JOURNAL OF
ENVIRONMENTAL HYDROLOGY
The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com
VOLUME 9 2001

IMPROVING THE WATER QUALITY CALCULATION IN WATERSHED MODELS

Scott A. Lowe
Department of Environmental Engineering
Manhattan College, Riverdale, U.S.A.

This paper provides some insight into how the water quality calculations performed in watershed models can be improved by integrating the latest methodology employed by state-of-the-art water quality models. Suggestions include adding a sediment submodel, allowing for the addition of another phytoplankton group, and adding a two- or three-dimensional capability for modeling the receiving waters.

INTRODUCTION

Watershed and water quality models provide an invaluable tool with which to analyze natural and engineered systems. The results of such analyses can be used in a multitude of ways. Typical applications often include the evaluation of management alternatives and the prediction of future impacts on a system. Despite the shortcomings that models may have, and all models have shortcomings, they still represent the best, and sometimes only, rational, scientific way to answer many of the questions posed about such systems.

In this paper the present status of watershed and water quality models will be briefly reviewed. In particular the water quality components within watershed models will be examined and some suggestions made as to how to improve the calculation.

THE PRESENT STATUS – WATERSHED AND WATER QUALITY MODELS

In this section the Hydrologic Simulation Program - FORTRAN (HSPF) will be used as the reference watershed model (Bicknell et al.,1997). HSPF is representative of the state-of-the-art of watershed models.

HSPF has been in use for many years. The model has its origins in the Stanford Watershed Model, which was developed in the 1960’s. Over this period of time HSPF has grown considerably in complexity. In fact, HSPF is now a suite of programs rather than just one program. At the present time HSPF development and maintenance is sponsored by the U.S. Environmental Protection Agency and the U.S. Geological Survey.

The model provides two main calculations: water budget and water quality. The model also allows for three types of segments: pervious and impervious land segments, and a stream reach segment that can also be used to simulate other hydraulic objects, like man made channels, reservoirs, lakes and the like. The water budget calculation is very thorough and requires quite a lot of input data including precipitation, potential evapotranspiration, air temperature, dewpoint, radiation, and wind. Included in the calculation are both pervious and impervious segments, interception, infiltration, interflow, surface runoff, snow accumulation and melt, and evaporation. An overview of the water budget calculation alone could easily fill an entire paper but suffice it to say that with good input data (quality and quantity), one can expect to get a good representation of the water cycle for a watershed.

The water quality calculation in HSPF, as well as in water quality models, can be characterized by the constituents that are modeled. The overland constituents that can be modeled in HSPF are given in Table 1. The constituents shown in Table 1 can be grouped into four categories: toxics, solids, nitrogen and phosphorus. The latter two could also be classified as nutrients.

Once transport moves the constituent load to the edge of the receiving water, the load then becomes a non-point source input to a water quality model. This modeling can either be done within HSPF or by a specialized water quality model. It is interesting at this point to compare how the water quality model within HSPF compares to state of the art specialized water quality models, such as HydroQual’s RCA (HydroQual, 1992) or the Corps of Engineers CE-QUAL-ICM (Cerco and Cole, 1993). A comparison is shown in Table 2. Note that all state variables listed in Table 2 are not likely to be used in any particular application of either model, but rather a subset that is relevant to the particular problem.

Discussing the implications of Table 2 also leads into suggestions about what may be done to improve the water quality aspect of watershed models. This will be covered next.

Table 1. Overland Constituents Modeled in HSPF

Number	**Constituent**
1	Pesticides
2	Solids
3	Particulate organic nitrogen – refractory
4	Particulate organic nitrogen – labile
5	Dissolved organic nitrogen – refractory
6	Dissolved organic nitrogen – labile
7	Ammonia – absorbed
8	Ammonia – dissolved
9	Nitrate
10	Plant nitrogen – above ground
11	Plant nitrogen – below ground
12	Litter nitrogen
13	Organic phosphorus
14	Phosphate – absorbed
15	Phosphate – dissolved
16	Organic phosphorus
17	Plant phosphorus
18	Non-reactive tracer

Table 2. Comparison of HSPF and Specialized Water Quality Models

Water Quality Models	**HSPF**
3 dimensional	1 dimensional
Advective transport	advective transport
Dispersive transport	▨
Wetting/drying of segments	▨
Solids	solids
Temperature	temperature
Phytoplankton 1	phytoplankton
Phytoplankton 2	▨
Phytoplankton 3	▨
Zooplankton	zooplankton
Benthic algae	benthic algae
Benthic biomass	▨
aquatic vegetation	▨
Particulate organic phosphorus – refractory	particulate organic phosphorus - refractory
Particulate organic phosphorus – labile	▨
Dissolved organic phosphorus – refractory	▨
Dissolved organic phosphorus – labile Particulate organic phosphorus – refractory	▨
Orthophosphorus	orthophosphorus
Particulate organic nitrogen – refractory	particulate organic nitrogen - refractory
Particulate organic nitrogen – labile	▨
Dissolved organic nitrogen – refractory	▨
Dissolved organic nitrogen – labile	▨
Ammonia	ammonia
nitrite + nitrate	nitrite + nitrate
Biogenic silica	▨

Table 2. Comparison of HSPF and Specialized Water Quality Models (continued)

Water Quality Models	**HSPF**
total silica	▨
Particulate organic carbon – refractory	particulate organic carbon - refractory
Particulate organic carbon – labile	▨
Dissolved organic carbon – refractory	▨
Dissolved organic carbon – labile	▨
Dissolved organic carbon – reactive	▨
Dissolved organic carbon – algal exudate	▨
Dissolved oxygen	dissolved oxygen
total inorganic carbon	total inorganic carbon
PH	pH
Sediment phosphorus flux	▨
Sediment ammonia flux	▨
Sediment nitrate flux	▨
Sediment silica flux	▨
Sediment oxygen demand	▨
Sediment methane/sulfide flux	▨
Metals	▨

IMPROVING THE WATER QUALITY CALCULATION IN WATERSHED MODELS

This section will focus on the “in stream” water quality calculation made by HSPF and will not discuss the overland water quality model. Based on the information in Table 2, several observations are summarized below.

1. Water quality models are fully three-dimensional. HSPF water segments are one-dimensional. This limits the type of water body that can be modeled if that particular water body has definite two- or three-dimensional behavior. This is a significant limitation as most reservoirs and lakes, for example, exhibit strong vertical behavior (Thomann and Mueller, 1982). In general, water quality models will use two- or three-dimensional models for most applications other than small/medium size rivers.

2. HSPF does not include dispersive transport. The role of dispersion may be extremely important depending on the problem being modeled. In watershed models the stream segments are usually so long that this is not really an issue. At this point the problem is in the scale used to resolve a watershed and this is a separate problem (Thomann and Linker, 1998).

3. Water quality models have the capacity to have more than one phytoplankton group. This is significant as many systems show distinct summer and winter behavior, and the cycle of one group may have a large effect on the other. Also the internal stoichiometry of the different groups may be quite different.

4. Although HSPF does model a nitrogen and phosphorus cycle it does not model silica. Silica may not be important for many of the applications where HSPF would be used. However if diatoms are a major phytoplankton group in the system then silica may be very important. This is because diatoms have a very large silica requirement and their growth may be silica limited.

5. Advanced water quality models include an interactive sediment sub-model to calculate

sediment fluxes such as phosphorus, ammonia, SOD, etc. The inclusion of the sediment model has been a large step forward for water quality models. Previously sediment fluxes had to be specified as an input and so were not truly an interactive part of the modeling procedure. This was a significant deficiency considering the important role that sediments can play in many systems. If the model is being used to generate "what if" scenarios for load reduction, then the inability of the sediment to respond becomes a liability.

An example of a water quality model with and without a sediment model is shown in Figure 1. The effect on minimum dissolved oxygen (DO) is shown. In this case the system being modeled is a mesocosm (5m deep, volume 13.1m^3) that has been subject to various loads of nitrogen, phosphorus and silica (Lowe and DiToro, 2000). The model is represented by the line and the points are actual data. Minimum DO is often one of the most important criteria used to evaluate water quality and, as can be seen from the figure, the results are markedly different.

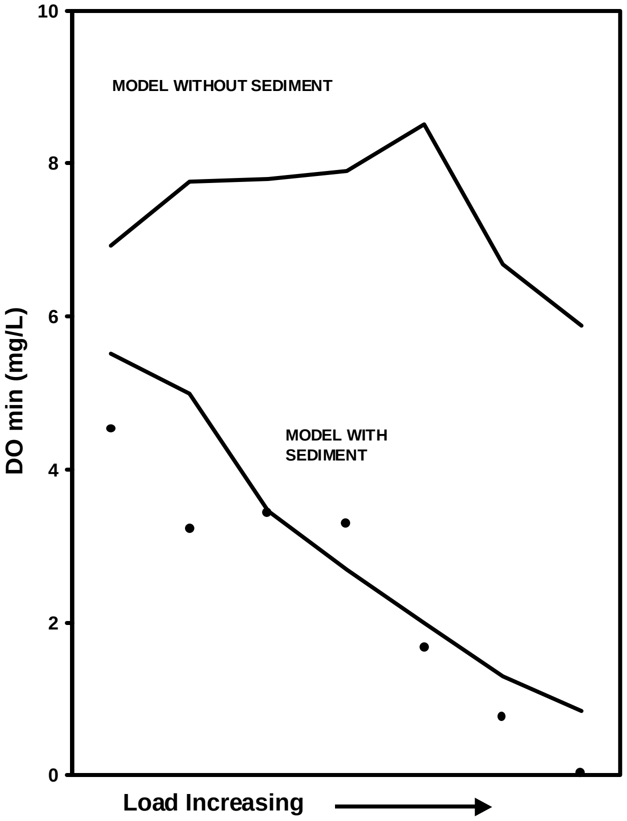

Figure 1. Effect of sediment model on minimum DO.

An example of another problem that is encountered when the sediment is not included is predicting the recovery of a system once loading is reduced. A plot of chlorophyll A levels of the same mesocosms is shown in Figure 2, with and without sediment. Without sediment the system just flushes out after the load is removed. With the sediment included all the previous load that has been deposited in the sediment (mainly via settling of biomass) causes elevated recycle fluxes of nutrients. This in turn keeps the water column eutrophied for an extended period of time. The difference in predicted recovery period can be very large. For the example shown the mesocosm was heavily loaded for 5 years. Without the sediment included the system recovered completely in about 90 days (approximately 3 detention times). With the sediment included the effects could still be seen years later.

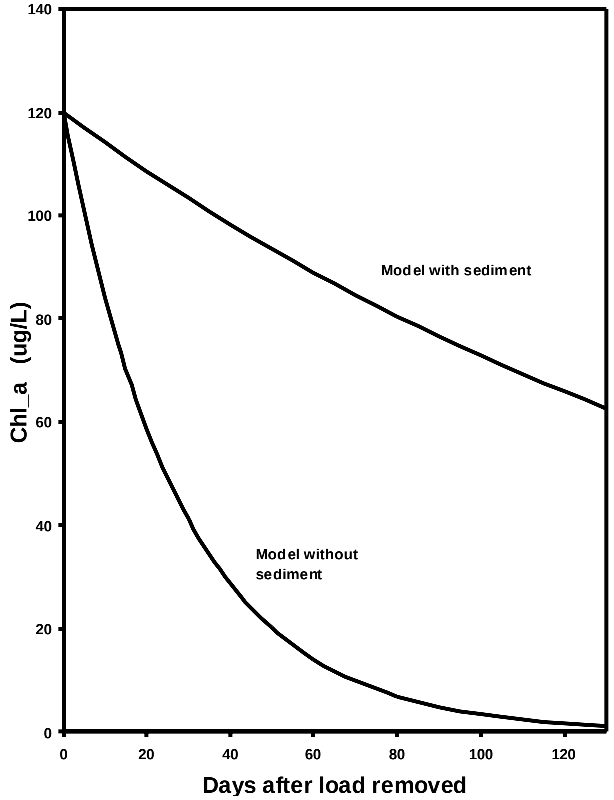

Figure 2. Effect of sediment model on system recovery.

CONCLUSIONS

In this paper the present status of watershed and water quality models were briefly reviewed. Some suggestions were made as to how the water quality components of watershed models could be improved. These included adding a sediment submodel, adding the capacity to model receiving waters in two- or three-dimensions, and also adding additional phytoplankton groups

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ADDRESS FOR CORRESPONDENCE
Scott A. Lowe
Department of Environmental Engineering
Manhattan College
Riverdale, NY 10471
U.S.A.
E-mail: slowe@manhattan.edu