

HYDRODYNAMIC AND QUALITY MODELING OF YAMCHI RESERVOIR

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ABSTRACT

Hydrodynamic and quality modeling of reservoirs and lakes has been considered as one of the most important management tools in the last decades. Prediction of Eutrophication and the effects of management measures is one of the capabilities of these tools. Eutrophication is the most common problem in Iran. Yamchi reservoir is located in northwest of Iran and is the main source of drinking water of Ardabil town, the capital of Ardabil province. Serious taste and odor problems, has been reported in recent years. Field investigation represents algal bloom that is the main ecological effect of eutrophication. In this study, Yamchi reservoir is simulated using a 2-D laterally averaged hydrodynamic and water quality model, CE-QUAL-W2. Input data include bathymetry of reservoir, meteorological data, inflows, temperatures and constituents concentrations of inflows, outflows and initial conditions. The duration of *calibration* is two years and the model has been verified for 2010 data. Finally, some practical solutions have been recommended.

1 INTRODUCTION

Reservoirs are artificial lakes, built to water supply, power generation, irrigation, flood prevention, water diversion and recreation. According to region geographic and atmospheric conditions and physical characteristics of reservoir, Dam construction affects water quality. Thermal stratification, increasing retention time and interactions among water quality variables inside the reservoir lead to considerable difference between inflow and outflow quality.

A common cause of impairment to reservoir use is eutrophication, or increase in lake productivity. Eutrophication is a natural process that is not inherently negative. It easily becomes a problem in reservoirs because the main tributaries import large nutrient loads over time scales that are short relative to the ability of the aquatic ecosystem to adapt to the loading. The nutrient loads facilitate large populations of primary producers. These can impact uses such as recreation and habitat maintenance or increase the cost of uses such as drinking water (Wu et al., 2004).

Taste, smell, color and water treatment problems, water toxicity due to some phytoplankton species, Increases in biomass of phytoplankton, water turbidity and fish kill and decreases in dissolved oxygen in bottom layers are the most important consequences of eutrophication.

Considering the growing rate of eutrophication in reservoirs of Iran, Decision makers need some reliable predictive tools for interdisciplinary management of reservoirs. Numerical models could serve this purpose. There are many numeric models available for simulating water quality in reservoirs.

CE-QUAL-W2 is a two-dimensional laterally averaged water quality and hydrodynamic model supported by the USACE Waterways Experiments Station. This model has been in use for the last two decades as a tool for water quality managers to evaluate the impacts of management strategies on reservoirs, lakes, and estuaries (Wells).

The main purpose of this study is simulating water quality variables and evaluating the impacts of thermal stratification in the Yamchi Reservoir, Iran that is under eutrophication conditions. The simulation tool is CE-QUAL-W2 model (Cole and Wells 2008). This study includes:

- Predicting general condition of water quality of reservoirs for two years
- calibration and verification of model by the observational data
- Recommending some solution for improving water quality.

2 STUDY AREA

Yamchi reservoir is located 25 km southwest of Ardabil town, Iran (Fig. 1). Filling of the reservoir began in 2004 and is used for irrigation and public water supply. Climate is typically cold and semi-arid. The minimum temperature is -24 celsius and maximum is 35 celsius. Mean annual rainfall is 380 mm.

The reservoir has a surface area of 4 km², a maximum depth of approximately 50 m near the dam, and a water storage capacity of 80 million cubic meters. It is 6.1 km long and has an average width of 650 m. The water column is thermally stratified from June to mid September.

The most important flow of reservoir named Baliqlı Chay, originates from the Sabalan Mountains and passes through many villages and townships. It also irrigates 15000 hectares of the agricultural lands in Ardabil province. Since, this river is polluted by municipal effluent, runoff from agriculture/irrigation, urban runoff from unsewered areas. These pollutants are the origin of nutrients. According to this situation, entering nutrients and thermal stratification lead to Eutrophication in reservoir. Following reports of undesirable taste and odor problems in 2007, study of water quality in the reservoir initiated. Accordingly, a study about this reservoir was done in 2010 (Yazdekhasti et al., 2003). after completion of data in 2010, this study simulates the reservoir for longer duration.

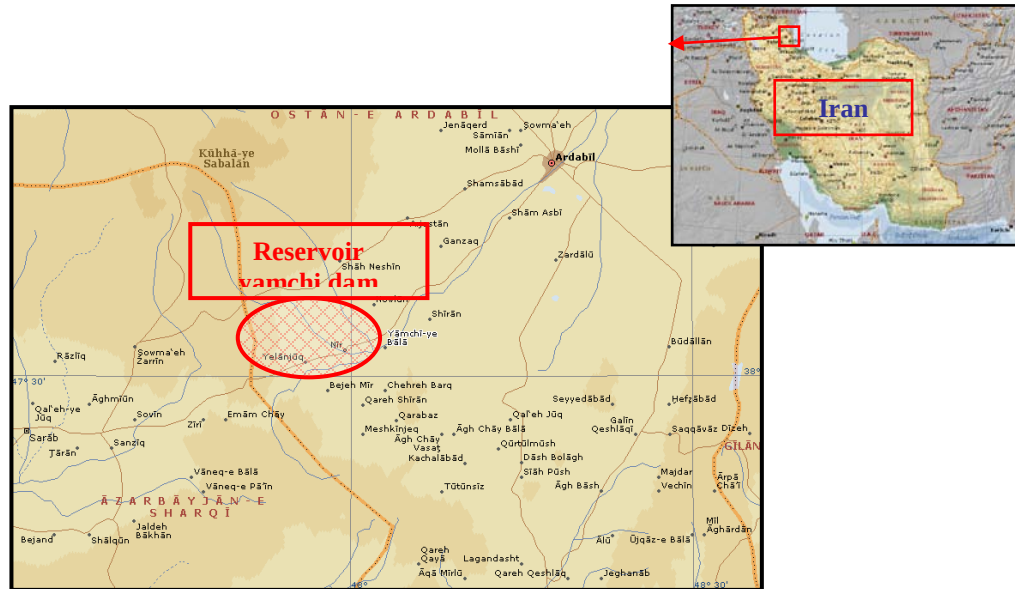


Figure1. Yamchi reservoir map

3 MODEL CALIBRATION AND VERIFICATION

The basic input data for CE-QUAL-W2 model include topography of reservoir as a bathymetry file, inflow and outflow streams, temperature and quality concentrations of inflow, initial conditions of water quality variables, meteorological data and wind sheltering coefficient.

According to Figure 2, the Yamchi reservoir is described with 62 longitudinal segments and 55 vertical layers. The length of each segment is 100 m and the thickness of every layer is 1 m. Daily average meteorological data were used. The model was used to simulate temperature, dissolved oxygen, CBOD, orthophosphate (PO₄), ammonium (NH₄), nitrate (NO₃), total dissolved solids (TDS) and chlorophyll-a. Simulation starts on January 1, when mixing occurs. The station locations are shown in Figure 2.

The duration of model calibration is two years (from January 2008 to January 2010) and the model has been verified for 2010 data.

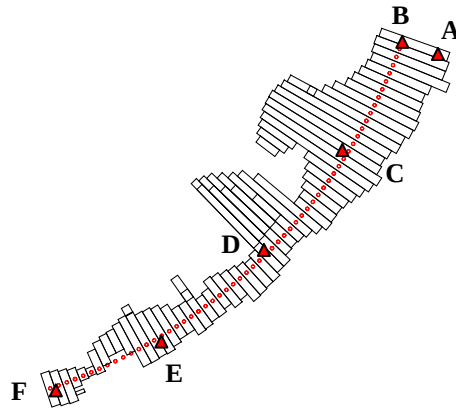


Figure 2. Computational segments and the location of measurement stations

3.1 Temperature

Temperature is a primary determinant of the rate of biochemical reactions. Reaction rates increase as a function of temperature although extreme temperatures result in the mortality of organisms (Park et al., 2000).

Results represent that stratification starts in early June and lasts about 3 months. Observations confirm this representations (Fig. 3a, 3b). Mixing occurs in early September (Fig. 3c, 3d).

3.2 Dissolved oxygen

DO is the most important component in aquatic systems that represents the health of ecosystem. The three main processes that consume DO are respiration, decay of organic matters and nitrification. Photosynthesis and aeration are the sources of DO. The maximum difference between oxygen concentration of Epilimnion and Hypolimnion in reservoir is about 6mg/l during stratification season. Observed and simulated DO data from modeling for 3 stations of Yamchi Dam in stratification time and mixing time are illustrated in Fig. 4a, 4b and 4c respectively. Since station A is located in the deepest part of the reservoir, there is a 4 mg/l difference in Do concentrations in top and bottom layers of this station in the starting time of mixing (Fig. 4)

3.3 CBOD

This group of organic matters exerts dissolved oxygen during decay process and also settles. Several groups of CBOD can be modelled in CE-QUAL-W2, One group is considered in this study. CBOD variation during stratification time in station C and D are illustrated in Figure 5a and 5b respectively

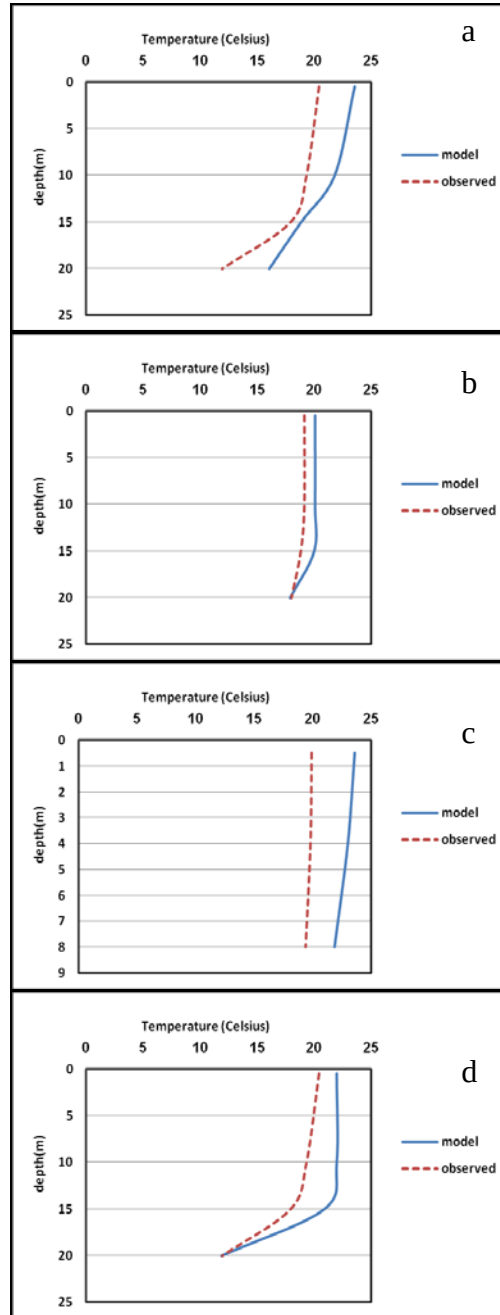


Figure 3. Predicted and observed water temperatures for 2010 Verification simulations (a, b: stratification time, A-station and c, d: mixing time A and E-station respectively)

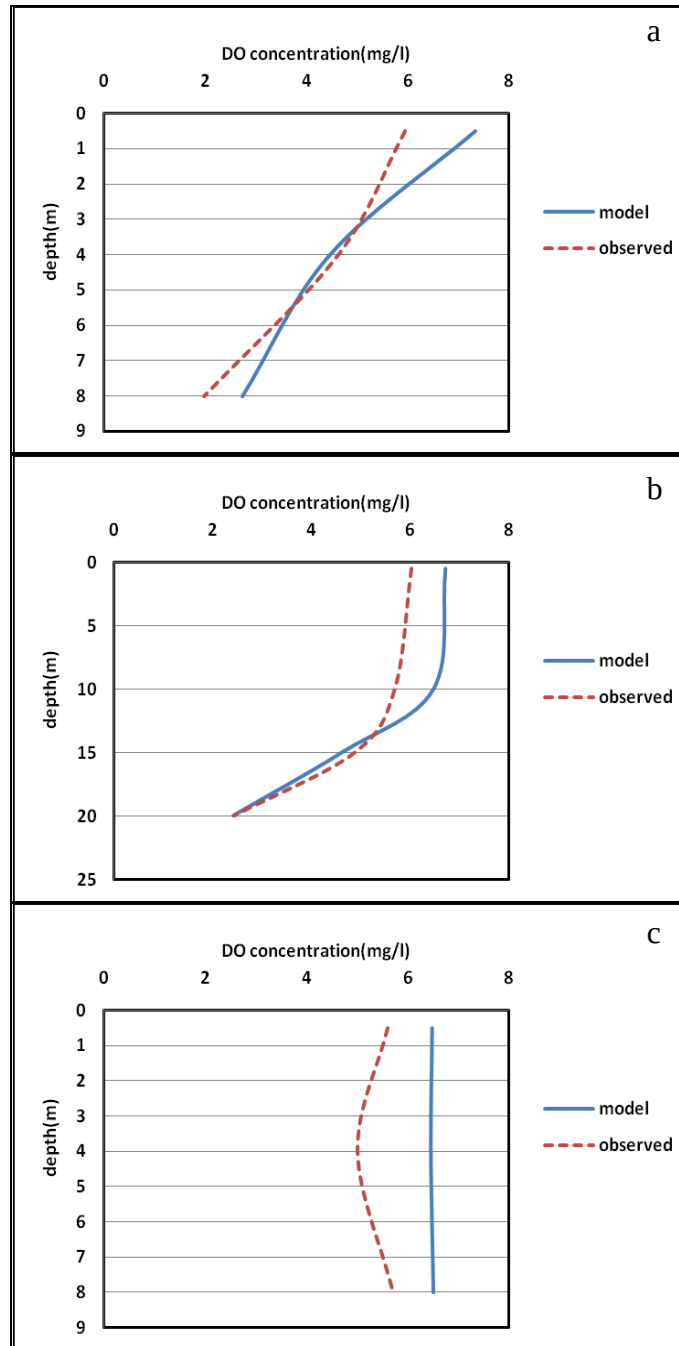


Figure 4. Predicted and observed DO concentrations for 2010 Verification simulations (a: stratification time, D-station, b: stratification time, A-station and c: mixing time, D-station)

3.4 Total Coliform Bacteria

Coliform bacteria is commonly used as an indicator of pathogen contamination. Predictions of coliform bacteria are important because of their impact on recreation and water supply (Cole and Wells, 2002). Decay and settling are the two sinks of this component. Figure 6a represents the concentrations of coliform bacteria during stratification time in station A and Figure 6b illustrate the concentrations of this component in station C in early mixing time.

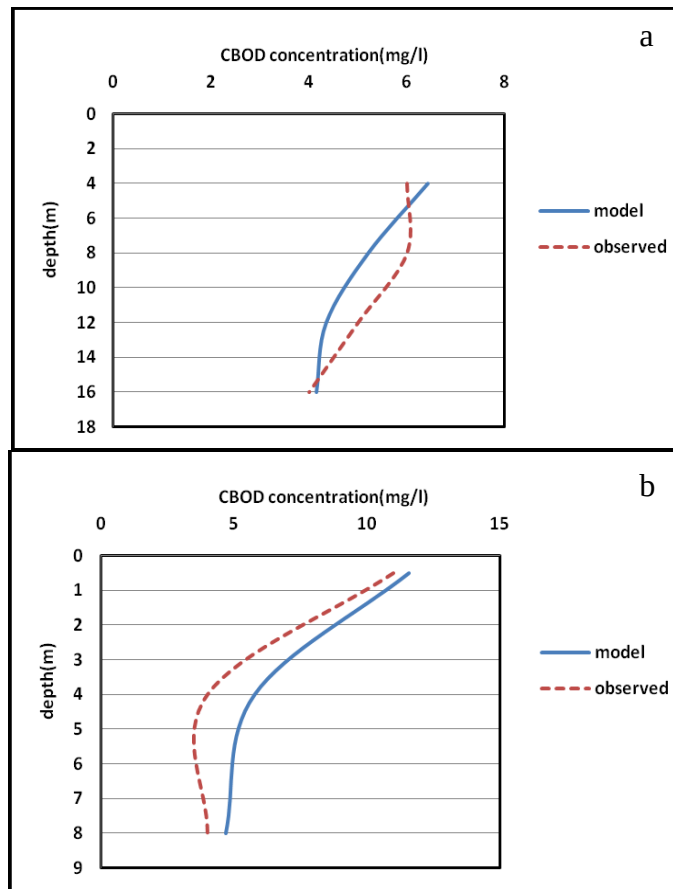


Figure 5. Predicted and observed CBOD concentrations for 2010 Verification simulations (a: stratification time, C-station, b: stratification time, D-station)

3.5 Phosphate

Phosphate is one of the necessary nutrients for algal growth. In many cases, phosphate is considered to be the limiting nutrient for controlling eutrophication. Phosphate variation trends in stratification time in station A is shown in Figure 7a and in mixing time in station D is shown in Figure 7b. In anoxic condition, phosphate is

released from sediments. Since Sediment is not considered in this simulation, during stratification, concentrations of hypolimnion phosphate in model is lower than observed data.

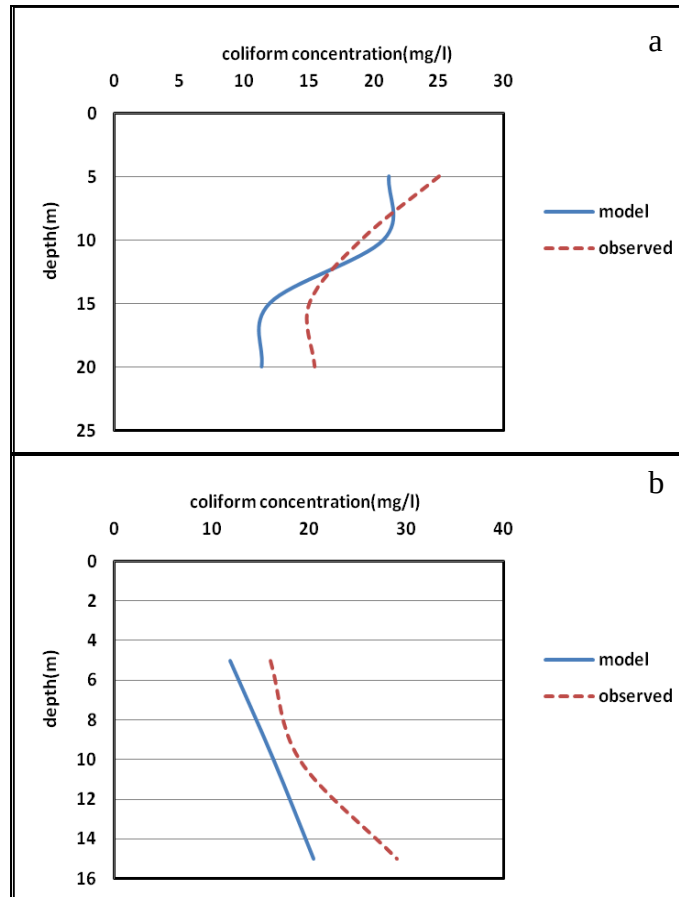


Figure 6. Predicted and observed Coliform concentrations for 2010 Verification simulations(a: stratification time, A-station, b: mixing time, C-station)

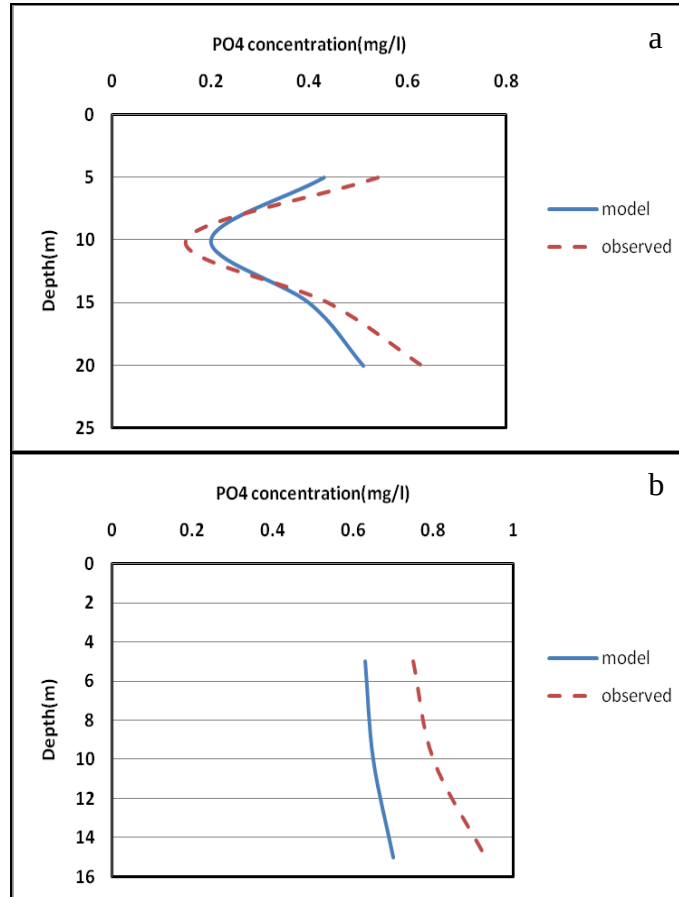


Figure 7. Predicted and observed PO4 concentrations for 2010 Verification simulations(a: stratification time, A-station, b: mixing time, D-station)

4 CONCLUSION AND RECOMMENDATION

A 2-D laterally averaged model was applied for Yamchi reservoir as a management tool of waterbody using CE-QUAL-W2 code. Considering odor and taste problem of this reservoir, the aim of this study was to survey its eutrophication condition. The model calibrated and verified with data from 2008, 2009 and 2010. The model was used to simulate temperature and 7 state water quality variables. Calibration coefficients are illustrated in Table 1.

Table 1. calibration coefficients

Parameter	definition	Unit	Calibration value
Ax	Longitudinal eddy viscosity	m ² /sec	1.0
Dx	Longitudinal eddy diffusivity	m ² /sec	1.0
AG	Maximum algal growth rate	day ⁻¹	0.8
AR	Maximum algal respiration rate	day ⁻¹	0.04
AE	Maximum algal excretion rate	day ⁻¹	0.04
AM	Maximum algal mortality rate	day ⁻¹	0.1
AS	Algal settling rate	m day ⁻¹	0.1
AHSP	Algal half-saturation for phosphorus limited growth	g m ⁻³	0.003
AHSN	Algal half-saturation for nitrogen limited growth	g m ⁻³	0.014
AP	Stoichiometric equivalent between algal biomass and phosphorus		0.005
AN	Stoichiometric equivalent between algal biomass and nitrogen		0.08
NH4DK	Ammonium decay rate	day ⁻¹	0.02
NO3DK	Nitrate decay rate	day ⁻¹	0.05
KBOD	5-day decay rate @ 20°C	day ⁻¹	0.005
CBODS	CBOD settling rate	m day ⁻¹	0.0
CG1DK	1 st –order decay rate	day ⁻¹	0.04
CGS	Settling rate	m day ⁻¹	0.0
ASAT	Light saturation intensity at maximum photosynthetic rate	W m ⁻²	55
EXH2O	Extinction for pure water	m ⁻¹	0.45
BETA	Fraction of incident solar radiation absorbed at the water surface		0.45

The figures show suitable agreement between the observations and the model results. There are some differences between model and observed values that stem from measurement errors of inflow data including discharge, temperature and water quality variables concentrations and monitoring data. Also sediment is not considered in this model that influences the concentration of phosphate in bottom layers especially at the time of stratification when anoxic condition occurs in hypolimnion. During summer, thermal stratification was seen in the reservoir, so thermocline acts as an obstacle for vertical movement of water quality constituents.

Currently withdrawal elevation is located 8 meters above bed. Considering the

elevation of thermocline in summer, the primary solution for improving the water quality can be increasing the elevation of catching water. Some other solutions are:

- Artificial mixing
- Hypolimnion aeration

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