Impacts of Nitrogen (N) loads on the Water Quality of Lake Taal, Philippines: A System Dynamics Approach

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ABSTRACT

System dynamics (SDs) is an advance tool that has been instrumental in evaluating and addressing issues and problems of complex systems, characterized by delays, feedback, and nonlinearities. The identification of and use of feedback loops differentiates SDs from other systems approaches and have developed in various areas in the natural and social sciences, such as policy design, biological and medical modeling, energy and the environmental analysis, like nutrient pollution. This study presents the quantitative and qualitative development and critical testing of an extensive system dynamics compartmental model for predicting the nitrogen load concentrations and its eutrophication effects on the water quality in lake ecosystems, driven by easily accessible lake variables.

The keystone is a dynamic nitrogen simulation model based on ordinary differential equation. By calculating mass fluxes of nitrogen into, within and out from a lake, concentrations of this nutrient of different forms (stoichiometry) in various compartments of the lake were estimated.Nitrification is one of the challenging nutrient processes in assessing the environmental health of a complex freshwater ecosystem. A dynamic and mechanistic mass balance model for predicting the effect of nitrification (i.e. nitrogen loads) on the water quality of Lake Taal has been developed and calibrated using published parameter values from local experiments and published data on Lake Taal fish kills reported from 2000 to 2017. Developed using the STELLA™ ver. 10.0.3 modeling software, the model structures include: fish growth, stoichemistry of nitrogen transformation (i.e. nitrogen {organic, total ammonia and nitrate}), dissolved oxygen and phytoplankton, harmful algal blooms (HABs). The processes included in the model are fish population, crop biomass growth, allochthonous and autochthonous organic matter production, organic matter decomposition, nitrogen input, nitrogen mineralization, nitrification, denitrification, diffusion, uptake and leaching (sediments, water column). The conceptual model elucidates the interrelationship among these key components to understand further the complex behavior of the system, while adhering to the principles of mass balance and steady state.

Model simulations for 12-mo at DT=0.25, revealed a rapid increase in nutrient nitrogen on the water quality of the whole lake system which caused a rapid decrease on fish population, increased HABs, slow decrease of nitrogen in the water column and a simultaneous steady state increase of detritus. Furthermore, a typical variation pattern of nutrient loads from allochtonous sources showed an increase from January to June and a decrease in July to an slow increase until December. The sensitivity analysis feature of STELLA™ was used in the process in order to refine the calibration. The validation for the model was conducted using the data from January to December 2015 generated from the sum total values of variables of the municipalities of North and South basins.

KEY WORDS: Water Quality, Lake Taal, System Dynamics Approach, nitrification, HABs, STELLA™ ver. 10.0.3.