The Simulation of Dissolved Oxygen and Orthophosphate for Large Scale Watersheds Using WASP7.1 with Nutrient Luxury Uptake

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Objective

- **Demonstrate the importance of the nutrient luxury uptake for dynamic water quality simulations when primary productivity is high and the supply of DOPO4 is limited.**

- **Compare dissolved oxygen output obtained with the Water Quality Analysis Program (WASP) assuming the Monod and Droop methods for nutrient uptake.**

Methodology

- **The new WASP7.1 with the Droop method for luxury uptake was calibrated at selected locations within a New Jersey Watershed.**

- **The previous version of WASP (WASP 7.0), which adopts the Monod method for attached algae nutrient uptake, was applied to the same areas.**

- **Dissolved oxygen output obtained with the Monod and Droop methods were compared to determine the importance of nutrient luxury uptake according to site characteristics.**

Droop and Monod Methods

Dissolved oxygen concentrations are normally adopted to assess water quality. Low levels of dissolved oxygen can be associated with excessive algae and plant productivity. Phosphorus is generally considered to be the primary nutrient limiting algal and plant growth in fresh waters.

The role of nutrients in fresh waters and its effects on dissolved oxygen can be quantified using water quality models. Most water quality models adopt the Monod method to represent the dynamics of nutrients in aquatic systems.

The Monod method relates plant and algae growth with available nitrogen and phosphorus in the water column to simulate the biological uptake of nutrients by algae. Once the growth rate of algae or plants is determined by the Monod Method, the nutrient pool and dissolved oxygen concentrations in the water column are calculated according to the rates of algae consumption and release of nutrients and oxygen.

The Monod method, which is also called the Michaelis-Menten model (Chapra, 1997) consists of calculating the maximum specific growth rate *G(N)* that can be achieved, according to the water column concentration of phosphorus [P] or nitrogen [N] and their respective half saturation constant K_p or K_n.

$$G(N) = \frac{[P]}{K_p + [P]}$$

The Monod approach ignores the phenomenon of luxury uptake, where nutrients are absorbed and stored by algae during times of excess concentrations in the stream. The excess phosphorus stored can be used to support productivity during times of low phosphorus concentrations in the water column. By drawing on internal nutrient reserves, algae can grow at nearly maximum rates during periods of water column nutrient depletion (Effler, 1996).

Droop (1974) developed a method that relates algae and plant growth with the internal nutrient levels that can be used to simulate nutrient luxury uptake.

The Droop method relates algae and plant growth with the internal nutrient levels, cell quota (*Q*), and the minimum cell quota (Q_0), which is the internal nutrient concentration where growth ceases. This method allows nutrient luxury uptake to be taken into account, but it is more complex from a computational standpoint.

The Droop method requires the mass balance of the internal nutrient pool to be calculated, considering the contributions from nutrient uptake from the water column, and the losses through demand and growth (Effler, 1996).

$$G(N) = 1 - (Q_0 / Q)$$

Application of WASP 7.1 for New Jersey Watershed

WASP 7.1 is the latest version of the Water Quality Analysis Program. It allows the simulation of attached algae with the luxury uptake of nutrients (Ambrose et al., 2006).

Three existing monitoring stations (Sites 1, 2 and 3), located in a New Jersey watershed, were selected to test the WASP 7.1 model and the importance of simulating nutrient luxury uptake in these areas.

A one-dimension and continuous WASP 7.1 application was developed for the selected areas. The model includes a hydrodynamic file with continuous flows, non-point source inputs from contributing sub-watersheds, known point source dischargers, time series of temperature and solar radiation, settling rates and kinetics parameters. The PERIPHYTON algorithm was selected for the simulations.

The selected areas are monitoring stations containing measurements of nutrient concentrations and continuous diurnal dissolved oxygen (DO). The sites differ in terms of average flows, concentration of dissolved orthophosphorus (DOPO) and diurnal DO variation.

The analysis was performed during times of low flow and high primary productivity during the summer months of 2004.

The model was calibrated using monitoring data collected by Omni Environmental LLC (TRC Omni Environmental, 2005). Calibration consisted of adjusting kinetic parameters such as periphyton growth rates, phosphorus cell quotas and maximum phosphorus uptake by periphyton.

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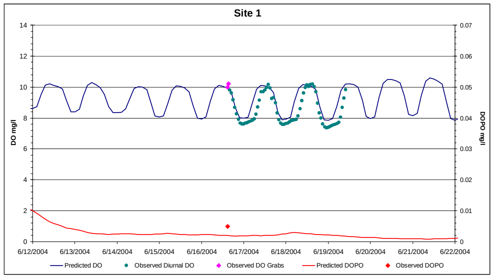
Calibration Results

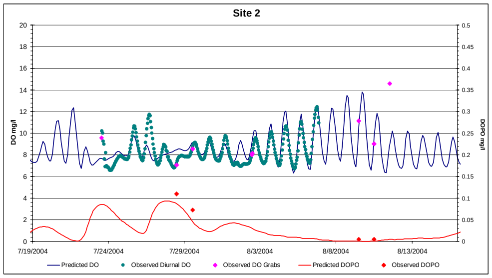
Figures 1, 2 and 3 show the observed and predicted diurnal DO and DOPO for sites 1, 2 and 3, respectively.

Figure 1



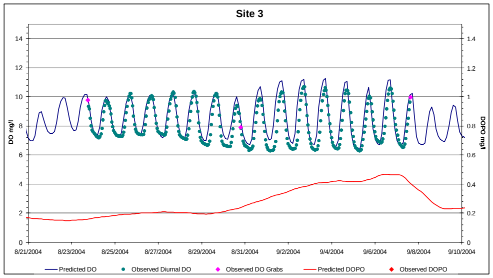
Site 1 is characterized by steady flow conditions (22 cfs), moderate productivity, and very low DOPO concentration. Diurnal variation of dissolved oxygen and DOPO concentrations are fairly constant. The detection limit of orthophosphorus is 0.01 mg/l. When diurnal DO measurements were performed, DOPO concentrations were consistently below detection. The DOPO sample, shown as half of the detection limit in Figure 1, confirms the low phosphorus levels simulated by the model. Even though simulated phosphorus was below detection limits, WASP 7.1 was able to capture the diurnal variation of dissolved oxygen very well

Figure 2



Results at Site 2 reflect more nutrient variability due to storm events that occurred during the sampling event. The DOPO sampled during the storm events show the non-point source inputs to the model. Strong diurnal DO variation is observed at times of poor DOPO availability. The simulated peak flow at Site 2 is 1655cfs. The lowest flow at the time of high productivity was 170 cfs. Diurnal DO variation is well represented during times of high and low DOPO availability.

Figure 3



Site 3 presents strong diurnal DO variation and high DOPO concentrations. Dissolved orthophosphate was not sampled during the time of the diurnal sampling event. However, sampling performed at this site for different time periods reveal an average concentration of 0.21 mg/l and minimum concentration of 0.07 mg/l of DOPO. Average low flow during the time period shown in Figure 3 is 350 cfs. Therefore, the results obtained with WASP 7.1 with nutrient luxury uptake algorithm are able to capture observed levels of primary productivity under conditions of high and low phosphorus availability.

Comparison of Monod and Droop Methods

An application of WASP 7.0, which adopts the Monod method for nutrient limitation, was developed for the same sites. The results obtained with WASP 7.0 and WASP 7.1 were compared to demonstrate the importance of the nutrient luxury uptake for the simulation of sites presenting high productivity under scarce nutrient supply.

The same input data and kinetic parameters were used for both WASP applications. No additional calibration was performed for the WASP 7.0 application. Therefore, periphyton growth rates and half-saturation uptake rates for nutrients from the water column, which are calibration parameters for both approaches, were assumed to be the same. The comparison of diurnal DO variation obtained with the Droop method and the Monod method is shown in Figures 4, 5 and 6.

Figure 4

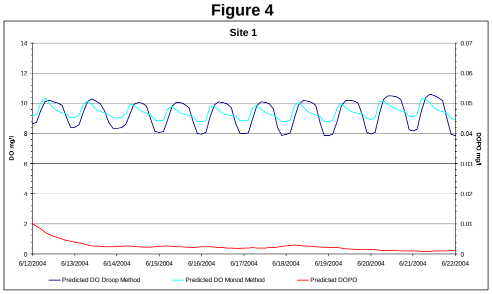


Figure 4 shows the comparison for Site 1, where DOPO concentrations are below the detection limit for a ten day period. The Monod method captures only half of the diurnal dissolved oxygen variation. In addition, the diurnal dissolved oxygen simulated with WASP 7.0 does not present the typical sinoidal shape. This indicates that phosphate concentration in the water column is not enough to support growth during times of nutrient depletion.

Figure 5

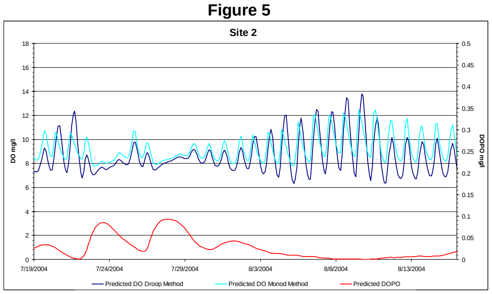


Figure 5 shows the comparison for Site 2, where DOPO concentrations vary during a 25 day period. This site allows a comparison during times of different phosphorus availability. The Monod method provides a realistic response of nutrient limitation when phosphorus is less scarce. When phosphorus concentrations are above 0.05 mg/l, the diurnal DO simulation is similar for both WASP versions. However, when DOPO drops under 0.025 mg/l, the Monod method is not able to sustain the same growth levels as the Droop method.

Figure 6

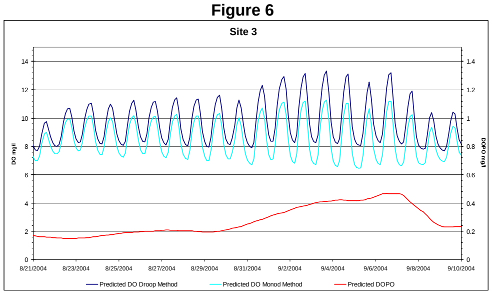


Figure 7 shows the comparison for Site 3, where DOPO is above 0.15 mg/l. The degree of diurnal DO variation simulated for this site is the same according to both methods. The Monod method seems to provide concentrations approximately 1 mg/l lower than the Droop method. This lower DO average could be addressed by changing calibration parameters in the WASP 7.0.

Conclusions

The Monod method does not provide an adequate representation of diurnal DO when the phenomenon of luxury uptake of nutrients is important. The Droop method can successfully address the problem of luxury nutrient limitation. The importance of the nutrient luxury uptake was demonstrated by comparing the simulations obtained with WASP 7.1 and WASP 7.0. The simulations with WASP 7.0, which adopt the Monod method, cannot capture the diurnal dissolved oxygen when the nutrient supply is short.

References

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