The Economics Of Flow Enhancement Vs. Nutrient Controls In Meeting Water Quality Standards

Leslie Marbury and Andrew G. Keeler
University of Georgia
Contact: akeeler@uga.edu

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, July 1-4, 2004

The Economics Of Flow Enhancement Vs. Nutrient Controls In Meeting Water Quality Standards

Leslie Marbury and Andrew G. Keeler

The University of Georgia

Introduction

Meeting TMDL water quality standards has become a central challenge for public policy in Georgia. There is still considerable uncertainty about what TMDLs will be, how they will be implemented, and how state, regional, and local government institutions will organize to meet this challenge. The fundamental idea behind TMDLs is to limit the pollutant loads from anthropogenic sources in order to support ecosystem functions and protect public health.

Reductions in the loads of pollutants emitted into surface waters can be achieved through the terms of the NPDES permits that must be held by point sources, and by the adoption of improved management practices by non-point sources. These management practices are typically encouraged but not required by regulation.

In many cases, the influence of pollutant loads on aquatic ecosystems depends on the level of flow in waterways as well as loadings. One reason for this is that it is the concentration of pollutants that has the most important influence on environmental effects. Another is that flow is an important variable in supporting ecosystem services in and of itself, and so flow levels can in some cases serve as a substitute for pollutant loads.

Georgia does relatively little to manage flow levels in support of water quality goals outside of setting and enforcing minimum flows. Its regime of managing water withdrawals is implemented through a permitting program managed by the state's Environmental Protection Division (EPD).

The purpose of this paper is to explore the economics of using enhanced flow as part of strategies to meet water quality standards. We begin by briefly sketching the relevant economics theory, which we then apply to a case study of a dissolved oxygen impaired stream segment in the Flint River Basin. We conclude with some observations about the significance of these results.

Case Study: Water Quality Modeling

We examine the case of a dissolved oxygen impaired stream in Georgia. In the Flint River Basin of Georgia, eight stream segments were designated as partially or not supporting their designated use due to unacceptable dissolved oxygen concentration levels. Our site is Spring Creek, a 22-mile stream located at SR62 near Arlington and within Early, Miller, Calhoun and Clay counties. Spring Creek watershed is a primarily agricultural area that has experienced intermittent low or zero flows in the last few years.

As required by the Clean Water Act, Spring Creek was listed on the 303(d) list as partially supporting it's designated use of fishing due to failure to achieve water quality standards for dissolved oxygen (DO). Since observed dissolved oxygen concentration were driven by low flows and high temperature, which occurred over several summer months, a steady state modeling approach was adopted as appropriate for TMDL analysis. It relates dissolved oxygen concentration in a flowing stream to carbonaceous biochemical oxygen demand (CBOD), nitrogenous oxygen demand (NBOD), sediment oxygen demand (SOD) and reaeration. The model allows the loading of CBOD, NBOD and SOD to the stream to be partitioned among different land uses (nonpoint sources) and point sources such as wastewater treatment facilities. The model was then used to evaluate base flow augmentation scenarios to remedy dissolved oxygen problems.

There are a number of factors influencing the DO depletion in the watershed including the NPDES permitted point sources, runoff from the nonpoint sources, low flows and high temperatures in the summer months, and growth of algae. In fact, the lowest DO concentrations have been found during periods of low or zero flow. This occurs during the summer months when withdrawals for agriculture and evapotranspiration rates are high. Diversions that occur during this time reduce flow and therefore increase residence time of oxygen-demanding substances in the stream. Studies done by Lee et al. have found in their study that increasing flows, or water quantity in the case of lakes, decreased the DO deficit within the watersheds

Water quality modeling attempts to relate specific water quality conditions to natural processes using mathematical relationships. The model used here is an adaptation of the Streeter-Phelps dissolved oxygen deficit equation with modifications to account for the oxygen demand resulting from nitrification of ammonia and oxygen demand found in water body sediment. An excel spreadsheet is used to calculate runoff volumes and loads from identified point and nonpoint sources using land use data and watershed information such as depth, drainage area, and temperature. The model also allows the user to assign organic loadings on the basis of land use.

The model assigns differing pollutant concentrations to flow from headwaters, tributaries, and incremental inflow (all natural stream flow not considered by the other two sources of natural flow) according to the major land use percentages in the watershed. The selected stream reach is then divided into individual segments in order to account for changing physical features of the stream. These would include the addition of flow and pollutants from tributaries, incremental inflow, and point sources, changes in stream slope, velocity, and any of the reaction rates.

For the purposes of this study, we run the model for three representative years. During the 1999 and 2000 water years (October 1998-September 2000), South Georgia experienced record drought conditions (USGS 2000). Both low rainfall and human use of aquatic resources in the region are thought to have caused the record-low levels, even causing some streams to dry up (Johnson et al, 2000). Due to data availability, which is incomplete prior to 1997, the years chosen were 1997, 1999, and 2000.

After running the water quality models and simulating the loads that will occur from the point and nonpoint sources, a list of management options is developed. The adaptation of the Streeter-Phelps equation is:

$$D = \frac{K_1 L_0}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right) + \frac{K_3 N_0}{K_2 - K_3}\left(e^{-K_3 t} - e^{-K_2 t}\right) + \frac{SOD}{K_2 H}(1 - e^{-K_2 t}) + D_0 e^{-K_2 t}$$

Where:

D = dissolved oxygen deficit at time t, mg/l

L_0= initial CBOD, mg/l

N_0= initial NBOD, mg/l (NBOD = NH_3- N x 4.57)

D_0= initial dissolved oxygen deficit, mg/l

K_1= CBOD decay rate, 1/day

K_2= reaeration rate, 1/day

K_3= nitrification rate, 1/day

SOD = sediment oxygen demand, g O2/ft2/day

H= average stream depth, ft

T = time, days

As can be seen from the equation that expresses the resulting DO in streams and rivers, there are several points at which engineering control can be utilized to improve the DO. These points can be grouped as follows:

1. Point and non-point reduction source of CBOD and NBOD through reduction of effluent concentration and/or effluent flow.
2. Aeration of the effluent of a point source to improve initial value of DO.
3. Increase in river flow through low flow augmentation to increase dilution.
4. Instream reaeration by turbines and aerators.
5. Control of nutrients to reduce aquatic plants and resulting DO variations.

This study examines BMPs for agriculture and forestry, reducing loads from point sources, and augmenting flow. Spring Creek has potential for augmenting flow through reducing irrigation from surface and ground waters. Flow could possibly be augmented by converting the surface withdrawals to ground water withdrawal, increasing the amount of small reservoirs, increasing water use efficiency, land retirement or dry cropping (no irrigation), or decreasing irrigation. Three flow scenarios were evaluated in addition to the control scenario (no flow augmentation).

Economic Model

A least-cost strategy for meeting TMDLs would involve picking the least expensive set of management practices that would meet a concentration target at the reference streamflow volume. The cost of reducing pollution can vary depending on the cost of the management of the sources of pollution. Economic theory says that the least expensive management practices per unit of reduction should be chosen until a concentration goal is reached.

Once consideration of enhancing flow volumes is admitted as a policy choice, then this becomes an additional management practice and should be chosen as long as its cost per unit of improvement is lower than other alternatives. The choice of management practices and flow enhancements depends on the stringency of the TMDL relative to baseline loads, the costs of the management practices, and the costs of reducing withdrawals (or conceivably pumping groundwater) to enhance flow.

After determining the cost of the various management practices, a spreadsheet modeling framework was developed to identify cost effective allocations under physical and legal requirements. The framework allows us to identify the management practices and decisions that meet the water quality criteria while achieving cost minimization objectives. Furthermore, the model allows us to identify the amount and location of BMP implementation and flow augmentation necessary to meet the requirements.

We define the equations that model water quality as a function of streamflow and pollutant loading as well as the cost minimization problem used to achieve water quality targets at the least cost. The decision variables in the model are the flow variables for each stream segment (which are a function of the amount of water saved by decreasing agricultural water withdrawals) and the degree of BMP implementation throughout the watershed. Upper bounds, derived from the amount flow could be augmented from irrigation reductions or efficiency improvements, are placed on the flow augmentation variables. There are two requirements for the model. The first is that the average DO should not be below 5mg/l. The second is that DO concentration should not go below 4mg/l at any point. The objective is to minimize the cost of meeting these requirements.

For each iteration in the optimization process, the following steps occur. First, the model selects new values for the decision variables; (2) decisions variables are used to estimate costs and loads; (3) loads and impact coefficients assumptions are used to forecast concentration distribution; and (4) the model compares concentrations to criteria requirements and determines the degree to which the objective is satisfied.

Our analysis found filter strips to be more cost effective than conservation tillage for improving DO concentration. Filter strips are therefore the only agricultural BMP considered here. The mathematical equation to be solved is:

$$\text{Min } R(y) + C(w) + \lambda\ (S + A^*Y + B^*W)$$

Where,

R = cost of reducing load

C = cost of increasing water flow

S = ambient standard

y = reduction in load compared to status quo

w= quantity of water increased relative to status quo

A = matrix of transfer coefficients for load reductions

B = matrix of transfer coefficients for flow augmentation

The first order conditions for a minimum to equation () are that

$$\frac{\partial L}{\partial Y} = \frac{dR}{dY} + (-A) = 0$$

$$\frac{\partial L}{\partial W} = \frac{dR}{dW} + (-B) = 0$$

$$\frac{\partial L}{\partial \lambda} = R + AY + BW$$

$$\lambda = \frac{dR}{dY} * \frac{1}{A}$$

$$\lambda = \frac{dC}{dW} * \frac{1}{B}$$

The predicted concentrations associated with minimum cost allocation satisfy environmental goals. The model is run with both observed conditions in June 2000 (the calibrated model), the 7Q10 flow (both low flow conditions), and with observed conditions in1995. In 1995, which was a ‘wet’ year, the DO concentration met the water quality criteria both in actuality and in the model results. For each of these flow scenarios, the model was run allowing both flow and load parameters to change simultaneously, allowing only flow to change, and allowing only load reductions to change.

Our results show that the least cost way to reach the water quality targets in the year 2000 would be to implement BMPs on 12% of the row crops in the watershed and to increase flow by 5,158 AF per year, at a cost of $465,528. This is based on the assumption that 23% of all irrigation for the year would occur during the study period. The reason for high amount of flow augmentation is that the flows in this year were so low that in order to have an average concentration of 5mg/l throughout the stream, flow would have to be increased throughout the stream. The results suggest that locating the filter strips in more critical areas is more effective than evenly distributed throughout. They also suggest that augmenting flow in the same area as the filter strips is successful at improving DO concentration. Because 2000 experienced such low flows, it is impossible to reach the concentration goal of 5mg/l using only BMP implementation.

Applying filter strips on all feasible acres of row crops gives us an average DO concentration of 4.9mg/l, with portions of the stream falling below 4mg/l. This would cost $1,091,520. Using the 7Q10 flow rate, the least cost way to reach the concentration goal is by applying BMPs to 10% of the row crops and augmenting flow by 1,984

AF/year. This would cost $291,648. Even with the 7Q10 flow rates, the minimum DO concentration cannot be met by load reductions alone.

Table 1: Relative Costs of Meeting Water Quality Goals

Flow rate	Cost with both load reductions and flow augmentation	Cost with only BMP
June 2000	$465,528	Infeasible ($1,091,520)
7Q10	$291,648	Infeasible ($1,091,520)
June-July 1995	$0	$0

Policy Implications

Water management as well as nonpoint source control has been proven as an important control technique in improving DO concentration levels. If water management for dilution purposes is ignored, then methods to reduce loading, or increase DO concentration, result in an unnecessarily high social cost of control. An effective combination of management options should involve both BMPs to reduce runoff concentration and increasing the assimilative capacity of the waterbody. The results of this research can be used as a springboard to discuss the important link between water quality and water quantity issues. The recognition of this link is becoming increasingly critical as state policies are beginning to address the quality and scarcity of our water resources.

A three year drought in Georgia along with the state’s political and legal battle with Florida and Alabama have brought more attention to the issue of water supply, especially in the heavily irrigated lower part of the Flint. This has brought a necessity for new policies to deal with water supply issues. There has been increasing concern over the amount of water available not only for withdrawal purposes but also for the protection of fish and wildlife habitat and for dilution of loads discharged into our waterbodies. At the community level, water use restrictions have been implemented throughout the state as supplies of clean fresh water fail to meet the demand. At the municipal and industrial level, any new permit is already required to consider the withdrawal's effect on the water quality of that portion of the water body. There have been additional holds on assigning new permits and the changing of existing ones. Other attempts to protect instream flows have focused on irrigation withdrawals. Farmers will reduce their water consumptive use when the marginal benefits of selling one acre-foot of water is equal to or greater than the marginal benefits of using that acre-foot of water in growing crops. Farmers will decide whether to abandon irrigated lands, substitute crops requiring less water, etc. Cost-sharing programs to improve irrigation efficiency and the Flint River Drought Protection Act's attempt to take land out of irrigation recognize this and subsidize farmers, in many cases at a high cost. All of these efforts aim to change the amount of water withdrawals, which will in turn affect the assimilative capacity of the waterbody.

At the same time, TMDLs must account for variation in flow, or seasonal variation, but few actually do. The first step in developing a TMDL is determining whether or not the there are impairments that cause a waterbody not to support its designated use. The most basic issue is whether there is sufficient water in our streams and rivers to maintain the designated uses. Concern over this may lead to increased reliance on programs to maintain instream flow. The amount of water withdrawn and returned to a waterbody will affect the dilution of pollutants in that system. Therefore, reducing withdrawals or using water more efficiently may be a management option worth examining when developing a TMDL. Especially in dry conditions, water supply will have to be balanced against ecological considerations.

Discussion and Conclusion

The study indicated that increasing base flow in the stream increased the mean daily DO concentration at a cost well below that of BMPs. The results of this initial application of our model should be treated with caution, particularly because the results are location-specific. We believe that these findings indicate the explicit consideration of flow augmentation in meeting water quality standards should be part of any effective and efficient management approach. We plan to expand this model to more reaches and reality-check these results as the next stage of this research.

References

Baumol, W.J., Oates, W.E. *The Theory of Environmental Policy,* 2nd ed. Cambridge: Cambridge University Press, 1988.

Carpentier, C.L., Bosch, D.J., and Batie, S.S., Using Spatial Information to Reduce Costs of Controlling Agricultural Nonpoint Pollution, *Agricultural and Resource Economics Review.*

Cummings, R.G., Norton, N.A., and Norton, V.N., Enhancing In-stream Flows In the Flint River Basin: Does Georgia Have Sufficient Policy Tools?, Water Quality Working Paper # 2001-002. September 2001.

Georgia Soil and Water Conservation Commission, 1994. *Agricultural Best Management Practices for Protecting Water Quality in Georgia.*

Johnson et al, The Effects of Drought on Freshwater Mussels and Instream Habitat in

Coastal Plain Tributaries of the Flint River, Southwest Georgia, July-October, 2000.

Ribuado, M.O., Horan, R., Smith, M.E., Economics of Water Quality Protection from Nonpoint Sources: Theory and Practice. Agricultural Economics Report 728. U.S. Department of Agriculture, Economic Research Service, Washington D.C., 1999.

Thomann, R.V. and J.A. Mueller, 1987. Principles of surface water quality modeling and control. Harper Collins Publishers Inc., New York.

U.S. Geological Survey, 2003. *Flow data at gauge station 0235700- Spring Creek near Iron City*. (http://www.usgs.gov)