Application of Three-Dimensional Hydrothermal Model for the Temperature Dynamics at Small and Shallow Lakes

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A three-dimensional time-dependent hydrodynamic and heat transport model of Binaba Lake, a shallow and small dam reservoir in Ghana, has been developed, which emphasize the dynamics and thermal structure of the lake. Most numerical studies of temperature dynamics in reservoirs are based on one- or two-dimensional models. These models are not applicable for reservoirs characterized by complex flow patterns and unsteady heat exchange between the atmosphere and water surface.

Continuity, momentum and temperature transport equations have been solved. Proper assignment of boundary conditions, especially surface heat fluxes, has been found crucial in simulating the lake's hydrothermal dynamics. This model is based on the Reynolds Average Navier-Stokes equations, using a Boussinesq approach, with a standard $k-\varepsilon$ turbulence closure to solve the flow field. The thermal model includes a heat source term, which takes into account the short wave radiation as well as heat convection at the free surface, which is a function of air temperatures, wind velocity and stability conditions of atmospheric boundary layer over the water surface.

The governing equations of the model have been solved by OpenFOAM®; an open source, freely available CFD toolbox. As its core, OpenFOAM® has a set of efficient C++ modules that are used to build solvers. It uses colocated, polyhedral numerics that can be applied to unstructured meshes and can be easily extended to run in parallel. In the framework of this study, a new solver was developed to solve the hydrothermal model of lake. The simulated temperature was compared against a 15 days field data set. Simulated and measured temperature profiles at the probe locations show reasonalble agreement. The model is able to compute total heat storage of water bodies to estimate evaporation from water surface.

Keywords

Three-dimensional hydrothermal model, Shallow and small lake, OpenFOAM, Temperature profile, Evaporation from water surface