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Subject: Recommendation of the WASP model for in-lake water quality simulations

Dear BMW Technical Committee:

This letter presents a recommendation for the in-lake portion of the Barr Lake-Milton Reservoir numerical modeling that will be completed by ENSR. To date, the watershed model development has progressed satisfactorily, albeit somewhat behind schedule due primarily to data availability issues. The **S**oil **W**ater **A**ssessment **T**ool (SWAT) model selected for the watershed simulations has performed well, following a few computer code modifications to provide a better representation of the BMW watershed than would otherwise have been possible. The SWAT model has been demonstrated to effectively predict water volumes in Barr Lake and Milton Reservoir and water quality at the inlets to the Barr-Milton Reservoir system (i.e. the O'Brian Ditch just upstream of Barr Lake and the Platte Valley Canal just upstream of Milton Reservoir) but has proven, as yet, to be inadequate at representing water quality in the reservoirs due to an over-simplification of eutrophication processes.

ENSR is recommending that the SWAT model be used to provide predicted flows and nutrient concentrations to a more complex instream eutrophication model. In that way, the boundary conditions of the instream model will be predicted by the calibrated SWAT watershed model rather than fixed by the user if a stand-alone instream model were employed. The instream model will then run independent of the watershed model but will be based on the flows and loads applied to the model from SWAT. Based on ENSR's experience in stream and lake water quality modeling, it is recommended that the EPA's WASP (**W**ater Quality **A**nalysis **S**imulation **P**rogram) model be used to simulate water quality in both Barr Lake and Milton Reservoir. The WASP model is being recommended based on the following:

- WASP is a public domain model with a long history of development and application and has excellent technical support available through the USEPA's Center for Exposure and Assessment Modeling (CEAM) located in Athens, GA.
- WASP has been modified to provide a very user-friendly Windows® interface.
- WASP uses a hydrodynamic interface file that can easily be developed from the SWAT model output for a nearly seamless transition from the watershed modeling to the lake modeling.
- WASP is a fully dynamic, one-dimensional model that simulates the complex processes associated with eutrophication without over-complication of the hydrodynamics.

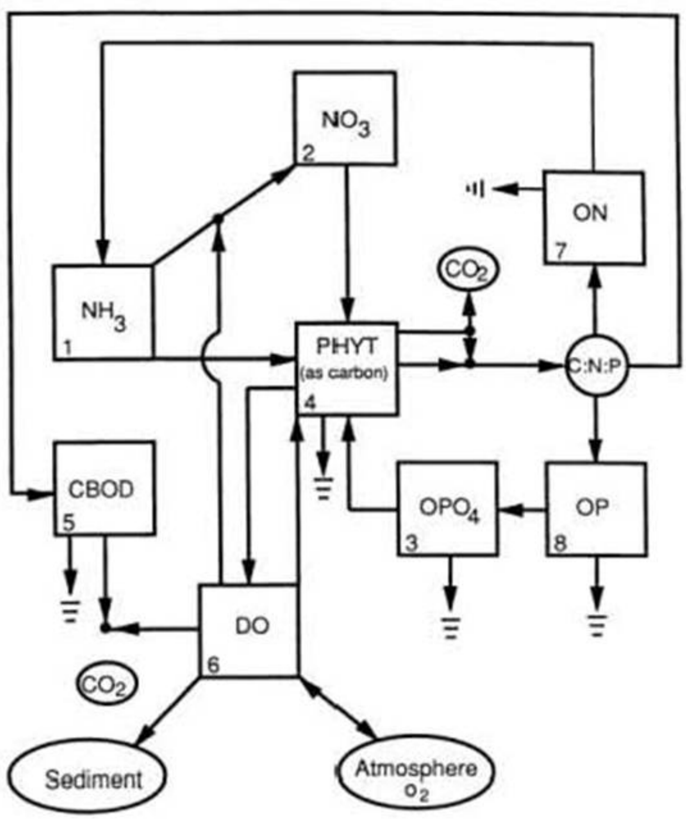
Detailed Description of WASP

The WASP (Version 7.2) modeling system is recommended for use to simulate nutrient dynamics within the Barr and Milton Reservoir impoundments using the hydrodynamic and nutrient predictions developed by SWAT as boundary conditions to generate water quality predictions throughout the Barr-Milton Reservoir system. The WASP model can represent the Barr-Milton Reservoir system as a series of interconnected segments extending, from the inflow to Barr Lake, downstream to the outflow from Milton Reservoir. The WASP model system includes two distinct model frameworks, one for the simulation of nutrients and eutrophication (EUTRO) and another for the simulation of organic chemicals and metals (TOXI). The EUTRO model framework, which includes representations of the fate, transport, and transformation of nitrogen, phosphorus, and oxygen consuming wastes, is recommended for simulating eutrophication in the Barr-Milton Reservoir system. Because the known pH issue is directly linked to the eutrophication problem, we hope to link the EUTRO model output to pH through simple, empirical correlations.

Instream Water Quality Processes Simulated by WASP

The EUTRO subroutine of the WASP modeling system describes a variety of eutrophication processes in a segmented system. Each interconnected stream segment is described by a set of fixed and time-variable external parameters and a set of kinetic reaction rates to control the transformation of constituents from one model time step to the next. The EUTRO subroutine simulates eutrophication as four interacting systems including the phosphorus cycle, the nitrogen cycle, the dissolved oxygen balance, and phytoplankton kinetics according to Figure 1.

Figure 1: Schematic of Eutrophication Cycling Represented by the WASP Model



- Phosphorus Cycle – The forms of phosphorus simulated in the WASP model include organic and dissolved inorganic phosphorus. Dissolved inorganic phosphorus is taken up by phytoplankton for growth and is then incorporated into phytoplankton biomass. Phosphorus is returned from the phytoplankton biomass pool to organic phosphorus through endogenous respiration and non-predatory mortality. Organic phosphorus is converted to dissolved, inorganic phosphorus at a temperature dependent mineralization rate.

- Nitrogen Cycle – Ammonia and nitrate are taken up by phytoplankton for growth, and incorporated into phytoplankton biomass. Nitrogen is returned from the phytoplankton biomass pool to organic nitrogen and ammonia through endogenous respiration and non-predatory mortality. Organic nitrogen is converted to ammonia at a temperature-dependent mineralization rate and is then converted to nitrate at a temperature- and oxygen-dependent rate.

- Dissolved Oxygen Cycle – The DO cycle is the most complex to simulate because of its interdependence on the nutrient and phytoplankton cycles. Dissolved oxygen can be added to the system from atmospheric reaeration and photosynthesis and can be lost from the system by the effects of biological oxygen demand (BOD), the formation of nitrate, endogenous respiration, and sediment oxygen demand.

- Phytoplankton Cycle – The growth of phytoplankton in a natural environment depends on the species present and their differing responses to solar radiation, temperature, and nutrient availability. Rather than considering the problem of different species and their associated environmental and nutrient requirements, the EUTRO subroutine of the WASP model characterizes the phytoplankton population as a total biomass represented as chlorophyll *a*. Phytoplankton kinetics are simulated in the WASP model by incorporating available nutrient concentrations, light, and a number of reaction rates and modifying coefficients into a set of governing equations to describe the growth, death, and loss of phytoplankton in a natural system. Growth rates are modified by nutrient limitation formulations to simulate the natural preference of species to specific nutrient concentration ranges and most reaction rates are temperature dependent. The model uses a combination of predicted and input environmental conditions to control the prediction of chlorophyll concentrations throughout a simulation.

The model segments can be assigned boundary conditions, which are specific, potentially time-varying, values assigned as input to a model segment rather than values predicted within a segment. In the case of the Barr-Milton Reservoir system, the boundary conditions would be derived from the flows and nutrient concentrations predicted by the SWAT model. The use of WASP should provide more realistic predictions of water quality in the Barr-Milton Reservoir system than using the existing reservoir water quality component already included in the SWAT model, although there could still be issues associated with excess nutrients. For purposes of prediction of response to management actions, however, WASP is expected to provide results superior to the in-lake component of SWAT. The setup and execution of the WASP model would only require reformatting the output from the SWAT model using a simple Visual Basic® program, followed by calibration of the in-lake model independent of the SWAT model.

ENSR is requesting approval for this recommendation to use the EPA's WASP model to complete the water quality modeling for the Barr-Milton Reservoir system. We feel that this is a better approach than use of the overly simplified water quality algorithms available in the SWAT model.

Sincerely yours,

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