Henry Hagg Lake Water Quality Model

Introduction

Henry Hagg Lake is a reservoir located in the foothills of the eastern slope of the Coast Range Mountains of northwestern Oregon (map), approximately 5 miles southwest of the city of Forest Grove and 25 miles west of the city of Portland. The lake was formed by Scoggins Dam, an earthfill structure that impounds Scoggins Creek, a tributary of the Tualatin River. Sain Creek and Tanner Creek also drain directly into Hagg Lake; the total drainage area upstream of the dam is 40.6 square miles. Hagg Lake was filled and began normal operation in 1975. At a maximum water elevation of 93.2 meters (305.8 feet) above sea level, the lake's total storage capacity is 64,812 acre-feet, with a maximum surface area of 1.8 square miles (Ferrari, 2001). The normal full pool water elevation is 92.5 meters (303.5 feet), with a capacity of 62,216 acre-feet, and a surface area of 1.7 square miles. The dam was built and is owned by the Bureau of Reclamation, which contracts with the Tualatin Valley Irrigation District for operation and maintenance. More information about the Scoggins Dam project is available from the Bureau of Reclamation.

The lake is used for recreation in the summer and flood control in the winter. It provides irrigation water to agricultural areas of the basin, and municipal and industrial water to the cities of Forest Grove, Cornelius, Hillsboro, Beaverton, and several smaller towns. Water from Hagg Lake also is used by Clean Water Services, the primary wastewater- and stormwater-management agency in the Tualatin River Basin, to augment flow in the lower Tualatin River in order to enhance water quality and help the river meet water quality standards.

Municipal and industrial demand for water in the Tualatin Basin is projected to almost double by 2050 due to population growth (see the Tualatin Basin Water Supply Feasibility Study by Montgomery Watson Harza, 2004). Several options are being considered to meet this expected demand, including structural changes to Scoggins Dam. Modifications under consideration include raising Scoggins Dam by 6.1 or 12.2 meters (20 or 40 feet) to increase water storage. Any dam raise probably would include modification of the lake's outlets, and may include a selective withdrawal tower. A diversion of water from the upper Tualatin River into Hagg Lake (a "Sain Creek tunnel") is also under consideration, as normal annual rainfall in the basin is not enough to fill the increased volume of an enlarged Hagg Lake (Montgomery Watson Harza, 2004). The effects of these proposed structural changes on lake water quality, and the quality of water withdrawn and released from an enlarged lake are important considerations for water planners.
Objectives & Approach

The objectives of this study were to develop a model of Hagg Lake that could:

1. simulate the circulation, temperature, and water quality in the lake,
2. aid in developing a better understanding of lake circulation and water quality and the processes affecting them, and
3. predict the changes in circulation, temperature, and quality that might result from a suite of proposed dam modifications.

To meet these objectives, USGS personnel constructed, calibrated, and tested a model of circulation, water temperature, and water quality for Henry Hagg Lake. The model was constructed to simulate conditions that occurred in the years 2000 through 2003. Model calibration focussed on the years 2000 and 2001; the calibrated model was then tested with data from 2002 and 2003. Hydrologic conditions during this period were variable, from near-normal conditions in most years to extreme drought conditions in winter 2000-2001, which caused the lake to only reach approximately 50% of storage capacity in 2001.

After the model was constructed and calibrated, it was used to simulate a suite of dam-raise scenarios to help predict the water-quality changes that might occur in the lake and downstream if the dam were to be increased in height.

Analysis & Results

The Hagg Lake model was constructed using CE-QUAL-W2 version 3.12 (Cole and Wells, 2002). CE-QUAL-W2 is a laterally averaged, two-dimensional flow and water-quality model developed by the U.S. Army Corps of Engineers and Portland State University. The simulated dimensions are longitudinal (along the length axis of the waterbody) and vertical (from water surface to bed sediment). The model simulates flow, horizontal and vertical velocities, water temperature, and a suite of water quality constituents. It has been applied to more than 400 lakes and reservoirs around the world, and is well documented and supported. USGS personnel modified the model for this application, adding the capability to simulate a community of zooplankton (Rounds and others, 1999; Rounds and Wood, 2001).

Input data for the Hagg Lake model included lake bathymetry, meteorologic conditions, tributary inflows, tributary temperature and water quality, and lake outflows. Calibrated output included lake hydrodynamics, water temperature, orthophosphate, total phosphorus, ammonia, algae, chlorophyll-a, zooplankton, and dissolved oxygen. Other simulated constituents included nitrate, dissolved and particulate organic matter, dissolved solids, and suspended sediment. Two algal groups (blue-green algae, and all other algae) were included in the model to simulate the lake's algal communities. Measured lake stage data were used to calibrate the lake's water balance; calibration of water temperature and water quality relied upon vertical profile data taken in the deepest part of the lake near the dam.

Sensitivity tests were performed to examine the response of the model to specific parameters and coefficients, including the light-extinction coefficient, wind speed, tributary inflows of phosphorus, nitrogen and organic matter, sediment oxygen demand, algal growth rates, and zooplankton feeding preference factors.

The details of Hagg Lake model construction and calibration have been documented in USGS Scientific Investigations Report 2004-5261:

The report describes the objectives and results of the modeling work, including a quantification of model performance, a discussion of those processes that influence water quality in the lake, and the results of sensitivity tests. A second report describes the use of the model to predict the effects of various dam-raise scenarios. In these scenarios, the model was used to assess the changes in temperature and water quality that might result after an increase in the height of Scoggins Dam. The results are documented in USGS Scientific Investigations Report 2006-5060:

[Available online at http://pubs.usgs.gov/sir/2006/5060/]

**Significant Findings**

The following findings were the result of an investigation of Henry Hagg Lake as it existed in 2000-2003. For the results of the model predictions for possible future conditions, see the dam-raise scenarios page.

1. Lake levels were highest in late spring and early summer and decreased through the summer and fall as downstream users required water for irrigation, drinking water, flow augmentation, and municipal uses. Lake levels were lowest in November and began to rise with the onset of winter rains. A drought during the winter of 2000-2001 caused the reservoir to not fill in 2001. The annual cycle in lake level was an important factor that affected lake temperature and water quality.

2. Spatial and temporal patterns in water temperature in Hagg Lake were similar in all 4 years modeled in this study. A thermocline developed each year by early summer, isolating cold, dense water near the bottom, below the lake's outlet structure. Withdrawals from the lake, as well as other seasonal factors, tended to draw the thermocline down to the level of the lake's outlet structure by mid-summer. Hagg Lake typically turned over in November and remained uniformly mixed and isothermal until early March, when temperature stratification began. Meteorological factors (solar energy, air temperature, wind) and reservoir operations (lake stage, elevation of the withdrawal) were found to have significant influences on the lake's water temperature.

3. During normal years, dissolved oxygen became depleted in the hypolimnion by late September; during the drought year, this occurred earlier, by late August. Colder temperatures and lake turnover in November reoxygenated the water column and ended hypolimnetic anoxia in each year. Dissolved oxygen levels in Hagg Lake were controlled mainly by water temperature (solubility) and sediment oxygen demand, and to a lesser degree, by algal photosynthesis and respiration.

4. Ammonia concentrations generally were low throughout Hagg Lake. However, in all years studied, accumulation of ammonia in the hypolimnion occurred once dissolved oxygen was depleted. Ammonia concentrations as high as 0.43 mg/L as N were measured in November of 2000.

5. Algae were separated into two groups in the model: blue-green algae, and all other algae. The general algae group had its highest abundance in the spring, due in part to inputs of algae from tributaries and possible resuspension of algal cells during storms. The blue-green algae group tended to bloom in late summer (in August, typically). Orthophosphate concentrations, as well as zooplankton grazing, water temperature, and light, controlled the levels and timing of algal blooms in the model. Concentrations of bioavailable phosphorus appeared to limit the size of the annual blue-green algae bloom.

6. While a community of zooplankton was found in Hagg Lake, its interactions with other zooplankton and with the lake's algal communities appears to be significantly more complex than what was represented in the model. Future work may be required to better describe the influence of
7. The model captured the dominant processes affecting water quality (temperature, dissolved oxygen, nutrients, and algae) in Hagg Lake and simulated the lake’s water quality dynamics with sufficient accuracy for the planned purposes of the model. Comparing measured and modeled water temperature profiles for the 4 years simulated, the mean absolute error (MAE) was less than 0.7°C and the root mean square error (RMSE) was less than 1°C. Comparing measured and modeled dissolved oxygen profiles in the 3 years having reliable data (2000-2002), the model errors typically were less than 1 mg/L.

Model

The model code, program, and all data necessary to run it for the years 2000 through 2003 are available from the links below. The model was compiled to run on the Windows operating system, but can be compiled and run on any system that has a FORTRAN 95 compiler. Although CE-QUAL-W2 is available with a graphical user interface, the copy distributed in these packages is a generic version that does not include the interface. The generic version produces the same results, but simply provides less feedback to the model user during the run. The generic version of the model was used exclusively by USGS personnel in this investigation.

The USGS model was a modification of version 3.12 (dated 15-Aug-2003) of the CE-QUAL-W2 source code. Modifications included the addition of a zooplankton group and several updates to correct coding bugs, as documented on the CE-QUAL-W2 website. The model was compiled using the Compaq Visual Fortran compiler (version 6.6.A) with the following options:

```
/fast /nodebug /real_size:64
/warn:(argument_checking,nofileopt,unused,nousage)
```

In particular, the "/real_size:64" option was important in avoiding memory alignment problems.

Data

Most of the lake and tributary data used to calibrate and confirm the model’s performance were collected as part of a Hagg Lake monitoring program carried out by various water agencies in the Tualatin Basin. Data from that program are available through the annual reports of the Tualatin River Flow Management Technical Committee.

Downloads

- **Download reports:**
  - Henry Hagg Lake model construction & calibration
  - Henry Hagg Lake model scenarios

- **Download GIS coverages:**
  - Scoggins Creek drainage & Hagg Lake bathymetry

- **Download the model and the data to run it:**
  - [Calibrated model for the year 2000](#) [ZIP, 1.1 Mb]
  - [Calibrated model for the year 2001](#) [ZIP, 1.1 Mb]
  - [Calibrated model for the year 2002](#) [ZIP, 1.1 Mb]
  - [Calibrated model for the year 2003](#) [ZIP, 1.1 Mb]
View animations of calibrated model output:
- water temperature - year 2000
- dissolved oxygen - year 2000
- ammonia - year 2000
- orthophosphate - year 2000
- water age - year 2000

References


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Henry Hagg Lake Model Scenarios page

URL: http://or.water.usgs.gov/tualatin/hagg_lake/index.html
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