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Dam Reservoirs Water Quality Simulation in Arid Areas: A Tool for Determining the Optimum Water Withdrawal Level (A Case Study of Baghan Dam)

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Abstract: Meeting the water demand for domestic and agricultural uses is the primary goal in dam construction. Controlling and maintaining water quality along with water quantity is of notable value. The dominant climatology is dry and tropical (high evaporation and little precipitation) which has made salinity the most challenging water quality limitation in the area. Dam construction is a major expense in water resources management. Hence, simulating water quality in reservoirs to ensure water quality for different uses and obtaining optimum depth for water withdrawal is essential and it's a reliable tool for water quality management. In this study, Baghan dam reservoir in 52° 56' East and 28° 8' North in Bushehr Province located in south of Iran with dry and warm climate is simulated and discussed. For this purpose, based on available data and results from water quality-quantity monitoring, temperature and salinity stratification situation of the dam reservoir is simulated using CE-QUAL-W2 and the quality of withdrawn water is determined. Due to simulation results, Baghan dam reservoir would have strong and stable temperature stratification. This stratification is so severe that in warm season (July and September) the temperature difference between the upper and lower layer reaches about 20°C. The temperature gradient is very high in depth between 25-40 m in deeper and shallower depths the temperature gradients are milder or even constant. The results show that the Electrical Conductivity (EC) in different depths is between 2000-3000 µmhos/cm and the optimum level for the water withdrawal structure in order to obtain the best EC is 20-25 meters from the bottom of the reservoir.

Key words: Baghan dam · CE-QUAL-W2 · Quality simulation · Quality stratification · Temperature stratification and Withdrawal level

INTRODUCTION

Iran is located in an arid/semi-arid area. In such regions, dam construction is of vital importance in controlling water steams for future uses such as drinking, agricultural irrigation, industrial uses and hydropower. To meet such demands, dam construction and surface water controlling establishment were always of special focus in economic development planning. Considering several restrictions on water quality and quantity, the demand for a decision tool becomes important.

Several factors affect water quality in a dam reservoir. This could be to an extent where the water quality at the outlet is significantly different from that of inlet. Climate, reservoir shape, inlet stream quantity and quality are the most affecting features triggering such factors.

Temperature stratification and subsequent qualitative stratification are the most important processes occurring in dam reservoirs. Such phenomena are directly affected by surface water temperature, which cause temperature and density gradient from water surface to the depth. Stability of this phenomenon is basically related to stratification power and mixing factor forces. Mixing forces include wind and dynamic forces from inlet and outlet streams. Required work to be done is also dependent to stratification power, size and shape of the reservoir. Stratification power is a function of temperature difference between upper layer (Epiliminion) and lower

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layer (Hypoliminion). As a result, since dam construction is an expensive and effortful item, to ensure water quality features for different uses and also reservoir water quality management, identifying relationship, rules and factors affecting water quality is essentials [1, 2].

For exact assessment of dam construction effects on water quality in ordinary situations long waiting time until the end of construction and putting into operation and then sampling different depths (for at least 1 year) is required. This involved time-taking, costly efforts which are only practical during exploitation period. Today, water quality simulation has extended its application in water resources planning and policy making to reduce costs and save time. These models are prepared by using mathematical methods, such as, finite elements to solve physical, chemical and biological processes' equations and depict reservoir and outlet stream water quality overview [3].

Baghan dam which was constructed to meet drinking demands, irrigation uses and industrial needs is located over a branch of Mand River, 6 km southeast of Baghan village, 170 km southeast of Bushehr in 52° and 56' East and 28° and 8' north, as shown in Figure 1. Baghan dam is 55 m height with the dam reservoir volume of 30.5 MCM and a lake area of about 2.05 km^2. Average precipitation is estimated about 376 mm and average annual temperatures of the basin and construction site are 21.7 and 24.8°C accordingly. Based on hydrologic studies, average annual yield of the river in construction site is 31.1 MCM with minimum, maximum and average EC of 785, 11620 and 2383 µS/cm [4].

Based on previous researches [5], many of the dams in Iran, has been affected by several environmental problems like high salinity and eutrophication due to different factors such as weakness of accurate studies and water quality monitoring in all stages, from designing to operation and even after operation-time [3].

Numerous models have been composed in order to simulate and evaluate water quality systems; HEC-5Q, WASP7T DYRESSM, CE-QUAL-W, WQRRS are among these models [5, 6]. In this study, based on previous researches and comparisons on models abilities to simulate water quality, CE-QUAL-W has been chosen to simulate outlet water quality for different uses.

In a research by Arhami *et al*. [7], Temperature changes, Dissolved Oxygen and Total Dissolved Solids in Latian dam reservoir was modeled using HEC-5Q. Results of the study show acceptable reliability of the model in simulating parameter changing trends and stratification [7]. Also, Bani saeid [1] studied water quality changes and stratification in Cheragh Weiss dam using HEC-5Q [1]. They estimated minimum environmental water demand, released from dam outlet, using maximum allowable Nitrogen and Phosphorus concentration in release water. Sarang [8] compared in-situ observations in Boukan dam reservoir with that result from HEC-5Q in simulating water quality and stratification [9]. Maleki [10], suggested that drainages are among the most affecting sources of pollution in Pasikhan river, Guilan [10].

In this study, Ammonium, Nitrate, Nitrogen and Phosphate concentrations were measured and compared to simulation results from WASP6. Results show that WASP6 model could simulate river water quality with great accuracy. Tafarroj [2] simulated TDS and temperature in Kandak dam reservoir using HEC-5Q. Results show that selective release during non-irrigation months in order to save flood streams leads to reservoir water quality improvement [8, 11]. Results from eutrophication and temperature stratification simulation in Shahr-e-Bijar dam reservoir using CE-QUAL-W2 model showed that the reservoir water is classified as fresh and outlet water has high BOD and low dissolved oxygen concentration [3]. Markofsky and Harleman [12] have developed a mathematical water quality model based on DO concentration, which is then put together with temperature stratification simulation model [12]. Kuo and Yan [13] simulated water quality of the Fitsui dam reservoir using WASP5 and CE-QUAL-W2 model. Results from the study showed that the reservoir is rich in nitrogen, but algae expansion is limited due to lack of phosphor [13].

Since Baghan river water salinity is the primary limiting water quality factor, in this study it is desired to study water quality changes of the Baghan dam reservoir from temperature stratification and electric conductivity point of view, using CE-QUAL-W2. The main goal is to investigate temperature stratification situation and reservoir salinity and determining salinity in different depths in order to manage withdrawals with reliable quality for different uses from determined water levels. For this mean, changes in upstream inlet water quality (temporal Electric conductivity changes along with changes in different levels) were simulated using gathered base data, exact dam components identification, choosing indicator period, that were themselves extracted from long-time water quality data and monthly quality monitoring during a one year period. To do so, in addition to simulation of dam reservoir water quality, the quality of releasing water is also simulated.

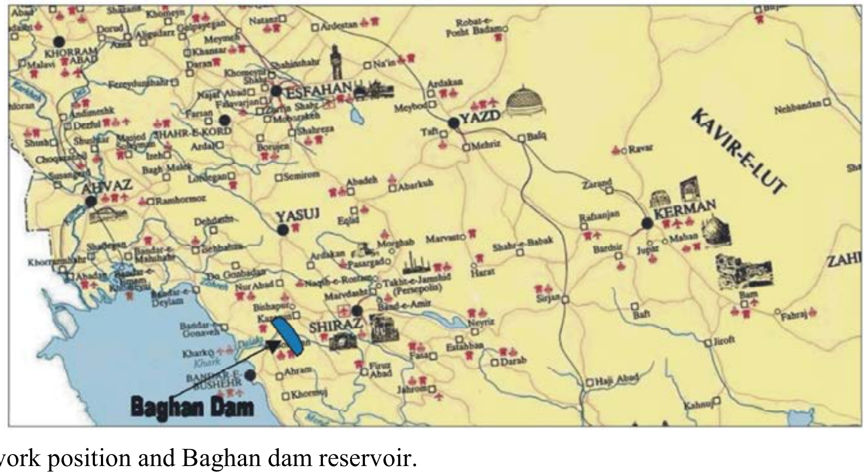
MATERIALS AND METHODS

In this study, the results from stratification and salinity simulations of Baghan dam reservoir are presented. Taking into account salinity limitations of water resources in Bushehr province and Baghan River, the main goal in this study is to assure water salinity condition in dam reservoir and its outlet stream and also comparing it with irrigation standards. CE-QUAL-W2 model is used for the reason. This model was developed by Environmental Engineering Center of the US Army with cooperation of civil and environmental engineering department of the Portland State University, in order to simulate the river-reservoir system. From a hydrodynamic point of view, CE-QUAL-W2 model can forecast changes in water level, velocity and temperature. Since temperature changes leads to subsequent changes in water density, calculations related to temperature is implanted in hydrodynamic system and it should not be eliminated from calculation processes. In water quality investigations every combination of water quality parameters in simulation could practically be taken into account or be eliminated from the process. The algorithm to study water quality in this model is completely componential and other water quality parameters could be easily added via additional sub-plans.

Input model data is reservoir's shape and geometry, initial and boundary conditions, hydraulic parameters, daily inlet and outlet discharges, daily water temperature, water quality concentrations and meteorological parameters. Input data which is presented as *bth.npt* files is extracted from topographic maps by taking elements within the reservoir length. Volume-area and height relationships are important in assessing geometrical shape presentation accuracy. In this section each element's width, length and angle within the reservoir length is presented to the model. Meteorological data that are presented to the model in *met.npt* format involves: air temperature, dew point, cloudiness, wind velocity and wind direction in daily time scales. Inlet and outlet stream daily data are presented in *qin.npt* and *qot.npt* file formats. Water quality data includes studied factors in weekly format by cin.npt are presented to the model. Water temperature is also presented separately in daily time scales under tin.npt file formats. Using long time data history in the construction site, the time period between 1997 and 1998 was chosen due to existence of rainy, dry and average precipitation seasons and the model was simulated in daily time scale.

RESULTS AND DISCUTION

Figure 1 shows simulated water temperature in Baghan dam reservoir within a 5 years period. As is shown in this figure, reservoir includes a stratification cycle which lasts for at least 10 months of a year. This stratification starts in mid February and reaches its peak during summer months. The stratification is weakened during the cold season due to decline in input energy to the reservoir and gradually disappears. Results show that the complete mixing occurs during late January and early February and temperature changes from surface to depth is not meaningful. New cycle commences again from mid-February.



Map 1: River network position and Baghan dam reservoir.

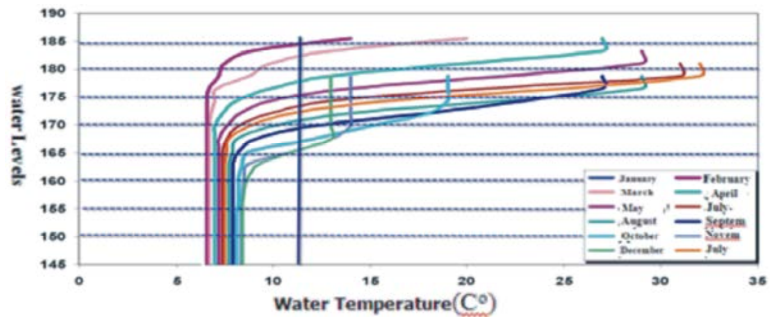


Fig. 1: Water temperature profile in Baghan dam reservoir's depth in monthly time-scale.

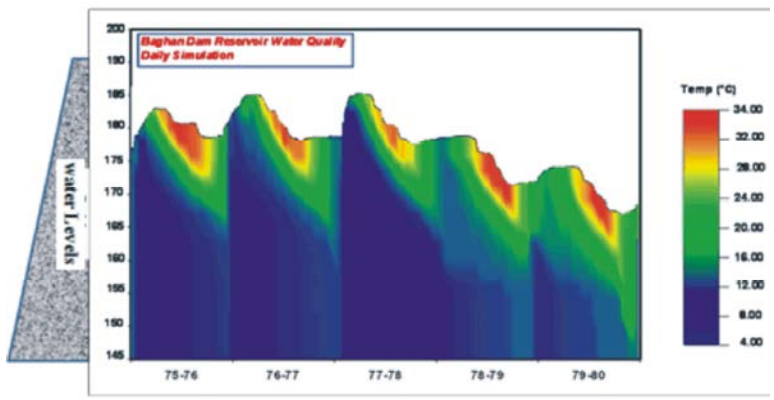


Fig. 2: Water temperature simulation results in depth during the 5 year period.

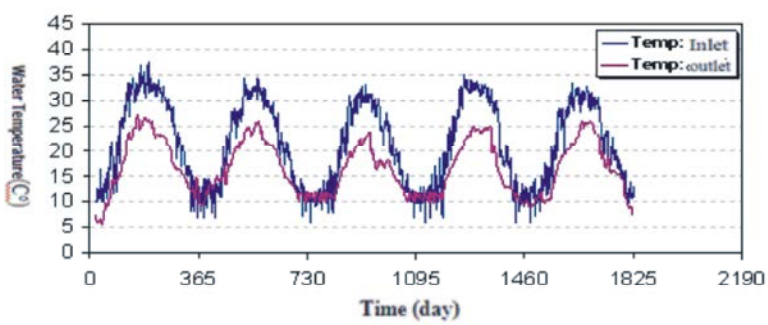


Fig. 3: Changes in inlet and outlet water temperature of the Baghan dam reservoir during the simulation period.

Based on simulations, maximum difference between upper and lower levels of the reservoir is about 24°C which occurs during June. Within June and July the depth of upper layer is about 2 to 4 meters and the mid-layer is 10-15 meters. However, by decreasing input solar energy, the depth of upper layer gradually increases. This depth reaches 6-10 meters during early fall. At the same time, depth of the mid-layer reduces to 10 meters. The procedure goes on until the two layers mix and overturn occurs.

Figure 2 shows temperature profile in Baghan dam reservoir depth during selected days of the year. As shown in this figures, trends in water temperature changes within the depth and also changes in layer depths are detectable. In addition to this, as could be noticed in the same Figure 3, changes in the temperature of inlet water to the reservoir and outlet water from it during the 5 years simulated period is shown. It is clear from the diagram that the temperature of the outlet stream from the reservoir during the cold seasons is less or merely equal to that of inlet stream and is lower than the inlet water otherwise. This difference is maximized during the summer. Analyzing results from the simulations of the outlet stream shows that strong fluctuations in upstream entering water temperature to the reservoir is balanced in outlet streams.

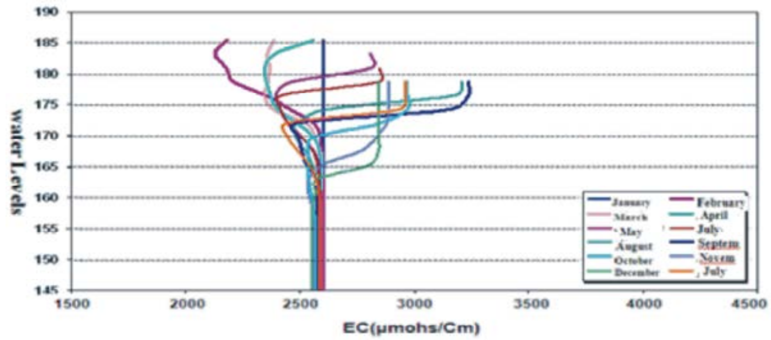


Fig. 4: Baghan dam reservoir EC-depth profile in different months.

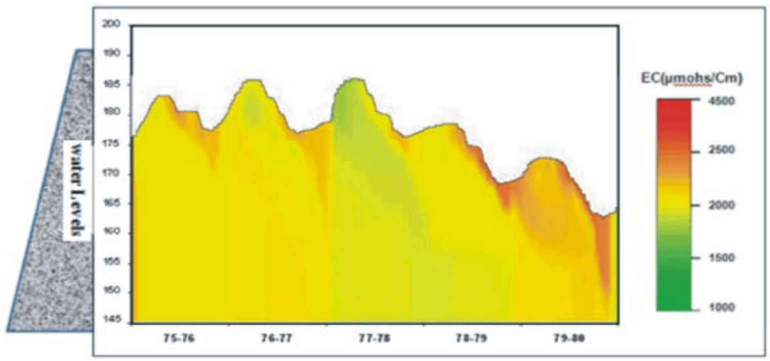


Fig. 5: Results of the 5 years EC simulation in different depth.

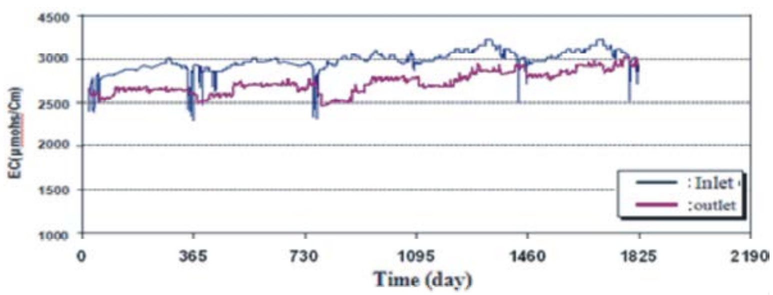


Fig. 6: Changes in EC of inlet and outlet streams during simulation Baghan dam reservoir.

As discussed before, analyzing existing and performed water quality records suggests that water salinity (Electrical Conductivity) is known as the most critical restricting water quality parameters. Water EC fluctuates between 785 µS/cm during flood season to 11620 µS/cm within the dry period with an average EC of about 2383 µS/cm. Comparing these results with those presented by FAO (700-3000 µS/cm: low to moderate restriction, more than 3000 µS/cm: high restriction for irrigation), Baghan river water quality is of low to moderate restriction in average situation and high restriction in extreme events (FAO 1985).

Figure 4 shows the Electrical Conductivity simulation in Baghan dam reservoir dam during a 5 year periods. As it is clear from this figure, changes in the reservoir water EC are simultaneous with those of temperature stratification. Temperature stratification also changes depending on fluctuations of the inlet stream to the reservoir. These fluctuations are particularly a function of river hydrologic features. For example, the electric conductivity of the water increases during the dry season. Based on these results, during the dry season, which is also simultaneous with the end of chosen period, EC increases (the ending part of Figure 1). This could be mainly because of decreased entering flood streams to the Baghan dam reservoir, which works during normal time periods as an adjustment to the reservoir's water quality.

Figure 5 shows the EC profile in Baghan dam reservoir depth during different months of the year. As it could be noticed in the figure, a detectable trend in EC of

Table 1: Average EC of different water levels of the dam and proposed optimum level for withdrawal

Month	Electrical conductivity in different levels of Baghan dam (µS/cm) Upper levels (180-175)	Mid levels (170-165)	Lower level (155-150)	Preferred withdrawal level
January	2577	2572	2575	All
February	2150	2518	2568	Upper
March	2257	2540	2565	Upper
April	2350	2586	2564	Upper
May	2710	2520	2558	Mid - lower
June	2717	2525	2560	Mid – lower
July	2945	2430	2570	Mid
August	3185	2450	2565	Mid
September	3220	2455	2562	Mid
October	3005	2510	2565	Mid
November	2880	2752	2565	Lower
December	2830	2780	3571	Lower

different depths and changing layer depths is recognizable. During January, while no stratification could be detected, EC is merely constant in all depths. In other months, such as; February, March, April and May, EC of upper layers is less than that of lower levels, while in other unnamed months the phenomenon is inverse. The important point here is the inter-dependency of temperature stratification and EC layering. As for Figure 2, EC alteration within the upper 15-17 meters is not significant, while a dramatic variation could be detected within 17-25 meters and again from these depths to the river bed, changes are not considerable.

Figure 6 shows changes in EC of inlet and outlet streams within a 5 years period. Results show that the salinity of in-stream and out-streams differ significantly and that the difference is of bigger domain during raining seasons, compared to dry season. The diagram shows that, although the salinity of out-stream water is lower than that of in-stream; fluctuations in outlet streams' EC are also of very smaller amplitudes. This could be explained by longer retention times of reservoir water (almost a year) and also water quality balancing because of high volume, less saline inlet streams during floods. As it is observed in the results of simulation, the electric conductivity of the released water is always below 3000 µS/cm, which could be even lower during wet periods. An interesting point is the increasing trend of the outlet stream EC during the simulation of the dry period along with a decrease in the difference between inlet and outlet stream ECs.

Analyzing EC of outlet streams from sluices with different levels, as shown in Table 1, shows the variations in water quality of different levels, as well as stratification in all months. Based on model results, the best water quality could be reached in upper levels between February and April, mid-levels during May and June and lower levels for months July to December. In January water quality is homogenous within all layers due to complete mixing.

CONCLUSION

The temperature stratification in Baghan dam reservoir is actually very strong and stable. This phenomenon is more severe during summer hot seasons, particularly July and August. During these months, the temperature difference between upper and lower layers reaches 20°C. Temperature variation gradient is very high between 20-25 and 35-40 meters, while little or no variation is detected in upper and lower layers.

In dam reservoirs, outlet stream water quality shows less variation, compared to that of inlet water due to temperature stratification, longer retention time and water quality layering. During summer, outlet stream temperature is about 5-10°C cooler than inlet water. The latter is very important from an ecological point of view, since dissolved oxygen concentration increases and maintains aquatic life. Inversely, inlet and outlet stream temperature converges during cold season.

In addition to longer retention time in dam's reservoirs, stratification due to EC has caused alterations between inlet and outlet water streams. The difference between the two ECs ranges from 0 to 500 µS/cm during different months and years. Figure 6 shows that released water salinity was significantly higher than inlet water during flood events. However, during following months after the flood season, salinity of the outlet stream decreases, causing considerable difference between in and out water qualities; this difference ranges from 500 μS/cm, within the first and second months after the flood season, to lower difference. Analysis show that the difference between in and out water salinity was higher during upper-normal water year (1997-1998) and lower differences within lower-normal months (last months of the simulation period) because of lower precipitations and diminution of flood streams.

The electrical conductivity, which assumes to be the major restricting parameter in Baghan river for drinking and irrigation uses, is balanced in the reservoir during the year, meaning less limitations for water withdrawals. Simulation results suggests an average outlet water salinity of about 2600 μS/cm which ranges from 2400 to 3000 μS/cm, while time averages salinity of inlet water streams is about 3000 μS/cm. Table 1 shows that the release water quality from different sluices differ within months and that water quality simulation results could be utilized as a reliable tool to manage water withdrawals for different uses and required qualities.

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