MANAGEMENT AND DEVELOPMENT OF WATER RESOURCE SYSTEMS

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Abstract

This paper explores the performance of the water resource systems located in the Tundja River basin, Bulgaria. It includes multiple water intakes and two large reservoirs with complex purpose. The reservoir cascade "Koprinka" -"Jrebchevo" is used to regulate the water in the basin of the Tundja River and contribute to the increasing complexity of water allocation and implementation of rational use of water resources. The goal of this paper is to test the impact of various transferred water amounts to the Stara Zagora irrigation fields on the satisfaction of water consumers with irrigation water from the reservoir "Jrebchevo". Summarized research of the influence of water amounts supplied through HPP "Stara Zagora" on irrigation from reservoir "Jrebchevo".

Key words: *complex water resource systems, water resource management, decision support system*

1. INTRODUCTION

Water resource systems (WRS) are the tool through which the river runoff has been used and managed. They consist of one or more reservoirs as water sources and many hydraulic structures such as dams, canals, tunnels, irrigation systems (IRS), hydropower plants (HPP), water supply systems, etc. Their water resources are used to satisfy multiple objectives – irrigation water demand, industrial demand, drinking and municipal water demand, hydropower production, low flow augmentation, recreation, fishery demand, and provision of minimum river flow needed for ecosystems. So a great number of these objectives – natural, engineering, social, ecological, etc. – have stochastic nature like river runoff. Others are not commensurable, often not quantifiable and some have conflicting demands to the water use.

WRS are complex systems with stochastic and dynamic character and include a great number of mutually joined and interacted elements. The main difficulty in the process of WRS operation and planning is to obtain determinate rules for their management because some water demands and river runoff are random variables. This makes the mathematical description and modeling a difficult task which can be solved by the successfully application of probability theory and statistics, mathematical programming, simulation technique and multiple- objective optimization.

The management of water resource systems (WRS) represents a key element in achieving the balance between social-economic and ecological objectives of water usage.

This study is connected with the WFD implementation and the results are obtained from water resource balances (WRB) for a real WRS in Bulgaria with the use of multiple-objective optimization and simulation technique. These two methods are applied to the water resource system located in the Tundja River basin in the scope of the whole river basin.

2. BRIEF DESCRIPTION OF THE FEATURES AND CHARACTERISTICS CONCERNING THE TASK

One of the most important WRS in Bulgaria was built in the basin of the river Tundja. It includes multiple water intakes and two large reservoirs with complex purpose. The reservoir cascade "Koprinka" -"Jrebchevo" (fig.1) is used to regulate the water in the basin of the Tundja River and contribute to the increasing complexity of water allocation and implementation of rational use of water resources. The management of reservoir "Jrebchevo" is related to the management of the reservoir

"Koprinka". The basin of the river is characterized by a wide variety of users, the most important of which is irrigation, separated into a number of large irrigation systems and numerous irrigation fields. Drinking water and industrial water supply are also large consumers of water resources. Hydropower production in the watershed is not a priority.



Fig. 1 Reservoir "Koprinka"and HMS Pavel Banya

The main objective of this study is a schedule for water resource use of reservoir "Koprinka" with justification of water volumes transfered out of the watershed of Tundja River.

The WRS "Koprinka" is created on the Tundja River and includes the reservoir "Koprinka", two HPPs, two Irrigation systems (IRSs) – IRS "Stara Zagora" and IRS "Kazanluk". It is necessary to satisfy the irrigation and industrial water demand to produce maximum electricity and to provide the ecological flow in the river after the dam.

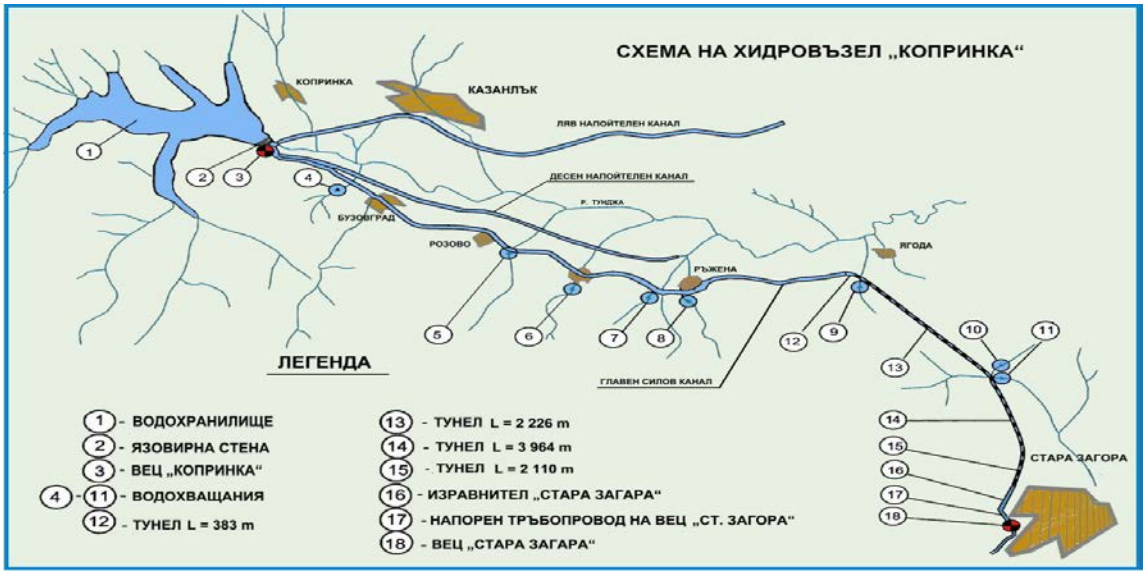


Fig. 2 Scheme of WRS"Koprinka" (source: Hydro-complex Koprinka)

Dam Koprinka is built on Tundja River in 1955. Scheme of WRS “Koprinka” is shown on figure 2, where: 1. reservoir “Koprinka” ; 2. dam “Koprinka”; 3. HPP “Koprinka”; 4-11. water intakes; 12-15. tunnels; 16. upper equalizing reservoir of HPP “Stara Zagora”; 17. pump main of HPP “Stara Zagora”; 18. HPP “Stara Zagora”.

Reservoir “Koprinka” has total storage of $142*10^6$ m^3 from which $136*10^6$ m^3 is an effective storage capacity. HPP “Koprinka” is built for maximum water amount of $30m^3/s$. The installed capacity is 7.0 MW, and reassessed design electricity is $10.75*10^6$ kWh (average electricity $12.98*10^6$ kWh).

Withdrawn waters from the reservoir are processed by the HPP “Koprinka" then one part is transferred in the basin of the Maritsa River from the lower equalizing reservoir of HPP “Koprinka” enters the main derivational canal M_0 of IRS “Stara Zagora”. From the derivation canal in its 12 km started tunnel derivation under the Sredna gora mountain with Q = 22.0 m^3/s and length 12.726 m. In this tunnel by the pumping station "Yagoda" some additional water from the Tundja River is transferred. The tunnel reaches to the upper equalizing reservoir of HPP “Stara Zagora”. Before HPP "Stara Zagora" from window of the tunnel with water intake of the Bedechka river the canal P17 is supplied for irrigation of some fields of the IRS “Stara Zagora”. Processed by the HPP water sent to the two main irrigation canal M1 and M2 of IRS “Stara Zagora”. Industrial water consumption as part of the enterprises of the city of Stara Zagora is also satisfied from reservoir “Koprinka” by canal M2 (fig.3).

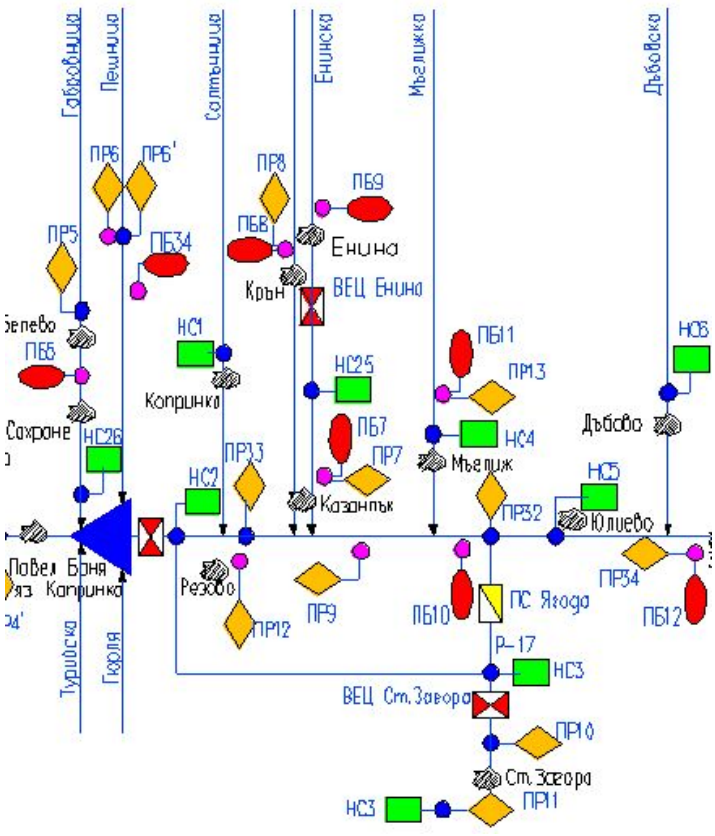


Fig.3 Part of scheme of WRS of Tundja River – reservoir “Koprinka”

HPP "Stara Zagora" was built at elevation 199.5m in the city Stara Zagora with 135.0 m net head and processed water to 178.66 mln m^3/year received from the derivation tunnel "Sredna gora" from reservoir Koprinka. Processed by the HPP “Stara Zagora” water is used for irrigation of the large areas from the Stara Zagora irrigation system, in this way significant water quantities are transferred from the Tundja watershed to the catchment area of Sazliika River.

Under suitable conditions the HPPs can be used in energy, irrigation and industrial water supply mode. During the irrigation season HPP Koprinka and HPP Stara Zagora work in subordinate mode imposed by irrigation.

Reservoir "Koprinka" is the main source for irrigation of the IRS "Stara Zagora. The transfer of water volumes in Stara Zagora field practically violates the filling of "Jrebchevo" reservoir.

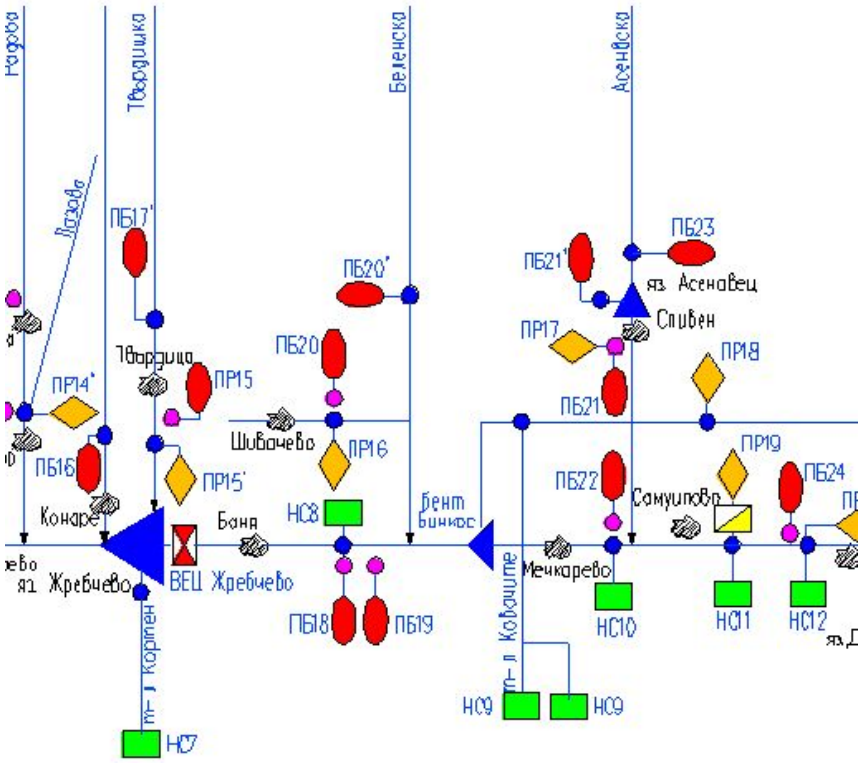


Fig.4 Part of scheme of WRS of Tundja River – reservoir "Jrebchevo"

3. USED APPROACH

For giving a solution to the problem it is necessary to examine the impact of the transferred volume of water on the operation of "Jrebchevo" reservoir and as well as the opportunities for satisfaction the water users located between both reservoirs with the reduced runoff although they have issued water permits.

The goal of this paper is to test the impact of various transferred water amounts to the Stara Zagora irrigation fields on the satisfaction of water consumers with irrigation water from the reservoir "Jrebchevo".

Summarized research of the influence of water amounts supplied through HPP "Stara Zagora" on irrigation from reservoir "Jrebchevo".

The influence is studied by simulation-modeling technique within the framework of the whole river basin using the SYMIL program (Niagolov, I. et al., 2011-2014).

Water resource system balance (WRSB) is updated. A detailed description of WRS and WRSB are given in (Nikolova, 2007; Niagolov, 2007, Shopova, 2008, Kolcheva, Kr., 2012).

The updated computational scheme of WRS of Tundja River takes into account new water consumers; drop out some old as well as updated amount of water quantities of existing users. The final version simulation model includes:

- Water supply for drinking water consumers, 50 (10 of which are new)
- Irrigation - 24 water consumers (11 of which are changes);
- Industrial water supply 38 water users (5 of which are changes); 5 fishpond (3 of which are new);
- HPPs - 7 (2 new) and 3 small HPP.

The principal scheme of WRS is updated. Compared with the developed in 2006 graphical scheme of the WR balance it is updated as new time horizon (2010). In the present study is used computational scheme (Kolcheva, Kr., 2012) where are shown above-mentioned amendments and additions.

Irrigation after HPP "Jrebchevo" is as follows:

- Reservoir "Jrebchevo" is a major water source of the large scale irrigation system "Sredna Tundja" and particularly the branch "Nova Zagora" and IRS "Mlekarevo". They both take water directly from the reservoir "Jrebchevo" using non-pressure tunnel "Korten" (IRS 7). IRS "Binkos-Marash" (IRS 14) and IRS "Mladovo-Kermen-Roza-Kovachite" (IRS 9) take water through the big intake "Binkos", as the water for the second IRS passes a tunnel "Kovachite".
- Irrigation System Shivachevo-Chervenakovo (IRS 8), Irrigation system "Sredna Tundja" -dam "Mechkarevo" (IRS 10), "Sredna Tundja" in village Krushare (IRS 12), "Sredna Tundja" - PS (pumping station) "Samoilovo" (IRS 11) all they receive water by direct abstractions from the Tundja river.

The accepted approach in the described research is as follows: - for the developed scheme of water allocation for meeting water users demand in the river basin, the water amounts transferred to the Stara Zagora field after being processed by HPP "Stara Zagora" are changed. For this purpose, a simulation of water supplied to hydropower is made by changing the water amount from $36*10^6 m^3$ to $210*10^6 m^3$ and the degree of satisfaction of water demand for irrigation users from reservoir "Jrebchevo" are determined.

The supply reliability assessment is implemented by water resource balance for above-mentioned irrigation systems (with water resources from reservoir "Jrebchevo") are presented in table 1 (observing priority to allocation water prescribed by the Water Law).

W_{HPP} $*10^6$ m^3	Reliability by years, **%**						
	IRS 7	**IRS 12**	**IRS 9**	**IRS 10**	**IRS 14**	**IRS 11**	**IRS 8**
36	96	100	96	100	96	100	98
54	96	100	96	100	96	100	98
72	94	100	96	100	96	100	98
90	94	96	96	96	94	96	96
108	94	96	96	96	94	96	96
126	94	96	96	96	94	96	96

Tab.1 Reliability by years

W_{HPP} *10^6 m^3			**36**	**54**	**72**	**90**	**108**	**126**
Reliability by volume and reliability by months, %	IRS 7	Rv	99.6	98.7	97.5	97.4	97.2	96
		Rm	98.9	98.3	98	97.7	97.4	97.4
	IRS 12	Rv	100	100	100	99.7	99.4	99.4
		Rm	100	100	100	99.4	99.1	99.1
	IRS 9	Rv	99.6	99.6	99.5	99.2	98.9	98.4
		Rm	99.1	98.9	98.9	98.6	98.3	98
	IRS 10	Rv	100	100	100	99.7	99.6	99.4
		Rm	100	100	100	99.4	99.1	99.1
	IRS 14	Rv	98.7	97.6	97.6	96.6	94.9	94.7
		Rm	98.3	98.3	98.3	97.7	97.4	97.4
	IRS 11	Rv	100	100	100	99.7	99.5	99.5
		Rm	100	100	100	99.4	99.1	99.1
	IRS 8	Rv	100	100	100	99.6	99.6	99.6
		Rm	99.4	99.7	99.4	98.9	98.9	98.9

Tab. 2 Reliability by volume and reliability by months

In setting high priority (more than prescribed by the Water Law) for supplying water for HPP "Stara Zagora", the results for the reliability by years of irrigation are given in Table 3.

W $_{HPP}$ *10^6 m^3	Reliability by years, %						
	IRS 7	**IRS 12**	**IRS 9**	**IRS 10**	**IRS 14**	**IRS 11**	**IRS 8**
60	96	98	96	98	96	98	96
90	94	96	94	96	94	96	94
120	94	96	94	96	94	96	94
150	92	96	94	96	92	96	94
180	90	96	90	96	90	96	90
210	90	96	90	96	90	96	90

Tab. 3 Reliability by years in case of high priority for supplying water

W_{HPP} *10^6 m^3			60	90	120	150	180	210
Reliability by volume and reliability by months, %	IRS 7	Rv	97.9	97.4	96	95.6	92.6	92.2
		Rm	98.3	97.7	97.4	96	95.1	95.1
	IRS 12	Rv	100	99.6	98.9	98.4	98.4	97.4
		Rm	99.7	99.1	98.6	98.6	98.6	98.3
	IRS 9	Rv	99.5	98.9	97.2	95.9	95.1	94.2
		Rm	98.9	98.3	97.7	97.4	96.6	96
	IRS 10	Rv	100	99.6	99.3	98.8	98.5	98
		Rm	99.7	99.1	98.9	98.6	98.6	98.3
	IRS 14	Rv	97.5	96.6	94.6	93.1	92.6	91.6
		Rm	98.3	97.4	97.1	96.3	96	94.9
	IRS 11	Rv	100	99.7	98.9	98.5	98.5	97.4
		Rm	99.7	99.1	98.6	98.6	98.6	98.3
	IRS 8	Rv	99.6	99.6	98.5	97.3	95.8	94.7
		Rm	99.1	98.6	98.3	98	96.9	96.3

Tab. 4 Reliability by volume and reliability by months in case of high priority for supplying water

Reliabilities by volume and by months are given in Table 2, Table 4 and Table 6.

Naturally, the results for reliability by volume and reliability by months are better than those for reliability by years but are given here for completeness.

SUMMARY AND CONCLUSIONS

Possibilities of the system for meeting the needs for irrigation (Water consumption for irrigation) after reservoir “Jrebchevo” are estimated by reliability by years between 90% and 100%, exceeding the normative reliability of 75%. It could be said that there is a minimal influence on the water amounts given for irrigation the fields from “Jrebchevo reservoir” due to the significant changes of water volumes diverted towards IRS “Stara Zagora”.

In this connection, simulation was made for the case of a missing link between the reservoirs “Koprinka” and “Jrebchevo”. The results are given in table 5. Reliability by years for irrigation water consumption decreases and range from 80% to 96%, but again exceeding the normative reliability.

W_{HPP} *10^6 m^3	Reliability by years, %						
	IRS 7	IRS 12	IRS 9	IRS 10	IRS 14	IRS 11	IRS 8
60	80	94	86	94	84	94	86
90	80	94	86	94	84	94	86
120	80	94	86	94	84	94	86
150	80	94	86	94	84	94	86
180	80	96	86	96	84	96	86
210	80	96	86	96	84	96	86

Table 5 Reliability by years

W_{HPP} *10^6 m^3			**60**	**90**	**120**	**150**	**180**	**210**
Reliability by volume and reliability by months, %	IRS 7	Rv	88.1	88.1	88.1	88.1	88.1	88.1
		Rm	91.4	91.4	91.4	91.4	91.4	91.4
	IRS 12	Rv	97.3	97.3	97.3	97.3	97.4	97.3
		Rm	98	98	98	98	98.3	98
	IRS 9	Rv	91.5	91.5	91.5	91.4	91.5	91.4
		Rm	94.3	94.3	94.3	94.3	94.3	94.3
	IRS 10	Rv	97.3	97.3	97.3	97.3	97.4	97.4
		Rm	98	98	98	98	98.3	98.3
	IRS 14	Rv	87.7	87.7	87.7	87.7	87.7	87.7
		Rm	93.1	93.1	93.1	93.1	93.1	92.9
	IRS 11	Rv	97.4	97.4	97.4	97.4	97.4	97.3
		Rm	98	98	98	98	98.3	98
	IRS 8	Rv	94.7	94.7	94.7	94.7	94.7	93.9
		Rm	95.4	95.4	95.4	95.4	95.4	95.1

Table 6 Reliability by volume and reliability by months

Based on the results of the experiments can be concluded that the effect of water released from the reservoir “Koprinka” towards the reservoir “Jrebchevo” at this stage of irrigation water consumption is minimal. Given that in the last experiment was simulated even interruption the filling of the reservoir “Jrebchevo” with river flow to maintain river ecosystem is obvious that there are conditions to maximize the use of water amounts for hydropower through HPP “Stara Zagora”, whose specific water consumption is 3.3 m^3/kWh compared to HPP “Jrebchevo”, which is 10.0 m^3/kWh. It should be noted that it is accepted uniform distribution of the percentages of monthly water use for the three hydropower plants.

On the other hand the results obtained have another meaning - a confirmation of the correctness of the approach used for the development of dispatching schedules reservoirs “Koprinka” and “Jrebchevo”. These reservoirs are seen as separate and independent water resource systems.

ACKNOWLEDGMENTS

This document has been prepared with the financial support of the European Social Fund through Project BG051PO001-3.3.06-0063.

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