THE ECONOMICS OF FLOW ENHANCEMENT VS. NUTRIENT CONTROLS IN MEETING WATER QUALITY STANDARDS: A CASE STUDY OF SPRING CREEK

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Abstract. Many of the rivers and streams in Georgia are still not supporting their designated uses. The TMDL program is a key policy tool to address this problem. While the TMDLs written for impaired segments in Georgia address load reduction from point and nonpoint sources, the role of instream flow is not addressed as a management option. 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. Preliminary results from our study show that reaching the targeted water quality by increasing flows may be cost-effective in comparison to TMDL-mandated pollutant removal alternatives. We conclude with some observations about the general applicability of the results.

INTRODUCTION

Land use by humans in the form of agricultural, construction, forestry, and other commercial uses invariably has an impact on water quality and the surrounding ecosystems. This includes increased nutrient loads from point and nonpoint sources, toxic loadings from point sources, increase or decrease in the stream flows – all of which might lead to a decline in the overall water quality of the streams and make them unfit for recreation or human and wildlife consumption. While the Clean Water Act has led to improvements in water quality, less than 45% of Georgia's streams meet designated uses with the major source of stream degradation being non-point source pollution. It is with this backdrop that the TMDL program is becoming a key component to improving water quality in Georgia.

Developing and implementing TMDLs 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. Reduced flows can lead to higher concentrations of substances that have been discharged to a stream or other water body. Another is that flow is an important variable in supporting ecosystem services in and of itself. Improvements in water quality, wetland and riverine habitat, and the waste assimilative capacity of a stream can be achieved by flow augmentation. It is therefore feasible in some cases that flow levels 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 managed 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 general applicability of these results.

THEORY

A least-cost strategy for meeting numeric water quality standards 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. Costs of agricultural best management practices such as filter strips include the farmer's share of installation and maintenance costs and opportunity costs of land removed from production.

CASE STUDY

In order to illustrate this argument, 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. Dissolved oxygen concentration is a primary indicator of overall water quality and the viability of the aquatic habitat. Various point and nonpoint sources of pollution such as wastewater treatment discharges and agricultural runoffs can affect DO concentration in streams. Low base-flow in stream can also aggravate DO problems. Our site is Spring Creek, a stream with 22 miles of impaired waters located 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 numeric 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 waste water 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 evapotransporation 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 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, 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:

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

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, 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).

RESULTS

The model was run using USGS water quality and quantity data collected in the years of the study and land use characteristics determined from Georgia's Multiple Resolution Land Coverage. Current NPDES permits and GIS files that locate each permitted outfall were obtained from Georgia EPD. An initial analysis done by EPD indicated that low DO concentrations were found to coincide with low or zero flows, slow stream velocities, shallow water depths, and high temperatures.

Preliminary results from our study show that reaching the targeted water quality using reductions in loads from point and nonpoint sources alone may not be the most cost effective option, and may not be sufficient to reach state targets.

Compared to the base flow scenario, increasing flow by 1cfs and 5cfs increases the mean DO concentration in the stream 0.438 mg/l and 1.159mg/l, respectively. The scenario in which the flow was increased 10 cfs led to a mean DO increase of 1.28 mg/l.

Using an estimate derived from the Flint River Protection Act (where the estimated average cost of decreasing irrigation was $30.90 per acre foot), increasing flow by 1cfs, 5cfs, and 10cfs would cost $25,800, $129,000, and $258,000. Thus the cost per 0.1 mg/l improvement in DO concentration would be $5,890 (1 cfs), $11,130 (5 cfs), and $20,156 (10 cfs).

Improvements made by reducing nitrogen using various BMPs such as filter strips or conservation tillage systems cost approximately $7.31/acre/year and $17.34/acre/year, respectively (EPA 1993). These are median annual costs per acre for acres benefited by the practice and include operation and maintenance, planning, and technical assistance. Though actual effectiveness depends on site-specific conditions, these BMPs have been shown to reduce nitrogen runoff on agricultural lands by approximately 70% and 55%. The reductions of pollutants by BMPs were assumed to be constant and not to change by field location with respect to the streams. Compared to the base case scenario a 55% reduction in N loads from the acres planted in row crops increases average DO concentration 0.097 mg/l. A 70% reduction would lead to a 0.124 increase in average DO concentration. When you consider the same reductions from agricultural nonpoint source pollution when flows have been augmented 5cfs and 10cfs, the average DO concentration is increased by 0.045 and 0.07mg/l, respectively.

Applying a BMP that reduces N by 70% to all the acres in row crops would cost $656,920, and the 55% reduction would cost $1,558,280. This implies a cost per 0.1 mg/l in DO of $529,774 (70% reduction) and $1,606,474 (55% reduction).

DISCUSSION AND CONCLUSION

The study indicated that increasing base flow in the stream increased the mean daily DO concentration in the stream at a cost orders of magnitude below that of BMPs. Improvements made by reducing nitrogen using various BMPs such as filter strips or conservation tillage when, for example, the filter strips are applied to the agriculture lands in the model, the result is a change of 0.124 in the average DO concentration. The same results can be obtained by increasing the headwater flow by .25 cfs. Increasing flows appears to be cost-effective in comparison to TMDL-mandated pollutant removal alternatives.

While the results of this initial application of our model should be treated with caution, 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.

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