood regime since there is a 15% difference between the position parameters and a 35% difference between the shape parameters. This corresponds to small shifts between the distribution of sampled QCXs for a same duration ‘d’. The tests are assumed to be very sensitive, the Wilcoxon test being more sensitive than the Kolmogorov test in this case. Here, we only present results from the Wilcoxon. In the case of urbanization, both the position and shape parameters of the QCXd distributions are expected to change.

Model validation for the last decade

The calibration performance was assessed using the statistical tests over several ‘d’ durations of 1, 3, 6, 12 and 24 hours. These durations are representative of the flood regime dynamics. The smallest durations describe properly the peak flood form and the largest ones give a good idea of the recession part of the flood curve. We reported in Table 1 the results of the nul hypothesis with ‘yes’ if it was accepted and ‘no’ if it was rejected. The nul hypothesis was rejected for the QCX duration of 24 hours. It reveals that the calibrated model is well-fitted to the short durations representative of peak-floods and earlier urban response during events. The 24-hour duration is mainly representative of the rural discharges that sustain the flood recession curve.

Table 1: Model validation using a comparison test on observed and simulated flood characteristics

Wilcoxon-Mann-Whitney / unilateral test			
significance level			
QCX durations	**10%**	**5%**	**1%**
1h	yes	yes	yes
3h	yes	yes	yes
6h	yes	yes	yes
12h	yes	yes	yes
24h	no	no	

Comparison between pre and post urbanization periods

The two simulated flood series, corresponding to the two decades, have been compared using the statistical tests. The imperviousness rate increased by 15% over these periods. Such an increase was expected to have a significant effect on flood characteristics. Two sets of QCXd characteristics were used. The first (Table 2.a) only included the largest floods over a two-year recurrence interval, while the second one (Table 2.b) included also small floods whose frequency and magnitude are very sensitive to the urban increase (Hollis, 1975). In the first case, and in spite of the imperviousness increase, no statistical differences were observed between the flood regimes from the 1970s and the 1990s. When including the small floods, we observed that short duration QCX distributions (from 1 to 3 hours) were significantly different between the two periods. This result confirms the fact that urbanization increases mainly the frequency of small floods but does not alter large floods in a mixed land use basin where the rural area is dominant.

Table 2: Comparison tests on simulated flood characteristics from the 1970s and 1990s (a) without small floods and (b) all floods included

Wilcoxon-Mann-Whitney / unilateral test			
significance level			
QCX durations	**10%**	**5%**	**1%**
1h		yes	yes
3h		yes	yes
6h		yes	yes
12h		yes	yes
24h		yes	yes

Wilcoxon-Mann-Whitney / unilateral test			
significance level			
QCX durations	**10%**	**5%**	**1%**
1h	no	no	yes
3h	no	yes	yes
6h	yes	yes	yes
12h	yes	yes	yes
24h	no	yes	yes

Flood risk evolution

As a consequence of the land use change in the vicinity of the stream corridor the global amount of acceptable flooding return period has doubled from years 79 to 96 meaning the need for protection did it so (see table 3). Looking at figure 3 we can see the most important variations in flood peaks between the two periods relate mainly to the small recurrence interval less than 3 years. It confirmed the results presented by Hollis (1975). It can be expressed as a shift in frequency which is about one year for the 70s two years flood. If we consider the two years flood is representative of the full bank flow, it means the just flooding process as turned to an annual recurrence interval. It should not be noticeable enough. This means that at the Yzeron basin scale the flood risk has mainly increased as the result of the increase in vulnerability rather than in the flood hazard itself.

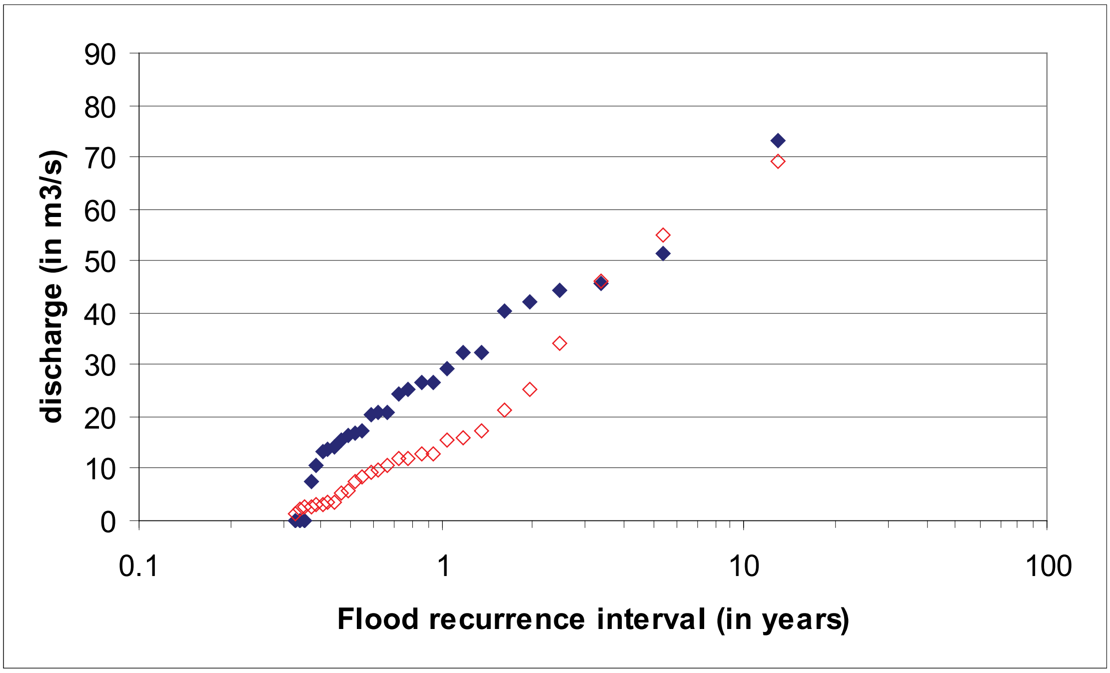

Figure 3: 70s to 90s frequency- peak flood distribution

5. Conclusions and perspectives

This research allowed us to formalize a reproducible methodology that can be used to assess the influence of land-use evolution on flood regime for mid-size catchments.

In our specific case we demonstrated that the urbanization process significantly affects frequent floods (return period less than 2 years), but does not seem to have a major influence on larger ones (return period more than 10 years) as observed in the 1990s. To avoid any effect of the evolution of the rainfall regime we used the 1990s rainfall series in our model with 1970s and 1990s land covers. It seems that, in this case, other factors must be invoked. A 5% increase in forested areas seems too few, but a 12% increase in the periurban is not, as we can expect one main effect to be acceleration of flow transfer but not reduction in rural flood production. This is quite complex to capture with a model based on distributed hydrological units. The reason is that a range of periurban types exist where the artificial and natural drainage network patterns and interconnections are determinant factors in transferring rural floods (Li and Wong 1998). As observed from table 2-b and figure 8 the periurban development mainly affects the frequent floods. This means that mainly the transfer of water is speeded and that the water volume is not affected. Simulations not presented here with an imperviousness rate of 43% planed on 2025 indicate a drastic change in flood hazard : the one year flood observed in the 90s becomes a 10 years flood. The urban expansion was based on the diffuse growing of the imperviousness like for the observed periurban development. This indicates the flood hazard increase do not follow a linear process during the periurban development. A key challenge would be to define hydrological signatures corresponding to typical periurban developments.

Climate Change in Serbia and Impact on Water Resources

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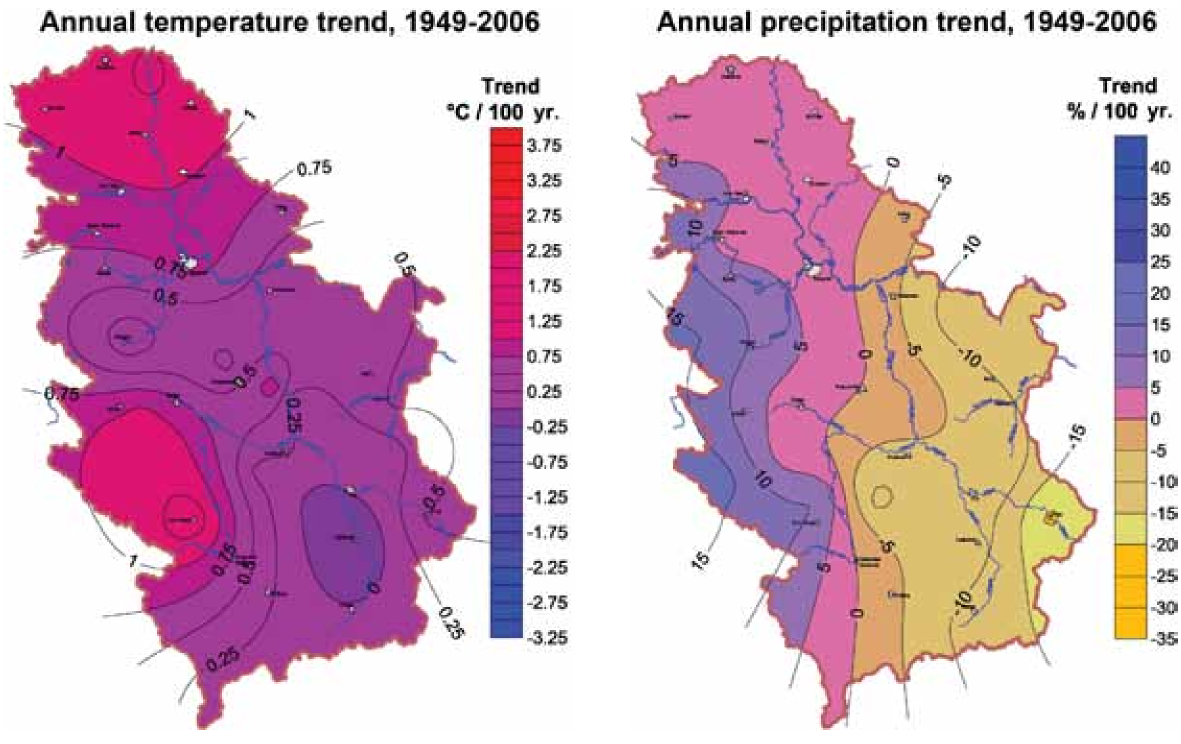
Abstract

During the past ten years, Jaroslav Černi Institute for the Development of Water Resources conducted numerous studies of recorded temperatures, precipitation levels and river discharges in Serbia, and established certain significant correlations between them. The outcomes of these efforts are largely consistent with globally observed trends, but our region exhibits certain specific features and even differences, which are important, above all, from a water management planning perspective.

With regard to climate parameters, the **average** recorded upward trend of mean annual temperatures in Serbia is about 0.6 °C/100 years, where a higher trend was noted in the high-altitude (mountainous) areas and in the north of the country (occasionally exceeding 1°C/100 years). The lowest trend was recorded in southeastern Serbia (about 0°C/100 years). During the year, a downward temperature trend was noted in the fall, while the other seasons exhibited an upward trend.

The **average** recorded trend of annual precipitation totals in Serbia is about 0 to mildly negative, but the geographic distribution of this trend varies. A distinct upward trend was noted in the (south)western part of the country and a downward trend in the eastern part. In most of Serbia it was within +10%/100 years. A distinct upward trend shift during the year was recorded in the late summer/early fall, and a downward shift during the winter months and in May.



Recorded annual temperature and precipitation trends in Serbia (1949-2006).

It is important to keep in mind that climate change involves events coupled with a significant degree of uncertainty. The recorded changes involve **moderate uncertainty**, while future events entail **considerable uncertainty**, particularly in the long term.

The observed hydrological trends match the recorded climate trends rather well. Still, it should be kept in mind that river discharges depend on a number of factors. Climate change is only one of them, noted at all river gauging stations, but its level of significance varies (it is ubiquitous, but in the eastern part of the country it is generally dominant, while elsewhere it is not major or is occasionally even minor). The average recorded downward trend of mean annual river discharges in Serbia is about -30%/100 years. Consistent with the distribution of the precipitation and temperature trends, the smallest river discharge trend shifts were noted in the southwestern part of Serbia, and the largest negative shifts in the eastern part.

In general, during the low-flow season (July-October), the recorded trend was much lower (close to zero), as a result of an upward precipitation trend during these months and often due to the existence of a reservoir upstream from the gauging station, which evens out the annual flow rates. There has been no steady increase in the number of months with minimum monthly river discharges. However, this does not mean that such a trend will not be noted in the future (if temperature continues to increase), particularly at gauging stations where there are no upstream reservoirs.

It seems clear that water management planning must take into account the recorded trends and observed phenomena.

If in addition to the river discharge trend there is a periodicity of, say, 15 dry years followed by 15 wet years, then drought issues are likely in the near term.

Annual and monthly data were compiled and analyzed → flood trends were not assessed.

Keywords: climate change, temperature, precipitation, water resources, river discharges.

Stochastic Structure of the Forming Process of the River Runoff on Rivers with Longest Time Series in the World

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Abstract

Modern hydrological practice requires relatively reliable knowledge of the internal structure of the development of hydrological processes in time. This is primarily related to the uncovering regularities related to dry and rainy periods/years, the knowledge of which is of great importance for the development of a long-term strategy of development of certain areas, particularly in the areas of water use (accumulations), agriculture, hydropower and so on. Latest announced and expected climate changes only enhance this type of analysis. Sudden changes in some climatic parameters result in a change of character of basic stochastic hydrological time series during multiyear time period. This is primarily related to the appearance of a more pronounced trend in the mean value of the considered stochastic time series or change in the parameters of the periodic (cyclic) components of the series, such as cyclic periods, amplitudes or phase shift.

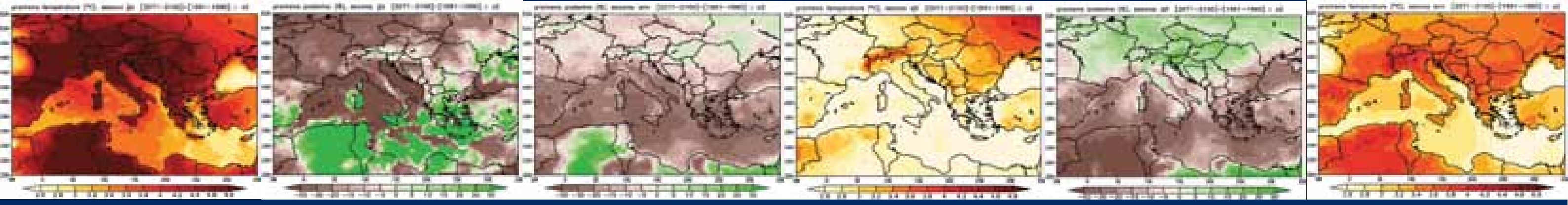
The subject of this paper is to analyze the stochastic structure of available hydrological registered longest series in the world. In this case, we consider hydrological time series that represent the principal characteristics of the water regime which are average annual flow time series.

All computational procedures that were used in this study are based on the practical application of correlation and spectral theory of random processes. The basic elements for the detection of the internal structure of these time series processes of river runoff represent calculation results with the following characteristics: determining the existence of a trend in the series under consideration, then period graph and spectral analysis. The purpose of these calculations is to expose the (non) existence of natural and anthropogenic trends in very long time series of mean annual flow, as well as to identify possible trends caused as a result of climate change. Correlation and spectral theory, and period graph analysis with the results of the analysis of the Fourier transformation, should suggest the existence of a cyclic components in the considered flow series, identify possible violation of the same, with the assessment of the possible causes.

Due to the limited space of this paper, all the time series were analyzed in terms of the identification of current trends and cyclical components. In this regard, an outline of the methodology applied for stochastic identification of these characteristics is given to assess their statistical significance, which is trend in the mean value and cyclic periods. After defining cyclic periods in a hydrological series should be cyclic component should be excluded, i.e. detracted from the basic series in which the component of the trend was previously excluded. The series keeps only random component, which basically has mean value of zero, and the values of random variables are mutually independent and equally distributed.. This type of analysis is not the subject of this paper.

For practical application of the methodology developed, longest available time series of mean annual discharge are selected from the whole world. A total of 27 selected streams, with 29 gauging stations: 10 rivers in Europe (11 gauging station) in Africa, 4 streams (4 g.s.), in North America 3 rivers (4 water g.s.), in South America 3 rivers (three g.s.); 4 rivers in Australia (4 g.s.) and in Asia, 3 rivers (three g.s.). Available lengths of the period of observation are different from continent to continent. Water gauging stations with the longest observations are located in Europe, Germany – g.s. Koeln at the river Rhine (193 years) and Lithuania – g.s. Smalinikai on the river Nemen (192 years) while the shortest periods of observations were in South America in Argentina – g.s.Timbues on the river Parana (90 years).

Keywords: stochastic processes, time series, the structure of the time series, correlation theory, spectral analysis, period graph, trend in the mean value, periodicity, cyclic periods, mean annual flow, the Earth.

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