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## ORIGINAL ARTICLE

# Prediction of thermal stratification of Seymareh Dam using CE-QUAL-W2 Model

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**ABSTRACT**

*One of the most important problems of water quality in the world particularly in dams, is thermal stratification and consequently water qualitative problems of dam and its outlet. An important qualitative problem is reduction of oxygen level of the solution resulted from thermal stratification. In this study, CE-QUAL-W2 qualitative model was used to investigate thermal stratification conditions of the reservoir of Seymareh Dam and its qualitative status in Ilam province. In this regard, the used input data included geometric data (bathymetry), boundary conditions, hydraulic and kinetic parameters. Quantitative and qualitative calibration of the reservoir was carried out by entering the input and output data of the reservoir water. The amount of oxygen demand in the bottom of the tank was assessed in qualitative model as Sediment Oxygen Demand (SOD). Results of the first stage (April to November 2011) shows that, at the first stage of dewatering, thermal stratification begin since May and reaches its peak in June and July. In September, by decreasing water temperature, thermal stratification gradient gradually decrease and in the early November, when the reservoir temperature become the same at the depth, the reservoir is disturbed. In continue, in the months December to March, the reservoir reaches completely mixed state. Thermal stratification begins again since April 2012 and lasts until December 2012. With regard to the increase of the reservoir water depth at the second stage of dewatering, thermal stratification period in longer than the first stage; so that, Seymareh reservoir is also faced with thermal stratification in autumn. The results of this study showed that, low water volume and depth at dewatering time of Seymareh dam reservoir is considered as a factor affecting qualitative problem of this dam; since, with regard to the low water depth, anaerobic conditions is transferred to the upper layers of the water. Therefore, by increase of water volume and depth, the occurrence probability of this problem is decreased partly in the upper layers.*
***Keywords:*** *Seymareh Dam, Thermal stratification, Dissolved oxygen, CE-QUAL-W2.*

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## INTRODUCTION

Required water supply with acceptable quality and quantity is a fundamental issues of the human life. Nowadays, the reservoirs play a role in the human life higher than water supply so that, there is a new view of the goals of dams' reservoirs which is to provide the required quality of water [4]. The first step in investigating the biological – physical processes in the reservoirs is awareness about thermal stratification phenomenon, how to generate it and its consistent processes because, temperature affects accelerating of reactions and material decomposition, and on the other hand, concentration and spatial and temporal trends of these materials and elements represent the reservoir water quality. Temperature and stability state of dams' reservoirs water can be predicted using mathematical models and in case of environmental problems, various methods can be considered to improve its conditions [1].
Saeedi *et al.* [3] studied thermal stratification of Pishin dam in Sistan-o-Baloochestan by CE-QUAL-W2 model and predicted the existence of a steady thermal regime which is completely mixed only in case of seasonal flood occurrence. Zohrevand *et al.* [5] in investigation of thermal stratification of Mamloo dam reservoir in downstream of Latian dam on Jajrood River by CE-QUAL-W2 model, first produced the dam' information including geometric, meteorological and hydrological information of the dam' reservoir and modeled the simulation of thermal behavior of Mamloo dam based on temperature variations after water

level calibration. Nazariha *et al* [6] Used CE-QUAL-W2 model to predict thermal stratification in Bakhtiari dam and studied the results of two scenarios of normal and dry years.

Enkon (2006) investigated the effects of Yousefali dam located in Turkey on the reservoir thermal stratification using one-dimensional model (DYRESM). Sarang*et al.* [2] carried out the simulation of the reservoir water quality of Bukan dam located on Zarrinehrood in Kordestan province using other modes such as one-dimensional model (HEC5-Q). In this research, parameters of pH, Nitrogen, Dissolved Oxygen, Electrical Conductivity, etc. were simulated in reservoir of the mentioned dam, and the results of model were assessed and compared with the measured data from the dam reservoir. Chang Wawe, [13]conducted the calibration and verification of Daecheong reservoir using CE-QUAL-W2 model. They could model water temperature with mean error by 0.11 to 1.19 ºC in calibration period using sensitivity analysis on parameters of Chezy coefficient, heat and sediment transfer coefficient. With regard to 50 km length of Seymareh dam reservoir and its low width, (averagely 1 km) and also, the situation of available information (topography of the reservoir bed, qualitative and quantitative information of inflow and dam reservoir utilization), CE-QUAL-W2 model was selected to simulate thermal stratification of Seymareh dam reservoir.

## MATERIALS AND METHODS

### *Study area*

Seymareh dam is located 700 km far from the southwest of Tehran, with a 2.8 billion m3 reservoir, and is as the highest dam of Ilam province and one of 10 largest dams of Iran. This dam has a powerhouse with three 160 MW units and annual production capacity by 850 GWH of electricity power. Seymareh dam is located 40 km far from the northwest of DarrehShahr and 106 km far from the southeast of Ilam city. The dam is placed on Seymareh River and upstream of its intersection with Kashkan River in 47 º 12' of eastern longitude and 33 º 17' of northern latitude. Seymareh dam has been constructed between Ilam and Lorestanprovinvce on Seymareh River located in 40 km far from northwest of DarrehShar city [6]. There is nutrition-oriented conditions in the stations of upstream catchments due to industries and agriculture [7] On the other hand, thermal stratification also affects water quality, hence, its modeling in the dam reservoir is important for more appropriate management.

### *Methods*

Hydrodynamic and qualitative two-dimension model of CE-QUAL-W2 is a program to model the reservoirs but, it can be used also to simulate rivers or a combination of water constructions by distinguishing boundary conditions of upstream and downstream. This software can simulate vertical and longitudinal distribution of thermal energy and selected chemical and biological material in the water mass over time, using finite difference method. Ability to simulate volume, water table, density, vertical and longitudinal velocity and concentration of qualitative components of water is also considerable. This model is suitable for relatively long and narrow reservoirs and rivers to show Vertical and longitudinal profile of qualitative water parameters [14]. In current study, CE-QUAL-W2 model was used to simulate water quality of Seymareh dam.

### *Required data of the software*

The used input data to apply CE-QUAL-W2 include geometric data, initial boundary conditions, hydraulic parameters and calibration data. Initial conditions are: beginning temperature profile and components, and boundary conditions are inflows, outflows and meteorological data. Meteorological statistics and information used in the model include hourly temperature data, dew point temperature, wind speed and direction and air cloudiness. To achieve these data, daily information of Koohdasht synoptic station, considering its low distance with the dam location [6].

In this modeling, input water temperature values have been calculated through indicator equations of river water temperature using air temperature in two different periods. These equations have been defined as below:

$$T_w = -0.0154\,T_\alpha^2 + 1.3202\,T_\alpha + 0.0666 \qquad \text{Equation 1}$$

$$T_w = 0.0004T_\alpha^3 - 0.0304T_\alpha^2 + 1.2939T_\alpha^{0.0814} \qquad \text{Equation 2}$$

Where $T_\alpha$is air temperature and $T_w$ is water temperature. Equation 1 and 2 are usable since January until August and since September until December.

## RESULTS

With regard to dewatering program of the reservoir of Seymareh dam, the first stage of dewatering began since 27 April 2011 and lasted until 10 June 2011. The second stage of dewatering began since the beginning of flood period since the second half of November and lasted until April 2012 when reaching the reservoir level to 670 m. with regard to the available in the studies, qualitative modeling of the dam reservoir was carried out for the first and second dewatering stages. Input, output and reservoir level values during dewatering period of the first and second stages have been shown in Table 1.

Table 1.Monthly values of input, output, reservoir storage and level during the first and second stage of the reservoir dewatering

| Reservoir volume million $m^3/s$ ) ( | Approximate level of the reservoir (m) | Reservoir outflow $m^3/s$ | Reservoir inflow $m^3/s$ | | Year |
|---|---|---|---|---|---|
| 93.35 | 629.58 | 41.3 | 79.5 | May | |
| 117.84 | 632.75 | 13.3 | 22.4 | Jun | |
| 108.62 | 631.60 | 8.0 | 4.6 | Jul | |
| 98.99 | 630.34 | 8.0 | 4.4 | Aug | |
| 92.05 | 629.40 | 7.8 | 5.3 | Sep | |
| 90.2 | 629.1 | 7.8 | 7.1 | Oct | 2011 |
| 136.9 | 635.0 | 7.9 | 26.0 | Nov | |
| 171.5 | 638.0 | 13.0 | 26.0 | Dec | |
| 191.0 | 641.0 | 14.0 | 22.0 | Jan | |
| 230.0 | 645.0 | 15.0 | 30.0 | Feb | |
| 415.0 | 656.0 | 15.0 | 89.0 | Mar | |
| 532.0 | 662.0 | 25.0 | 69.0 | Apr | |
| 739.0 | 670.0 | 25.0 | 102.0 | May | |
| 754.0 | 670.0 | 15.0 | 21.0 | Jun | 2012 |
| 754.0 | 67.0 | 13.0 | 13.0 | Jul | |
| 754.0 | 67.0 | 9.0 | 9.0 | Aug | |
| 754.0 | 67.0 | 9.0 | 9.0 | Sep | |
| 754.0 | 67.0 | 7.0 | 7.0 | Oct | |
| 780.0 | 671.0 | 15.0 | 26.0 | Nov | |
| 800.0 | 672.0 | 15.0 | 26.0 | Dec | |

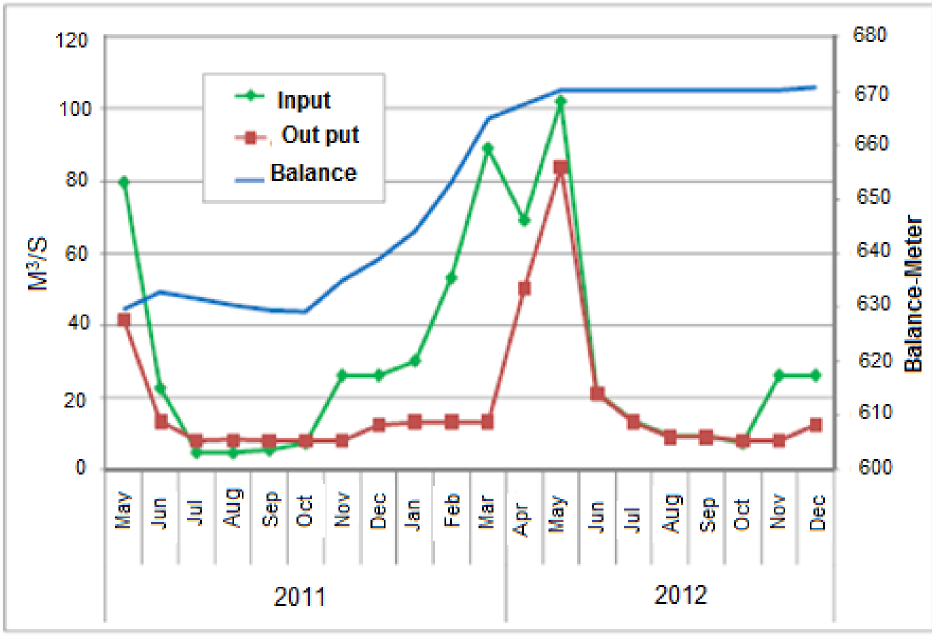


Figure 1. Monthly average distribution of inflow and outflow and reservoir storage level of Seymareh dam during dewatering period

In order to model Seymareh dam reservoir quantitatively, the sampling data of dam and power plant environmental impact assessment studies Sazbon [13]on Seymareh River have been used. Monthly information of qualitative parameters of Seymareh dam reservoir inflow has been shown in Table 2.

Table 2. Monthly information of Seymareh dam reservoir inflow quality

| Average | Dec | Jan | Feb | March | Apr | may | June | July | Aug | Sept | Oct | Nov | parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17.9 | 10.5 | 11.2 | 19.5 | 24 | 26.1 | 29 | 27.3 | 22.6 | 16.2 | 12 | 10.5 | 5.6 | Water-(c)temp |
| 307 | 337 | 360 | 425 | 364 | 351 | 172 | 258 | 283 | 150 | 334 | 312 | 337 | TDS(mg/L) |
| 881 | 8.58 | 8.13 | 8.68 | 11.43 | 8.31 | 9.43 | 8.13 | 7.32 | 8.71 | 9.1 | 8.12 | 9.72 | DO(mg/L) |
| 0.83 | 0.51 | 3.111 | 1.01 | 0.29 | 0.39 | 0.25 | 0.46 | 0.76 | 0.12 | 0.44 | 0.94 | 1.68 | $PO_4$(mg/L) |
| 1.02 | 0.86 | 0.138 | 0.911 | 1 | 0.89 | 0.46 | 2.19 | 4.27 | 0.303 | 0.181 | 0.569 | 0.526 | $NO_3$(mg/L) |
| 0.28 | 0.18 | 0.073 | 0.403 | 0.02 | 0.49 | 1.02 | 0.2 | 0.21 | 0.23 | 0.11 | 0.34 | 0.03 | $NH_4$(mg/L) |
| 6.4 | 4 | 3 | 2 | 13 | 10 | 16 | 20 | 2 | 2 | 2 | 1 | 2 | BOD(mg/L) |
| 0.3 | 0.01 | 0.09 | 1.15 | 0.029 | 1.08 | 0.84 | 0.052 | 0.029 | 0.141 | 0.169 | 0.025 | 0.018 | Chlorophyll a (mg/L) |

In order to develop qualitative simulation model, the reservoir shape was investigated. In Figure (2), digital elevation model (DEM) map of the reservoir has been shown. This map has been used to describe the reservoir geometry to the model. Characteristics of the reservoir length and the number of pieces have been indicated in Table (3) with regard to selecting 2000 m length for the plots.

Table (3). Geometric properties of the reservoir and model plots

| Value | Parameter | Number |
|---|---|---|
| 50 km | Length | 1 |
| 27 | Number of plots | 2 |
| 2000 m | Length of plots | 3 |

Deep divisions of the reservoir in the model was carried out to the layers with 2m and 62 layers. Deep reservoir layers have been considered 598 from normal level to the floor level of the reservoir. Considered segmentation plan for input of CE-QUAL-W2 model, and plan and stratification segments and segmentation of Seymareh dam reservoir have been shown in Figure (3) and Figure (4) respectively.

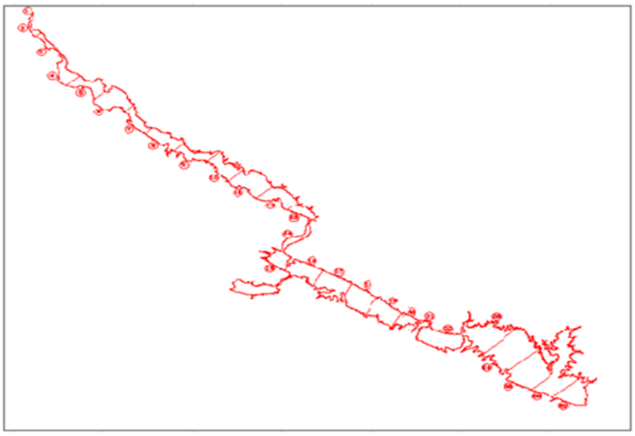

Figure 3. Considered segmentation plan for input of CE-QUAL-W2 model

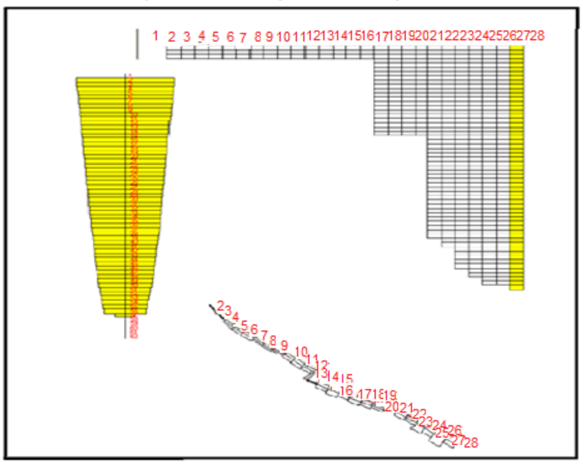


Figure 4. Plan and stratification segments and segmentation of Seymareh dam reservoir model

**Calibration of curve of reservoir surface, volume and height:**

In order to calibrate the reservoir geometry, results obtained from digital maps of segments were used, so that, the segments volume was calculated in different levels, and these values were entered to the model with a specific format. By performing the preparing file of the model, the results of reservoir volume and height calculation are saved in a file by the model. By comparing these results and real volume-height of the reservoir, input values of volume-height are modified if there is any significant difference. In Figure (5), real and input values of surface-height have been compared. As it has been shown in this graph, surface-height values obtained from the model and real values are appropriately consistent.

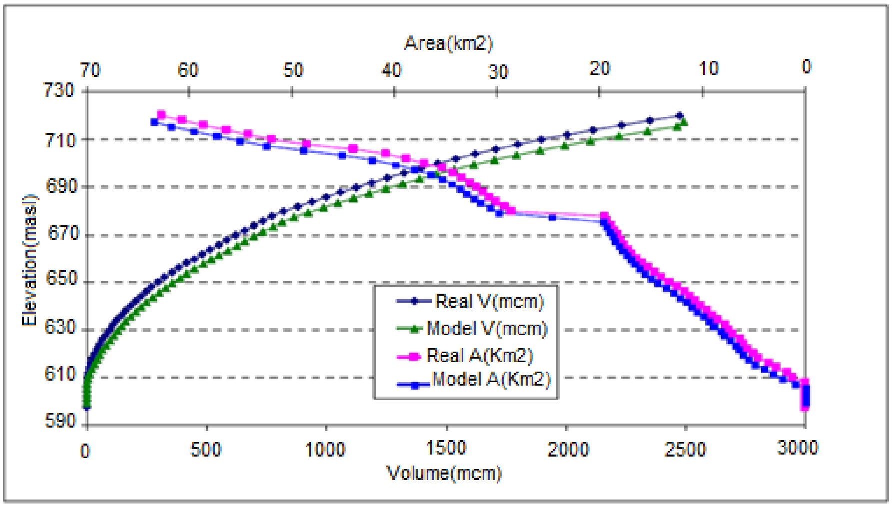


Figure 5. Surface-volume-height curve of Seymareh dam reservoir

Calibration of reservoir utilization:

In order to adapt the reservoir storage level in the conditions of qualitative model run and water resources programming in dewatering of the first and second stage, calibration of reservoir utilization has been conducted. In this regard, side software package of the model named Water balance was used. By running this program and defining the level file, adjusted values of the reservoir outflows are calculated. In Figure (6) the curve of real storage level and model qualitative output have been shown. According to this graph, level curve of qualitative model output storage after calibration, has corresponded to the real curve satisfactory.

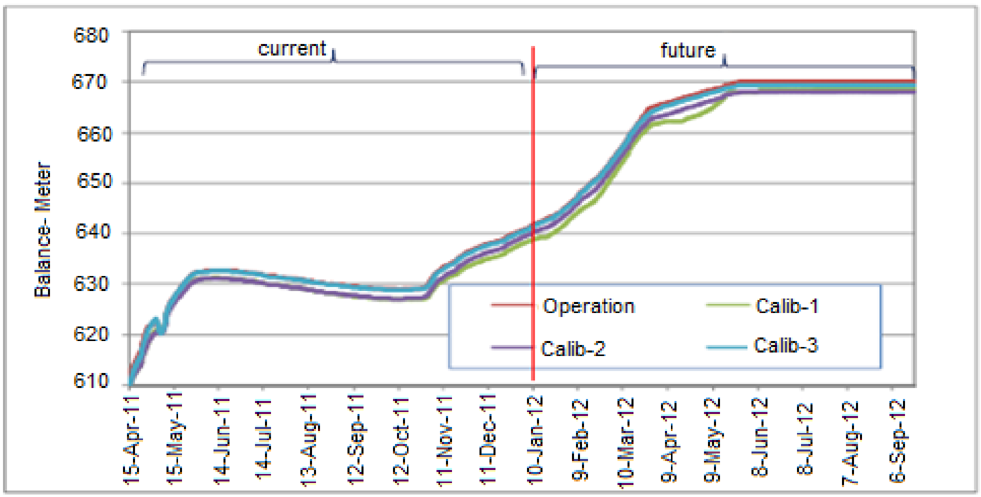


Figure (6) the curve of real storage level and model qualitative output

Calibration of depth profile of reservoir water temperature

In this section, output values of qualitative model of Seymareh dam were compared with the real achieved results by qualitative sampling through statistical and empirical methods. Used standards in this section for validation including:

 

Mean absolute error: this standard indicates the level of model reliability. The following equation is used to calculate percentage of the model error [8].

$$\text{Mean absolute error} = \frac{\sum_{i=1}^{n} |O_i - S_i|}{n}$$

Where n is number of sampling data, o is observed data, s is output data of qualitative model. Results obtained from this standard calculation are presented in continue. About this standard, with regard to the importance of qualitative parameter and parameter variations precision, the amount of error is analyzed.
Error percentage: this standard is also another model reliability standard. In order to calculate model error percentage, following equation is used [8].

$$\text{Error percentage} = \frac{\sum_{i=1}^{n} \frac{|O_i - S_i|}{S_i} \times 100}{n}$$

Variable parameters in the equation above also are like variables of mean absolute error. Analysis of error percentage for different qualitative parameters along with investigation of mean absolute error can largely show the amount of model reliability.
Proposed allowable error
This standard is empirical in which values close to 1 indicate very high reliability of the model results. Values between 0 and 1 high reliability of model. It is needed to be mentioned that, values less than zero show weak reliability in the model. This standard is calculated by the following equation [8]:

$$E_{ns} = 1 - \frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2}$$

Where n is number of sampling data, o is observed data, s is output data of qualitative model and Ô is mean of observed values. In Table (4), investigation of allowable error of temperature modeling has been shown.

Table 4. Investigation of allowable error of temperature modeling

| Data | Depth | temperature | Temperature model | Difference | The mean absolute error | Percent error | (o-s)^2 | (o-omin)^2 |
|---|---|---|---|---|---|---|---|---|
| June2011 | -1 | 28 | 28.7 | 0.7 | 0.7 | 2.4 | 0.490 | 13.161 |
| | -10 | 26 | 25 | -1 | 1 | 4.0 | 1.000 | 2.650 |
| | -20 | 24.2 | 23.8 | -0.4 | 0.4 | 1.7 | 0.160 | 0.030 |
| | -30 | 23.7 | 22.5 | -1.2 | 1.2 | 5.3 | 1.440 | 0.452 |
| July | -1 | 31.2 | 30 | -1.2 | 1.2 | 4.0 | 1.440 | 46.619 |
| | -10 | 25.3 | 25.2 | -0.1 | 0.1 | 0.4 | 0.010 | 0.861 |
| | -20 | 22.4 | 24 | 1.6 | 1.6 | 6.7 | 2.560 | 3.890 |
| | -30 | 22 | 22.4 | 0.4 | 0.4 | 1.8 | 0.160 | 5.627 |
| August | -1 | 29.3 | 29.3 | 0 | 0.4 | 0.0 | 0.000 | 24.283 |
| | -10 | 26.6 | 29 | 2.4 | 0 | 8.3 | 5.760 | 4.963 |
| | -20 | 23.3 | 23.5 | 0.2 | 2.4 | 0.9 | 0.040 | 1.150 |
| | -30 | 23.3 | 23 | -0.3 | 0.2 | 1.3 | 0.090 | 1.150 |
| October | -1 | 25.1 | 24 | -1.1 | 1.1 | 4.6 | 1.210 | 0.530 |
| | -10 | 23.9 | 24 | 0.1 | 0.1 | 0.4 | 0.010 | 0.223 |
| | -20 | 22.8 | 24 | 1.2 | 1.2 | 5.0 | 1.440 | 2.472 |
| | -30 | 22.8 | 22.8 | 0 | 0 | 0.0 | 0.000 | 2.472 |
| November | -1.5 | 19.5 | 19.2 | -0.3 | 0.3 | 1.6 | 0.090 | 23.739 |
| | -10 | 19.3 | 18.7 | -0.6 | 0.6 | 3.2 | 0.360 | 25.727 |
| | -20 | 17.6 | 18 | 0.4 | 0.4 | 2.2 | 0.160 | 45.863 |
| | -30 | 17.9 | 18 | 0.1 | 0.1 | 0.6 | 0.010 | 41.890 |
| | | | | | 13.3 | | 16.430 | 247.749 |
| | | | | | 0.67 | 2.71 | Ens: | 0.934 |

In Figure (7), depth profile of reservoir water temperature resulted from modeling and sampling has been shown.

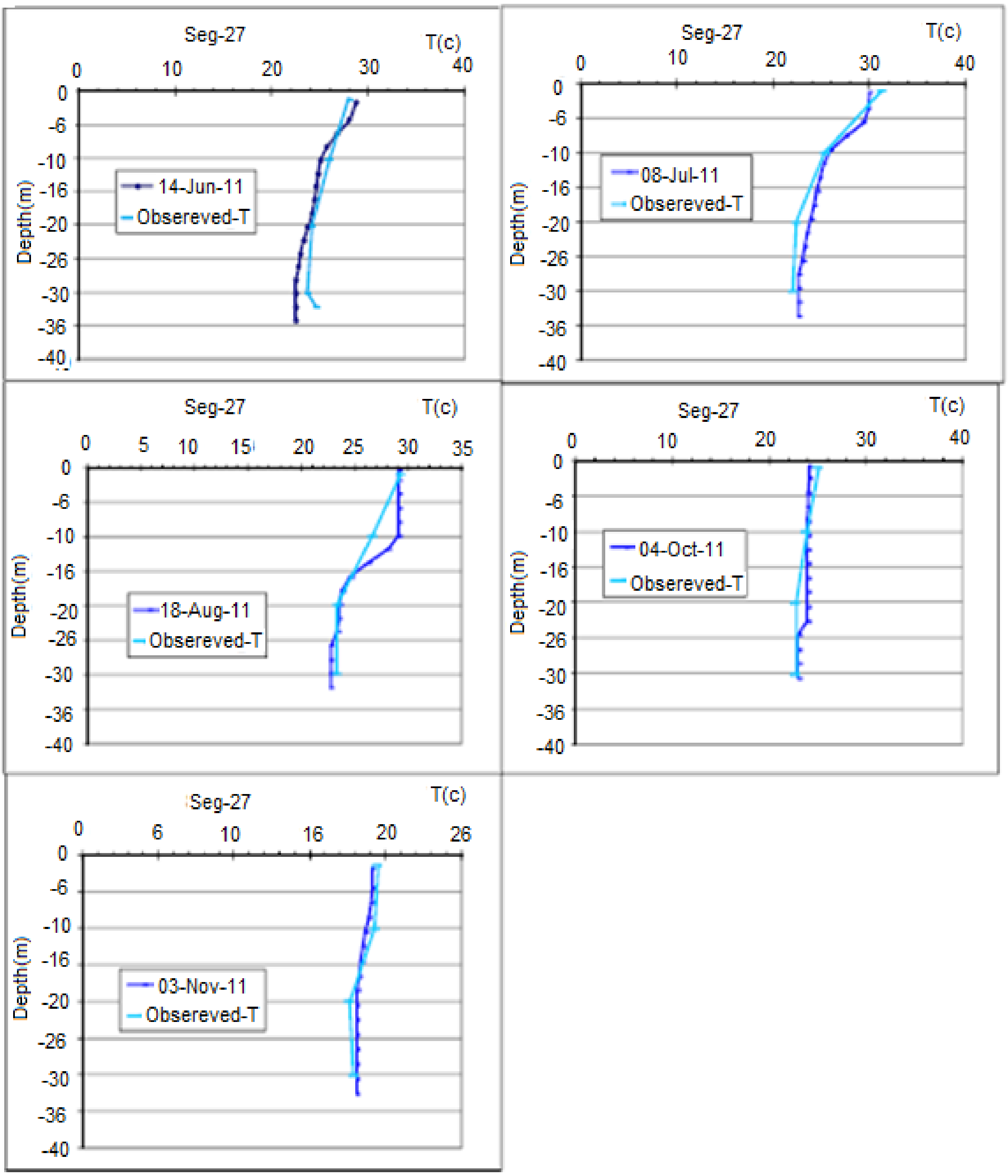


Figure 7. Comparison of depth profile of reservoir water temperature based on modeling and sampling

Thermal stratification of Seymareh dam

By running the model for temperature parameter and considering default values of the model, stratification profiles were achieved for the first stage (April 2011 till November 2011) and second stage of dewatering (November 2011 till December 2012) in segment 27 close to Seymareh dam axis as Figures (80) and (9). Figure (7) shows temperature monthly depth profiles for segment 27 in the vicinity of Seymareh dam at the first stage of dewatering, and Figure (10) shows Seymareh dam outflow temperature variations at the first and second stage of dewatering (April 2011 till December 2012).

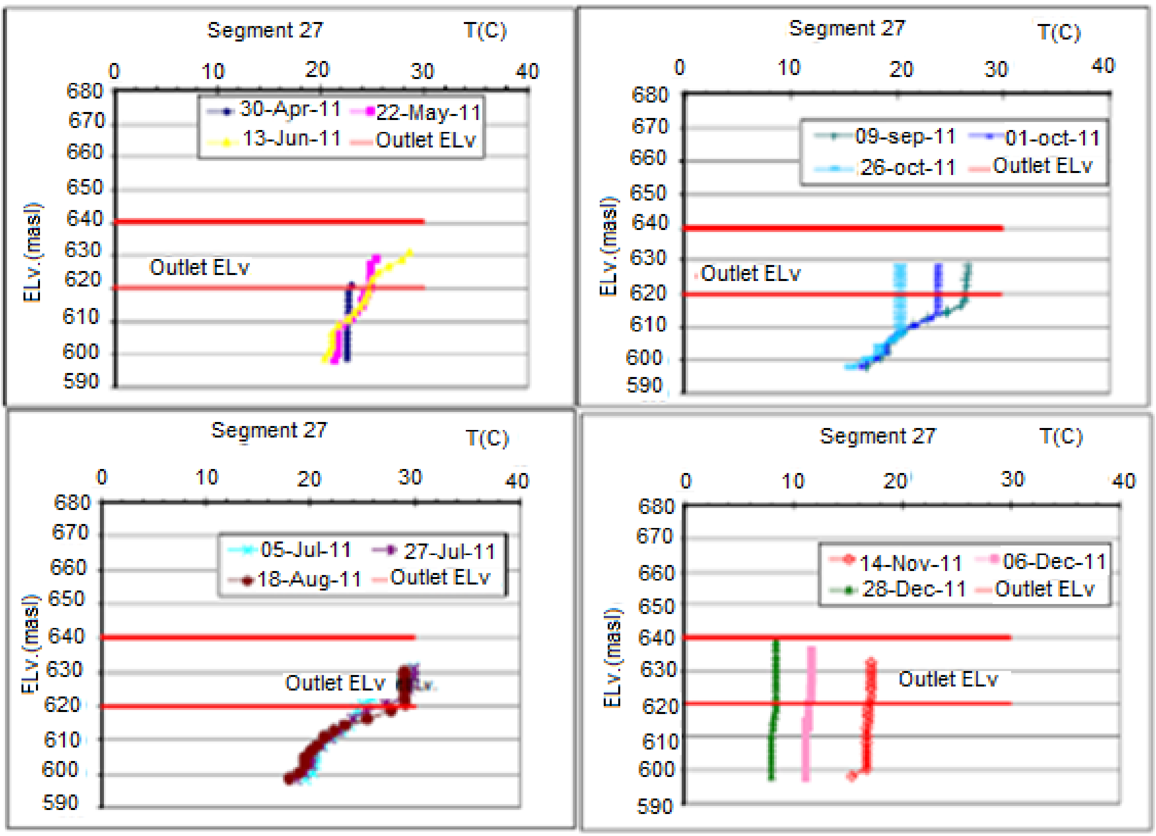


Figure 8. Temperature monthly depth profiles for segment 27 in the vicinity of Seymareh dam at the first stage of dewatering

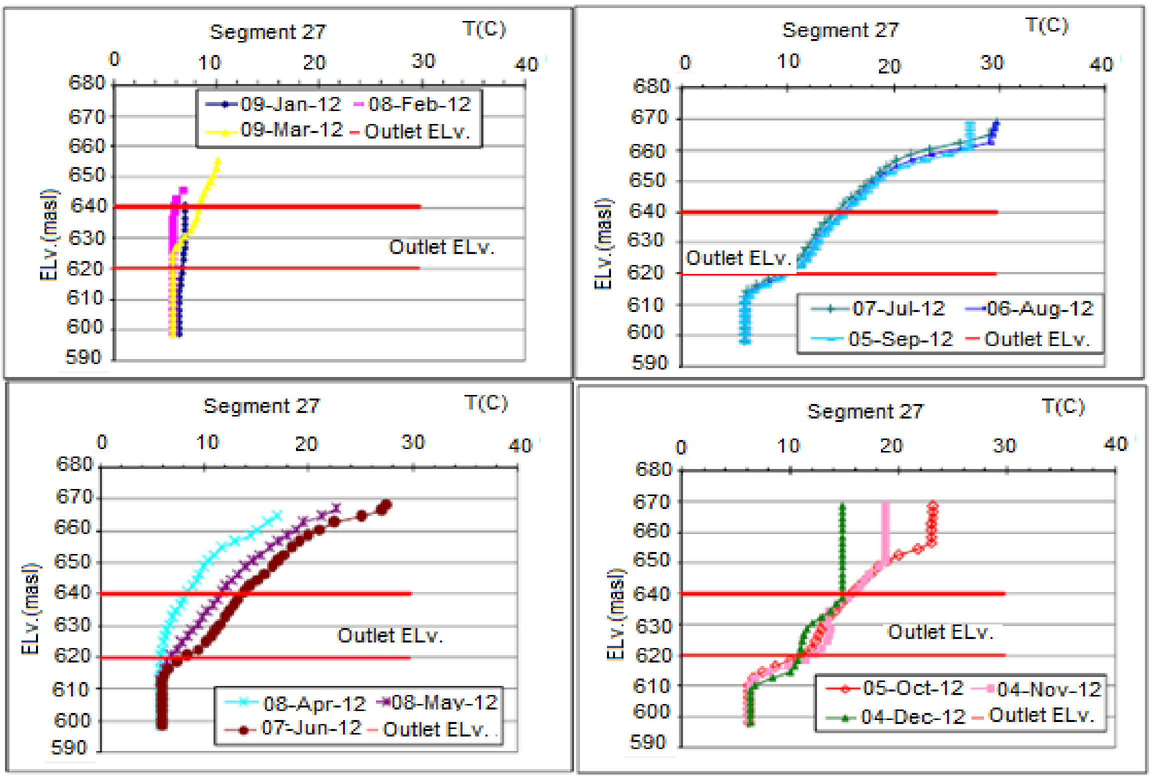


Figure 9.Temperature monthly depth profiles for segment 27 in the vicinity of Seymareh dam at the second stage of dewatering

 

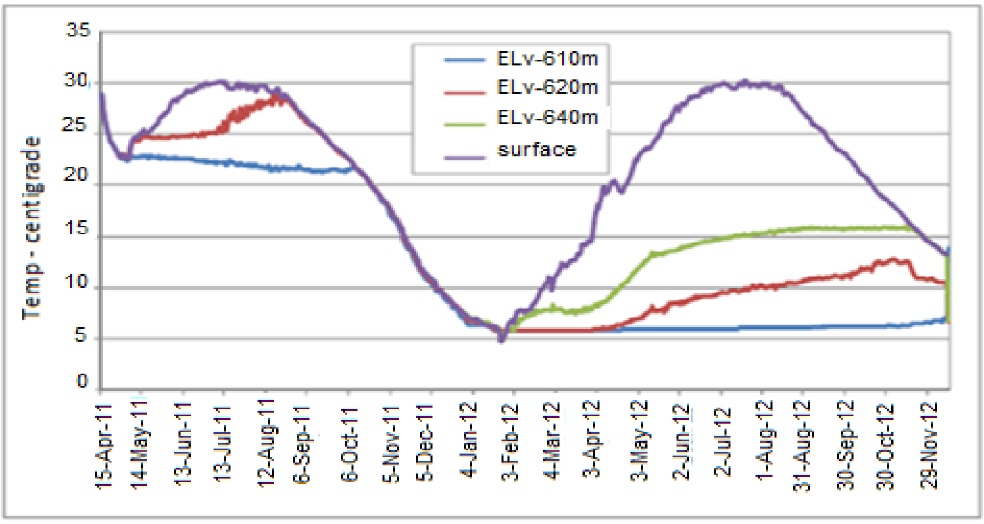


Figure 10.Seymareh dam outflow temperature variations at the first and second stage of dewatering

In Figures (11) and (12) show the amount of water temperature variations and DO in reservoir depth since early dewatering period (May 2011). Also, in these figures, reservoir thermal mixing and decrease of DO in whole the reservoir in early November coincides with the day 300 and in early May coincides with the day 150.

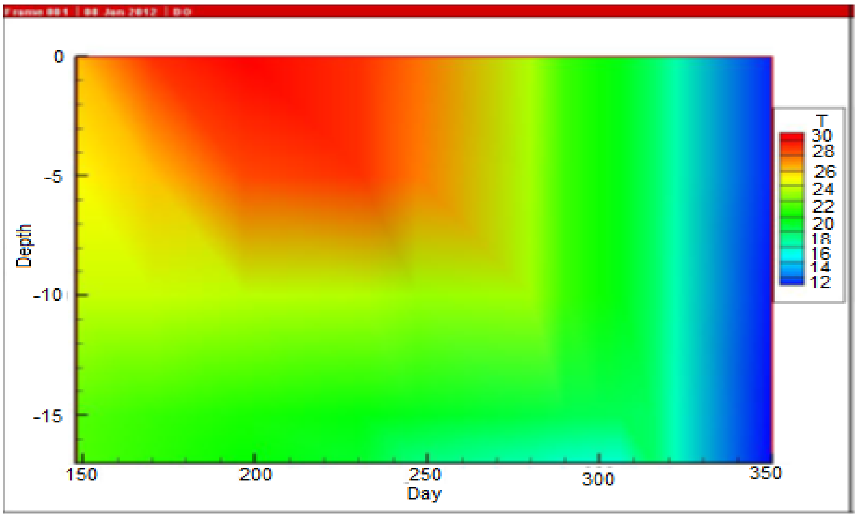


Figure 11. Temporal and spatial variations of water temperature at Seymareh dam reservoir depth since early dewatering period (May 2011).

## DISCUSSION

Results of the first stage (April to November 2011) demonstrate that, in the first stage of dewatering, thermal stratification begins since May and reaches its peak in July. In this month, thermocline depth reaches 10 m and in deeper points, water temperature decreases dramatically, and decreases from 30 $^{0}$C at surface to 19$^{0}$C at the bottom of reservoir. This situation leads to separation of qualitative relation between upper and lower layer in these months. In September by decreasing water temperature, thermal stratification gradient gradually decreases, and in early November, when the reservoir temperature at depth becomes uniform, reservoir disturbance occurs. In continue, the reservoir reaches complete mixture situation.

Thermal stratification begins again since April 2012 and lasts until December 2012. With regard to increase of reservoir water depth at the second stage of dewatering, the reservoir thermal stratification period; so that, Seymareh reservoir is faced with thermal stratification in autumn. According to Figure (10), water temperature of lower layer at the second stage of dewatering is always 5 $^{0}$C and maximum outflow water temperature reaches 15 $^{0}$C if discharges from 640 m floodgate. As it is seen in Figure (12), by the beginning of dewatering, the amount of dissolved oxygen in different reservoir lower layers is less

 

than 2 mg/L and by the reservoir mixture in early November, the amount of water dissolved oxygen in water surface layers also is dramatically decreased within a week and after that, the amount of dissolved oxygen increases.
With regard to the available data of temperature at the depth of reservoir, the model qualitative calibration was conducted for qualitative parameter of water temperature, also, Table (4) shows that, Esn is 0.934 and satisfactory. Mean absolute error is 0.67 and error percentage is 2.71. Therefore, these values represent high reliability of the model.
The amount of oxygen demand at the bottom of reservoir has been assessed as parameter SOD. Considering that, there is no accurate data about this parameter in Seymareh dam and the results of observed dissolved oxygen in the reservoir, SOD has been considered 1.2 gr/m$^2$/day at the bottom of reservoir. In order to final approve, accurate analysis and measurement of SOD at the bottom of reservoir is essential.

## CONCLUSION

In recent decades at the beginning of current century, water issue is one of the people's concerns especially countries located in dry regions so that, access to water with appropriate quantity and quality has become a major challenge. Dams' reservoirs outflow changes their quality compared with inflow water due to increased water retention time and stratification phenomenon [7].In this research, in order to investigate Seymareh dam reservoir conditions and its qualitative situation in Ilam province, two dimension hydrodynamic and qualitative CE-QUAL-W2 model was used. According to the results, thermal stratification begins since May 2011 and reaches its peak in June and July. Stratification lasts again since April 2012 until December. Seymareh reservoir is also faced with thermal stratification in autumn. Reservoir mixture deigns in last autumn and reaches complete mixture situation in winter. With the beginning of reservoir dewatering, the amount of water dissolved oxygen in water lower layers is dramatically decreased within a week and after that, the amount of dissolved oxygen increases. The results showed that, low volume and depth of water in Seymareh dam reservoir, are effective factors in qualitative problem resonance of this dam. Because, with regard to low depth of water, anaerobic conditions have been transferred to the upper layers of water. Therefore, by increasing water volume and consequently water depth, the occurrence probability of this problem decreases in upper layers.

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