



Experimental research on the effective water abstraction permitting regime

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Abstract: Modelling and analysis of water rights become more and more important for the adaptation to the changing management conditions of the water resources in river basin, considered as an integrated system, where the water consumers are interconnected. A measure in this sense is the development of a science-based water abstraction permit regime, consistent with the objectives of the Water Framework Directive 2000/60/EC (WFD) and the River Basin Management Plans (RBMP). The main point of the procedure is the development of an assessment tool granting water right through mathematical modeling of water distribution in a certain watershed, clarifying the degree of supply of the requested volumes and the free volumes for satisfaction of future needs. For the first time in Bulgaria a new methodological approach is proposed, based on research and analysis of foreign and own experience, including distribution of water resources, water rights analysis and estimation of free water volumes. For its practical application is selected SIMYL simulation model, developed by the former Institute of Water Problems at the Bulgarian Academy of Sciences and further modified for the purpose. The experiments carried out for the real pilot basin of Tundja river prove the contribution of the approach for taking an informed decision about a certain water request, as well as for reassessment of the current permit system, and for a risk assessment of water deficits in the river basins designated in the RBMP.

Keywords: permit regime, water abstraction, water right, methodological approach, assessment tool, integrated water management

1. INTRODUCTION

The long-term protection of the subjected to significant pressure water resources considering the increasing water consumption, taking into account the needs of aquatic

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ecosystems, changed climatic factor and intensive pollution of water resources is more frequently a subject of scientific studies, adaptive strategies, plans and programs with active public participation. For that reason, the UN designated the decade 2005÷2015 under the motto „Water in Life“ to stimulate the coordinated international activities in the field of water, and the European Water Framework Directive 2000/60 defined objectives of reaching good water status by 2015 (*WFD, 2000*). This goal, though more focused on the water quality, requires an understanding of the institutional and hydrological accessibility to water and prevents the exhaustion of the water resources, affecting the amount as an integral part of the overall status. A main tool for realization is an adequate program of measures containing different types and kinds of measures in these two main aspects. Such a program is already a fact with the entry into force in March 2010 of the first River Basin Management Plans (*RBMP EABD, 2010*) in Bulgaria.

Exceptfore being planned as a key measure for reduction of the pressure on water resources, an additional reason for developing of an effective permitting regime for water consumption in Bulgaria is the subjectivity in its current implementation. Defined as a system of legislative rules and conditions, and an assessment tool supporting the decision makers (DM) or institutions in allowance or denial of water right, this regime is on the basis of the integrated water management.

The practical solution of the measure includes water distribution based on the issued permits with an evaluation of the available water resources satisfying the existing needs and determination of the free (not used) water volumes for exedance probability of future requests for water abstractions (*Wurbs, R., 2005, 2009; Wang, L., L.Fang, K.W.Hipel, 2007*). Moreover, regarding the complex configuration of the water systems, their stochastic and dynamic nature, and the numerous water consumers, the decision requires an application of a mathematical modeling, flexible priorities of water abstraction, ecological (recognition of the ecosystems as a fully legitimate consumer) and economic (“water consumer pays“) principles (*WFD, 2000*).

The such created permitting regime will identify the water users and their water shares with the corresponding probabilities of exceedence as well as the inclusion of new users, the changes in the type and amount of water consumption, and/or in the variance of river flow.

In the current paper, through experimental studies within a real water management system (WMS) in Bulgaria, the one of Tundja river basin, is proved the feasibility of the proposed methodological approach and the mathematical model, mainly for improvement and efficiency of the procedure for issuing permits for water abstractions.

2. SUMMARY OF THE APPROACH OF PERMITS ISSUEANCE

In the basis of the proposed methodical approach on a decision making for water abstraction permits issuance through justified coordination of the requested demands with the available water resources or, for modeling of the water rights at a basin/sub-basin level stands the decision

of a three-stage task with the following *formulation*: in a certain situation - available water resource in a basin/sub-basin or river section with preliminary set priorities for water use to specify how (under what conditions) and how much (annual limit or water share) should be permitted from the requested target abstraction in such a way that the ecosystems are preserved. Similar problem is already solved (*Wurbs, R. and WBWalls, 1989; Wurbs, R., 1996*), but with different formulation, other legal framework and with another mathematical model.

The solution includes:

First stage: Distribution of water resources.

Based on the distribution of the available water resources between water users and water consumers in a certain watershed, taking into account the abstraction priorities, is intended to clarify the extent of the provision of the requested demands for water and not requested free volumes in separated river sections, as well as the availability/deficit of ecological flow and the way of functioning of the WMS. Through repeated simulation experiments under different scenarios of water use a reasonable distribution of water resources for all users from the point of view of the DM can be achieved.

Second stage: Analysis of the submitted requests for obtaining of water use right based on the results from the first stage.

In case of a disagreement of the applicants with the results from the first stage or a doubt from the controlling body about the reliability of the requested abstraction amounts and/or a negative impact on the environment and neighboring users, an additional information supporting the request is required. Thus, analyzing the new data in interactive regime both parties may agree to correct the limits. The results from the new water distribution will show if the taken decision is a basis for the provision of water use right, and if it is not, a refusal or further discussion follows. In such a way every next change, for which there is a ground and agreement, is associated with a new simulation and evaluation.

Third stage: Determination of the unused water to cover additional requests.

Simulations of different variants for the water use and water resources availability is meant to give a general assessment of the free volumes in a basin/sub-basin/water body levels and the estimate „For“ or „Against“ a particular request, taking into account the interconnectivity between the users in a particular watershed, requires the implementation of the first stage.

For solving the problem is used the SIMYL simulation model, developed by the Assoc. Prof. Eng I. Nyagolov, successfully applied for distribution of water resources within a certain river basin. A graphic diagram of the WMS (water users, river and monitoring network, water abstractions with the type of water use and the related infrastructure) is made up first for the model, based on the computing (network model). The latter is a directed graph - a system of nodes and arcs, where the nodes are the points of the tributaries inflow into the main river, the discharge of wastewater and the returning water, the abstractions and the reservoirs as components of the water resources and water use. The arcs (canals, river sections, tunnels, pipelines, etc.) are the connections between the nodes. In order to represent adequately the real system, parameters and

constraints are set for the particular elements of the model, such as reservoirs volume, permitted water amounts, water-carrying capacities of the installations, priorities of the reservoirs and water users, determined by their usefulness.

Criteria for analysis and evaluation of the results in water distribution modeling are mainly the probability of exedance probability by years, months and water volumes for the respective user, and the occurrency of water shortage or deficit.

$$P_y = k/n * 100 \%, \quad (2.1.)$$

$$P_m = l/12n * 100 \%, \quad (2.2.)$$

$$P_v = V_1/V * 100 \%, \quad (2.3.)$$

where k – number of years and months without disturbance in water use; n – total number of years and months for the research period; V_1 – discharged volume and V – necessary water volume.

The same criterion, but called “reliability” (used by (Wurbs, R., 2005), R – reliability) is used in the Western-European publications in water rights modeling and it is calculated in the same way:

$$R = n/N, \quad (2.4.)$$

where n is the number of the months without disturbance in water use, and N is the total number of months for the research period.

Regulatory exedance probability (Pr) is given by years. It is different for each consumer and generally it is estimated by the economic evaluation of the losses of a particular enterprise, hydropower plant, irrigation system (IS), fish farms etc., due to the water deficits. Depending on the category of water supply system and the functional type of the settlement, the exedance probability for domestic and industrial purposes is normatively defined in (*Ordinance № 2/22.03.2005 for design, construction and operation of water supply systems*), varying from 95% for the first category and settlements of I and II functional type, 90% for the second category and settlements – III and IV functional type, to 85% for the third category and settlements – V to VIII functional types. For the irrigation water economic practice has proved $P_r = 75\%$ and for the Hydroelectric power plant (HPP) operating in an independent mode – 85%. The lower values of the exedance probability in the irrigation can be explained by the possibility of yield in dry conditions, and in the hydropower production can be explained with the possibility of substitution with Thermal power plant (TPP).

General prerequisites, assumptions and constraints of the solution:

- The hydrology of the basin is represented by the available hydrological time series for a past period assuming that it is valid also for a future period. This concerns also the data for the evaporation from reservoirs. If a climatic scenario is applied, new estimates are used for the water quantities, water use and evaporation;
- The series for the water flow are those for undisturbed (natural) flow;
- To provide data for the water flow in the nodes without information from gauging stations are used different hydrological methods and tools such as transposition of the runoff from the HMS etc.;
- From the groundwater sources are considered those located in the river terraces (floodplains), interconnected with the surface water flow;

- The issued permits are the main source of data for water consumption and therefore specified quantities are set;
- In case of water shortages in a particular node the needs are satisfied by stages according to the Bulgarian Water Act;
- To decrease the dimensionality of the task, the smaller water users are grouped into a particular node;
- The ecological water flow after the abstractions is ensured;
- The requirements of Article 62 of the Water Act (WA) regarding the new water abstractions are observed, considering the provisions of the current RBMPs, public interests and acquired water rights;
- The interval of calculation is one month;
- The new requests for water should not cause changes in the so set permitting system.

3. EXPERIMENTAL STUDY

3.1. Summary characteristics of the pilot basin

Tundja River is 390 km long, springs from the Central part of the Balkan mountain east to the Peak of Botev and being the largest tributary of Maritsa River, flows into it on Turkish territory. The catchment area is 7884 km², occupies 22% from the East Aegean region and 7% of the Bulgarian territory. The relief is hilly to flat in the western part of the basin, mostly flat in the middle and slightly hilly in the south, and the climate varies from humid continental in the western part to Mediterranean continental in the south.

River and hydrometric network – the tributaries of first order are 44 with a total length of 393,9 km, as the larger ones are: Mochuritsa, Sinapovska and Popovska, and hydrometric and meteorological gauging stations are respectively 14 and 28 (Fig. 1).

Water resources – the river flow calculated for the representative 44-years period – 1961÷2004 as an annual value for the main river at Kalofer station compared to that at the border with the Republic of Turkey should change as follows: the minimum from 7,27.10⁶m³ to 524,25.10⁶ m³; average from 14,82.10⁶ m³ to 1256.10⁶ m³ and the maximum from 30,43.10⁶ m³ to 2254,64.10⁶ m³.

The analysis of the results shows that monthly distribution of the water flow through the year is similar to the rainfall patterns, as for the above mentioned period it is indicated a decrease in the values of the minimum monthly flow compared to the period 1961÷1998 (*Water use and water resource balance of the Tundja River Basin, 2006*).

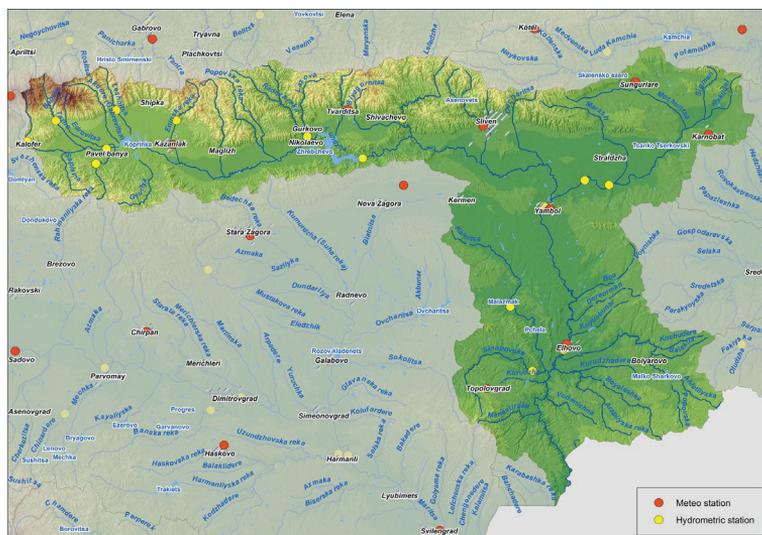


Fig. 1 – Tundja River Basin

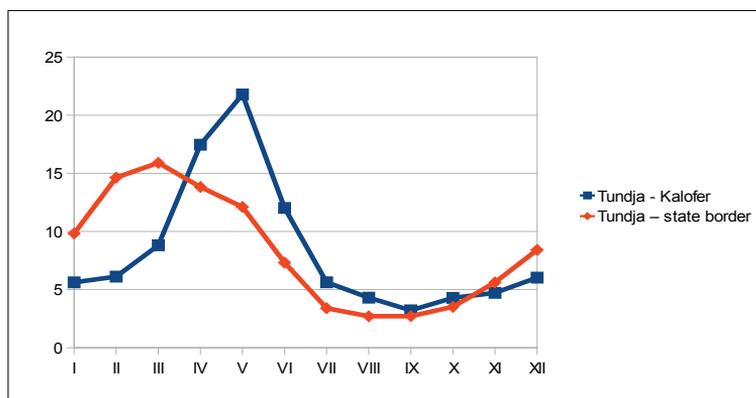


Fig. 2 – Percentage distribution of Tundja river water flow by months through the year at two stations in the period 1998÷2004

In the main aquifers of the basin is generated 8085 l/s natural flow in total, belonging mainly to the alluvial and proluvial formations and 4995 l/s exploitation groundwater resources (pore water), which is almost 10% from the average multiannual flow of the river.

The population in 2008 was 19% from that of the East Aegean region and almost 6% from the population of Bulgaria. According to the realistic forecast it is expected to drop with 21% by the year 2027.

Economy – priority economic sectors are agriculture and industry, represented by the following sectors: chemicals, metals processing and textiles.

A *specific feature of the river basin* is the transfer of significant water amounts of surface and groundwater from Tundja river basin into Maritsa River basin for the irrigation and industry needs in the regions of Stara Zagora and Nova Zagora, into the Danube region for drinking water supply of the town of Tryavna and back from the watershed of Kamchiya river (Black Sea region) into the catchment area of Tundja river for irrigation.

The main river is hydrotechnically assimilated and there are some hydrotechnical constructions at its larger tributaries – Asenovska, Mochuritsa and Popovska rivers. From a total number of 259 reservoirs (state and municipal property), complex and important according to the Water Act are Koprinka, Zhrebchevo, Asenovetz and Malko Sharkovo.

3.2. Water consumption and water rights

The nature and the amount of water consumption are determined by the economic and demographic development of the region. In this case, to study the dynamics of the water rights in Tundja river basin, a comparison is made between the water consumption up to 2004, considered as the base (reference) time period for the existing water users and the issued permits in the period 2004÷2008, considered as new ones.

Through review and analysis of 279 permits for water abstractions from surface and groundwaters (in the river floodplains) issued by BDWM of EAR – Plovdiv till 2008, are identified the new significant water consumers with permitted annual limit of over 150 thousands m³ and a great number of small water users. This allows to set an updated diagram for the water consumption in the studied river basin.

The biggest water consuming sector is the irrigation, with four major irrigation systems (Kazanlak, Stara Zagora, Central Tundja and Bolyarovo) and a number of smaller systems and fields. In the period 2004÷2008 are localized eleven new users joined to five of the existing irrigation systems.

The next big consumer is the household sector, provisioned primarily by groundwater sources – wells (united in water supply groups), constructed mainly around the big towns of Kazanlak, Sliven, Yambol, etc. Surface water sources are few – Asenovetz reservoir and several river intakes for partial water supply of the towns of Kalofer, Tvarditsa, Shivachevo and some smaller settlements. The dynamics of permits issuing for water consumption in this sector in the considered period shows an increase, taking into account ten new water requests and update of the annual limit of two existing users.

The industrial consumption is concentrated mainly in the large urban centers – Kazanlak, Stara Zagora, Sliven and Yambol. It is provisioned mostly from groundwater sources and has a considerable share from the total consumption in the river basin. In the period 2004÷2008 an increased intensity of the permitted requests for water consumption is observed but also a dropping out of one of the major consumers – nitrogen fertilizer factory (NFF) Stara Zagora. The availability of six fish-breeding farms by 2008, the bigger ones from which are near the towns of Nikolaevo and Yambol determines the

fish-breeding as a priority sector of the industry in the region. The industrial users in total by 2008 are with 41 more compared to 2004.

The hydropower production, considered as a water consumer, is not typical for the basin. It is represented by five hydroelectric power plants (HPP) and the significant ones are: „Koprinka“, „Stara Zagora“ and „Zhrebchevo“, operating in subordinated mode, due to the complex nature of the reservoirs and the prevailing irrigation. HPP „Taja“ and „Enina“ are daily compensators and work in energy regime only.

Water consumption and water use in the key sectors and in total for Tundja river basin in number, and the permitted annual limits in the considered two time periods up to 2004 and up to 2008, are presented in Table 1. The graph in Fig. 3 shows the abstracted water volumes in main sectors without hydropower.

Table 1 – Number of the water consumers and users, and permitted limit in the Tundja River Basin

Main sectors	Number of water consumers and users - 2004	Number of water consumers and users - 2008	Permitted limit - 2004 (m ³ /y)	Permitted limit - 2008 (m ³ /y)
irrigation	24	35	226735324	227508301
household water supply	40	50	92529192	96777468
industry	111	149	78898372	54318466
ish-breeding	3	5	10336984	11262694
hydropower plants	7	7	391500000	391500000
Total	185	246	799999872	781366929

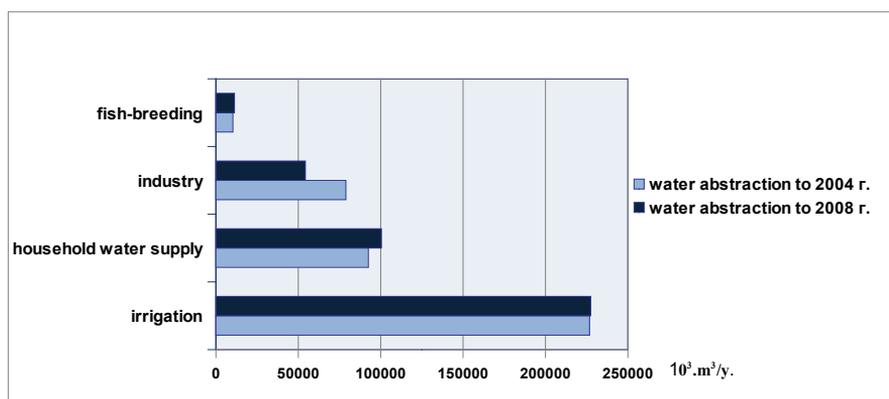


Fig. 3 – Water abstraction (without hydropower) in the Tundja river basin - 2004 and 2008

In conclusion, it can be summarized that water consumption in 2008 compared to 2004 shows an increase in household water consumption with 8,60%, for fish-breeding –

8,96%, for irrigation – 0,34% and for industry, a decrease of 45,25% due to the dropping out of NFP – Stara Zagora.

3.3. Modelling of the water rights in Tundja river basin

In accordance with the principle formulation of the problem (defined in section 2) and considering the referred in 3.1. available water resources and water consumption in Tundja river basin, formulation of a well-grounded estimation „For“ or „Against“ particular water demand includes:

- • *First stage*: water distribution between all permits in the watershed according to their needs and available water resources;
- • *Second stage*: analysis and estimate of the submitted water requests based on the results from the first stage;
- • *Third stage*: estimation and current updating of the free water resources in order to assess the compatibility with the new (future) requests for water consumption or possible redistribution of the water rights. How and to what extent will be affected the water consumption with the change of the climatic conditions is considered as a variant of the current task.

3.3.1. Compilation of graphical and computational diagram

Based on the latest data for water anstraction and water rights in the studied river basin, according to section 3.2., the graphical diagram of the consumption and use of water resources in the basin (Fig. 4), using the primary diagram from (*Water use and water resource balance of the Tundja River Basin, 2006, Niagolov, I, et al. 2007*) reflects the changes in the configuration of the water economic diagram up to 2008. To simplify the diagram, but without disturbing the adequate representation of the real WMS, an aggregation of the water consumers is done and, where possible, some of the new users (shown with dotted line) are added to the existing ones by amounts, while others are independently set at particular places. This diagram is based on the computing scheme or so called network model with 138 nodes and 143 arcs representing the real WMS. Part of it is shown in Figure 5 as the new users and the changes in the water consumption are shown in *Italic* or with dotted line.

3.3.2. Input information

The data required for the program input files by the nodes of the network model concerns, as already mentioned, water consumption and water flow. Water consumption by nodes in the two time periods is shown in Table 2 and part of it is presented with the changes. For the calculation of the surface runoff were used time series of 44-years for undisturbed monthly runoff in the period 1961÷2004, and for the calculation of the groundwater flow are used the data from the permits for the local exploitation resources.

In both points: after PS (Pump station) "Yagoda" and after Zhrebchevo reservoir are set the ecological water quantities according to the existing Water Act with the respective annual value and monthly distribution.

The modelling with a computational interval of one month was implemented by the simulation program SIMYL and the specified criteria given in section 2 were used for the assessment of the results.

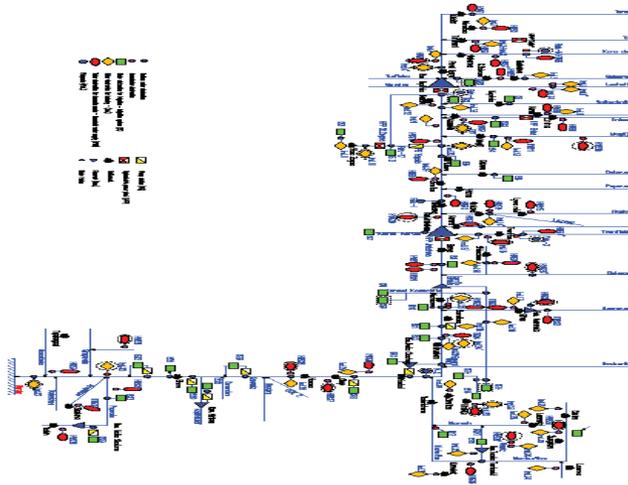


Fig. 4 – The graphical diagram of the allocation, consumption and use of water resources in the river basin of Tundja

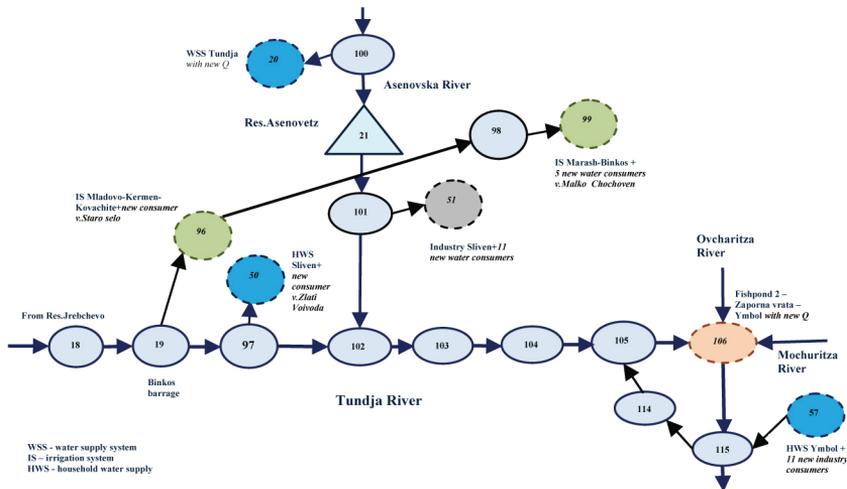


Fig. 5 – Network model of the river section after Zhrebchevo reservoir to the town of Yambol

Table 2 – Water consumers and permitted annual limit by nodes for both time periods – 2004 and 2008 (extract)

No node	Representation nodes	Water consumer	Permitted annual volume 2004 (m ³)	Permitted annual volume 2008 (m ³)
1	Tundja1+HWS 1	Household water supply of t.Kalofer from Tundja river	473040	473040
3	Tundja+HWS4+Ind.4+Ind.4'	1. To Household and industry water supply of t. Pavel Banya from GW + <i>new household water supply of villages around Pavel Banya from Sokolitza river</i> – 1261440 m ³ /y; 2. To industry water supply of Hospital Pavel Banya from GW; 3. <i>New quantity for a fishpond do Kumaks from SW</i> – 225710 m ³ /y.	956420	3991010
8	Tundja+ Irrigation 2	To IS Kazanlak + 3 new consumers from GW – 44 053 m ³ /y	14224600	14267200
138	Fishhold 4 (new)	New Fishhold of a company Throne near the v. Koprinka	0	178000
17	Tundja+Q ecol. 2	environmental needs Jrebchevo reservoir	67200000	67200000
20	HWS 21'	WSS «Tundja»– city Sliven <i>with new Q</i>	3600000	4730400
21	Res.Asenovec+HWS 21	Household water supply of Sliven from Asenovetz reservoir	15000000	15000000
24	Res.M.Sharkovo1+Irrigation 23	IS Bolyarovo	9440200	9440200
31	Irrigation 26	To Irrigation of Rouz Treiding + <i>new consumer in v.Gabarevo</i> – 78 000 m ³ /y	47000	125700
36	Ind.10+Ind.11	1. To industry water supply of t.St.Zagora + <i>new consumer</i> – 68 700 m ³ /y; 2. <i>Nitrogen fertilizer factory with 31 m³/y - dropped</i>	34103900	3172600
51	Ind.17	To industry water supply of Sliven + <i>11 new consumers from GW</i> – 5141845 m ³ /y + <i>new from SW</i> – 687000 m ³ /y	4203348	5828845
52	HWS.24+Ind.24' (new)	1. To industry water supply of Sliven and v.Krushare + <i>new household water supply of v.Panaretovci from GW</i> – 25550 m ³ /y; 2. <i>New industrial consumer from GW in v.Gergevec</i> – 394200 m ³ /y.	610000	1029750
54	Ind.23+ Ind.28	To industry water supply of t.Straldja + <i>new industrial consumer from GW in v.Devetak</i> – 65897 m ³ /y	200284	266181

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56	<i>HWS35+Ind. 21+Ind.29+Ind.34</i>	1. To Household water supply of t.Sungulare + <i>new household water supply of v.Lozarevo from GW – 110376 m³/y</i> ; 3. To industry water supply of t. Sungulare + <i>2 new consumers – 22862 m³/y</i> .	110090	243328
57	HWS 26+ <i>Ind.25</i>	1. Household water supply of city of Yambol; 2. To industry water supply + <i>new 11 consumers from GW – 771742 m³/y</i> .	18953989	19725731
136	r.Karadere+ <i>Fishhold 5 (new)</i>	<i>New Fishhold of a company GIV on the Kara dere river</i>	0	225710
88	Tundja+ <i>HWS 39 (new)</i>	<i>Household water supply of t. Nikolaevo from GW – new consumer</i>	0	227059
89	r.Lazova+Ind.14'	Industry water supply of Gurkovo	121255	121255
93	r.Belenska+ <i>HWS20'</i>	To Household water supply of t. Shivachevo + <i>new household water supply of v.Sborishte from Dolap dere river – 110376 m³/y</i>	158000	268376
99	<i>Irrigation 14</i>	To Marash-Binkos IS + <i>5 new consumers from GW in v.Malko Chochoven – 117911 m³/y</i>	57212300	57784400
112	<i>HWS 25</i>	To Household water supply of t. Straldga+ <i>2 new consumers from GW in v.Devetak and v.Zimen – 118475 m³/y</i>	431011	549486
125	<i>Ind.35 – (new)</i>	<i>New industrial consumer from GW– v.Boyanovo</i>	0	59570
126	Irrigation 23	IF Dobrich	1311000	1311000
133	Tundja+ <i>Ind.27</i>	To industry water supply of v.Ustrem + <i>new consumer – 1500000 m³/y</i>	120000	1620000

Note: In *Italic* are shown the data from the new permits up to 2008, including; SW – surface water; GW – groundwater

3.3.3. Basic assumptions of the solution

Considering the general assumptions and limitations mentioned in section 2, the particular practical solution is based on the following assumptions:

- Water consumers with the permitted water volume in the first time period – up to 2004 are considered as existing ones and this variant is taken as a reference one, while those in the second time period – up to 2008 are considered as new ones and the requested by them water amounts will be a subject of analysis and evaluation based on the results from the simulations;

- The priorities set in the model correspond to the given normatives in the Bulgarian Water Act (Article 50, paragraphs 4 and 5);
- Twelve (12) coefficients accounting to the seasonal fluctuations in water consumption are determined through analyses.

In the experiment, considering climate changes, is accepted a conditional decrease of the water runoff with 8% due to the lack of a climate scenario for drought.

3.3.4. Simulation experiments for the basic solution of the task

- **First Stage:** Includes two variants of water distribution between all permits in the pilot river basin, corresponding to the two time periods.

In the first variant are considered the existing water consumers up to 2004, and in the second one are added newly requested volumes up to 2008. After setting the water consumption in the model with the permitted annual limits from the Table 2, simulations of the water distribution are carried out. The obtained results are presented consequently in excerpts from Table 3 (the first variant) and 4 (second variant), and analyzed.

Table 3 – Results from the first variant – First stage (excerpt)

№ node	Representation nodes	Water consumption by nodes - 2004 (*10 ² m ³ /y)	D1 (*100 m ³ /y)	P1 (%) ^v	P1 (%) ^v	P1 (%) ^m
3	Tundja+HWS 4+Ind.4+Ind.4 ⁷	9546	0	100.00	100.00	100.00
20	HWS 21	35998	955	97.35	45.45	90.91
21	Res. Asenovetz	150000	483	99.68	97.73	99.62
24	Res.M.Sharkovo1+ Irrigation 23	94402	3751	96.03	97.73	98.45
36	Ind.10+Ind.11	340908	1368	99.60	95.45	99.43
51	Ind. 17	42033	0	100.00	100.00	100.00
52	HWS 24	6098	0	100.00	100.00	100.00
54	Ind. 23+ Ind. 28	2001	12	99.40	93.18	99.24
56	Ind. 30	1099	0	100.00	100.00	100.00
57	HWS 26+Ind. 25	189540	0	100.00	100.00	100.00
77	Irrigation 3 P-17	96460	1199	98.76	93.18	98.70
78	Irrigation 3 M1-M2	439444	26468	93.98	93.18	97.08
89	r.Lazova+Ind.14 ^c	1212	24	98.02	81.82	97.73
93	r.Belenska+HWS 20	1582	6	99.62	93.18	99.24
99	Irrigation 14	572123	0	100.00	100.00	100.00
133	Tundja+Ind. 27	1197	0	100.00	100.00	100.00
134	r.Ovcharica+HWS 37	44472	1159	97.39	77.27	94.89

Explanations of the designations in the table and the subsequent tables of results: D1 is average multiannual water deficit, P1_v – average multi-annual reliability by volume,

$P1_y$ – average multi-annual reliability by years, $P1_m$ – average multi-annual reliability by months the number after D and P indicates the subsequent number of the experiment (in this case it is 1, as it refers to the first experiment).

Table 4 – Results from the second variant – First stage (excerpt)

No node	Representation nodes	Water consumption by nodes - 2004 (*10 ² m ³ /y)	D2 (*100 m ³ /y)	P2 _v (%)	P2 _y (%)	P2 _m (%)
3	Tundja+HWS 4+Ind.4+Ind.4'	39909	0	100.00	100.00	100.00
8	Tundja+ Irrigation 2	142672	439	99.69	95.45	98.94
138	Fishhold 4 (new)	1780	0	100.00	100.00	100.00
20	HWS 21'	47305	2837	94.00	15.91	79.92
21	Res. Aenovetz	150000	1252	99.17	97.73	99.05
24	Res.M.Sharkovo1+ Irrigation 23	94402	3751	96.03	97.73	98.45
31	Irrigation 26	1257	40	96.82	93.18	97.17
36	Ind.10+Ind.11	31716	300	99.05	95.45	99.05
39	HWS 7+ Ind.7	63250	0	100.00	100.00	100.00
43	Ind.32	3003	29	99.03	95.45	99.03
47	HWS 17+Ind.15	5479	52	99.05	95.45	99.05
50	HWS 22+Ind.22 (new)	33448	0	100.00	100.00	100.00
51	Ind.17	58288	0	100.00	100.00	100.00
52	HWS 24+Ind.24' (new)	10298	0	100.00	100.00	100.00
53	Ind.30+HWS 30' (new)	1716	13	99.24	97.73	99.24
54	Ind.23+ Ind. 28	2658	93	96.50	72.73	95.64
56	HWS 35+Ind. 21+Ind.29+ Ind.34	2432	0	100.00	100.00	100.00
57	HWS 26+Ind.25	197256	0	100.00	100.00	100.00
77	Irrigation 3 P-17	96460	1417	98.53	93.18	98.38
78	Irrigation 3 M1-M2	439444	21330	95.15	93.18	97.40
93	r.Belenska+HWS 20'	5605	63	98.88	86.36	98.48
96	Irrigation 9	177749	0	100.00	100.00	100.00
99	Irrigation 14	577844	1856	99.68	97.73	99.35
112	HWS 25	5494	93	98.31	81.82	97.16
113	r.Mochurica+ Irrigation 17	2790	0	100.00	100.00	100.00
125	Tundja+Ind.27	720	0	100.00	100.00	100.00
133	Tundja+Ind.27	16200	0	100.00	100.00	100.00

Note: In *Italic* are given the added nodes for the new water consumers by the end of 2008 and the new nodes.

Analysis of the results from the first experiment:

- The permitted water consumption for irrigation is almost entirely satisfied, i.e. 2/3 of the water rights of the users are provisioned at 100% and the rest at 98% ÷ 93%. There is a higher average multiannual deficit for IS “Bolarovo” (node 24), and especially for IS “Stara Zagora” – 27667.10² m³ (nodes 77 and 78);
- The most significant variations are in the permits for the household water supply, as fully satisfied with water are 71% of the water demands, 21% have an annual exedance probability – 98÷93% and for about 9% it is below 77%. To the latter refer household water supply of the town of Sliven from the WMS Tundja (node 20) and that of the settlements from Sliven Municipality at Ovcharitsa river floodplain (node 134), which due to their disturbance for the first case in 24 years, and for the second case in 10 years of the 44-year studied period and respectively 48 and 26 from total 528 months (134) are determined as risky;
- In the *industry*, the water rights of 72% of 111 consumers are fully supplied with water, the rest 28% are disturbed slightly (92%÷98%). Of lowest annual reliability – 82% is the industrial water supply of the town of Gurkovo in the catchment area of Lazova River (node 89).

Thus summarizing the reliability of the permitted water consumption in the first time period – up to 2004, it can be concluded that, with few exceptions for the drinking water supply, it is sufficient. Yet some conditions should be included in the permits – introduction of water efficiency and annual re-estimation of the permitted limits based on the presented by the holder at the beginning of the year report for the previous year and plan for the upcoming year.

Analysis of the results from the second simulation:

- The addition of 11 new irrigation fields to the existing irrigation systems – IS “Kazanlak” and “Mladovo-Kermen-Roza”, and IS “Rose Trading”, “Terra Agro” and Binkos-Marash (nodes 8, 96, 31, 113 and 99), changes insignificantly their reliability. But here, besides the presence of the highest average multi-year deficit for the same as in the first experiment: IS “Bolyarovo” and “Stara Zagora”, a new one appears for the irrigation of “Marash-Binkos” IS (node 99), considering the new areas in Malko Chochoveni village. Therefore, compared to the first variant for satisfaction of the needs of the water users for the irrigation no significant changes were observed;
- With the inclusion of 10 new household consumers and the satisfaction of the requests for increase of the permitted limits of two existing ones, the consumers fully supplied with water are less with 1,3%, 8 users have annual reliability of 98 ÷ 93% and 4 have reliability of 86÷77%. The determined in the first experiment as a risky consumption for the town of Sliven from the WMS “Tundja” has a significantly lower value – 15.9% and three times higher deficit. Regarding the exceeding values of the deficits can be summarized, that the situation in the household water supply sector, compared to the previous period, is worse;

- Two from the new consumers in the industrial sector has 73% reliability. The water deficit has increased five times for the villages of Yagoda and Venetz and the town of Stralja in nodes 43, 53 and 54 due to the addition of new consumers, and for Stara Zagora in node 36 due to the dropping out of the significant consumer – NFP has decreased respectively. As risky water consumer is appeared to be the pig farm “Krumovo Gradishte” AD in the village of Devetak (node 54).
- Thus, decisions for the allowance of a water right have received:
- The new users in irrigation, joined to the pointed IS and IF in nodes 8, 31, 96, 99 and 113 with the inclusion of additional conditions for the application of good irrigation practices and possible reestimation of the permitted limits in case of a change in the cultivated crops and irrigated areas in drought conditions;
- Almost all new requests in the household water supply sector. To more stringent control should be subjected the permits of the villages Sborishte and Devetak, and those included to the towns Straldzha and Shivachevo (nodes 93 and 112), due to the lower annual reliability - 86% and 82%. Water deficit is distributed among more years but it is small by volume;
- The new industrial users in nodes: 3, 36, 39, 43, 47, 50, 51, 52, 53, 56, 57, 125 and 133.

No confirmation of the right have received:

- WSS “Sliven” because in case of a permit for the requested water volume by the applicant amounting at 4,7 million m³/y $P_y = 15,91\%$, there will be a deficit in 37 years and 106 months, which defines it as controversial or negotiable applicant and will be a subject of study in the second stage of solving the task;
- The request for water of the pig farm „Krumovo-Gradishte“ AD in the village of Devetaki, is added to the industry of the town of Straldzha in node 54 due to insufficient reliability, available deficit and probable pressure on the existing water users, will also be a subject of analysis in the next stage.
- The decision for allowance or denial of these applications will be a subject of the study in the second stage of solving the task.
- *Second stage*: an analysis of the submitted requests for obtaining water use right

The simulation experiments – variants 3 and 4 are meant to support the competent authorities to resolve the disputable candidates – WSS „Sliven“ and Pig Farm „Krumovo Gradishte“ AD in the village of Devetaki through discussion with them.

The Competent authority, referring to the results from the previous stage notifies both applicants that the requested water quantity can not be permitted in such volume and requires further proving information. It is assumed that WSS „Sliven“ submits a similar detailed report for five years back on the real-used water quantities with reported losses and calculations of the required amount based on the number of real consumers and water supply norm, and the industrial candidate - less water consuming technological scheme. Thus, in interactive mode both sides reach an agreement to reduce the quantity.

After the input in the data file of the new annual water consumption values for node 20 – 2 838 240 m³ and for node 54 – 259 951 m³, a new water distribution is done.

Table 5 – Results from the third variant (excerpt)

N _o node	Representation nodes	Water consumption by nodes - 2004 (*10 ² m ³ /y)	D2 (*100 m ³ /y)	P2 _v (%)	P2 _y (%)	P2 _m (%)
20	HWS21'	28382	482	98.30	68.18	96.40
54	Ind.23+ Ind.28	2601	87	96.66	75.00	95.83

Analysis of the results from the simulation experiment:

- HWS in node 20, despite the reestimated water volume of 2,8 million m³/y, will again, considering Py = 68%, have 14 years and 19 months with water deficit;
- The change in node 54 is insignificant – the annual exedance probability has increased only with 2% and still, during more than a half of the studied years – 29, the water consumption will be disrupted.
- The unsatisfactory results require further consideration with searching for an alternative and new water distribution.

The fourth variant, similar to the previous one estimates how the new agreement with the applicant has affected the output data from the simulation. It is assumed that WSS „Sliven“ proposes a variant with an alternative water source, and the pig farm – a scheme for reuse of the wastewater. With the new values for the water consumption of these two users, respectively, for a node 20 – 946 080 m³ and for a node 54 – 186 327 m³ a new water distribution is done.

Table 6 – Results for the fourth variant (extract)

N _o node	Representation nodes	Water consumption by nodes – 2004 (*10 ² m ³ /y)	D2 (*100 m ³ /y)	P2 _v (%)	P2 _y (%)	P2 _m (%)
20	HWS21'	9460	55	99.42	93.18	99.05
54	Ind.23+ Ind.28	1857	39	97.90	84.09	97.54

For both applications are reported values for the exedance probability, complying with the norms, and the average multi-annual deficit, compared to the second variant, is negligible. Although this is mainly due to the negotiated lower consumption, respectively – 946 000 m³ and 185 700 m³ compared to the initially requested, it is a cause for issuing a permit for water abstraction of WWS „Sliven“ and the pig farm „Krumovo Gradishte“ JSC.

- *Stage Three:* Estimation of the unused water to satisfy the future requests.

Through several consequent simulations is estimated the free water resource for undertaking the new requests for water abstractions in certain river sections of the main

river and some for the major tributaries, selected as being burdened with more users and respectively with a greater risk of water shortages.

The results from the simulations, shown in Tables 7 and the graphs in Figures 6 and 7, presented downstream the river (from the springs to the state border), reported availability of unused resource and its increase after the reservoirs and at the border. From the studied tributaries of highest capacity to satisfy the new requests is Mochuritsa River. But it must be taken into consideration that Mochuritsa falls within „Natura 2000“ zone according to Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora and RBMP of EABD, where the maintenance or improvement of the state of the water is an important factor for their preservation.

Table 7 – Free water volumes for future requests from the Tundja river and the main tributaries

River Sections along the Tundja river and the main tributaries	Free water volume (*100 m ³)
from the spring up to the Koprinka reservoir	213184
Koprinka reservoir - Jrebchevo reservoir	191191
from Jrebchevo reservoir to the mouth Asenovska river	783078
from the mouth Asenovska river to the v.Zavoi	757032
from v.Zavoi to v.Hanovo	651749
from v.Hanovo to the mouth Povska river	498098
from the mouth Povska river to the border	798164
the river mouth of Gabrovica	160770
the river mouth of Asenovska	175467
the river mouth of Mochurica	437705
the river mouth of Tvardica	98791

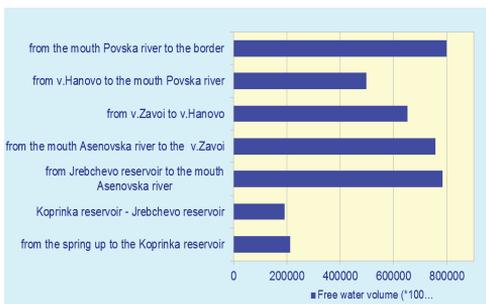


Fig. 6 – Change in the free water volumes along the Tundja river

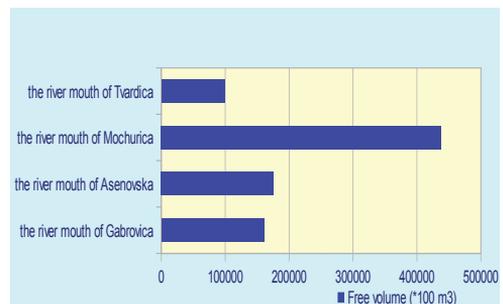


Fig. 7 – Free volume in the mouths of main tributaries of Tundja river

Such a summary evaluation is useful for the water resource management at basin and sub-basin levels, as well as for filling up of the missing estimates at this stage regarding the

quantitative status in the first water management plans, with identification of watersheds and water bodies in the so-called "water stress" or water deficit. For more detailed evaluation of a specific request, taking into account the interconnectivity between the users in a given watershed, sub-basin or river section (water body) the first stage of the task solution should be applied.

3.3.5. Solution variants of the problem

The purpose of the solution variants is to assess how the permit regime along the main river sectors will react to draught conditions, how the water deficit will change if limitations will be imposed in the permits and what mitigation measures may be proposed.

Simulation experiment was carried out under an adverse scenario – water consumption data from the second variant is used, i.e. for the second time period – up to 2008 and the input information for the water flow is the available series at all observation gauging stations reduced by 8%. As a result from the comparison of the current with the second variant in Table 9 are shown the users with considerable changes in the reliability and deficits.

Analysis of the results from the simulation experiment (comparing the current experiment 2A with the second variant):

- Water deficit in average for the whole period has risen with almost 70%. The most affected is the industry sector, which average deficit has increased with 80%, followed by the irrigation – with 75% and households – with 53%. With a new deficit compared to the second variant are the industry in the town of Sliven, IS "Shivachevo-Chervenakovo" and IS "Kazanlak", and about five times higher deficits will be sustained in the irrigated areas Marash-Binkos, Middle Tundja and Kazanlak, as well as in the planned new IS „Mlekarevo“. The risk of failure to provide the ecological flows is also increased, especially after Zhrebchevo reservoir;
- About 40% from all consumers in the basin, including also the ecological needs, have lower values of the annual exedance probability. The observed deviations in the exedance probability by volume and by months are lower (about 1% on average). With lower values of the annual reliability are: the industry of Yagoda village, Rozovo village, the towns of Sliven, Gurkovo and Straldja as for the latter it is 73%, the irrigation systems – Kazanlak, Shivachevo-Chervenakovo, Stara Zagora, Central Tundja, Bolyarovo, Koprinka and Dobrich, the irrigation of Marash-Binkos and the private grower „Rose Trading“, and for the household sector of Sliven regarding the very low value of exedance probability by years $P_y = 6.82\%$ it can be determined as the most risky consumer, followed by the settlements in the municipality and the towns of Kalofer, Kazanlak, Straldzha and Gabarevo village.

Table 9 – Variant 2 and 2A (excerpt)

№ node	Representation nodes	Water consumption by nodes – 2008 (*100m ³ /y)	Variant 2 without change in the water flow				Variant 2A with water flow decreased by 8%			
			D2 (*100 m ³ /y)	P2 _v (%)	P2 _y (%)	P2 _m (%)	D2A (*100 m ³ /y)	P2A _v (%)	P2A _y (%)	P2A _m (%)
1	T1+HWS 1	4731	129	97.27	77.27	95.45	177	96.26	75.00	94.51
8	Tundja+ Irrigation 2	142672	439	99.69	95.45	98.94	2274	98.41	93.18	97.17
17	environmental needs 2	672000	0	100.00	100.00	100.00	250	99.96	97.73	99.81
20	HWS 21'	47305	2837	94.00	15.91	79.92	3516	92.57	6,82	77.08
21	Reservoir Aenovec	150000	1252	99.17	97.73	99.05	3121	97.92	93.18	97.54
24	Yz. M. Sharkov1 + Irrigation 23	94402	3751	96.03	97.73	98.45	4688	95.03	95.45	97.67
31	Irrigation 26	1257	40	96.82	93.18	97.17	109	91.33	90.91	95.76
51	Ind.17	58288	0	100.00	100.00	100.00	256	99.56	93.18	98.86
54	Prom.23+ Prom.28	2658	93	96.50	72.73	95.64	110	95.86	72.73	95.27
89	r.Lazova+ Ind.14'	1212	25	97.94	81.82	97.35	30	97.52	77.27	96.78
93	r.Belenska+ HWS 20'	5605	63	98.88	86.36	98.48	67	98.80	84.09	98.30
99	Irrigation 14	577844	1856	99.68	97.73	99.35	9159	98.41	95.45	98.70
112	HWS 25	5494	93	98.31	81.82	97.16	105	98.09	79.55	96.97
126	Irrigation 23	13110	398	96.96	97.73	98.45	467	96.44	95.45	98.06
134	r.Ovcharica+ HWS 37	44472	1159	97.39	77.27	94.89	1258	97.17	75.00	94.13

*Note: In **Italic** are designated the consumers with changes compared to the second variant.*

4. CONCLUSION

With the experimental study carried out in the current paper is supported the first attempt to develop a permitting regime for water consumption, as a main tool to obtain water consumption rightm taking into consideration the changes in the economy, the structure of water sector and climatic changes. The proposed methodological approach, based on the available water resources in a certain time interval, water abstraction priorities and requirements for their rational distribution can be successfully used for reevaluation of the existing permitting system. This measure becomes increasingly important in the emerging trend of increased extreme events (floods and droughts) regarding the regional and temporal heterogeneity of the allocation of the water resources in Bulgaria.

The variant solution of the task in drought conditions can be a reason for reassessment of the permitted quantities as well as the conditions of the permits, but above all it is useful to identify the consumers in risk regarding their reliability. These users have to be audited, and restrictions should be discussed and applied for prevention.

Completely suitable for the three-staged problem and for the reassessment is the selected simulation model SIMIL, which has opportunities not only for consideration of the climatic changes and flexible priorities for water abstraction (the highest one is for the drinking water supply), but also for provision of the ecological needs according to the specific character of the watershed.

In conclusion, the introduction of the approach proved its applicability, considering the pilot study, and not only the current permit regime in Bulgaria could work more effectively by using it but it also could be a good basis for analysis and assessment of the quantitative status of water in the update of the first river basin management plans and the development of management plans for drought conditions. Additionally, the assessment of the pressure on neighboring consumers and the environment, and the introduction of economic principles will ensure better monitoring and control. The establishment of such models of real water management systems for other river basins in the country will facilitate the necessary revision of their current state and the future reassessments according to the continuously changing conditions, which, undoubtedly, will make contribution to their sustainable management.

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