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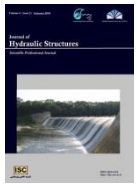

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# Determining Thermal Stratification of Zayandeh Roud Dam Reservoirs Using Two-Dimensional CE-QUAL-W2 Model

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## Abstract

Dam reservoirs, serving as critical repositories of water resources, play an important role for satisfying water demands. However, the pollution of various sources poses significant challenges to the preservation of water quality of these reservoirs. Here, effective management of these resources is necessary. For this purpose, the modeling and simulation of dam reservoirs should be done investigating the impact of pollution. This study focuses on the Zayandeh Roud Dam reservoir in Isfahan province, using historical data from 2016 to 2021. Here, the CEQUAL-W2 model is used for simulation and determining the temperature of water stored in reservoir and release from the dam. Calibration and verification process of model are done for the periods 2016 to 2020 and 2021, respectively. The simulation results show that absolute mean error (AME) of the water temperature release the reservoir are 0.80 degrees Celsius for calibration and 1.16 degrees Celsius for validation process. The results highlighted the performance of advanced modeling approaches, the CEQUAL-W2 model, for the proper management of dam reservoirs.

**Keywords:** Qualitative Simulation, Thermal Layering, Zayandeh Roud Dam, CE-QUAL-W2 Model

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## 1. Introduction

These days, dam reservoirs serve as fundamental repositories of surface water for satisfying different demand including agriculture, drinking water, industrial processes, and hydropower. Consequently, different challenges and concerns are arisen when this resource is polluted or restricted effective for management of water resources. In general, dam reservoirs, as vital components of surface water sources, are constructed and operated for different quantitative and qualitative goals.

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To achieve these objectives, qualitative simulations of reservoirs should be done to identify the key parameters influencing the simulation process. Various methods and models have been proposed for qualitative simulation of dam reservoirs, in which each of them unique advantages and disadvantages. Among these models, the CE-QUAL-W2 model is widespread used and attended by researchers due to its unique capabilities.

Reviewing the researches shown that numerous studies have been done in this field. For example, Ma et al. [1] investigated the thermal layering for the Koris Dam reservoir in Cyprus using the two-dimensional model CE-QUAL-W2. The reservoir has been thermally stratified throughout the year, and mixed occurs in early February to initiate the mixing in the reservoir.

Çalışkan and Elçi [2] proposed a selective withdrawal method to regulate the temperature of the water released from the dam reservoir. Here, effects of selective harvesting on the hydrodynamics of reservoir layering numerical modeling and sensitivity analysis were investigated. By Using the Environmental Fluid Dynamics Code (EFDC) hydrodynamic model, the effects of selective withdrawal from the four outlet located along the water intake structure of Tahtali Reservoir in Turkey on water temperature and analyzed the impacts of thermal stratification structure were investigated. Withdrawal of the water at the bottom outlet was found to be the most effective choice encouraging the mixing of the water column and finally reducing anoxia.

Afshar et al. [3] used the Particle Swarm Optimization algorithm to automatically calibrate temperature simulation models within the CE-QUAL-W2 model. This model was used to simulate temperature variations in the Karkheh Dam reservoir. Parameters such as solar radiation absorbed in surface layer (BETA), extinction coefficient for pure water (EXH2O), and wind sheltering coefficients (WSC) were selected as effective parameters in temperature calibration process.

Mohammadnejad et al. [4] simulated the trophic state of the Mahabad Dam reservoir using the CE-QUAL-W2 model. Subsequently, the model was calibrated and validated based on the temperature and quality parameters, including nitrate, phosphate, total phosphorus, and total nitrogen. Furthermore, the analysis of the results revealed that nutrient distribution and adverse conditions play a dominant role in the Mahabad Dam reservoir. These factors limit phosphorus availability within the reservoir. Additionally, the reservoir profile analysis indicates the presence of summer thermal stratification.

Aboutalebi et al. [5] used the two-dimensional CE-QUAL-W2 simulation model to simulate the concentration of pollution in the Karaj river-reservoir system. In this study, support vector regression (SVR) and artificial neural network (ANN) data-driven models were used to address the time-consuming issue associated with the CE-QUAL-W2 simulator model. Finally, the Support Vector Regression (SVR) and Artificial Neural Network (ANN) models were integrated using a genetic algorithm (GA) optimization method. The results indicated that the performance of the SVR model outperformed the artificial neural network model.

Ziaie et al. [6] used the two-dimensional model CE-QUAL-W2 to simulate temperature and quality parameters for the reservoir of the Zayandeh Roud Dam. In this research, the parameters and coefficients selected for model calibration included temperature and quality parameters such as total coliform, nitrate, dissolved oxygen. Furthermore, the water quality of the reservoir was assessed using the IRWQISC index. The results indicated that the reservoir's water quality is good and relatively high.

Arefinia et al. [7] used a statistical approach to investigate water pollution patterns in the reservoirs. In this research, temperature and nitrate parameters of the Amirkabir Dam reservoir were simulated using the CE-QUAL-W2 model. Subsequently, input data of the genetic programming (GP) methods, artificial neural networks, and support vector machines (SVM) were constructed for reservoir quality modeling using the CE-QUAL-W2 hydrodynamic simulator model.

Rasouli et al. [8] investigated the thermal layering and water quality of the Glaber Dam reservoir located in Zanjan. For this purpose, the two-dimensional CE-QUAL-W2 model was used to simulate hydrodynamics, dissolved oxygen, and total dissolved solids for the one-year period from 2014 to 2015. The simulation results showed summer thermal stratification. In addition, the water quality in different parts of the reservoir at different times was evaluated using Iran's water quality index.

Hanjaniamin et al. [9] used the CE-QUAL-W2 model to investigate the water quality of the Yamchi Dam reservoir located in Ardabil province. The CE-QUAL-W2 model was used for simulating and determining the concentration of dissolved oxygen for this purpose. The results showed that the Yamchi Dam reservoir is one of the eutrophic reservoirs, and practical solutions should be implemented to improve these conditions.

In general, the CE-QUAL-W2 model was used by considering quality parameters such as temperature, nitrate, dissolved oxygen, etc., to investigate water quality in dam reservoirs. Reviewing the researches shows the good performance of the CE-QUAL-W2 model in simulating quality parameters of dam reservoirs. In this research, Zayandeh Roud Dam reservoir is selected as a case study. Here, the CE-QUAL-W2 model is used to simulate the temperature for water stored in the dam reservoir as the desired qualitative parameter. A comparison of results shows the good performance of the model for determining the temperature and characterizing the thermal stratification of water stored in the dam reservoir.

## 2. Simulation Model

The CE-QUAL-W2 simulation model is a versatile and widely used tool in the domain of trophic modeling and thermal stratification assessment of dam reservoirs. This longitudinal-depth, hydrodynamic (unsteady), and water quality model is demonstrated success across various water bodies worldwide, ranging from steep rivers to big reservoirs. By using a two-dimensional approach and finite difference solution method, the CE-QUAL-W2 model is particularly well-suited for portraying qualitative parameters through vertical and longitudinal profiles, in which it is highly effective for relatively lengthy reservoirs and lakes.

The most important capabilities of the CE-QUAL-W2 model is hydrodynamic modeling of rivers and reservoirs, temperature simulation, water quality modeling, and nutrient analysis. The model requires a set of input files including tank geometry, meteorological data, water inflow discharge, water inflow temperature and water release from reservoir, shade coverage, wind protection, and a control file. Through meticulous calibration of quality parameters based on input data, the CE-QUAL-W2 model shows exceptional accuracy in dam reservoirs simulation. In this research, the performance of CE-QUAL-W2 simulation model is investigated, highlighting its applications, methodologies, and notable features in the context of managing dam reservoirs. The model's robust capabilities are valuable asset for researchers and insightful simulations for effective reservoir management.

## 3. Case Study

In recent decades, the instability of water resources is a significant challenge in the Zayandeh Roud watershed. Therefore, a comprehensive analysis and investigation of the challenges within this watershed are imperative. For this purpose, the Zayandeh Roud catchment basin and the dam constructed on the Zayandeh Roud River within this basin, is selected as a case study.

The volume of Zayandeh Roud Dam Lake, is 1470 MCM with the area of approximately 54 $KM^2$. In addition, the elevation is 2063 meter above the sea level in the eastern part of the Western Zagros mountain range. This reservoir was constructed in 1970 multiple purposes, including the generation of hydroelectric energy, mitigation of seasonal floods, regulation of agricultural water supply, and provision of water for industrial demands in Isfahan. Figure 1 illustrates the geographical location of the Zayandeh Roud Dam reservoir.

In this research, the data necessary for simulating the Zayandeh Roud Dam reservoir, from September 2016 to September 2021, were collected. For this purpose, meteorological information from the Chadegan synoptic station, encompassing air temperature, wind speed, dew point, and etc. were collected. In addition, the dataset for the Zayandeh Roud Dam reservoir incorporates water inflow and release values, along with the temperature of water inflow in to the reservoir. These parameters serve as crucial boundary conditions for our simulation model. The daily average air temperature, wind speed, water inflow and release values from reservoir, and water temperature of inflow values are presented in figures 2, 3 and 4.

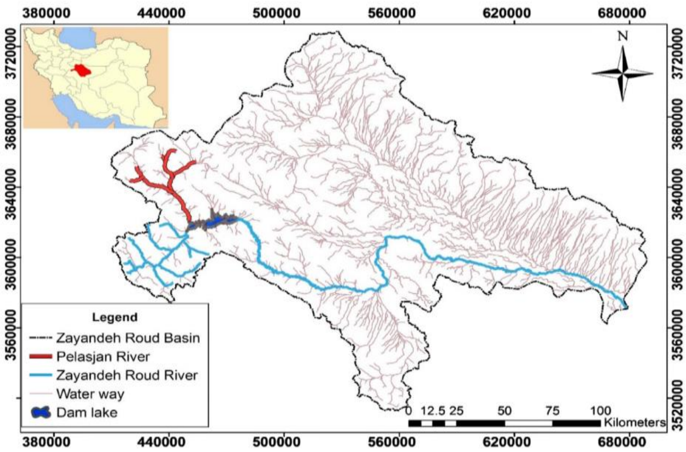


**Figure 1. Location of the Zayandeh Roud Dam [6]**

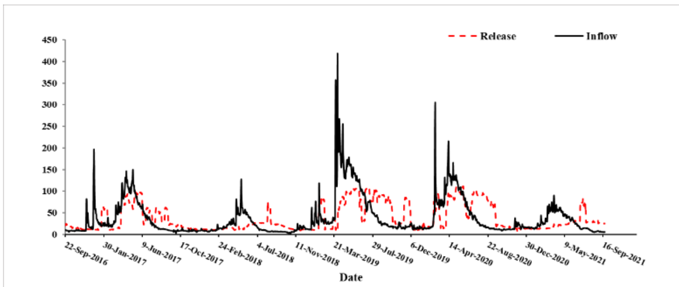


**Figure 2. Water Inflow and release from reservoir values**

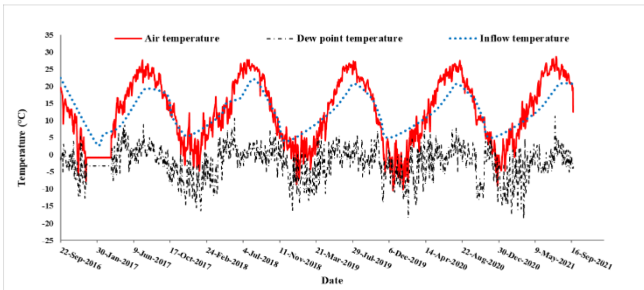

**Figure 3. Inflow temperature, air temperature, and dew point temperature values**

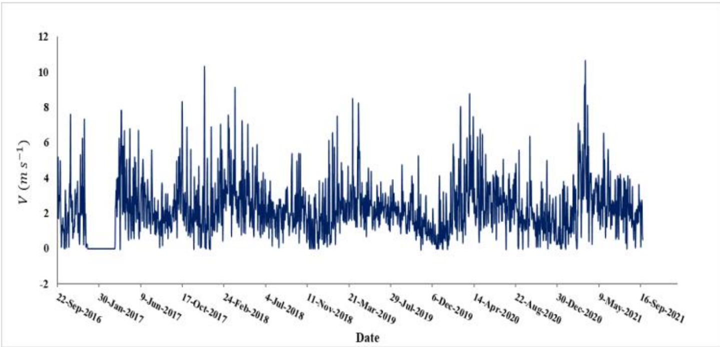

**Figure 4. Wind speed values**

## 4. Results and Discussion

In this research, the CE-QUAL-W2 model is used to determine the thermal layering of the Zayandeh Roud Dam reservoir during the water year period from 2016 to 2021. In this model, the initial step for simulating various natural parameters involves calibrating the model with regard to effective parameters. This calibration process aims to fine-tune the model for the specific conditions governing the study area. The final goal is to obtain the accurate coefficients within the model to yield optimal results when compared to observational data. The calibration of the CE-QUAL-W2 model can be done both manually and automatically, encompassing multiple stages such as tank geometry, water level, and water temperature. Each stage is systematically presented as follow. The geometry error of the dam reservoir and the water level error during the calibration stages are presented in table 1 and 2, respectively. Moreover, comparisons the model segmentation and vertical view of the Zayandeh Roud Dam reservoir are presented in Figure 5 and 6. The results of Tables 1 and 2 highlight the remarkable accuracy achieved by the model during the calibration process of the dam reservoir geometry.

Statistical parameters of absolute mean error (AME) and root mean square error (RMSE), presented in Eqs. (1) and (2), were calculated to compare the simulated and observed data

$$AME = \frac{|P - O|}{N} \tag{1}$$

$$RMSE = \sqrt{\frac{\sum(P-O)^2}{N}} \tag{2}$$

Where, P = predicted (simulated) data; O = observed data; and N = number of observations.

**Table 1. Geometry Errors of the Zayandeh Roud Dam Reservoir for calibration and validation process**

| RMSE (MCM) | AME (MCM) |
|---|---|
| 6.19 | 5.73 |

**Table 2. Water Level Errors for Zayandeh Roud Dam Reservoir**

| Calibration process (Meters) | | Validation process (Meters) | |
|---|---|---|---|
| RMSE | AME | RMSE | AME |
| 0.28 | 0.24 | 0.21 | 0.15 |

By doing the calibration and validation process for the reservoir geometry, the results of both the reservoir geometry and water level are ready for the subsequent modeling process leading to water temperature of the dam reservoir. In the temperature calibration and validation process, the parameters affecting the temperature are initially identified using sensitivity analysis. Subsequently, by comparative analysis of simulated and observed temperatures, adjustments are made to the parameters, for optimal alignment between the model results and observed data.

In this research, calibration process is done from 2016 to 2020, and the validation process is done for 2021. The water validation is done for three monitoring stations including Segment 33, Segment 26 and Segment 22. The model's results are presented at these strategically chosen monitoring points and compered with observed data. Figures 7 to 12 show the obtained water temperature results, in comparison with observed data, during both the calibration and validation process. In addition, the RMSE and AME values for temperature for the specified points during simulation period are presented in table 3. The results show the unique performance of the model for accurate simulation of the stored water temperature of the Zayandeh Roud Dam reservoir.

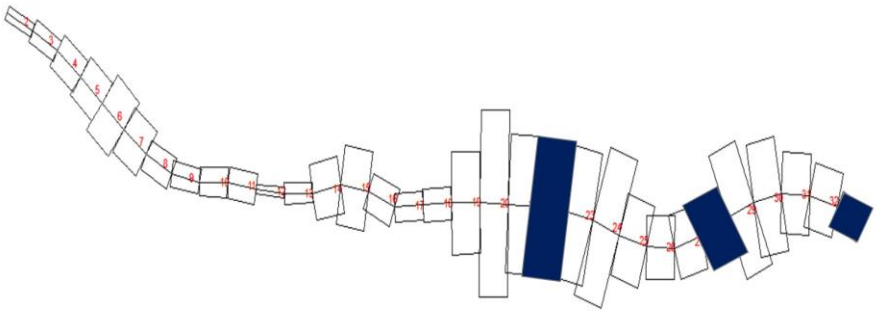

**Figure 5. Zayandeh Roud Reservoir model segmentation and location of monitoring stations**

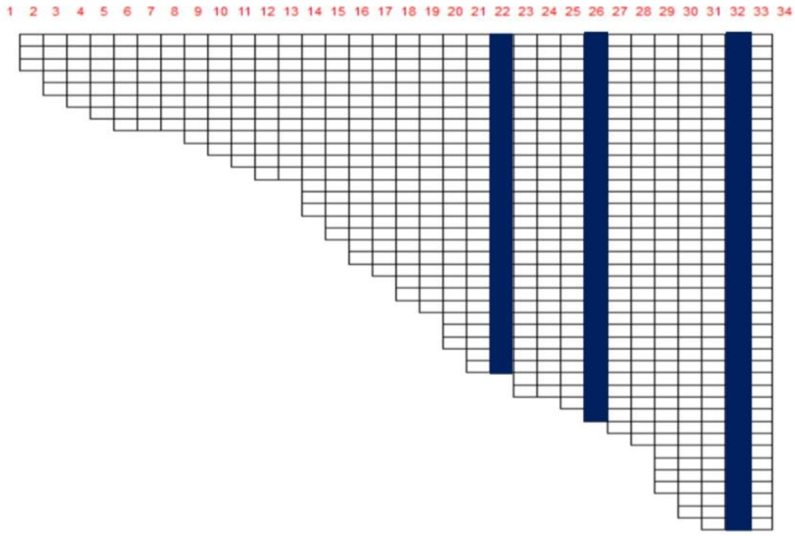


**Figure 6. Vertical view of Zayandeh Roud Reservoir for monitoring stations (Dark shades monitoring station)**

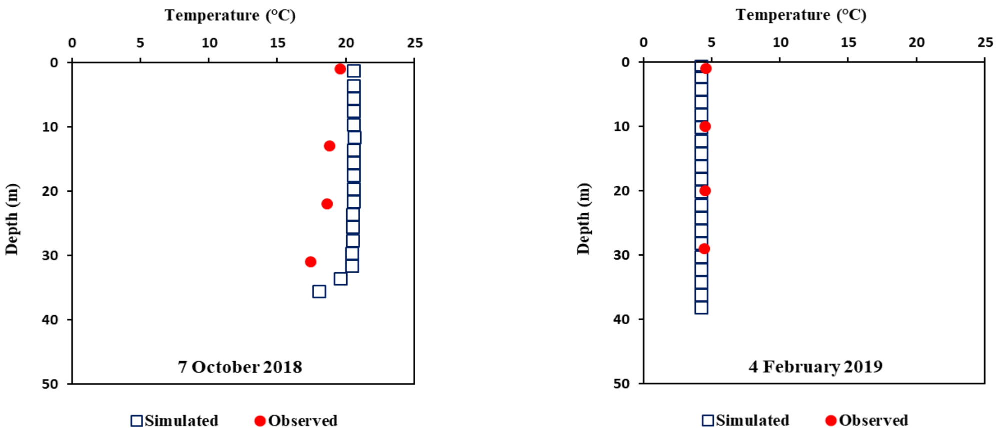


**Figure 7. Results of water temperature calibration process (Segment 33)**

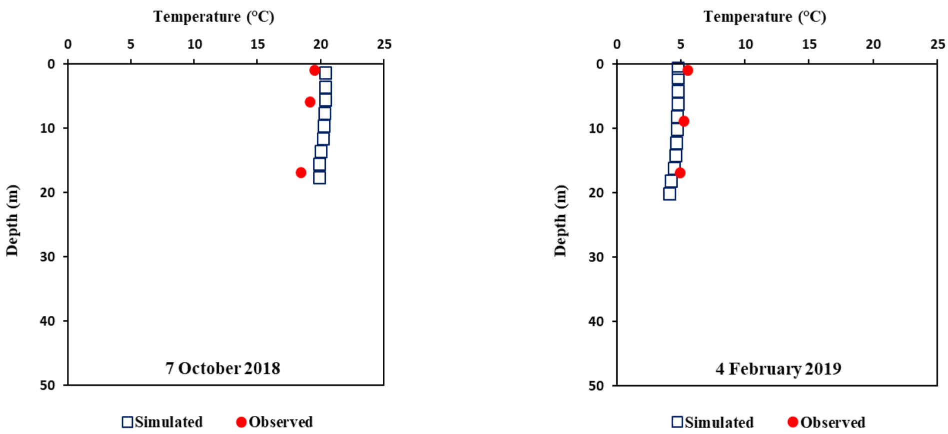


**Figure 8. Results of water temperature calibration process (Segment 26)**

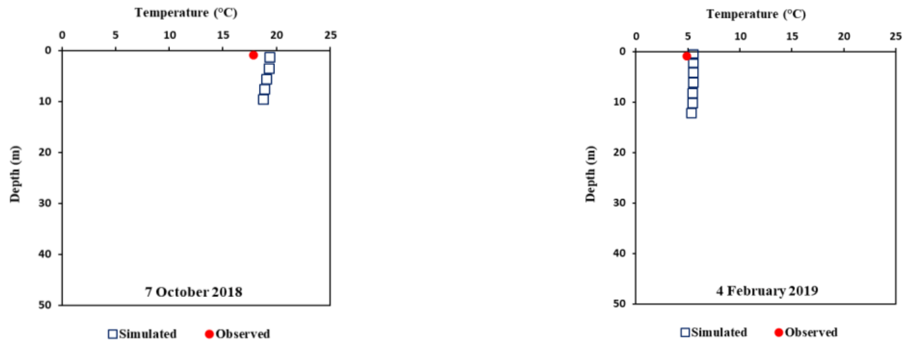


**Figure 9. Results of water temperature calibration process (Segment 22)**

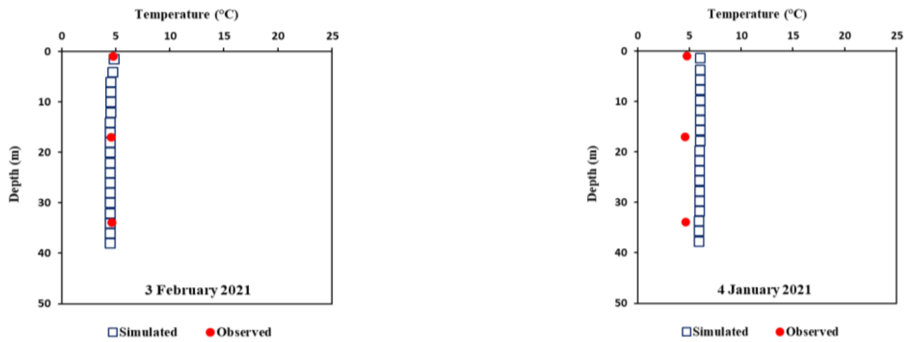


**Figure 10. Results of water temperature validation process (Segment 33)**

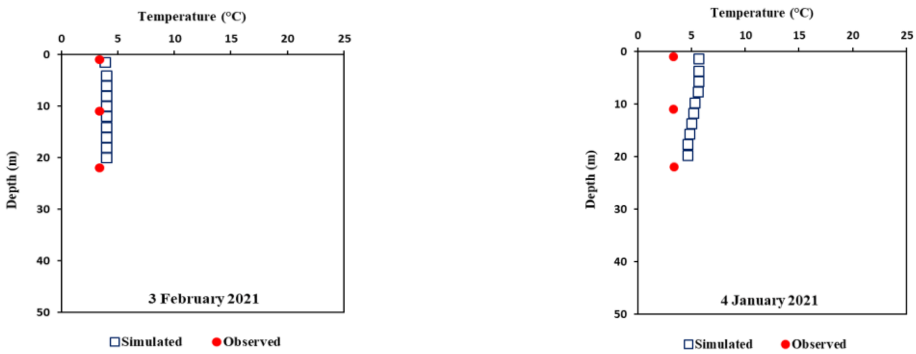


**Figure 11. Results of water temperature validation process (Segment 26)**

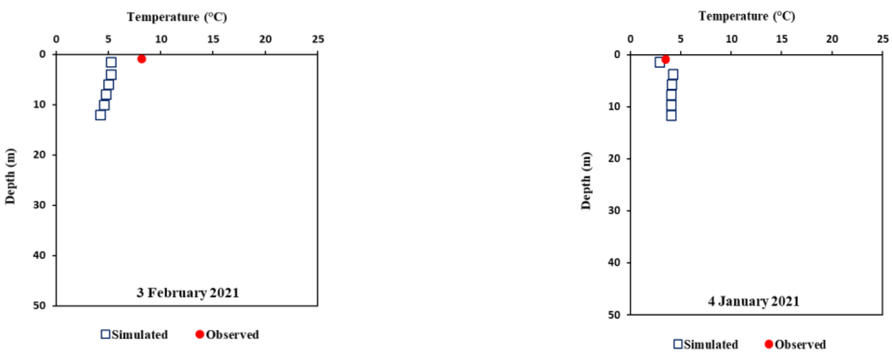


**Figure 12. Results of water temperature validation process (Segment 22)**

**Table 3. RMSE and AME values of Water Temperature of the Zayandeh Roud Dam Reservoir for the Period 2016-2021**

| Date | location of monitoring stations | $AME$(℃) | $RMSE$ (℃) |
|---|---|---|---|
| 05/March/2017 | Segment 33 | 0.39 | 0.48 |
| | Segment 26 | 0.58 | 0.60 |
| | Segment 22 | 0.82 | 0.82 |
| 05/January/2018 | Segment 33 | 0.63 | 0.66 |
| | Segment 26 | 0.11 | 0.11 |
| | Segment 22 | 1.15 | 1.15 |
| 04/April/2018 | Segment 33 | 1.12 | 1.17 |
| | Segment 26 | 1.38 | 1.45 |
| | Segment 22 | 0.88 | 0.88 |
| 06/July/2018 | Segment 33 | 0.56 | 0.56 |
| | Segment 26 | 0.00 | 0.00 |
| | Segment 22 | 0.76 | 0.76 |
| 07/October/2018 | Segment 33 | 1.85 | 1.96 |
| | Segment 26 | 1.12 | 1.15 |
| | Segment 22 | 1.47 | 1.47 |
| 04/February/2019 | Segment 33 | 0.34 | 0.34 |
| | Segment 26 | 0.71 | 0.72 |
| | Segment 22 | 0.56 | 0.56 |
| 06/October/2020 | Segment 33 | 0.69 | 0.59 |
| | Segment 26 | 0.83 | 1.01 |
| | Segment 22 | 1.64 | 1.64 |
| 04/January/2021 | Segment 33 | 1.28 | 1.28 |
| | Segment 26 | 2.03 | 2.05 |
| | Segment 22 | 0.43 | 0.43 |
| 03/February/2021 | Segment 33 | 0.15 | 0.16 |
| | Segment 26 | 0.55 | 0.55 |
| | Segment 22 | 2.91 | 2.91 |

## 5. Conclusion

In this research, the CE-QUAL-W2 model was used to simulate and determine the temperature of water released and thermal validation of the Zayandeh Roud Dam reservoir during the period from 2016 to 2021. For this purpose, the data from 2016 to 2020 were used for calibration and the year 2019 for validation process. Here, at first the dam reservoir geometry calibration process was done leading to RMSE values of 6.19 million cubic meters for reservoir volume and 0.28 meters for water surface elevation. Then, the results of water temperature simulation were compared with observed data at three monitoring stations including Segment 33, Segment 26 and Segment 22. A compression of the results indicated the unique performance of the model in simulating reservoir water temperature. In other words, the average error of temperature of water released from the reservoir during the calibration and validation periods were 0.80 and 1.16 degrees of Celsius, respectively.

## References


1. Ma, S., Kassinos, S. C., Fatta Kassinos, D., & Akylas, E. (2008). Effects of selective water withdrawal schemes on thermal stratification in Kouris Dam in Cyprus. Lakes & Reservoirs: Research & Management, 13(1), 51-61. Çalışkan, A., & Elçi, Ş. (2009). Effects of selective withdrawal on hydrodynamics of a stratified reservoir. *Water resources management, 23, 1257-1273.*
2. Çalışkan, A., & Elçi, Ş. (2009). Effects of selective withdrawal on hydrodynamics of a stratified reservoir. *Water resources management, 23, 1257-1273.*
3. Afshar, A., Kazemi, H., & Saadatpour, M. (2011). Particle swarm optimization for automatic calibration of large scale water quality model (CE-QUAL-W2): Application to Karkheh Reservoir, Iran. *Water resources management*, *25*, 2613-2632.
4. Mohammadnejad, B., Parchami, N., & Bahmanesh, J. (2014). Simulation of Nutrient Loading in the Mahabad Dam Reservoir Using the CE-QUAL-W2 Two-Dimensional Model. *Journal of Civil and Environmental Engineering, 44(4), 107-115.*
5. Aboutalebi, M., Bozorg-Haddad, O., & Loáiciga, H. A. (2017). Multiobjective design of water-quality monitoring networks in river-reservoir systems. *Journal of environmental engineering, 143(1), 04016070.*
6. Ziaie, R., Mohammadnezhad, B., Taheriyoun, M., Karimi, A., & Amiri, S. (2019). Evaluation of thermal stratification and eutrophication in Zayandeh Roud Dam Reservoir using two-dimensional CE-QUAL-W2 Model. *Journal of Environmental Engineering, 145(6), 05019001.*
7. Arefinia, A., Bozorg-Haddad, O., Oliazadeh, A., & Loáiciga, H. A. (2020). Reservoir water quality simulation with data mining models. *Environmental Monitoring and Assessment, 192, 1-13.*
8. Rasouli, S., Bazargan, J., & Shoaei, S. M. (2020). Application of IRWQISC Index in the Water Quality Evaluation of Dam Reservoirs (Case Study: Golabar Dam Reservoir, Zanjan). *Iranian Journal of Irrigation & Drainage, 13(6), 1820-1831.*
9. Hanjaniamin, A. E., Tabrizi, M. S., & Babazadeh, H. (2023). Dissolved oxygen concentration and eutrophication evaluation in Yamchi dam reservoir, Ardabil, Iran. *Applied Water Science, 13(1), 1-12.*