Development of Decision Support System for Optimization of Dams' Management on Complex River Systems

by

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TABLE OF CONTENTS

General abbreviations

SCE – selection criteria ensemble;

MCA - model construction algorithm;

DB – database;

GA – genetic algorithm;

HES – hydroengineering system;

HPP – hydroelectric power plant;

DES – dynamic expert system;

IS – intelligent system;

ICS – intelligent control system;

MM – mathematical model;

NHL – normal headwater level;

LCL – lower control level;

AES – advisory expert systems;

ACL – average control level;

BS – basic situation;

DSL – dead storage level;

NOL – navigation operating level;

SRL – surcharge reservoir level;

SDC – state dependent coefficient.

INTRODUCTION

Nowadays, the life of a modern man could not be practically imagined without the use of electricity; we can even observe the constant growth of people demand in electricity. However, the resources in the most common sources of energy, such as oil, gas and coal, are rapidly decreasing; so, more often we start thinking the renewable alternatives thereof.

The energy of rivers, which is being employed by the hydroelectric power plants (HPP) for many years, still is considered to be one of the most thoroughly studied sources.

For a long-time period and in many countries, gaining the maximum benefits from electricity generation remained the priority criterion in the management and control of the hydraulic structures. Such an approach demonstrated its inconsistency more than once, leading to serious problems.

At the same time in recent years, the problem of the mean sea level increase has attracted a lot of attention from the scientific community [1] Fig. 1 shows estimated, observed, and predicted global sea levels from 1800 to 2100. Estimates from proxy data drawn in red between 1800 and 1890, pink band shows uncertainty. Tide gauge data is depicted in blue for 1880 - 2009. Satellite observations are shown in green from 1993 to 2012. The future scenarios range from 0.66 ft to 6.6 ft in 2100. This, in particular, results in increase of average floods all over the world. Potential for use of social vulnerability assessments to aid decision making for the Colorado dam safety branch [2]. Furthermore, increased population enhances the severity of the flood aftermaths. It is estimated that within 2050 the population will be increased by 130 million, which will demand for a huge increase of water reservoirs.
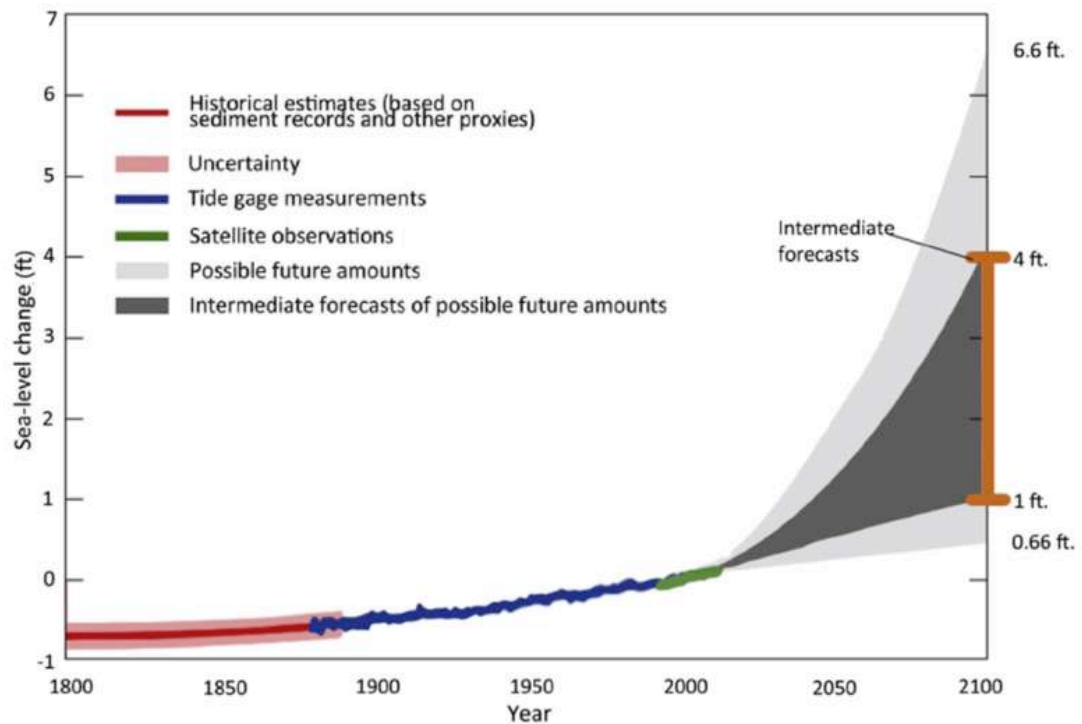
Fig. 1. Estimated, observed, and predicted global sea level rise from 1800 to 2100. (Redrawn from Melillo et al., 2014)

Floods are considered to be the most hazardous natural disaster effecting population. In the territories exposed to regular flooding more than 1 billion people permanently reside [3]. Flooding of cities bears a serious threat to the population. Under the conditions of demographic growth, urbanization trends and climate change, the reasons for causing floods are changing, and the impact thereof is becoming more serious. This scale and permanently escalating threat mean that more is needed to be done in order to better understand current and future risks, as well as to effectively manage and control them.

A steady growth tendency in the number of the registered cases of floods is observed. This is connected not only with the increase in the peak sediment activity, but, to a greater extent, with the construction works started in territories, where construction was previously prohibited.

At the same time, it should be noted that the number of victims is increasing at a slower rate or even decreasing, which reflects the successful implementation

of measures to manage and control the flood risks. However, the problem of territories and population protection has not yet been resolved [4].

As a first step on the way of finding a solution, it is required to understand the causes of flooding. Cities could be flooded by rivers, coastal water setups, storm water or groundwater, as well by overflows caused by the failure of artificial systems; but the major number of floods is registered as a result of seasonal showers. Special danger for cities is presented by occasional heavy rains.

One of the most devastating and discussed (i.e. [4]) floods of the recent years in Russia was the flood in Krymsk in the summer of 2012, which resulted in deaths of about 160 people. According to the Hydro meteorological Center report, on the night of July 6 to 7, 2012 in Krymsk itself 220 mm of rainfall fell down, while in the neighboring Gelendzhik and Novorossiysk - 250 mm and 275 mm with the norm for this region of 70 - 100 mm.

Most often, the relevance thereof is explained by alterations in the nature of precipitation and the increase in the number of anomalies. In particular, paper [5] analyzes the temporal series of the annual and monthly arid and rainy period anomalies within a season (Fig. 2) for the period from 1936 to 2016.

Based on the data provided in paper [5], a conclusion could be made that during the last 70 years a steady trend towards an increase in the number of rainy anomalies is registered. Moreover, this trend is observed both for the average annual temporal series and for the seasonal analysis. The greatest increase in the number of anomalies is a characteristic feature of the spring period.

However, according to papers [6, 7], a significant increase in damage resulting from the effects of floods was observed lately. It should be noted that the damage caused by catastrophic floods to material resources and the number of human victims resulting from such floods are growing at an equally rapid rate.

This problem could be explained by an increase in the population density in areas of potential flooding, poor quality of the hydraulic technical facilities maintenance, as well as by the lack of a unified integrated control and management policy in the enlarged section of a river pattern. The first reason possesses a natural

worldwide character, is caused by the general population growth and, in particular, by urbanization. In order to solve the second problem, it is necessary to carry out technical reconstruction of the existing hydraulic technical systems. However, even complete renovation of the equipment and timely technical maintenance thereof will not allow solving the flood problem unequivocally, since currently any comprehensive approach to regulating water discharge in major river systems around the world is missing.
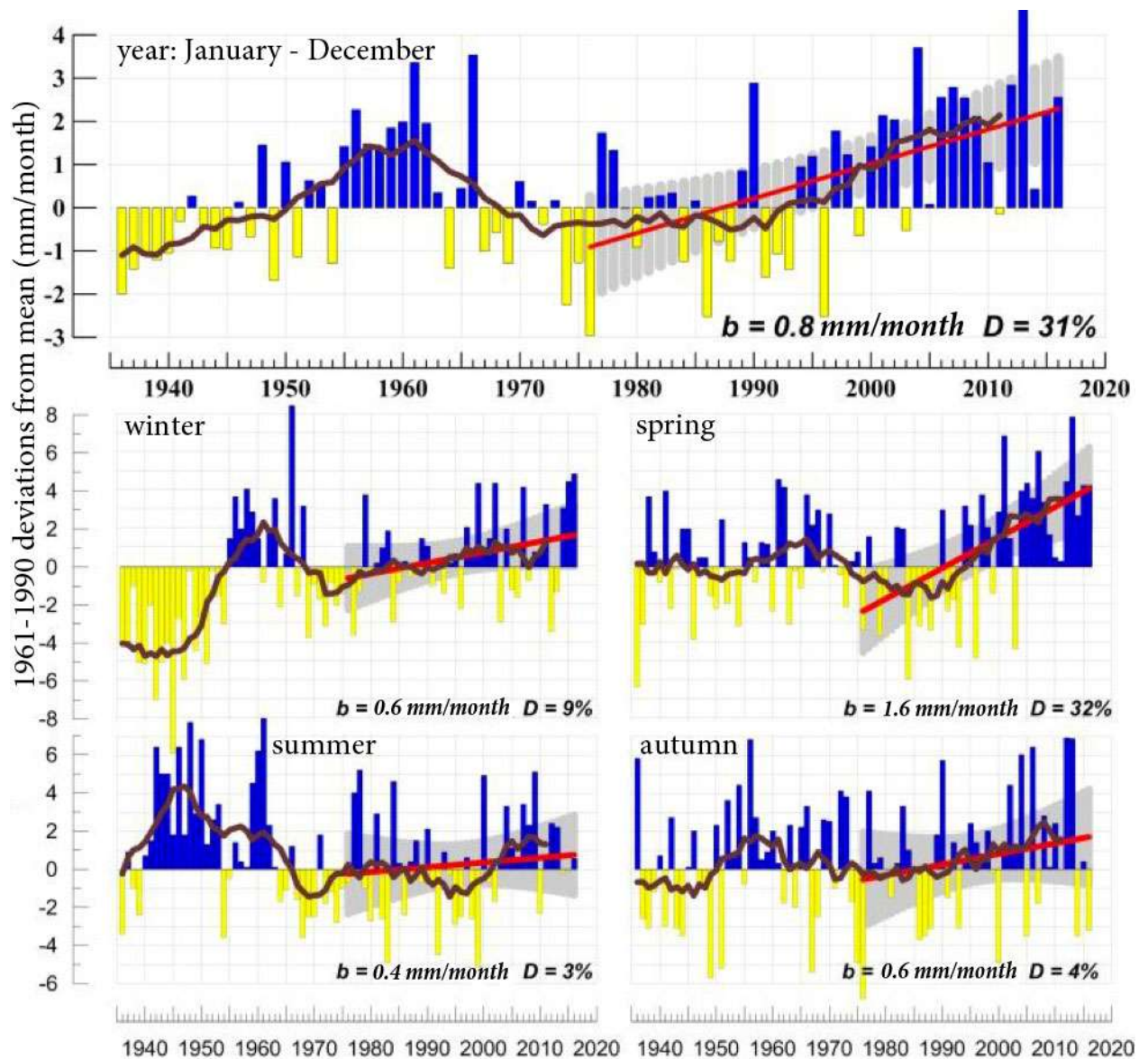

Fig. 2. Average annual and seasonal anomalies of arid and rainy periods, averaged over the territory of Russia.

b - trend coefficient (mm/month /10 years), D - the trend contribution in total dispersion (%).

8

Problem statement

Nowadays a lot of attention is devoted to catastrophic floods. Due to their rarity, they cause much greater local floods can cause significant damage to the national economy. In addition, due to the growing population of the Earth, there is the need to develop new territories that have not historically been inhabited, for example, due to the increased risk of floods.

At the same time, regular floods are much better studied and forecasted, so it seems possible to concentrate on management water release in order to improve the safety of the adjacent territories.

According to one of the possible explanations, the flood occurred due to the emergency water dump from the reservoir, because there appeared a threat of overflow over the edge. According to another possible explanation, the cause was found to be the insufficient water transmission capacity in the alignment of Adagum river highway bridge because of the accumulated domestic and natural waste, which resulted in a rapid accumulation of water. During the night this improvised dam could not resist to the water head; and the uncontrolled flow of water wiping away everything in its path gushed out in the city direction. These explanations both pointed out that through proper management of the reservoirs cascade similar events could be avoided [8].

Thus, the economic feasibility of implementing preventive methods of flood protection compared to costs of eliminating the consequences of emergency situations is obvious.

But even characterized by their destructiveness, floods could become beneficial to the society. For example, the floods provide the inflow of silt and nutrient substances in the floodplains. Obviously, in order to find the right balance between benefit and threat, strategies for risks integrated management and control shall be required.

Accordingly, such an approach is needed, which would ensure the balance between benefit and threat, i.e. the strategies for integrated management and

control of land and water resources within the natural geographical, rather than administrative or political boundaries, are necessary.

Such an approach is required, which:

1. Provides maximum benefit from the use of water and land resources.

2. Minimizes human casualties.

This holistic approach shall integrate the land and water resources management and control, widen the knowledge about the risks of floods and be aimed at reducing vulnerability to flood consequences accompanied by a simultaneous understanding of the driving forces of the system as a whole. This involves implementation of an integrated approach within the river basins, which takes into account the natural geographical and hydrological boundaries, and not the administrative or political ones.

However, the integrated flood management and control within the frames of integrated water resources management and control also involves the risks management and control accompanied by recognition of the fact that floods consequences could become beneficial, but they could never be controlled in full.

In the course of many years, power generation was considered to be the major criterion for analyzing the efficiency of the dam cascade and level of water in the reservoirs control and management in Russia and around the world [9, 10]. In a number of cases, additional criteria were introduced, such as possibilities for navigation [11], irrigation [12], etc. However, in all cases, two scenarios were considered: emergency – high water or flood discharge and operational - during the low water period. In both cases dispatch schedules were compiled in such a way as to either quickly discharge water through a hydraulic technical facility or to ensure maximum power generation.

In addition, in most cases, the given dispatch schedules are compiled for a separate hydraulic technical facility. At the same time, the mutual influence thereof on each other is not taken into consideration. In rare cases, small systems consisting of two or three reservoirs are considered. As a rule, this option is analyzed for such systems, where reservoirs are located very close to each other

[13, 14]. Besides, in a number of cases, an integrated approach is available for a river system, such as the Volga cascade [15]. However, even in these cases, numerous tributaries and the river systems thereof, as well hydraulic technical facilities are not taken into consideration.

In this connection and within the framework of the given research, the possibility of an integrated simulation of a complex branched river system is considered taking into account the multicriteria nature of water discharge through reservoirs.

Thus, this **research aims** development of strategies and decision support system ensuring integrated land and water resources management due to a steady growth in the number of registered floods.

In order to achieve the main aim of the research following tasks have been formulated:

1. Perform analysis of current researches in complex river systems management models and approaches.
2. Develop the method and mathematical model for managing a cascade of dams in a river system for maintaining required power production while minimizing ecological and economical impact of floods at the river system.
3. Assess the applicability of the developed mathematical model and method on the Valle d'Aosta river system.
4. Create of the decision support system for water discharge over a system of dams with consideration of developed mathematical approach for river system management.
5. Apply the developed method for a Volga-Kama river system in Russia.
6. Assess ecological and economical impact after introduction of the developed method and approach

Work approbation. Research results were reported and discussed at: international scientific-practical conference "Basic and applied research" (Moscow, 2014), Winter Modeling Conference (Hong Kong 2017), World

Congress of Engineering and Computer Science (San Francisco 2017), Hydraulics (Moscow, 2019), Korolev's readings (Moscow, 2019), World Congress of Engineers (London, 2019) etc..

Publications. 15 scientific papers on the topic of the dissertation were published, of which 9 papers indexed in Scopus.

The structure and scope of work. The dissertation consists of introduction, five chapters, conclusion, list of references. The text of the dissertation is presented on 135 typewritten pages, contains 51 figures. References contain 95 sources.

CHAPTER 1. An overview of modern methods of managing hydraulic structures of a river network

1.1. Common Approaches in Water Management

A modern reservoir is a complex hydraulic structure. Its functions are simultaneously aimed at solving several problems: ensuring the required flow rate for water consumers, generating electricity at HPP, providing maritime traffic, irrigation of land, etc.

Herewith, depending on the purpose of the reservoir, it has to be managed differently:

1. water supply (domestic, industrial, including thermal and nuclear power) - optimized maintenance of the normal headwater level. Estimated water yield - 95-97% by the number of years of uninterrupted use.

2. irrigated agriculture - the main part of water consumption accrues to the growing season (usually April - September), the maximum water consumption matches the time of the most intensive irrigation. At the end of the season, the reservoir wears out to the minimum level. But in those backwaters where irrigation canals start, a water level needs to be maintained so to ensure the normal operation of these water intakes. Water yield for the systems powered by live flow (uncontrolled) is usually taken equal to 75%. For the systems with flow control – 90%. Another requirement is the need to ensure 0.7 - 0.8 of normal water feed in dry years.

3. marine industry and fisheries - which are interested in the greatest possible navigation water depths along the greatest path extent. Water yield in this case is set in the range of 75-90%.

4. Power generation - the water flow rate through the turbines is maximized so to reach the limit values of power generation, after which a further increase of the water flow rate through the turbines worsens their efficiency. Usually, water supply engineering implies to establish 80-95% of water yield by the number of years of uninterrupted use.

5. The sanitary purpose of the reservoir - it requires establishment of a minimum water discharge rate at which the quality compliance of the tailwater is ensured. And at the same time, water yield should be in the range of 95-97%.

All these conditions at the multipurpose hydraulic structure are fulfilled through establishing and providing the so-called *firm yield* of a reservoir. And thus, it includes the consumption of water taken from the headwaters for irrigation, water supply to consumers and other needs; water flow into the tailwaters for transport, fisheries and forestry; and water flow required to generate hydraulic energy [16].

Firm yield is established in accordance with the purpose of the reservoir: daily regulation is established to redistribute a uniform river flow during the day; weekly regulation is established to redistribute an almost uniform flow during the week; and the redistribution of uneven runoff is carried out by seasonal regulation in low-water and high-water seasons in order to prevent flooding of territories.

In complex river systems, consisting of several HS, combined into one network, firm yield is the sum of all water flow rates of all reservoirs in the network [16]. At the same time, there are both independent regulation when each reservoir is considered as an independent source for consumer supply, and compensating when the operating mode of each reservoir is set so as to ensure maximum efficiency of the entire river network [17]. In compensating (or compensatory) regulation, the water resources of an overlying reservoirs are used to maintain water loss and the statutory state of the underlying reservoirs.

Compensatory regulation is more advanced, it requires large computational resources in planning, and as a consequence, is much less applicable. However, only so the most efficient water management of a complex river network can be implemented, which would ensure both economic efficiency and environmental safety. In this regard, further in this work, main attention will be paid to compensatory regulation.

The most common in Russia and in the world management system for the hydraulic structures of a river network for the maintenance of firm yield is based on the dispatch graphs.

In accordance with [18] the basis of the dispatch graphs is the rule that, at each time interval of any given season of the year, the water yield rate of the hydraulic system is set in accordance with water storage in a reservoir.

In general case, the dispatch graphs show the following rules:

- of preserving water resources to ensure firm yield;
- of emptying the reservoir to receive flood flow;
- of redistribution of water over time, in case of exceeding firm yield.

The detailed content of these rules is determined by the purpose of the hydraulic structure, its regulatory capabilities and its place in the river network [19].

The analytical form of a dispatch graph looks as follows [20]

$$u_t = f(x,t), \qquad\qquad (1)$$

which shows what yield (electricity generation, water flow to the irrigation canal, water flow to the tailwaters, etc.) should be set during operation of the structure in the tth time interval, depending on the water level x, in the reservoir at the beginning of this interval.

On the dispatch graph, there are the high-water phase and the low-water phase, which are usually divided by the dates of the start of a new month.

To pass the high waters to reservoirs, the surcharge storage capacity is set, which is between the normal headwater level (NHL) and the – surcharged reservoir level (SRL). The surcharge reservoir level may vary from 0.5 to 5 meters, and the surcharge storage capacity - up to 15% of the effective storage capacity. The dispatch graphs for the high-water period are made with account to the surcharge storage capacity. In this case, the high-water wave is regulated by the reservoir by the cut-off method. It means the advance lowering of water level to the reservoir drawdown, and then maintaining the average daily discharge flow rate below the

inflow flow rate, as a result the reservoir is filled with inflow water to a certain level (up to SRL).

Currently, the construction of dispatch graphs with independent regulation of the flow has been worked out extremely well and is presented in detail in many works and calculation methods. [21, 22, 23].

To build dispatch graphs, it is necessary to plan the release of water at the hydraulic structures of the river network. Currently, a water balance equation is being compiled for this, which is written as:

$$Q_n + Q_g + Q_d + Q_{trf} \pm Q_{rsvr} - Q_s - Q_{trt} - Q_{ev} - Q_{gw} - Q_{out} \gtrless 0 \quad , (2)$$

where:

Water input:

Q_n – natural surface runoff

Q_g – share of groundwater's spending, which is not hydraulically connected with surface water

Q_d – return, drainage, mine drainage waters and wastewater entering the river within the basin or its section

$Q_{tr\ fr}$ – water transferred from the other basins

Q_{rsvr} – water of reservoir drawdown for the calculated time intervals

Water-resources output:

Q_s – waters taken from the river above the cross-section for irrigation, feeding of lakes, as well as for domestic and industrial water supply (minus return flow, if the discharge is performed above the alignment)

$Q_{tr\ to}$ – waters transferred to the other basins

Q_{ev} – waters loss for additional evaporation from the surface of reservoirs and ponds

Q_{gw} – river flow losses caused by the collection of drained groundwater

Q_{out} – water-resources output of the outflows below the estimated target

Based on the equations of water balance, compiled for all hydraulic structures of the river network, a model of water release is created.

However, there is no a unified methodology oriented to the various factors influence, for dispatch graphs for the compensatory regulation of a complex river network. In each particular case, an optimization model of water pass to the reservoir is made and, based on the obtained decisions, a decision on the how to manage particular river network is made.

At the same time, the more factors are taken into account when making the model and the more complex the river network is, the more resource-intensive calculations become. In [24] the most comprehensive review of all the factors influencing the process of water exchange in the river basin is given. There are 3 groups of factors in total:

1.   Factors influencing the channel network and redistributing the stock in time and territory. These include the high-water, ice formation, etc.

2.   Factors influencing vast areas of the basin and changing the relations between the elements of the water balance. These include accounting for water supply for various consumers, irrigation, electricity generation, siltation of reservoirs, locks, etc.

3.   Mixed factors influencing both the channels and the catchment area and causing the redistribution of the stock and the transformation of water balance elements. These include accounting for precipitation, including high-intensity, water evaporation, filtering water under the dam and bypassing the dam.

1.2. Known mathematical approaches for river system management.

Since 1960 various system modeling tools have been developed to use extensively in hydroelectric generation and water management. The study focusing on a non-traditional simulation models has been developed by Forrester in the sixties at MIT [25]. System dynamic models involve simulation and optimization algorithms to develop planning programs [26]. Since dynamic modeling allow to evaluate the effect of any change over time, simulation models have become the primary tool of hydropower modeling system. Under a given set of conditions, simulation model can result in the response of a system. Classical simulation

models can be divided into water balance method and mass balance method. Mass balance models are best for water management, using flow routing to determine release from reservoirs or system of reservoirs. System dynamics uses a conceptual tool for creating dynamic behavior of complex system. A system dynamic model for multiple reservoir hydropower operation was first developed. Models focused on real time operation of hydropower systems have been created by means of many tools such as Powersim, STELLA, iThink, Exted, and Venisim. Some model includes managing hydraulic structure operational modes to ensure safety from flooding. Furthermore, a complex approach of modeling of a tandem reservoir system for drainage management gives optimal water to be drained with minimizing chance of flood keeping the effective power production [27, 28].

Complex reservoirs water management may be performed basing on the analysis of water flow forecast (water volume, transition duration, max discharges and others), the existing water levels in the reservoirs, and the available receiving volumes. In any case the water management policy is developed in several steps. Firstly, a complete water demand plan has to be estimated with respect of its change with time. Secondly, technological constraints have to be set that would limit possible regulation of the water flow through the reservoir system. Finally, an optimal water discharge graph has to be constructed so that it would minimize flood risk, and meet the requirements of all stakeholders (power production plants, fisheries, ships' navigation, agriculture and others) considering the developed water demand plan.

The second step is relatively easy implemented as long as all relevant data regarding the water reservoir system has been provided. However, it is much more complicated to correctly assess all the stakeholders as far as increasing its number will result in complication of the water reservoir management model. Therefore, most of the known management models limit the constraints with power production.

Optimization of energy management and conversion in the multi-reservoir systems based on evolutionary algorithms [29]. In many cases considering a single

constraint may not be enough and an additional parameter is introduced. This could be maintaining required energy production while minimizing water pollution while water allocation for agriculture use, meeting water demands in severe conditions, i.e., in drought, or minimizing flood risks and aftermaths, and many others [29, 30, 31, 32, 33]. In some cases, up to three different constraint may be set. Considering more constraints simultaneously is performed very rarely as this significantly complicates the known model and increases the computation time.

Up to now, many approaches to modelling to support water policy management of complex reservoir systems have been proposed. Most of them commonly use a Monte Carlo optimization [34, 35]. It performs optimization over long period of time (several centuries) of historical or synthetically generated discharges. However, optimal management policies may not be applied to any other time series among the one that was calculated. Another widely used approach is based on linear programming, which is often combined with Monte Carlo simulation [36]. The main disadvantage of this method is that all mathematical apparatus has to be linear or linearizable. Another approach is based on the representation of a river network through a set of nodes and links, which is called a network flow optimization. Nodes represent reservoir and links – channels and flows. Such approach is even faster than the others. One of the first attempt to introduce this approach at Missouri river is reported in [14], where it shown that even a simple river basin is very complex to be modelled using this approach when many constraints are considered.

Methods based on linearization may encounter a number of difficulties to be applied precisely due to its large scale or the lack of precision. In these cases, a nonlinear programming models might be applied. Nowadays they are considered to be the most advanced due to its power and robustness. However due to its nonlinearity there is always a risk for a model not to converge. Another widely used and well-studied approach is dynamic programming [37]. Dynamic programming tools decompose an original task into a several sub tasks, i.e. split with time, which can be solved separately. This approach may be easily used for a

multi-constraint system and is very robust. However, it requires a careful selection of the initial data that will be analyzed and may be very difficult to extend to large river systems.

Other approaches are based on explicit stochastic optimization. In all cases optimization is performed without knowledge of the forecast. The modelling may be done using stochastic linear programming, stochastic dynamic programming, and stochastic optimal control. Such approaches require high computational capacities and thus may be hardly applied for large river basins. The last one, on the contrary, may be easily applied for large scales, however does not provide high precision in calculations. Another stochastic optimization approach is multi-objective optimization model. It allows setting many simultaneous constraints with subjective weights (relative magnitude of importance). In [38] this method is analyzed with four objectives: maximize energy production, improve energy production quality, minimize water discharges for water supply and maximize reliability of water supply.

1.3. Known optimization techniques for determining the reservoirs management operating policy

Application of simulation and optimization techniques for determining the optimal operating policy for reservoirs is very important in water resources planning and management. There are many publications devoted to solving this issue using various simulation and optimization tools. In [39] is described an economic optimization model for water management was developed to facilitate policy makers' decision making. The model includes the response of rice and fish yields to key factors including reservoir water levels, the timing and quantity of water release, and climatic conditions. The model accounts for variation in rainfall patterns, irrigation requirements, and the demand for low water levels during the fish harvest season. The optimization is performed to maximize profits in each of three production scenarios where the reservoirs water is used for: (1) only producing rice, (2) only producing fish, and (3) producing rice and fish. Fang et al

(2014) propose a new storage allocation rule based on target storage curves using a developed simulation-optimization model. The model aims to alleviate water shortages in recipient regions by optimizing the key points of the water diversion curves, the hedging rule curves, and the target storage curves using the improved particle swarm optimization algorithm. Mayer and Muñoz-Hernandez in [11] describe integrated water resources optimization models to determine and maximize economic benefits of withdrawing water for various use categories. Optimization has been carried out to maximize economic benefits from agricultural water use, water used in aquaculture production, residential water use, industrial water use, hydroelectric power use, water allocated for ecosystem functioning, and recreational use, respectively. In [40] a simulation/optimization model was presented that integrates linear reservoir decision rules, detailed simulations of stream/aquifer system flows, conjunctive use of surface and ground water, and delivery via branching canals to water users. The optimization module can perform two alternative functions: develop reservoir decision parameters that maximize conjunctive use of surface and ground water; or maximize total surface and ground water provided to users. In [41] a model was formulated as a linear programming problem with monthly management periods and a total planning horizon of 5 years to minimize the cost of water supply while satisfying various physical and institutional constraints such as meeting water demand, maintaining minimum hydraulic heads at selected sites, and not exceeding water-delivery or pumping capacities. The decision variables are water deliveries from surface water and ground water. The state variables are hydraulic heads. Basic assumptions for all simulations are that the cost of water varies with source but is fixed over time, and only existing or planned city wells are considered; that is, the construction of new wells is not allowed.

However, genetic algorithms (GA), due to evolution techniques, have become popular for solving optimization problems in various fields of science [42]. Particularly, this approach became widely used in water resources management. I.e. a simple optimization model for single and a cascade hydro-

electricity reservoirs system using GA was created in [43]. The objective function was to minimize the difference between actual and installed generation capacity of plants. The genetic algorithm technique was used in [44] to evolve efficient pattern for water releases at multi-objective reservoir for maximizing annual power production and irrigation demands. Constraints include the release for power and turbine capacity, irrigation demand, storage continuity equation and reservoir storage restrictions. Fi-Jihn Chang and Li Chen in [45] have examined for function optimization and applied to the optimization of a flood control reservoir model two types of genetic algorithms, real-coded and binary-coded. Optimization has been carried out to reduce the outflow during the peak time and at the end of the flood to return the storage close to its initial value to reserve storage for the next flood coming. Hincal, Sakarya and Ger in [46] have explored the efficiency and effectiveness of genetic algorithm in optimization of three reservoirs in the Colorado River Storage with a simple optimization to maximize energy production. Another more complex combined simulation–genetic algorithm (GA) optimization model is developed to determine optimal reservoir operational rule curves of the Nam Oon Reservoir and Irrigation Project in Thailand was developed in [47]. Both models operate in parallel over time with interactions through their solution procedure. The objective function was maximum net system benefit subject to given constraints for three scenarios of cultivated areas. An optimal irrigation water allocation was developed in [48] using genetic algorithm under four weather conditions that were identified by combining the probability levels of rainfall, evapotranspiration and inflow. Moreover, two irrigation strategies, full irrigation and deficit irrigation were modeled under each weather condition. The Objective function maximizes the total farm income and is considered for the optimal operation of the reservoir and the irrigation of crops at any time interval during the irrigation season.

Thus, it may be seen that most of the papers aim usage of GA to do a simple optimization of one parameter either to minimize costs, or to maximize the revenue

(of energy, production or whatsoever). While a more complex optimization is obviously needed with several contradictory constraints.

1.4. Known software for river system management

As was shown earlier in many cases, the main result of the development of a mathematical model for the management of river systems is the development of software that can be used as a decision support system for managing river systems, or even for automatic or semi-automatic control of water intake at HPP.

Such software products can be contingently divided into those that are created to simulate the water flow in the river system under the influence of various factors and those that are created primarily for automatic or semi-automatic control of HS on a river network. The second group of software products often uses the results of the first group. [49].

The first group include such world leaders in this field as MIKE 11 Software (MIKE Hydro river) and Pusola Software.

MIKE11 - the world's most popular 1D river modeling software package. The software package was developed by DHI Water & Environment to model flood zones, the effects of hydraulic accidents, break dams, high-water forecasts in a complex system of rivers and channels.

The Pusola Software is a package for the Delphi programming language and is used to model sections of the river network. In the thesis [50] in this programming language, a section of the Volga River was described with detailed consideration of hydraulic features, tributaries, etc. The author claims that it was possible to increase the accuracy of modeling the water pass, but does not give any verification with real data. Nevertheless, this product is of great interest because of its versatility and the possibility of almost unlimited modeling of any hydrological systems with any restrictions. But since modeling is carried out in a programming language, this product cannot be applied in real conditions.

There is also the information modeling complex ECOMAG [51]. It includes a mathematical model, a geographic information system (GIS), a database of territory characteristics and a control shell. The model used in the complex is a version of a spatially distributed model of the hydrological cycle, flow formation, transport and transformation of pollutants in the river basin. However, this software product does not calculate water levels, but only water consumption. Therefore, to fully use this software, you need to combine it with other software, for example, with MIKE 11 [52].

The second group includes software directly for reservoir management.

Similarly to the first group, the world leader in this field is also the product of DHI Water & Environment - MIKE BASIN [53]. The software allows planning and managing water resources within one or several river basins, development of general schemes for the use of water resources, and solving a wide range of water management problems. However, the versatility of this software imposed a number of limitations on it. The main disadvantage is the impossibility to form directly the rules for HS management on a river system based on the data entered. The software allows you to solve only a direct problem: according to the entered data on the estimated water bypass to the HS and according to the restrictions introduced, to obtain the result of modeling a water spill. Undoubtedly, on the basis of such data it is possible to evaluate the effectiveness of the proposed bypass, but such a way is very time-consuming from the point of view of the HS operators and is more likely to be used for research and analytical tasks.

That is why, in the Russian Federation, several analogues were created that were more suitable for water resources management.

In 2012, the Ministry of Natural Resources of Russia developed the automated information management system "Water Resources" [54], designed to select the operating modes of the cascade of reservoirs. This control system is based on the ECOMAG information-modeling complex and the reservoir modeling unit developed by the author for the specified dispatch graphs. According to the creators of the program, it allows one to "more clearly (compared with its

counterparts) predict the flood situation, identify areas of possible flooding at various water levels, and assess material damage". The program contains not only a detailed map of the area, but also even the passport data of people living in areas of possible flooding. Since 2012 AIUS "Water Resources" has been used to calculate the operating modes of reservoirs in the Volga-Kama cascade.

Multitasking Cascade software is well known and widely used. [55] It is designed to build automated process control systems, automated energy control and metering systems, automated operational dispatch control systems and other industrial automation systems and allows you to automatically build discharge hydrographs when choosing the optimal modes for high-water pass and reservoirs to work during low-water periods. However, for several reasons, this software is not widely used in river systems in Russia.

The "BASSEIN" program developed at MPEI at the Department of Hydropower and Renewable Sources is of much greater interest. This program implements a calendar method for calculating flow regulation. The entire space of the cascade basin is divided into design sections, in which the hydraulic characteristics of the river regime and the technical characteristics of the waterworks are determined. The water balance equation is used as the main equation of the mathematical model of the HPP cascade [56]. The block diagram of the program is presented in Fig. 3 [22].
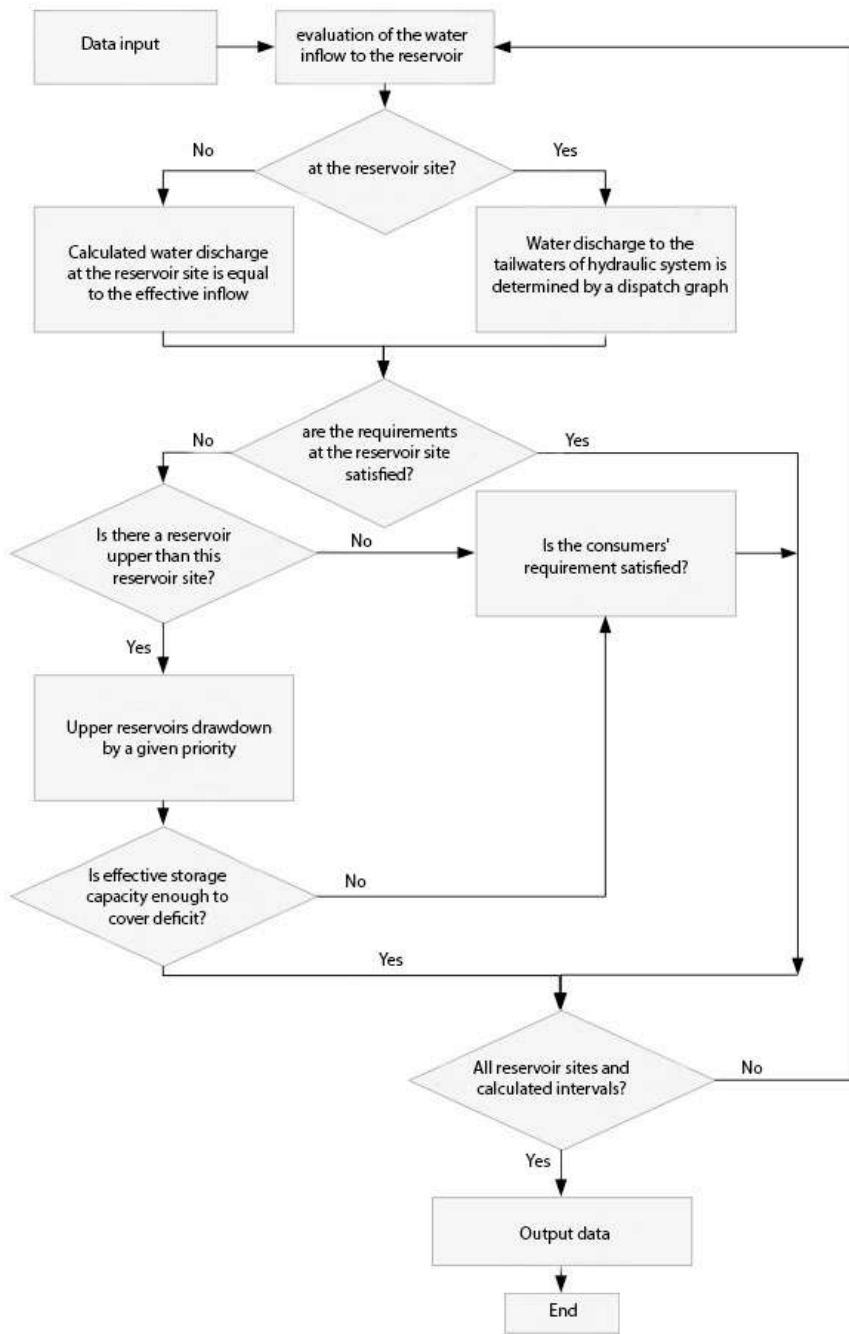
Fig. 3. Block-scheme of the "Bassein" software

The program "Bassein" allows you to determine the regime of the water management system under design conditions for a river basin with several settlement sections. The river system can be defined as you like, and in general terms it consists of the main channel and tributaries. At the same time, design intervals of arbitrary duration are set. Hydrological information is introduced in the form of inflow calendar series. Requirements for water levels in the reservoir, minimum flow rates in the tailwaters of the hydraulic system, and water delivery in each design interval are in three versions: guaranteed, reduced and increased, and, if necessary, energy transfer requirements.

The program can calculate both the isolated operation of the reservoir and the compensation regulation in the cascade. After the calculations, the ordinates of the curves of the duration of the reservoir levels, the discharge of water in the tailwaters, the average levels of the tailwaters, the HPP pressure levels and capacities are generated [22].

The disadvantages of this program include the need to perform optimization by sequential variant task of reservoir operation modes, which leads to an increase in the calculation complexity.

Nevertheless, this software "Bassein" is one of the best at present for decision support on the management of the cascade of reservoirs, and its updating and improvement of the program code the current computer power will significantly increase its efficiency, reliability, simplicity and, as a result, expand the range of its application.

In addition to the above programs, there are also the HS models on the river network, created in universal programs for simulating various technological and operational processes, such as Powersim, STELLA, iThink, Exted, and Venisim [28]. However, they are distinguished from other programs by insufficient detailing of all processes, the impossibility of scaling or changing the river network and a rather narrow range of application.

1.5. Flood Impact Assessment

In order to compare the proposed management approach with the existing one a flood risk assessment has to be performed. According to [3] risk assessment comprises of three distinct steps:

-the identification of hazards likely to produce hazardous events,

-estimation of the risks of such events and their contingent consequences,

-the social evaluation or weighting of the risk so derived.

The social evaluation of the risk is major research by itself and will not be discussed in this research, while the first two steps are highly important for comparison of two river system management approaches.

To assess possible damage from an accident at a hydraulic structure, the methodology presented in [57]. Total damage can be determined as follows:

$$D_{total} = D_1 + D_{stock} + D_2 + D_3 + D_4 + D_5 + D_6 + D_7 + D_{7r} + D_{7e} +$$
$$+D_8 + D_9 + D_{10} + D_{11} + D_{12} \qquad (3)$$

where:

D_{total} - general environmental and economic damage;

D_1 - damage to basic production assets;

D_{stock} - damage to stock production assets;

D_2 - damage to stock products of enterprises;

D_3 - damage to transport and communications;

D_4 - damage to housing stock and property of citizens;

D_5 - accident costs;

D_6 - damage to agricultural production;

D_7 - damage to forestry;

D_{7r} - damage from forest loss as raw material;

D_{7e} - environmental damage from forest flooding;

D_8 - damage to the environment from the discharge of hazardous substances into the environment;

D_9 - damage caused by water supply disturbance due to accident of water intake facilities;

D_{10} - damage to water transport facilities;

D_{11} - damage to fisheries;

D_{12} - other types of real damage.

As input data for the calculation, we set maximum depths and flow rates; time from the beginning of the accident to the arrival of a wave at a given point in the terrain; flooding duration; total area of the flood zone.

Thus, this approach requires a thorough long-term study of the territory, its tangible and intangible assets, as well as constant updating of the data. Therefore, such complex approaches cannot be applied for operational forecasting and management of water systems.

The identification of the hazards for a river system can be performed by modelling water inundation and identification floodable areas. This is done mainly by flood mapping [4].

GIS-based mapping of floods and other natural hazards is actively used in the scientific environment [5, 6, 7]. A good case study of such mapping using a self-developed software is presented in [8]. They use FloodCalc urban tool to model flood and evaluate the risk at most populated areas of Leipzig. Another example from Bangladesh using NOAA-AVHRR satellite images is provided in [9]. Likewise, satellite digital elevation model (DEM) was used in [10] when modelling flood plain delineation of a South Nation River system in Canada. A hydrologic Engineering Center's River Analysis System (HEC-RAS) has been successfully validated and used.

After having the flood plain mapped the flood risk may be evaluated as a combination of the recurrence probability of a damaging flood event and a number of potential negative consequences in a given area [11].

Estimation of the contingent consequences of floods can also be performed in various ways.

In [12] a methodology has been developed for assessment of flood risk arising from fluvial and coastal sources that explicitly considers defense failures represented through fragility curves. This method evaluates risk of separate

flooded cell as a product of a contingent event probability of exceeding any particular flood depth by economic consequence for this flooded cell. The total risk of the flood area is the sum of the risk of the associated with each impact cell. Additionally, the approach considers a probability of flood defense systems failure. However, this approach does not consider the severity of flood, which could be measured by the depth of the flood above surface level.

For this purpose stage-damage-functions are used for different building types and considered as internationally accepted standard approach for flood damage estimation [13]. But they are very hardly applicable when considered vast landside, e.g. when risk assessment is performed at the national level [14]. Furthermore, such functions introduce high uncertainties [15].

There are simpler approaches to assessing potential flood damage. In [58] flood risk is defined as the probability of occurrence of a given flood P multiplied by possible negative consequences C_n.

$$R = P \cdot C_n$$

(4)

Negative consequences C_n in [59] are defined as a combination of economic, social and environmental damage of the territory.

The advantages of this method include the relative simplicity and high speed of calculations. However, this method does not use geographic information systems, but carries out an integrated assessment of the effects of flooding over the entire area.

An extensive research that would consider most of the above-mentioned drawbacks is presented in [16]. In this paper a new damage estimation approach was presented that is based on the developed by the authors GIS tool. In the software tool a possibility to apply different damage functions was implemented. These are: Linear Polygon Function, Square Root Function, and Point based Power Function. These three options allow performing different level of damage estimation depth. One of the simplest ones is square root function, where damage is defined as follows:

$$D = b \times \sqrt{h} \hspace{4cm} (5)$$

with b – constant that stands for damage for h = 1 m, h – water depth.

This approach implements a whole group of simplified methods based on the construction of so-called "flood susceptibility curves" [60, 61] for each section of flooded area. The curve shows the change in total damage (environmental, economic and social) depending on water level. It is built simultaneously for all sections of the terrain and is used in predicting the risks of flooding territories. The disadvantages of this method include the need for periodic updating of data on a given area and updating the curves, which in some conditions may be impossible. In addition, this approach is difficult to implement when analyzing large areas of floods (for example, at the national level) [62].

Thus, the existing mathematical, methodological, and software products do not allow efficient and effective forecasting and assessment of potential flood damage. For the most part, they are aimed at accurate assessment of the flood that has already occurred, and not at the real-time forecast.

Moreover, according to [63] in the real-time forecast of potential flood damage, the following three tasks should be solved:

- An acceptable accuracy and accuracy of the forecast should be provided. Its value should be maximum, but at the same time, it should be possible to quickly calculate this parameter under changing conditions.
- Whenever possible, all factors should be taken into account: social, economic and environmental. This statement is true until the installation of many different factors complicates the process of operational calculation.
- Flood damage should be geo-tagged and individually assessed for different areas of the flooded area. The integral indicator of potential damage can only be obtained as the sum of all local indicators for a given territory.

CHAPTER 2. Description of studied river systems

2.1. Valle D'Aosta river system

The region Valle d'Aosta accounts for an important share of hydropower network system in Italy, consisting of mountainous region situated in North Western Italy bordered by Switzerland and France. Around 20% of this area is less than 1500 meters from main sea level. Fig.1 shows the region of interest Valle d'Aosta. In actual practice the region consists of glaciers and snowpack in winter determine the runoff regime characterized by minimum flow values in winter and maximum flows in spring and summer. The principal river of the valley is 100 km through the whole Region between Courmayeur (near the Mont Blanc) and Quincinetto, (near the Pont St Martin) the outlet of the valley. The ice covers 5.5% of the total area and a great number of lakes are located in Valle d'Aosta. Some of such lakes are artificial and are used for the regulation of hydropower production. The availability of water to be stored in a certain elevation provides favorable conditions for hydroelectric production. In the year 2011 the hydroelectric network capacity of the region was about 900 MW with a power production of 2743 GWh per year.

The first step in the modeling was the determination of an appropriate schematization of network of flows and reservoirs called as a hydropower system network. Every hydropower plant is characterized by the minimum and maximum flow of water available for the turbines and by an energetic coefficient that represents the actual power produced in MW. For each reservoir the maximum height must be provided for finding the power produced in each plant. Finally, the maximum flow and the time of concentration must be inserted for the dam and rivers connecting each other. These data, together with the initial and final conditions for the reservoir capacities, complete the conceptual model of the system.
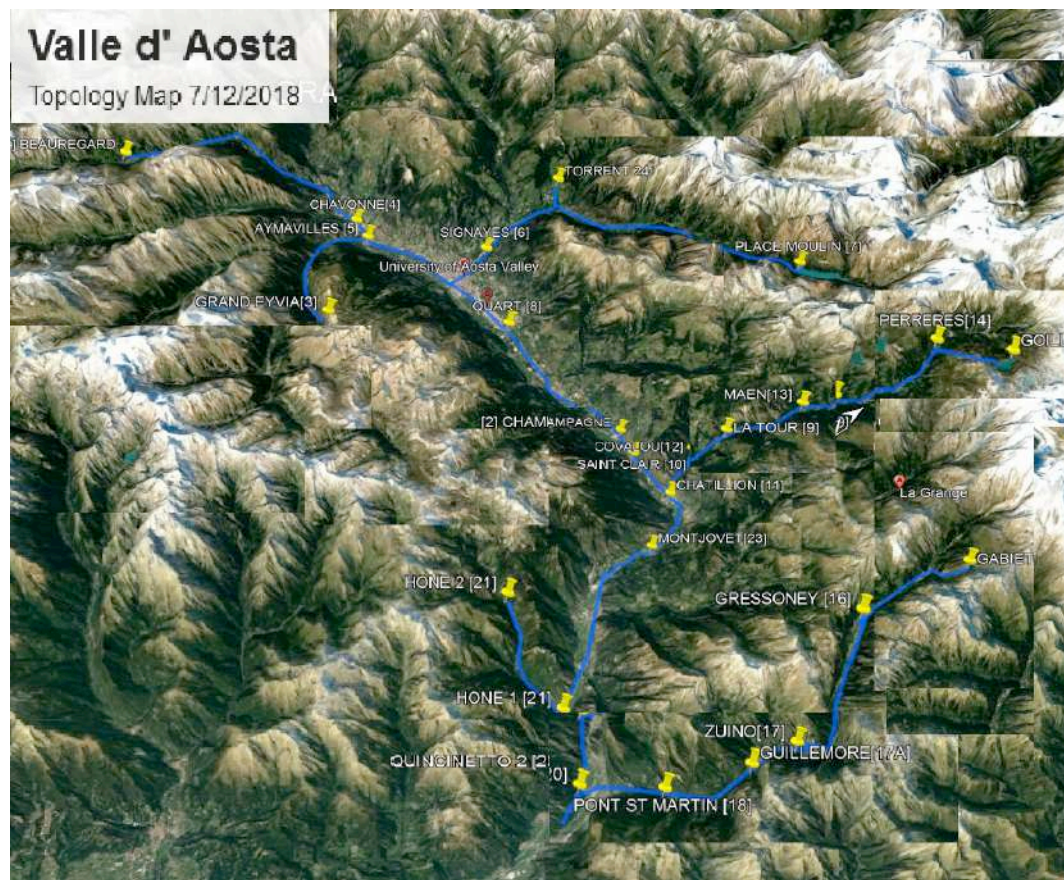
Fig. 4. Topological map of Valle d'Aosta with terrain

The elevation and availability of water leads the network of reservoirs to function effectively. The Fig. 4 shows the topology of the region with terrain reflects the need for controlling the flow buy a simulation and optimization preventing flood without affecting power production.

The scheme of river system of Valle D'Aosta region is shown in Fig. 5.

In this research a system of Butier river has been studied thoroughly.

Fig. 5. A scheme of Valle D'Aosta river system

2.2. Volga-Kama river system

As the object of research, the Volga-Kama HPP cascade was selected on the Volga river section from the Nizhny Novgorod HPP and lower down to the Volga HPP, and on the Kama river section from the Kama HPP until it flows into the Volga river. The scheme of the river system section is presented in Fig. 6 [64].

Fig. 6. A scheme of the Volga-Kama river system

The selected area is characterized by the complex sequentially parallel structure of the HS in the system, containing a total of 8 large reservoirs with HPP located in places of dense population.

Currently, RusHydro, which manages most of the stations in the cascade, is modernizing equipment, raising capacity and productivity. In particular, from 2007 to 2015, the cascade capacity was increased by more than 310 MW and by 2023 it is planned to increase the capacity by more than 520 MW [65]. Also, design work is underway to change the NHL value at a number of system reservoirs.

The largest of these is the Volgograd Reservoir with the Volga HPP, located in the lowest part of the Volga River [66]. The normal headwater level of the reservoir is 15 m above sea level (according to the BES), the surcharge reservoir level is 16.3 m, the dead storage water level is 12 m [67]. The reservoir regulates the flow on seasonal basis and weekly with a diurnal cycle basis. The reservoir is also used for energy, water transport, irrigation and water supply. The cities of Saratov, Engels, Kamyshin, Dubovka, Volsk, Marx are located on the banks of the Volgograd reservoir. Volga HPP, in turn, is the largest one in Europe. Its installed capacity is 2671 MW, and the average annual electricity generation is 11.1 billion kWh.

The next reservoir upstream of the river is the Saratov reservoir with the Saratov HPP. The reservoir area at the full reservoir level is 1831 km², length is 357 km, maximum width is 25 km, average depth is 7 m. The Saratov reservoir is not designed to regulate the flow; therefore, the HPP bypasses all the incoming water to the tailwaters in transit mode [68].

The Saratov HPP is located on the border of the Middle and Lower Volga region, 1129 km above the mouth of the river. Volga, near the city of Balakovo, on the left bank floodplain.

The surcharge reservoir level is currently 31.4 m, the normal headwater level is 28 m, the dead storage level is 27 m.

The Kuibyshev reservoir is the upstream after the Saratov reservoir, the largest in Eurasia and the third largest in the world by area. The main purpose of

the reservoir is to generate electricity, improve shipping, water supply, irrigation, and fishing.

The length of the reservoir along the Volga is 510 km, the largest width is 27 km, the area of the water mirror is 6150 km², the total volume of water is 57.3 km³, the working volume is 25.3 km³. The estimated maximum discharge rate through the facilities is 69,400 m3 / s (with a probability of 0.1%) [69].

Such large cities as Kazan, Tolyatti, Ulyanovsk, Novocheboksarsk, Dimitrovgrad, Zelenodolsk are located on the shore of the reservoir. [70].

Zhigulevsk HPP is a low-pressure riverbed hydroelectric power plant. The installed capacity of the power plant is 2488 MW. The surcharge reservoir level is currently 55.3 m, the normal headwater level is 53 m, the dead storage level is 45.5 m.

The Kama River flows into the Kuibyshev reservoir at its beginning, and thus the Volga-Kama basin is divided into two parallel river systems: Verkhnevolzhsk and Kama.

Along the Upper Volga basin, beyond the Kuibyshev reservoir, there is the Cheboksary reservoir and the Cheboksary HPP, which covers the territories of three constituent entities of the Russian Federation - the republics of Chuvashia and Mari El, as well as the Nizhny Novgorod region.

The total capacity of the Cheboksary HPP- 800 MW. [71].

The surcharge reservoir level is currently 69.5 m, the normal headwater level is 63.3 m, the dead storage level is 62.5 m. This NHL is lowered due to the incomplete construction of the Cheboksary HPP and the arrangement of the reservoir zone. Moreover, the startup of the operation of the reservoir was in 1980 at a reduced pressure level with a mark of 61 m, but in the spring of 1981, it was increased to its current value to ensure navigation. The NHL design value is 68 m.

Further along the Upper Volga basin beyond the Cheboksary reservoir, the Gorky reservoir and the Nizhny Novgorod HPP are located [72]. The Nizhny Novgorod HPP is a typical low-pressure hydroelectric power plant of a channel type. The HPP installed capacity at the NHL is 523 MW.

The surcharge reservoir level is currently 85.5 m, the normal headwater level is 84 m, the dead storage level is 81 m.

The Nizhny Novgorod reservoir ends with the section of the Verkhnevolzhskaya river system studied in this work. The further hydropower system, including the Rybinsk, Sheksninsk, Uglichsk, Ivankovsk and Verkhnevolzhsk reservoirs, was not considered due to their relatively small size and low capacity of HPP (less than 1000 MW).

Along the Kama River Network, the Nizhnekamsk Reservoir and the Nizhnekamsk HPP follow the Kuibyshev Reservoir. Nizhnekamsk Reservoir is a channel, flat type reservoir.

Similarly to the Cheboksary reservoir, Nizhnekamsk was not filled up to the design level of 68 m, but is currently operating at 62 m [73]. In such an operation, the regulation of the flow of the reservoir is not carried out.

The total design capacity of the Nizhnekamsk HPP is 1248 MW. Design electricity generation 2.5 billion kWh.

The Votkinsk reservoir and the Votkinsk HPP follow the Nizhnekamsk reservoir on the Kama River. The reservoir solves the problems of energy, shipping, is used for seasonal regulation of runoff, providing a highly operational reserve for various violations and deviations of the planned regime, fishing, water intake and recreation. [74].

The surcharge reservoir level is currently 90 m, the normal headwater level is 89 m, the dead storage level is 84 m.

The available capacity of the Votkinsk HPP is 1,065 MW. Long-term average power generation - 2670 million kWh. [75].

The Votkinsk reservoir ends with the section of the Kama river system studied in this work. The further hydroelectric complex, which includes the Kama reservoir and the Kama HPP, was not considered because of its relatively small size and low capacity of the HPP (less than 1000 MW).

Thus, the studied system of HS is a complex river network with waterworks connected in parallel-series. At the same time, for a number of hydroelectric

facilities (Cheboksary reservoir, Nizhnekamsk reservoir) there are restrictions on the regulation of runoff and water flow control.

Modeling of such a system will make it possible to fully explore the capabilities of the developed algorithms, which will ensure their applicability to other river systems.

CHAPTER 3. Development of the method and mathematical model for managing a cascade of dams in a river system

3.1.   Mathematical modelling of water discharge in a river system

Hydroelectric power plants may be located either in parallel to each other or in series. In this research, it was selected a combination of two parallel reservoirs (A) and (B) and one installed in series after the parallel ones (C) in a way that the outlet water flow from reservoirs (A) and (B) falls into the third reservoir (C). (Fig. 7). Such a combination is considered to be one of the simplest for calculation but at the same time very commonly used.
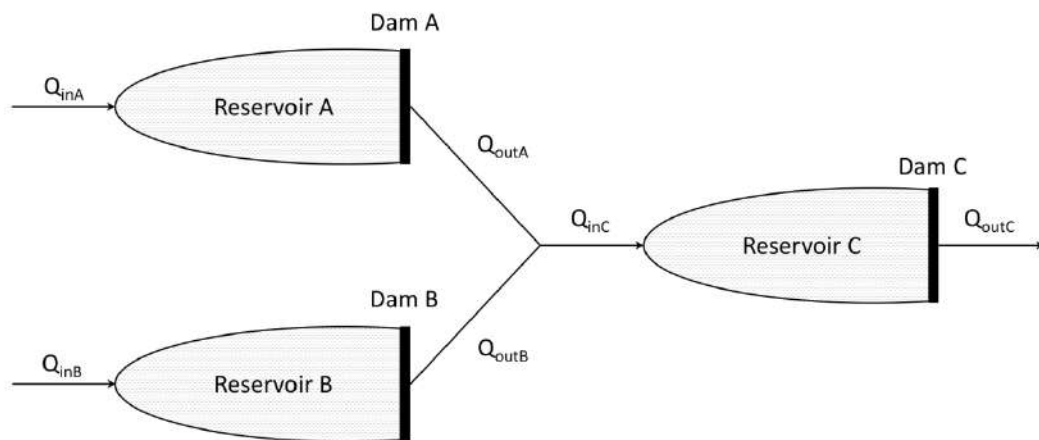

Fig. 7. A general scheme of reservoirs connection

For each of the reservoirs, the following indicators were specified: input flow, hydrodynamic and geometric characteristics, electricity generation and agriculture demands. Besides, for each section of the river network the largest peak discharge was determined, which exceed was assumed to be the flood event.

Each reservoir was operating according to the scheme shown in Fig. 8. Thus, the reservoir received a total flow of different affluxes varying in origin and nature. In addition, the precipitation falling over the reservoir bowl and the groundwater, which could be either positive, or negative depending on the direction of filtration, were separately taken into account. The reservoir filling process was described in

detail in the previous work currently in press and is based on a methodology based on SD as in [76]. Besides, the model describes the evaporation process, which could pass to the condensation process depending on the difference between the values of the water vapor pressure. Irreversible water consumption is going to meet the agricultural and domestic needs. The tail-water receives the flow that consists of water passing through the turbines and bypass, which is employed in order to avoid the reservoir bowl overflow.
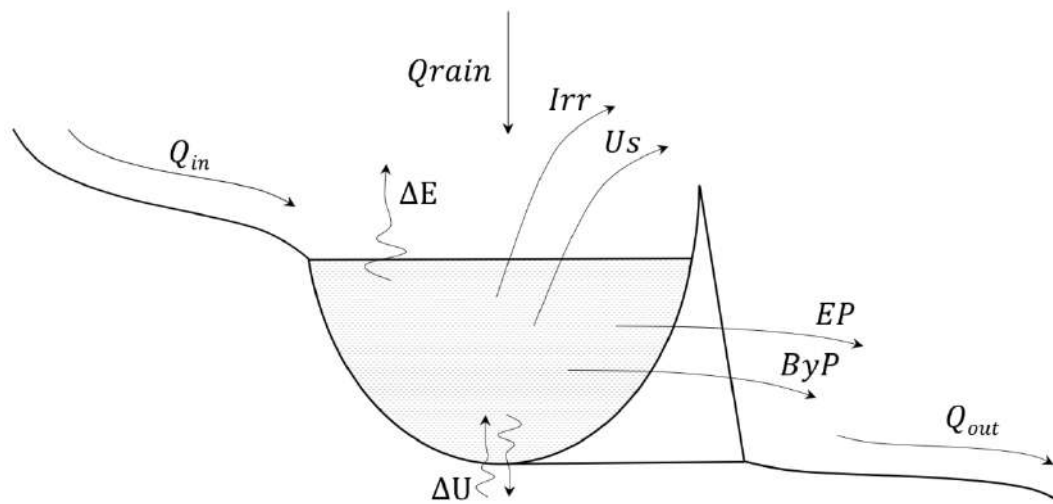

Fig. 8. Reservoir model

The basic equation to describe the reservoir operation process appears to be the balance equation given below:

$$Q_{in} = \Delta E \pm \Delta U + Irr + Us + EP + ByP \qquad (6)$$

where:

Q_{in} – incoming flow;

ΔE – evaporation;

ΔU – underground water (could be positive or negative);

Irr – water, spent for irrigation;

Us – water for household usage;

EP – discharge for energy production;

ByP – discharge through bypass;

Q_{out} – discharge from reservoir.

The reservoir incoming flow indicated in the InFlow chart consists of the surface waters influx from the upstream pool; it could include streamflow, rainfall runoff, etc., and is set in the form of the flow and groundwater hydrograph. In addition, the model includes a possibility of receiving rain precipitation falling directly over the reservoir. It is calculated in accordance with the following formula:

$$Q_{rain} = Dsurf * AvgRain, \tag{7}$$

where: *Dsurf* is the water catchment surface area;

AvgRain is the amount of precipitation per area unit and per time unit.

The model also considers water evaporation from the reservoir surface; in the scheme this flow is designated as Qevap and could be calculated as:

$$Q_{evap} = W * D_{surf}, \tag{8}$$

where W is the evaporation rate.

Empirical formulas were most widely used in assessing evaporation from unexplored lakes and reservoirs; such formulas were based on using the standard observations data obtained from a network of meteorological stations located on land accompanied by subsequent recalculation of hydrometeorological elements for the water surface conditions. Among such formulas, the SHI one became extremely popular, when assessing evaporation from water basins during warm periods:

$$E = 0{,}14n(e_0 - e_2)(1 + 0{,}72v_2), \tag{9}$$

where:

n is the calculation period;

e_0 is the average value of the maximum water vapor pressure above the water surface determined from the water surface temperature (mbar);

e_2 is the average value of the water vapor pressure (absolute air humidity) above the water basin at a height of 2 m (mbar);

v_2 – is the average daily wind speed (m/sec).

Comparison of the daily evaporation amounts calculated in accordance with this formula with the measured amounts demonstrated that the average error constituted 13.5% and in 75% of cases it did not exceed 8 - 10%. The maximum error values reached 25 - 30%, they were referred to the arid regions and were bearing a negative mark.

As evaporation is offering relatively small contribution to the overall water exchange in the reservoir, the error would produce a very insignificant effect upon the result, which allows us to adopt this formula for further calculation.

The initial water level in the reservoir is equal to the normal headwater level (NHL), which appears to be the desired level and is set in Des_Volume. The difference between the available and expected volumes of water in relation to the expected volume in Differ element is calculated using the following formula:

$$Differ = \frac{|Dam - Des\_Volume|}{Des\_Volume}. \qquad (10)$$

Water discharge from the reservoir occurs only, when the required water volume in the reservoir is available and is calculated in the Release element according to the following condition:

$$MIN\left(\frac{Dam}{Timestep}, QPower + QIrrigation + QUsers + Qbypass\right), \qquad (11)$$

where:

$QPower$ is the water flow directed to the electricity production;

$QIrrigation$ is the water flow spent to meet the agricultural needs;

$QUsers$ is the water flow consumed for domestic needs;

$Qbypass$ is the water flow discharged to the downstream bypassing the turbines;

$QIrrigation$, $QUsers$ and $QPower$ values are defined as a range of values that cover the needs of water consumption.

The revenue resulting from the electricity production is calculated in the Revenues element; and it further stored in the Earnings element:

$$Revenues = EnergyCost * QPower, \qquad (12)$$

where: $EnergyCost$ is the cost of electricity produced from the 1 m^3/sec flow.

As of today, we do not possess efficient and economical methods for storing the generated electricity, that is why, we limit the production to a certain value indicated in the Des_Revenues element. In the Yield element, we constantly compare the revenue derived from the generated electricity with the expected income:

$$Yield = \frac{Earnings}{Des\_Revenues}, \qquad (13)$$

where:

$Earnings$ is the received profit;

$Des\_Revenues$ is the expected income.

The capacity of HPP in kilowatts at each moment of time is determined by the formula [22]:

$$N_{HPP} = 9{,}81\eta_t\eta_g Q_{HPP}H_{NETTO}, \qquad (14)$$

where:

Q_{HPP} − water flow rate used by HPP for energy production, i.e. water flow rate passed through HPP turbines, m^3/s;

H_{NETTO} - available pressure head, determined by the difference in the levels of the headwater and tailwater levels, taking into account hydraulic losses in waterworks, m;

η_g − generator efficiency (0,89…0,95);

η_t - turbine efficiency (0,92…0,98)

For simulation, you can take the average value of the efficiency factors and determine the capacity of HPP by the formula:

$$N_{HPP} = 7{,}9Q_{HPP}H_{NETTO}. \qquad (15)$$

Electric energy generation (kWatt·h) is determined by the formula:

$$E = \overline{N}_{HPP}T, \qquad\qquad (16)$$

where:

T – hours of operation of (8760 per year).

$\overline{N}_{HPP}$ - average capacity of HPP for the period of operation (interval T).

The capacity of HPP should tend to a certain set value - guaranteed capacity - the minimum average monthly, average seasonal or average annual capacity that the HPP provides with a given reliability:

$$\frac{E_{actual}}{E_{guaranteed}} \to 1. \qquad\qquad (17)$$

At the same time, the HPP capacity is limited by the capabilities of the turbine and the capabilities of the generator (Fig. 9)

The turbine is limited in capacity when the nozzle of the turbine is fully open. The capacities at a water head below the design are called available.
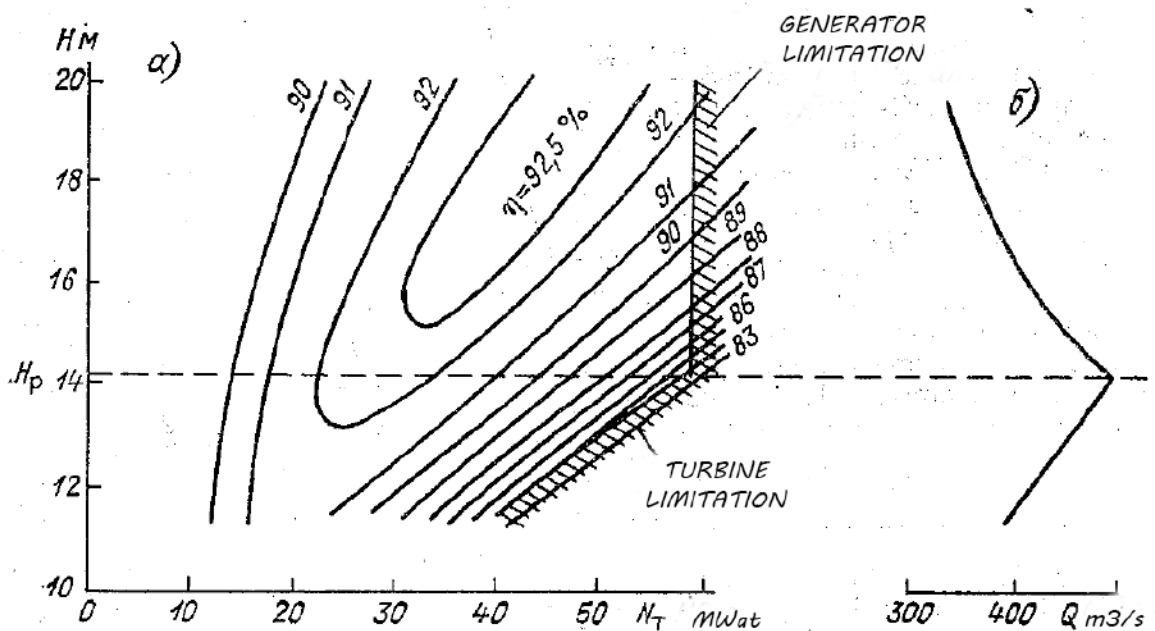

Fig. 9. Hydropower plant performance chart (a) and its discharge capacity (b)

[22]

In case the water inflow into the reservoir proves to be so great that after covering all the needs there still a remaining surplus, which accumulation leads to exceeding the permissible level, an emergency discharge passing by the turbines

shall be involved, i.e. the bypass. Below you could find the formula illustrating the said condition:

$$if\ (Dam \geq DesVolume, (InFlow + Qrain - Qevap - QIrrigation - QUsers - QPower) + ByPass),\qquad(18)$$

The water flow passing to the tail-water is calculated in the Qout element using the following formula:

$$Qout = Release - QUsers - QIrrigation,\qquad(19)$$

The water level in the reservoir depends on many factors: the water inflow rate, the water discharge flow rate of the reservoir, evaporation, precipitation, filtration through the dam body, etc. However, for regulation purposes, within this work, it is allowed to consider only the water inflow rate into reservoir and the flow rate of the reservoir discharge, because other values can be neglected.

Since for a given NHL the volume of water in the reservoir is known, this criterion can be modified as maintaining the optimal volume in the reservoir (such a criterion is easier to calculate).

In this case, the volume of water in the reservoir can be defined as:

$$V = V_{NHL} + Q_{inflow} \cdot T + Q_{HEPS} \cdot T\qquad(20)$$

So:

$$\frac{Q_{HEPS}}{Q_{inflow}} \rightarrow 1\qquad(21)$$

where: Q_{inflow} - total discharge from all tributaries to the reservoir (including rain, water inflow from the next reservoir upstream, etc.)

Moreover, according to [16] the limited effect of water pass to depth can be calculated by the formula:

$$Q = k \times h^{n},\qquad(22)$$

where: k – proportionality coefficient, h – filling of the prismatic channel with a constant slope, n is a constant equal to approximately two.

In this work above, we stated that the safety and security criterion should become one of the criteria required for the reservoir integrated management and control, that is why, we introduced the Ist_Flooded_water element in this scheme, which determines the amount of water that left the channel. It works according to the following condition:

$$MAX(0, Qout - Max\_for\_floods),\qquad(23)$$

where: Max_for_floods is the maximum permissible water flow in the channel that does not cause damage to the environment.

Normalization of the value of the aggregate volume of water released to the flood plain is performed in the FloodRatio element:

$$\frac{Q_{HEPS}}{Q_{max}} \to 1 \qquad(24)$$

where: Q_{max} − the maximum possible discharge through the dam so that in the river / canal downstream the water level does not rise above the pre-set level.

This level can be either empirically defined or simulated using the Saint-Vennan equations (there is no need to study and model them, there are already many programs like Mike11 that allow you to do this conveniently and simply).

3.2. Sensitivity analysis of the developed mathematical model

In order to perform a proper verification of the developed approach a PowerSIM software was used.

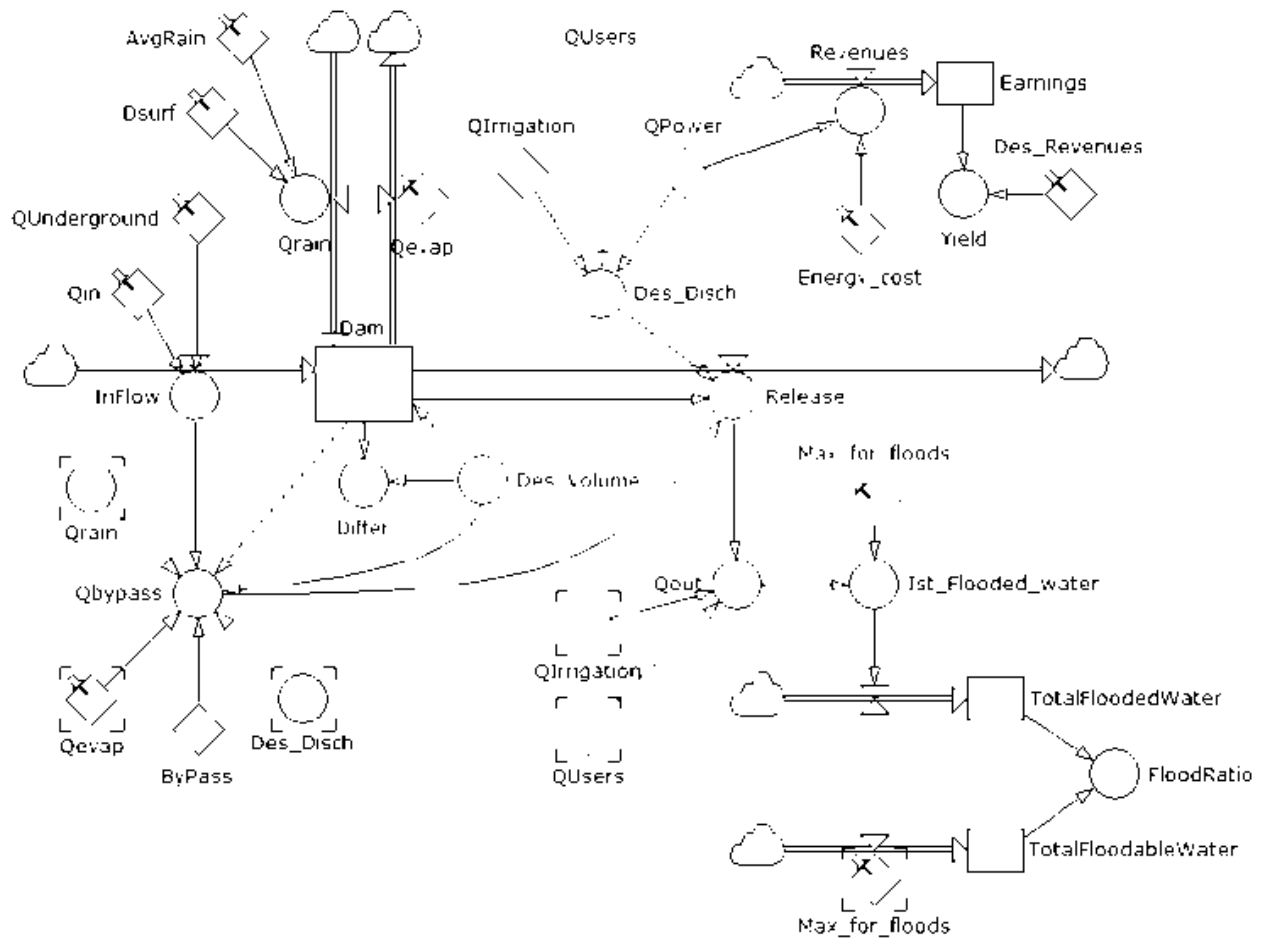Firstly, a model of a single reservoir was created. It is shown on Fig. 10.

Fig. 10. Dynamic model of a single reservoir

In order to analyze how sensitive, the developed model is to variations in the assumptions that were made for it a sensitivity analysis has been carried out. It allows to understand what assumptions have the highest influence on the model. Among various assumptions have been selected any inflows from balance equation (1), such as incoming flow, evaporation, underground water, irrigation discharge, household water, discharge for energy production, discharge through bypass, discharge from reservoir. To perform the sensitivity analysis any of these may be set within a fixed, normal, truncated normal, uniform, triangular or exponential distribution with an expected value and a standard deviation.

The possible decisions are set in a way to fulfill all requirements for all stakeholders of the river systems, i.e. minimum possible and maximum water supplied for household usage, power production, irrigation and water bypass.

The chosen objectives assure high performance of the systems and were chosen according to the equations 13-15. For objectives estimation a confidence level calculation was chosen. In this case a percentage of runs fulfilling each objective's target is calculated. This percentage is in turn compared to the confidence level for the objective, and a deviation is calculated.

The sensitivity analysis is performed as a combination of the optimization (evolutionary search) method and the risk analysis (Latin Hypercube) method to find the optimal decisions. As a result, optimized values for FloodRatio (equation 24), Yield (equation 21), and Differ (equation 17) is calculated for a given range of various assumptions.

Repeating the abovementioned procedure for various possible inflow ranges results in a thorough walk-through model verification.

The developed model allowed to perform determining the optimal operating policy for a system of reservoirs from the point of view of water resources planning and management. In particular, it was performed model optimization, and walk-through validation. It resulted in a number of runs with various input data relevant for different modelled water systems with an outcome of a preferable system management.
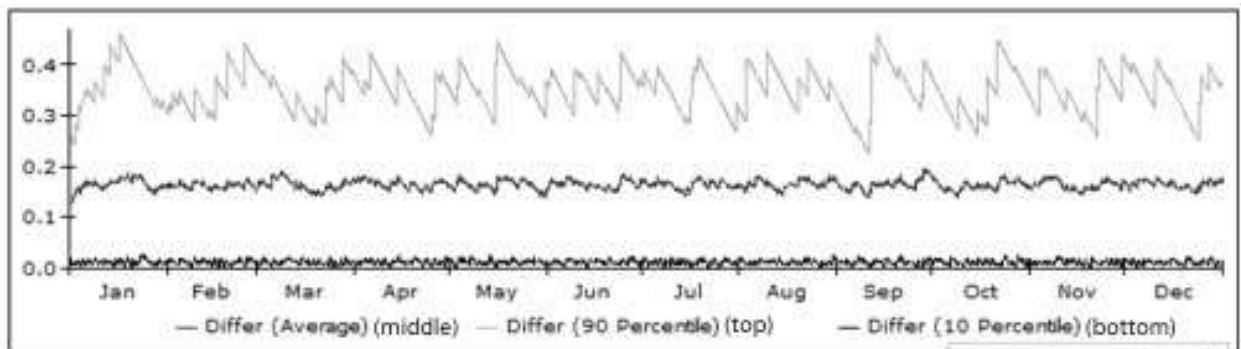

Fig. 11. Optimized operation policy for the water management in reservoir system for low rain period.

For this a set of criteria is evaluated and presented their optimal values range. The model provides us with a range of values for a Differ ratio, that describes the current and expected water volume in the reservoirs, Yield ratio that describes the power production revenue, and FloodRatio that characterizes flood

occurrence. Each of these values are provided as a range with an average, confidence interval and percentiles (5, 10, 25, 75, 90 or 95%) upon demand. Modelling term can be selected from a range of 1 to 25 years. Fig. 11 and Fig. 12 present results of one of such runs with a certain given inflow that correspond to a low rain period. The incoming flow was set to 6000 m3/s with standard deviation 4000 m3/s, lower minimum 1000 m3/s and maximum limit 14000 m3/s. The underground flow was set to 500 m3/s with standard deviation 400 m3/s, and maximum limit 1500 m3/s.
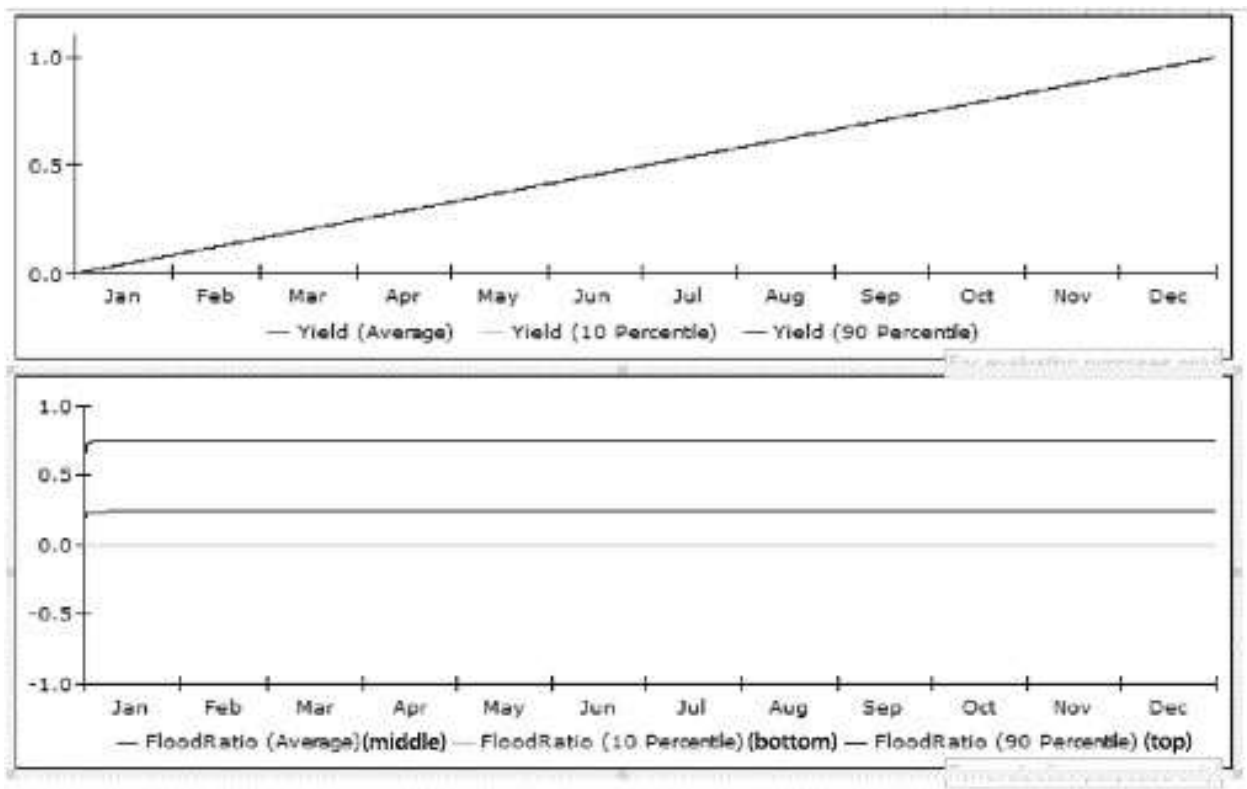

Fig. 12. Obtained reservoir system operation objectives at optimal water management policy for low rain period

In order to simulate a system of several reservoirs a model presented on Fig. 10. was continuously repeated to achieve the required number of segments in the river with specific parameters for each segment until the necessary number of segments was reached. It may be seen that with the suggested operation policy provided at Fig. 11 the flood will not occur in the area at any case as the Flood

ratio will not exceed one, while the revenue from power production (Yield) will achieve its maximum possible value within one year (Fig. 12).

If the inflows are changed to the values that characterize heavy rain period (see Fig. 13), even the optimal operation policy will result in the high flood probability. The incoming flow was set to 16000 m3/s with standard deviation 5000 m3/s, lower minimum 1000 m3/s and maximum limit 25000 m3/s. The underground flow was set to 2000 m3/s with standard deviation 100 m3/s, and maximum limit 6000 m3/s. The evaporation was set to 2000 m3/s with standard deviation 200 m3/s, and maximum limit 4000 m3/s.
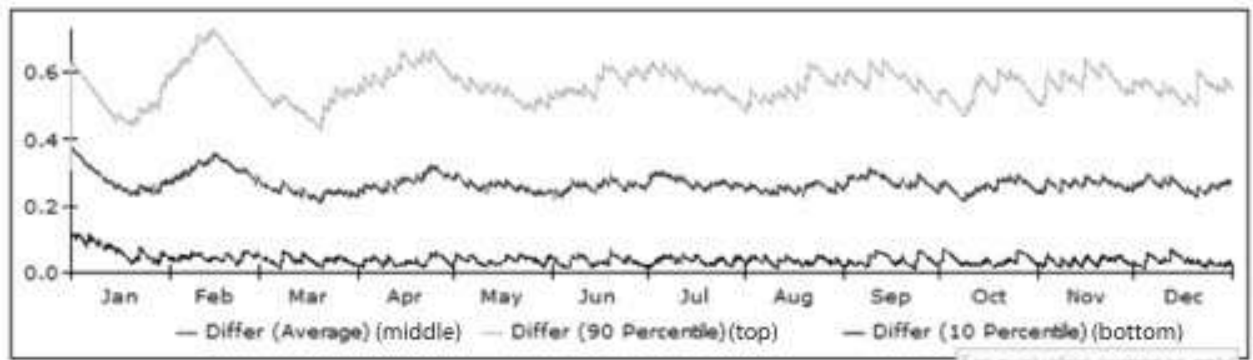

Fig. 13. Optimized operation policy for the water management in reservoir system for heavy rain period.

The results are presented on Fig. 14. It may be seen that the probability of flood non-occurrence is less than 15%. However, this would be the flood with the lowest possible water level increase and, hence, damages incurred. Meanwhile, the power production remains to maintain at its optimal value.
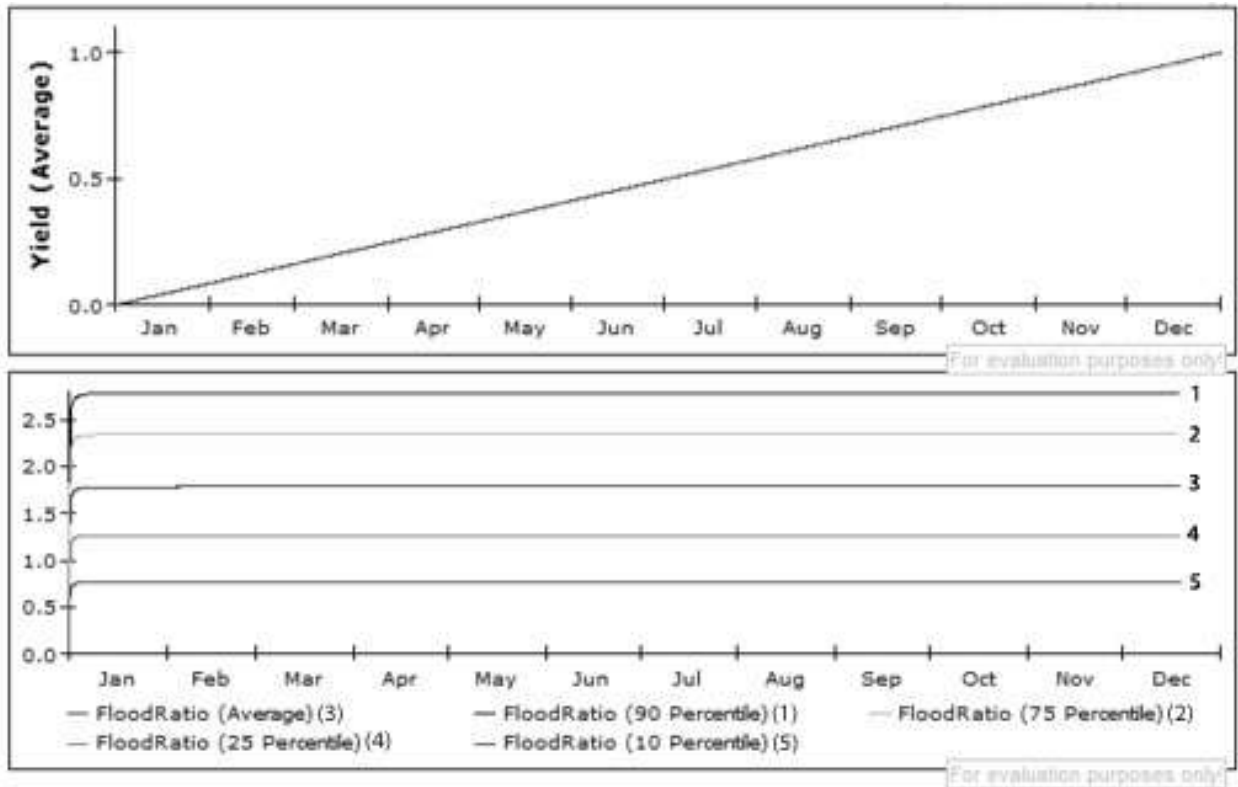
Fig. 14. Obtained reservoir system operation objectives at optimal water management policy for heavy rain period.

Furthermore, the inflow values were set for an average range, that corresponds to the moderate weather conditions (see Fig. 15). The incoming flow was set to 9000 m3/s with standard deviation 5000 m3/s, lower minimum 1000 m3/s and maximum limit 19000 m3/s. The underground flow was set to 1000 m3/s with standard deviation 500 m3/s, and maximum limit 3000 m3/s. The evaporation was set to 400 m3/s with standard deviation 100 m3/s, and maximum limit 1000 m3/s.
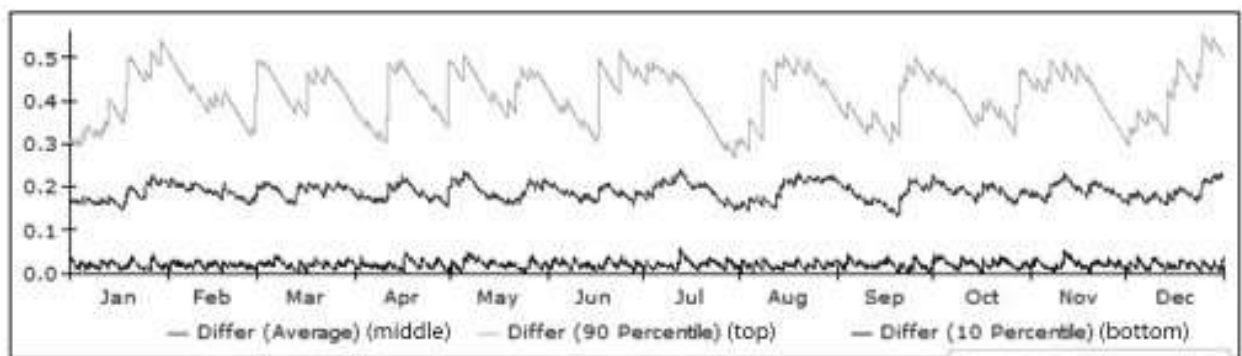

Fig. 15. Optimized operation policy for the water management in reservoir system for moderate rain period.
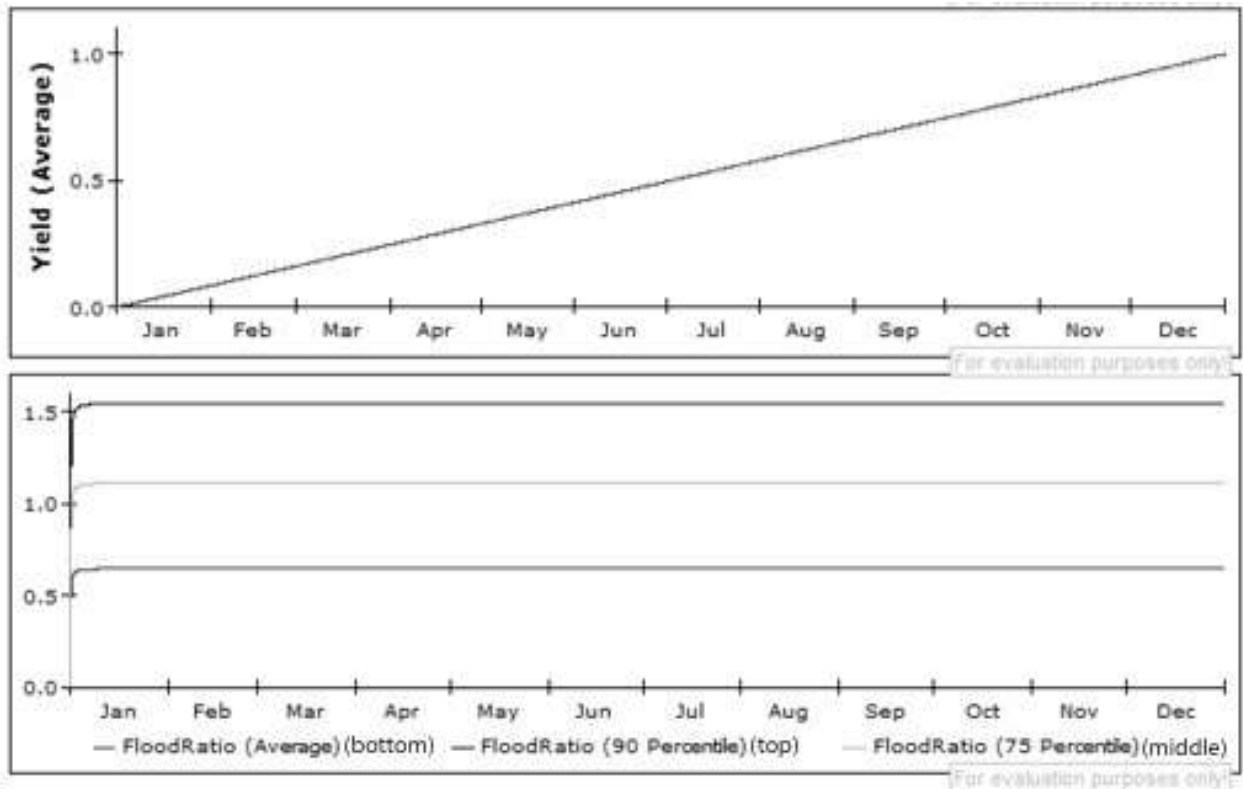
Fig. 16. Obtained reservoir system operation objectives at optimal water management policy for moderate rain period.

This resulted in a FloodRatio average close to 0,65. And only 70 percentile of floods has exceeded the critical value and resulted in flood event. Power production has also remained to maintain at its optimal value. Results were obtained after an extensive simulation campaign based on the minimization of the experimental errors as in [77].

The proposed model allows to perform simulation of water drainage policy for a tandem of reservoirs at the complex river system. This model has been verified on a walk-through basis. It resulted in high reliability disregards broad possible variations of the managed parameters: in all cases it has produced a stable result, that was consisting of an optimal water reservoir operation policy with the desired criteria set before, such as ratio of current and expected water volume in the reservoirs, highest possible power production revenue, and minimal possible flood occurrence.

3.3. Verification of the developed mathematical model at Valle D'Aosta river system

We can consider a general case of hydroelectric power plant in order to understand the conceptual modelling because the region Valle D'Aosta consists of 32 reservoirs mutually connected and we have to consider each dam separately before connecting it to a single network. Generally, the reservoir has three levels of capacity shown in Fig. 17, which are as follows: Dead storage level (DSL) - water level below which no electricity generation is possible, Normal headwater level (NHL)- Accepted level in reservoir, Surcharged Reservoir level (SRL) – Water level aimed to store water during rainy season. In our case, we are considering only two basic levels the DSL and NHL.   The reservoir will receive water from different sources like precipitation, ground water and water inflow from upstream reservoir.
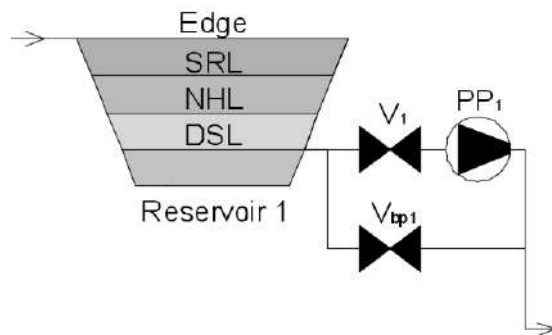
Fig. 17. A reservoir representing different levels of water based on constraints. SRL- Surcharged Reservoir Level, NHL- normal Head water level and DSL – Dead storage Level.

The management of hydroelectric power plant can be characterized by several constraints. Our main aim is to prevent the overflow of water which results in the collapse of dam and this is prevented by maintaining a mass balance on each node and at each time interval. So, in general the following boundary conditions can be chosen for creating a model:

1. Performance criteria – water level above the Dead storage level (DSL) the electricity generation range and below surcharge reservoir level (SRL) preventing flood and collapse

2. Optimal mode of operation for maintaining the Normal Headwater level (NHL).

3. Production of rated power.

The software can be useful to compare different scenarios arising, for example, by a change of climatic conditions, or by different management politics. In this work, analyzed scenario of water availability and simulation is done for a period of one year with an interval of one hour. The computer model begins with defining rated capacity, rated flow rate, rated power and head at which the plant works. In order to fulfil the boundary conditions an equation governing the flow rate has to be input which will keep the capacity of the reservoir within the Dead Storage Level (DSL). Also, a mass balance is created by adding or exiting a specified flow rate according to our rated value. The equation for the flow rate from each reservoir is defined by:

$$MIN\ ((dam\_A-minlimit\_A)/TIMESTEP;flimit\_A) \qquad (25)$$

Where, *MIN* – Minimum is a Powersim function which returns the minimum between two values. This constraint will limit the capacity within the DSL i.e. the minimum level will be returned to zero when capacity of reservoir reaches the minimum limit of dam. *Dam_A* is the rated capacity of reservoir, *minlimit_A* is the allowable level or DSL after that water should not be increased *TIMESTEP* is taken as one hour and *flimit_A* is the rated flow of water for the energy production.

Similarly, energy production is given by the equation:

$$flowrate\_A*3600*g*h\_A*etaA*\rho \qquad (26)$$

Where, g is the acceleration due to gravity in meter per second square, h_A is the head of reservoir in meter; ρ is the density of water in kilogram per meter

cub, and *eta_A* is the efficiency of plant and *flowrate_A* is the rated flow from reservoir A in meter cube per second. The above equations are inserted in the definition box of each building block and on insertion the unit of each quantity should also be specified. So we have defined the governing equations and now we can model our network which is shown in Fig. 18.
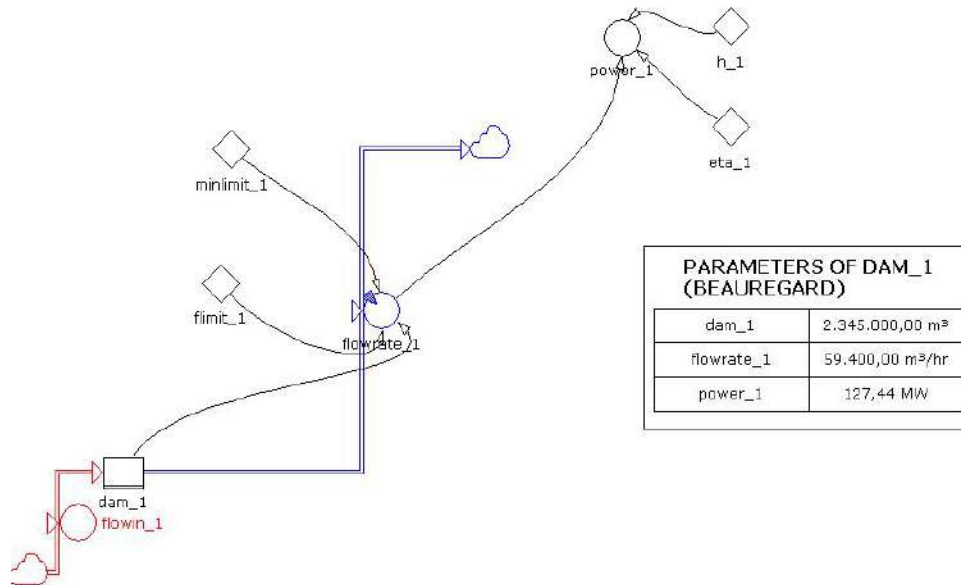

PARAMETERS OF DAM_1 (BEAUREGARD)	
dam_1	2.345.000,00 m³
flowrate_1	59.400,00 m³/hr
power_1	127,44 MW

Fig. 18. Water movement in a reservoir Beauregard (a segment in Valle d'Aosta)

Here a reservoir Beauregard in the region of Valle d' Aosta is considered and hydroelectric power plant is represented by using Levels, Flow rate, constants and Auxiliaries. In the above equation we can find the dependence of minimum limit on flow rate and energy production based on flow rate, head and efficiency. This all variables are treated as constants because in our case they are used defined. A 10 percent of capacity is made for all the reservoirs and efficiency is considered to be 81 percent. But from the network we can clearly see that the power production cannot be maintained to the optimum value i.e. rated value because the capacity is decreasing with respect to time. So, in order to solve this here we are considering a mass balance on each power plant based on the flow rate at which it works. In Fig. 18 the *flowin_1* represents the mass balance for the optimum working of reservoir for period of one year. Afterwards more than one reservoir in a particular region of Valle d' Aosta are cascaded and connected by using the exit flow from upstream turbine.

Subsequently we can now simulate the obtained network for a period of one year from 2018 to 2019 with a time interval of one hour. Thus, the model is verified after one run of simulation.
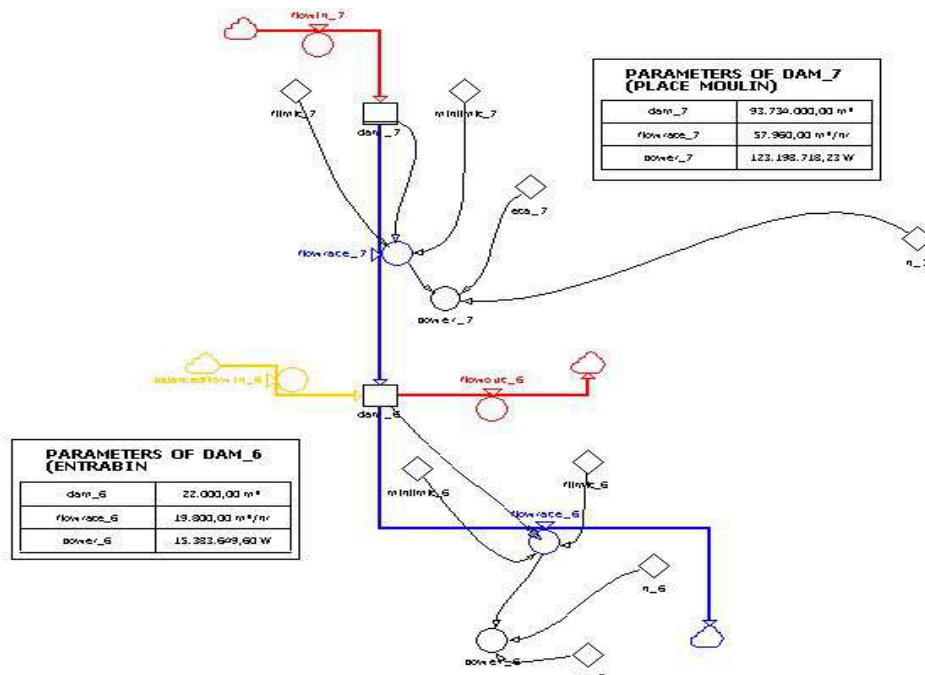

PARAMETERS OF DAM_7 (PLACE MOULIN)	
dam_7	93.734.000,00 m³
flowrace_7	57.960,00 m³/nr
power_7	123.198.718,23 W

PARAMETERS OF DAM_6 (ENTRABIN	
dam_6	22.000,00 m³
flowrace_6	19.800,00 m³/nr
power_6	15.383.649,60 W

Fig. 19. Representation of cascaded reservoirs with balanced flow in a regional area of Valle d' Aosta

On interconnection some reservoirs will be affected with overflow or exceeding Surcharge Reservoir Level (SRL). So this is slashed by creating a by-pass from the reservoir to the water channel. Thus the overall network of the proposed case study is shown in Fig. 19.

Similarly, all other 31 reservoirs are modelled and balanced Fig. 20. This mass balance can be assumed to be rainfall or from other resources which we took as a general case as flow- in our work, it may also from the exit of turbine to the next reservoir. Wide arrow indicates the direction of water course and thin arrow indicates the logical and structural relationship between the operators and flow chart elements.

Next step is to cascade all this separately modelled power plant into a single network. This is accomplished by calling each separately modelled plant to a single network by using slice variable tool in Powersim.
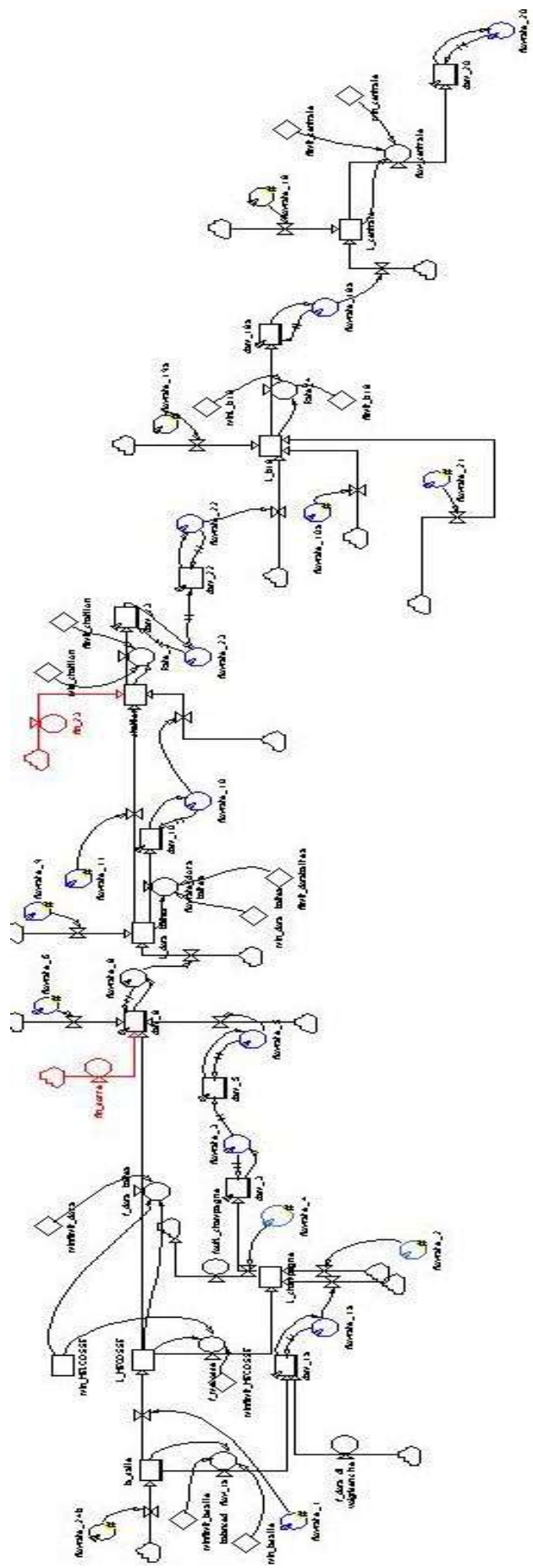
Fig. 20. Representation of whole coupled flow network in Valle d'Aosta

The proposed case study of Valle d'Aosta was modelled and successfully simulated in Powersim. It results in the creation of a real multi cascade river network and ensured the water release from each dam based on the considered constraints. The major inputs shall include the following:

1. Reservoir DHL and NHL levels
2. Reservoir storage capacity
3. Rated flow rate from reservoir
4. Head of reservoir
5. Efficiency of power plant

After entering all the required data's and initial conditions we can simulate the model by clicking a suitable button on the relevant control panel. The results are plotted in the Fig. 21. Graphical representation of simulation for a period of one year and we can see that the capacity of each reservoir is in its rated value i.e. it is maintained constant for each run and hence the modelled is verified and a balanced flow rate is obtained. The overall annual production is found to be 265.355 GW.
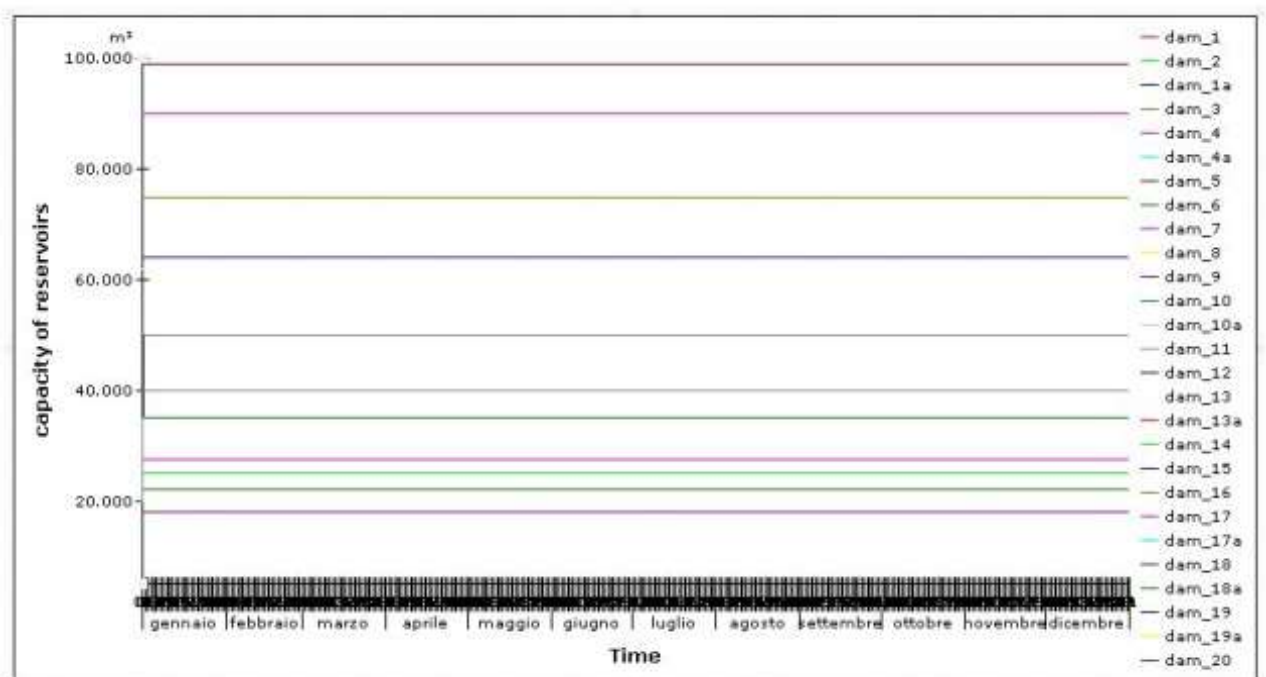

Fig. 21. Model verification by simulation of network and plotted a graph showing capacity with respect to time for a period of one year.

We can generate a dependence of power produced from each reservoir based on its capacity and it is plotted in excel by importing the simulated results into it shown in Fig. 22.
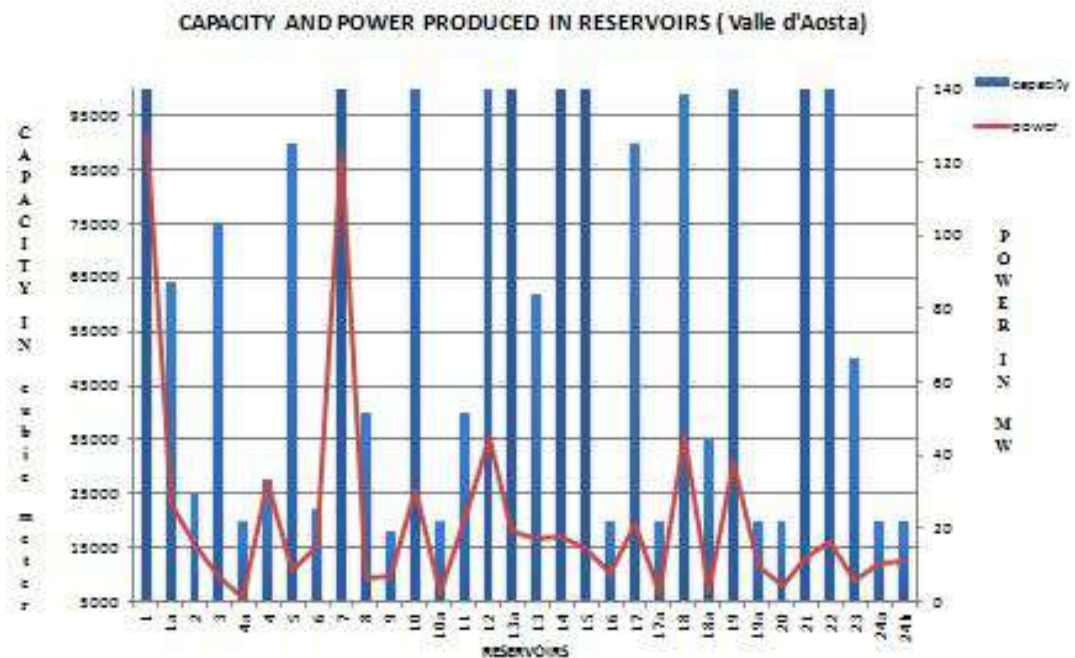

Fig. 22. Showing capacity and power produced of reservoirs in Valle d'Aosta.

Modeling of hydroelectric systems with economic objectives are mostly difficult, it requires understanding the complex relationship between load market system and social safety. The model developed provide basis for an operational policy through numerous runs of simulation model throughout one year. This work is a way to develop powerful and transparent models to address hydroelectric generation systems of long term planning. Using the advantage of newly developed algorithms to solve various types of optimization problem. We can optimize the reservoir operations keeping the power market and water distribution network without uncertainty of flood in region. The key success of any optimization problem if effective implementation of any model to take system features that lead to simple mathematical model and proper algorithms to overcome stability. In the management of hydroelectric generation system, there are lots of uncertain and complex information.

CHAPTER 4. Development of the decision support system for water discharge over a system of dams

4.1. Self-organizing model of water release in the cascade of reservoirs

The algorithm for constructing predictive models (ACPM) builds a model of changes in the water level in the reservoir, which is used to predict the status of an individual reservoir and the reservoir system as a whole. Based on this information, the management center staff can make an informed decision on the management of the water discharge system.

Analysis of the main known methods of building models showed that the most accurate models can be built using genetic algorithms [44], neural networks [46] and self-organizing algorithms [27].

For further research, an algorithm of self-organization has been chosen, which allows building predictive models in the conditions of minimum a priori information about the hydraulic structure under study. At the same time, for each basic function, the vector of parameters is assigned. Consider the case of a two-dimensional vector $(a, f)^T$, where a – amplitude, f – frequency. Then we have a parameterized set of basis functions.

$$F_\text{п} = \{a_{ii}(f_i x) \mid i = 1, \quad , N\}$$

The set of basic functions is determined taking into account a priori information about the process under study. The model has the form:

$$M(x) = \sum_{i=1}^{N} a_i \mu_{ni}(f_i x)$$
, *(27)*

where N – number of basic functions in the model; μ_{ni} – basis functions from $F_\text{п}$.

The predictive model is built on the basis of the chosen basic functions by the self-organizing algorithm constructed using the method of group accounting of arguments (MGAA). The scheme of implementation of this self-organization algorithm is shown in Fig. 23.

The scheme of this algorithm consists of several successive stages of self-selection of the resulting model. At each stage of self-selection, the variants obtained by the generator of random combinations are searched and the best ones are selected on the basis of the established selection criteria (ensemble of selection criteria). At the first stage, the basic functions are set, which are compared with the measurement sample by means of an ensemble of selection criteria.

At subsequent stages of selection, the results of selection at the previous stage, which best meet the selection criteria, are submitted to the input of the next stage. In this case, the hypothesis is accepted that ineffective combinations rejected in the first rows of self-selection could not have given the optimal combinations of the next row if they were missed further. Thus, when building a model of a hydraulic structure under study, a result can be obtained that meets the criteria usually for 5–9 generations of breeding.
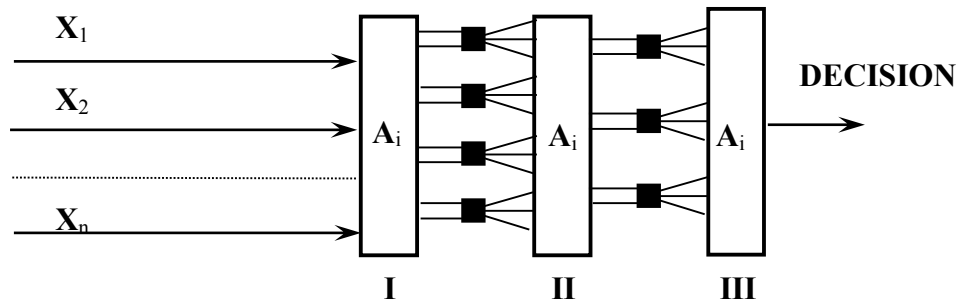

Fig. 23. Scheme of the algorithm of self-organization, based on the principle of MGAA

In Fig. 23 the following notation is introduced : X_i – basis functions; A_i – threshold self-selection of useful information; I, II, III – criteria for self-selection; ■ - generator of random combinations (hypotheses).

The adequacy of the obtained mathematical model is determined by the minimum selection criteria. Well-chosen selection criteria make it possible to eliminate unnecessary, random and non-informative state variables, to determine their relationships in an optimal way. There are general and special selection criteria. Special criteria are selected from physical considerations in each specific

formulation of the problem as it was described in the previous chapter [27]. Common criteria are universal [78].

When synthesizing MGAA algorithms, the following model selection criteria are commonly used: regularity criterion, model minimum displacement criterion, balance criterion, as well as less popular model simplicity criteria, diversity of arguments, information and so on. Each of the listed criteria has significant drawbacks. Thus, the criterion of the minimum bias, which requires the coincidence of the models obtained on different samples, can reveal the same non-optimal models. The criterion of balance consists of choosing the model whose brighter patterns can be traced, revealed in the process of observation. As a rule, at a certain time interval, many models correspond to a predetermined pattern. This criterion, like the criterion of minimum displacement, leads to the ambiguity of the choice of model. In this case, the criterion of regularity was chosen as a general criterion. It is an rms error calculated for the sequence B that was not involved in the construction of the mode:

$$\Delta^2(B) = \frac{\sum_{i=1}^{N_B}(y_i - q_i)^2}{\sum_{i=1}^{N_B} y_i^2}.$$

(28)

where: N – the number of sample points, which can be divided into two parts: A - the training part on which the models are built and B - the test sequence; y_i – sample values; q_i model values calculated at x_i.

The selection criteria are combined into ensembles. The greatest freedom of action is provided by the ensemble adopted in this computational model, of the type:

$$w_i I + w_\Delta \Delta^2 + w_n n_b^2,$$

(29)

where: w_α – weights of relevant criteria.

The use of this type of selection criterion allows you to change the weight of the individual components of the criterion during the operation of the algorithm from level to level and to make corrections in the course of work.

Thus, at the output of the developed algorithm for constructing models by the method of self-organization, a we make a nonlinear forecasting model of the water level in the reservoir, presented in Fig. 24.

Measuring sample ψ is formed on the basis of data on monitoring the water level in the reservoir. At the first stage of modeling, we compare the used basis functions with the measurement sample z. Using SCE, the basic functions closest to the measuring sample are selected, which become candidate models and are used for further selection.
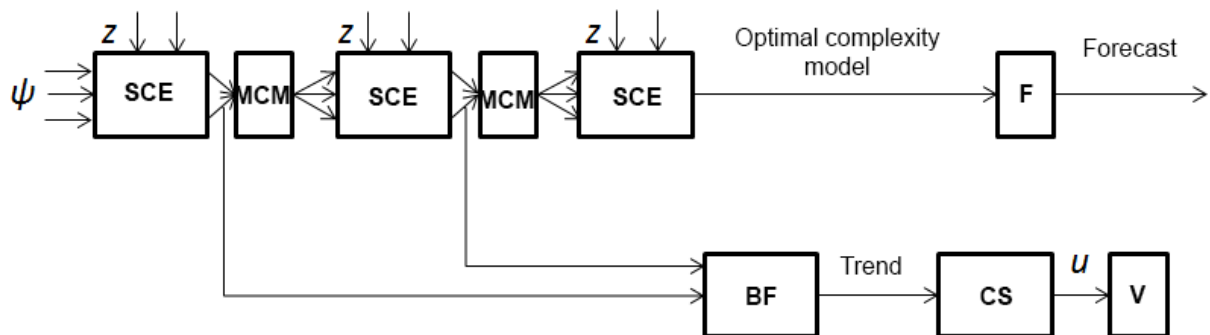

Fig. 24. Functional scheme of water river system management with self-organization algorithm.

where ψ – basic functions, z – measuring sample, SCE – selection criteria ensemble, MCM – model crossing method, F – forecast block, TF – trend forming block, CS – control system, c – control signal, V – reservoir drain valve.

In accordance with the principle of Gabor [79] several candidate models come for each next row of selection. Next, in block C, models become more complex, for example, by pairwise crossing. Models are crossed by algebraic addition and subtraction, as well as multiplication and division. Thus, sophisticated models are inherently combinations of basis functions. After complication, the

models re-enter the SCE for selection. On each row of selection in the self-organization algorithm, trends are reserved. Trends are selected using the model simplicity criterion, which is included in the ensemble of selection criteria. Trends from each selection line are sent to the TF block, where the resulting trend is formed. This non-linear trend is used in the control system to generate control actions on the damper of the reservoir drain system.

And the optimal complexity model obtained at the output of the self-organization algorithm is used in block F to obtain predicted values of the water level in the reservoir.

The mathematical models made by the modeling algorithm have a pronounced nonlinear character. The task of maintaining the optimal water level in the reservoir system is multicriteria and, considering the constantly changing non-linear model, in general it is not always possible to find a solution. Existing methods for finding solutions to multicriteria nonlinear controls based on stably-effective compromises [80], definitions of permissible controls [81] etc. are difficult to implement and have a number of limitations in use. Therefore, it seems appropriate to develop a reliable and easy to implement control algorithm.

4.2. Algorithm for managing water release in the cascade of reservoirs

Thus, it is advisable to develop a nonlinear control algorithm for the presented cascade of reservoirs.

Let us carry out the synthesis of the control algorithm for the nonlinear model in continuous form. The nonlinear model has the form:

$$\frac{d}{dt}x(t) = f(t,x) + g_1(t,x)w(t) + g_2(t,x)u(t), \quad x(t_0) = x_0,$$
$$y(t) = h(t,x).$$

$$(30)$$

Here $f(t,x)$, $g_1(t,x)$, $g_2(t,x)$, $h(t,x)$ are valid and continuous.

In order to develop control $u(t)$ we have to transform (35) into equivalent form: the model has the structure of linear differential equations with parameters that depend on the state (State Dependent Coefficient, SDC).

Transformed using the SDC-representation method, equations (35) are:

$$\frac{d}{dt}x(t) = A(t,x)x(t) + g_1(t,x)w(t) + g_2(t,x)u(t), \quad x(0) = x_0,$$
$$y(t) = H(t,x)x(t). \tag{31}$$

SDC-formed equations (36) are controllable if:

$$rank\left[D(t,x), \; A(t,x)D(t,x), \; A^2(t,x)D(t,x), \; ..., \; A^{n-1}(t,x)D(t,x)\right] = n,$$
$$rank\left[B(t,x), \; A(t,x)B(t,x), \; A^2(t,x)B(t,x), \; ..., \; A^{n-1}(t,x)B(t,x)\right] = n.$$

where n – equations system order

Gramians of controllability $P_w(t,x)$ and $P_u(t,x)$ exist and are solutions of the Lyapunov equations:

$$A(t,x)P_{C1}(t,x) + P_{C1}(t,x)A^T(t,x) + g_1(t,x)g_1^{\,T}(t,x) = 0,$$
$$A(t,x)P_{C2}(t,x) + P_{C2}(t,x)A^T(t,x) + g_2(t,x)g_1^{\,T}(t,x) = 0. \tag{32}$$

The optimal control actions have the form:

$$w(t) = P^{-1}g_1^T(x)\left[\hat{S}(x)x(t) + \hat{q}(x)\right],$$
$$u(t) = -R^{-1}g_2^T(x)\left[\hat{S}(x)x(t) + \hat{q}(x)\right]. \tag{33}$$

To find the matrix $S(x)$ and $q(x)$ in, we use the inverse sweep method [82]. In the matrix estimates $\hat{S}(x)$ and $\hat{q}(x)$ are determined by solving equations:

$$\frac{d}{dt}\hat{S}(x) + A^T(x)\hat{S}(x) + \hat{S}(x)A^T(x) - \hat{S}(x)\Pi(x)\hat{S}(x) + C^TQC = 0, \hat{S}_0 = \hat{S}(x_0),$$
$$\frac{d}{dt}\hat{q}(x) + \left[A^T(x) - \hat{S}(x)\Pi(x)\right]\hat{q}(x) = 0, \hat{q}(x_0) = q_0, \tag{34}$$

where $\Pi(x) = g_2(x)R^{-1}g_2^T(x) - g_1(x)P^{-1}g_1^T(x).$

Model (35) with control (37) is transferred to:

66

$$\frac{d}{dt}x(t) = f(t,x) - \Pi(x)\left[\hat{S}(x)x(t) + \hat{q}(x)\right], \; x(t_0) = x_0, \qquad (35)$$

$$y(t) = H(t,x)x(t) \; .$$

Control is performed in accordance with the algorithm:

$$u(t) = -R^{-1}B(\hat{x})^T S_0 \hat{x}(t), \qquad (36)$$

where S_0 – positive definite matrix, which is determined by solving the equation:

$$S_0 A_0 + A_0^T S_0 - S_0 B_0 R^{-1} B_0^T S_0 + H^T QH = 0. \qquad (37)$$

The resulting controls using a linear model and a quadratic quality criterion ensure the stability of this model under any initial conditions. It should be noted that in the general formulation the problem of the global asymptotic stability of a nonlinear system with a control synthesized using the SDC method is not solved. Therefore, when using such a control for a nonlinear system, additional research is needed.

4.3. Development of a decision support system for managing the water release from a cascade of reservoirs of a river network at a dynamic expert system

Intelligent systems involve the implementation of a mechanism for target formation of the functioning of the system, as well as a mechanism of reverse afferentation. The quasi-intelligent system under consideration has only one of these mechanisms - the inverse afferentation chain [83].

It is assumed that the purpose of the HS organization is set a priori and does not change during the operation at a limited interval.

The mechanism of reverse afferentation involves the use of a self-organization algorithm for constructing predictive models. Based on these models, a forecast of the organization's development scenario is carried out and, depending on the environmental models, the best scenario is selected.

Environment models can be built in the process of a preliminary analysis of the functioning conditions of the organization on the basis of a priori information or in the process of functioning of the organization on the basis of a posteriori information.

Naturally, in the latter case, the models will better reflect the real situation and contribute to the selection of the best scenario for the functioning of the organization.

The implementation of the control system of a HS is much simpler than the intellectual system. In view of the fact that the development and implementation of the mechanism of afferent target synthesis, which is a distinctive feature of intelligent systems, is the most difficult.

Within the concept of synthesis of intelligent control systems, a modern complex control system is designed as a functional system of HS with its inherent adaptive effect.

The main advantages of the theory of functional systems for the theory and practice of an intellectual control system are the universal architecture of functional systems, as well as the mechanisms of functional systems perfected by evolution.

The design of the action acceptor is carried out in accordance with the principles of the development of algorithmic support. One of the basic principles is the principle of rational unification. Increasing the degree of unification of algorithmic support reduces the cost of the system, reduces algorithmic errors and computational errors. However, at the same time, this leads to algorithmic and software redundancy, the result of which is some rise in the price of the system.

Functional scheme of the control system can be represented as follows (Fig. 25).

In the proposed control system, on the basis of the information on the target, the state of the external environment of the functioning of the dynamic object, as well as the forecast of the results of the action, we carry out an expert

assessment of the situation and the selection of the best scenario of the dynamic object.

Dynamic object management is developed on the basis of the decision and is implemented through a set of measures by various executive subsystems.
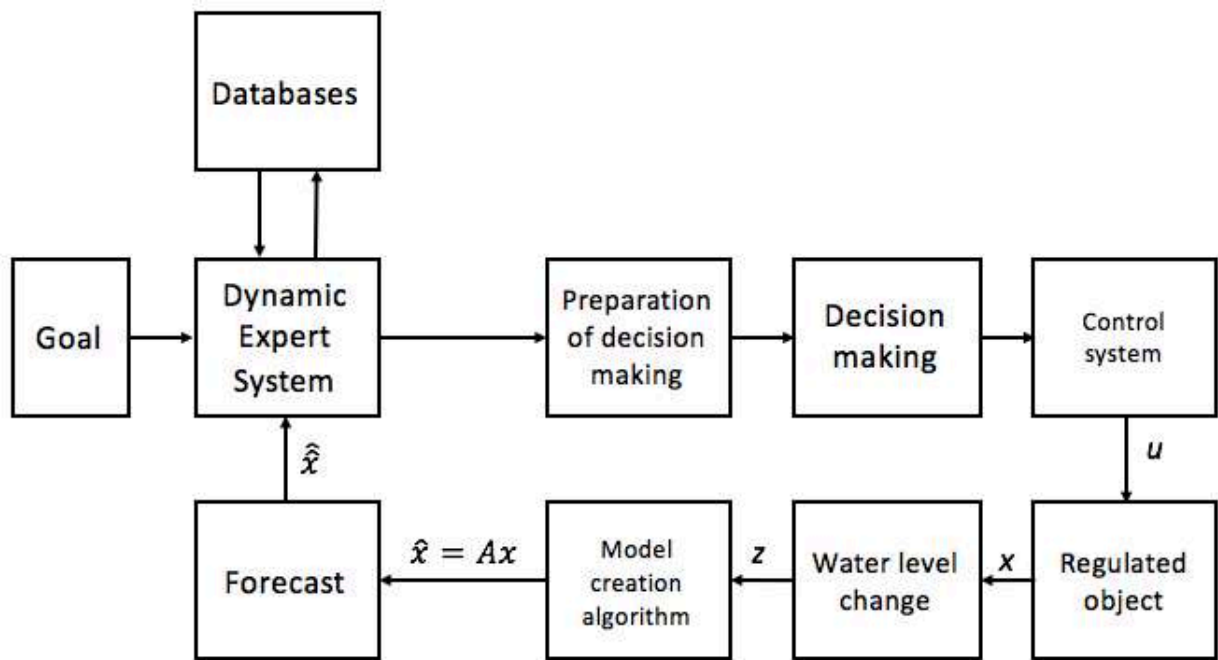

Fig. 25. Functional scheme of the decision support system for river system management

Management results and copies of commands are used to predict the results of an action. The forecast can be carried out using models that are advisable to obtain a variety of methods, for example, using the self-organization approach. Further, when a dynamic object is functioning, the practical result is compared with the forecast and the correctness of its operation is confirmed. Otherwise, the control action is adjusted or another scenario of the behavior of the dynamic object is generated, which leads to the correspondence of the predicted values and the practical result.

CHAPTER 5. Application of the developed dynamic expert system on the river network of the Volga-Kama basin

To obtain a specific model of the water level in the reservoir, we use a real measuring sample of the state of the water level in the area of the Volga-Kama basin, described in Chapter 3, obtained from September 1, 2013 to August 30, 2015 [84]. An example of initial data for a section of the Volga basin from July 1 to November 30, 2013 is presented in Appendix No. 1 to ensure the reliability and repeatability of the results obtained in this work. The full amount of source data can always be obtained at PJSC RusHydro [84].

5.1. Optimization of water pass on the selected river network

The equations of trends of state variables are as follows:

$$D(t) = D(t)_1 + D(t)_2 + \cdots + D(t)_i; \tag{38}$$

where

$$D(t)_i = \alpha_{i0} + \alpha_{i1} \sin\left(\frac{2\pi}{T}t\right) + \alpha_{i2} \cos\left(\frac{2\pi}{T}t\right); \tag{39}$$

Calculated values for the first five trends. The remaining values are calculated in the same way

$$D(t)_1 = -27.7141 + 77.5322 \sin\left(\frac{2\pi}{T}t\right) - 33.0889 \cos\left(\frac{2\pi}{T}t\right), T = 13.02;$$

$$D(t)_2 = -44.7933 - 78.2831 \sin\left(\frac{2\pi}{T}t\right) + 103.5872 \cos\left(\frac{2\pi}{T}t\right), T = 8.92;$$

$$D(t)_3 = -0.0828 + 53.5574 \sin\left(\frac{2\pi}{T}t\right) - 10.0088 \cos\left(\frac{2\pi}{T}t\right), T = 21.72;$$

$$D(t)_4 = -0.7436 - 45.6069 \sin\left(\frac{2\pi}{T}t\right) - 50.6196 \cos\left(\frac{2\pi}{T}t\right), T = 27.52;$$

$$D(t)_5 = 0.5392 - 62.5526 \sin\left(\frac{2\pi}{T}t\right) + 23.0743 \cos\left(\frac{2\pi}{T}t\right), T = 3.74;$$

Using the obtained model, the state of the HS is forecasted, the values of which are used in a fuzzy dynamic expert system.

Table 1. Fragment of the diagnostic matrix of the HS

№	D_N$_2$	D_G$_v$	D_N$_2$	D_T$_2$	D_P$_2$	D_T$_3$	D_P$_4$	D_P$_6$	D_F$_c$	D_G$_t$	D_R	RESULT
1	0	0	0	0	0	0	0	0	0	0	0	ETALON
2	0,24	0,04	0,01	-0,03	0	0,27	-0,34	-0,04	0,12	-0,39	0,18	SCE 1%
3	0,11	0,17	-0,80	0,30	0	0,35	-0,87	0,21	0,24	0,68	0,58	SCE 3%
4	1,30	1,65	-0,71	1,45	0	1,15	1,86	-0,98	-1,30	0,76	1,09	SCE 5%
5	0,51	0,89	0,85	0,82	0	-0,82	-0,98	0,96	0,88	0,44	0,01	SCE1 1%
6	-1,58	0,91	0,37	0,45	0	0,32	1,57	0,84	-0,69	0,18	0,02	SCE1 3%
7	-0,81	0,35	0,67	-0,97	0	0,91	0,59	0,29	-0,64	-0,06	0,25	SCE1 5%
8	-0,45	-0,65	0,15	-0,33	0	-0,65	-0,29	-0,30	0,34	0,08	0,01	SCE2 1%
9	-0,46	-1,24	-0,27	1,68	0	0,71	0,41	1,97	1,20	-1,06	1,86	SCE2 3%
10	1,09	1,48	-0,28	-2,01	0	1,63	-1,91	-0,71	0,42	-1,81	1,86	SCE2 5%
11	0,30	-0,46	-0,66	-0,02	0	0,24	0,60	-0,80	-0,08	-0,27	0,03	SCE3 1%
12	-0,23	0,17	0,05	0,20	0	0,37	0,27	0,37	-0,04	-0,20	0,42	SCE3 3%
13	0,05	0,64	-0,59	-0,34	0	0,22	-0,36	-0,99	-0,24	-0,62	0,32	SCE3 5%
14	-1,73	-2,17	-0,13	3,93	0	4,08	-2,20	-2,01	-4,80	-3,08	4,01	SCE4 1%
15	-0,92	-0,93	-1,90	1,29	0	-1,32	1,85	0,90	1,65	1,48	1,84	SCE4 3%
16	0,46	-2,75	-2,95	-0,43	0	2,14	2,04	-2,92	-2,49	-1,07	1,58	SCE4 5%

The diagnostic matrix of a specific HS in a certain mode is a table of numerical values of the coefficients a_{ij} and b_{ij}, allowing by deviations of a number of measured parameters δy_{ij} determine deviations of directly not measured state parameters δx_{ij}.

Let the following parameters be measured in the process of determining the state of the HS: Q_{river} – upstream inflow; Q_{rsrvr} – inflow/outflow as a result of precipitation/evaporation; V – reservoir capacity; Z_{hw} – headwater level; Q_{HPP} – flow rate through HPP (power generation); Q_{ic} – idle consumption (discharge through spillways); Z_{tail} – tailwater level; $Q_{tail} = Q_{HPP} + Q_{ic}$; H – HPP water head; N – energy output.

Table 2. Fragment of the base of fuzzy expert rules

Attributes and values	Result
If $(\Delta T_2 = Z) \wedge (\Delta P_4 = Z) \wedge (\Delta P_6 = Z) \wedge (\Delta F_c = MP)$	Then Y_1=SCE
If $(\Delta N_2 = Z) \wedge (\Delta T_2 = Z) \wedge (\Delta F_c = MN) \wedge (\Delta G_t = MP)$	Then Y_2=SCE1
If $(\Delta N_2 = LN) \wedge (\Delta T_2 = Z) \wedge (\Delta P_2 = LP) \wedge (\Delta R = LP)$	Then Y_3=SCE2
If $(\Delta N_2 = LN) \wedge (\Delta G_v = Z) \wedge (\Delta P_2 = Z) \wedge (\Delta R = Z)$	Then Y_4= SCE3
If $(\Delta N_2 = MP) \wedge (\Delta G_v = Z) \wedge (\Delta T_2 = Z) \wedge (\Delta R = MP)$	Then Y_5= SCE4

Table 3 shows the deviation parameters and their corresponding linguistic variables: *LN* - very small; *MN* - small; *Z* - near zero; *MP* - average; *LP* - very big. The process of testing the working capacity of a dynamic expert system is checked according to those lines of the rule base (Table 2) that were not included in the learning set: according to the two previous lines (with a deviation of the HS state parameters in the nodes by 1 and 3% respectively).

In the process of DB populating, in addition to the current measurements, the forecast values of the analyzed HS parameters were used additionally. The DES with an algorithm for constructing predictive models by the method of diagnostic matrices and fuzzy logic rules allows to determine the degree of reliability of the HS information, and the decision block, the regulator, allows to obtain information for the management personnel on the HS optimal performance support.

The DES use significantly increases the efficiency of HS functioning. Prompt analysis of various information about the current state allows decision making on the HS status and prospect.

Thus, the structure of the decision support system for the HS management personnel using fuzzy DES was developed as well as the DB population process and the FDI-method implementation. The DES diagnostic matrix was built.

The base of fuzzy rules is formed on the basis of a diagnostic matrix, the rows of which formed the basis for creating the knowledge base and membership functions of the corresponding linguistic variables.

For a 1% deviation of the Z_{hw}, estimate, based on the base of fuzzy rules of the dynamic expert system and the operation of crossing fuzzy sets. Then we have:

$$min \begin{pmatrix} \mu_z\left(\Delta T_2^{(k)}\right) \& \quad \mu_z\left(\Delta P_4^{(k)}\right) \\ \& \mu_z\left(\Delta P_6^{(k)}\right) \& \mu_z\left(\Delta F_c^{(k)}\right) \end{pmatrix} \rightarrow 0{,}85 \qquad (40)$$

This means that the reliability of the decision on the HS optimal functioning is 0.85.

For the row of the diagnostic matrix corresponding to a 3% deviation of the Z_{hw}, estimate, we have

$$min\ (\mu_{Z_{\in i}}) \rightarrow 0{,}59. \qquad (41)$$

The reliability of the decision on the HS optimal operation is 0.59. In case of faulty HS condition, the confidence coefficient is 0.24. In the situation considered, there is a high probability that the HS exits the zone of stable operation.

Below are the results of modeling changes in the water level in reservoirs without regulation and using the developed control algorithm.

We used the period from September 1, 2013 to February 23, 2019 as the modeling and regulation period. This period was chosen to ensure the greatest reliability of management, as well as to include the greatest number of exceptional events in the simulation period.

Since the section of the Volga-Kama basin from the Nizhny Novgorod HPP on the Volga river and the Votkinsk HPP on the Kama river to the Volga HPP on the Lower Volga was chosen as a modeling object, a change in levels in the Gorky and Votkinsk reservoirs (water flow through the Nizhny Novgorod HPP and the Votkinsk HPP) was taken as the input value for the developed control system and was used to calculate the inflow to hydropower plants located downstream. In addition, in the first after the inlet HPP (Cheboksary and Nizhnekamsk) regulation

was severely limited due to the impossibility of regulating water inflow, and regulation was carried out only by limiting the discharge of water through the HPP data. At the same time, the discrepancy between the design NHL and the real one of the Cheboksary HPP limited the possibility of raising the water level in it above the current temporary limit.

So
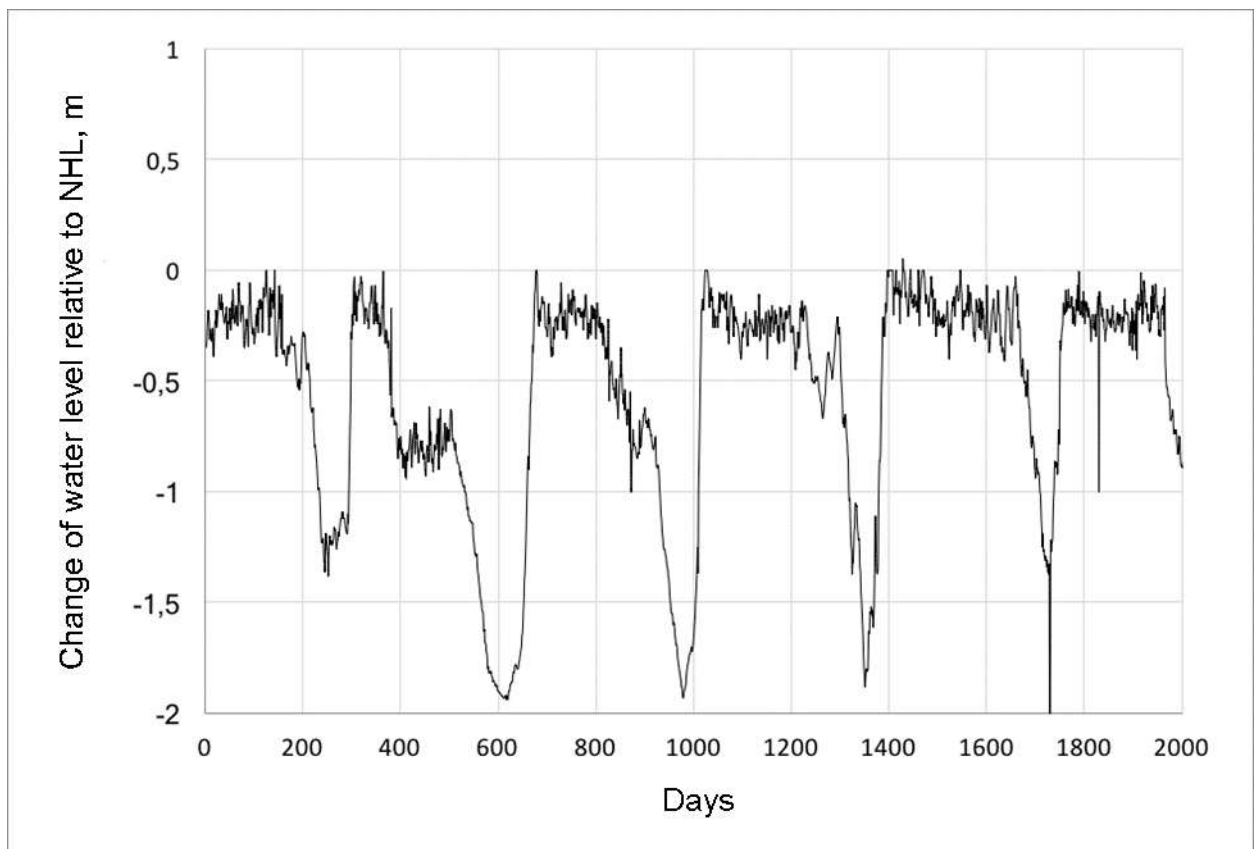
Fig. 26 and Fig. 29 show the changes in water levels in the Gorky and Votkinsk reservoirs, respectively, which were used as input to the developed management policy.

Fig. 27

Fig. 26. Change of water level with days in Gorky reservoir under current management policy

Fig. 27. Change of water level with days in Cheboksary reservoir under current management policy

Fig. 28. Change of water level with days in Cheboksary reservoir under suggested management policy

Fig. 29. Change of water level with days in Votkinsk reservoir under current management policy
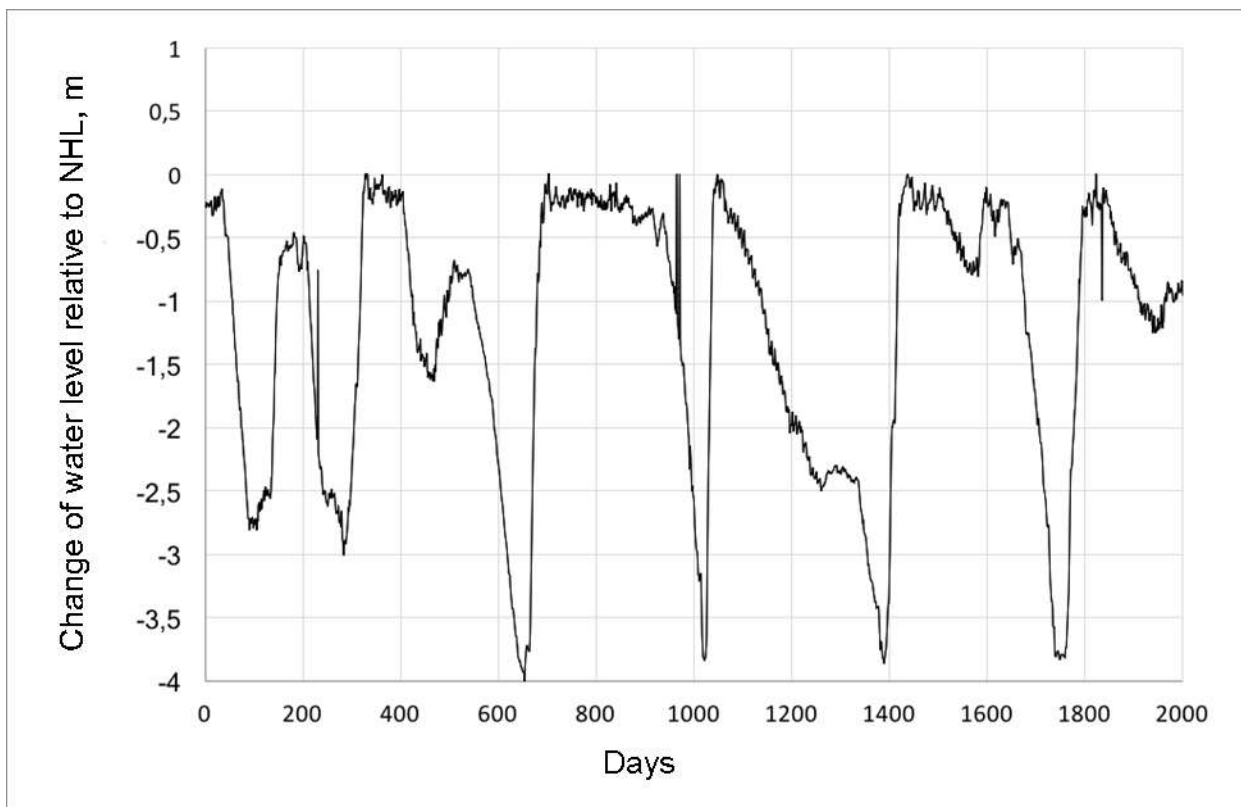
Fig. 30. Change of water level with days in Nizhnekamsk reservoir under current management policy
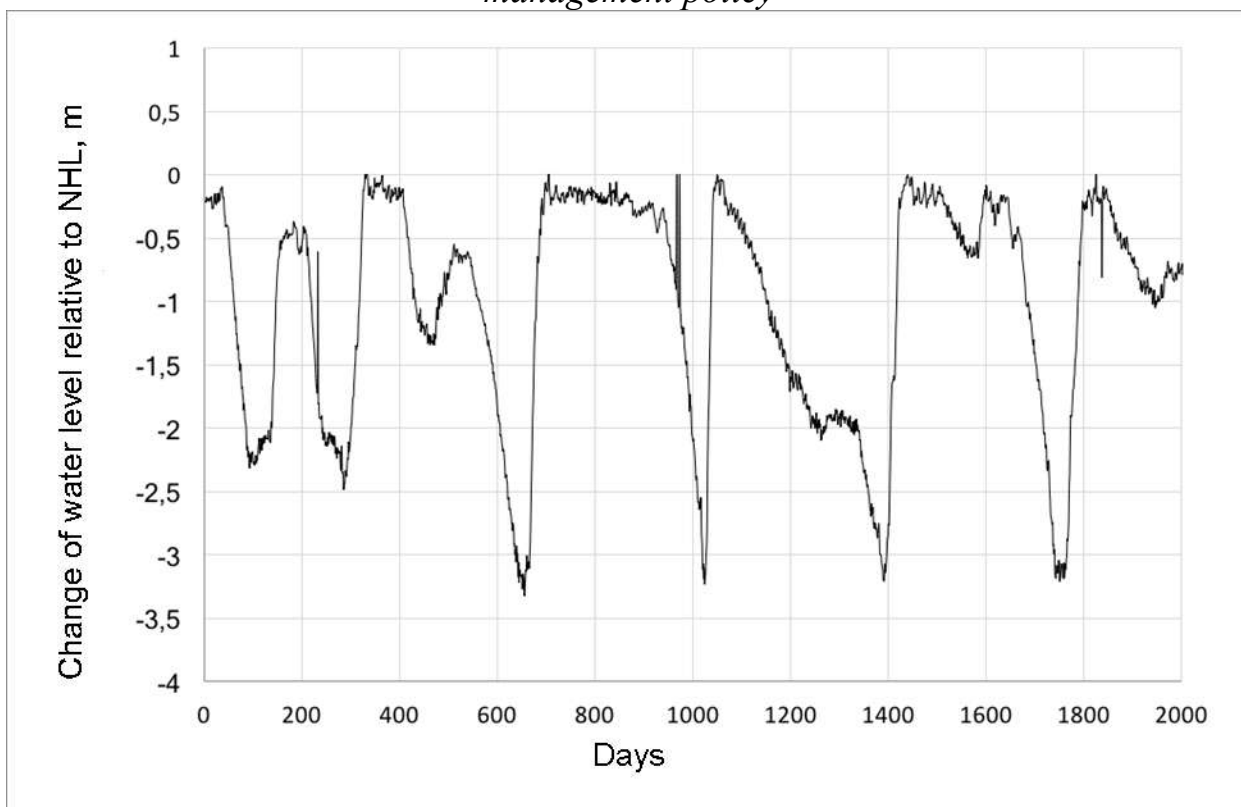
Fig. 31. Change of water level with days in Nizhnekamsk reservoir under suggested management policy
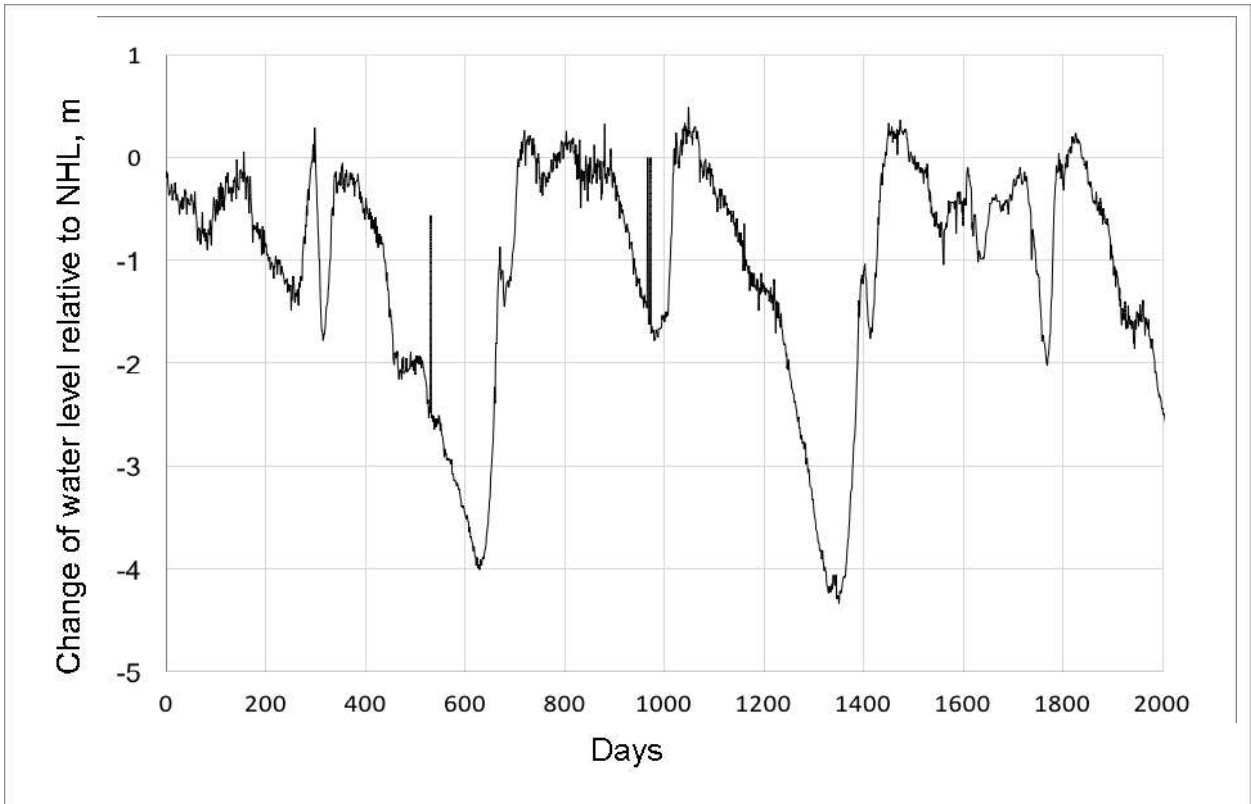
Fig. 32. Change of water level with days in Zhiguly reservoir under current management policy
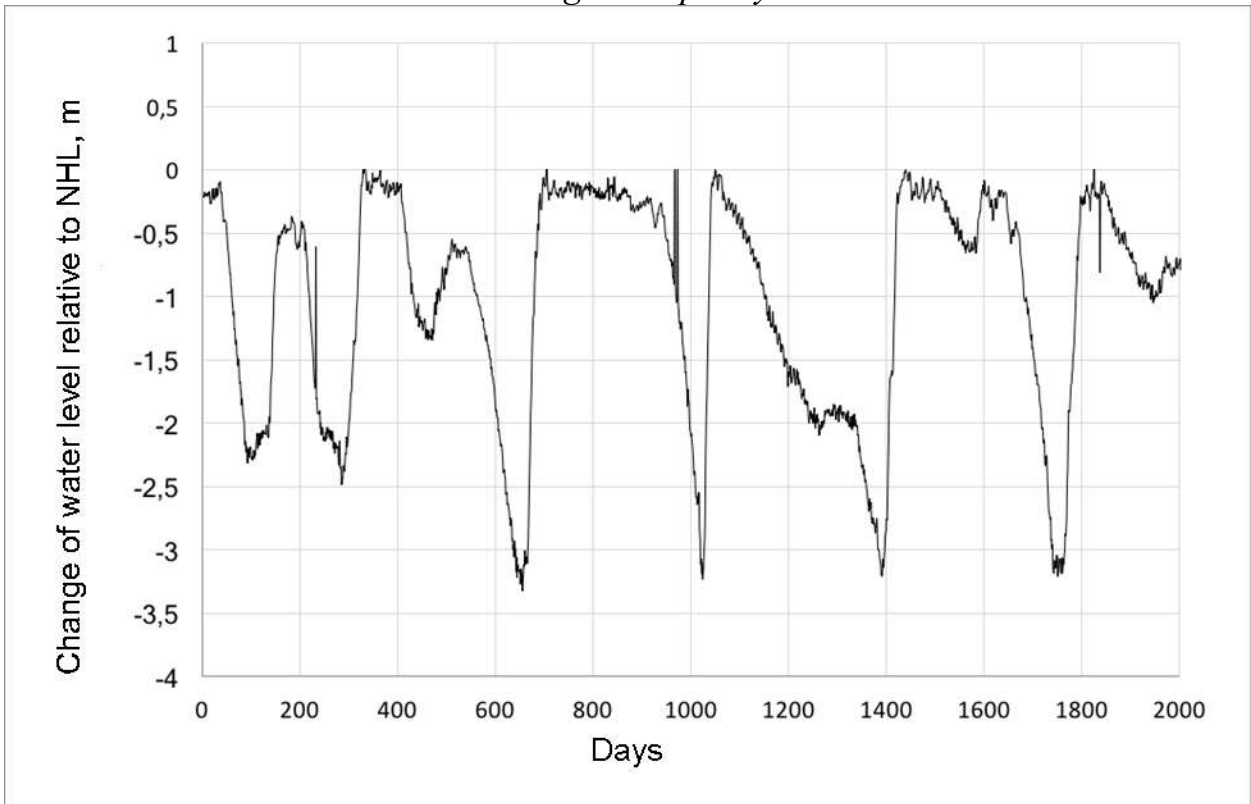
Fig. 33. Change of water level with days in Zhiguly reservoir under suggested management policy
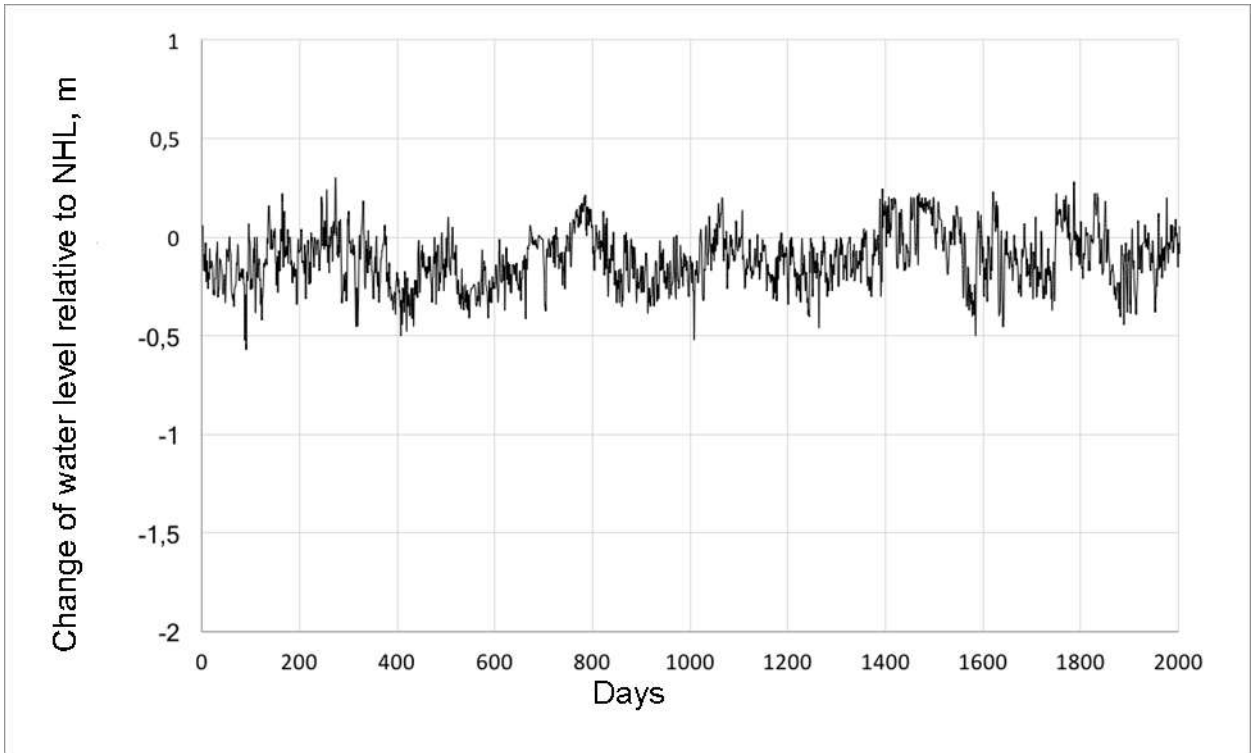
Fig. 34. Change of water level with days in Saratov reservoir under current management policy
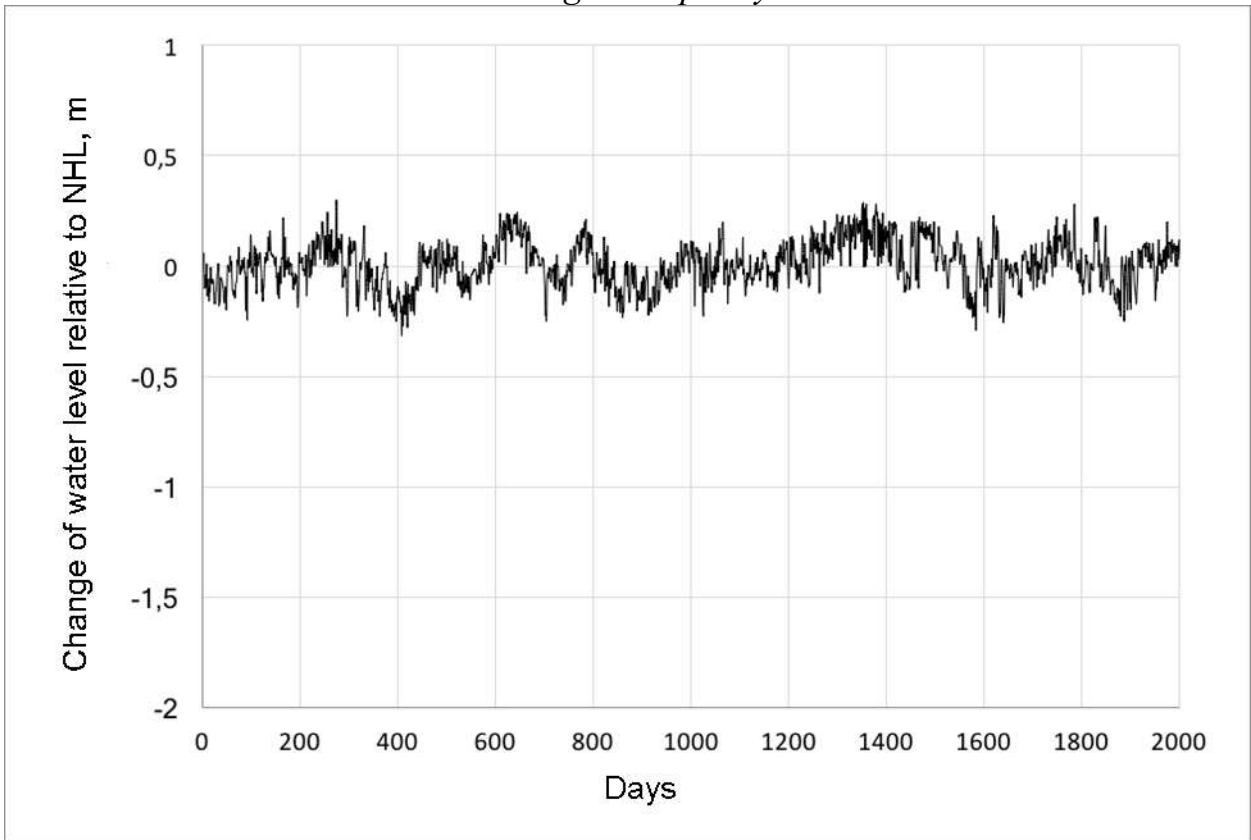
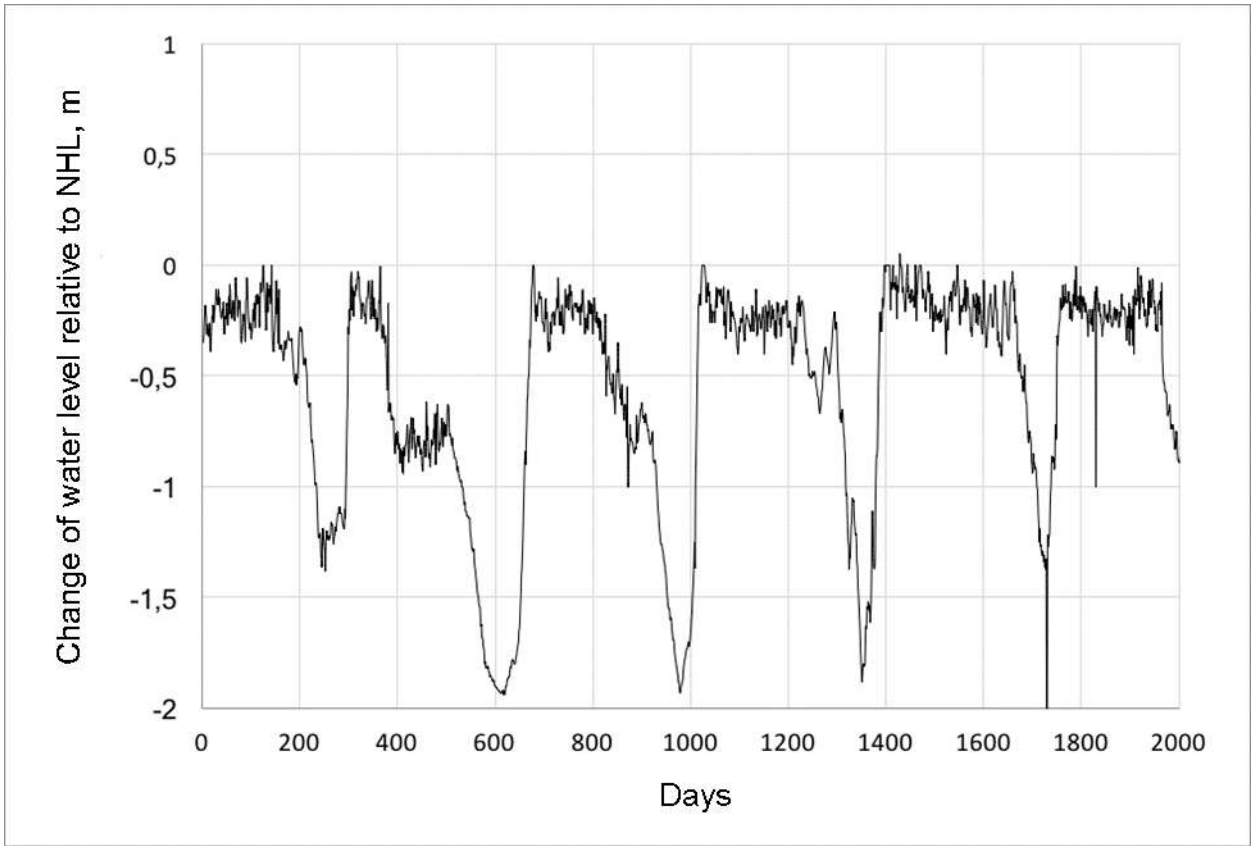*Fig. 35. Change of water level with days in Saratov reservoir under suggested management policy*

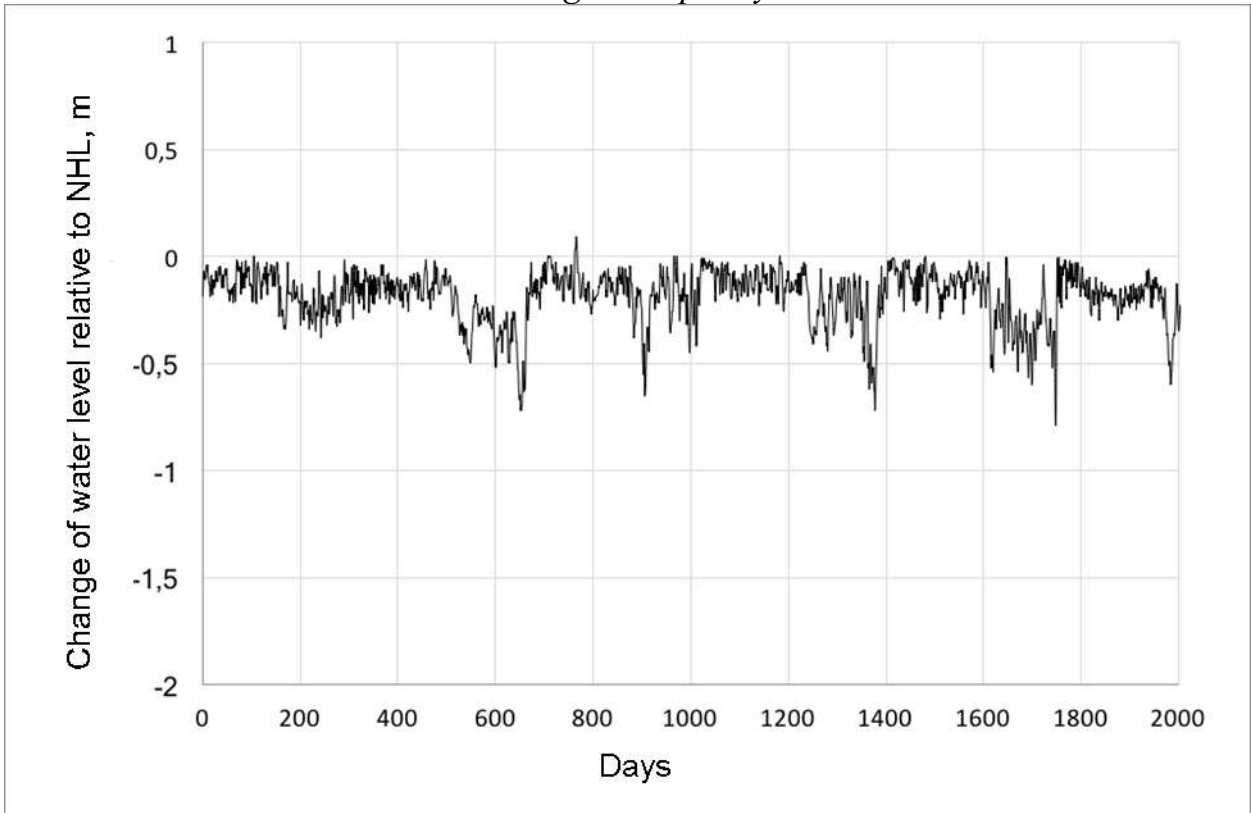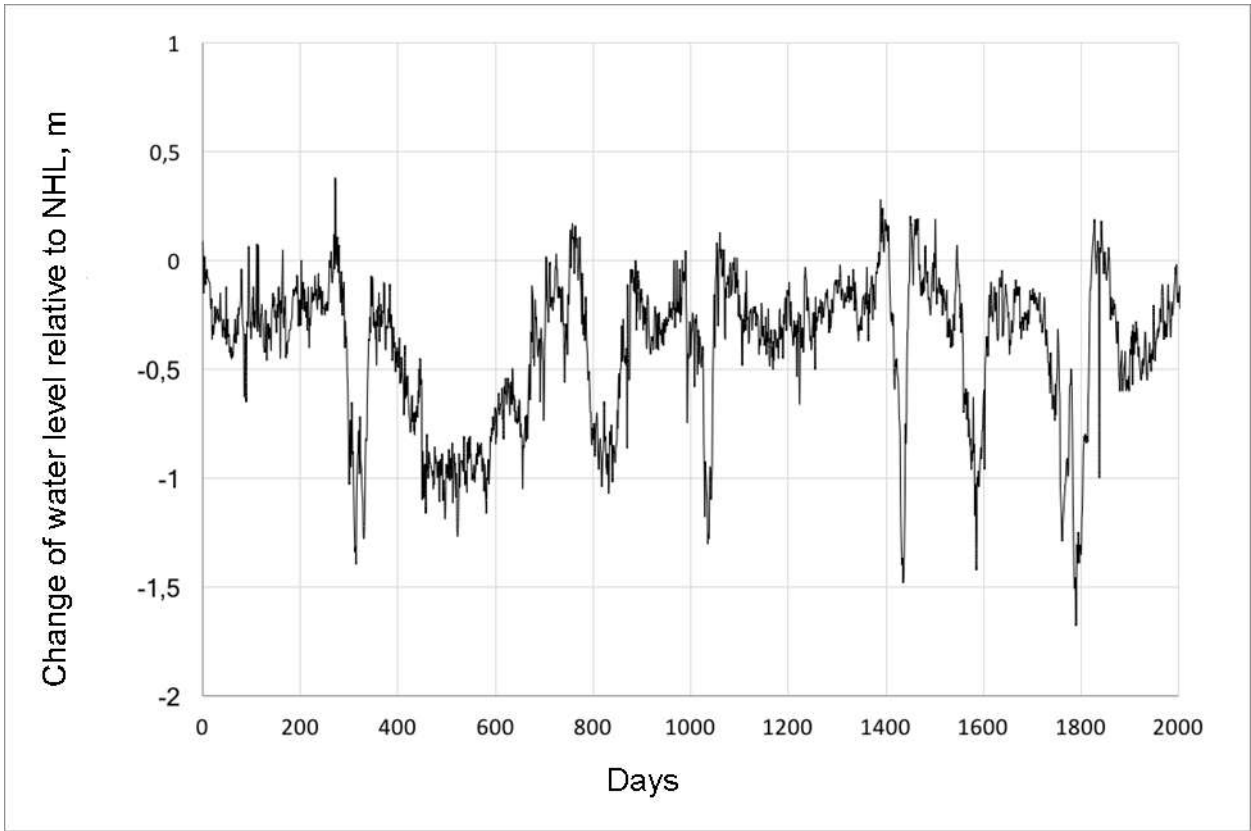*Fig. 36. Change of water level with days in Volzhsk reservoir under current management policy*
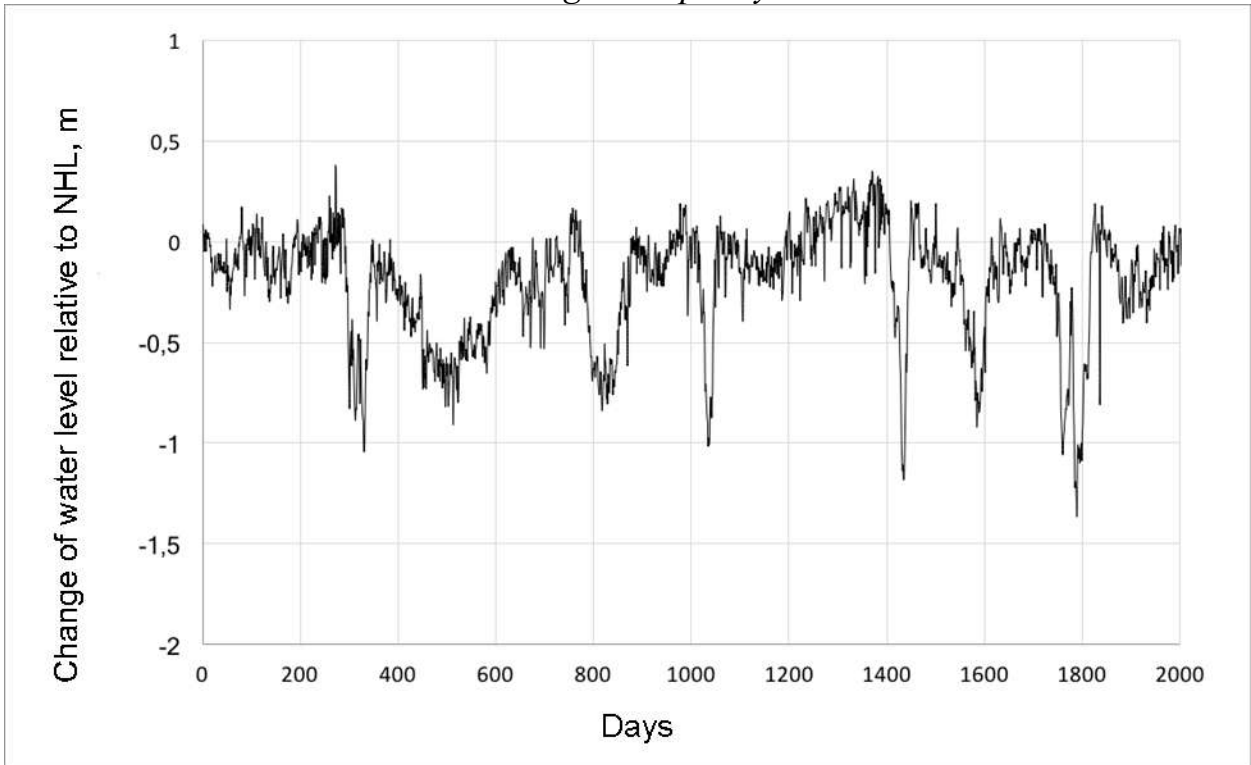
Fig. 37. Change of water level with days in Volzhsk reservoir under suggested management policy

Thus, the developed management algorithm for the system of hydraulic structures, comprehensively considers the entire cascade of reservoirs and allows for the required generation of electricity throughout the HPP cascade, but to minimize deviation from the NHL of reservoirs. In particular, as a result of the introduction of the developed algorithm, it was possible to reduce the standard deviation of the water level in the reservoir from the NHL by 16-22% compared to the current methodology in PJSC RusHydro.

The simulation results analysis showed that the developed algorithmic provision for decision support systems allows increasing the efficiency of the HS personnel by advance recognition of the moment when the system exits the optimal mode and maintain the HS stable operation with fewer deviations from the NHL.

Chapter 6. Assessment of the environmental and economic effect of using the developed decision support system

To assess the environmental and economic effect of using the developed decision support system, we simulated the movement of water along the Volga-Kama basin in the studied river section for two management scenarios: the current scenario implemented by PJSC RusHydro and the one proposed as a part of this work. We estimated flood surface areas, flooding depths, and based on these data, an environmental and economic assessment was carried out.

6.1. Modeling a water spill in a river network for various management modes

River flood modelling was performed in HEC-RAS software. As it was shown in the introduction this tool has been many times tested and validated and successfully used by other research groups.

Since the objective of this study was not to assess the absolute value of the environmental and economic effect of a particular river system management algorithm, but to compare two different algorithms, the accuracy of setting the boundaries of the river system, river bottom profile and other parameters did not play a key role until they changed when choosing various river management systems. In this regard, we chose as the initial data for the digital terrain model the data of the radar topographic mission of the SRTM shuttle [85, 86, 87], which are in the public domain [88] and allow obtaining a digital elevation model with a resolution of 30 meters.

In order to set the heights of land surface a Shuttle Radar Topography Mission (SRTM) data was used that provides digital elevation model (DEM) with spatial resolution of 30 meters [87]. Bathymetry of Volga and Kama rivers were taken from the rivers' bathymetry atlases and [89]. A general view of the modelled section of the Volga-Kama river system is given in the Fig. 38.

For the given region of Volga-Kama basin in 1D modelling of HEC-RAS rivers center lines, bank lines, flow paths lines and cross sections were entered. A zoomed view of the Volga – Kama junction with the above-mentioned lines is shown on Fig. 39.
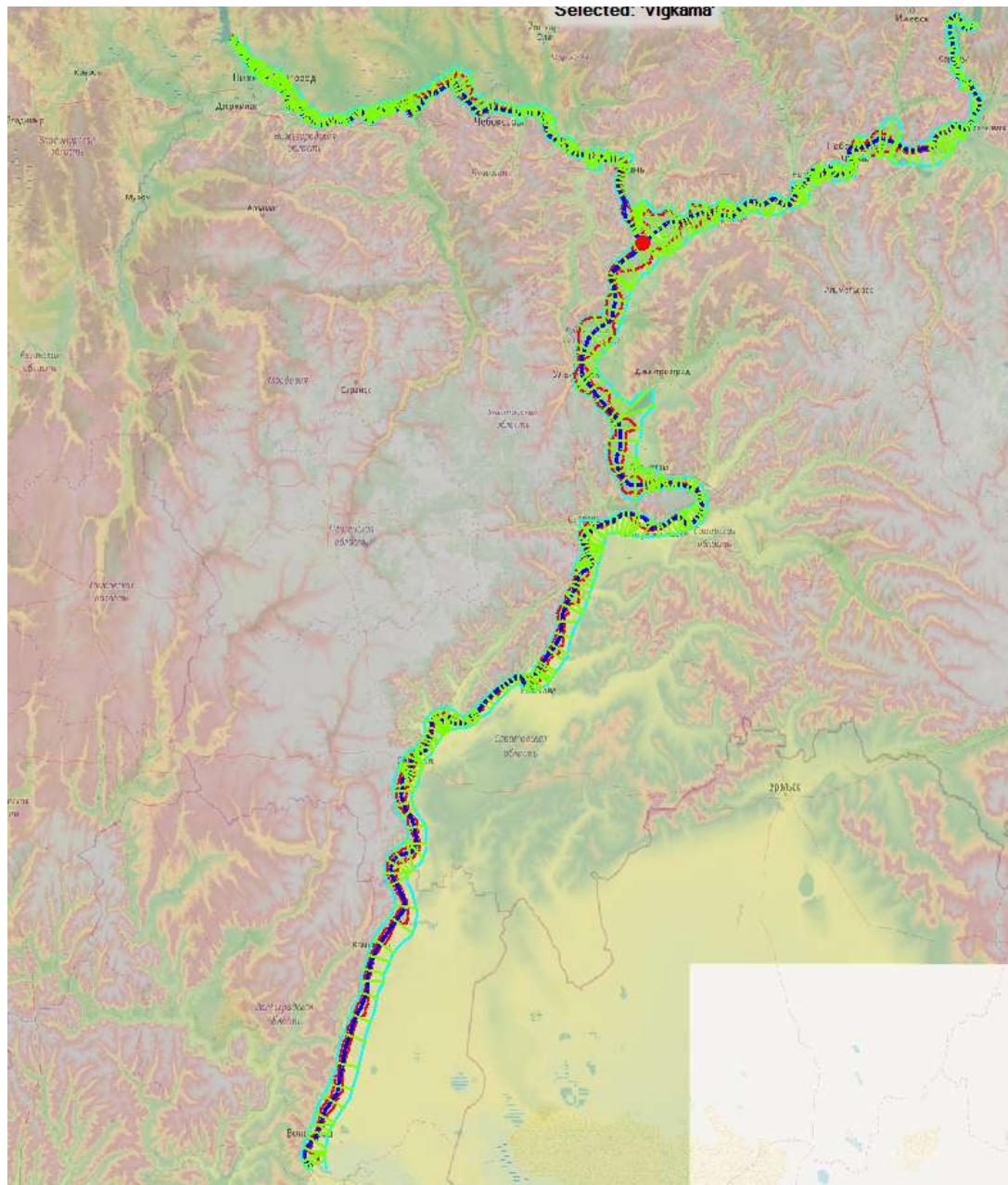
Fig. 38. general view of the modelled section of the Volga-Kama river system
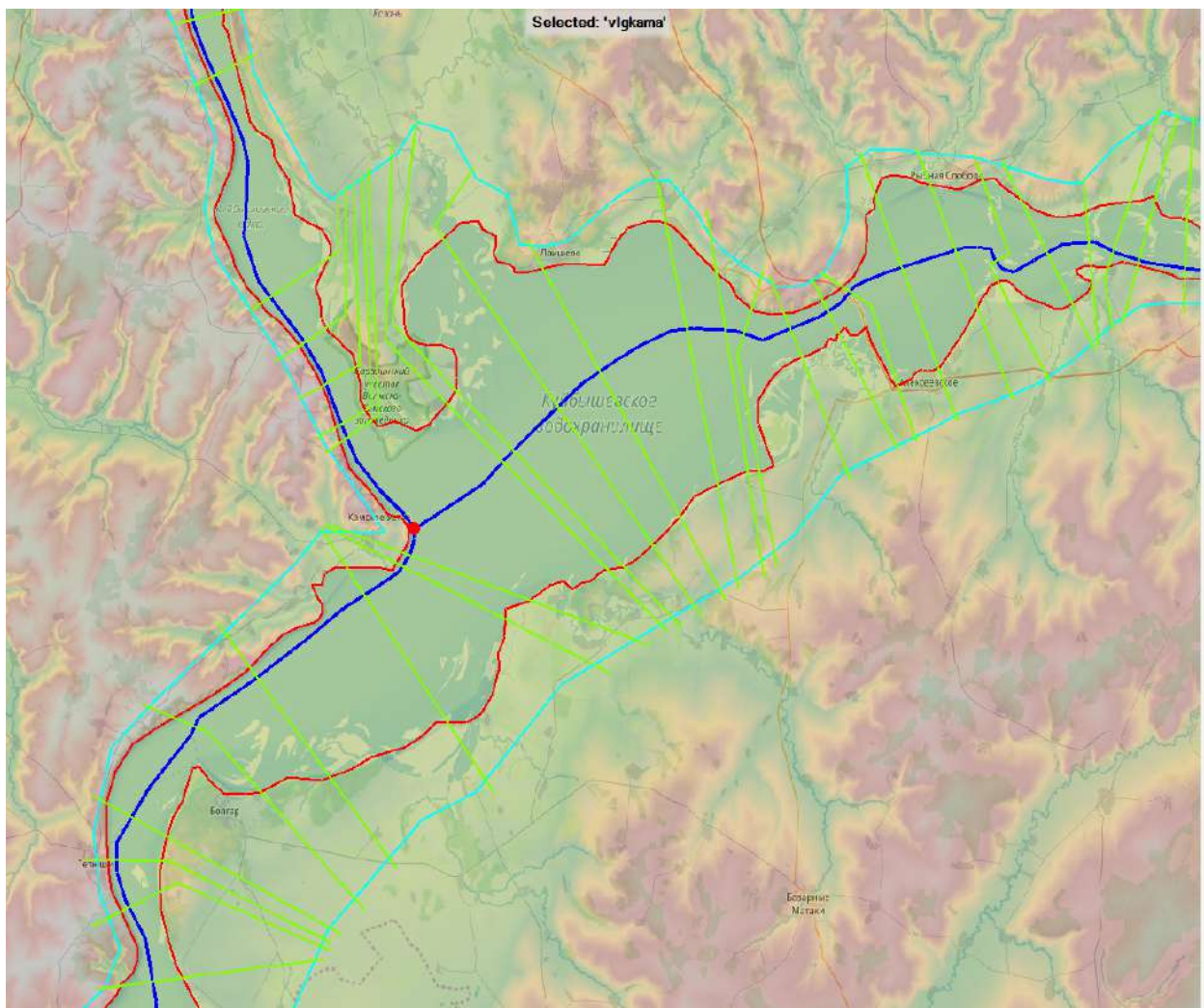
Fig. 39. Volga-Kama junction with center lines, bank lines, flow path lines and cross sections.

3D-model of Volga river from the Kama junction to the Volga HPP is shown in Fig. 40.

Lateral straightened profile of Volga river below the junction with Kama river is shown at Fig. 41.

Throughout the river network, based on bathymetric data, the transverse profile of the river channel is set and adjusted. An example of such a profile of the Volga riverbed is shown in Fig. 42.

Similarly, the transverse profile of the rivers at the locations of the hydroelectric facilities (HPP, dams, etc.) is set and the location of these hydroelectric facilities is marked on this profile. An example of such an arrangement of the dam of the Cheboksary hydroelectric complex is shown in Fig.

43. Similarly, all other dams and waterworks in the river system of the Volga-Kama basin are defined.
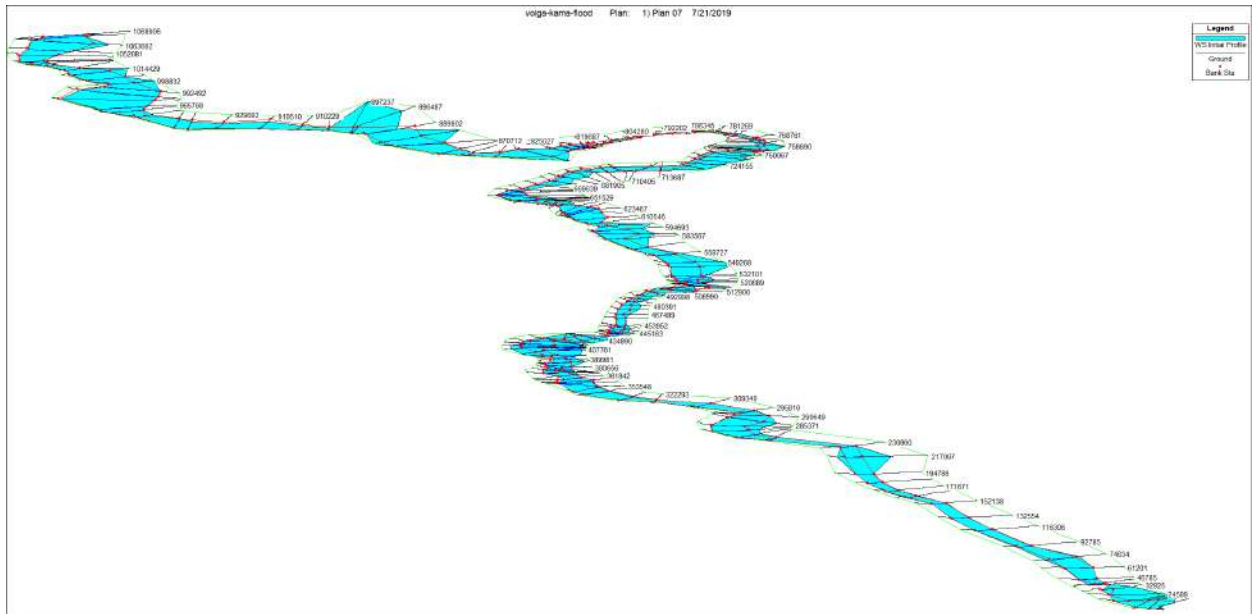
Fig. 40. 3D-model of Volga river from the Kama junction to the Volga HPP.
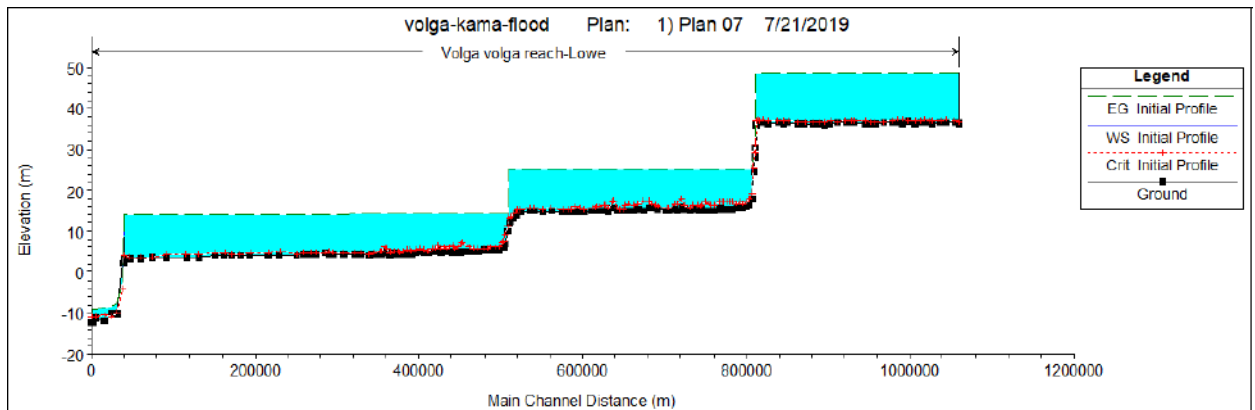
Fig. 41. Lateral straightened profile of Volga river below the junction with Kama river
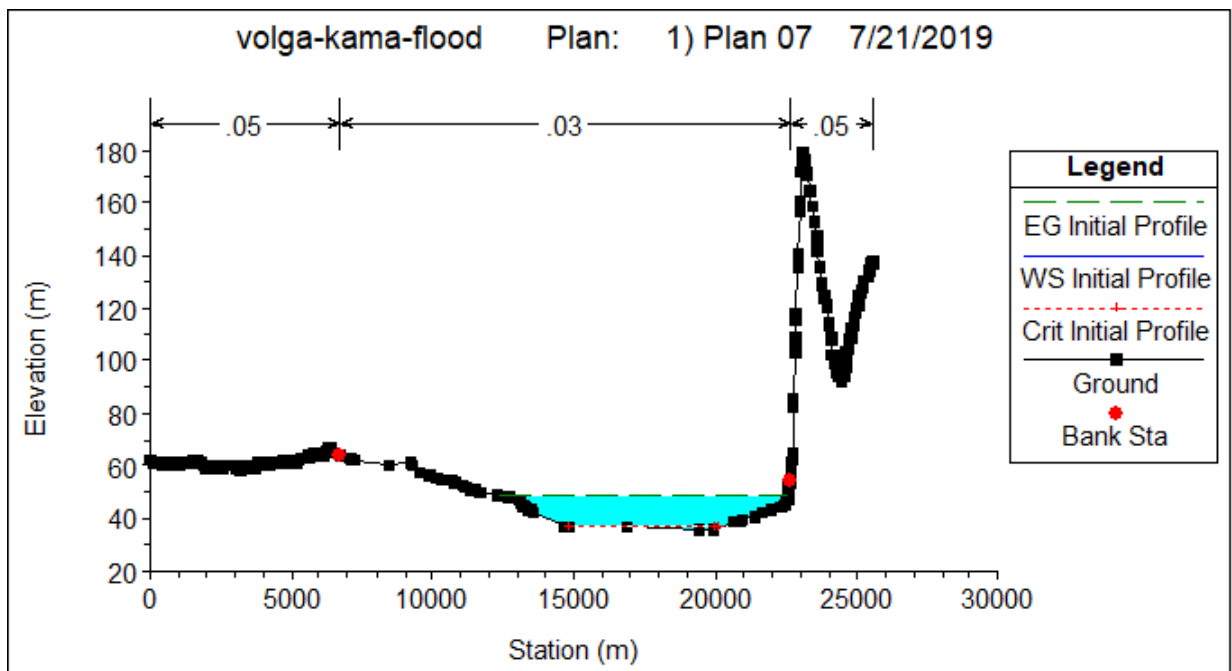
Fig. 42. An example of the cross-section plot at Volga river
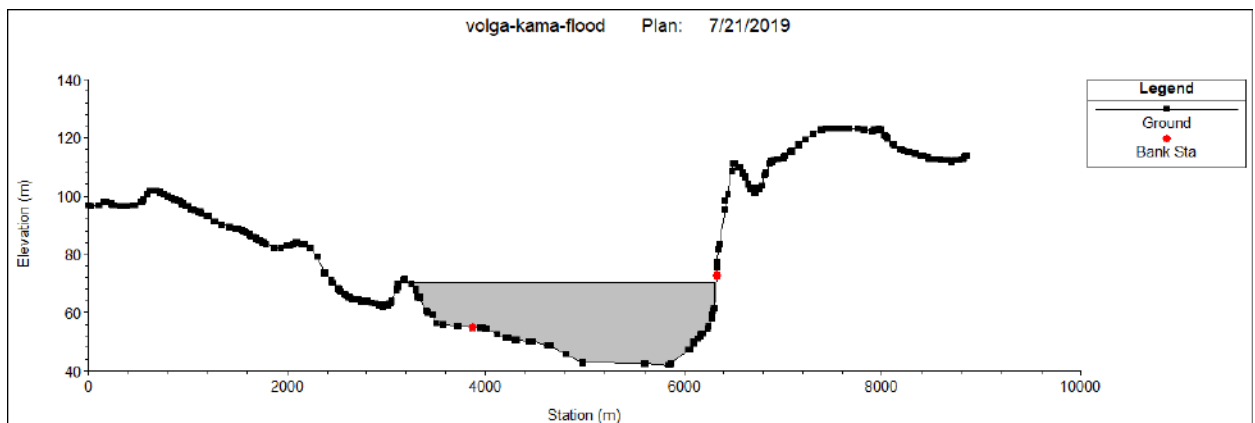
Fig. 43. Schematic view of a dam of Cheboksary HPP in Volga river cross-section

Also, the water level is set as the boundary condition of the main river bed. Since there are no hydraulic structures behind the Volga HPP, and the river flows into the sea, it is possible to assume that the water level in this place is always equal to the mark on the elevation map and does not change (that is, accumulation and discharge are impossible).

The model is calibrated mainly by varying the roughness coefficient and until the discrepancy with real data is less than 1/6 of the data of the measurement results of water rise in the river system (Data from FSBI Channel of Moscow, PJSC RusHydro, Volga Basin Administration [90, 91]). At that the roughness

coefficient is set different for every river section along both the longitudinal and the transverse profile of the river: for the channel and floodplain parts of the rivers, the roughness coefficient is different. Currently, there is a large amount of scientific research devoted to the accurate measurement and determination of the roughness coefficient, however, within this study, the use of basic values of the roughness coefficient is permissible (e. g. [92]).

As the initial data, water flows and level changes in reservoirs are set according to according to the data of Appendix 1, the visualization of which is given in Chapter 5 in Fig. 27

Fig.   30
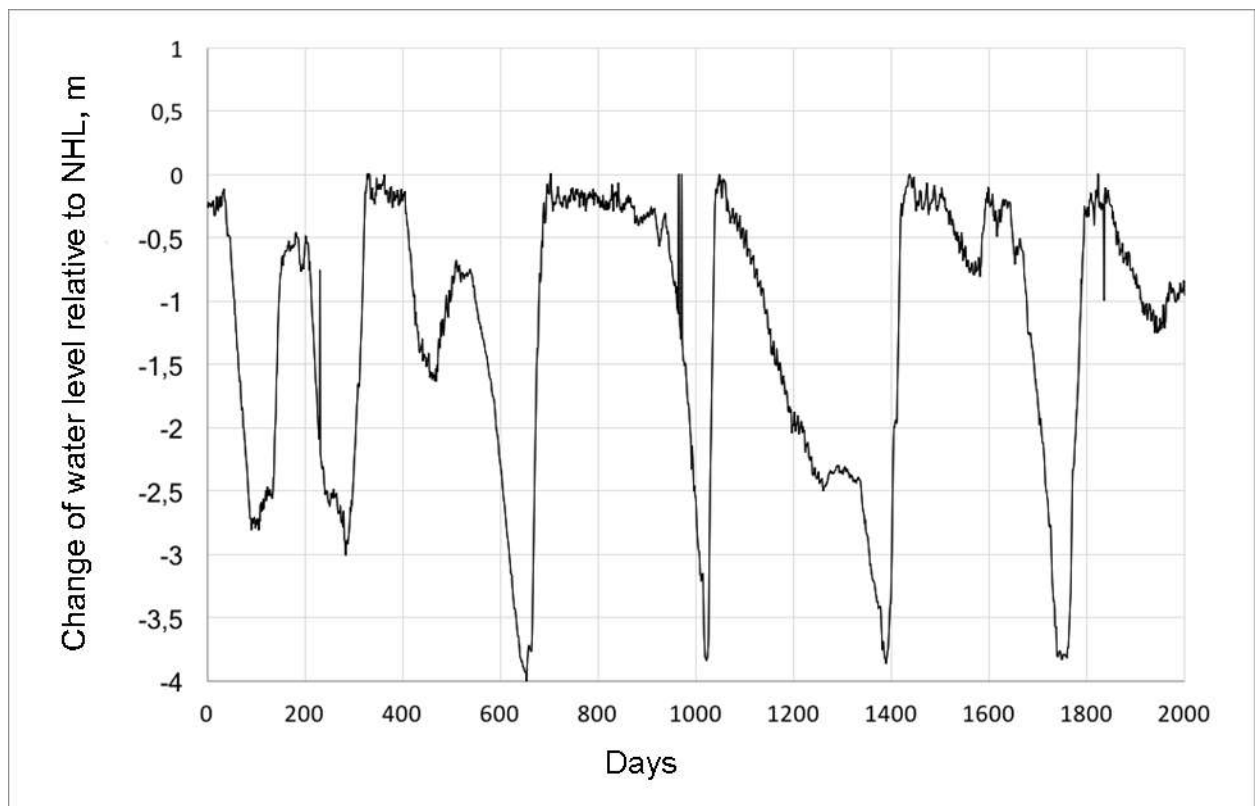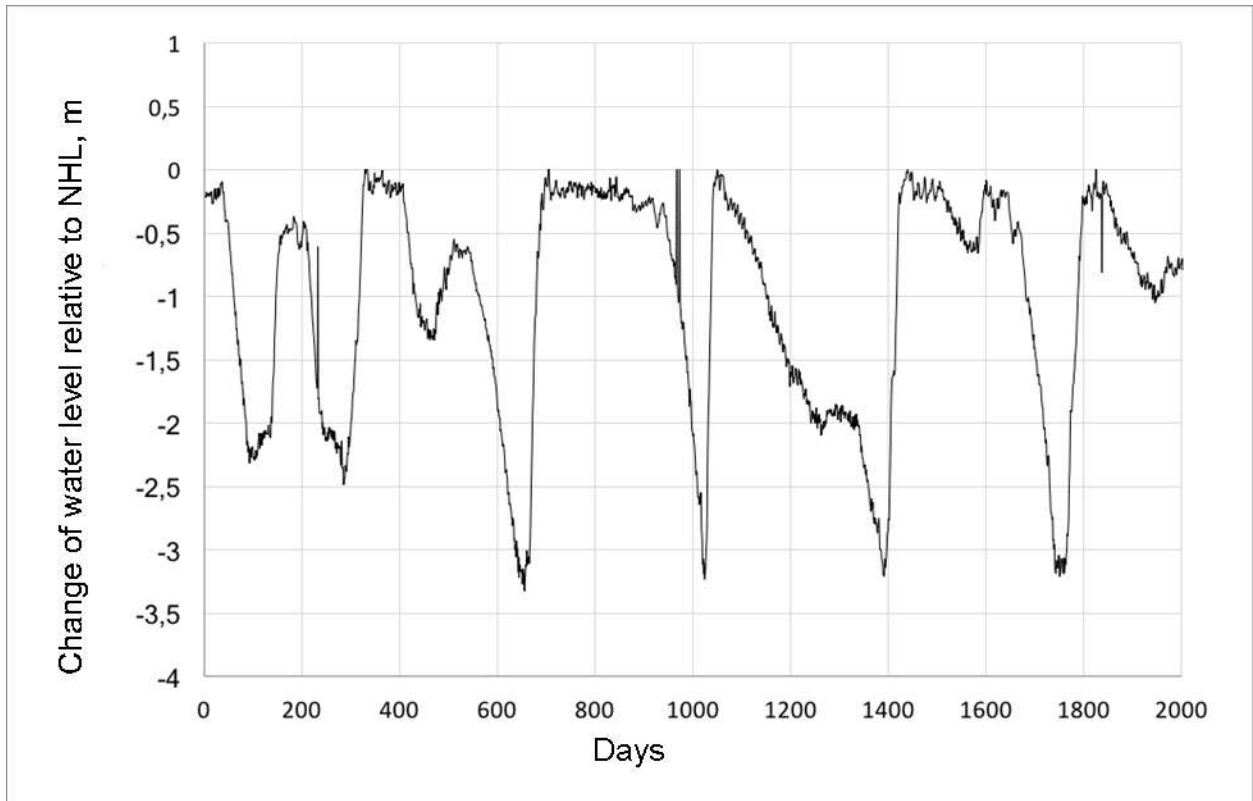
Fig. 32 Fig. 34 Fig. 36 for the Cheboksary, Nizhnekamsk, Zhigulevsk, Saratov and Volga reservoirs, respectively, when managed according to the system currently adopted by PJSC RusHydro and in Fig. 28 Fig. 31 Fig. 33 Fig. 35 Fig. 37 for the same reservoirs, for managing them using the algorithm developed in this work.

In contrast to the calculation in Chapter 5, a shorter period of time was used in modeling the water spill - from September 1, 2013 to August 30, 2014, covering one year of management, in order to save computing resources.

The results of the modeling of water spills for the largest spill in the river system of the Volga-Kama basin for the considered calendar year are presented in Fig. 44 and Fig. 45 for the control algorithm used in PJSC RusHydro and for the proposed management algorithm.

The color scale above the water border indicates the level of water rise in meters above sea level (BES).

However, from these figures, at such a small scale, the difference is not visible. In order to make the difference more [4] [4] noticeable, we need to significantly increase the map scale.
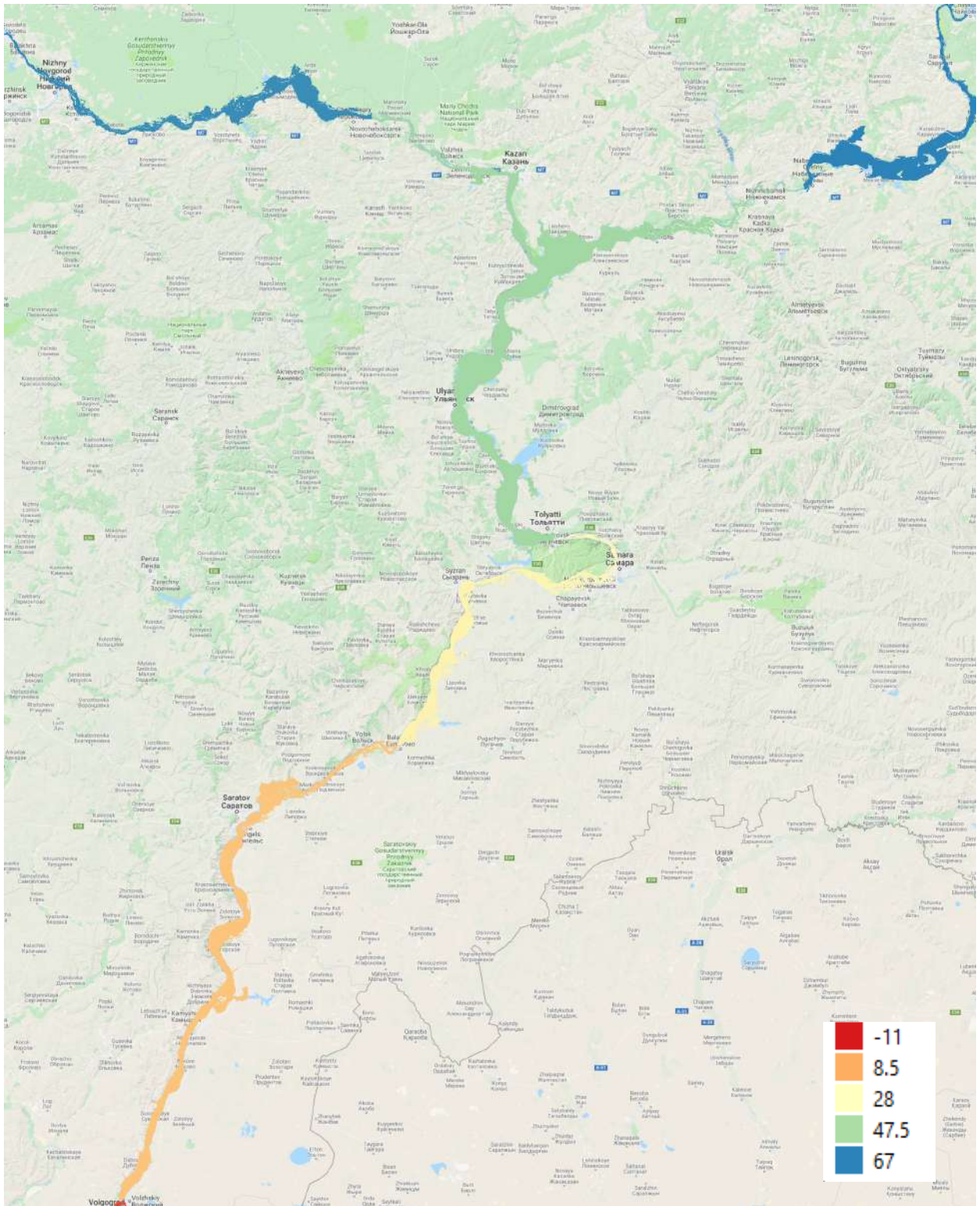
Fig. 44. Water surface elevation (in meters) for the current control scenario at Volga-Kama river basin
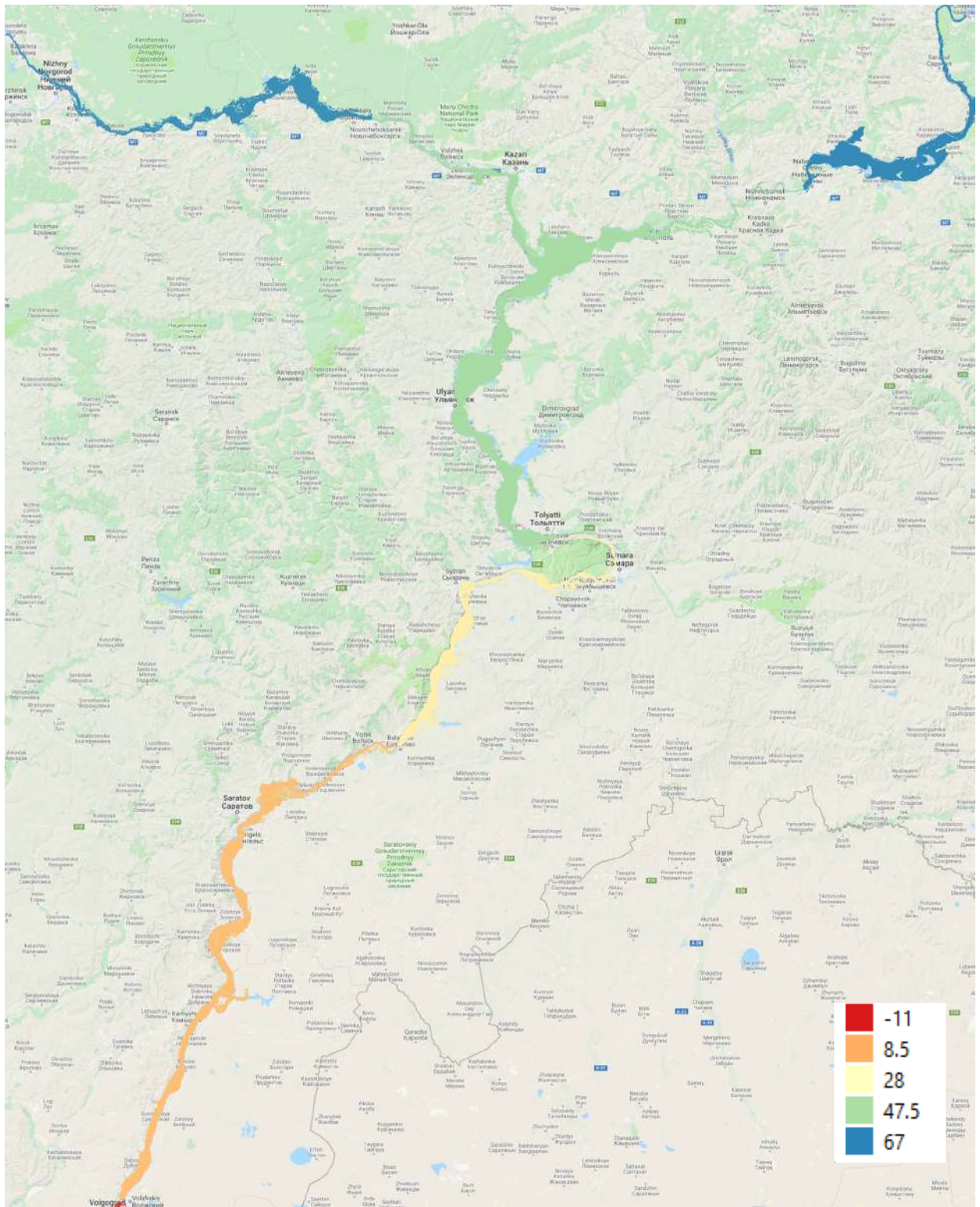
Fig. 45. Water surface elevation (in meters) for the suggested control scenario at Volga-Kama river basin
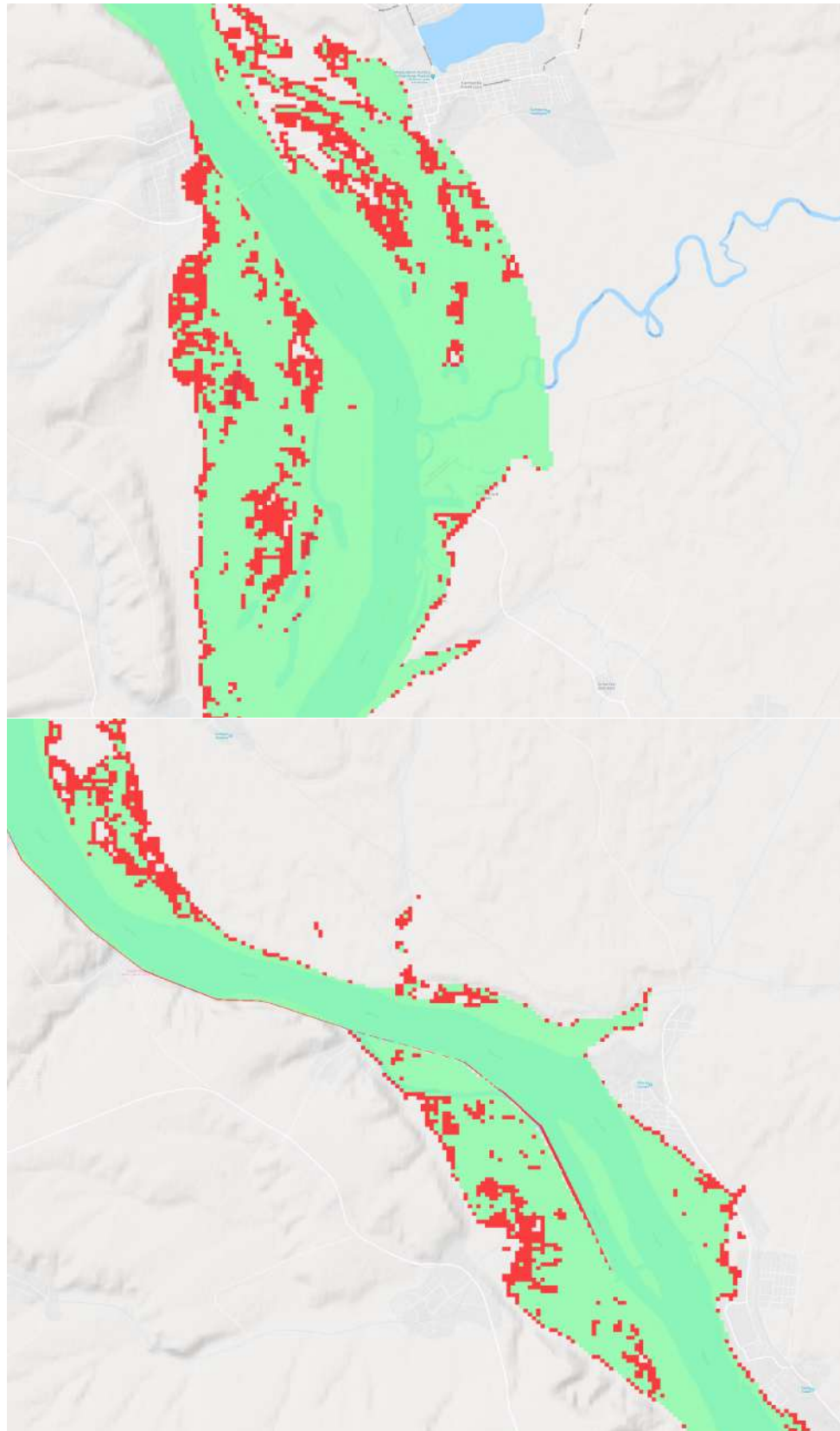
Fig. 46. Comparison of two scenarios for water surface elevation: the proposed water management scenario (lighter color) and given by given scenario (darker color).

Fig. 46 shows the difference in water spills in the floodplain of the river during the flood in two characteristic sections of the river network with different river system management algorithms: the current from PJSC RusHydro is shown (in red) and proposed in this work (in green). In this case, it is obvious that the proposed algorithm, by reducing the deviation of the water level from the NHL by 17-22%, can significantly reduce the flooded area during floods.

6.2. Assessment of the environmental and economic effect of the implementation of the developed measures

6.2.1. Simplified methodology for assessing the environmental and economic effect of a water spill for operational planning and management of water release on a river system

As shown in paragraph 1.5, there is currently no suitable and generally accepted methodology for assessing the environmental and economic effects of water spills in the operational planning and management of water releases on a river system.

In this regard, the present work proposes a utmost simplified methodology for assessing the environmental and economic effect, satisfying all the criteria for such techniques listed in par. 1.5, namely:

- Use of GIS technologies for spatial assessment of the effect.
- Consideration of social factors in assessing the effect.
- The utmost simplification of the process of calculating the effect so that it is possible to ensure high speed operational calculations.

Calculation and visualization on a map of the area and flooding depth h_i of the territories with planned water release on a river system

↓

Splitting the map into a finite number of segments (squares)

↓

Estimation of the population in various settlements in areas of potential spill

↓

Assigning to each segment (square) of the map the values of the levels of the flooding depth h_i, population P_i and economic damage at a flooding depth of 1 m D_1.

↓

Normalization of Flooding Depth Levels $\widetilde{h_i}$, population $\widetilde{P_i}$ and economic damage $\widetilde{D_i}$ for each segment (square) relative to the largest value of each of the parameters.

↓

Calculation of the index of environmental and economic effect S_i for each segment (square) by the formula:

$$S_i = \widetilde{h_i} \cdot \widetilde{P_i} \cdot \widetilde{(D_1 \cdot \sqrt{h_i})}$$

↓

Calculation of the index of environmental and economic effect S from a water spill by the formula:

$$S = \sum_i S_i$$

Fig. 1. Simplified methodology for assessing the environmental and economic effect of a water spill for operational planning and management of water release on a river system

In addition, it was previously shown that material damage can be estimated indirectly by estimating the flooding depth, at which the amount of damage is proportional to the multiplication of the contingent damage at a flooding depth of 1 m per square root of the flooding depth.

Based on the foregoing, in this paper, a simplified methodology is proposed for assessing the environmental and economic effect of a water spill for operational planning and management of water release on a river system, presented in Fig. 1.

The essence of the methodology is to determine the index of the ecological and economic effect of flooding the territory.

Initially, in a spatial form, using GIS programs, a spill of water is specified with the planned release on the river system on a map of the area. At the same time, the area of flooding and the flooding depth of territories are noted.

Next, the territory map is divided into a finite number of segments (squares). The size of one segment determines the accuracy of further forecasting and the required amount of computing power. To optimize computing power, it is possible to divide into segments of different sizes: larger in places with a low population density and smaller in places with a high population density. In particular, for territories outside the settlements, the linear size of one segment can reach 30-50 m, small settlements - 20-30 m, while for large settlements - 1-5 m.

Then the total population is determined in all settlements located in places of potential flooding.

The next step is to assign for each segment the value of the flooding depth, population and potential economic damage. Potential economic damage for each segment is determined by the formula (48) the multiplication of the contingent damage at a depth of flooding of 1 m per square root of the flooding depth. Contingent economic damage with a flooding depth of 1 m should be determined individually for all segments (squares) in the initial assessment. If this is not possible for a number of reasons, then specific damage to residential areas may be used as such an indicator [93].

$$D_i = D_1 \cdot \sqrt{h_i} \qquad (42)$$

where: D_1 – contingent economic damage at a flooding depth of 1 m, or specific damage to residential areas by [93];

h_i – flooding depth.

Further, all parameters of each segment (square) must be normalized in the range from 0 to 1 by the maximum value of each indicator according to the formulas:

$$\widetilde{h_\iota} = \frac{h_i}{h_{max}}, \quad \widetilde{P_\iota} = \frac{P_i}{P_{max}}, \quad \widetilde{D_\iota} = \frac{D_i}{D_{max}} \qquad (43)$$

where: $\widetilde{h_\iota}$, $\widetilde{P_\iota}$, $\widetilde{D_\iota}$ – normalized flooding depth, population and contingent economic damage, respectively, for each segment (square) on the map.

Then, the index of the ecological and economic effect S_i is calculated for each segment (square) according to the formula:

$$S_i = \widetilde{h_\iota} \cdot \widetilde{P_\iota} \cdot (\widetilde{D_1 \cdot \sqrt{h_\iota}}) \qquad (44)$$

After that, the general index of the ecological and economic effect S from the water spill is determined by the formula:

$$S = \sum_i S_i$$

At the same time, during the initial assessment, a breakdown is made by segments (squares). The population and contingent economic damage are also specified, which requires adjustment from time to time.

In repeated calculations, it is enough to only update the height maps and use them to calculate the index of environmental and economic effect, which can then be compared for various scenarios of water release and based on which conclusions can be drawn about the safety of these measures.

In addition, the calculation of this index can easily be supplemented by other coefficients that will make it more accurate in absolute value, and not when comparing different scenarios.

6.2.2. Assessment of the environmental and economic effect of the implementation of the developed algorithm for managing water release in the Volga-Kama basin.

Based on the method described in paragraph 6.2.1. and water spills calculated in paragraph 6.1., in the Volga-Kama basin under the current management regime of water release on the river system and using the algorithm developed in this work, an assessment of the environmental and economic effect for this river system was carried out.

The QGIS 3.0 software product was used as a GIS system [94], which is built on the basis of open source and allows to carry out analytical operations in a wider range with overlaying them on the cards.

NextGIS company data were used as initial population data [95], which are built on the OpenStreetMap platform and are as relevant as possible at the time of their use. The result of population mapping with the definition of the boundaries of settlements in the QGIS software product is presented in Fig. 47 and Fig. 48.

Further, according to the proposed simplified methodology for assessing the environmental and economic effect of a water spill for operational planning and management of water release on the river system, the map of the area was divided into segments (squares). In this case, to simplify the calculations, segments of the same size were used: squares 30x30 meters. For further analysis, the segments were excluded in which there is no population, settlements and which will not be affected by the flood according to the forecast.
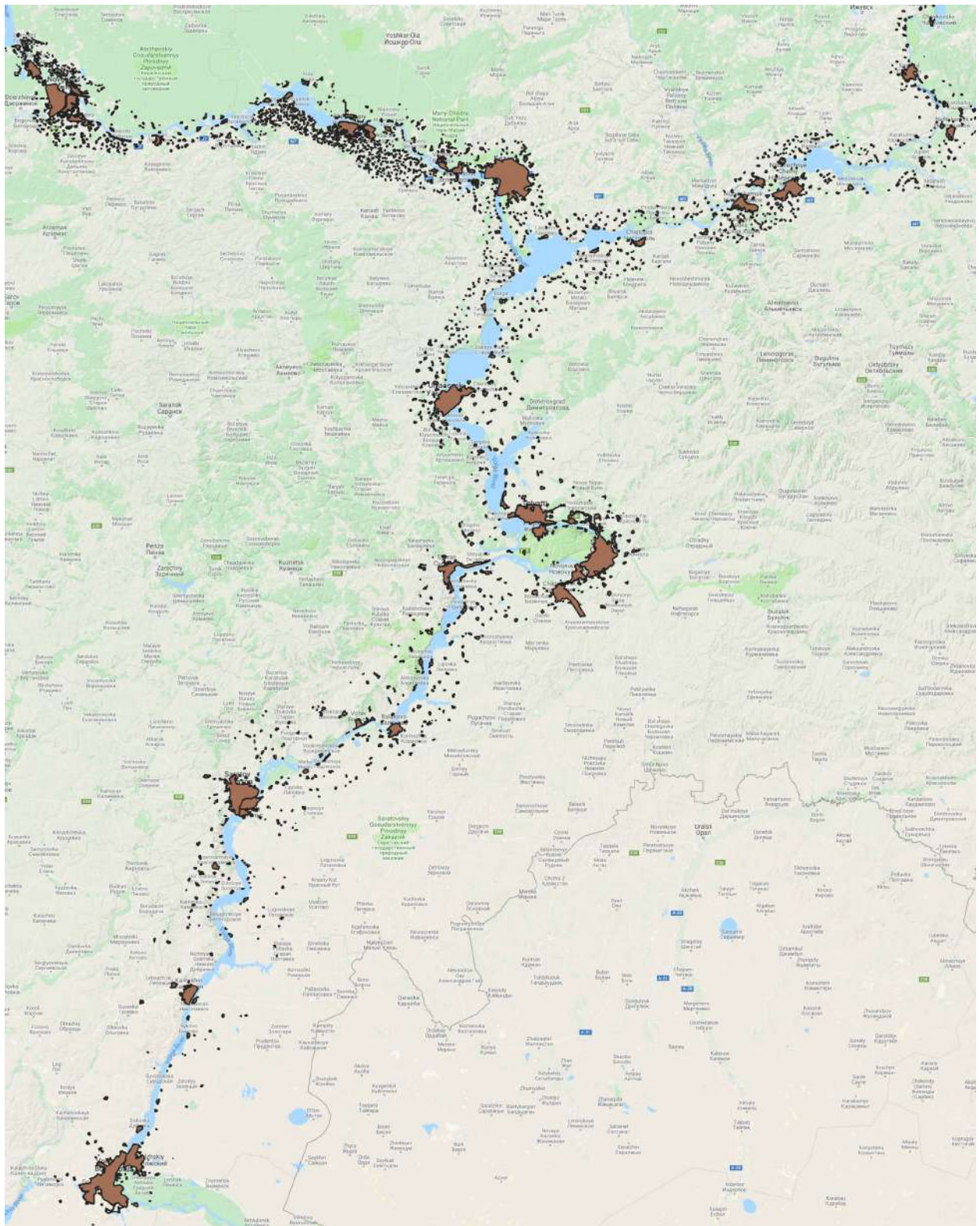
Fig. 47. Populated localities along Volga-Kama river basin
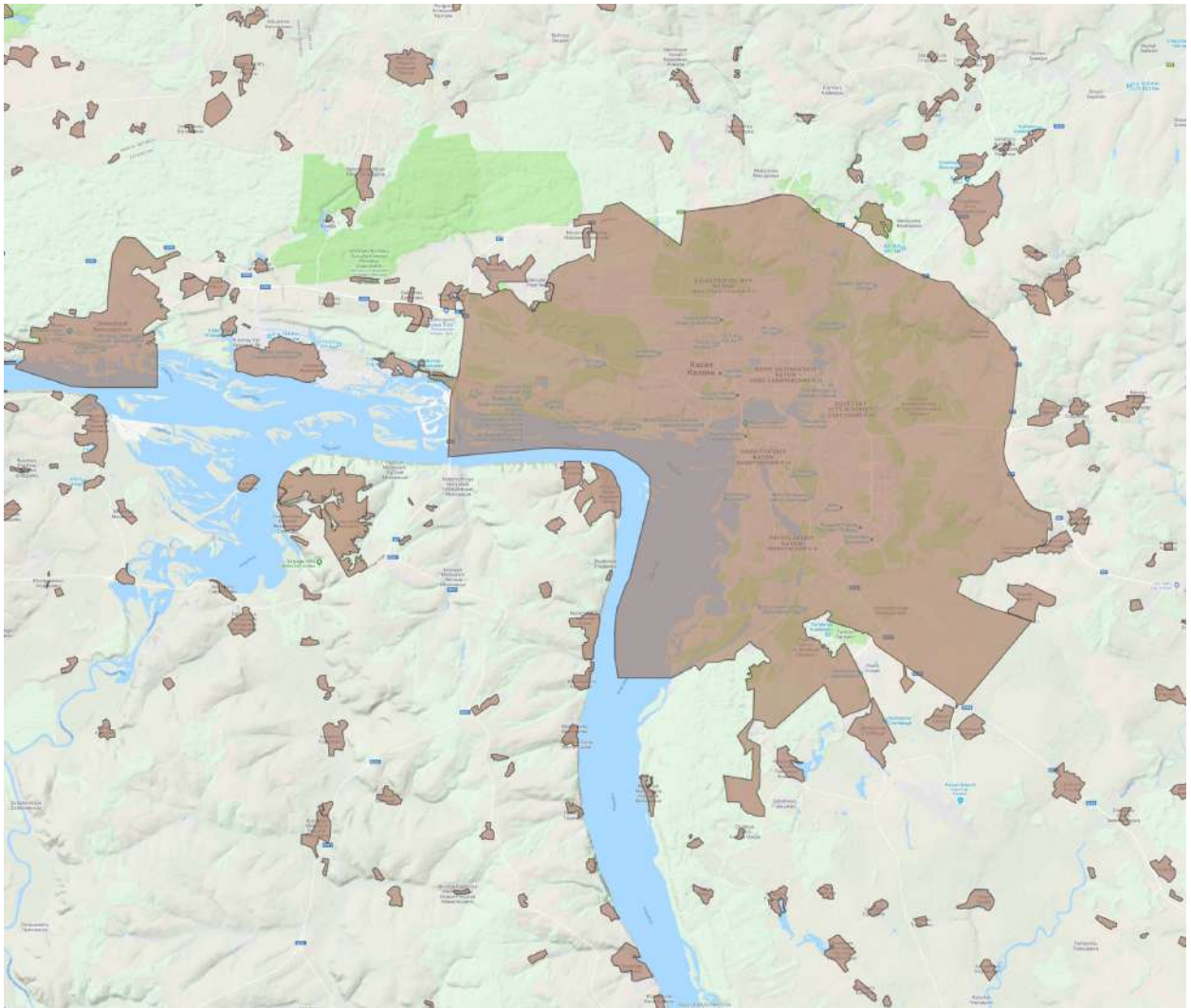
Fig. 48. Populated localities in polygons along Volga river: Kazan city and surroundings

Fig. 49 shows the location patterns of flooded populated segments for two sections of the Volga-Kama basin for two scenarios: green indicates flooding of settlements under the management scenario of PJSC RusHydro, and gray indicates management by the developed algorithm. Since the gray color is superimposed on top of the green, under the current scenario management, the flooded areas will be both gray and green ones. In the case of using the developed algorithm, only gray segments will be flooded.

Thus, it is obvious that in the above diagrams the number of gray segments is much less than green.

a)

b)

Fig. 49. Intersection of the flooded and populated areas clustered in 30 m size pixels (lighter color – Scenario 2 overlaid to darker color – Scenario 1).
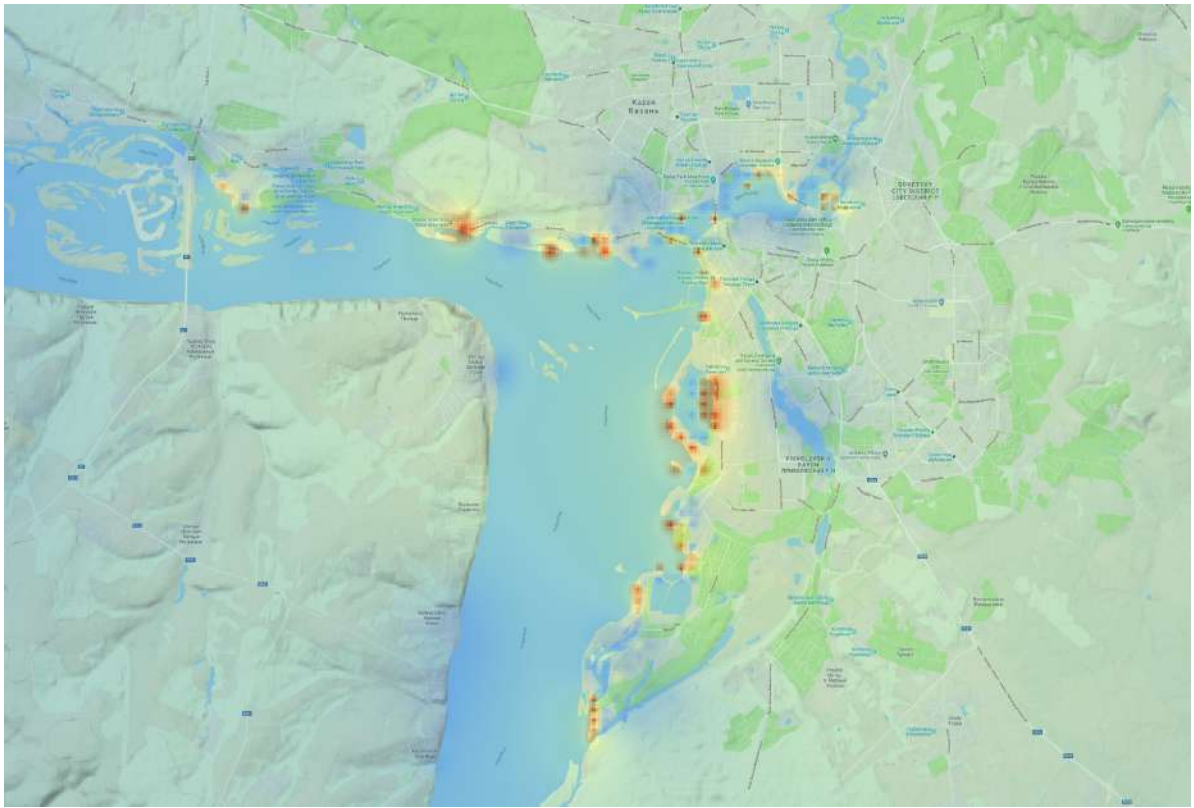
a)

b)

Fig. 50. Flood impact incurred after implementing current water management scenario (Scenario 1).

However, the features of the developed algorithm include the possibility of increasing the water spill in the unsettled or sparsely populated territories. Therefore, in order to assess the overall environmental and economic effect in addition to measuring the area of flooding in two scenarios, it is necessary to additionally evaluate the intensity of the impact of flooding by possible damage and population.

For this, according to the developed methodology, the index of environmental and economic damage is calculated for two scenarios - the current management scenario (Fig. 50) and management according to the developed algorithm (Fig. 51). Fig. 50 and Fig. 51 show the results of calculating the index for two sections of the river network. In this case, the color shows the value of this index, where red corresponds to its largest value, and green to the smallest.
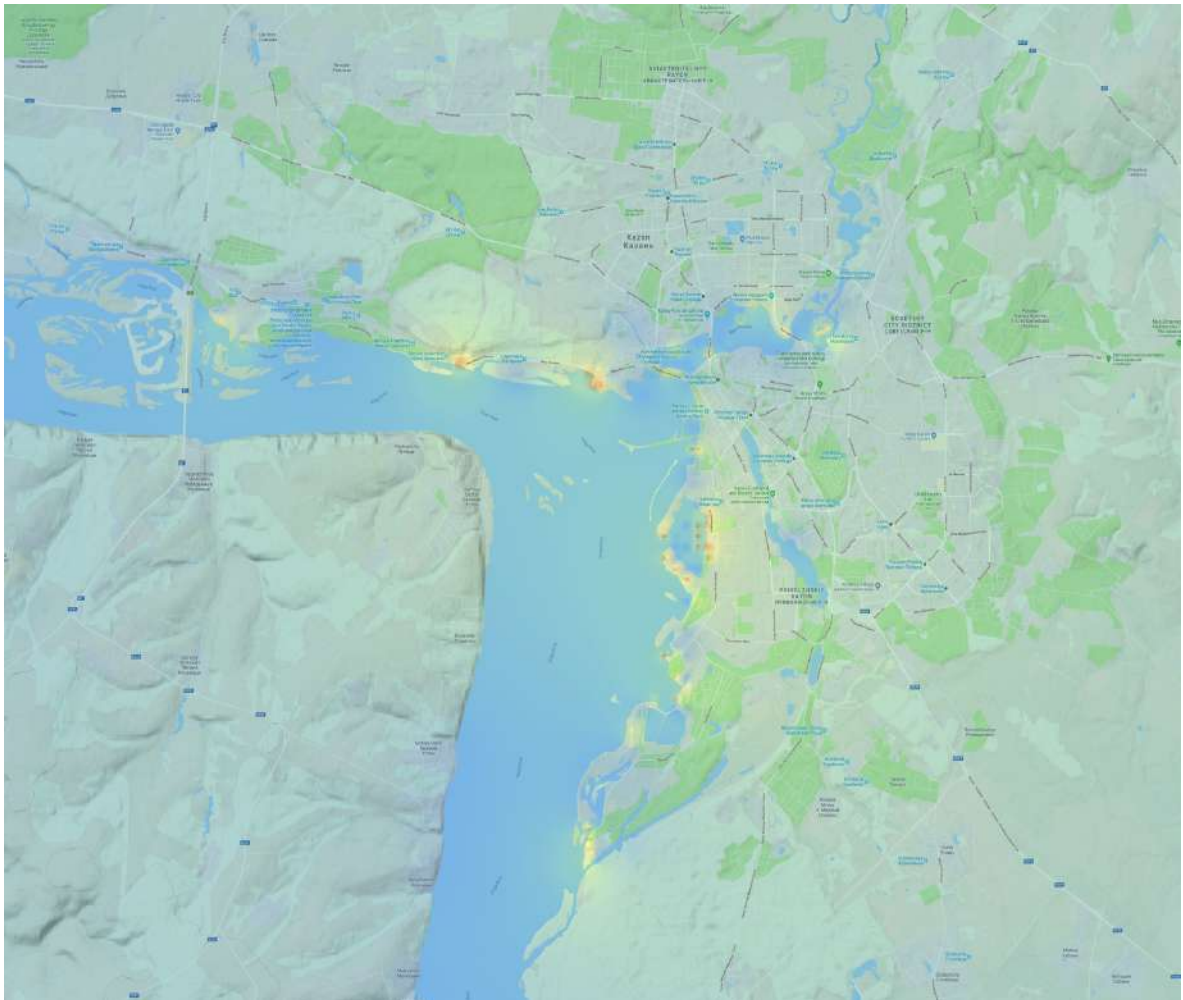
a)
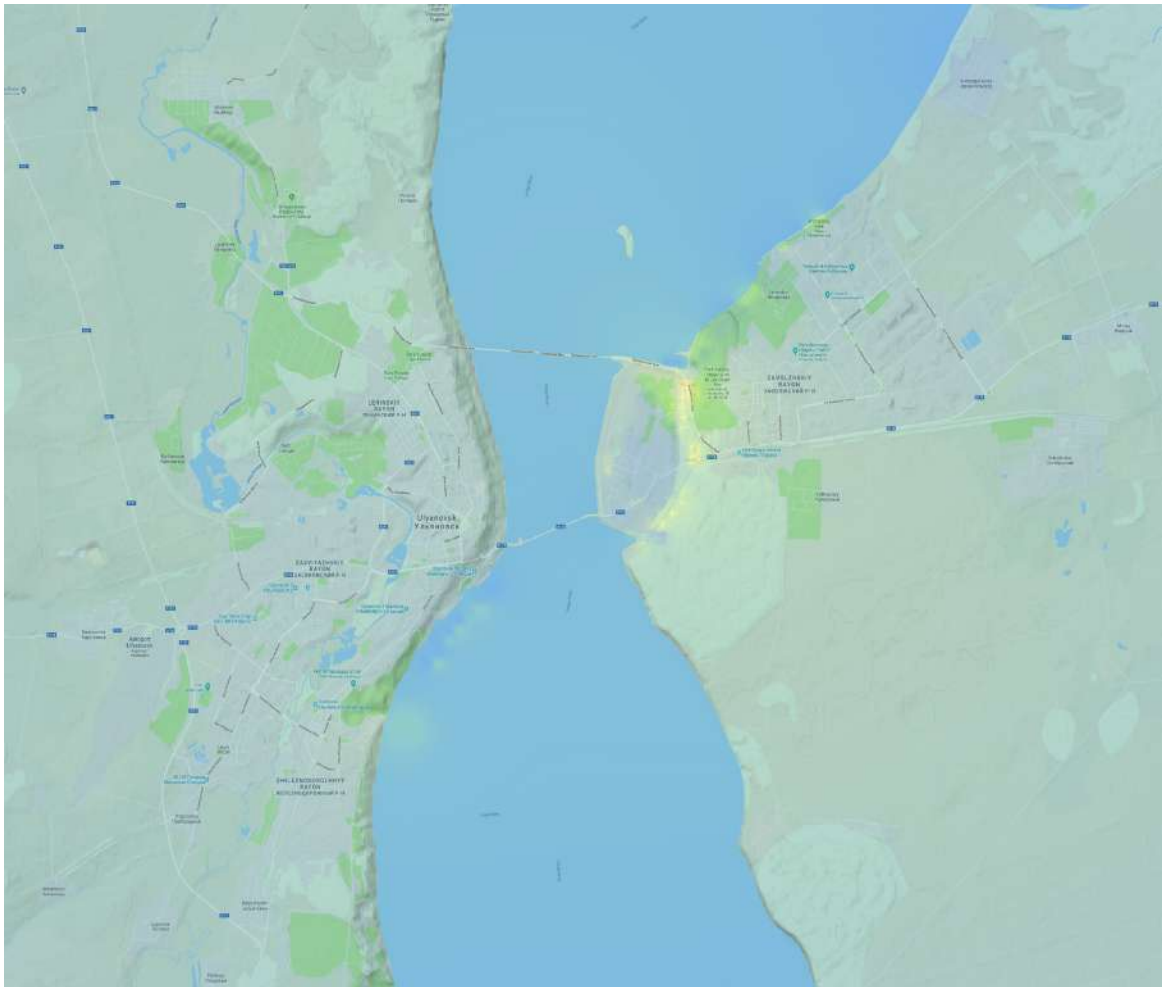
b)

Fig. 51. Flood impact incurred after implementing proposed water management
scenario (Scenario 2)

Next, the general index of environmental and economic damage was
assessed, which showed that for the current management mode it was 0.143, and
for the developed algorithm - 0.095. Thus, it is possible to reduce environmental
and economic damage through the use of the proposed management algorithm by
33%.

CONCLUSIONS

1.   A system analysis for various factors affecting reservoir operation has been performed with consideration of existing models and management tools. It was shown that there are specific problems in complex river system management unsolved: Known approaches do not perform multi-criteria operation of a complex river system that would provide required power production and minimization of flood risks. Known approaches for ecological and economical impact assessment for the river systems do not allow operative management of the river systems.

2.   A method and mathematical model for managing a cascade of dams in a river system for maintaining required power production while minimizing ecological and economical impact of floods at the river system has been developed.

3.   The developed model has been tested with PowerSim for applicability at Valle D'Aosta river system. It was shown that model results in creation of trends for water level change for each reservoir of the river system.

4.   A decision support system on the basis of equations with State Dependent Coefficients for water discharge over a system of dams with consideration of developed mathematical approach for river system management was created and applied at Volga-Kama river system in Russia.

5.   Usage of the developed model with decision support system allows to decrease standard deviation of the water level change for the reservoirs by 16-22% maintaining required power production.

6.   A reduced methodology for estimation of index for ecological and economical impact has been developed. It allows performance of operative index calculation and may be used in in operative management of the river systems.

7.   Usage of the developed model with decision support system allows to decrease index for ecological and economical impact calculated with the developed methodology for Volga-Kama river system by up to 30%.

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APPENDIX

Appendix 1. Initial data on changes in water levels in the reservoirs of the Volga river basin in the period from July 1, 2013 to December 1, 2013 according to the data of PJSC RusHydro

Date	Nizhny Novgorod HPP							
	SRL, m	Available storage, million m3	Total discharge, m3/s	Actual water level, m	NHL, m	Inflow, m3/s	Discharge through spillways, m3/s	DSL, m
2013-07-01 00:00:00	85,5	525000000	1300	83,65	84	1300	0	81
2013-07-02 00:00:00	85,5	465000000	1310	83,69	84	695	0	81
2013-07-03 00:00:00	85,5	441000000	1330	83,75	84	1243	0	81
2013-07-04 00:00:00	85,5	315000000	1300	83,79	84	1865	0	81
2013-07-05 00:00:00	85,5	270000000	1300	83,82	84	1890	0	81
2013-07-06 00:00:00	85,5	315000000	1300	83,79	84	1715	0	81
2013-07-07 00:00:00	85,5	345000000	1290	83,77	84	1715	0	81
2013-07-08 00:00:00	85,5	1677000000	1290	83,69	84	510	0	81
2013-07-09 00:00:00	85,5	405000000	1470	83,73	84	216	0	81
2013-07-10 00:00:00	85,5	450000000	1310	83,7	84	744	0	81
2013-07-11 00:00:00	85,5	480000000	1310	83,68	84	1370	0	81
2013-07-12 00:00:00	85,5	465000000	1340	83,69	84	1445	0	81
2013-07-13 00:00:00	85,5	390000000	1340	83,74	84	1638	0	81
2013-07-14 00:00:00	85,5	405000000	1330	83,73	84	1638	0	81
2013-07-15 00:00:00	85,5	570000000	1330	83,62	84	500	0	81
2013-07-16 00:00:00	85,5	585000000	1420	83,61	84	711	0	81
2013-07-17 00:00:00	85,5	495000000	1270	83,67	84	1243	0	81
2013-07-18 00:00:00	85,5	390000000	1250	83,74	84	1940	0	81
2013-07-19 00:00:00	85,5	345000000	1230	83,77	84	2050	0	81
2013-07-20 00:00:00	85,5	360000000	1220	83,76	84	2044	0	81
2013-07-21 00:00:00	85,5	270000000	1220	83,82	84	1840	0	81
2013-07-22 00:00:00	85,5	390000000	1230	83,74	84	950	0	81
2013-07-23 00:00:00	85,5	375000000	1220	83,75	84	481	0	81
2013-07-24 00:00:00	85,5	300000000	1260	83,8	84	1029	0	81
2013-07-25 00:00:00	85,5	285000000	1230	83,81	84	1740	0	81
2013-07-26 00:00:00	85,5	240000000	1960	83,84	84	1735	0	81
2013-07-27 00:00:00	85,5	165000000	1380	83,89	84	1730	0	81
2013-07-28 00:00:00	85,5	210000000	1210	83,86	84	1730	0	81
2013-07-29 00:00:00	85,5	225000000	1210	83,85	84	500	0	81
2013-07-30 00:00:00	85,5	255000000	1220	83,83	84	365	0	81
2013-07-31 00:00:00	85,5	270000000	1220	83,82	84	1037	0	81
2013-08-01 00:00:00	85,5	165000000	1580	83,89	84	1730	0	81
2013-08-02 00:00:00	85,5	255000000	1250	83,83	84	1590	0	81

2013-08-03 00:00:00	85,5	225000000	1220	83,85	84	1304	0	81
2013-08-04 00:00:00	85,5	300000000	1230	83,8	84	600	0	81
2013-08-05 00:00:00	85,5	315000000	1220	83,79	84	550	0	81
2013-08-06 00:00:00	85,5	345000000	1220	83,77	84	329	0	81
2013-08-07 00:00:00	85,5	360000000	950	83,76	84	965	0	81
2013-08-08 00:00:00	85,5	345000000	1590	83,77	84	1625	0	81
2013-08-09 00:00:00	85,5	300000000	1220	83,8	84	1605	0	81
2013-08-10 00:00:00	85,5	315000000	1220	83,79	84	1630	0	81
2013-08-11 00:00:00	85,5	255000000	926	83,83	84	130	0	81
2013-08-12 00:00:00	85,5	465000000	1210	83,69	84	130	0	81
2013-08-13 00:00:00	85,5	465000000	1300	83,69	84	292	0	81
2013-08-14 00:00:00	85,5	465000000	1700	83,69	84	906	0	81
2013-08-15 00:00:00	85,5	465000000	1220	83,77	84	1740	0	81
2013-08-16 00:00:00	85,5	360000000	1220	83,76	84	1935	0	81
2013-08-17 00:00:00	85,5	270000000	1540	83,82	84	1955	0	81
2013-08-18 00:00:00	85,5	255000000	1200	83,83	84	1805	0	81
2013-08-19 00:00:00	85,5	390000000	1210	83,74	84	0	0	81
2013-08-20 00:00:00	85,5	405000000	1250	83,73	84	243	0	81
2013-08-21 00:00:00	85,5	360000000	1290	83,76	84	1020	0	81
2013-08-22 00:00:00	85,5	210000000	1210	83,86	84	1860	0	81
2013-08-23 00:00:00	85,5	330000000	1210	83,78	84	1930	0	81
2013-08-24 00:00:00	85,5	135000000	1220	83,91	84	1945	0	81
2013-08-25 00:00:00	85,5	165000000	1210	83,89	84	500	0	81
2013-08-26 00:00:00	85,5	255000000	1210	83,83	84	500	0	81
2013-08-27 00:00:00	85,5	330000000	1260	83,78	84	203	0	81
2013-08-28 00:00:00	85,5	360000000	1180	83,76	84	842	0	81
2013-08-29 00:00:00	85,5	345000000	1230	83,77	84	1500	0	81
2013-08-30 00:00:00	85,5	270000000	1220	83,82	84	1595	0	81
2013-08-31 00:00:00	85,5	240000000	1210	83,84	84	1695	0	81
2013-09-01 00:00:00	85,5	255000000	1210	83,83	84	1695	0	81
2013-09-02 00:00:00	85,5	330000000	10	83,78	84	475	0	81
2013-09-03 00:00:00	85,5	375000000	1210	83,75	84	239	0	81
2013-09-04 00:00:00	85,5	300000000	1220	83,8	84	872	0	81
2013-09-05 00:00:00	85,5	90000000	1220	83,94	84	1560	0	81
2013-09-06 00:00:00	85,5	135000000	1210	83,91	84	1700	0	81
2013-09-07 00:00:00	85,5	210000000	1210	83,86	84	1820	0	81
2013-09-08 00:00:00	85,5	210000000	1210	83,86	84	1820	0	81
2013-09-09 00:00:00	85,5	345000000	1210	83,77	84	840	0	81
2013-09-10 00:00:00	85,5	315000000	1210	83,79	84	385	0	81
2013-09-11 00:00:00	85,5	285000000	1210	83,81	84	1067	0	81
2013-09-12 00:00:00	85,5	285000000	1210	83,81	84	1845	0	81
2013-09-13 00:00:00	85,5	240000000	1590	83,84	84	1860	0	81
2013-09-14 00:00:00	85,5	270000000	1220	83,82	84	1640	0	81

2013-09-15 00:00:00	85,5	330000000	1210	83,78	84	760	0	81
2013-09-16 00:00:00	85,5	510000000	1210	83,66	84	760	0	81
2013-09-17 00:00:00	85,5	525000000	1220	83,65	84	302	0	81
2013-09-18 00:00:00	85,5	495000000	1230	83,67	84	728	0	81
2013-09-19 00:00:00	85,5	420000000	1220	83,72	84	1470	0	81
2013-09-20 00:00:00	85,5	405000000	1220	83,73	84	1805	0	81
2013-09-21 00:00:00	85,5	330000000	1220	83,78	84	1780	0	81
2013-09-22 00:00:00	85,5	375000000	1220	83,75	84	580	0	81
2013-09-23 00:00:00	85,5	345000000	1220	83,77	84	580	0	81
2013-09-24 00:00:00	85,5	450000000	1220	83,7	84	311	0	81
2013-09-25 00:00:00	85,5	510000000	1220	83,66	84	866	0	81
2013-09-26 00:00:00	85,5	240000000	1220	83,84	84	1585	0	81
2013-09-27 00:00:00	85,5	225000000	1190	83,85	84	1860	0	81
2013-09-28 00:00:00	85,5	90000000	900	83,94	84	2020	0	81
2013-09-29 00:00:00	85,5	135000000	1190	83,91	84	450	0	81
2013-09-30 00:00:00	85,5	225000000	1200	83,85	84	420	0	81
2013-10-01 00:00:00	85,5	330000000	1200	83,78	84	494	0	81
2013-10-02 00:00:00	85,5	375000000	2220	83,75	84	859	0	81
2013-10-03 00:00:00	85,5	390000000	1120	83,74	84	1282	0	81
2013-10-04 00:00:00	85,5	435000000	1210	83,71	84	1333	0	81
2013-10-05 00:00:00	85,5	390000000	920	83,74	84	1342	0	81
2013-10-06 00:00:00	85,5	405000000	1200	83,73	84	1000	0	81
2013-10-07 00:00:00	85,5	495000000	1200	83,67	84	500	0	81
2013-10-08 00:00:00	85,5	465000000	900	83,69	84	318	0	81
2013-10-09 00:00:00	85,5	450000000	1200	83,7	84	977	0	81
2013-10-10 00:00:00	85,5	360000000	1200	83,76	84	1765	0	81
2013-10-11 00:00:00	85,5	330000000	1270	83,78	84	1690	0	81
2013-10-12 00:00:00	85,5	300000000	1180	83,8	84	1373	0	81
2013-10-13 00:00:00	85,5	375000000	1180	83,75	84	1373	0	81
2013-10-14 00:00:00	85,5	255000000	900	83,83	84	0	0	81
2013-10-15 00:00:00	85,5	420000000	1190	83,72	84	287	0	81
2013-10-16 00:00:00	85,5	390000000	943	83,74	84	1228	0	81
2013-10-17 00:00:00	85,5	210000000	1200	83,86	84	2075	0	81
2013-10-18 00:00:00	85,5	270000000	1050	83,82	84	1985	0	81
2013-10-19 00:00:00	85,5	255000000	1065	83,83	84	1665	0	81
2013-10-20 00:00:00	85,5	195000000	1120	83,87	84	500	0	81
2013-10-21 00:00:00	85,5	255000000	920	83,83	84	500	0	81
2013-10-22 00:00:00	85,5	210000000	1140	83,86	84	248	0	81
2013-10-23 00:00:00	85,5	240000000	1130	83,84	84	881	0	81
2013-10-24 00:00:00	85,5	420000000	933	83,72	84	1125	0	81
2013-10-25 00:00:00	85,5	270000000	1140	83,82	84	1112	0	81
2013-10-26 00:00:00	85,5	120000000	1190	83,92	84	1399	0	81
2013-10-27 00:00:00	85,5	180000000	1170	83,88	84	1399	0	81

2013-10-28 00:00:00	85,5	185000000	945	83,88	84	531	0	81
2013-10-29 00:00:00	85,5	180000000	1120	83,88	84	273	0	81
2013-10-30 00:00:00	85,5	120000000	960	83,92	84	1026	0	81
2013-10-31 00:00:00	85,5	15000000	1180	83,99	84	1720	0	81
2013-11-01 00:00:00	85,5	0	1180	84	84	1570	0	81
2013-11-02 00:00:00	85,5	120000000	1585	83,92	84	1339	0	81
2013-11-03 00:00:00	85,5	165000000	1590	83,89	84	1339	0	81
2013-11-04 00:00:00	85,5	210000000	1120	83,86	84	1339	0	81
2013-11-05 00:00:00	85,5	315000000	1110	83,79	84	1339	0	81
2013-11-06 00:00:00	85,5	315000000	1120	83,79	84	386	0	81
2013-11-07 00:00:00	85,5	435000000	1100	83,71	84	908	0	81
2013-11-08 00:00:00	85,5	120000000	1120	83,92	84	1379	0	81
2013-11-09 00:00:00	85,5	120000000	1120	83,92	84	1393	0	81
2013-11-10 00:00:00	85,5	225000000	1360	83,85	84	600	0	81
2013-11-11 00:00:00	85,5	315000000	1310	83,79	84	600	0	81
2013-11-12 00:00:00	85,5	165000000	1100	83,89	84	566	0	81
2013-11-13 00:00:00	85,5	210000000	1320	83,86	84	1036	0	81
2013-11-14 00:00:00	85,5	210000000	1160	83,86	84	1339	0	81
2013-11-15 00:00:00	85,5	135000000	1160	83,91	84	1044	0	81
2013-11-16 00:00:00	85,5	210000000	1210	83,86	84	870	0	81
2013-11-17 00:00:00	85,5	255000000	1220	83,83	84	720	0	81
2013-11-18 00:00:00	85,5	0	1220	84	84	500	0	81
2013-11-19 00:00:00	85,5	375000000	1220	83,75	84	615	0	81
2013-11-20 00:00:00	85,5	510000000	1370	83,66	84	697	0	81
2013-11-21 00:00:00	85,5	570000000	1220	83,62	84	697	0	81
2013-11-22 00:00:00	85,5	585000000	1810	83,61	84	776	0	81
2013-11-23 00:00:00	85,5	480000000	1010	83,68	84	1436	0	81
2013-11-24 00:00:00	85,5	450000000	1000	83,7	84	1330	0	81
2013-11-25 00:00:00	85,5	375000000	993	83,75	84	1200	0	81
2013-11-26 00:00:00	85,5	300000000	1210	83,8	84	1242	0	81
2013-11-27 00:00:00	85,5	105000000	1210	83,93	84	1310	0	81
2013-11-28 00:00:00	85,5	105000000	1210	83,93	84	1310	0	81
2013-11-29 00:00:00	85,5	330000000	1380	83,78	84	1173	0	81
2013-11-30 00:00:00	85,5	225000000	1210	83,85	84	1100	0	81
2013-12-01 00:00:00	85,5	525000000	1060	83,65	84	1100	0	81

Date	SRL, m	Available storage, million m3	Total discharge, m3/s	Actual water level, m	NHL, m	Inflow, m3/s	Discharge through spillways, m3/s	DSL, m
				Cheboksary HPP				
2013-07-01 00:00:00	69,5	209000000	2500	63,11	63,3	2680	0	62,5
2013-07-02 00:00:00	69,5	132000000	2760	63,18	63,3	2660	0	62,5
2013-07-03 00:00:00	69,5	60000000	2210	63,23	63,3	2630	0	62,5
2013-07-04 00:00:00	69,5	88000000	2250	63,22	63,3	2620	0	62,5
2013-07-05 00:00:00	69,5	121000000	2730	63,19	63,3	2610	0	62,5
2013-07-06 00:00:00	69,5	121000000	2940	63,19	63,3	2550	0	62,5
2013-07-07 00:00:00	69,5	110000000	2290	63,2	63,3	2540	0	62,5
2013-07-08 00:00:00	69,5	465000000	2210	63,25	63,3	2530	0	62,5
2013-07-09 00:00:00	69,5	77000000	2460	63,23	63,3	2510	0	62,5
2013-07-10 00:00:00	69,5	44000000	2410	63,26	63,3	2490	0	62,5
2013-07-11 00:00:00	69,5	55000000	2430	63,25	63,3	2650	0	62,5
2013-07-12 00:00:00	69,5	110000000	2770	63,2	63,3	2480	0	62,5
2013-07-13 00:00:00	69,5	132000000	2750	63,18	63,3	2470	0	62,5
2013-07-14 00:00:00	69,5	143000000	2370	63,17	63,3	2490	0	62,5
2013-07-15 00:00:00	69,5	143000000	2410	63,17	63,3	2480	0	62,5
2013-07-16 00:00:00	69,5	209000000	2540	63,11	63,3	2470	0	62,5
2013-07-17 00:00:00	69,5	176000000	2410	63,14	63,3	2470	0	62,5
2013-07-18 00:00:00	69,5	99000000	2130	63,21	63,3	2590	0	62,5
2013-07-19 00:00:00	69,5	99000000	1820	63,21	63,3	2450	0	62,5
2013-07-20 00:00:00	69,5	176000000	2420	63,14	63,3	2430	0	62,5
2013-07-21 00:00:00	69,5	198000000	2330	63,12	63,3	2410	0	62,5
2013-07-22 00:00:00	69,5	154000000	2260	63,16	63,3	2390	0	62,5
2013-07-23 00:00:00	69,5	121000000	1990	63,19	63,3	2380	0	62,5
2013-07-24 00:00:00	69,5	895000000	2010	63,15	63,3	2340	0	DSL
2013-07-25 00:00:00	69,5	165000000	2260	63,15	63,3	2310	0	62,5
2013-07-26 00:00:00	69,5	884000000	2250	63,16	63,3	2340	0	62,5
2013-07-27 00:00:00	69,5	851000000	2290	63,19	63,3	2310	0	62,5
2013-07-28 00:00:00	69,5	807000000	2370	63,23	63,3	3040	0	62,5
2013-07-29 00:00:00	69,5	840000000	2610	63,2	63,3	2460	0	62,5
2013-07-30 00:00:00	69,5	132000000	2750	63,18	63,3	2290	0	62,5
2013-07-31 00:00:00	69,5	132000000	2570	63,18	63,3	2310	0	62,5
2013-08-01 00:00:00	69,5	132000000	2470	63,18	63,3	2330	0	62,5
2013-08-02 00:00:00	69,5	88000000	2340	63,22	63,3	2380	0	62,5
2013-08-03 00:00:00	69,5	55000000	2140	63,25	63,3	2770	0	62,5
2013-08-04 00:00:00	69,5	99000000	2380	63,21	63,3	2470	0	62,5
2013-08-05 00:00:00	69,5	88000000	2690	63,22	63,3	2480	0	62,5
2013-08-06 00:00:00	69,5	55000000	2670	63,25	63,3	2520	0	62,5
2013-08-07 00:00:00	69,5	77000000	2780	63,23	63,3	2540	0	62,5

2013-08-08 00:00:00	69,5	143000000	2910	63,17	63,3	2550	0	62,5
2013-08-09 00:00:00	69,5	165000000	2660	63,15	63,3	2290	0	62,5
2013-08-10 00:00:00	69,5	143000000	2510	63,17	63,3	2940	0	62,5
2013-08-11 00:00:00	69,5	99000000	2440	63,21	63,3	2560	0	62,5
2013-08-12 00:00:00	69,5	165000000	2520	63,15	63,3	2570	0	62,5
2013-08-13 00:00:00	69,5	110000000	2700	63,2	63,3	2280	0	62,5
2013-08-14 00:00:00	69,5	110000000	2690	63,2	63,3	2560	0	62,5
2013-08-15 00:00:00	69,5	110000000	2550	63,23	63,3	2620	0	62,5
2013-08-16 00:00:00	69,5	66000000	2530	63,24	63,3	2960	0	62,5
2013-08-17 00:00:00	69,5	88000000	2730	63,22	63,3	2470	0	62,5
2013-08-18 00:00:00	69,5	99000000	2810	63,21	63,3	2450	0	62,5
2013-08-19 00:00:00	69,5	66000000	2660	63,24	63,3	2760	0	62,5
2013-08-20 00:00:00	69,5	143000000	2640	63,17	63,3	2410	0	62,5
2013-08-21 00:00:00	69,5	176000000	2760	63,14	63,3	2410	0	62,5
2013-08-22 00:00:00	69,5	187000000	2500	63,13	63,3	2420	0	62,5
2013-08-23 00:00:00	69,5	176000000	2430	63,14	63,3	2430	0	62,5
2013-08-24 00:00:00	69,5	198000000	2860	63,12	63,3	2330	0	62,5
2013-08-25 00:00:00	69,5	231000000	1750	63,09	63,3	2320	0	62,5
2013-08-26 00:00:00	69,5	176000000	1860	63,14	63,3	2320	0	62,5
2013-08-27 00:00:00	69,5	176000000	2630	63,14	63,3	2300	0	62,5
2013-08-28 00:00:00	69,5	198000000	2320	63,12	63,3	2300	0	62,5
2013-08-29 00:00:00	69,5	165000000	2100	63,15	63,3	2330	0	62,5
2013-08-30 00:00:00	69,5	165000000	2250	63,15	63,3	2230	0	62,5
2013-08-31 00:00:00	69,5	165000000	2210	63,15	63,3	2270	0	62,5
2013-09-01 00:00:00	69,5	242000000	2130	63,08	63,3	2260	0	62,5
2013-09-02 00:00:00	69,5	154000000	2100	63,16	63,3	2250	0	62,5
2013-09-03 00:00:00	69,5	165000000	2240	63,15	63,3	2250	0	62,5
2013-09-04 00:00:00	69,5	143000000	2340	63,17	63,3	2260	0	62,5
2013-09-05 00:00:00	69,5	209000000	2200	63,11	63,3	2260	0	62,5
2013-09-06 00:00:00	69,5	231000000	2300	63,09	63,3	2280	0	62,5
2013-09-07 00:00:00	69,5	132000000	2010	63,18	63,3	2290	0	62,5
2013-09-08 00:00:00	69,5	44000000	1790	63,26	63,3	2290	0	62,5
2013-09-09 00:00:00	69,5	22000000	1880	63,28	63,3	2320	0	62,5
2013-09-10 00:00:00	69,5	66000000	2100	63,24	63,3	2350	0	62,5
2013-09-11 00:00:00	69,5	33000000	2820	63,27	63,3	2450	0	62,5
2013-09-12 00:00:00	69,5	77000000	2750	63,23	63,3	2520	0	62,5
2013-09-13 00:00:00	69,5	55000000	2990	63,25	63,3	2590	0	62,5
2013-09-14 00:00:00	69,5	66000000	3410	63,24	63,3	2670	0	62,5
2013-09-15 00:00:00	69,5	55000000	3070	63,25	63,3	3170	0	62,5
2013-09-16 00:00:00	69,5	99000000	2940	63,21	63,3	2870	0	62,5
2013-09-17 00:00:00	69,5	198000000	2820	63,12	63,3	2910	0	62,5
2013-09-18 00:00:00	69,5	99000000	3030	63,21	63,3	2980	0	62,5
2013-09-19 00:00:00	69,5	33000000	2130	63,27	63,3	3110	0	62,5

2013-09-20 00:00:00	69,5	165000000	3480	63,15	63,3	3220	0	62,5
2013-09-21 00:00:00	69,5	110000000	4170	63,2	63,3	3160	0	62,5
2013-09-22 00:00:00	69,5	110000000	3490	63,2	63,3	3160	0	62,5
2013-09-23 00:00:00	69,5	88000000	3740	63,22	63,3	3160	0	62,5
2013-09-24 00:00:00	69,5	154000000	3530	63,16	63,3	3160	0	62,5
2013-09-25 00:00:00	69,5	165000000	3500	63,15	63,3	3150	0	62,5
2013-09-26 00:00:00	69,5	33000000	2900	63,27	63,3	3170	0	62,5
2013-09-27 00:00:00	69,5	22000000	2700	63,28	63,3	3210	0	62,5
2013-09-28 00:00:00	69,5	110000000	3920	63,2	63,3	3250	0	62,5
2013-09-29 00:00:00	69,5	66000000	3750	63,24	63,3	3290	0	62,5
2013-09-30 00:00:00	69,5	77000000	3500	63,23	63,3	3070	0	62,5
2013-10-01 00:00:00	69,5	66000000	3780	63,24	63,3	3360	0	62,5
2013-10-02 00:00:00	69,5	77000000	3720	63,23	63,3	3520	0	62,5
2013-10-03 00:00:00	69,5	55000000	3830	63,25	63,3	3630	0	62,5
2013-10-04 00:00:00	69,5	110000000	4600	63,2	63,3	4700	0	62,5
2013-10-05 00:00:00	69,5	154000000	4770	63,16	63,3	3670	0	62,5
2013-10-06 00:00:00	69,5	143000000	4150	63,17	63,3	3850	0	62,5
2013-10-07 00:00:00	69,5	143000000	4020	63,17	63,3	3880	0	62,5
2013-10-08 00:00:00	69,5	143000000	4150	63,17	63,3	3920	0	62,5
2013-10-09 00:00:00	69,5	176000000	4220	63,14	63,3	3920	0	62,5
2013-10-10 00:00:00	69,5	231000000	4210	63,09	63,3	3640	0	62,5
2013-10-11 00:00:00	69,5	154000000	4060	63,16	63,3	3960	0	62,5
2013-10-12 00:00:00	69,5	231000000	3470	63,09	63,3	3890	0	62,5
2013-10-13 00:00:00	69,5	0	3660	63,3	63,3	3910	0	62,5
2013-10-14 00:00:00	69,5	0	2960	63,3	63,3	3960	0	62,5
2013-10-15 00:00:00	69,5	44000000	4510	63,26	63,3	3650	0	62,5
2013-10-16 00:00:00	69,5	165000000	4650	63,15	63,3	3300	0	62,5
2013-10-17 00:00:00	69,5	231000000	4260	63,09	63,3	3510	0	62,5
2013-10-18 00:00:00	69,5	176000000	3550	63,14	63,3	3170	0	62,5
2013-10-19 00:00:00	69,5	242000000	2880	63,08	63,3	3310	0	62,5
2013-10-20 00:00:00	69,5	77000000	2990	63,23	63,3	3140	0	62,5
2013-10-21 00:00:00	69,5	44000000	2710	63,26	63,3	3100	0	62,5
2013-10-22 00:00:00	69,5	33000000	3240	63,27	63,3	3110	0	62,5
2013-10-23 00:00:00	69,5	66000000	3320	63,24	63,3	2890	0	62,5
2013-10-24 00:00:00	69,5	77000000	3860	63,23	63,3	3090	0	62,5
2013-10-25 00:00:00	69,5	110000000	3560	63,2	63,3	3080	0	62,5
2013-10-26 00:00:00	69,5	143000000	3640	63,17	63,3	2880	0	62,5
2013-10-27 00:00:00	69,5	154000000	3670	63,16	63,3	3140	0	62,5
2013-10-28 00:00:00	69,5	198000000	3360	63,12	63,3	3140	0	62,5
2013-10-29 00:00:00	69,5	220000000	3420	63,1	63,3	3120	0	62,5
2013-10-30 00:00:00	69,5	132000000	3040	63,18	63,3	2900	0	62,5
2013-10-31 00:00:00	69,5	154000000	2810	63,16	63,3	3070	0	62,5
2013-11-01 00:00:00	69,5	99000000	2960	63,21	63,3	2910	0	62,5

2013-11-02 00:00:00	69,5	88000000	2970	63,22	63,3	3130	0	62,5
2013-11-03 00:00:00	69,5	121000000	3410	63,19	63,3	3140	0	62,5
2013-11-04 00:00:00	69,5	121000000	3330	63,19	63,3	3430	0	62,5
2013-11-05 00:00:00	69,5	55000000	2940	63,25	63,3	3430	0	62,5
2013-11-06 00:00:00	69,5	110000000	3290	63,2	63,3	3100	0	62,5
2013-11-07 00:00:00	69,5	132000000	3590	63,18	63,3	3090	0	62,5
2013-11-08 00:00:00	69,5	143000000	3320	63,17	63,3	3150	0	62,5
2013-11-09 00:00:00	69,5	33000000	3310	63,27	63,3	3140	0	62,5
2013-11-10 00:00:00	69,5	198000000	3270	63,12	63,3	3170	0	62,5
2013-11-11 00:00:00	69,5	110000000	3760	63,2	63,3	3180	0	62,5
2013-11-12 00:00:00	69,5	88000000	3600	63,22	63,3	3420	0	62,5
2013-11-13 00:00:00	69,5	99000000	3400	63,21	63,3	3360	0	62,5
2013-11-14 00:00:00	69,5	99000000	3350	63,21	63,3	3150	0	62,5
2013-11-15 00:00:00	69,5	99000000	3510	63,21	63,3	3370	0	62,5
2013-11-16 00:00:00	69,5	66000000	3520	63,24	63,3	3220	0	62,5
2013-11-17 00:00:00	69,5	77000000	3530	63,23	63,3	3300	0	62,5
2013-11-18 00:00:00	69,5	44000000	3390	63,26	63,3	3300	0	62,5
2013-11-19 00:00:00	69,5	55000000	3450	63,25	63,3	3340	0	62,5
2013-11-20 00:00:00	69,5	99000000	3890	63,21	63,3	3380	0	62,5
2013-11-21 00:00:00	69,5	154000000	3500	63,16	63,3	3410	0	62,5
2013-11-22 00:00:00	69,5	132000000	3550	63,18	63,3	3600	0	62,5
2013-11-23 00:00:00	69,5	88000000	3550	63,22	63,3	3480	0	62,5
2013-11-24 00:00:00	69,5	55000000	3680	63,25	63,3	4080	0	62,5
2013-11-25 00:00:00	69,5	132000000	3580	63,18	63,3	3290	0	62,5
2013-11-26 00:00:00	69,5	154000000	3480	63,16	63,3	3250	0	62,5
2013-11-27 00:00:00	69,5	88000000	3050	63,22	63,3	3200	0	62,5
2013-11-28 00:00:00	69,5	88000000	3050	63,22	63,3	3200	0	62,5
2013-11-29 00:00:00	69,5	55000000	3350	63,25	63,3	3330	0	62,5
2013-11-30 00:00:00	69,5	33000000	3210	63,27	63,3	3330	0	62,5

Date	SRL, m	Available storage, million m3	Total discharge, m3/s	Actual water level, m	NHL, m	Inflow, m3/s	Discharge through spillways, m3/s	DSL, m
2013-07-01 00:00:00	55,3	775000000	6676	52,87	53	6292	0	45,5
2013-07-02 00:00:00	55,3	1192000000	6396	52,8	53	5489	0	45,5
2013-07-03 00:00:00	55,3	1151000000	6566	52,84	53	5912	0	45,5
2013-07-04 00:00:00	55,3	1490000000	6219	52,75	53	5119	0	45,5
2013-07-05 00:00:00	55,3	1787000000	6209	52,7	53	5158	0	45,5
2013-07-06 00:00:00	55,3	2204000000	6253	52,63	53	5561	0	45,5
2013-07-07 00:00:00	55,3	2204000000	5957	52,63	53	5739	0	45,5
2013-07-08 00:00:00	55,3	55000000	5762	52,66	53	4644	0	45,5
2013-07-09 00:00:00	55,3	2026000000	5817	52,66	53	4521	0	45,5
2013-07-10 00:00:00	55,3	1847000000	5295	52,69	53	5521	0	45,5
2013-07-11 00:00:00	55,3	1549000000	5019	52,74	53	5046	0	45,5
2013-07-12 00:00:00	55,3	1668000000	4618	52,72	53	4945	0	45,5
2013-07-13 00:00:00	55,3	2443000000	5012	52,59	53	5413	0	45,5
2013-07-14 00:00:00	55,3	2085000000	4444	52,65	53	5614	0	45,5
2013-07-15 00:00:00	55,3	2085000000	4556	52,65	53	4572	0	45,5
2013-07-16 00:00:00	55,3	1966000000	4749	52,67	53	4585	0	45,5
2013-07-17 00:00:00	55,3	2085000000	4888	52,65	53	5543	0	45,5
2013-07-18 00:00:00	55,3	1490000000	4749	52,75	53	5204	0	45,5
2013-07-19 00:00:00	55,3	1728000000	4611	52,71	53	4668	0	45,5
2013-07-20 00:00:00	55,3	2383000000	4713	52,6	53	4357	0	45,5
2013-07-21 00:00:00	55,3	2502000000	4703	52,58	53	4357	0	45,5
2013-07-22 00:00:00	55,3	2145000000	4271	52,64	53	4208	0	45,5
2013-07-23 00:00:00	55,3	2324000000	5198	52,61	53	4193	0	45,5
2013-07-24 00:00:00	55,3	2422000000	5506	52,6	53	4427	0	45,5
2013-07-25 00:00:00	55,3	2443000000	5702	52,59	53	4707	0	45,5
2013-07-26 00:00:00	55,3	2839000000	6108	52,53	53	5154	0	45,5
2013-07-27 00:00:00	55,3	3316000000	6066	52,45	53	5191	0	45,5
2013-07-28 00:00:00	55,3	3018000000	6128	52,5	53	5310	0	45,5
2013-07-29 00:00:00	55,3	2899000000	5988	52,52	53	4240	0	45,5
2013-07-30 00:00:00	55,3	2681000000	6147	52,55	53	4475	0	45,5
2013-07-31 00:00:00	55,3	2502000000	4838	52,58	53	5539	0	45,5
2013-08-01 00:00:00	55,3	2979000000	4773	52,5	53	5412	0	45,5
2013-08-02 00:00:00	55,3	2324000000	4742	52,61	53	5721	0	45,5
2013-08-03 00:00:00	55,3	2681000000	4742	52,55	53	5100	0	45,5
2013-08-04 00:00:00	55,3	2979000000	4470	52,5	53	4810	0	45,5
2013-08-05 00:00:00	55,3	2562000000	4518	52,57	53	4601	0	45,5
2013-08-06 00:00:00	55,3	2145000000	4609	52,64	53	4980	0	45,5

2013-08-07 00:00:00	55,3	1907000000	4825	52,68	53	5598	0	45,5
2013-08-08 00:00:00	55,3	2085000000	4896	52,65	53	5565	0	45,5
2013-08-09 00:00:00	55,3	2026000000	4786	52,66	53	5692	0	45,5
2013-08-10 00:00:00	55,3	2860000000	4865	52,52	53	5448	0	45,5
2013-08-11 00:00:00	55,3	3277000000	4505	52,45	53	5425	0	45,5
2013-08-12 00:00:00	55,3	2383000000	4125	52,6	53	4368	0	45,5
2013-08-13 00:00:00	55,3	2562000000	5117	52,57	53	4409	0	45,5
2013-08-14 00:00:00	55,3	2443000000	5366	52,59	53	5607	0	45,5
2013-08-15 00:00:00	55,3	2443000000	5291	52,54	53	5619	0	45,5
2013-08-16 00:00:00	55,3	2681000000	5273	52,55	53	5522	0	45,5
2013-08-17 00:00:00	55,3	2800000000	5516	52,53	53	5563	0	45,5
2013-08-18 00:00:00	55,3	2502000000	4798	52,58	53	5776	0	45,5
2013-08-19 00:00:00	55,3	2145000000	4902	52,64	53	4951	0	45,5
2013-08-20 00:00:00	55,3	2145000000	5607	52,64	53	4493	0	45,5
2013-08-21 00:00:00	55,3	2502000000	5486	52,58	53	5391	0	45,5
2013-08-22 00:00:00	55,3	2502000000	5662	52,58	53	5535	0	45,5
2013-08-23 00:00:00	55,3	2622000000	5195	52,56	53	5360	0	45,5
2013-08-24 00:00:00	55,3	3277000000	5206	52,45	53	5314	0	45,5
2013-08-25 00:00:00	55,3	3277000000	4496	52,45	53	5743	0	45,5
2013-08-26 00:00:00	55,3	2502000000	3602	52,58	53	3825	0	45,5
2013-08-27 00:00:00	55,3	2026000000	5094	52,66	53	3900	0	45,5
2013-08-28 00:00:00	55,3	2860000000	5304	52,52	53	5495	0	45,5
2013-08-29 00:00:00	55,3	3098000000	5477	52,48	53	5063	0	45,5
2013-08-30 00:00:00	55,3	3515000000	5597	52,41	53	4679	0	45,5
2013-08-31 00:00:00	55,3	3873000000	5414	52,35	53	4543	0	45,5
2013-09-01 00:00:00	55,3	4766000000	5725	52,2	53	4500	0	45,5
2013-09-02 00:00:00	55,3	4826000000	5420	52,19	53	4349	0	45,5
2013-09-03 00:00:00	55,3	4290000000	4939	52,28	53	3632	0	45,5
2013-09-04 00:00:00	55,3	4051000000	5917	52,32	53	4786	0	45,5
2013-09-05 00:00:00	55,3	4171000000	5809	52,3	53	4902	0	45,5
2013-09-06 00:00:00	55,3	4171000000	5706	52,3	53	4633	0	45,5
2013-09-07 00:00:00	55,3	5005000000	5706	52,16	53	4633	0	45,5
2013-09-08 00:00:00	55,3	4826000000	5209	52,19	53	4756	0	45,5
2013-09-09 00:00:00	55,3	4469000000	5048	52,25	53	3843	0	45,5
2013-09-10 00:00:00	55,3	4051000000	5561	52,32	53	3450	0	45,5
2013-09-11 00:00:00	55,3	3158000000	5554	52,47	53	4829	0	45,5
2013-09-12 00:00:00	55,3	4409000000	4936	52,26	53	5241	0	45,5
2013-09-13 00:00:00	55,3	4349000000	4867	52,27	53	5188	0	45,5
2013-09-14 00:00:00	55,3	4588000000	5102	52,23	53	5475	0	45,5
2013-09-15 00:00:00	55,3	4111000000	4374	52,31	53	5904	0	45,5
2013-09-16 00:00:00	55,3	4588000000	4300	52,23	53	4682	0	45,5
2013-09-17 00:00:00	55,3	4826000000	4526	52,19	53	4542	0	45,5
2013-09-18 00:00:00	55,3	4469000000	4950	52,25	53	5391	0	45,5

2013-09-19 00:00:00	55,3	4409000000	5020	52,26	53	5610	0	45,5
2013-09-20 00:00:00	55,3	5064000000	4567	52,15	53	4719	0	45,5
2013-09-21 00:00:00	55,3	5362000000	4634	52,1	53	6062	0	45,5
2013-09-22 00:00:00	55,3	4826000000	4035	52,19	53	6839	0	45,5
2013-09-23 00:00:00	55,3	4171000000	3060	52,3	53	5815	0	45,5
2013-09-24 00:00:00	55,3	4290000000	4411	52,28	53	5846	0	45,5
2013-09-25 00:00:00	55,3	4469000000	4717	52,25	53	6257	0	45,5
2013-09-26 00:00:00	55,3	3694000000	5200	52,38	53	5957	0	45,5
2013-09-27 00:00:00	55,3	3932000000	5679	52,34	53	5355	0	45,5
2013-09-28 00:00:00	55,3	4588000000	5769	52,23	53	5174	0	45,5
2013-09-29 00:00:00	55,3	5124000000	5312	52,14	53	6414	0	45,5
2013-09-30 00:00:00	55,3	3932000000	4627	52,34	53	5344	0	45,5
2013-10-01 00:00:00	55,3	3575000000	5164	52,4	53	5322	0	45,5
2013-10-02 00:00:00	55,3	3456000000	5285	52,42	53	6284	0	45,5
2013-10-03 00:00:00	55,3	2860000000	5647	52,52	53	6254	0	45,5
2013-10-04 00:00:00	55,3	2324000000	4843	52,61	53	6394	0	45,5
2013-10-05 00:00:00	55,3	2681000000	5086	52,55	53	6383	0	45,5
2013-10-06 00:00:00	55,3	2860000000	5079	52,52	53	7159	0	45,5
2013-10-07 00:00:00	55,3	3694000000	4991	52,38	53	6047	0	45,5
2013-10-08 00:00:00	55,3	3277000000	5589	52,45	53	5947	0	45,5
2013-10-09 00:00:00	55,3	2443000000	5656	52,59	53	6915	0	45,5
2013-10-10 00:00:00	55,3	3217000000	5810	52,46	53	6775	0	45,5
2013-10-11 00:00:00	55,3	2622000000	5447	52,56	53	6659	0	45,5
2013-10-12 00:00:00	55,3	3336000000	6067	52,44	53	6833	0	45,5
2013-10-13 00:00:00	55,3	2979000000	5200	52,5	53	6606	0	45,5
2013-10-14 00:00:00	55,3	1728000000	4967	52,71	53	5638	0	45,5
2013-10-15 00:00:00	55,3	2562000000	4774	52,57	53	4966	0	45,5
2013-10-16 00:00:00	55,3	3039000000	4857	52,49	53	7358	0	45,5
2013-10-17 00:00:00	55,3	2383000000	5186	52,6	53	6926	0	45,5
2013-10-18 00:00:00	55,3	1490000000	5045	52,75	53	6694	0	45,5
2013-10-19 00:00:00	55,3	2383000000	5342	52,6	53	5915	0	45,5
2013-10-20 00:00:00	55,3	1668000000	4991	52,72	53	5509	0	45,5
2013-10-21 00:00:00	55,3	2860000000	4732	52,52	53	4853	0	45,5
2013-10-22 00:00:00	55,3	1787000000	5198	52,7	53	4621	0	45,5
2013-10-23 00:00:00	55,3	1907000000	5125	52,68	53	6034	0	45,5
2013-10-24 00:00:00	55,3	3039000000	5346	52,49	53	6102	0	45,5
2013-10-25 00:00:00	55,3	2502000000	5422	52,58	53	6738	0	45,5
2013-10-26 00:00:00	55,3	2383000000	4685	52,6	53	7026	0	45,5
2013-10-27 00:00:00	55,3	2026000000	4749	52,66	53	6623	0	45,5
2013-10-28 00:00:00	55,3	1132000000	4160	52,81	53	5823	0	45,5
2013-10-29 00:00:00	55,3	1251000000	4905	52,79	53	5468	0	45,5
2013-10-30 00:00:00	55,3	1430000000	5215	52,76	53	6176	0	45,5
2013-10-31 00:00:00	55,3	1192000000	5227	52,8	53	6096	0	45,5

2013-11-01 00:00:00	55,3	894000000	6241	52,85	53	5871	0	45,5
2013-11-02 00:00:00	55,3	1787000000	6418	52,7	53	6212	0	45,5
2013-11-03 00:00:00	55,3	2085000000	6482	52,65	53	6034	0	45,5
2013-11-04 00:00:00	55,3	1907000000	6304	52,68	53	5728	0	45,5
2013-11-05 00:00:00	55,3	1847000000	6550	52,69	53	5686	0	45,5
2013-11-06 00:00:00	55,3	1728000000	6684	52,71	53	5345	0	45,5
2013-11-07 00:00:00	55,3	1847000000	6540	52,69	53	6488	0	45,5
2013-11-08 00:00:00	55,3	2264000000	6449	52,62	53	7114	0	45,5
2013-11-09 00:00:00	55,3	2562000000	6499	52,57	53	7156	0	45,5
2013-11-10 00:00:00	55,3	1787000000	7239	52,7	53	7447	0	45,5
2013-11-11 00:00:00	55,3	2085000000	6540	52,65	53	5759	0	45,5
2013-11-12 00:00:00	55,3	2026000000	6950	52,66	53	6207	0	45,5
2013-11-13 00:00:00	55,3	1311000000	6404	52,78	53	7624	0	45,5
2013-11-14 00:00:00	55,3	1430000000	6058	52,76	53	6672	0	45,5
2013-11-15 00:00:00	55,3	1192000000	6020	52,8	53	6556	0	45,5
2013-11-16 00:00:00	55,3	1370000000	6166	52,77	53	6823	0	45,5
2013-11-17 00:00:00	55,3	2026000000	6389	52,66	53	7432	0	45,5
2013-11-18 00:00:00	55,3	2324000000	6632	52,61	53	7058	0	45,5
2013-11-19 00:00:00	55,3	179000000	6834	52,97	53	6721	0	45,5
2013-11-20 00:00:00	55,3	1668000000	5960	52,72	53	7931	0	45,5
2013-11-21 00:00:00	55,3	1787000000	5793	52,7	53	7118	0	45,5
2013-11-22 00:00:00	55,3	1668000000	5789	52,72	53	6772	0	45,5
2013-11-23 00:00:00	55,3	1907000000	5789	52,68	53	6805	0	45,5
2013-11-24 00:00:00	55,3	1430000000	5565	52,76	53	6773	0	45,5
2013-11-25 00:00:00	55,3	775000000	5681	52,87	53	6842	0	45,5
2013-11-26 00:00:00	55,3	715000000	5663	52,88	53	6552	0	45,5
2013-11-27 00:00:00	55,3	715000000	6056	52,88	53	7097	0	45,5
2013-11-28 00:00:00	55,3	715000000	6056	52,88	53	7097	0	45,5
2013-11-29 00:00:00	55,3	1251000000	6745	52,79	53	6714	0	45,5
2013-11-30 00:00:00	55,3	1192000000	6129	52,8	53	6890	0	45,5

Date	SRL, m	Available storage, million m3	Total discharge, m3/s	Actual water level, m	NHL, m	Inflow, m3/s	Discharge through spillways, m3/s	DSL, m
Saratov HPP								
2013-07-01 00:00:00	31,4	113000000	6710	28,06	28	6810	0	27
2013-07-02 00:00:00	31,4	144000000	6911	27,92	28	6530	0	27
2013-07-03 00:00:00	31,4	315000000	7365	27,83	28	6698	0	27
2013-07-04 00:00:00	31,4	162000000	6980	27,91	28	6346	0	27
2013-07-05 00:00:00	31,4	252000000	6779	27,86	28	6336	0	27
2013-07-06 00:00:00	31,4	306000000	6510	27,83	28	6379	0	27
2013-07-07 00:00:00	31,4	54000000	6040	27,97	28	6080	0	27
2013-07-08 00:00:00	31,4	2026000000	5759	27,78	28	5884	0	27
2013-07-09 00:00:00	31,4	288000000	6427	27,84	28	5926	0	27
2013-07-10 00:00:00	31,4	216000000	5923	27,88	28	5417	0	27
2013-07-11 00:00:00	31,4	378000000	6002	27,79	28	5137	0	27
2013-07-12 00:00:00	31,4	468000000	6061	27,74	28	4732	0	27
2013-07-13 00:00:00	31,4	324000000	5262	27,82	28	5126	0	27
2013-07-14 00:00:00	31,4	378000000	4099	27,79	28	4558	0	27
2013-07-15 00:00:00	31,4	108000000	4093	27,94	28	4673	0	27
2013-07-16 00:00:00	31,4	270000000	4563	27,85	28	4961	0	27
2013-07-17 00:00:00	31,4	288000000	4472	27,84	28	5000	0	27
2013-07-18 00:00:00	31,4	270000000	5371	27,85	28	4863	0	27
2013-07-19 00:00:00	31,4	216000000	5464	27,88	28	4871	0	27
2013-07-20 00:00:00	31,4	234000000	5668	27,87	28	4829	0	27
2013-07-21 00:00:00	31,4	270000000	4705	27,85	28	4471	0	27
2013-07-22 00:00:00	31,4	414000000	4437	27,77	28	4318	0	27
2013-07-23 00:00:00	31,4	522000000	6323	27,71	28	5304	0	27
2013-07-24 00:00:00	31,4	486000000	6472	27,73	28	5611	0	27
2013-07-25 00:00:00	31,4	522000000	5657	27,71	28	5806	0	27
2013-07-26 00:00:00	31,4	378000000	5622	27,79	28	6212	0	27
2013-07-27 00:00:00	31,4	378000000	5419	27,79	28	6170	0	27
2013-07-28 00:00:00	31,4	234000000	5009	27,87	28	6232	0	27
2013-07-29 00:00:00	31,4	162000000	5183	27,91	28	6092	0	27
2013-07-30 00:00:00	31,4	126000000	6474	27,93	28	6251	0	27
2013-07-31 00:00:00	31,4	54000000	4346	27,97	28	4942	0	27
2013-08-01 00:00:00	31,4	540000000	5871	27,7	28	4877	0	27
2013-08-02 00:00:00	31,4	486000000	6702	27,73	28	4846	0	27
2013-08-03 00:00:00	31,4	486000000	6233	27,73	28	4432	0	27
2013-08-04 00:00:00	31,4	324000000	4480	27,82	28	4576	0	27
2013-08-05 00:00:00	31,4	198000000	4067	27,89	28	4624	0	27
2013-08-06 00:00:00	31,4	216000000	4971	27,88	28	4714	0	27
2013-08-07 00:00:00	31,4	216000000	5019	27,88	28	4931	0	27

2013-08-08 00:00:00	31,4	270000000	7816	27,85	28	5000	0	27
2013-08-09 00:00:00	31,4	324000000	5413	27,82	28	4891	0	27
2013-08-10 00:00:00	31,4	378000000	5903	27,79	28	4953	0	27
2013-08-11 00:00:00	31,4	504000000	4768	27,72	28	4612	0	27
2013-08-12 00:00:00	31,4	522000000	4182	27,71	28	4231	0	27
2013-08-13 00:00:00	31,4	468000000	5698	27,74	28	5226	0	27
2013-08-14 00:00:00	31,4	342000000	4108	27,81	28	5474	0	27
2013-08-15 00:00:00	31,4	342000000	4901	27,81	28	5291	0	27
2013-08-16 00:00:00	31,4	594000000	5903	27,67	28	5381	0	27
2013-08-17 00:00:00	31,4	468000000	6600	27,74	28	5624	0	27
2013-08-18 00:00:00	31,4	306000000	5098	27,83	28	4906	0	27
2013-08-19 00:00:00	31,4	108000000	3078	27,94	28	4902	0	27
2013-08-20 00:00:00	31,4	126000000	4810	27,93	28	5607	0	27
2013-08-21 00:00:00	31,4	180000000	5292	27,9	28	5486	0	27
2013-08-22 00:00:00	31,4	162000000	5151	27,91	28	5767	0	27
2013-08-23 00:00:00	31,4	216000000	5204	27,88	28	5300	0	27
2013-08-24 00:00:00	31,4	54000000	5467	27,97	28	5310	0	27
2013-08-25 00:00:00	31,4	0	4735	28	28	4660	0	27
2013-08-26 00:00:00	31,4	126000000	4680	27,93	28	3706	0	27
2013-08-27 00:00:00	31,4	144000000	6121	27,92	28	5194	0	27
2013-08-28 00:00:00	31,4	342000000	6302	27,81	28	5404	0	27
2013-08-29 00:00:00	31,4	486000000	6220	27,73	28	5577	0	27
2013-08-30 00:00:00	31,4	522000000	6308	27,71	28	5697	0	27
2013-08-31 00:00:00	31,4	558000000	6201	27,69	28	5514	0	27
2013-09-01 00:00:00	31,4	576000000	5800	27,68	28	5805	0	27
2013-09-02 00:00:00	31,4	522000000	5508	27,71	28	5442	0	27
2013-09-03 00:00:00	31,4	630000000	5928	27,65	28	5024	0	27
2013-09-04 00:00:00	31,4	486000000	6259	27,73	28	6007	0	27
2013-09-05 00:00:00	31,4	450000000	6002	27,75	28	5907	0	27
2013-09-06 00:00:00	31,4	450000000	5240	27,75	28	5804	0	27
2013-09-07 00:00:00	31,4	414000000	5240	27,77	28	5804	0	27
2013-09-08 00:00:00	31,4	234000000	4965	27,87	28	5305	0	27
2013-09-09 00:00:00	31,4	252000000	4559	27,86	28	5144	0	27
2013-09-10 00:00:00	31,4	144000000	5558	27,92	28	5640	0	27
2013-09-11 00:00:00	31,4	72000000	5759	27,96	28	5649	0	27
2013-09-12 00:00:00	31,4	216000000	6017	27,88	28	5032	0	27
2013-09-13 00:00:00	31,4	360000000	6481	27,8	28	4966	0	27
2013-09-14 00:00:00	31,4	396000000	5812	27,78	28	5190	0	27
2013-09-15 00:00:00	31,4	360000000	4408	27,8	28	4482	0	27
2013-09-16 00:00:00	31,4	324000000	4033	27,82	28	4408	0	27
2013-09-17 00:00:00	31,4	360000000	5712	27,8	28	4636	0	27
2013-09-18 00:00:00	31,4	288000000	5085	27,84	28	5059	0	27
2013-09-19 00:00:00	31,4	360000000	5301	27,8	28	5129	0	27

2013-09-20 00:00:00	31,4	306000000	4823	27,83	28	4676	0	27
2013-09-21 00:00:00	31,4	378000000	4557	27,79	28	4743	0	27
2013-09-22 00:00:00	31,4	288000000	3922	27,84	28	4132	0	27
2013-09-23 00:00:00	31,4	432000000	3587	27,76	28	3146	0	27
2013-09-24 00:00:00	31,4	432000000	4672	27,76	28	4517	0	27
2013-09-25 00:00:00	31,4	934000000	5869	27,48	28	4833	0	27
2013-09-26 00:00:00	31,4	630000000	5522	27,65	28	5294	0	27
2013-09-27 00:00:00	31,4	540000000	5550	27,7	28	5780	0	27
2013-09-28 00:00:00	31,4	1019000000	5458	27,43	28	5869	0	27
2013-09-29 00:00:00	31,4	324000000	4221	27,82	28	5412	0	27
2013-09-30 00:00:00	31,4	360000000	3879	27,8	28	4727	0	27
2013-10-01 00:00:00	31,4	396000000	5435	27,78	28	5265	0	27
2013-10-02 00:00:00	31,4	324000000	5881	27,82	28	5387	0	27
2013-10-03 00:00:00	31,4	113000000	5439	28,06	28	5749	0	27
2013-10-04 00:00:00	31,4	0	5288	28	28	4937	0	27
2013-10-05 00:00:00	31,4	36000000	5596	27,98	28	5192	0	27
2013-10-06 00:00:00	31,4	90000000	4972	27,95	28	5185	0	27
2013-10-07 00:00:00	31,4	468000000	5182	27,74	28	5097	0	27
2013-10-08 00:00:00	31,4	396000000	5995	27,78	28	5695	0	27
2013-10-09 00:00:00	31,4	378000000	5889	27,79	28	5764	0	27
2013-10-10 00:00:00	31,4	468000000	6225	27,74	28	5920	0	27
2013-10-11 00:00:00	31,4	468000000	6279	27,74	28	5458	0	27
2013-10-12 00:00:00	31,4	270000000	6530	27,85	28	6176	0	27
2013-10-13 00:00:00	31,4	108000000	4457	27,94	28	5308	0	27
2013-10-14 00:00:00	31,4	234000000	3961	27,87	28	5048	0	27
2013-10-15 00:00:00	31,4	0	5329	28	28	4873	0	27
2013-10-16 00:00:00	31,4	216000000	5903	27,88	28	4954	0	27
2013-10-17 00:00:00	31,4	684000000	6285	27,62	28	5295	0	27
2013-10-18 00:00:00	31,4	450000000	6494	27,75	28	5154	0	27
2013-10-19 00:00:00	31,4	252000000	5742	27,86	28	5449	0	27
2013-10-20 00:00:00	31,4	0	4414	28	28	5100	0	27
2013-10-21 00:00:00	31,4	360000000	3972	27,8	28	4841	0	27
2013-10-22 00:00:00	31,4	270000000	5415	27,85	28	5307	0	27
2013-10-23 00:00:00	31,4	252000000	5698	27,86	28	5234	0	27
2013-10-24 00:00:00	31,4	198000000	5851	27,89	28	5455	0	27
2013-10-25 00:00:00	31,4	198000000	5803	27,89	28	5531	0	27
2013-10-26 00:00:00	31,4	396000000	6432	27,78	28	4792	0	27
2013-10-27 00:00:00	31,4	378000000	3407	27,79	28	4854	0	27
2013-10-28 00:00:00	31,4	612000000	5103	27,66	28	4262	0	27
2013-10-29 00:00:00	31,4	468000000	6159	27,74	28	5009	0	27
2013-10-30 00:00:00	31,4	756000000	5380	27,58	28	5316	0	27
2013-10-31 00:00:00	31,4	540000000	5578	27,7	28	5335	0	27
2013-11-01 00:00:00	31,4	540000000	3795	27,7	28	6349	0	27

2013-11-02 00:00:00	31,4	432000000	5628	27,76	28	6526	0	27
2013-11-03 00:00:00	31,4	270000000	5500	27,85	28	6590	0	27
2013-11-04 00:00:00	31,4	234000000	6165	27,87	28	6412	0	27
2013-11-05 00:00:00	31,4	270000000	6670	27,85	28	6629	0	27
2013-11-06 00:00:00	31,4	216000000	6990	27,88	28	6792	0	27
2013-11-07 00:00:00	31,4	198000000	6862	27,89	28	6648	0	27
2013-11-08 00:00:00	31,4	234000000	7616	27,87	28	6558	0	27
2013-11-09 00:00:00	31,4	252000000	7175	27,86	28	6609	0	27
2013-11-10 00:00:00	31,4	18000000	6273	27,99	28	7352	0	27
2013-11-11 00:00:00	31,4	54000000	5732	27,97	28	6652	0	27
2013-11-12 00:00:00	31,4	132000000	6912	28,07	28	7061	0	27
2013-11-13 00:00:00	31,4	301000000	6000	28,16	28	6415	0	27
2013-11-14 00:00:00	31,4	301000000	6603	28,16	28	6169	0	27
2013-11-15 00:00:00	31,4	169000000	7303	28,09	28	6126	0	27
2013-11-16 00:00:00	31,4	94000000	7771	28,05	28	6268	0	27
2013-11-17 00:00:00	31,4	108000000	6598	27,94	28	6485	0	27
2013-11-18 00:00:00	31,4	108000000	6744	27,94	28	6726	0	27
2013-11-19 00:00:00	31,4	75000000	7713	28,04	28	6929	0	27
2013-11-20 00:00:00	31,4	108000000	6928	27,94	28	6055	0	27
2013-11-21 00:00:00	31,4	108000000	7061	27,94	28	5888	0	27
2013-11-22 00:00:00	31,4	90000000	7106	27,95	28	5884	0	27
2013-11-23 00:00:00	31,4	19000000	6645	28,01	28	5582	0	27
2013-11-24 00:00:00	31,4	56000000	5657	28,03	28	5577	0	27
2013-11-25 00:00:00	31,4	0	5502	28	28	5773	0	27
2013-11-26 00:00:00	31,4	75000000	6420	28,04	28	5753	0	27
2013-11-27 00:00:00	31,4	234000000	6562	27,87	28	6146	0	27
2013-11-28 00:00:00	31,4	234000000	6562	27,87	28	6146	0	27
2013-11-29 00:00:00	31,4	432000000	7171	27,76	28	6834	0	27
2013-11-30 00:00:00	31,4	342000000	6700	27,81	28	6220	0	27

Date	SRL, m	Available storage, million m3	Total discharge, m3/s	Actual water level, m	NHL, m	Inflow, m3/s	Discharge through spillways, m3/s	DSL, m
				Volga HPP				
2013-07-01 00:00:00	16,3	293000000	7713	15,09	15	6810	0	12
2013-07-02 00:00:00	16,3	65000000	7830	15,02	15	6931	0	12
2013-07-03 00:00:00	16,3	19000000	7500	14,85	15	7400	0	12
2013-07-04 00:00:00	16,3	60000000	7730	14,98	15	7000	0	12
2013-07-05 00:00:00	16,3	65000000	6700	15,02	15	6799	0	12
2013-07-06 00:00:00	16,3	89000000	6200	14,97	15	6600	0	12
2013-07-07 00:00:00	16,3	328000000	6200	14,89	15	6600	0	12
2013-07-08 00:00:00	16,3	396000000	5110	14,95	15	5779	0	12
2013-07-09 00:00:00	16,3	238000000	6110	14,92	15	6527	0	12
2013-07-10 00:00:00	16,3	119000000	5930	14,96	15	5943	0	12
2013-07-11 00:00:00	16,3	238000000	6130	14,92	15	6022	0	12
2013-07-12 00:00:00	16,3	238000000	5430	14,92	15	6081	0	12
2013-07-13 00:00:00	16,3	268000000	5400	14,91	15	5300	0	12
2013-07-14 00:00:00	16,3	298000000	5400	14,9	15	4100	0	12
2013-07-15 00:00:00	16,3	298000000	5090	14,9	15	4113	0	12
2013-07-16 00:00:00	16,3	358000000	5340	14,88	15	4563	0	12
2013-07-17 00:00:00	16,3	596000000	5330	14,8	15	4572	0	12
2013-07-18 00:00:00	16,3	656000000	5390	14,78	15	5400	0	12
2013-07-19 00:00:00	16,3	536000000	5340	14,82	15	5484	0	12
2013-07-20 00:00:00	16,3	1073000000	5200	14,64	15	5768	0	12
2013-07-21 00:00:00	16,3	894000000	5200	14,7	15	5660	0	12
2013-07-22 00:00:00	16,3	954000000	4900	14,68	15	4457	0	12
2013-07-23 00:00:00	16,3	1013000000	5340	14,66	15	6343	0	12
2013-07-24 00:00:00	16,3	904000000	5240	14,69	15	6492	0	12
2013-07-25 00:00:00	16,3	834000000	5260	14,72	15	5677	0	12
2013-07-26 00:00:00	16,3	606000000	5260	14,79	15	5642	0	12
2013-07-27 00:00:00	16,3	844000000	5200	14,71	15	5642	0	12
2013-07-28 00:00:00	16,3	814000000	5200	14,72	15	5642	0	12
2013-07-29 00:00:00	16,3	725000000	4950	14,75	15	5203	0	12
2013-07-30 00:00:00	16,3	715000000	5350	14,76	15	5603	0	12
2013-07-31 00:00:00	16,3	656000000	5270	14,78	15	4366	0	12
2013-08-01 00:00:00	16,3	685000000	5400	14,77	15	5971	0	12
2013-08-02 00:00:00	16,3	805000000	5260	14,73	15	6722	0	12
2013-08-03 00:00:00	16,3	745000000	5200	14,75	15	6300	0	12
2013-08-04 00:00:00	16,3	834000000	5200	14,72	15	4500	0	12
2013-08-05 00:00:00	16,3	626000000	4880	14,79	15	4087	0	12
2013-08-06 00:00:00	16,3	447000000	5240	14,85	15	4991	0	12
2013-08-07 00:00:00	16,3	715000000	5470	14,76	15	5039	0	12

2013-08-08 00:00:00	16,3	805000000	5390	14,73	15	6800	0	12
2013-08-09 00:00:00	16,3	805000000	5310	14,73	15	5500	0	12
2013-08-10 00:00:00	16,3	983000000	5400	14,67	15	5910	0	12
2013-08-11 00:00:00	16,3	1043000000	5400	14,65	15	4800	0	12
2013-08-12 00:00:00	16,3	924000000	5120	14,69	15	4202	0	12
2013-08-13 00:00:00	16,3	805000000	4940	14,73	15	5718	0	12
2013-08-14 00:00:00	16,3	954000000	5120	14,68	15	4128	0	12
2013-08-15 00:00:00	16,3	954000000	5160	14,69	15	4921	0	12
2013-08-16 00:00:00	16,3	1073000000	5150	14,64	15	5923	0	12
2013-08-17 00:00:00	16,3	1043000000	5150	14,65	15	6750	0	12
2013-08-18 00:00:00	16,3	358000000	5200	14,88	15	5100	0	12
2013-08-19 00:00:00	16,3	1132000000	4870	14,62	15	3098	0	12
2013-08-20 00:00:00	16,3	894000000	4700	14,7	15	3078	0	12
2013-08-21 00:00:00	16,3	805000000	5180	14,73	15	5312	0	12
2013-08-22 00:00:00	16,3	1043000000	5220	14,65	15	5171	0	12
2013-08-23 00:00:00	16,3	1013000000	5270	14,66	15	5224	0	12
2013-08-24 00:00:00	16,3	1013000000	5270	14,66	15	5224	0	12
2013-08-25 00:00:00	16,3	1252000000	5270	14,58	15	5000	0	12
2013-08-26 00:00:00	16,3	1192000000	5140	14,6	15	4700	0	12
2013-08-27 00:00:00	16,3	1311000000	5290	14,56	15	6141	0	12
2013-08-28 00:00:00	16,3	1192000000	5120	14,6	15	6302	0	12
2013-08-29 00:00:00	16,3	1341000000	5020	14,55	15	6240	0	12
2013-08-30 00:00:00	16,3	1281000000	5070	14,57	15	6328	0	12
2013-08-31 00:00:00	16,3	1252000000	5100	14,58	15	6201	0	12
2013-09-01 00:00:00	16,3	1311000000	5100	14,56	15	5900	0	12
2013-09-02 00:00:00	16,3	1162000000	4870	14,61	15	5528	0	12
2013-09-03 00:00:00	16,3	1013000000	5040	14,66	15	6028	0	12
2013-09-04 00:00:00	16,3	1103000000	5120	14,63	15	6528	0	12
2013-09-05 00:00:00	16,3	805000000	5040	14,73	15	6022	0	12
2013-09-06 00:00:00	16,3	983000000	5230	14,67	15	5260	0	12
2013-09-07 00:00:00	16,3	1132000000	5230	14,62	15	5260	0	12
2013-09-08 00:00:00	16,3	1073000000	5100	14,64	15	5000	0	12
2013-09-09 00:00:00	16,3	924000000	5010	14,69	15	4579	0	12
2013-09-10 00:00:00	16,3	745000000	4990	14,75	15	5600	0	12
2013-09-11 00:00:00	16,3	1013000000	5060	14,66	15	5779	0	12
2013-09-12 00:00:00	16,3	656000000	4980	14,78	15	0	0	12
2013-09-13 00:00:00	16,3	745000000	5000	14,75	15	6501	0	12
2013-09-14 00:00:00	16,3	656000000	5000	14,78	15	5912	0	12
2013-09-15 00:00:00	16,3	656000000	5000	14,78	15	4900	0	12
2013-09-16 00:00:00	16,3	596000000	4810	14,8	15	4053	0	12
2013-09-17 00:00:00	16,3	507000000	4930	14,83	15	5732	0	12
2013-09-18 00:00:00	16,3	119000000	5020	14,96	15	5105	0	12
2013-09-19 00:00:00	16,3	268000000	5150	14,91	15	5321	0	12

2013-09-20 00:00:00	16,3	685000000	4910	14,77	15	4843	0	12
2013-09-21 00:00:00	16,3	864000000	5000	14,71	15	4700	0	12
2013-09-22 00:00:00	16,3	924000000	5000	14,69	15	4022	0	12
2013-09-23 00:00:00	16,3	1013000000	4800	14,66	15	4022	0	12
2013-09-24 00:00:00	16,3	1848000000	4990	14,38	15	4692	0	12
2013-09-25 00:00:00	16,3	1579000000	5030	14,47	15	5889	0	12
2013-09-26 00:00:00	16,3	1013000000	5080	14,66	15	5522	0	12
2013-09-27 00:00:00	16,3	1073000000	4960	14,64	15	5570	0	12
2013-09-28 00:00:00	16,3	1937000000	5010	14,35	15	5460	0	12
2013-09-29 00:00:00	16,3	1043000000	5000	14,65	15	4221	0	12
2013-09-30 00:00:00	16,3	834000000	4810	14,72	15	3899	0	12
2013-10-01 00:00:00	16,3	894000000	4890	14,7	15	5455	0	12
2013-10-02 00:00:00	16,3	596000000	4940	14,8	15	5901	0	12
2013-10-03 00:00:00	16,3	196000000	4850	15,06	15	5459	0	12
2013-10-04 00:00:00	16,3	149000000	4890	14,95	15	5288	0	12
2013-10-05 00:00:00	16,3	596000000	4900	14,8	15	5600	0	12
2013-10-06 00:00:00	16,3	924000000	5000	14,69	15	5600	0	12
2013-10-07 00:00:00	16,3	834000000	5090	14,72	15	5202	0	12
2013-10-08 00:00:00	16,3	1073000000	5450	14,64	15	6015	0	12
2013-10-09 00:00:00	16,3	924000000	5270	14,69	15	5909	0	12
2013-10-10 00:00:00	16,3	864000000	5340	14,71	15	6245	0	12
2013-10-11 00:00:00	16,3	507000000	5290	14,83	15	6299	0	12
2013-10-12 00:00:00	16,3	745000000	5300	14,75	15	6299	0	12
2013-10-13 00:00:00	16,3	358000000	5300	14,88	15	4697	0	12
2013-10-14 00:00:00	16,3	894000000	4930	14,7	15	0	0	12
2013-10-15 00:00:00	16,3	685000000	5460	14,77	15	5329	0	12
2013-10-16 00:00:00	16,3	924000000	5000	14,69	15	5923	0	12
2013-10-17 00:00:00	16,3	834000000	4980	14,72	15	6305	0	12
2013-10-18 00:00:00	16,3	596000000	5600	14,8	15	6400	0	12
2013-10-19 00:00:00	16,3	268000000	5600	14,91	15	5800	0	12
2013-10-20 00:00:00	16,3	-228000000	5400	15,07	15	4500	0	12
2013-10-21 00:00:00	16,3	954000000	5400	14,68	15	4500	0	12
2013-10-22 00:00:00	16,3	775000000	5480	14,74	15	5435	0	12
2013-10-23 00:00:00	16,3	228000000	5480	15,07	15	5700	0	12
2013-10-24 00:00:00	16,3	745000000	5410	14,75	15	5871	0	12
2013-10-25 00:00:00	16,3	894000000	5560	14,7	15	5823	0	12
2013-10-26 00:00:00	16,3	924000000	5500	14,69	15	5803	0	12
2013-10-27 00:00:00	16,3	1043000000	5300	14,65	15	5820	0	12
2013-10-28 00:00:00	16,3	745000000	5020	14,75	15	5103	0	12
2013-10-29 00:00:00	16,3	745000000	5220	14,75	15	6179	0	12
2013-10-30 00:00:00	16,3	596000000	5580	14,8	15	5400	0	12
2013-10-31 00:00:00	16,3	745000000	5640	14,75	15	5598	0	12
2013-11-01 00:00:00	16,3	864000000	5560	14,71	15	3815	0	12

2013-11-02 00:00:00	16,3	1013000000	5600	14,66	15	3815	0	12
2013-11-03 00:00:00	16,3	1192000000	5700	14,6	15	5500	0	12
2013-11-04 00:00:00	16,3	1192000000	5700	14,6	15	5500	0	12
2013-11-05 00:00:00	16,3	1252000000	5700	14,58	15	6670	0	12
2013-11-06 00:00:00	16,3	894000000	6040	14,7	15	7010	0	12
2013-11-07 00:00:00	16,3	685000000	6630	14,77	15	6882	0	12
2013-11-08 00:00:00	16,3	1073000000	6990	14,64	15	7636	0	12
2013-11-09 00:00:00	16,3	1371000000	6990	14,54	15	7275	0	12
2013-11-10 00:00:00	16,3	1162000000	6600	14,61	15	7275	0	12
2013-11-11 00:00:00	16,3	864000000	6170	14,71	15	5752	0	12
2013-11-12 00:00:00	16,3	1013000000	6840	14,66	15	6932	0	12
2013-11-13 00:00:00	16,3	864000000	6330	14,71	15	6020	0	12
2013-11-14 00:00:00	16,3	1073000000	5990	14,64	15	6623	0	12
2013-11-15 00:00:00	16,3	924000000	5800	14,69	15	7323	0	12
2013-11-16 00:00:00	16,3	924000000	6100	14,69	15	7570	0	12
2013-11-17 00:00:00	16,3	1073000000	6100	14,64	15	6698	0	12
2013-11-18 00:00:00	16,3	1222000000	5960	14,59	15	6764	0	12
2013-11-19 00:00:00	16,3	745000000	6020	14,75	15	7733	0	12
2013-11-20 00:00:00	16,3	656000000	5720	14,78	15	6948	0	12
2013-11-21 00:00:00	16,3	566000000	5710	14,81	15	7081	0	12
2013-11-22 00:00:00	16,3	447000000	6500	14,85	15	7126	0	12
2013-11-23 00:00:00	16,3	626000000	6000	14,79	15	7126	0	12
2013-11-24 00:00:00	16,3	507000000	6000	14,83	15	5857	0	12
2013-11-25 00:00:00	16,3	775000000	6070	14,74	15	5522	0	12
2013-11-26 00:00:00	16,3	685000000	6050	14,77	15	6440	0	12
2013-11-27 00:00:00	16,3	805000000	6090	14,73	15	6582	0	12
2013-11-28 00:00:00	16,3	805000000	6090	14,73	15	6582	0	12
2013-11-29 00:00:00	16,3	983000000	5960	14,67	15	7191	0	12
2013-11-30 00:00:00	16,3	805000000	6000	14,73	15	6700	0	12