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Recalibration of the Lake Okeechobee Water Quality Model (LOWQM) to extreme hydro-meteorological events

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ABSTRACT

The Lake Okeechobee Water Quality Model (LOWQM) was developed using an enhanced version of WASP5 to improve understanding of nutrient cycling – specifically total phosphorus – and to assess lake-wide averaged nutrient and algal responses to management alternatives. Previously, the LOWQM was calibrated/validated to hydro-meteorological and monitoring data from 1983 to 2000. Subsequently, a series of extreme hydro-meteorological events, including three hurricanes and two major droughts, occurred from 2005 to 2008 that were outside the range of observations in this original LOWQM model calibration (original simulation). These events affected the light environment, nutrients and phytoplankton communities in the lake. The LOWQM was recalibrated and revalidated (new simulation) to the time period 1983–2012. When compared to the original simulation using the same set of forcing functions (e.g. flow, rain, temperature, nutrient loads, and resuspension of sediments), there were some improvements in model predicted nitrogen and phytoplankton, based on goodness-of-fit measures to observed data. Major differences between the two simulations were found in nutrient cycles. The differences in these cycles and the similarity of goodness-of-fit measures between the new and original simulations indicate the importance of sediment-water interactions and the effect that model structure (e.g. equations) have on the ability to improve calibration results. Further evaluation of these two simulations suggest that model accuracy can be improved through changes of model segmentation, additional lake sampling of biological processes simulated by the LOWQM, and revising model equations to allow for variation in algal nutrient to carbon ratios and uptake rates of nitrogen.

1. Introduction

The Lake Okeechobee Water Quality Model (LOWQM) was developed to improve understanding of the fate and transport of phosphorus within the lake and to predict the effects of external phosphorus load reduction on the lake's water quality (Bierman and James, 1995; James and Bierman, 1995). The model was enhanced to improve representations of sediment-water interactions (James et al., 1997), and phosphorus, nitrogen and algal dynamics (James et al., 2005). Calibrated to observed monitoring data from 1983 to 2000 (James et al., 2005), the LOWQM has been used to evaluate decadal-scale responses of algae and nutrients to external nutrient load reductions. This has included various scenarios to reduce the nutrient loads to reach the Lake Okeechobee Total Maximum Daily Load (TMDL, Florida Department of Environmental Protection (FDEP), 2001) and management of internal sediment load reductions (i.e. sediment resuspension and flux, James and Pollman, 2011).

1.1. Extreme hydro-meteorological events

Hurricanes Frances on September 5, 2004, Jeanne on September 26, 2004, and Wilma on October 24, 2005 passed over Lake Okeechobee, resulting in high waves, increased sediment resuspension and increased water-column nutrient concentrations (James et al., 2008). This was followed by one of the most severe droughts in south Florida history, with water levels in Lake Okeechobee falling to daily record low values between 2.7 and 3.2 meters NGVD from July 2007 to April 2008 (Zhang et al., 2009). This series of daily record low values ended when tropical storm Faye passed through south Florida in August 2008 resulting in lake water levels that increased by more than a meter within a month (McCormick et al., 2010). Water levels then remained within a preferred range until another drought occurred from May to October 2011 (Zhang and Sharfstein, 2013).

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1.2. Objectives

These extreme events and dramatic changes in water quality were outside the range of observations simulated by the LOWQM model. The first objective of this study was to add the 2001 to 2012 period to the simulation and recalibrate the model (new simulation). Comparing and contrasting the original model calibration (original simulation) and new simulation for the 1983 to 2012 period will answers these five questions:

(1) Does the original simulation provide reasonable results for the extreme event period from 2005 to 2012?
(2) Can a recalibration provide better results for the extreme period and for the entire period of record?
(3) What are the major calibration changes in the new simulation?
(4) Are there major differences in the predictions by the two simulations?
(5) Are there changes in model equations and/or structure that could enhance the reliability of the LOWQM?

2. Methods and materials

2.1. Model description

The Lake Okeechobee Water Quality Model (LOWQM) is a deterministic, mass balance model based on an enhanced version of EUTRO5, the eutrophication submodel of the Water Quality Analysis Simulation Program, Version 5 (WASP5) (Ambrose et al., 1993a,b). The model partitions the lake into three homogenous compartments: water column, oxic surface sediment and anoxic deeper sediment. It simulates the nitrogen (N), phosphorus (P), silica (SI) and oxygen cycles, as well as phytoplankton dynamics of three algal groups: cyanobacteria, diatoms, green algae (James et al., 2005, Fig. 1). In addition it simulates four classes of organic phosphorus: labile, moderately labile, dissolved and non-reactive.

2.2. Site description

Lake Okeechobee is a large (1730 km^2) shallow (mean depth 2.7 m) lake in the south central region of the Florida Peninsula (Fig. 2). This eutrophic lake has been affected by long term excess nutrient loadings (Havens and James, 2005), resulting in numerous algal blooms (Havens et al., 1995). The lake is very turbid with flocculent and easily resuspended sediments occuring through a majority of its open water region (Jin et al., 2011). Secchi depths in the open water average 30 cm (Phlips et al., 1995). This lake is important for native wildlife, sport and recreation, flood control and water supply for the surrounding area as well as the Everglades and the Caloosahatchee and St. Lucie Estuaries. The lake has been studied extensively (Aumen and Wetzel, 1995) and has been monitored for hydrology and water quality on a routine basis since 1972 (James et al., 1995a,b; Zhang and Sharfstein, 2013).

2.3. Monitoring data

Lake Okeechobee water quality has been measured at 32 inflow/outflow locations on a monthly to biweekly basis from 1973 to present (Fig. 2). Water flow has been estimated on a daily basis at these structures. Water quality samples have been collected for the same time period at nine in-lake locations. Nutrient loads and water inflow/outflows to/from the lake are calculated from these water quality and flow measurements and summed by month (Havens and James, 2005; James et al., 1995a). Flow and flow-weighted nutrient concentrations (calculated from flow and load) are used as boundary conditions for the model. The hydrology and water quality data are available from the South Florida Water Management District's (SFWMD) DBHYDRO database (SFWMD, 2012a).

Phytoplankton density and biovolumes were measured at four stations between 1988 and 1992 (Cichra et al., 1995). After 1993, samples were taken from two of the original phytoplankton

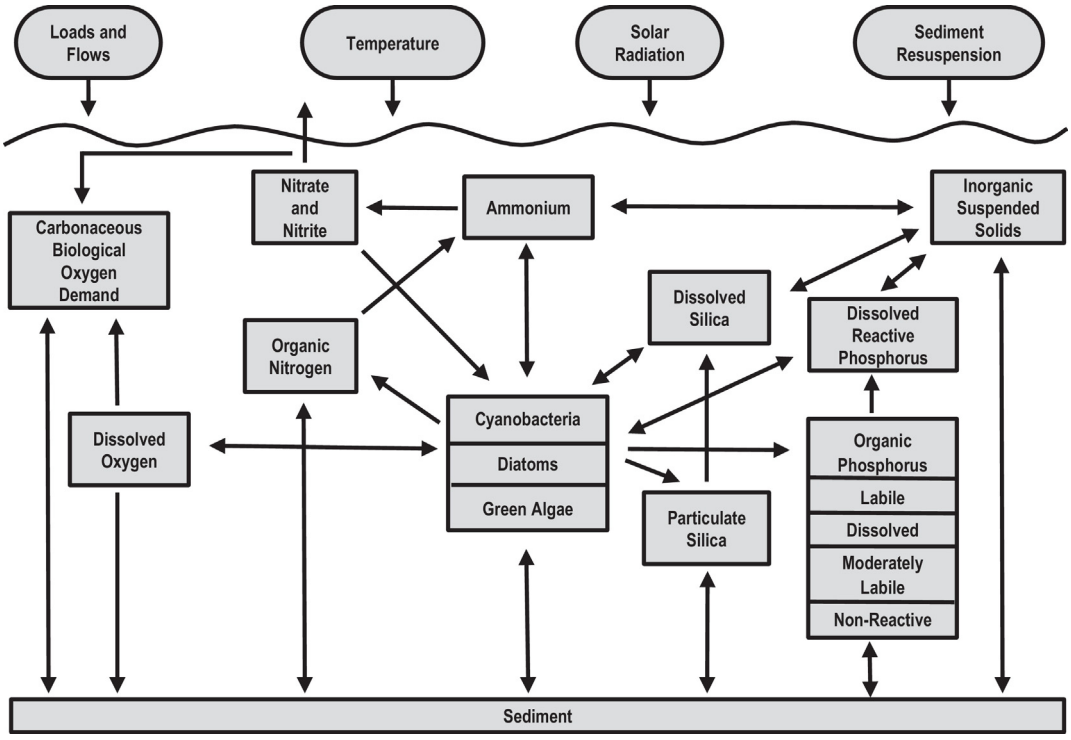

Fig. 1. Schematic of the Lake Okeechobee Water Quality Model indicating forcing function in ovals, standing stocks in boxes (LOWQM adapted from James et al., 2005).