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M E M O R A N D U M

To: Susan Beede, Organization for the Assabet River
Subject: Comments on Assabet River TMDL
Date: June 19, 2003

Pursuant to our agreement, I have reviewed the assessment and modeling reports supporting the Assabet River TMDL for phosphorus (ENSR, 2000; 2001). Following are my responses to specific questions that you have posed. Detailed, quantitative answers are not possible in some cases, given that I have not performed an independent analysis. In these cases, I have tried to be as specific as possible in formulating my opinions in a qualitative sense and in describing important factors and limitations.

1) Is dissolved oxygen a good surrogate for biomass (in ENSR's model)?

In the model, dissolved oxygen is influenced by biomass and several other factors (reaeration, sediment oxygen demand, BOD loadings, temperature, flow, solar radiation, etc.). While there is a linkage (both in the model and in reality) between biomass and dissolved oxygen, it is not one-to-one and not all of the mechanisms are represented in the model. The linkage is complex because there are many forms of biomass (phytoplankton, periphyton, floating mats, rooted plants) and many mechanisms (photosynthesis, respiration, dieoff & decay, sediment coupling, and physical effects related to stagnation and reductions in reaeration rates). Because of this complexity, there is a great deal of uncertainty in modeling these interactions and in the quantitative forecasts.

In a qualitative sense, there would be a tendency for dissolved oxygen conditions to improve with sufficient reductions in nutrients and biomass. It is possible that the system could meet the DO standard in the main channels (modeled portion), but not the DO or narrative nuisance aquatic growth standards in the peripheral areas and backwaters of the impoundments or following episodic vegetation dieoff events.

Based upon experience modeling phosphorus dynamics in treatment wetlands (Kadlec & Walker, 1999; 2003), biomass is likely to be more responsive to reductions in P load than indicated by the HSPF simulations. Similarly, the following statement is somewhat pessimistic (ENSR, 2001, Page ES-6) "*For each nutrient constituent, concentrations were observed to be at least one order of magnitude (i.e. 10 times) higher than nutrient limiting concentrations indicating that concentrations of these* *nutrients would have to be reduced dramatically before biologic productivity in the system diminished"*. This statement may apply somewhat to suspended phytoplankton, but not necessarily to other vegetation types (mats, periphyton, rooted plants), which account for a much higher percentage of the plant biomass & associated organic loads.

Given the abundant vegetation and the dominance of point sources, it would not be unrealistic to classify the river impoundments as "treatment wetlands" during summer low flows. For a given set of hydrologic conditions, average phosphorus storage in treatment wetland vegetation (on a mass per unit area basis) has been observed to vary roughly in proportion to average ambient water column total P concentration at levels up to and exceeding 1 mg/liter, well above those experienced in the Assabet (Kadlec & Walker, 1999; 2003). Similar relationships have been observed on a seasonal basis for treatment wetlands in Michigan, as well as Florida. Variations in P storage reflect variations in biomass and tissue P content (luxury uptake) that occur in response to variations in water column P concentration. HSPF does not represent all of these mechanisms.

Similarly, there may be qualitative shifts in vegetation types (loss of duckweed, floating mats) at P concentrations that are above "growth-limiting" levels. Floating vegetation can pose a particular problem with respect to dissolved oxygen because they restrict reaeration, contribute dissolved oxygen to the air instead of the water (unlike phytoplankton & submerged plants), and can impose a substantial oxygen demand upon death, sedimentation, and decay. Sas (1989) showed that dominance of nuisance blue-green algae was generally eliminated when total phosphorus concentrations were reduced from >.10 mg/L to the 0.05-0.08 mg/L range in European shallow lakes and impoundments subject to restoration activities. Achievement of "growth-limiting levels" (say .005 mg/L of soluble reactive P) is not necessary to accomplish such improvements.

2) How much confidence can we have in the model's prediction that the minimum DO criterion will be met in all reaches under 7Q10 with the WWTPs at 0.1 mg/TP and current sediment phosphorus release reduced by 90%?

These measures would likely result in substantial reductions in river TP concentrations, reductions in aquatic productivity, and improvements in dissolved oxygen regime.

Given limitations in the data and modeling, it is not possible to specify with much certainty the precise degrees of point-source and sediment control required to achieve the numeric dissolved oxygen standard throughout the river. Based upon the historical data showing decreasing P concentrations from upstream to downstream and upon basic water and mass-balances, it seems more likely that P concentrations consistent with meeting the oxygen standard would be achieved in the lower reaches than in the upper reaches. The lower reaches appear to be more susceptible to algal growth because impoundment water residence times are longer.

It is not clear that snapshots of the river provided by 2 synoptic summer low-flow surveys (primary basis for model calibration) reflect the true critical conditions with respect to dissolved oxygen. Significantly lower DO levels may occur in the more stagnant backwater areas of the impoundments (vs. the main channel stations that were monitored and modeled) and/or following episodic die-off of algal blooms or mats. For example, I have noticed distinct odors of hydrogen sulfide in the vicinity of the Power Mill dam occasionally in late summer. These may have been associated with hot, calm weather and/or episodic dieoff of vegetation. Dissolved oxygen levels must have been significantly below those observed in the surveys in order for hydrogen sulfide to be present.

So, there is no assurance that the standard would be met in all reaches and at all times, even if the model were “perfect” and simulations showed compliance in the main channel under summer low flows. But, there is little doubt that significant water quality improvements would result from implementation of a 0.1 mg/l limit.

3) Is it reasonable to assume that 90% of the sediment phosphorus contribution can actually be removed from the Assabet?

Probably not.

Based upon fundamental mass-balance concepts, the sediment should not be considered an independent source of phosphorus. Sediment P releases represent recycling of P historically discharged into the river from the watershed and point sources. So, in the long run (possibly a few years to decades), some reduction in sediment P release rate would be expected following a significant reduction in external P loads. The model does not reflect this feedback mechanism. Therefore, the effects of sediment P release on water column P concentrations are likely to be over-estimated in model runs with reduced external loadings but constant sediment flux (i.e. the model forecasts are pessimistic in this regard).

Management scenarios modeled by ENSR involve various combinations of effluent P limits (e.g., 0.05, 0.1, 0.2, existing) and assumed reduction in sediment flux (e.g., 0%, 25%, 50%, 75%, 90%). It is not appropriate to consider these as independent factors because the sediment P flux is, in the long run, dependent on the external P load to the river. Without extraordinary measures to reduce sediment P flux (e.g., dredging, chemical treatment), it is unlikely that the percent reduction in sediment P flux would exceed the percent reduction in external P load (point + nonpoint). Mass balance calculations for 1999 summer low-flow conditions indicate that effluent P concentrations of 0.2, 0.1, and 0.05 mg/l correspond to total load reductions of 76%, 86%, and 91%, respectively. These would be upper bound estimates of percent reduction in sediment P load without special intervention.

Laboratory sediment flux measurements are subject to experimental artifacts and may not reflect actual conditions in the field. For one thing, the measurement process involves removal of biological components that may offset or enhance P releases. The predicted benefits of sediment P reductions based upon direct application of measured flux rates in the model are questionable.

Reductions in sediment P release could be accelerated by instream measures, such as dredging or alum application. Additional sediment P data (horizontal & vertical profiles with P speciation) would be needed to evaluate the potential effects of dredging. Depending on vertical distributions, there is some risk that sediment P releases would increase following dredging. For example, the sediment P content may be higher in deeper layers of the sediment (potentially exposed by dredging) because substantially higher P concentrations were typical of domestic wastewaters (up to ~5 mg/liter vs. ~1 mg/L) prior to the late 1970's when use of phosphate detergents were curtailed and when treatment plants were not being designed or operated to remove phosphorus. Dredging may, however, have beneficial effects on dissolved oxygen that are not directly related to P release (removal of organic matter and improved circulation). Alum treatment may have more direct immediate effects than dredging, but would probably have to be repeated at regular intervals because the alum would be buried by new sediment loads.

Based upon the laboratory studies and field measurements conducted by ENSR, the P releases occur primarily under aerobic conditions and are probably related to decomposition of plant material and other organic substances, as opposed to chemical mechanisms which would trigger much higher release rates under anaerobic conditions. The latter may occur in deep holes or episodically following plant dieoff events. Since the measured aerobic release rates are already relatively low, I doubt that a 90% reduction could be achieved or that a reduction of this magnitude is necessary to achieve water quality standards if external loads are sufficiently reduced.

Because a portion of the historical P loads will bleed back into the water column via the sediment for a period of time, there may be a time lag between reduction in current point-source loads and full response of water column P concentrations in the River and its impoundments. Sediment P feedback is more likely to be important in the lower impoundments with longer residence times than in the upper reaches. Additional river monitoring, sediment studies, and model refinements will help to develop realistic expectations for the river response time and to apply instream treatments (dredging, chemical treatment), should the projected response times be unacceptably long.

Despite the uncertainties, it is not defensible to use the existence of a sediment P load as a basis for balking at implementation of point-source controls. Most of the P being recycled from the sediments came from the wastewater plants to begin with. If historical loads were used to justify future loads, impaired water bodies would never be restored.

4) The Assabet River Consortium has argued that increasing the volume of wastewater discharged to the river to design flows would have a small impact on water quality. Do you agree?

It would depend upon your definition of "small impact". While it is not possible to answer your question quantitatively without conducting an independent modeling exercise, a few relevant concepts are outlined below.

While secondary to concentration, variations in point-source flows should also be considered in the TMDL. Specification of concentration limits alone would be insufficient to guarantee that water quality standards would still be met if point-source flows were increased.

When the river is ~100% effluent, the inflow P concentrations to the upper reaches are independent of flow. However, concentration within and downstream of the impoundments would increase with flow because hydraulic residence times and phosphorus sedimentation would decrease. This would be a second-order effect (not proportionate). Rough calculations using a simple phosphorus retention model suggest that a 70% increase in total wastewater flow (say, from 10 to 17 mgd) at a discharge concentration of 0.1 mg/l would result in ~30% increase in P concentration in the lower reaches of the River.

Treating the sediment reflux as an independent source (inappropriate, as discussed above), would tend to artificially reduce the sensitivity of the simulated river P concentrations to point-source flow.

To the extent that the river functions as a treatment wetland in the summer, higher flows and loads would potentially increase biomass and nutrient storage in the rooted or otherwise anchored vegetation. This process would occur over a seasonal time scale. P releases resulting from respiration and decay of that vegetation may, in turn, supplement organic loads, nutrient loads and algal productivity during the critical summer low-flow conditions. It is not clear whether this type of mechanism is reflected in the HSPF simulations. While the model stores phosphorus in biomass, it does not appear to account for fluctuations in tissue P content in response to water column P concentration (luxury uptake), which can be very important.

Higher flows and loads would be a potential concern for the downstream Concord River. Potential impacts on that system would be controlled more by the phosphorus load from the Assabet than by its concentration. For that reason, total P load to the Concord River should be considered as a criterion in evaluating alternative wastewater management scenarios for the Assabet.

Given existing modeling uncertainties, it would be difficult, at this point, to establish an absolute requirement to limit discharge volumes. If an adaptive approach to the TMDL were taken (i.e. involving incremental decreases in discharge concentrations and/or implementation of instream control measures until water quality standards are met, see

Question 6), then the end point (expressed in terms of final effluent P concentration limits) might be lower if discharge volumes are allowed to increase. This would depend upon how the river actually responds to implementation of interim P limits.

5) Is it appropriate to use EPA's recommended numeric phosphorus criterion of 0.024 mg/L (for subecoregion 59) as a basis for setting NPDES permit limits?

For reasons stated above, dissolved oxygen in the main channel under summer low flows is only a surrogate for system-wide compliance with water quality standards with respect to DO, pH, and nuisance plant growths. Because of the difficulties associated with modeling (and monitoring) all of the mechanisms controlling dissolved oxygen, consideration should be given to adopting an instream goal for total phosphorus that would serve as an alternative surrogate. Major advantages of doing this are (1) phosphorus is the primary causal factor driving the water quality problems (2) success can be gauged more readily through monitoring (3) TP concentrations can be forecast with greater certainty using HSPF or simpler mass-balance models for impoundments (e.g., BATHTUB, Walker, 1999). This approach has apparently been taken in evaluating eutrophication problems in other local basins (Mass DEP, 2002, Draft). Adoption of a P criterion would simplify the process and enable determination of an "end point" with greater certainty using HSPF and/or a simpler mass-balance model.

In my opinion, EPA's 0.024 mg/L P criterion (USEPA, 2000) would probably be a defensible and protective goal for the Assabet. This criterion is based upon a statistical summary of regional data and does not account for site-specific factors that would influence the linkage of phosphorus concentration to algal/plant growth and to violations of water quality standards. To some extent, these relationships can be characterized using simple empirical methods (Walker, 1999; 2003) applied to data from the Assabet impoundments and possibly others in the region. Further data analysis and modeling could be done to determine whether site-specific adjustment of the criterion is appropriate to account for any unique features of the Assabet impoundments.

EPA's "classical" criteria for phosphorus are 0.05 mg/L for streams entering impoundments and 0.025 mg/L for impoundments (USEPA,1976). These are based not upon ecoregion concepts, but upon generalized correlations between phosphorus levels and eutrophication-related water quality problems. Target P concentrations ranging from 0.01 to 0.035 ug/L were selected by Mass DEP in developing TMDL's for lakes and impoundments in the French River Basin (Mass DEP, 2002, Draft). Site-specific P criteria ranging from 0.008 to 0.060 mg/L have been developed for other lakes & impoundments based upon correlations with direct indicators of use impairment, such as frequencies of nuisance algal blooms, depressed transparency, and/or violations of pH or dissolved oxygen standards, and used as a basis for setting TMDL's (Walker, 2003). Given that summer water residence times in the Assabet River impoundments (particularly Ben Smith & Powdermill) appear to be sufficient to allow development of severe nuisance algal blooms (based upon measured chlorophyll-a concentrations > 30 ug/L), as well as extensive algal mats, periphyton, floating vegetation, and rooted vegetation, it is unlikely that an appropriate P criterion for these systems would be outside of the above range.

While subject to refinement through further data analysis and modeling, the 0.024 mg/L ecoregion criterion would appear to be a protective goal for the Assabet, based its similarity to the classical criterion for impoundments (0.025 mg/l, USEPA, 1976) and upon impoundment features that are known to support high algal and plant productivity.

Because of phosphorus sedimentation in the impoundments, it is possible that a 0.024 mg/l criterion could be met in some of them with effluent P concentrations higher than 0.024 mg/L. Mass balances indicate that the impoundments trap about two thirds of the external phosphorus load under summer low flow (i.e. the load discharged downstream to the Concord River is about one third of the total external load). Since point sources account for >95% of the load under such conditions, an average discharge concentration of 0.072 mg/L for all point sources in the basin would be consistent with achieving 0.024 mg/L in the outflow from the last impoundment (Powder Mill) if the percentage of the external load removed by all impoundments were assumed to be constant. With the same assumption, lower average effluent concentrations (approaching the 0.024 mg/L criterion) would be needed to meet the criterion in the upstream impoundments because less phosphorus is removed in those impoundments. The above preliminary calculations are intended only to illustrate a simpler, alternative method (vs. HSPF) to deriving effluent limits to achieve the impoundment P criterion. Results would vary depending upon how the mass balance is formulated (e.g., HSPF vs. the constant retention assumption vs. a variety of other empirical models).

If EPA’s (1976) criterion for streams entering impoundments (0.05 mg/L) were adopted, it would be directly applicable to the discharges because net phosphorus removal in stream segments is typically negligible and there is very little dilution of the effluents under summer low flows. For example, the Westboro discharge essentially constitutes the entire inflow to the first impoundment under summer low-flow conditions, so that the 0.05 mg/L instream criterion, if adopted, would be directly applicable to that discharge.

Although I have not undertaken an extensive review of the HSPF application, results presented by ENSR provide a basis for evaluating impacts of alternative permit limits. Figure 1 shows phosphorus concentrations as a function of river mile predicted by HSPF for various effluent P limits (0.2, 0.1, 0.05 mg/L) and assumed reductions in sediment P flux (0%, 90%). They are derived from ENSR’s simulations of 1999 summer low-flow conditions. Predicted concentrations are compared with the 0.024 mg/L criterion. As discussed above, one limitation of HSPF is that it does not simulate the coupling of the sediment and water column mass balances. The 0% and 90% flux reduction simulations probably bound the actual river responses. It is apparent that River miles 30-25 and 15-8 are the most susceptible to high P concentrations. The latter segment includes two impoundments (Gleasondale & Ben Smith). Predicted average phosphorus concentrations in this segment are 0. 035, 0.023, and 0.018 mg/L for effluent P levels of 0.2, 0.1, and 0.05 mg/L, respectively, and a 90% reduction in sediment P flux. HSPF simulations also indicate that the dissolved oxygen standard would be violated at frequencies of 2.4%, 0%, and 0%, respectively, also with a 90% reduction in sediment P flux.

The HSPF results indicate that point-source effluent P reductions at least to the 0.1 mg/L level would be required to meet the 0.024 mg/L phosphorus criterion in the impoundments, as well as to meet the dissolved oxygen standard. Simpler mass-balance calculations described above indicate that even lower effluent P levels (0.024 – 0.072 mg/L) may be required to achieve the phosphorus criterion in each impoundment. Given the likelihood that actual reductions in sediment P flux will be less than 90%, the modeling uncertainty, and the requirement under TMDL regulations to provide a margin of safety, permit limits well below 0.1 mg/L may eventually be required.

6) How should the TMDL be finished, i.e. P loads calculated?

Despite their limitations, existing data and modeling support the application of best available technology to reduce point-source loadings, at least to the 0.1 mg/l level as an interim permit limit. It is not clear that a 90% reduction in sediment P load can be achieved or is necessary in order to achieve water quality standards, provided that external P loads are sufficiently reduced. As discussed above, existing data or modeling do not support initial application of sediment control measures, pending further evaluation of the sediments and monitoring of river responses to interim load reductions.

Given data limitations and modeling uncertainties, the TMDL should be approached in an iterative or adaptive fashion, as recommended in a recent evaluation of the TMDL process by the National Research Council (NRC, 2001). Walker (2003b) describes how an iterative approach can be taken in developing phosphorus TMDL’s to achieve water quality goals with the desired margin of safety in a cost-effective manner, given the uncertainties that are typically involved in setting goals, predicting the performance of control measures, and predicting impoundment responses. Beyond the above first step (<=0.1 mg/L interim permit limit), further reductions in point, nonpoint, and/or sediment loads may be necessary to achieve water quality goals. Potential needs for such measures can be assessed after implementation of interim effluent limits under an adaptive process that is supported by additional monitoring, data analysis, model refinements, evaluation and possible implementation of instream measures, and possible refinement of water quality goals.

Continued water quality monitoring is essential to determine whether TMDL objectives are met and to evaluate the potential need for additional control measures. Future monitoring should include additional synoptic surveys under summer low-flow conditions (with multiple samples collected at each site over the course of week or so), as well as periodic (weekly or biweekly) sampling in and immediately downstream of the major impoundments over the course of the growing season. More frequent monitoring of effluent water quality would also be appropriate (daily during synoptic surveys, otherwise at least weekly). To account for diel variations in effluent quality, effluents should be monitored with 24-hour composite samples, as opposed to grab samples.

To reduce forecast uncertainty, refinements to the HSPF application should be made periodically based upon additional data and/or advances in the state-of-the art. Given uncertainties in HSPF (or any) model, the feasibility of also applying a simpler phosphorus-balance model should be investigated. Existing data are more than adequate to support this type of effort. Once calibrated, mass balance models are much easier and less expensive to use in evaluating alternative management strategies. A parallel modeling effort would provide an independent check on HSPF forecasts of phosphorus and chlorophyll-a under various allocation scenarios and a partial basis for evaluating the robustness of the model forecasts and any resulting management decisions.

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Figure 1

Total P vs. River Mile for Various Effluent P Levels & Sediment P Flux Reductions

ENSR HSPF Simulations, Summer Low-Flow, 1999