Journal of Research in Ecology

An International Scientific Research Journal

ISSN No: Print: 2319 –1546; Online: 2319– 1554

Journal of Research in Ecology

Original Research

Simulation of thermal stratification and eutrophication of Taham dam reservoir using CE-QUAL-W2 model

Authors:
Elnaz Abed[1], Mehdi Meftah[2], Abdolreza Zahiri[2] and Pouneh Saeidi[3]

Institution:

1. M.Sc of Water Resources Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

2. Ph. D Construction of Water Structures, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

3. Ph. D Student of Environmental Engineering, University of Tehran, Tehran, Iran.

Corresponding author:
Elnaz Abed

ABSTRACT:

Increasing water demand and spread of water pollution through the development of agricultural, urban, industrial, and mineral activities have caused unfavorable conditions in many parts of the world, including Iran. As water resources in Iran are limited, the quality of fresh water supplies is becoming more and more important. The models of simulating the quality of reservoir water are an appropriate tool for forecasting the water quality and estimating the effects of environmental pollution after the start of operation, regarding the physical and climatic conditions of the reservoir and the inflow of the river. This paper aims to simulate the thermal stratification and eutrophication of the Taham Dam reservoir using the CE-QUAL-W2 model. In this regard, first, the hydrodynamic model of the Taham Dam reservoir was constructed and calibrated with ce-qual-w2 software and used to simulate thermal stratification in the dam. The results showed that thermal stratification and eutrophication in this reservoir occurs from the late spring to early autumn. However, the thermal stratification is disappeared and mixing condition However, the thermal stratification is disappeared and mixing condition happens in the reservoir by approaching the winter. At the time of thermal stratification, temperature changes and its effect on water temperature, simultaneously on algae and other parameters affecting the concentration of dissolved oxygen reduce the concentration of this parameter in depth and liken the conditions of the reservoir floor to anaerobic state.

Keywords*s:*
Taham dam, Thermal stratification, Eutrophication, CE-QUAL-W2, Dam reservoir, Calibration.

Article Citation:
Elnaz Abed, Mehdi Meftah, Abdolreza Zahiri and Pouneh Saeidi.
Simulation of thermal stratification and eutrophication of Taham dam reservoir using CE-QUAL-W2 model
Journal of Research in Ecology (2019) 7(1): 2510-2521

Dates:
Received: 15 Sep 2018 **Accepted:** 02 Jan 2019 **Published:** 04 June 2019

Web Address:
http://ecologyresearch.info/documents/EC0640.pdf

INTRODUCTION

In recent years, in addition to paying attention to quantitative issues, special attention has also been paid to water quality problems due to the limitation of water resources and the growing population. The water behind the dam is categorized as surface water. The quality of such water resource is extremely affected by the drainage basin activities of that dam. In general, the occurrence of processes such as thermal stratification and eutrophication in reservoirs is one of the issues that causes a sharp drop in water quality and lack of water quality in various uses. Considering the importance of thermal and qualitative stratification of water reservoirs and lakes, the amount of water pumping is effective in the quality of outlet water and the water in the reservoir. Qualitative management of reservoirs and lakes is generally carried out through the control of input contaminations, changing the hydraulic regime, changing the state of chemical and biological processes inside the reservoir, and selective pumping of different layers. The increased temperature causes summer thermal stratification and with more air temperature fall in the autumn and winter, the temperature of water surface decreases more than its depth leading to the mixing in the dam reservoir.

Given that lake dams are considered as one of the most important sources of freshwater, their quality is one of the main priorities of a country's policies. The purpose of these studies is to simulate thermal stratification in different seasons in the Taham dam reservoir. According to the geometric characteristics of the Taham dam reservoir, the CE-QUAL-W2 model was proposed to simulate the thermal stratification of this dam. The most important points outlining the superiority of this model to other models are: compatibility of the geometric shape of the reservoir with two dimensional conditions, considering the topography of the bed in the CE-QUAL-W2 model, whose information is available, better prediction of the thermal stratification conditions of the reservoiur considering meteorological data and input current.

MATERIALS AND METHODS

In CE-QUAL-W2 software, for understanding the geometry of the dam reservoir, the length and depth of the reservoirs are divided and given to the model. The tank consists of a main branch with length of about 4,800 m and a sub branch with the length of about 1,000 m. The main branch is divided into 13 pieces with varying intervals of 100 to 400 m and the sub branch is divided into four pieces at intervals of 350 m. The depth of the reservoir is divided into 52 layers of 1 to 3 m in size. Figures 1 and 2 show the geometry of the dam reservoir in a schematic form in the software.

The initial water temperature is in the form of a profile entered into the model. The thickness of the ice is also considered by zero considering the geographic location. The type of water introduced is fresh. This model operates on the basis of solving two-dimensional unsteady hydrodynamic and advection-dispersion questions. This model can be used to determine the water level, flow rate and temperature. The temperature is due to the effect on the density of water in the hydrodynamic calculations. The basis of this model is solving the equations of mean transverse momentum, continuity and transfer to the Implicit Finite Difference (FDM) method, which is obtained by simultaneously solving the equation of equilibrium momentum and the equation of free water level. The results of this method in the long wave equation, solved at any time, provide a blue surface profile that can also be determined from the vertical pressure distribution. Then, the momentum is calculated horizontally and the internal cohesion and component of the transfer are calculated. In this program, the ultimate finite difference scheme is used to solve the transition processes in the equilibrium equation. The vertical momentum disturbance of the momentum and the vertical and horizontal cutting components

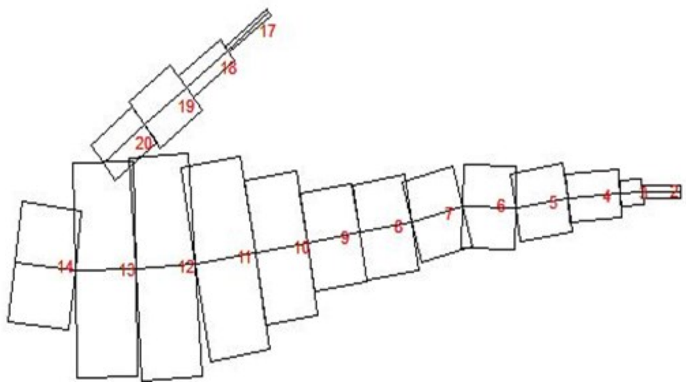

Figure 1. Reservoir level divisions to simulate the model

independent of the gradient are determined by the Richardson number function. Table 2 shows the formulas presented for calculating the vertical vertiginous diffusion.

In the section of the hydraulic coefficients of the model, the methods PNG, W2, W2N, OARAB, NICK, TKE, and TKE1 are available for calculating vertical vertiginous diffusion. However, the W2 method is chosen for this model because it is both a default model and a better match in calibration with observational data. At this stage and after implementing the model based on boundary conditions and initial values, the modeling is performed by changing the effective coefficients. Finally, the best value for effective coefficients is chosen by calculating the relative and absolute error between the observations and modeling.

The time of model was considered varied from 1 second to 3600 seconds in order to select the optimal time in this interval in each modeling step regarding the used time selection algorithm in the model. As mentioned, the method for solving the transport equations of the ULTIMATE method with a TETA coefficient of zero represented the best response to the model calibration.

RESULTS

The general specifications of the basin and reservoir of the Taham Dam are presented in Table 1. Considering that stratification has a great impact on the quality of lake and reservoir water and the nutritional phenomenon, prediction of thermal reservoir stratification potential is an important consideration. Direct measurement of the temperature profile and quality parameters at the points and depths of the reservoir is the best way to detect thermal imprinting. The purpose of this paper is to identify the thermal and nutritional status of the Tahm Dam reservoir to simulate its thermal behavior during a one-year sampling period (from Sep-

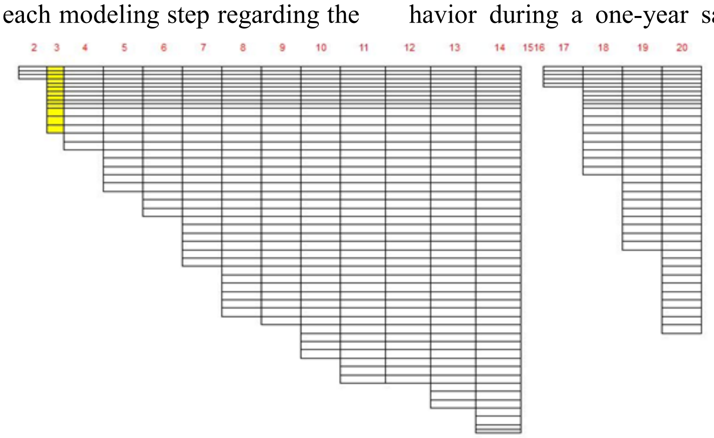

Figure 2. The simple façade of different sections' lateral depth

tember, 2014 to August, 2015). In Figure 3, the position of the dam and the sampling points are shown.

The results of temperature simulation from a modeling near the dam body indicated that the reservoir of Taham Dam once a year faces with the thermal stratification and once with mixing. Thermal stratification-starts from mid-spring and continues to early autumn.

At the peak of the thermal stratification July and August) near the dam crest which directly affects the quality of outlet water, the thickness of interlayer increases up to 21 m. Also, the temperature difference of the bottom and top of the interlayer reaches 14^{o}C, which is equivalent to a thermal gradient of 66.0^{o}C per meter. The thermocline level at this time varies from 1862 to 1864 m from the sea level, and accordingly the reservoir outflow levels are located in the thermal stratification continues and in mid-November, the vertical mixing of interlayer and substratum. But gradually, with the cooling of the air, this temperature difference decreases and the thermal stratification weakens. As time passes and with the cooling of the air, the process of reducing the reservoir is started and from December, the reservoir experiences a complete isothermal. This process continues until the winter and early April.

At the time of thermal stratification, the temperature of the reservoir's floor is between 7 and 10°C and at full mixing, this temperature reaches about 4 or 5°C. The reservoir of Taham dam has had complete vertical mixing during about four months of the year (December, January, February, March). Five months from the year (late May, June, July, August and September) has a temperature gradient in the range of 1855-18660 meters above sea level.

Accordingly, the critical time to control and manage the reservoir in terms of the thermal stratification phenomenon on and the limitation of the transfer of qualitative parameters, in particular the soluble oxygen from the surface to the reservoir floor, is three months of the summer eutrophication, especially during the peak of thermal stratification (summer), is felt more than ever. And in the other seasons, the thermal regime of the reservoir of the dam in this case is not problematic. According to the above results, the necessity of modeling and qualitative simulation of the parameters affecting the reservoir eutrophication, especially during the peak of thermal stratification (summer), is felt more than ever.

Figures 4 show the variation of dissolved oxygen during the simulation period at different depths of the final section in the dam. The output of the model is prepared for 12 o'clock at noon. By comparing these figures of thermal stratification, it is concluded that at the beginning of the simulation period (October), dissolved oxygen is at a different depth and surface, which is affected by the thermal stratification created in the reservoir. This difference is eliminated by mixing completely in the Taham reservoir in late autumn and winter and the concentration of dissolved oxygen in the reservoir becomes uniform.

However, with the onset of the heat season and the formation of the heat-sealing phenomenon, the difference in concentration in the dissolved oxygen and depth is repeated, and in the middle layer due to the activity of algae, a further decrease in the concentration

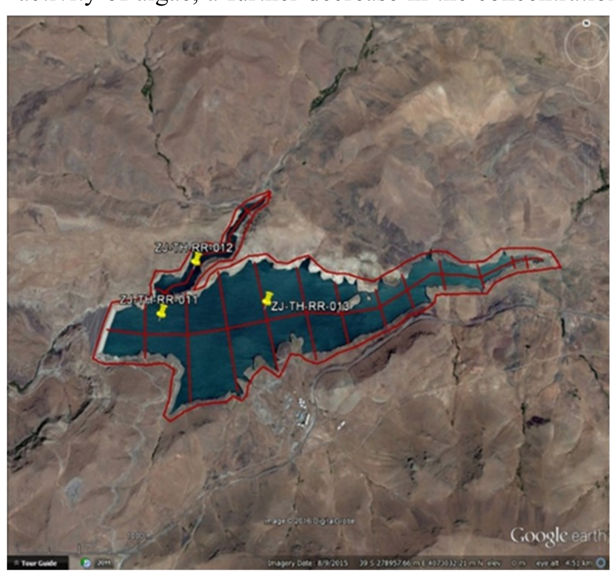

Figure 3. A view of the location of the design and location of the Taham Dam

Table 1. The specifications of Taham dam and reservoir

S. No	Variable	Amount
1	Dam height from sea	123.70 m
2	Crest length	451 m
3	Crest width	12 m
4	Dam crest level	1892.00 m
5	ormal level	1886.00 m
6	Maximum	1889.93 m
7	Minimum	1832.00 m
8	Total volume of the reservoir	87.78 million
9	Useful volume	82.7 million
10	Lake surface	317 hectares
11	Floor level	177 m from sea surface

of dissolved oxygen is observed. This decrease in the concentration of dissolved oxygen in the reservoir depth can be detected, and in August and September, the concentration of dissolved oxygen in the substrate is less than 2 and less than 4 mg / L, respectively.

In other words, in warm seasons that thermal stratification is performed, dissolved oxygen also experiences the stratification and decreases with increasing depth. In cold seasons when the thermal mixing is observed in the reservoir, dissolved oxygen is also homogeneous throughout the reservoir. Based on this, in the reservoir of the Taham dam along with algae activity, thermal stratification is one of the main reasons for creating anaerobic conditions in the reservoir depth and preventing vertical depositional oxygen transfer.

Figure 4 shows the concentration of the deep-dissolved oxygen. Reducing the concentration of dissolved oxygen in the reservoir's depth will result in a decrease in the total reservoir to less than 3 mg/L by starting the vertical mix in November. Although the amount of increased dissolved oxygen is appropriate through the winter by decreased temperature and continuous vertical mixing, the late summer and early autumn is a critical period for the reservoir of Taham dam and the quality of water decreases. Given that the outputs of the model were prepared at 12 noon, and considering the changes in the concentration of algae in the reservoir depth, the results of the model are clearly taken that the algal activity is directly related to changes in the concentration of dissolved oxygen. The highest amount of dissolved oxygen in this branch was observed at the end of winter and about 10 mg/L. The lowest amount of dissolved oxygen was observed at zero and under the layer at the end of the thermal imprint period.

The algae diagram is shown in Figure 5 during simulation time in different depth layers. The changes in the algal concentration in depth indicate the activity of this parameter in the interlayer and surface layer. The interpretation of the variation of this parameter without considering the concentration of dissolved oxygen and the weather process is impossible. Also, the presence of carbon and silica, which are essential ingredients in the growth of algae, is very effective in interpreting this parameter. As seen from the autumn chapter, in the months of October and November, when the concentration of this parameter reached its highest level, anaerobic conditions were observed at the depth of the reservoir. These results show the effect of algae growth and activity on reducing the quality of the reservoir.

In addition, the changes in the algal concentration in the reservoir depth follow the temperature regime of the reservoir of the dam. Therefore, changing the thermal regime of the reservoir of the dam or increasing the vertical mixing time will undoubtedly affect the concentration of this parameter.

Changes in phosphate and nitrate concentrations in the Taham dam reservoir are indicated in Figure 6 and 7. Since these two parameters are consumed by algae and other aquatic organisms, their changes depend on the input concentration and the changes in these factors in different layers as well as the changes in dissolved oxygen in the depth.

By comparing the above graphs with the concentrations of dissolved oxygen and algae, it is observed

Table 2. The formulae presented for calculating the vertical vertiginous diffusion

S. No	Formulae	Variables
1	$v_t = k\left(\frac{l_m^2}{2}\right)\sqrt{\left(\frac{\delta U}{\delta z}\right)^2 + \left(\frac{\tau_{wy} e^{-2kkz}}{\rho v_t}\right)} e^{(-CRi)}$ $l_m = H\left[0.14 - 0.08\left(1-\frac{z}{H}\right)^2 - 0.06\left(1-\frac{z}{H}\right)^4\right]$	W2 with Nicoradze mixing length (W2N)
2	l_m	Mixing length
3	u_*	Cutting speed
4	Z	Vertical spacing
5	K	Faun Carmen's constant
6	u	Horizontal speed
7	τ_{wy}	Tension due to the wind
8	Ri	Richardson number
9	k	Wave number
10	C	Constant coefficient which is usually 0.15
11	H	Depth
12	Δz_{max}	Maximum distance of networks
13	$V, \Psi(x) = \max(0, x)$	Molecular viscosity
14	C_1	Total constant (considered 100)

that phosphate and nitrate in the surface layers of algae decrease due to consumption by this parameter. In early autumn, due to the formation of anaerobic conditions on the floor, the release of phosphate from the foam sediments has led to the fact that the ratio of N: P is more than 2.7, phosphate is a limiting factor in this branch.

Considering the limitation of phosphate, its availability during this period (early fall) increases nitrate consumption by microorganisms and reduces nitrate in depth. The creation of such conditions is one of the effects of the thermal stratification phenomen on that leads to nutritional orientation of the environment.

DISCUSSION

Based on the results, the thermal stratification cycle of the Taham dam reservoir is a type of monomictic lake. In other words, the reservoir of this dam experiences thermal and thermal imbalances once a year, following the natural trend of its thermal latitude. Based on the results and charts of the CE-QUAL-W2 model, the peak of thermal imprinting occurs in the summer in the late June and early July, while the thermocline level is about 1863 m above sea level, and the thickness of the interlayer is about 20 m. Moreover, the thermal gradient between the layers is 0.65°C per meter depth.

Accordingly, the beginning of the thermal stratifications June, reaching its peak in July and August, also due to the thermal gradient. Celsius degrees per meter in November, this month can be considered as a time for thermal stratification analysis and the beginning of temperature mixing. Regarding the results of the simulations carried out in the reservoir of the Taham dam, vertical mixing is observed in winter. In the spring, with the warming of the air, the surface of the

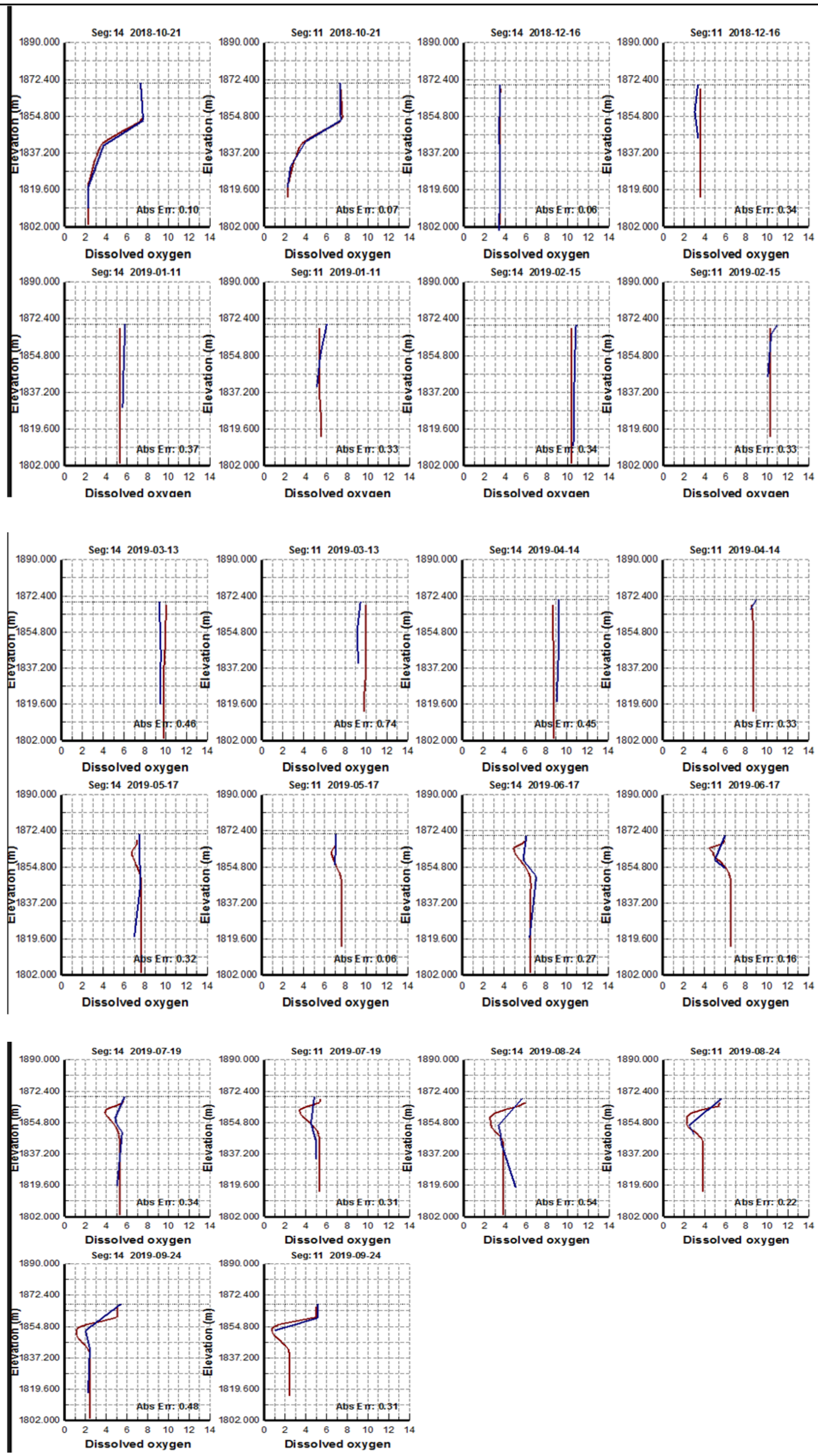

Figure 4. The results of calibration of dissolved oxygen in Taham dam reservoir

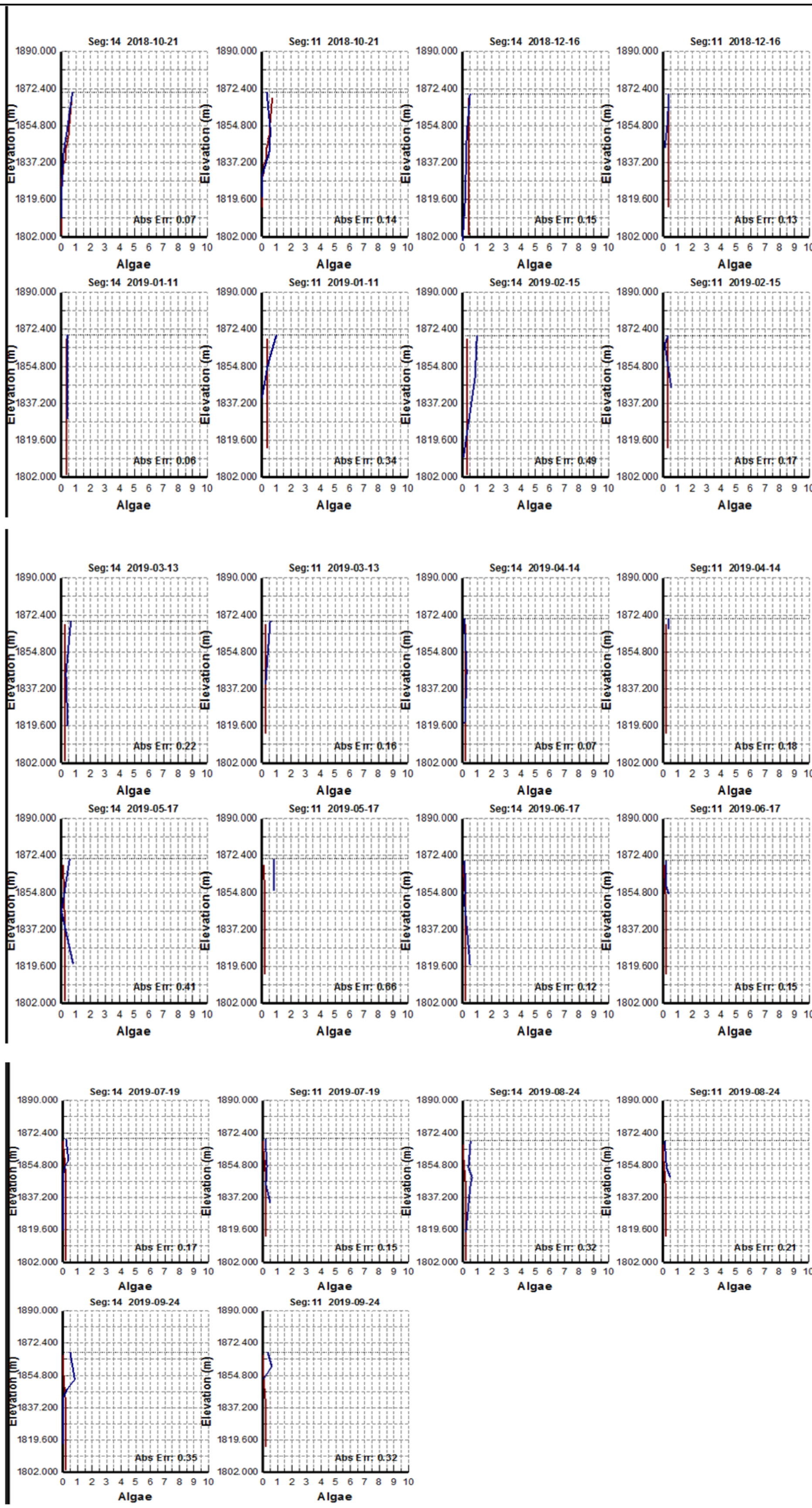

Figure 5. Algae calibration results at Taham dam reservoir

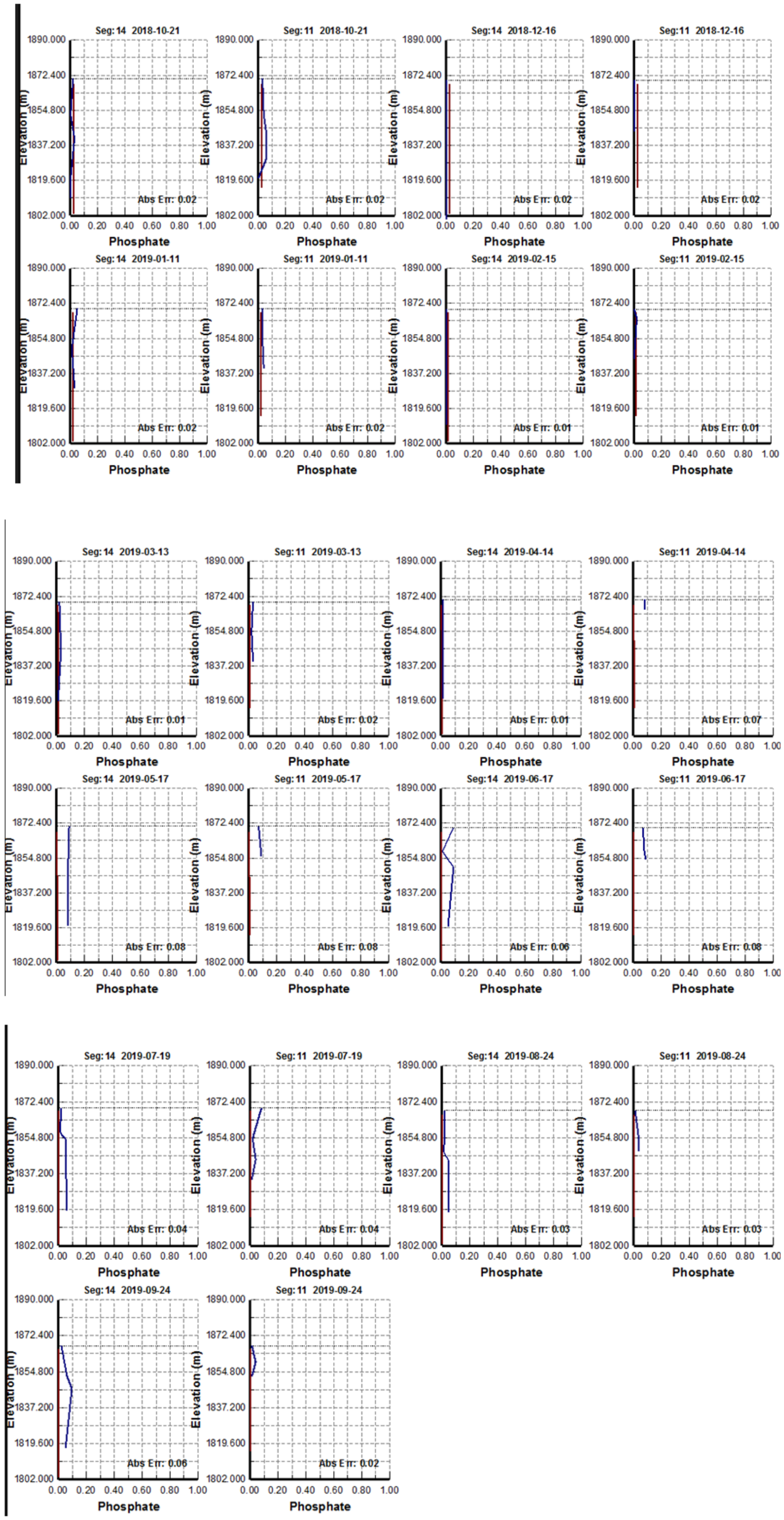

Figure 6. Phosphate calibration results in Taham dam reservoir

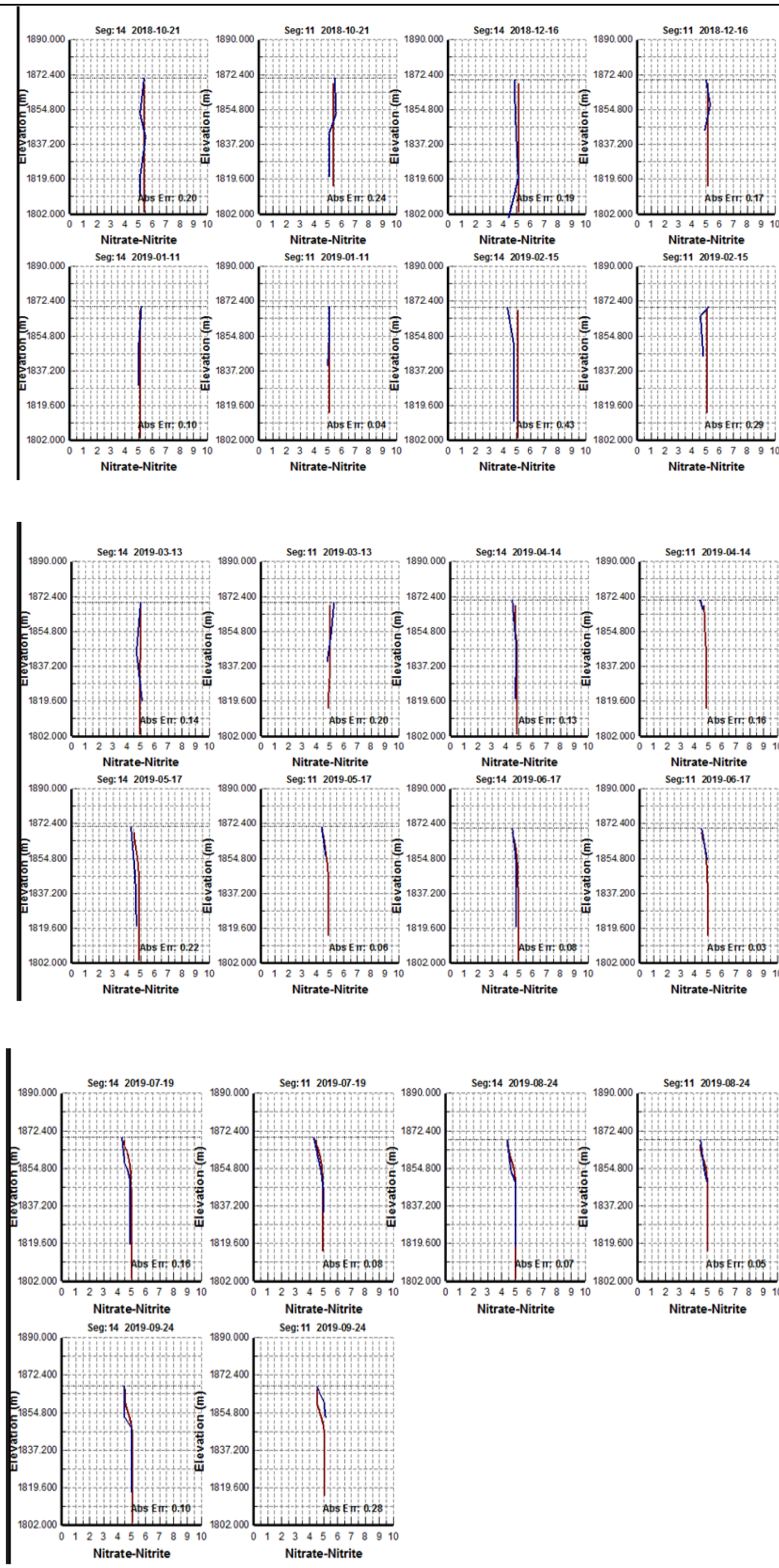

Figure 7. Nitrate calibration results in Taham dam reservoir

reservoir gradually becomes warmer and the water temperature of the surface layers is more than the depth. Due to the heat transfer rate from surface to depth and mixing caused by inlet and outlet flows, over time, a layer with a high thermal gradient is formed between the surface and depth of the reservoir and the temperature difference is more than 10° between the surface and depth. As mentioned earlier, the beginning of June could be the beginning of the thermal imprinting in the reservoir of Taham dam, which gradually became more intense in summer when the temperature of the air and the surface absorption are increased.

At the peak of the thermal stratification July and August) near the dam crest, which directly affects the water quality of the dam, the thickness of the layer is increased to 21 m. Moreover, the thermal difference between the bottom and top of the layer is up to 14°C, which is equivalent to a thermal gradient of 0.66°C per meter. The thermocline level at this time varies from 1862 to 1864 m from the sea level and accordingly the reservoir outflow levels are located in the midline and substrate. But gradually, with the cooling of the air, this temperature difference decreases and the thermal stratification weakens.

As time passes and the cooling of the air, the process of reducing thermal stratification continues and in mid-November, the mixing of the reservoir is started and from December, the reservoir experiences a complete mix of vertebrate. This process continues until the winter and early April.

The critical time for controlling and managing the reservoir in terms of thermal stratification phenomenon and the limitation of the transfer of qualitative parameters, especially the dissolved oxygen from the surface to the reservoir floor, is three months of the summer, and in other seasons, the thermal regime of the reservoir of the dam will not be problematic in this regard.

Raphael (1962) performed the first reservoir simulation. He represented an approach in order to predict water temperature changes using meteorological statistics, input and output characteristics, reservoir space and capacity. This method was recommended for shallow lakes that are not inter layered and are completely homogeneous. Orlob and Selna (1970) represented a one-dimensional simulation model for simulating thermal behavior in deep lakes. The development of this model was continued till 1975.

Mohammadnejad *et al*. (2014) investigated the thermal stratificationand its effect on the water quality of Maku dam. They declared that dam position, district climate, and type of dam exploitation were effective in the quality of surface water flow. The results of this study announced that the pumping from arbitrary levels, destruction of the reservoir stratification or mixing, and aeration of outlet water from the dam by behaviors such as hydraulic jump are suggested therapeutic approaches at different ages of a dam to prevent stratification and to increase the water quality of the dam.

Yu *et al*. (2010) investigated the effect of pollution distribution on the time and spatial dimensions of natural organic materials in thermal stratification of Daecheong dam. The results of CE-QUAL-W2 simulation showed the appropriate conformity of simulated data with observational values in dissolved organic matter including refractory dissolved organic carbon and dissolved organic carbon. Moreover, the input flows and stratification phenomenon in the reservoir were well described in this simulation.

Ma *et al*. (2015) studied three reservoir dams of Gorges in China. The filling of these three dams in China was due to the presence of phytoplankton and its significant flourishing in a sub branch. These dams were simulated by a qualitative and hydraulic model of CE-QUAL-W2. In Xiangxi gulf, there is a direct relationship between phytoplankton and flow concentration. The model was studied for the influence of different parameters such as water level in the main reservoir, temperature difference between the input main and minor rivers. Therefore, it perceives the ecosystems of sub branches with a better understanding of its dynamics of sub branches ecosystems.

Ma *et al*. (2015) studied qualitatively three parallel barriers (Yeongsan, Okcheon and Kumja) in the Southwest of South Korea. Due to continuous contaminant entry from the upstream of this system, the barrier had experienced a drop in quality. The purpose of this study was to prevent the entry of the pollutant to the dam and the integrated studies of the dam in terms of quality. The results showed that operational strategies can be very effective in reducing the nutritional status of the reservoir.

Fataei *et al*. (2014) obtained similar results. According to their study, the Seimare dam will be exposed to the phenomenon of thermal imprint and once upon a time with full mixing phenomenon.

Ebrahimi *et al*. (2015) concluded that in nine months of the year, the thermal stratification occurs in Baft dam. Morovatdoust *et al*. (2015) studied the water quality of Sefidrud river in Rudbar area and declared that DO level in Sefidrud river was favorable and above the minimum standard of WHO drinking water. The model used in this research also has the same capability as the QUAL2KW model and is capable of qualitative simulation and evaluation of the environmental response of pollutants.

CONCLUSION

It is suggested that in the further researches, the results of applying two models for the same environment be investigated to evaluate and compare these models.

REFERENCES

Ebrahimi M, Jabbari E and Abbas H. 2015. Simulation of thermal stratification and salinity in dam.

Fataei E, Ansari MD and Nasehi F. 2014. Prediction of thermal stratification of Seymareh.

Ma J, Liu D, Wells SA, Tang H, Ji D and Yang Z. 2015. Modeling density currents in a typical tributary of the three gorges reservoir, China. *Ecological modeling*, 296: 113–125.

Mohammadnejad B, Behmanesh J and Hamzehpour S. 2014. Investigation of thermal bonding and its effect on the quality of reservoir water (case study of Maku dam). Master thesis, Urmia University, Faculty of agriculture and natural resources.

Morovatdoust AM, Haeripour S and Amirnejad R. 2015. Water quality assessment of Sefidrud river in the Rudbar city. Scientific Quarterly Journal.

Orlob GT and Selna LG. 1970. Temperature variations in deep reservoirs. *Journal of the Hydraulics Division*, 96(2): 391-410.

Raphael JM. 1962. Prediction of temperature in rivers and reservoirs. *Journal of the Power Division*, 88(2): 157-82.

Yu SJ, Lee JY and Ha SR. 2010. Effect of a seasonal diffuse pollution migration on natural organic matter behavior in a stratified dam reservoir. *Journal of Environmental Sciences*, 22(6): 908-14.