MANAGEMENT OF WATER RESOURCES SYSTEMS WITH USE OF SIMULATION MODELS AND MODELS BASED ON MACHINE LEARNING

Frosina Panovska Georgievska
Teaching assistant
MSc in Civil Engineering
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia
fpanovska@gf.ukim.edu.mk

Stevcho Mitovski
PhD, Associate professor
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia

Ljupcho Petkovski
PhD, Professor
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia

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Throughout the history of humankind, in parallel with the progress of civilizations, the techniques and methods for analyzing structures in construction have undoubtedly progressed. As a tool of the latest date that finds application in undoubtedly every sector of construction, is the use of tools from machine learning - a branch of artificial intelligence. The tool offers opportunities for use in construction for optimization of structures, safety analysis, cost analysis and construction cost optimization, as well as help in their real time daily management. Undoubtedly, these machine-learning tools can be applied to dam and reservoir engineering as well as water management. As complex systems with deterministic output and stochastic input, machine-learning tools can help in all phases – from planning, construction, and operation to management of water systems. In this paper, the application of machine learning tools with analyses in the SOLDIER application in decision-making in the management of a complex water management system is described. A case study has been prepared for a part of the Crna Reka basin in RN Macedonia. In addition to the SOLDIER application, the HEC ResSim software was used to generate input and output data in the management of the systems – data used to train the model in SOLDIER.

Keywords: water management systems, reservoirs, hydropower, simulation model, machine learning, SOLDIER, HEC ResSim.

1. INTRODUCTION

Throughout the history of humankind, in parallel with the progress of civilizations, the techniques and methods for analysis of civil engineering structures have undoubtedly progressed. From the Stone Age, to the construction of the pyramids in Egypt, the construction of the Tower of Babylon, the sewers and water supply in Rome, the Great Wall of China, the Acropolis in Athens, to the construction of the Three

Gorges Dam in China with an incredible height of 181m and a crown length of 2335m , we have come at a moment in civil engineering history where structures reached incredible sizes, with new materials of carbon fiber, steel and concrete, maintaining their stability, defying the weather, gravity and natural stochastic incident occurrences (earthquake and flood).

From an engineering point of view, machine learning represents a process of forming a mathematical correlation between certain variables that are of interest in the analysis of the structures.

Undoubtedly, these machine-learning tools can be applied to dam engineering as well as water resources management. Water resources systems are complex systems with stochastic input and deterministic output and machine-learning tools can be applied in all stages – from planning, designing, construction and management of such systems.

In this paper, the application of machine learning tools with carried out analyses in the application SOLDIER in decision-making in the management of a complex water management system is described. A case study has been prepared for a part of the Crna Reka basin in RN Macedonia. In addition to the SOLDIER application, the HEC ResSim software was used to generate input and output data in the water management of the system – data used to train the model in SOLDIER.

SOLDIER application is developed by CIMNE – International center for numerical methods in engineering [2] based in Barcelona, Spain. The main goal of the CIMNE application is to analyze the relationship between different variables using machine learning. The main application of this software is focused in the field of technical monitoring of dams and appurtenant structures [3]. In the case study, it is applied to the analysis of operational rules for management of a complex hydropower multi storage system, by observing the correlation of the power production and the variables of the mathematical model, obtained with HEC ResSim.

HEC ResSim [4] software is open source, developed by the USACE Army Corps of Engineers. It is used for mathematical modeling of complex water management systems for determining operational management rules and for determining the physical parameters of the system.

2. CASE STUDY – CRNA REKA BASIN

As a case study, mathematical modeling was performed to determine operational parameters for the management of a complex hydropower system in the Crna Reka basin, specifically the gorge of the Crna Reka, where, according to the Water master plan from 1973, Chebren and Galishte reservoirs are planned for construction in addition to the existing Tikvesh reservoir.

Crna Reka is a right tributary of the Vardar River and it is one of the largest rivers in the Vardar River Basin with nearly ¼ of the total basin area, which is 5,890 km^2. The river flows through the Pelagonia and Tikvesh valleyes - both areas burdened with serious water management problems.

The course of the Crna Reka, from the spring to the confluence in the Vardar River passes through a mountainous, lowland and gorge part with a total length of 229 km. Along its course, Crna Reka receives several tributaries, the largest of which are: Shemnica river, on which hydro system Strezhevo is also built, Dragor river, Konjarka, Bela, Buturkica, Blešica, Raec and others. The average height above sea level of the Crna Reka basin is 863 masl. According to the Water Master plan of 1973, the course of Crna Reka can be divided into three parts:

- Spring, which is characterized by large falls and mountainous character of the basin;
- The middle course, which is characterized by small falls and is mostly flat - the part in which the Pelagonia valley is located;
- The gorge in the lower course of Crna Reka, which is characterized by large falls, distinctly mountainous terrain - very favorable for energy use of the water.

In the spring part of Crna Reka, as well as in the middle course, there are no favorable conditions for energy utilization of the water. Only the gorge in the lower course of the river provides solid opportunities for energy production. The gorge part of the course stretches from the town of Skochivir (108 km from the mouth of the Vardar River) to Tikvesh valley, near the village of Vozarci (26.3 km from the mouth of the Vardar River). In this part, with a total length of 81.7 km, the difference in terrain elevation is 400 m. On this stretch, the Tikvesh dam was built, with operational level of 265masl, with Tikvesh HPP, in which 4 Francis hydro turbines were installed with a total installed power of 113MW and installed turbine flow of 144 m^3/s. After the construction of the Tikvesh dam, there are still about 300m of potential energy height and a length of 52.5km from Crna Reka, which have very favorable possibilities for hydropower utilization. According to the Water Master plan from 1973, the most favorable scheme for energy production is construction of two dams upstream of Tikvesh dam, both with hydropower plants - HPP Galište at 53,6km with operational level of 392masl and HPP Chebren at 81km with operational level of 565masl (Figure 1).

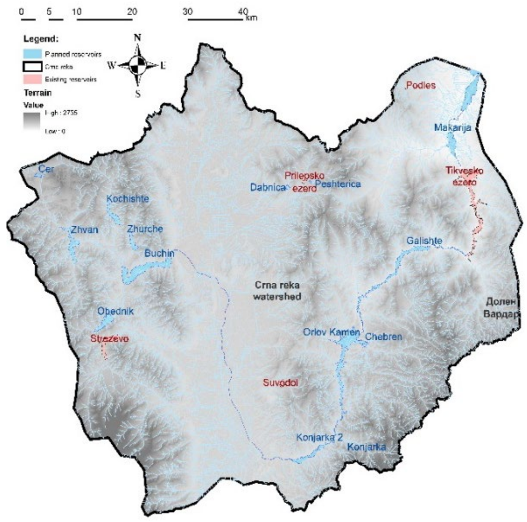

Figure 1. Planned and constructed reservoirs in the Crna Reka river basin, map created with Copernicus data [1]

The scheme for hydropower utilization of Crna reka in the gorge stretch consists of: 1) Chebren reservoir as the upstream reservoir and pumped-storage hydropower plant, 2) Orlov Kamen reservoir which will serve as a lower reservoir in pumping regime for HPP Chebren, 3) Galishte reservoir in the middle, and 3) Tikvesh reservoir as the downstream reservoir (Figure 2). HPP Galishte is planned as conventional hydropower plant.

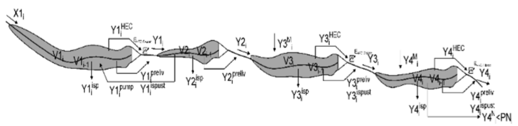

Figure 2. Schematic view of the analyzed scheme [2]

The dam profile for Chebren reservoir i the narrowest part of the Crna Reka course, with very favorable geotechnical and geological characteristics for the construction of a high dam. The dam site is located near the village of Manastir. The operational level in the reservoir is limited by the topography - up to 565masl - due to the danger of flooding of the Pelagonia valley. The volume of the formed reservoir up to the elevation of 565masl is $915\times10^6 m^3$, of which $555\times10^6 m^3$ are active volume. The reservoir is planned exclusively for the power production through HPP Chebren, and the size of the reservoir is sufficient for an annual leveling of the natural flows of Crna Reka. HPP Chebren will be located downstream of Chebren dam. If built with conventional units, the annual production of this plant with Francis hydro turbines is 352×10^6 kWh/year [3]. As a pumped-storage unit, the production is expected to be doubled – approximately 600×10^6 kWh/year [4].

Downstream of Chebren reservoir, Orlov Kamen reservoir is planned, as the lower basin for the pump regime of work of HPP Chebren. The operational level in this reservoir is 400masl.

The Galishte reservoir starts downstream from Orlov Kamen dam, all the way to the dam profile, which is located 56.3 km from the confluence of Crna Reka in the Vardar river. With the construction of the Galishte dam, a reservoir will form with operational level at 392 masl and a total capacity of 344×10^6 m^3 and active volume of 256×10^6 m^3. This hydropower plant is expected to deliver over of 224×10^6 kWh/year [5].

The next in line down the cascade of the river is the existing Tikvesh reservoir with HPP Tikvesh located downstream of Tikvesh dam. This plant delivers over 137×10^6 kWh/year [6]. The reservoir is also used for irrigation of Tikvesh valley - the primary water user in this scheme.

In the case study for which the water management planning was developed, the results of which are elaborated in this paper, the Chebren reservoirs with the Orlov Kamen and Galishte reservoirs were taken into account - as newly planned reservoirs, and the Tikvesh reservoir, as an existing reservoir.

3. APPLIED CODES

3.1. SOLDIER APP

The SOLDIER app is created by the CIMNE Institute in Barcelona, Spain, is a tool developed for machine learning application for dams and hydropower. The application works by applying regression sequences, ie. creation of mathematical correlation between multiple variables based on previously known data [7].

The application has so far been used for the development of models for the analysis of the structural behavior of several dams in Europe, it is actively used within the framework of the DOLMEN project, which is focused on the application of methodologies for defining dynamic warning thresholds in the operation of dams with reservoirs for different purposes [8]. The application also won the Verbund prize in a competition for innovative challenges in 2017 [8].

3.2. HEC RESSIM SOFTWARE

HEC-ResSim is a software used to model complex water management systems in order to comply with the demands of one or more water users. With the help of the software, it is possible to model water resources systems by creating simulation models, that include multi-dimensional and multipurpose aspects (flood protection, meeting of water supply and irrigation demands, determining the capacity of reservoirs for hydropower production, as well as combinations of operational policies and prioritizing more water users according to the demands).

HEC-ResSim consists of: (1) user interface (GUI-Graphical User Interface), (2) a mathematical background program that simulates reservoir management, (3) files for saving data from the simulations, and (4) tools for processing the output results. HEC-ResSim uses a data storage system HEC-DSS (Data Storage System), through which data is provided for the system as time series (inflow in the reservoir, water level, water quantities for different needs, etc.) [9].

HEC-ResSim offers three modules through which the simulation model is defined:

- Module for defining the elements present in the simulation model and their interrelationship – setting up a watershed area Watershed Setup (defining rivers, tributaries, reservoirs, embankments, canals) ;
- Module for defining the physical parameters of the elements – Reservoir Network;
- Module for simulating the defined system – Simulation.

For the needs of the research work, with the help of HEC ResSim, a large number of input and output data were created, which are used as data that feeds the model in SOLDIER , which will create a dependency between the various variables - inflow into the reservoir, water level, water needs, discharge from reservoir, energy production, etc.

4. INPUT DATA FOR THE MACHINE LEARNING MODELS

The main goal of this research is the determination of correlation between the parameters that impact the water management of the abovementioned reservoirs. As main variables, they include:

- Hydrological series of inflows in reservoirs, defined as hydrographs of inflows for the period 2020 - 2050
- Outflow from reservoirs, defined as runoff hydrographs for the period 2020 – 2050
- Delivered irrigation water, defined as an irrigation hydrograph for the period from 2020 to 2050, for the Tikvesh reservoir
- Hydropower production for the period from 2020 to 2050,
- Operation in pumping mode at the Chebren reservoir for the period from 2020 to 2050,
- Variations of the water level in the reservoirs for the period from 2020 to 2050.

The specified hydrographs were obtained by simulation model created in HEC ResSim software, with a time step in the models of 1 day.

To create the simulation model, it is necessary to define: (1) inflow hydrograph in each reservoir, (2) physical characteristics of the reservoir, (3) water needs, and (4) operational rules for managing the system. In addition to the listed steps, the models also need to define the location of the reservoirs and their mathematical connection in order to perform rational and effective water management. Namely, the outflow from the upstream reservoir is inflow into the downstream reservoir. This connection is defined according to Figure 2, and it can be seen how it is set up with the HEC ResSim application in Figure 3.

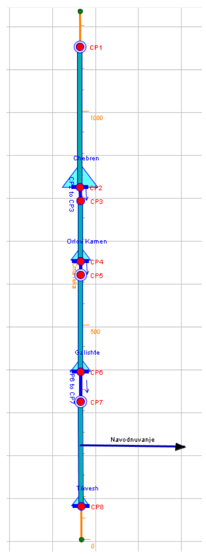

Figure 3. Schematic representation of the reservoirs in the study case apropos created model in HEC ResSim.

The hydrological input to the Chebren reservoir is taken from a historical series of measured mean monthly flows for the hydrological station Rasimbegov Most (Figure 4), for the Galishte reservoir - data from the hydrological station Galishte (Figure 6) and for the Tikvesh reservoir - data from the hydrological station Tikvesh (Figure 7). The time period of analysis is 30 years – from 2020 to 2050. The hydrological series of inflows correspond to the measured data from the period 1946 to 1976.

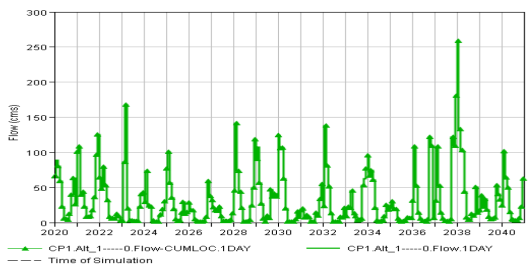

Figure 4. Inflow hydrograph for Chebren reservoir

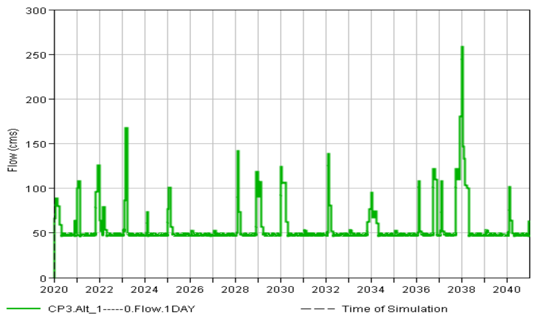

Figure 5. Inflow hydrograph for Orlov Kamen reservoir

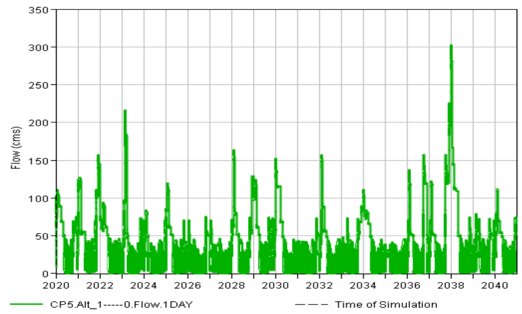

Figure 6. Inflow hydrograph for Galishte reservoir

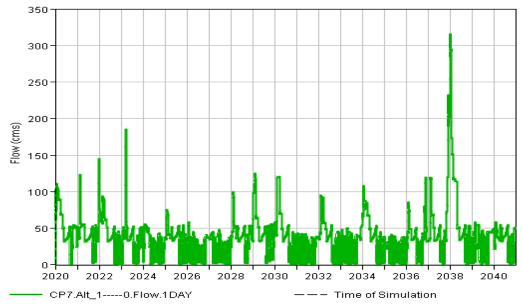

Figure 7. Inflow hydrograph for Tikvesh reservoir

As follows, the technical data for each reservoir is given in Tab. 1. It is a configuration consisting of a cascade system with four reservoirs on Crna Reka.

Table 1. Physical parameters of the reservoirs

Reservoir	Physical parameters		
Tikvesh	Normal operating level	265	masl
	Minimum operating level	233	masl
	Active volume	310 x 10^6	m^3
	Dam crest elevation	269	masl
	Installed power	115.32	MW
	Installed turbine flow	144	m^3/s
Galishte	Normal operating level	392	masl
	Minimum operating level	342	masl
	Active volume	256 x 10^6	m^3
	Dam crest elevation	398	masl
	Installed power	190.83	MW
	Installed turbine flow	180	m^3/s
Chebren	Normal operating level	565	masl
	Minimum operating level	515	masl
	Active volume	555 x 10^6	m^3
	Dam crest elevation	567.5	masl
	Installed power	458	MW
	Installed turbine flow	333	m^3/s
	Installed pump flow	150	m^3/s
Orlov Kamen	Normal operating level	400	masl
	Minimum operating level	393	masl
	Active volume	14.9 x 10 6	m^3
	Dam crest elevation	408	masl

The variation of water level in each reservoir is also used as a variable for making of correlation for management of the system, as well as the discharge from the reservoir. These data are shown for each reservoir in Figure 8, 9, 10 and Figure 11.

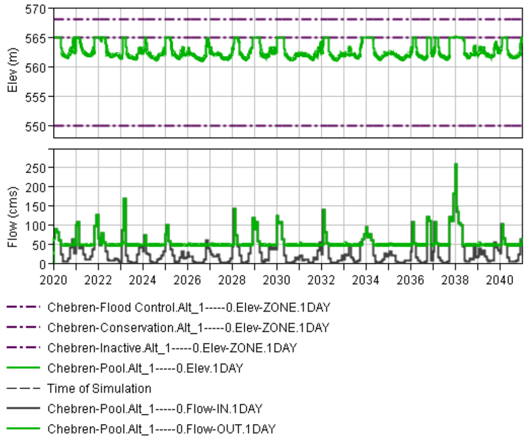

Figure 8. Variation of the water level in Chebren reservoir (upper graph), with a hydrograph of inflows and outflows (lower graph).

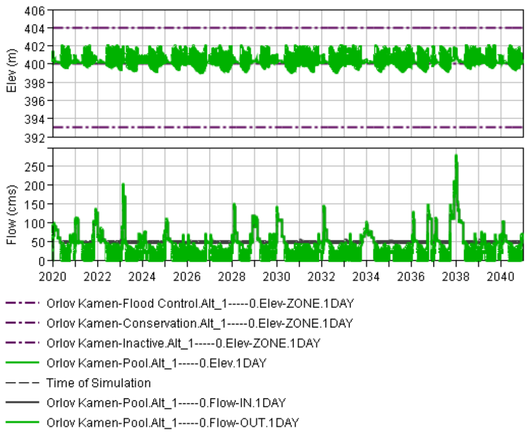

Figure 9. Variation of the water level in Orlov Kamen (top graph), with a hydrograph of inflows and outflows (bottom graph).

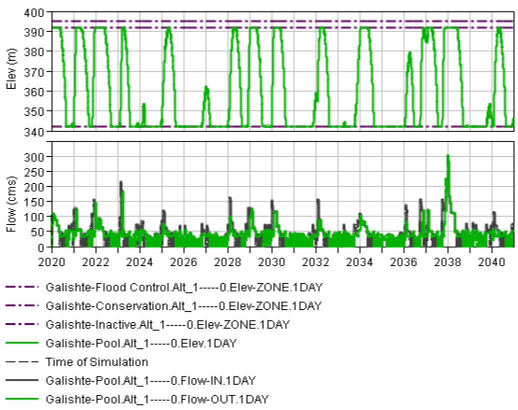

Figure 10. Variation of the water level in Galishte (top graph), with a hydrograph of inflows and outflows (bottom graph).

At the Tikvesh reservoir, in addition to power production, it is necessary to take in to account the quantities of delivered water for irrigation demands, for the analyzed period. This is a seasonal variation of the flows, for a period of 30 years (Figure 12).

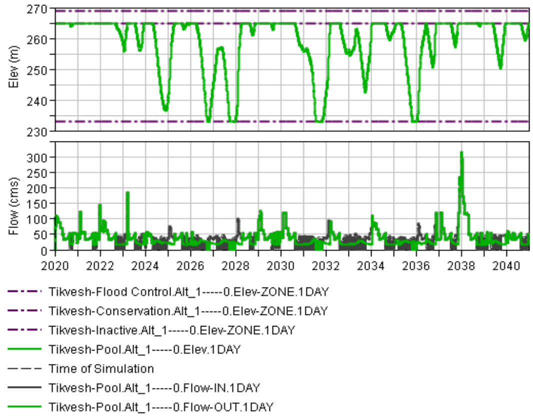

Figure 11. Variation of the water level in Tikvesh (top graph), with a hydrograph of inflows and outflows (bottom graph).

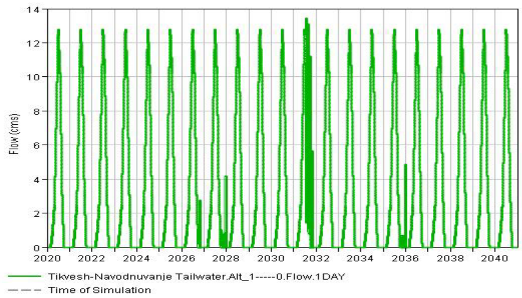

Figure 12. Hydrograph of supplied irrigation water from Tikvesh reservoir.

The primary purpose of each reservoir in the analysis is power production. Below are the output results of the power production in each hydropower plant, as a series of data for the analyzed period (Figure 13, 14 and 15).

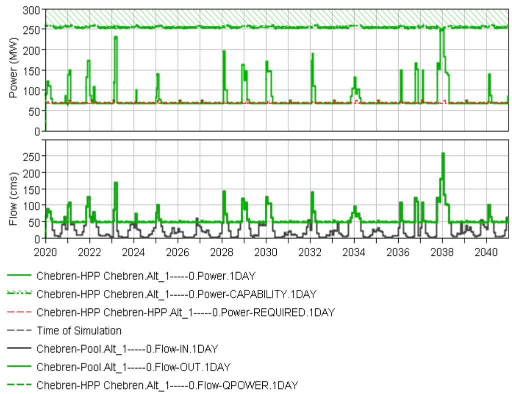

Figure 13. Time series of power production from HPP Chebren

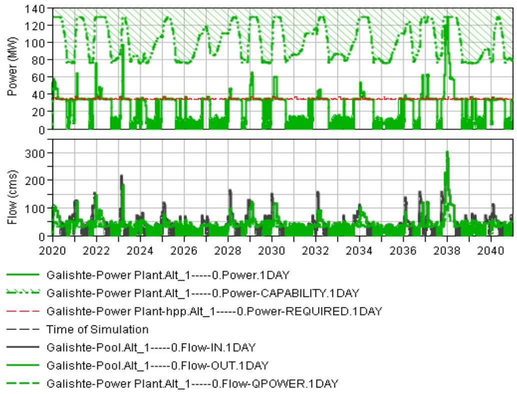

Figure 14. Time series of power production from HPP Galishte

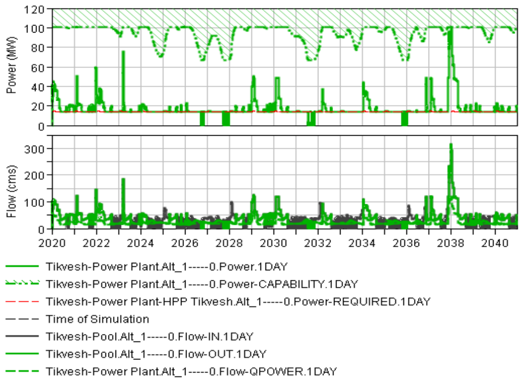

Figure 15. Time series of power production from HPP Tikvesh

5. OUTPUT RESULTS FROM THE MACHINE LEARNING MODELS

As follows, the output results from the models with machine learning are given. The model is fed with data obtained with the simulation models, for time series data for 30 years, in 1 day time step.

With the ML models, we will be able to observe the following correlations:

1. The hydropower production in correlation with the hydrological series of inflow into the reservoirs and the variations of the water level in the reservoir,

2. The overflow and downstream discharge for environmental flow in correlation with the hydropower production,

In the models, the principle of using 75% of the data for model training and 25% for testing the obtained results was applied.

To evaluate the suitability of the models, the mean absolute error (MAE) was calculated:

$$MAE = \frac{\sum_{i=1}^{N}|y_i - F(x_i)|}{N} \quad (1)$$

where N represents the number of data in the training zone or the validation zone, y_i are the observed outputs and $F(x_i)$ are the predicted values. This coefficient is measured in the same measurement units as the hypothesized variable, and it represents an intuitive measure of the model's accuracy [10].

In addition to the mean absolute error, the coefficient R^2 - coefficient of determination which is defined for a set of n - elements with $y_1 \dots y_n$ results and their assumed values $y_1' \dots y_n'$:

$$R^2(y, y') = 1 - \left(\frac{\sum_{i=1}^{N}(y_i - y_i')^2}{\sum_{i=1}^{N}(y_i - y')^2}\right), y' = \frac{1}{n}\sum_{i=1}^{N} y_i \quad (2)$$

The target value for the coefficient R^2 is 1, i.e. a score close to 1 indicates that the model made a solid mathematical correlation between the variables, and a score of 0 indicates that the model cannot establish any correlation between the variables [11].

5.1. CORRELATION BETWEEN POWER PRODUCTION, INFLOWS AND DISCHARGE FROM THE CHEBREN RESERVOIR

In order to understand the relationship between the hydropower production at Chebren HPP, a model has been prepared in the SOLDIER application in which the connection of the variables is analyzed: water level in the Chebren reservoir, inflows in the Chebren reservoir, hydropower production, overflow through the spillway, the released water through the bottom outlet and pump operation for return of water from the Orlov Kamen reservoir to the Chebren reservoir.

The target parameter in the analysis is hydropower production.

According to the output results, the MAE for the subject model is 9.68 for the learning period of the model, while it is 31.68 for the testing period. The coefficient R^2 is 1 for the model learning period, and 0.99 for the model testing period. The coefficients indicate a well-formed correlation between the variables and the target variable, and this can be seen in the graphic display of the adjustment of the target variable in Figure 16.

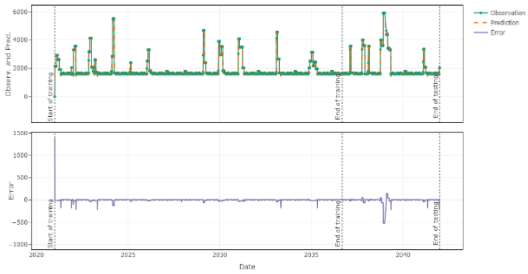

Figure 16. Adjustment of the variable – power production, in the learning zone of the model, and in the testing zone of the model at the Chebren reservoir.

The largest influence of the entered variables on the target variable is the HPP flow (Figure 17). The remaining variables have an insignificant influence on the formation of the mathematical relationship between the input variables and the target variable.

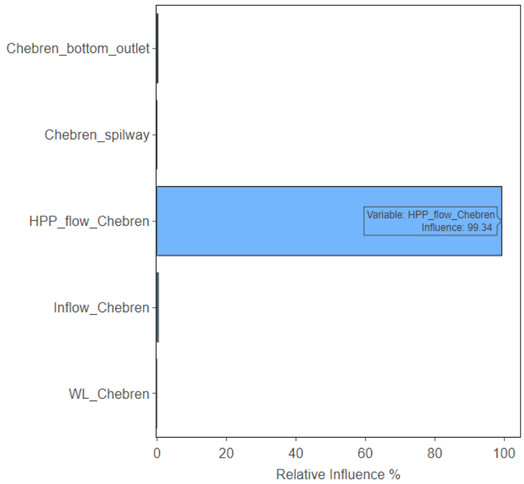

Figure 17. Relative influence of each variable in the target variable at Chebren reservoir

From Figures 18-21 it can be concluded that a higher inflow into the reservoir and a higher level of water in the reservoir generated higher hydropower production. Also, greater flow through the hydro plant and a higher level of water in the reservoir, generates increased hydropower production. These are logical and expected outcomes, by which it can be judged that the model provides realistic data and information regarding the correlation of the variables.

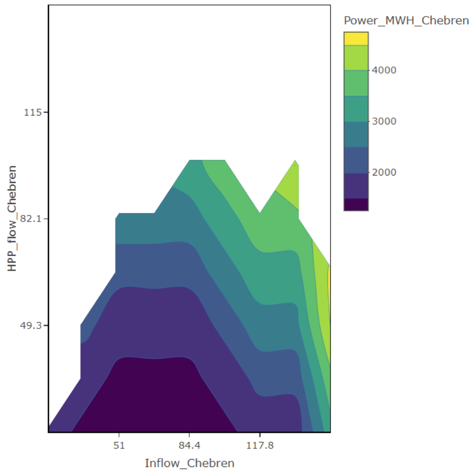

Figure 18. Partial dependence between the HPP flow, reservoir inflow and produced hydropower.

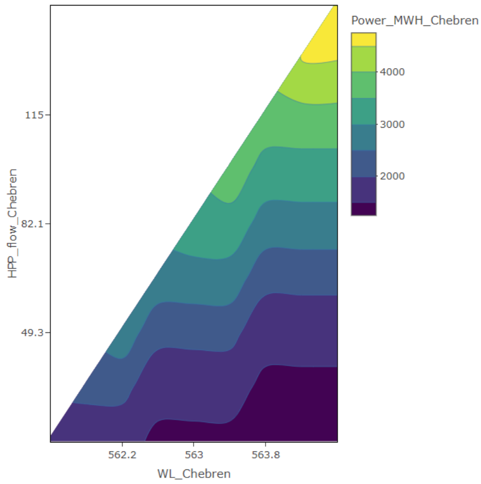

Figure 19. Partial dependence between the HPP flow, reservoir elevations and produced hydropower.

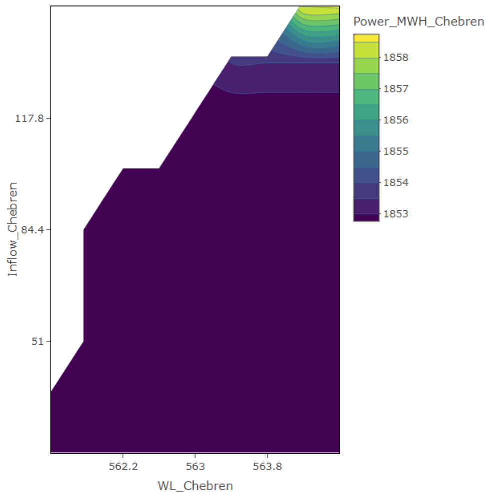

Figure 20. Partial dependence between inflows in the reservoir, reservoir level and hydropower production.

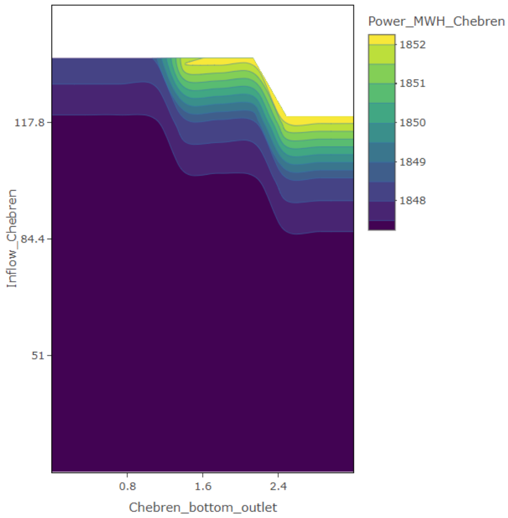

Figure 21. Partial dependence between inflow in the reservoir, bottom outlet flow produced hydropower.

5.2. CORRELATION BETWEEN PUMPED FLOW AND WATER LEVEL IN CHEBREN RESERVOIR

It is also of interest to see the correlation of the operation of HPP Chebren in pumping mode, ie. the operation of the pumps for filling the upper pool, for which a model has been prepared where the target variable is the operation of the pumps.

In this model, as variables that form the dependency for the target variable, the following are entered: water level in the Chebren reservoir and in Orlov Kamen, the produced hydropower, inflow into the Chebren reservoir and HPP flow.

According to the results, the MAE for the subject model is 0.19 for the learning period of the model, while it is 0.21 for the testing period. The coefficient R^2 is 1 for the model learning period, and 1 for the model testing period. The coefficients indicate a well-formed correlation between the variables and the target variable, and this can be seen in the graphic display of the adjustment of the target variable in Figure 22.

From the obtained results it can be concluded that the lower the water level in the Chebren reservoir, the more water is pumped into the upper pool, and the more the difference between the level in the upper and lower pool increases, the smaller the quantity of water that needs to be pumped (Figure 23 and 24). These are expected and logical results, which indicate a well-formed relationship between the variables in the model.

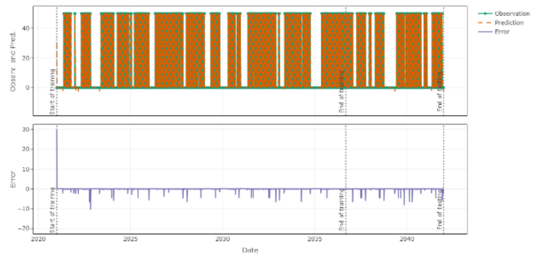

Figure 22. Adjusting the variable – the amount of water to be pumped into the upper basin in the learning zone of the model, and in the testing zone of the model.

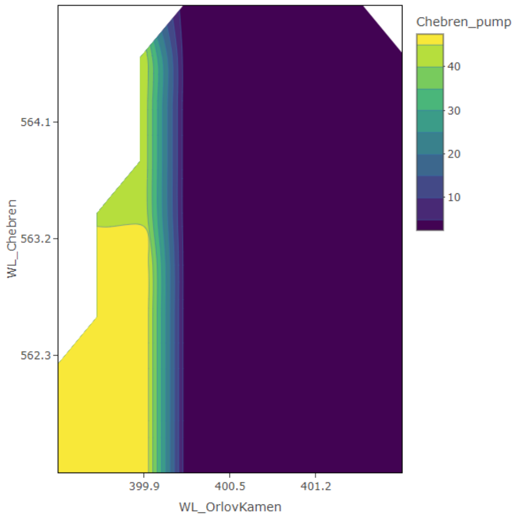

Figure 23. Partial dependence of the elevations in the Chebren and Orlov Kamen reservoirs on the amount of water pumped from the lower to the upper pool

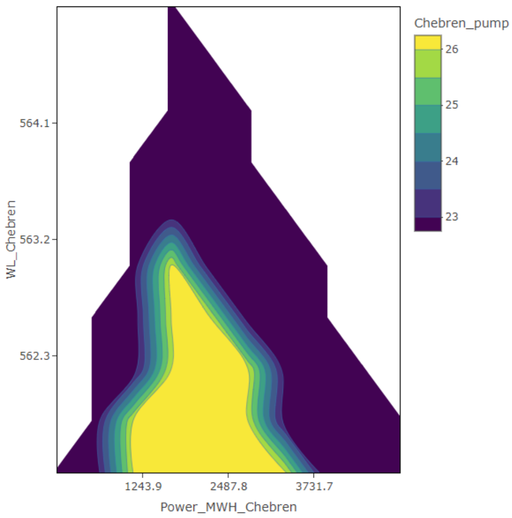

Figure 24. Partial dependence of the elevations in the Chebren reservoir with the produced hydropower and the required flow to be pumped into the upper pool.

5.3. CORRELATION BETWEEN HYDROPOWER PRODUCTION, INFLOW AND DISCHARGE FROM GALISHTE RESERVOIR

In order to understand the effect of hydropower production from HPP Galishte, a model has been prepared in the SOLDIER application in which the correlation of the variables is analyzed: water level in the Galishte reservoir, inflow in Galishte reservoir, hydropower production, spillway overflow and the flow through the bottom outlet.

The target variable in the analysis is hydropower production.

According to the results, the MAE for the subject model is 13.97 for the learning period of the model, while it is 19.94 for the testing period. The coefficient R^2 is 1 for the model learning period, and 0.99 for the model testing period . The coefficients indicate a well-formed correlation between the variables and the target variable, and this can be seen in the graphic display of the adjustment of the target variable in Figure 25.

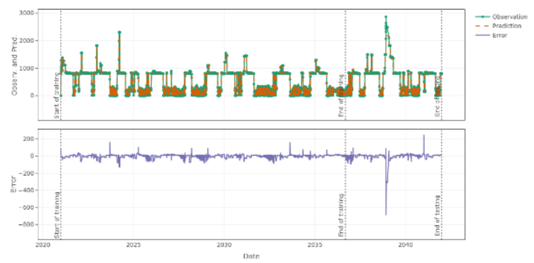

Figure 25. Adjustment of the variable – power production, in the learning zone of the model, and in the testing zone of the model at the Galishte reservoir.

Of the entered variables, the flow through HPP Galishte has the greatest relative influence on the target variable, with over 85% impact (Figure 26). Furthermore, it can be seen in Figure 26 that the spillway overflow also has a certain influence on the formation of the relationship between the variables and the target variable, as well as the water level in the Galishte reservoir. Inflow in the reservoir has an insignificant influence on the formation of the mathematical correlation.

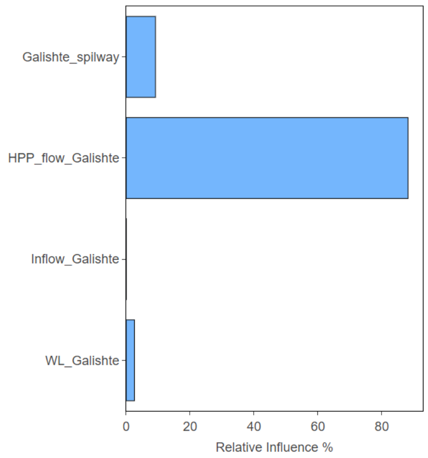

Figure 26. Relative influence of each variable in the target variable at Galishte reservoir.

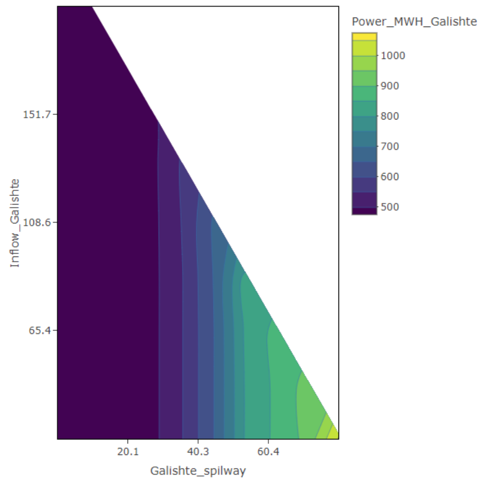

Figure 27. Partial dependence between inflow, spillway overflow and hydropower production at HPP Galishte.

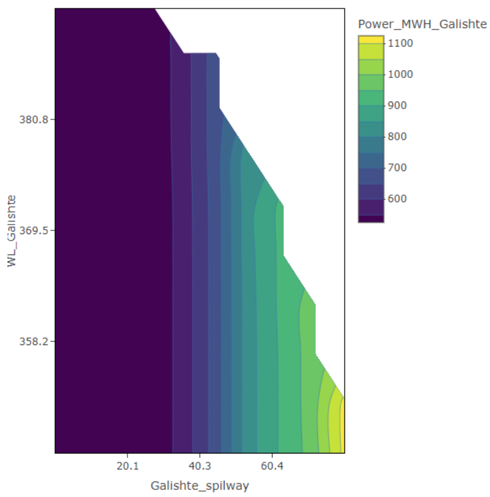

Figure 28. Partial dependence between the elevations in the Galishte reservoir, spillway overflow and hydropower production.

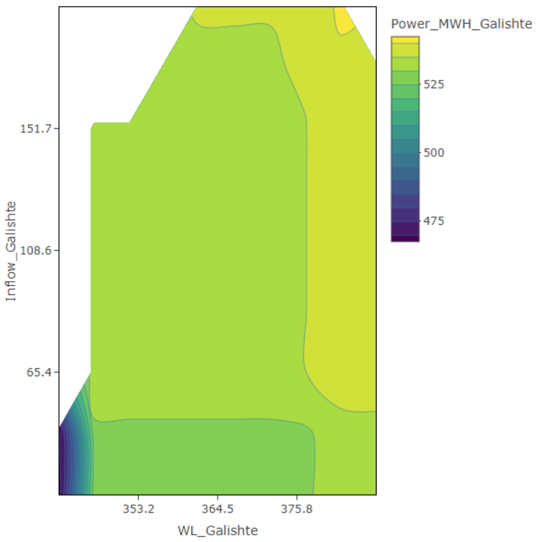

Figure 29. Partial dependence between the inflow, elevations in the reservoir and hydropower production at HPP Galishte.

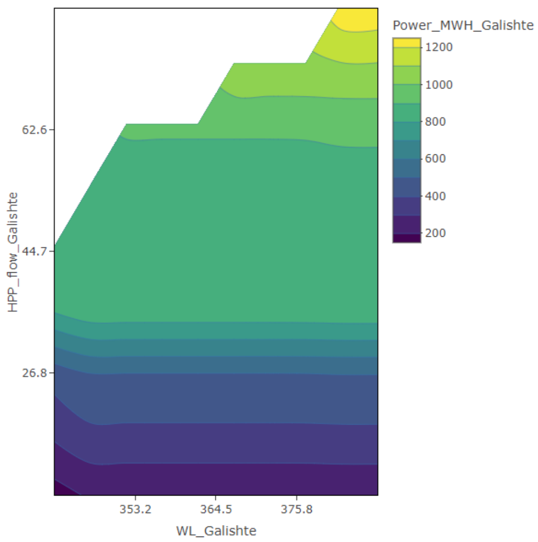

Figure 30. Partial dependence between the elevations in the Galishte reservoir, the HPP flow and hydropower production.

5.4. CORRELATION BETWEEN HYDROPOWER PRODUCTION, INFLOW AND DISCHARGE FROM TIKVESH RESERVOIR

In order to study the relationship between the hydropower production at HPP Tikvesh, a model has been prepared in the SOLDIER application in which the connection of the following variables is analyzed: water level in the Tikvesh reservoir, inflow in Tikvesh reservoir, hydropower production, spillway overflow, outflow in the bottom outlet and provided water for irrigation.

The target variable in the analysis is hydropower production.

According to the results, the MAE for the subject model is 7.36 for the learning period of the model, while it is 12.7 for the testing period. The coefficient R^2 is 1 for the model learning period, and 0.94 for the model testing period. The coefficients indicate a well-formed correlation between the inputs and the target variable, and this can be seen in the graphic display of the adjustment of the target variable in Fig. 31.

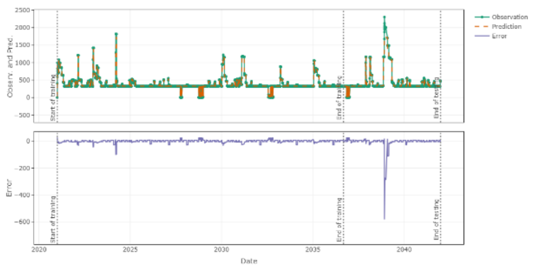

Figure 31. Adjustment of the variable – hydropower production at the HPP Tikvesh.

Of the entered variables, the spillway overflow has the greatest impact on the formation of the mathematical correlation, second is flow through the HPP and the reservoir inflow (Fig. 32).

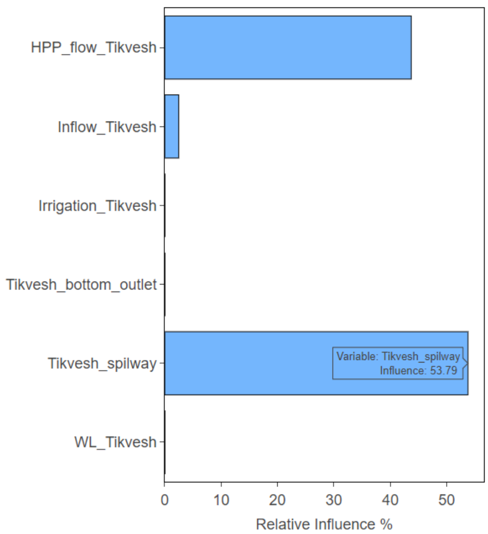

Figure 32. Relative influence of each variable in the target variable at Tikvesh reservoir.

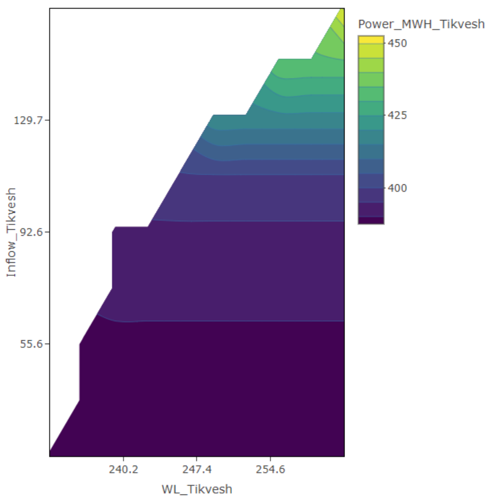

Figure 33. Partial dependence between the elevations in the Tikvesh reservoir, the reservoir inflow and hydropower production

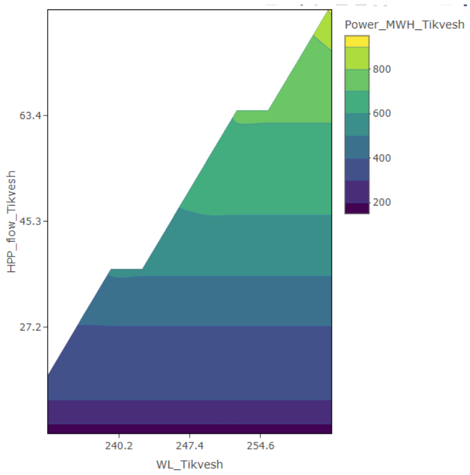

Figure 34. Partial dependence between the reservoir elevations, HPP flow and hydropower production at HPP Tikvesh.

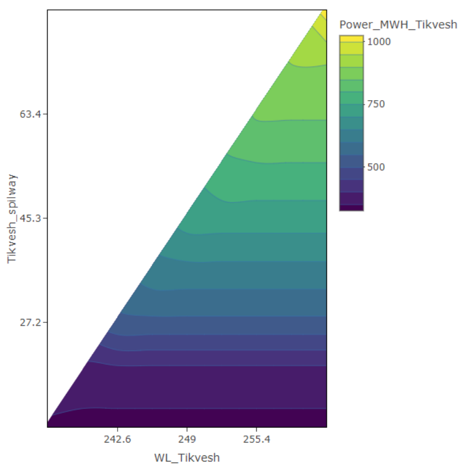

Figure 35. Partial dependence between the spillway overflow, reservoir elevations and hydropower production.

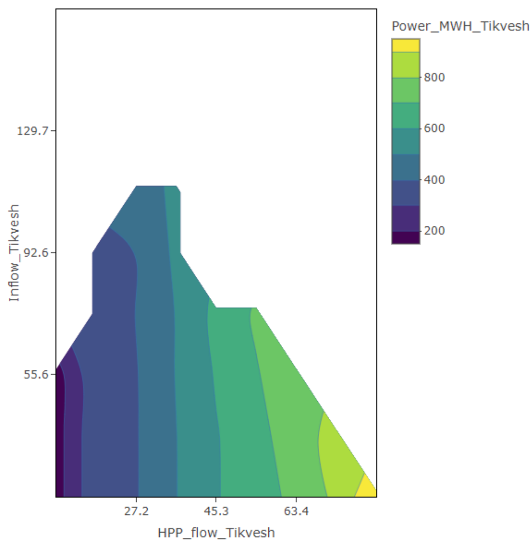

Figure 36. Partial dependence between reservoir inflow, HPP flow and hydropower production at HPP Tikvesh.

From the output results, it can be concluded that the higher the level in the reservoir, and the higher the inflow, the power production also increases. Also, the correlation between the flow through a hydropower plant and the elevations in the reservoir is similar – as they increase, the production of power also increases (Figure 33 and 34). In Figure 35 and 36 the correlation between the HPP flow and the inflow into the reservoir can be seen, in relation to the hydropower production. It is a non-linear connection, where for higher values of the flow through the hydropower plant; the highest values for power production are obtained.

CONCLUSION

Within the scope of the paper, the procedures for creating a simulation model and models with machine learning are described, with the aim of understanding the correlation of the target parameters on the variables in the management process of a complex hydropower system, with a "case study" of the Crna Reka basin, for the planned pump storage HPP Chebren and HPP Galishte.

To understand the impact on the target parameters of the management variables with the individual reservoirs, machine learning models were built using the SOLDIER application, developed by the CIMNE Institute in Barcelona, Spain.

To form a sequence of data to train the model with machine learning, a simulation model was prepared in HEC ResSim for the complex hydropower system Chebren-Galishte. From the model, the hydrographs of inflow into the reservoirs, reservoir outflow, delivered water for irrigation and time series of hydropower production were calculated, in order to form dependencies for the water management of the reservoirs with the help of the SOLDIER application.

Four reservoirs are included in the models: Chebren, Orlov Kamen, Galishte and Tikvesh. Of the specified reservoirs, the Tikvesh reservoir is existing, while the rest are planned reservoirs with hydropower plants. HPP Chebren is planned as a pumped-storage plant, and as such it is included in the study case.

For each reservoir, a separate model was created in SOLDIER, through which the impact of the individual variables on the target parameter – hydropower production is perceived.

From the conducted analyses, it can be concluded that in all models a solid relationship was established between the variables and the target parameter, and as an indicator of the relationship is the R^2 coefficient, which in all models is approximately 1, i.e. it ranges from 0.94 - 1 in the different models.

According to the carried out analytical procedure, at the PSHPP Chebren for the hydropower production, it can be concluded that there is a dominant correlation with the parameter hydropower plant flow. Also, logical results can be seen from the obtained dependencies – with an increase in the water level in the Chebren reservoir and with an increase in the inflow into the reservoir, the power production increases, while the overflow decreases. The water that is required to be pumped from the lower pool (Orlov Kamen reservoir) to the upper pool (Chebren reservoir) increases with the lowering of the water level in the Chebren reservoir.

At the Galishte reservoir, the dependencies are similar – the higher the water levels in the reservoir, the higher the power production, and the overflow decreases with the increase in power production.

The situation is identical with the Tikvesh reservoir - with an increase in the water level in the reservoir, a greater amount of power is generated.

In this initial phase of the research, the sensitivity of the target parameters from the simulation models by changing the variables is investigated, and it can be concluded that solid correlative dependencies have been established, which contribute to an improved study and understanding of the variables dependence in a complex hydropower system.

REFERENCES

[1] "Copernicus Land Monitoring Service," European Environment Agency, [Online]. Available: www.land.copernicus.eu.

[2] F. Panovska, "Simulation model for analyses of multi reservoir hydropower scheme" master thesis, Faculty of Civil Engineering, Ss. Cyril and Methodius University in Skopje, 2019.

[3] Водостопанска основа на Р. Македонија, Скопје, 1973.

[4] EXERGIA, "Main report on Optimization of the river Crna Reka, system for power production and preparation for tender documents for concession," 2003.

[5] USACE, "HEC RESSIM User's Manual, ver 3.3," 2021.

[6] АД Електрани на Р.С. Македонија, "Годишен извештај за работата на АД ЕСМ за 2021 година," АД ЕСМ, Скопје, 2021.

[7] F. Salazar, J. Irazabal and A. Conde, SOLDIER: SOLution for Dam behaviour Interpretation and safety evaluation with boosted regression trees, User Manual, 2023.

[8] F. Salazar, J. Irazabal and A. Conde, "SOLDIER: SOLution for Dam behavior Interpretation and safety Evaluation with boosted Regression trees," SoftwareX, vol. 25, 2024.

[9] US Army Corps of Engineers, "HEC ResSim application," [Online]. Available: https://www.hec.usace.army.mil/software/hec-ressim/.

[10] F. Salazar, M. A. Toledo, E. Onate and B. Suarez, "Interpretation of dam deformation and leakage with," Engineering Structures, 2015.

[11] M. A. Hariri-Ardebili and F. Pourkamali-Anaraki, "An Automated Machine Learning Engine with Inverse Analysis," Water, vol. 14, no. 3898, 2022.

[12] "CIMNE" [Online]. Available: https://www.cimne.com/.

[13] A.-M. Ali Najah Ahmed, O. A Karim, A. El-Shafie and A. El-Shafie, "Application of artificial neural networks for water quality prediction," Neural computing and applications, 2012.

[14] H. Robert Maier and G. Clyde Dandy, "Neural networks for the prediction and forecasting of water resources variables: A review of modelling issues and applications," Environmental Modelling & Software, pp. 101-124, 2000.

[15] F. Schulze, H. Wolf, H. Jansen and P. Van der Veer, "Applications of artificial neural networks

in integrated," Water Science & Technology, vol. 52, no. 9, pp. 21-31, 2005.

[16] A. A. Ahmed, S. Sayed, A. Abdoulhalik, S. Moutari and L. Oyedele, "Applications of machine learning to water resources management: A review of present status and future opportunities," Journal of Cleaner Production, vol. 441, 2024.