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Simulation of Thermal Stratification and Salinity in Dam Reservoir Using CE-QUAL-W2 Software (Case study: Baft Dam)

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ABSTRACT: Thermal stratification and salinity is one of the most important problems which affect quality of the reserved waters in dams. In the present research, using the 2D and hydrodynamic software CE-QUAL-W2 and given the different flows (low water, normal and high water), thermal stratification and salinity have been studied. It has been concluded that a thermal stratification occurs for 9 months of the year, which starts in early April and reaches its peak in August and September (with a temperature difference of about 19℃ between super stratums an substratum), while complete mixing occurs mostly in February to March. In addition, the results suggest presence of salinity stratification simultaneous with thermal stratification. The greatest amount of salinity is found to be 307mg/L which given the desirable maximum (i.e.500mg/L) indicates a desirable state for the Baft dam reservoir in terms of drinking and agricultural water. Also water quality in the intakes of the Baft dam has been investigated which for a major part indicates the water's desirable quality in the intakes. To increase quality of the Baft dam reservoir and to prevent its short life, such actions as discharge of the lower layers in September (thermal stratification peak) and in January (before mixing process), disturbing the thermal stratification created in the reservoir and the output water aeration from the intakes by the conventional methods can be taken.

Keywords: Baft dam, CE-QUAL-W2 Software, Thermal Stratification, Salinity

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INTRODUCTION

Thermal layering and the time length of water stay in the reservoir are two significant factors in changing of the quality of the river waters before and after the dam reservoir (Trainee and Krachyan, 2003). Layering occurs according to the influence of density differences caused by temperature, salinity and suspended solids. By the influence of the phenomenon of layering in the reservoirs, the warmer water will place top of the layer and creates Epilimnion is salty, less soluble materials and enough dissolved oxygen. The cold water is placed at the bottom of the reservoir and called substrate or Hypolimnion that the materials are more soluble and more salty. There's a middle layer or Metalimnion between these two layers that has severe temperature gradient. The middle layer (Thermocline) acts as a dam prevents the exchange of temperature, dissolved oxygen and nutrients in the water column and as a result, the quality of the water will decrease in the substrate. So, thermal layering is a phenomenon that affects the quality of the exiting water from the dam severely. It must be mentioned that the TDS (Total Dissolved Solids) is different from the salinity. Water saltiness occurs because of the existence of some anions (Chloride and Sulphate) and the cation (Sodium and Potassium), but since significant part of TDS is made of salinity, TDS has been used as an indicator for estimating the salinity of the water bodies (VesaliNaseh, 2005). Major factors influencing the salinity of water bodies, it can be point to the climatic factors, geological factors and hydro-geologic factors. Increasing salinity in the water has a major effect on the taste of water and barriers the plants growth and causes the drying of the plants roots. Increasing salinity increases the density of water. Also it is represented as one of the factors of reservoir layering emergence and the decreases the dissolved oxygen in the water. In this article, salinity has the same meaning of TDS (Total Dissolved Solids). The recent progress in the field of dam reservoir water quality studies have been led the development of comprehensive models such as 2D and hydro-dynamic software CE-QUAL- to investigate the thermal and salinity layering. In the field of the previous conducted studies about the investigation of thermal layering of dam reservoirs, the below cases can be cited: The history of thermal layering situation investigation is referred to 80s AD. Labadyeh simulated the quality status of Madsym River by using WESTEX quality model (Nurnberg, 1996). Tai Kuo have combined the quality simulating of water with a non-surface optimized model to achieve the optimal qualitative and quantitative conditions in lakes system (Tai Kuo et al., 2006). U. S. Army Corps of Engineers have used HEC-5Q model for Canava River in West Virginia to adjust the utilization plan from the three reservoirs to obtain the optimal conditions of dissolved oxygen in downstream of the three reservoirs (U. S. Army Corps of Engineers., 2011). Meybeck et al simulated the qualitative behaviour of the water in the Izikly reservoir in Turkey to fulfill the drinking water for Ankara by using 2D software CE-QUAL-W2. They have determined the management

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strategies of drinking water and catchment quality control (Meybeck, 1989). In a research by Ankon consulting company, they have studied the impact of Yousef-Ali under construction dam in Turkey on the reservoir's thermal layering using one dimensional model called DYRESEM (Chapra, 1997). VesaliNaseh investigated the thermal and salinity layering in Panzdah-Khordad reservoir using CE-QUAL-W2 software. He has concluded there is a strong period of thermal and salinity layering in reservoir which lasts 200 days in a year (VesaliNaseh, 2005). In a research by Amiri (2008), he studied the thermal layering of Sefid-rud dam reservoir using CE-QUAL-W2 software. He has concluded that Sefid-rud reservoir is lack of thermal layering since it is small and the short time length of water stay in the reservoir (Amiri, 2008). In all previous works the determination of thermal layering status and thermal profile are mentioned as the prerequisite and fundamental issue. The investigation of the formation of thermal layering periods in dam reservoirs for exploitation and sustainable development is an important matter that it is completely depends on the change in the form and condition of the reservoir as well. To this end, in this research it is tried choosing a recently exploited dam, to do a case-study. The present study is done to achieve the below:

1. The investigation of the status of thermal layering in Baft dam reservoir
2. The investigation of the salinity status in Baft dam reservoir
3. The investigation of the qualitative status of water in Baft dam basin area
4. Providing appropriate solutions to improve the quality of Baft dam reservoir water

MATERIALS AND METHODS

Studied Dam

Baft dam which is constructed on the Baft River and due to fulfill the drinking and agricultural water (Drinking water priority) of the region, is located in 160 km of western south of Kerman (4 km distance eastern north from Baft). The average of incoming water volume to this dam is 33/2mcm per year. Baft dam is made of rock fill and clay core with the capacity of 40mcm, which has been practically consumed for agricultural purposes since 2008, and after completion of water purification, it is also used for drinking water. In Figure 1 view of the Baft dam crest and the features of the dam are expressed in table 1.

In this article, by considering different scenarios of water scarcity, normal and abundance of water, we have investigated the salinity and thermal layering inside the Baft dam reservoir by using CE-QUAL-W2 model. The plotted diagrams about the salinity and thermal layering have been derived from the outputs of the mentioned software and their time interval were between the 10^{th} to 20^{th} days of the month and it is related to the closest element to the dam axis (19 element) which is the location of the basin. The investigation of thermal layering of Baft dam reservoir has been also done by using experimental relations that can be mentioned the time of high water stay (approx.. one year) from its outcomes in the reservoir and existence of severe thermal layering during late of summer with 20 centigrade temperature difference between the top layer and the lower layer. The outcomes of the experiencing relations were matched with the outcomes of the CE-QUAL-W2 software (Ebrahimi et al., 2012).

Simulation of thermal stratification and salinity byCE-QUAL-W2 software

The CE-QUAL-W2 software model is for evaluating the hydro-dynamic and qualitative features of the water in 2D mode which is averaged in width. This model has been developed for reservoirs, but it can be also used for rivers. This 2D model simulates the vertical and longitudinal distribution thermal energy, chemicals and chosen biological energy within the body of the water during the time period and it is capable to evaluate the utilization of the reservoirs regarding to water qualitative parameters (Vollenweider, 1976). The necessity data for using the model consist of four sets as follows:

Geometric data

The first input file which is called geometry file model of reservoir, we must define the coordinates of the principal points of Baft dam reservoir for the model. In this simulation, Baft dam reservoir is modelled in form of a water body with one branching (Baft river). This water body is divided in the length of 20 segments with length of 276 meters and in depth of 34 layers. Surface layers distance is one meter and the below layers distance are determined 2 meters. In Figure 2 the outcomes of this categorization is observed:

Meteorological Data

Meteorological data consists of daily average statistics of air temperature, dew point, the speed and the wind direction and the amount of cloud cover in different days which are taken from Baft Synoptic station for the statistical period 1989-1993 (including the water scarcity, Normal and abundance of water).

Boundary conditions

The border status of the top layer is determined by the flow and the monthly quality of inputs to the reservoirs and the temperature of the input water and the bottom line border status is defined to the model by the flow and monthly output from the reservoirs.

Initial conditions

This file includes the data related to the quality of the reservoir in the first day of the simulation.

Additional data

This file is completed by the existing menus in the software regarding to the information and the existing data. The years of water scarcity, normal and water abundance has been chosen regarding to the long term flows of Baft river (the highest flow of Baft river regarding to the recorded long term statistics were 4.36 cbm/s, the lowest were 0.04 cbm/s and the average were 0.83 cbm/s).

The simulation period has been chosen such that includes water scarcity, normal and abundance. Also, the salinity average in Baft River is 284 mg/L, the average of yearly rainfall in the region of Baft dam is 376 mm and

the average of yearly evaporation from the surface of the reservoir is 1298 mm (Water and Force consulting Engineers Co., 2006). It is necessary to mention that about the data related to the temperature and the water salinity during the index period (simulation), there is a linear correlation among the air temperature, water temperature and also the flow of Baft river and the salinity of the water that such correlations are mentioned below (units are based on cbm/s, mg/L and Celsius degree)

$$Tw = 0.39364562\ Tair + 5.2975 \quad (1)$$

$$TDS = -203.4354Q + 363.2357 \quad (2)$$

The analysis of the issues related to thermal and salinity layering by considering the location hydrological features, geometric characteristics of the reservoir, hydraulic features of the water flow and outcomes of the CE-QUAL-W2 software and the issues related utilization of dam reservoir will be possible.

RESULTS AND DISCUSSION

The results of the thermal layering in Baft dam reservoir

The results related to the thermal layering have been indicated in Figure 3. In this figure the related outcomes have been indicated near the Baft dam axis (Segment 19). Regarding to figure 3 we can describe the status of Baft dam reservoir thermal layering:

Baft dam reservoir has a 9 months period of layering that it starts from the late of April and reaches to its maximum level during August and September months, such that the reservoir experiences the temperature difference of 19 degrees between the top and the bottom layers. By beginning autumn season, the top and the bottom layers temperature difference will be decreased such that in months of January February March April, we witness the complete mixing in Baft dam reservoir. Of course, during water abundance year the complete mixing of the layers' temperature starts one moth earlier (from month January), it means, the complete mixing lasts for four months. The reason of shortening of the thermal layering time length period during water abundance years can be related to the start of a period with few water input in autumn and water output from the middle layers that let the top layers to stay in sunlight, the opportunity of sunlight penetration is given and the layer gets the temperature of the top layer faster (during water abundance year, the impact of Baft dam is more on reservoir's water regime). Also, regarding to below diagrams during May there are only middle layers and bottom layers. In Khordad the top layer stats to be formed and during July it becomes completely vivid. By the reduction of air temperature during Mehr the thermal gradient of the middle layer decreases and the thickness of top layer is enhanced. The thermal layering lasts up to January (Except the Water abundance years). Also, during Bahman and April months we witness mixing. Regarding that during August and Shahrivar months the highest thermal layering is observed inside Baft dam reservoir, and during the period the bottom layer has the worst qualitative status, the extraction of bottom layers water during late of August and earl of Shahrivar has been suggested. Also, regarding that the mixing process causes to distribute nutrients in the reservoir, andto shorten the life of the reservoir, the extraction of water from the bottom layers is suggested before the start of the mixing process of January month. Regarding that the time duration of water stay inside Baft dam reservoir is near to one year which is considered as a long time, the set of above suggestions are confirming the reduction of time of water stay in Naft dam reservoir that can considerably cause the improvement of the qualitative status of water. Also regarding to the severity of the thermal layering and specifically during summer season, the airing of output water from dam will considerably impact to improve the quality of water specifically for drinking because of the hydraulic jump.

Results of salinity in Baft dam reservoir

The outcomes of the analysis of salinity in Baft dam reservoir have been indicated in the diagram of figure 4. Regarding to the figure we can describe below the salinity status in Baft dam reservoir.

The optimal limit of TDS density is 500 mg/L (Iran Standard Institute and Research industry) and the limit of changes of TDS in Baft dam reservoir is between 220 to 310 mg/L. Therefore, Baft reservoir doesn't have the salinity problem currently. Also, the type of salinity changes in this reservoir is functioned by the temperature changes of the water. Such that in months which we witness the complete mixing within the reservoir, the salinity profile will also stay in stable depth. Regarding that the salinity average of inputs of Baft river to the reservoir is 284 mg/L, the salinity amount in the reservoir will be also the indication of the density of the inputs (with low average because of the vastness and water high volume in the reservoir). The salinity amount in different months of water abundance years is usually less than other years which is completely a vivid issue, but the salinity difference in water scarcity and normal years is changed depending on the input river flow during different months. Also, the salinity amount among different layers doesn't have considerable changes and the maximum amount is 50 mg/L. currently, the comparison of the salinity outcomes with the standards indicates the truth that despite the existence of severe thermal layering in Baft dam reservoir, the amount of TDS in this reservoir were less than 500 mg/L and is optimal for drinking and agricultural, but in case of continuing the increasing flow of reservoir salinity in coming years due to the reduction of rainfall and enhancing of the vaporing from the surface of the reservoir, it can cause problems about the mentioned above type of consumptions.

Evaluation of water quality in basin

In this part, we will discuss about the quality of water regarding to the temperature and salinity in Baft dam ponds. The level of bottom pond is 2317.5 meters and the level of top pond is 23380 meters. Also, in order to analyze more we assume a

Hypothetical pond at the level of 2327 meters (in the middle of the top and the bottom ponds). The bottom pond is planned for drinking and agricultural consumption and the top pond has been planned for drinking in form of basin tower.

Water temperature in basin

The diagrams of temperature changes in different situations of Water scarcity, Normal and water abundance, in the location of the ponds have been indicated in figures 5-7.

By investigating the above diagrams, we can consider the below hints:

1. In the location of the bottom pond and during the water scarcity year during autumn season the temperature of water is more than 10 centigrade and during other water years, the temperature is optimal.

2. In the location of the top pond, in different water scenarios the temperature of water during the autumn and summer is more than 10 centigrade that causes the quality decrease of the output water from the ponds.

3. In the location of the hypothetical pond in water scarcity scenarios and water abundance during autumn season the temperature is more than 10 centigrade.

Therefore, it is better to use the process of airing in dam bottom-line to increase the quality of the water for the modes which the temperature of the water is more than 10 centigrade. The action of airing can done by constructing stepped platforms or by providing the status of hydraulic jump. Also, it seems that if during the planning of the ponds, to locate a pond at the level of 2327 meters (hypothetical pond level), in order to obtain water with higher quality can be used instead of the top pond. Moreover, regarding to lowering down the water of Baft river and as a result the lowering of the level of the reservoir water, in many days of the year, existing of the ponds with 10 meter distances from each other doesn't seem strange comparing to the days which the level of bottom water is 2338 (the level of top layer), can use a pond with level of 2327 meters. In above description the criterion of the optimal temperature is assumed 10 centigrade. (There is no any common criterion for the water optimal temperature within the location of the ponds in scientific references.)

Salinity in basin

The salinity changes diagrams have been indicated in different situations of water scarcity, normal and water abundance, in the location of the ponds in figures8-10. By investigation of the above diagrams the below results can be taken:

According to what has already mentioned, the reservoir of Baft dam is not facing with salinity problem currently. Therefore, providing suggestions about the water salinity in the location of the ponds is not necessarily important. What is implied from the above diagrams that the salinity average in the hypothetical pond is lower than the top pond which in case of emerging problem in future years due to the high rate of vaporing and the reduction of rainfall in the location of Baft dam, can be used?

The amounts of measured temperature and salinity inside Baft dam reservoir and its comparison with the simulation outcomes:

Regarding that before the present research there were no any qualitative study with the orientation of thermal and salinity layering on Baft dam, the obtained amounts from it, is highly limited (Tables 2 and 3). But the set of the obtained limited data about temperature and salinity and its comparison with the simulated outcomes which comes in the below tables indicate the acceptable accuracy of the done simulation (the data belonged to 2010 and have been taken from the level 2320 meters and the level of reservoir water during the time of gaining data were 2330) (Water Wave Consulting Engineers Co., 2010).

CONCLUSION

As a conclusion of the analysis and the simulation, below notes can be mentioned:

1. Baft dam reservoir is a nine month thermal layering period that this layering starts from April reaches to its climax in August and September. In a way that the reservoir is experiencing the temperature difference of 19° C between in the vicinity of the dam axis (element number 19). Baft dam reservoir doesn't have thermal layering in watery and normal month of the year means February, March and April. Therefore, Baft dam reservoir has severe summer kind thermal layering and its circulating and it mixing occurs mainly in winter.

2. In water scarcity, complete mixing of earlier month (January) begins and it means the complete mixing will reach to four months and the thermal layering period is eight months. The reason of limitation of period of thermal stratification in water scarcity year, the greater impact is on Baft dam reservoir water regime. A period of low watering entering in fall and Withdrawing water from the middle layer which gives the opportunity of dominate to upper layers and isotherms upperlayer formed more quickly. In other words, thermal gradient decline faster between super stratum and substrate.

3. TDS Parameter concentrations (Total dissolved solids) in Baft dam reservoir and different watery scenarios (water scarcity, normal and plenty of water) is between 220 to 310 milligram per liter that will follow thermal layering graphs in terms of variation. In a way in months which there is no thermal layering, salinity graphs have constant concentration at depth and also no difference can be seen in terms of TDS value between super stratum and substrate (Maximum 50 mg per liter).

4. According to optimal value of TDS (500 mg per liter), water of Baft dam is evaluating for drinking purposes and optimal agricultural uses. But increasing salinity in coming years may have some problems in drinking and agricultural purposes based on high rate of evaporation (1298 mm per year) and decrease of rainfall in region.

5. In terms of water temperature at the site of watersheds, those items in which water temperature is more than 10 °C which naturally reduces the output of water quality, are as follows:

A. The upper watershed (balance 2338 m) in all watery scenarios in autumn and summer.

B. The lower watershed (balance 5/2317 m) in the dehydration scenario and in autumn

C. Hypothetical watershed (at 2327 m balance) in water scarcity scenarios and high rainfall in autumn.

6. Measuring limited number of temperature and salinity values in Baft dam reservoir and its comparison with the values derived from simulation which represents the simulation acceptable accuracy.

7. Due to the fact that during July and August the maximum thermal layering occurs in Baft dam reservoir

and at this time of the substrate has the worst quality, discharging water is recommended from the lower layers in late August and early September. Also during this period, outlet water aeration from dam, and attempt to disturb the extreme thermal layering caused by artificial aeration systems and water pumping from the substrate to super stratum (in lack of facilities using motorized boats)would be useful at dam location according to managers and planners' detection.

8.Since the mixing operation causes the nutrients distribution in the reservoir and decrease of its life, discharge water from the lower layers before starting mixing is recommended (for water scarcity in November, for the normal and high rainfall in January according to input increasing in reservoir.

9.Possibility of dewatering in the hypothetical watershed balance (balance 2327 m)is provided because of lower water temperature compared to upper watershed and lower salinity particularly in future years (due to lack of rainfall and high evaporation)

10.To improve the quality of water it can be possible to use aeration process at dam downstream for the times when the water temperature at watershed is more than 10 ° C (result Number seven).Aeration can be done through making stepped platforms or providing hydraulic jump conditions.

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