

MANAGEMENT OF COMPLEX RESERVOIRS UNDER EXTREME CONDITIONS

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Abstract

In terms of climate change and extreme events, the role of the complex water systems and dams management is increasing. Except for the preservation of stored water volumes to ensure reliable water supply and irrigation, maintaining high levels for effective power generation and to ensure the ecological minimum, the use of dams performs also the function for flood protection. In order to improve the complex and significant (Annex 1 of Water Law) reservoir management, in NIMH has initiated a phased development of a decision-making support system with the appropriate modules. The models, by assessing the current situation, needs and expectations of incoming runoff, enable to give relevant recommendations for solutions. Despite the diversity of situations, the recommendations for decision are synonymous to operate at expected high water as well as in drought conditions.

Key words: complex reservoir, water resource management, flood, drought, climate decision support system

1. INTRODUCTION

Water resources are subject of a growing pressure, due to changes in climate and land use. The results of global and regional climate models confirm that these trends will persist, exerting impact on water resources and water use (IPPC report 2011). In a number of regions of South Europe and the Mediterranean region water scarcity is observed even for priority users as drinking water supply and environmental needs. The increasing frequency of extreme phenomena – floods and droughts, aggravates this problem. To ensure water with sufficient quantity and quality for water supply in the future it is necessary to analyze climate change during the present century as well as the provoked by it changes in land use, demographic and economic development.

According to the EC the analysis of water resource management systems (WRMSs), particularly the complex and significant reservoirs are the main tools for vulnerability assessment and mitigation.

The purpose of the launched CC-WARE project (principal partner in the project – the Executive Forest Agency) is to evaluate the current and future vulnerability of water resources in South East Europe on the basis of jointly developed methodology. It is necessary to determine vulnerability indicators for water supply, representative for SEE, to evaluate the vulnerability in terms of quantity and quality of water resources, to classify the availability of drinking water under changing climate and socio-economic conditions, to take into account land use and forest ecosystems. A transnational vulnerability map will be also elaborated for the present and future, for the quantity and quality of water.

The main driving forces are: climate change, demographic development and water consumption, changes in land use or quality of water resources. The expected changes in temperature and precipitation for 2020-2050 are shown in Fig. 1 (Spiridonov, V., 2009). The trends for 2070-2100 are even more distinct. Warming and drought are outlined, which affect more the eastern part of Bulgaria and are most expressed in summer.

The demographic processes during the recent years are related to migration of population to big towns.

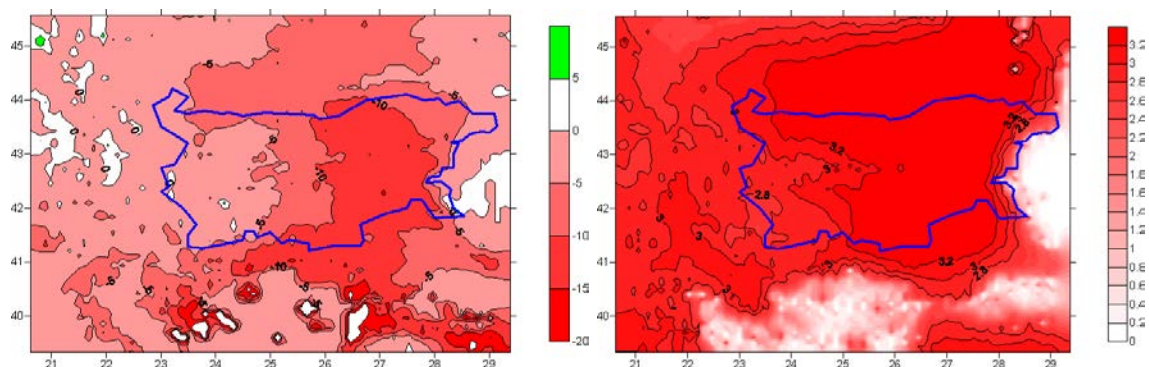


Fig. 1. Changes in precipitation, %, and temperature, °C – 2020-2050 is compared to 1960-1990

When a trend towards decreased precipitation and runoff coincides with a trend towards higher water consumption or deteriorated water quality, then a given region or river basin may turn out to be vulnerable in near or far future. This has to be assessed further on. In the so identified vulnerable regions, under conditions of climate change and extreme phenomena, with periods of water shortage and drought, alternating with flood periods, the role of adaptation measures becomes still more important. In Bulgaria the management of the complex water economy systems and dams, as well as the design and construction of new ones, should be in the first place. This holds true mostly for the drinking water supply reservoirs.

The aim of international project "Climate Change and Impacts on Water Supply" – CC_WaterS and its current continuation "Mitigating Vulnerability of Water Resources under Climate Change" (CC-WARE) is to develop measures to adapt to impending climate changes by means of a software system for water management, including water pumping optimization, taking into account the influence of land use and the necessary changes in this respect, to identify and evaluate the consequences of the impact of these changes on public drinking water supply during the coming decades.

Our experience in the NIMH is in the field of complex water resources system planning and management (under drought conditions), including new water sources or reservoirs or increase of storage volume of existing reservoirs, risk and decision models, decision support systems (reservoir operation: optimization models, simulation approach – complex reservoir system and simplified operation rules) etc. (Niagolov, I., I. Ilcheva, A.Yordanova, 2013; Niagolov, I., et al., 2013; Ilcheva, I. et al., 2012).

In the country has built over 2,000 dams. Of them, about 250, have greater economic and regional significance. Usually they are designed and built with one purpose, but currently they are used for different than the designated function. It is therefore necessary to assess the capacity of these reservoirs to meet attaching the water users and water suppliers now and in the future (in the period around 2050 and thereafter) . It is about a reassessment of the regulatory capacity of the dams in expected scenarios for the development of the main factors forms the runoff and different variants for water use and development rules for the management of dams in reducing runoff and drought.

On the other hand, to prevent of flooding risk, it is needed volumes to be provided free in dams timely, assuming high inflows. When designing dams, the maximum runoff with a certain probability is used. Usually by this value makes sizing major equipment (overflow). The case of the release of free volume to accommodate high wave is considered here. This volume is different for different months and vary considerably, which requires a thorough analysis and especially determining the monthly maximum runoff with a particular probability and related typical durations of their appearance.

2. METHODOLOGICAL APPROACH AND MODELING

The methodology, system of indexes and simulation model have been developed in the NIMH-BAS and used in the Basin Directorates as well as applied operatively in the Ministry of Environment and Waters (Methodology for Reservoirs Water Allocation and Methodology for water resources balances of river basins, Contract with Ministry of Environmental and Water (MEW), 2004; Niagolov, I. Operative water resource estimations agreement with MOEW, 2011-2013; CC_WaterS Monograph, 2012; Balabanova, S., I. Ilcheva et al., 2012).

СИСТЕМА ЗА ПОДДПОМАГАНЕ НА СЪЗДАВАНЕТО НА РЕЖИМНИ ПЛАН-ГРАФИЦИ ЗА РЕЗЕРВОИРИ			
ДУНАВСКИ РАЙОН РЕЗЕРВОИРИ	ЧЕРНОМОРСКИ РАЙОН РЕЗЕРВОИРИ	ИСТОЧНОБЕЛМОРСКИ РАЙОН РЕЗЕРВОИРИ	ЗАПАДНОБЕЛМОРСКИ РАЙОН РЕЗЕРВОИРИ
1. "ИСКЪР"	16. "ТИЧА"	23. "КОПРИНКА"	41. "ДОСНАТ"
2. "ВЕЛИ ИСКЪР"	17. "КАМЪРИ"	24. "ЖЕБЕЧЕНО"	42. "СТУДЕНА"
3. "ОГНЕНОВО"	18. "СЪЕДИНЕНИЕ"	25. "АСЕНОВИЦ"	43. "ПЪЧЕЛНА"
4. "КУЛА"	19. "ГЕОРГИ ТРАЙКОВ"	26. "М. ШАРКОВО"	44. "ДВКОВО"
5. "РИБАНА"	20. "ПОРОЙ"	27. "ДОМЪНИ"	45. "КАРАГОЛ"
6. "ОГОСТА"	21. "АХЕЛОЙ"	28. "ПИСЪНИК"	46. "КАЛИН"
7. "СРЕЧЕНСКА БАРА"	22. "ЯСНА ПОЛИНА"	29. "ТОПОЛИЦА"	
8. "ЕВНОЦА"		30. "БЕЛМЕКЕН"	
9. "СОПОТ"		31. "ГОЛЯМ БЕЛМЕК"	
10. "ГОРИ ДЪВНИК"		32. "ПРИЗ. ПОЛИНА"	
11. "А.Л. СТАМБОЛИНСКИ"		33. "БАТАК"	
12. "ХР. СМИРНЕНСКИ"		34. "ИЪМА"	
13. "БОВКОВИЦ"		35. "ТРАВЕЦ"	
14. "ВСТРЕЩАНИЕ"		36. "БОРОВИЦА"	
15. "БЕЛЦЛОМ"		37. "КОРДРАНИ"	
		38. "СТ. КЛАДЕНИЦ"	
		39. "ИВАЙЛОВГРАД"	
		40. "ГЛАВНИЦА"	



Fig. 2. Decision support system for reservoir operation

One possibility for improving the reliability of water supply is to implement better management of the water supply reservoirs. To this end NIMH has launched the development in stages of a Decision Support System (DSS) with the respective modules – Fig. 2. A series of models is implied, which are calibrated for the complex and important dams (Appendix 1 of the Water Act).

Water allocation of a reservoir is an important problem of rational utilization of natural resources. Water allocation is a complex problem. Water resources are usually limited and unevenly distributed. The water demand fluctuates considerably. Under such conditions the rational satisfaction of water user demands is a difficult task. The decisions have to consider many specific aspects: social, economic, and ecological ones.

At the present stage of development of society and economy, the problem water reliability is a component of the general problem of rational use of nature. Therefore it requires the use of the resources (distribution by sector or within an industry) to perform most efficiently. In this respect there are different difficulties. First - the distribution of resources is done in systems, composed of a large number of objects, in which participation is essential to man. For this reason, the establishment of adequate mathematical models of such systems is one of the main purposes, that need to be solved in the study and management. The second difficulty lies in solving the optimization problems in these models. Thirdly - the available resources are frequently associated with random processes, difficult predicted.

It should be emphasized that the determination of the free volume to accommodate an expected inflow to the dam is a complex task. That means, that the compromised decisions has to be made - to strive to maintain high water levels in the reservoirs to ensure reliable water supply or electricity or to maintain the lower levels and to reduce the potential damage from high water

Our experience in NIMH is in the three ways to solve the reservoir operation problem (Methodology for Reservoirs Water Allocation and Methodology for water resources balances of river basins, Contract with Ministry of Environmental and Water (MEW), 2004; Niagolov, I. Operative water resource estimations agreement with MOEW, 2011-2014, team leader D. Dimitrov):

- Optimization models – single or two reservoirs
- Simulation approach – complex reservoir system
- Simplified operation rules – single reservoir

The models provide the possibility of evaluating the current situation, impending needs and influx and relevant recommendations for solutions. Regardless of the diversity of the mentioned situations, the recommendations for solutions are concrete – from maintaining certain levels (operation at high water) to restricting individual water users (operation under conditions of drought and water shortage) – Fig. 3. Each zone ensure reaching desired reservoir performance:

- Water for consumptive use;
- Free storage for flood event covering

In case of Arda river reservoir cascade it seems that optimization model for operation of the three reservoir is the appropriate choice.

- The optimization criteria should be chosen between
- minimization of the spills or
- maximization of the power production

Usually monthly data (inflow, use) are used in our practice. When differences occurred between data forecast (inflow, use) – “in month” recalculation are made. The necessary correction of the release policy are applied. The BG Water Law prescribed obligatory “monthly release chart” can be changed. In this case (Arda cascade) the appropriate time period should be shorter than month – may be week.

In case of reservoir “Iskar” the simulation model is applied. The program SIMYL gives the opportunity for fast and flexible assessment of different scenarios connected with:

- Water resources (available, anticipated);
- Water consumption (anticipated);

- Operation (accumulation of different water volumes, quality of forecasts,). Operation in shortage conditions as well as in excess water conditions – both water stress situations.

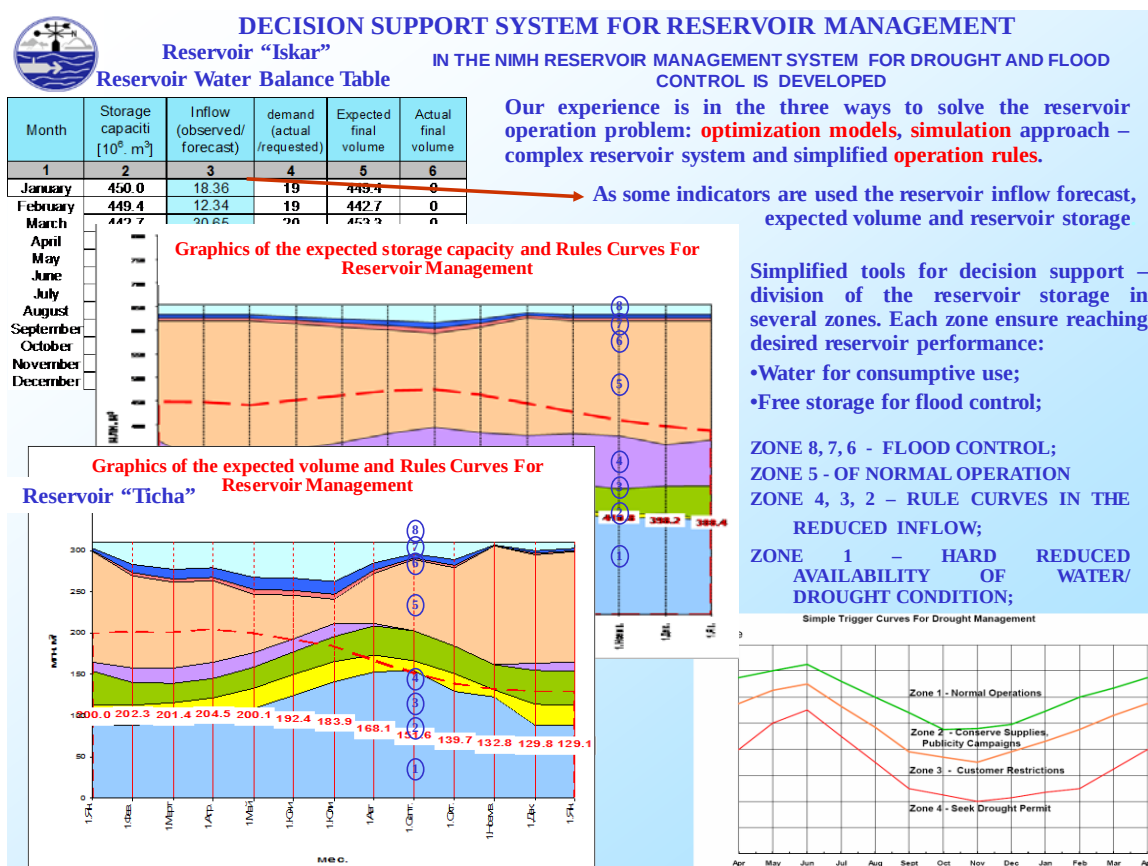


Fig. 3. Decision support system for reservoir operation – reservoirs “Ticha” and “Iskar”

A simulation model and application are developed for doing all above mentioned – simulation of different scenarios and situations. The model describes the main and important characteristics of WRS “Iskar”. A network flow representation of the system is used. The time interval is month – practice in MOEW. Several years ago an application was developed as a decision support system.

Recently there is an orientation in using simplified tools for decision support – division of the reservoir storage in several zones. Each zone ensure reaching desired reservoir performance:

- Water for consumptive use;
- Free storage for flood event covering

As of the present moment similar modules have been developed for dams from the four basin directorates. The models are at the stage of experimental application (Niagolov, I. et al., 2011-2014). Moreover the modules are calibrated to use short-term predictions for the influx to the reservoirs on the basis of processing the data from automatic hydrometric stations.

3. SUPPORT SYSTEM FOR DECISION-MAKING - A MODEL FOR RESERVOIR TICHA

As of the present moment similar modules have been developed for dams from the four basin directorates. The models are at the stage of experimental application (Niagolov, I. et al., 2011-2013). The two modules shown on Fig.3 demonstrates the obtained operating rules (dynamic operations schedule) of both reservoirs “Iskar” and “Ticha” based on estimation of the current situation e.g. expected water needs and inflow to the reservoir and relevant recommendations for solution.

The reservoir Ticha watershed (Fig. 4) is a subcatchment of the Kamchiya river. Ticha reservoir is created on the river Golyama Kamchiya near to the Ticha village.

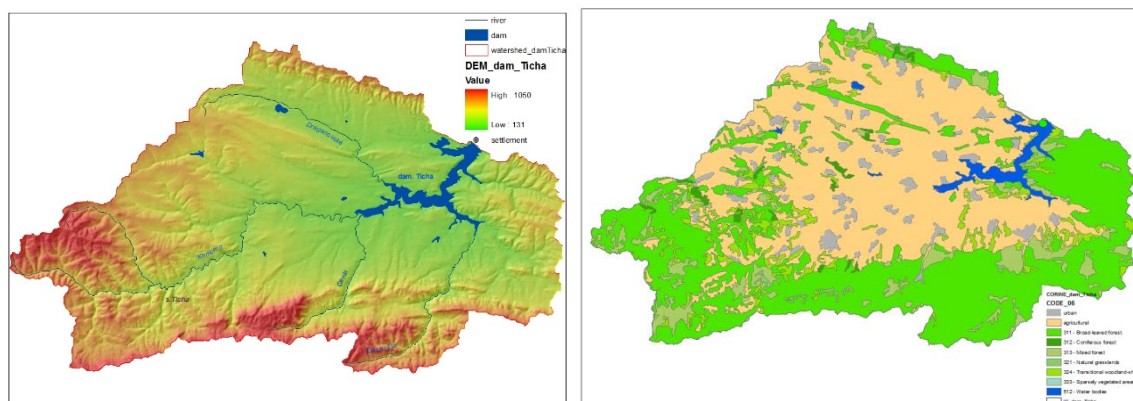


Fig. 4. Reservoir “Ticha” catchment

Ticha dam is a multi-year equalizer with complex purpose. The regulated water in it is used for:

- Water supply (towns - Shumen, Preslav and Targovishte);
- irrigation
- maintaining river ecosystem after the dam
- the possibility of giving water for power production.

Reservoir Ticha is the main water source for drinking water supply of the town of Shumen and Targovishte. Dam is used for irrigation system Vinnitsa. R. Ticha has a total volume of 311 million cubic m, and certain sanitary volume is 88 million cubic m. For a rational use of water in the reservoir is developed the proposed model. It is presented as a classic dispatch schedule (DG) in graphical form.

The purpose of developing this DG is to help in deciding to implement the authorization of water use in Water Law by reservoir draining.

Solving problems are two:

- recommendations to limit water supply in case of filling, which suggests severe deficits in the long time - avoiding sharp deficit situations;
- timely release of free volume to take the "high wave".

These two tasks are fundamentally different in their meaning. For the first task is accepted a "control" period of 7 (seven) years. For the second task is accepted a condition for response within days.

Basic requirements

For the model development following requirements are accepted:

1. Use a minimum amount of input data;
2. The input information is available and reliable;
3. Use data at monthly intervals for the first of the above-mentioned tasks;
4. Use generated 5 (7) daily high waves for the second task.
5. A possibility the results to be used for a schedule, realizing of article 53, in conjunction with Art. 151, paragraph 2, item 2, b. 'e' of the Water Law.

With these requirements we aim to simplify the use of the model (without neglecting of the important recorded information) and to obtain results of wide applicability.

Additional requirements

In the course of the research some additional requirements were put, aimed of creating the appropriate conditions of the model using. These requirements can be summarized as follows:

1. A simplified use within the well-known software products, in this case EXCEL;
2. Visualization of estimated future hydrograph filling of the reservoir in order to timely decision-making;
3. Opportunity to assess the impact of the expected scenarios for the inflow to the reservoir and hence to obtain solutions for more "conservative" or "free" control of the draught out water;
4. Ability to assess the impact of expected scenarios for water use from the reservoir and hence to obtain solutions for more "conservative" or "free" control of the draught out water.

Used approach

To solve the first task, the procedure is used, based on a modification of the tabular method Ripley. To determine the necessary stored water volume in the reservoir are implemented iterative water balance calculations. Based on the results, the size of the different zones in the reservoir is determined.

To solve the second task, the information about possible "high waves" of up to 7 (5) days and reliability of 1% and 0.1% are used. It is obtained by standard statistical processing, based on the output information for the maximum discharges, and its use is based on specific calculations.

With the made choice, the use of the so-call typical years for the characteristic lines of DG determination is avoided. These "typical years" are determined after volitional decisions to choose among the registered hydrographs or by selecting between predefined sets of hydrographs of shallow and watered years. That implies the inability to account for features of the registered hydrograph - sequences of shallow and watered periods within one year hydrograph. To overcome such situations in the research the follows is accepted:

- To determine the characteristic lines of the zones with restricted water supply, monthly runoff of averages are used. This is realized by algorithm SP with a modification
- To determine the characteristic lines of the zones for transformation of high wave, rows for maximum runoff are used. One possibility is a statistical analysis by approximation with appropriate probability distributions describing the characteristics of regional runoff formation.

Practical benefits of DG is described in any textbook. Based on filling the reservoir at the beginning of the month, inflows and requested water consumption determine the expected level (volume) of the reservoir at the end of the month. Depending in which zone of the DG is the water level, ones can determine the draught water. If the final level is within the zone without restrictions - it is allowed outflow for consumption. If there are imposed restrictions (the final level falls in the zone with restrictions), it should be made a reasoned choice about how to proceed.

The use of DG and Decision support system for reservoir operation (DSS) enables the assessment and provision of water supply to prioritize water users and limit water supply in the periods of decreasing runoff. In the case with restrictions these the options are possible:

- Restrict certain water users (according to the priorities of art. 50 (4) and (5) of the Water Law);
- Do not set limits because of the expectations of higher flow (at limit levels around the border zone of DG or at total forecast for water years).

The above must be substantiated on the basis of clear legal, economic, social and others views but not for more than a month.

For this purpose, in EXCEL workspace three tables are given:

- Descriptive (for areas in DG)
- Information (for forecasts)
- Water balance

Descriptive table provides tabular information, on which the chart of dispatch schedule is created. Information table contains data for possible predictions that can be used to determine the expected final filling of

the reservoir. In this case they are statistical values, but they can be replaced with the results of the predictive models.

Water balance table provides tabular information on the balance of water in the reservoir. The aim is to determine the expected final filling of the reservoir for each month. Accordingly, the used expression is:

$$\text{Initial filling} + \text{Inflow (forecast)} - \text{Water consumption (requested / granted)} = \text{total monthly filling}$$

Brief description of the resulting zones of DG (Fig.3).

- Zone 1 is the area due to work in a highly reduced runoff.
- Zone 2 and Zone 3 are the areas with the rules to work in terms of reducing runoff.
- Zone 4 is the area of practical work without restrictions
- Zone 5 is the area of the work without restrictions and normal water supply.
- Zones 6, 7 and 8 are areas to work on "high levels" with the relevant rules.

As some indicators are used the reservoir inflow forecast, expected volume and reservoir storage (Reservoir Water Balance Table – fig.3).

Although the uncertainty of future demand and hydrologic conditions, the recommendations have to be determined – from maintaining of certain levels (operation at high water) to restricting individual water users (operation under drought conditions and water shortage).

The Decision support system(DSS) for reservoir operation is very flexible and fits to any change in hydrology or water needs and is usefully applied in the Ministry of Environment and Waters (MOEW). Similar modules have been developed for reservoirs of the four Basin directorates using short-term forecasts for the inflow to the reservoirs on the basis of data processing from automatic hydrometric stations.

Moreover the modules are calibrated to use short-term predictions for the influx to the reservoirs on the basis of processing the data from automatic hydrometric stations.

SUMMARY AND CONCLUSIONS

Within the framework of the transnational cooperation on the *CC_WaterS* project a climate change monitoring has been realized in different geographical areas and 20 experimental test areas in South East Europe, selected under various climate conditions and representative of diverse types of water resources for water supply. Common methodology and tools have been developed for evaluating climate change impact on water resources and water supply. The contribution of Bulgaria consists in the elaboration of an approach and models for assessing climate change impact on rivers and dams, and taking under consideration the effect of climate change on land use and water ecosystems.

A System for Water Management is recommended for the identified vulnerable areas as an instrument for adaptation to the coming climate change, which comprises optimization of water pumping (including the use of regulating volumes), consideration of land use, identification and evaluation of the consequences from these changes for the drinking water supply during the next decades. The identification of areas at risk and the analysis of the driving forces are important for the development of measures to increase the reliability of water supply. The role of the prevention and adaptation measures increases under conditions of climate change and extreme events.

The role of the management of complex water economy systems and water reservoirs, especially those for drinking water supply, also increases. Other necessary measures are also: early warning systems, reliability/risk assessment, models for support of decision making, construction of new water supply systems. To this end a Decision Support System (DSS) is being developed at stages in NIMH for the management of water reservoirs with the respective modules. A series of models is implied, which are calibrated for complex and important dams.

The models provide the possibility of evaluating the current situation, the expected needs and influx and the relevant recommendations for solutions – from maintaining definite levels to operation under conditions of drought and water shortage. Modules have been already developed for dams from the four basin directorates, which are at the stage of experimental application.

The modules are calibrated for using in short-term forecasts of the influx to water reservoirs on the basis of processing data from automatic hydrometric stations. Their interrelation with the System of Indices for Drought Monitoring, developed by NIHM, is also under development.

The climate change analysis and the identification of vulnerable areas for water supply is directly related to the River Basin Management Plans and their impending updating, which should take into account climate changes, and include management plans for water shortage and drought, and update the Programme of Measures, including measures for planning and management of complex water economy systems and dams.

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