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Estimation of Total Nitrogen and Phosphorus in New England Streams Using Spatially Referenced Regression Models

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tobacco companies, not by state employees who could be deemed to have an interest in future private employment. Eliminating the NPM adjustment was not a viable option and any provision that did not allow the states the opportunity to oppose an adjustment through fact-based presentations would have been foolish. No reasonable person aware of the facts would think that a state employee had any power to use the NPM adjustment to secure private employment.

while Commission precedent leads to the correct conclusion,

Finally, it is worth noting that my question may present a good occasion to review the language of G.L. c. 268A, § 5(a). That section states that a former state employee shall not "knowingly **act[] as agent or attorney for, or receive[] compensation** directly or indirectly form anyone other than the commonwealth or a state agency, **in connection with any particular matter** in which the commonwealth or a state agency is a party or has a direct and substantial interest and in which he participated as a state employee while so employed . . .." [emphasis added].

The phrase "in connection with" limits the words "act" and "compensation." It asks whether the act or compensation would be connected with the same "particular matter." The word "particular" emphasizes the legislature's intent to avoid overly broad prohibitions that would result from construing "matter" too broadly.

The statute does **not** ask whether a new matter has a "connection with" an earlier particular matter – which would be a more indirect and more complex question than the Legislature asked, resulting in broader preclusion of opportunities (which would defeat the purpose of using the word "particular").

In this case, therefore, the question should be whether the NAAG Arbitration proceeding for 46 states regarding the applicability of the NPM adjustment to the issues arising in 2006 is the same "particular matter" as my participation in Massachusetts' limited role in the negotiations and signing of the MSA; the question is not whether the NAAG Arbitration has a connection with the earlier particular matter. For the reasons stated above, under a reading of the plain statutory language, the answer is even clearer that the two matters are not the same "particular matter" and therefore that representation in the NAAG arbitration proceeding is allowed.

Conclusion] bold

For all these reasons, I request an opinion that I may work on the NAAG Arbitration proceeding under the MSA under a contract with NAAG. I thank you for your time and advice to date and thank you in advance for your additional efforts.

Very truly yours,

Douglas H. Wilkins

Phosphorus

Calibration and bootstrap results for the phosphorus New England SPARROW model are presented in table 4. Significant predictor variables include (1) phosphorus from permitted municipal and pulp and paper wastewater discharges, (2) area of forested land, (3) area of agricultural land, (4) the area of developed urban and suburban land, (5) a reservoir loss variable for small lakes and reservoirs with surface area less than 10 km^2, and (6) an exponential loss term for streams with flows less than or equal to 2.83 m^3/s (100 ft^3/s). Parameter coefficient estimates and standard errors of the estimates are given in table 4. A comparison of the observations and model predictions for phosphorus is shown in figure 7. In general, the model results fit the observation load data, with a coefficient of determination (R^2) of 0.94, and a mean-squared error of 0.23. For comparison, the national phosphorus SPARROW model had an R^2 of 0.81 and a mean-squared error of 0.71 (Smith and others, 1997).

The p value for the reservoir loss variable was 0.096 in the calibration model, and 0.04 in the bootstrap model. These levels of significance, together with the initial coefficient and the bootstrap coefficient estimates being similar (109 and 105, respectively), provide justification for the inclusion of the reservoir loss as a predictor in reservoirs or lakes with surface areas less than 10 km^2. The p value for in-stream loss in small streams, with mean-annual flows less than or equal to 2.83 m^3/s (100 ft^3/s), was 0.27 in the calibration model but was 0.125 in the bootstrap model. Although statistically, this variable is only marginally significant ($p = .125$) in predicting phosphorus loads, further justification for inclusion is found in the coefficient estimates and in previous SPARROW model results. In previous SPARROW phosphorus models, phosphorus loss was significant in small rivers and streams (Smith and others, 1997; McMahon and others, 2003).

In the phosphorus model (table 4), the coefficient of 1.27 for discharges from municipal wastewater-treatment facilities and pulp and paper discharges indicates that for each estimated kilogram of phosphorus discharged into the rivers at the wastewater-discharge locations, the model is predicting an average of 1.27 (± 0.22) kg of phosphorus at the monitoring stations. The coefficients for forested lands indicate that about 13.4 (± 3.8) kg of phosphorus are estimated as entering streams for each square kilometer of forested land upstream per year. Likewise, the coefficients for agricultural lands indicate that about 108 (± 26) kg of phosphorus are estimated as entering the river system for each square kilometer of agricultural land upstream per year. The coefficients for developed lands indicate that about 38.9 (± 13.7) kg of phosphorus are modeled as entering the river system for each square kilometer of developed land upstream per year. Unlike with nitrogen, there is no Connecticut HSPF phosphorus model with which to compare model coefficients.

None of the variables that were used to test for phosphorus loss on the landscape (such as soil permeability) were significant predictors of phosphorus loads (at either 85- or 95-percent confidence levels). It is presumed that the land-delivery losses are factored into the source coefficients for forested, agricultural, and developed land areas where phosphorus is applied or distributed to the land area. Percent wetland was the land-delivery factor that performed the best, but it had a p value greater than 0.60.

The coefficients for reservoir and stream loss indicate that phosphorus is removed from small reservoirs and small streams (table 4). As with other studies, the reservoir loss coefficient of 109 m/yr in the calibration model, quantifies the length of the water column from which nutrients are removed per unit of time by benthic processes, including the settling and burial of particulates (Alexander and others, 2002; Chapra, 1975; Molot and Dillon, 1993; Kelly and others, 1987). The coefficient of 0.48 d^{-1} for loss in small streams equates to a half-life of about 1.5 days. This means that for each 1.5 days of transport in streams with flows less than 2.83 m^3/s, about half of the phosphorus load is lost, most likely from sedimentation or biological processes. This coefficient of 0.48 can be compared to a coefficient of 0.27 (2.6-day half-life) from the national phosphorus model for streams less than 28.3 m^3/s (Smith and others, 1997); and to a coefficient of 11.2 from a New Zealand phosphorus model for streams less than 1 m^3/s (1.5-hour half-life) (Richard Alexander, written commun., 2003).

Model Assumptions and Limitations

The SPARROW model is based on assumptions that define the form and context of a multiple regression analysis. These assumptions are (1) the functional form of the model is correct in terms of the variables included and their role in the model; (2) the error term is independent across the range of observations implying that there is no correlation in the errors among the monitored streams (Smith and others, 1997); (3) the residuals of the model are normally (or near normally) distributed; and (4) the residuals are homoscedastic; that is, the distribution of the residuals are similar throughout the range of predicted values. In addition, the bootstrap analysis is designed to provide robust coefficient estimates, model predictions, and prediction intervals in relation to the characteristics of both the model and sampling errors (Smith and others, 1997).

Preliminary analysis of the residuals for each model has been conducted. This analysis indicates that the residuals appear to be randomly distributed across the New England region with no spatial grouping of over- and under-predictions. But, statistically, the residuals are slightly positively skewed. Additional analyses of residuals as related to watershed characteristics and nutrient sources may help to define factors influencing the residuals.

As with any model, there are strengths and weaknesses associated with the model and its results. Strengths of the New England SPARROW models are the high R^2 and relatively good precision of most parameter coefficients obtained with the models. These results support the use of these models as water-quality-assessment tools. Other strengths of the models include the ability to provide regionally consistent characterizations of nutrient conditions and sources in streams, and the transport and

Table 4. Calibration results and bootstrap estimates for the New England SPARROW model for total phosphorus.

[kg/km^2/yr, kilograms per kilometer squared per year; m/yr, meters per year; d^{-1}, per day; km^2, square kilometers; m^3/s, cubic meters per second; ft^3/s, cubic feet per second; R-squared = 0.94; mean-square error = 0.23]

Significant predictor variables (coefficient units)	Calibration model coefficient	Standard error of coefficient	Bootstrap estimate of coefficient	Standard error of bootstrap coefficient
Sources:				
Municipal wastewater-treatment facilities and pulp and paper facilities[1]	1.27	0.22	1.28	0.22
Forested land (kg/km^2/yr)	13.4	3.8	12.7	4.1
Agricultural land (kg/km^2/yr)	108	25.7	110	27.5
Developed urban and suburban land (kg/km^2/yr)	38.9	13.7	37.8	14.3
Loss variables:				
Reservoir loss variable for small lakes and reservoirs[2] (m/yr)	109	64.5	105	59.7
Stream loss for small streams[3]	.48 d^{-1}	.43	.42	.41

[4] Dimensionless.

[5] Small lakes and reservoirs with surface area less than or equal to 10 km^2.

[6] Small streams with mean-annual flow less than or equal to 2.83 m^3/s (100 ft^3/s).

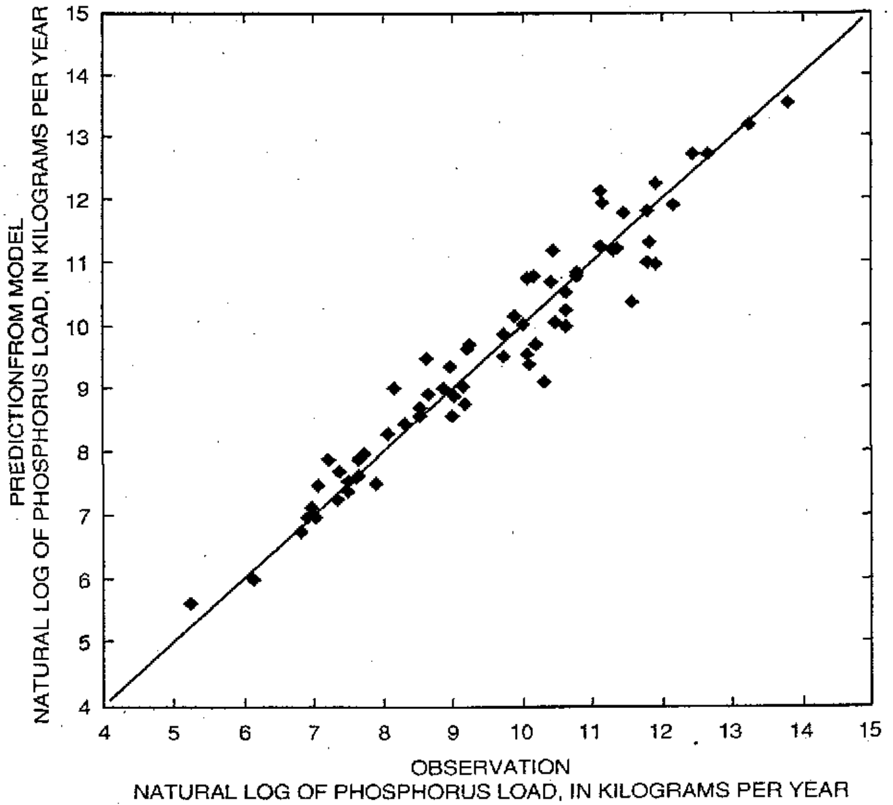

Figure 7. Relation of predicted and observed total phosphorus load values from the calibration of the New England SPARROW model.

loss of nutrients within watersheds, and to show prediction or confidence intervals associated with these assessments. Previously, these forms of data have not been available for most New England stream reaches.

Weaknesses of the model and results can be linked to the modeling process and the data used to calibrate and provide predictions of nutrient conditions. Smith and others (1997) note that the SPARROW model structure inherently oversimplifies nutrient transport processes. Many factors locally and regionally affect the transport and loss of nutrients in streams, many of which cannot be accounted for in the SPARROW model. However, model results do indicate that certain transport processes are regionally important. Also, there are limitations with the data used in the modeling process. These limitations include the following:

1. The model requires long-term water-quality datasets that include multiple samples per year. Because of this requirement, the models only incorporate data from limited number of sites throughout the entire New England region. Load datasets, with a greater number of load sites than were used in the existing SPARROW models, may increase the ability to identify statistically significant explanatory variables.
2. Predictor variables may be coarse (such as land uses) or of relatively poor quality (such as point source loads). These data sets may introduce error in the ability of the model to explain and predict the effect of these data on stream water quality. Because of the regional nature of the model, only data that were available for the entire study area could be used. This restriction prevents the use of many locally more precise data or data that characterize other nutrient source or transport processes.
3. Model results also have more uncertainty in smaller watersheds that tend to be further away from monitoring sites. This reflects a lack of monitoring data in New England for watersheds under 25-40 km^2. (There are only 2 sites in the nitrogen and phosphorus datasets with watersheds less than 25 km^2 and only 4 sites with watersheds less than 40 km^2.)
4. Finally, the models only predict mean-annual conditions, not necessarily critical conditions such as low-flow conditions that may be of more concern to water-quality managers and scientists.

Model Estimates of Nutrient Loads

The calibrated SPARROW models allow for the prediction of nutrient loads for nearly 42,000 unmonitored stream reaches throughout New England. The spatial variability of nutrient loads is an important consideration for water-resources managers and planners in prioritizing areas for management actions. Nutrient loads are predicted by applying the SPARROW regression equation to each reach catchment. Starting at the headwater catchments, the regression equation is applied and predicted nutrient loads from that catchment are used as sources in the calculation of the load prediction for the next reach downstream. This process continues downstream until the terminal reach at the mouth of the river is encountered. Reach-level catchment predictions of nutrient loads obtained from SPARROW-model runs are shown in figures 8 and 9. Considerable spatial detail from the use of the NHD can be observed in the predicted results. These predictions represent source-load conditions from 1992-1993.

Several other deterministic and stochastic nutrient models have been used to estimate nutrient balances in New England watersheds. Although these studies have different time frames and use different techniques, they are available for comparison with the New England SPARROW model predictions.

Nitrogen

The predicted nitrogen load generated by each of the 42,000 reach-catchment areas is expressed as a nitrogen yield (delivered to the catchment outlet) by dividing the predicted load generated from within each catchment (including only sources from within the catchment) by the area of the catchment. (Thus, yields are loads normalized by area.) Median catchment yield of nitrogen for the entire study area is 336 $kg/km^2/yr$ with the 10- and 90-percent quantiles at 134 and 782 $kg/km^2/yr$, respectively. The relative contributions from the various source inputs are also predicted by the SPARROW model. The contributions from these sources that go into the catchment yield (fig. 8) are apparent by comparing predicted catchment yield with predicted yield from atmospheric deposition of nitrogen (fig. 9a); predicted developed-land nitrogen yield (fig. 9b); and predicted agricultural-land nitrogen yield (fig. 9c). Because discharge is localized and not a distributed yield, the permitted wastewater discharge is not shown in figure 9.

The primary, or largest, contributing nitrogen source for each catchment is identified in figure 9d. Catchments having permitted municipal wastewater discharge as the primary nitrogen source are also typically in the highest yield category of nitrogen shown in figure 8 (over 1,000 $kg/km^2/yr$). These yields are especially high because the wastewater from a given sewer system is discharged to a single stream reach.

For the entire model area, SPARROW estimates that 86,100 metric tons (86.1 million kilograms) of nitrogen enter New England rivers and streams per year. Of this total, 50 percent (42,700 metric tons/year) is estimated to be from atmospheric deposition; 21 percent (18,000 metric tons/year) is estimated to be discharged from permitted municipal wastewater discharges; 15 percent (13,000 metric tons/year) is estimated to be from other developed land sources; and 14 percent (12,400 metric tons/year) is estimated to be from agricultural lands. The large contributions of atmospheric deposition to nitrogen loads in New England is a major finding of the New England SPARROW model for nitrogen. Model estimates of