An Analysis of Cost Effective Management Practices to Manage Water Pollution Problem: A Case of Tobesofkee Creek, Georgia.

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ABSTRACT

A cost minimization model was used to find the minimum cost and environmental friendly management practices(MCEFMP). Use of MCEFMP in cattle production seems to be the most cost effective means of reducing water pollution with a marginal cost of $1200 in comparison to use of MCEFMP on other agricultural operations.

INTRODUCTION

Non point source pollution activities are closely related to land uses. Many agricultural practices continue to accelerate water quality degradation, diminish land productivity, reduce recreational opportunities, impact real estate values, and threaten drinking water capacity. Nutrients, sediments, and bacteria in water resources arise mostly from the intensively cultivated agricultural lands and livestock production (Osmomd & Wossink, 2002) creating several negative impacts on surface or ground water resources. Contaminants associated with crop farming and livestock practices include sediment, nutrients (nitrogen and phosphorus) from inorganic fertilizers, microorganisms from livestock wastes, chemicals residuals from herbicides and insecticides application, and salts and trace elements from irrigation. Pollutants enter in to the surface and ground water resources as runoff and leaching from farmland along with the sediments and water.

Increasing level of excess nutrients (nitrogen, phosphorus), fecal coliform, and sediment entering the ground and surface water resources raises the major concern on water quality. If left unchecked, continued excessive pollutants in the watershed further intensifies water quality problem. Excess nutrients in surface water cause algal blooms and eutrophication, which leads to problems associated with odors, fish death, and other environmental problems.

Tobesofkee river, a segment of Ocmulgee River represents a severe non point source water pollution problem creek in Georgia. Pollution from the different non point sources contributed to severe water quality problems in the creek. Agriculture especially the flow of excess nutrients and sediments from the livestock operation remains as the major source of water pollution problem in the Tobesofkee Creek(EPA, 1998). Such degraded water has already been a serious economic problem to local community by increasing clean up cost and decreasing tourism activities, one of the major sources of local income. Failure to take measures to reduce further degradation of water quality might affect human health and local economy severely(NRCS, 2002).

Controlling water pollution in the Tobesofkee creek can follow many courses. Economics plays a vital role in identifying agricultural practices that ensures water quality at minimum cost. Rising water quality problem associated with different agricultural operations demands environmentally friendly farming practices and cost effective agricultural pollution abatement technologies. Environmental rules and regulations along with advanced technologies reduce the water pollution problem originated from different agricultural practices(Harrington et al 1986; Uri, N. D., 1991). However, implementation of environmentally friendly practices based on the environmental regulations of government might trim down the level of profit for the firms by adding up the cost of production.

The strict environmental standards and need of higher spending on water pollution abatement programs generate a strong public concern about the water quality abatement program. Realizing the public concern over the cost of pollution abatement program, there exist a urgent need to find out a sets of practices, which improve water quality problem at minimum cost possible. Therefore, our study focuses on identifying the most cost effective agricultural management practices that could reduce agricultural pollutants loading into the Tobesofkee Creek protecting the creek from the further water quality degradation. Though limited to Tobesofkee Creek, findings of our study might have great implications to solve the water quality problems in Georgia.

LITERATURE REVIEW

There exist a number of empirical studies examining the impacts of environmental regulations on economic performance of the firms (Gray & Shadbegin, 1995). The main focus of these studies lies on the total productivity of the firms. Most of these studies develop production and profit functions for industries such a paper mills using industrial pollution abatement cost variable as a input of production process. Rarely, these literature model agricultural production incorporating non point source pollutants as exogenous variables. Studies also ignore cost effective alternative of agricultural pollution abatement practices.

Agricultural activities are considered as the most significant source of water quality impairments in streams, lakes and rivers contributing more than one third of water pollution in the water (EPA,1998). Several studies indicate the negative impacts of agricultural activities on surface waters and ground water, public health, and as environmental health. Study reports the deterioration of ground water quality after excessive applications of animal manure and agricultural chemicals. Goldar et al (2001) and NRDC (1998) are also consistent with the result obtained from EPA.

Wossink and Osmond (2002) claim agricultural activities as a primary source non-point water pollution source. An estimate of about 60% of non-point source pollution load originates from Agricultural production process, the study claims. Sediment and nutrients originated from agricultural activities are the major polluting sources of surface and ground water.

In 1991, Uri & Boyd analyze the cost of implementing pollution abatement measures and report a significant increase in production cost due to the installation of pollution abatement facilities and technologies. The study result shows 0.224% increase in production cost of goods and services with the installment of pollution reducing devices.

Stanley (2000) studies economics of adopting Best Management Practices to control poor water quality problem in a shrimp farm. The study reports higher cost of the implementation is a major constraint to adopt Best Management Practices. Study further claims the cost of exchanging water quality for shrimp increased with the increase in number of water exchange, which is a function of water quality.

In general, formulation and estimation of a correctly specified abatement cost function has been a core for policy formulation in order to impose taxes or user-fees and to share social cost in presence of environmental pollution. Wossink and Osmond claim improved decision-making due to information on land use activity cost to improve water quality of runoffs. The study report agricultural land management is the best alternative to meet agricultural crop needs as well as to minimize water quality pollution problem (2002).

The least cost solution to the environmental damages is based on the assumption that the pollution is generated form different sources; therefore pollution abatement cost varies depending on the management cost of pollution sources. Under the least cost solution, a set of sources that can control pollution emission in most cost effective fashion are considered a minimum cost solution to meet the given pollution standards (Kim, 2000). Thus, pollution abatement at minimum cost is obtained by managing those sources that can be done at least cost compared to other sources. Using emission control instrument motivates the firms to increase profit by reducing cost to obtain specified level of output.

MODEL SEPECIFICATION

There exists a powerful argument in favor of using economic instrument which ensures abatement of pollution at least cost (Cowan, 1998). An economic instrument provides a cost efficient solution for a given water pollution problem only if marginal cost of pollution control differs with different sources of pollution. An important assumption in this analysis is that the regulator presents no concern regarding the water pollution sources.

A cost minimization economic model is used to find economically efficient management practices in case of air pollution by Kim (Kim, 2000). In our analysis, slightly modified version of Kim's model was implemented to find the least cost solution to the water pollution problem. The cost of controlling water pollution is considered to be a linear function of nitrogen and phosphorus loading into the creek. The model uses percentage of the total loading of nutrient to the creek to avoid working with huge numbers. Mathematical version of cost minimization mode is expressed as;

$$\textbf{Min} \sum_{j=1}^{m} C_j (X_j) \qquad \textbf{st.} \left(\sum_{j=1}^{m} X_j\right) \geq \textbf{D}$$

Where,

X_j = Percentage of pollutant loading jth source

D = Percentage reduction of pollutant needed to comply with Georgia EPD standards.

And;

This is equivalent to minimizing following the equation;

$$\textbf{Min L} = \textbf{Min} \sum_{j=1}^{m} C_j (X_j) + \lambda \left(D - \sum_{j=1}^{m} X_j\right)$$

From first order condition, the equation should be equivalent to;

$$\sum_{j=1}^{m} C`_j (X_j) = \lambda$$

$$D = \sum_{j=1}^{m} (X_j)$$

DATA

Information related to agricultural land use pollutants (nitrogen and phosphorus) was obtained from the Natural Resource Conservation Service (NRCS). Pollution abatement levels were calculated by deducting the EPD recommended nitrogen and phosphorus level from the present nitrogen and phosphorus level of Tobesofkee Creek. Acreage of land and number of animal farms are also obtained from the same source (NRCS, 2002). The land and numbers of animals are used to obtain nutrient yield, which flows in to the creek.

RESULT AND DISCUSSION

Estimated pollution reduction and associated cost.

Livestock farm produces the highest level of nutrients, which flow into the Tobesofkee creek. Table 1 shows more than 50% of nutrient pollution in the water originates from the livestock production. The level of nitrogen and phosphorus loading can be reduced to 18.269 tons per year, if the best management practices are implemented. Poultry contributes the least amount of pollution to the creek in the Tobesofkee creek. Out of two recommended pollution regulations, the stricter water pollution regulation (Nutrient reduction to 0.05mgP/lit & 0.3mgN/lit water) required more reduction on emission, which ultimately increases the cost of agricultural production.

Table 1. Nutrient reduction from current level of loading.

Total Activities	Current loading Ton/year	Nutrient reduction to meet 0.05mgP/lit & 0.3mgN/lit water			Nutrient reduction to remain under TMDL requirement		
		Desired loading Ton/year	Amount to be reduced Ton/year	Percent age to be reduced (%)	Desired loading Ton/year	Amount to be reduced Ton/year	Percent age to reduce (%)
Cropland	38.0458	8.1366	29.91	31.40	17.8722	20.17	32.12
Pasture	24.4924	9.1796	15.31	16.08	15.7209	8.77	13.97
Livestock	65.9843	18.2649	47.72	50.10	34.0584	31.93	50.83
Swine	2.2072	0.3654	1.84	1.93	0.6919	1.52	2.41
Poultry	0.5278	0.0677	0.46	0.48	0.1077	.42	0.67
Total	131.2565	36.0142	95.24	72.56	68.4513	62	47.85

The cost of reducing nutrient loading in Tobesofkee creek using different agricultural practices is shown in table 2. Analysis shows the higher annual marginal cost of $63290 to reduce the pollutions originated from the poultry operation using the best management practices. **M**arginal costs of controlling pollution from the cropland and pasture operation seem to be $28827 and $16240 per year respectively. Analysis reveals the lowest marginal cost of $1,200 to reduce the annual loading in Tobesofkee for pollutants originated from livestock operation. This information is very important in order to choose cost effective management practices in case of budget constraints and where priority should be given.

Table 2 Cost of reducing yearly nutrient loading in Tobesofkee Creek by 1% Using different management practices

Management	**Total cost $**	**Potential Reduction %**	**Marginal cost $**
Cropland	925969	32.12	28827.72847
Pasture	226820	13.97	16240.70868
Live stock	61002	50.83	1200.042812
Swine	37510	2.41	15547.48551
Poultry	42233	0.67	63290.34739

Cost effective management practices

Our model involves cost minimization through reducing pollution emission subject to desired water quality standards. Producers in agricultural sectors use land as a fixed input and management practices as variable inputs. Different land use activities discharge different amounts of emission entering directly or indirectly to the streams or creeks. Each practice determines different level of pollution emission. Nitrogen and Phosphorus are related to production activities in which the emission is a linear function with different land management practices (Nishizawa, 1998).

This analysis is restricted only to agricultural sector within the Tobesofkee creek watershed. Agricultural activities in the watershed produce nutrient pollutants such as nitrogen and phosphorus in such a large amount that nearly 48% of emission reduction from present state is required to meet Georgia EPD's standard. Mathematical model is expressed as follows:

$$C = C_{cr} * P_i + C_{pa} * P_i + C_{ls} * P_i + C_{sw} * P_i + C_{pol} * P_i \qquad \text{---------(i)}$$

Subject to; $P_1 + P_2 + P_3 + P_4 + P_5 \geq 47.85$

$P_1 \geq 32.12\%$, $P_2 \geq 19.97$, $P_3 \geq 50.83$ $P_4 \geq 2.41$, $P_5 \geq 0.67$

where the constraint is set to reduce pollution discharge not to exceed Total Maximum Daily Load of nutrient in the Tobesofkee creek.

Or,

Subject to; $P_1 + P_2 + P_3 + P_4 + P_5 \geq 72.56$

$P_1 \geq 31.40\%$, $P_2 \geq 16.08$, $P_3 \geq 50.10$ $P_4 \geq 1.93$, $P_5 \geq 0.48$

Where constraint is set according to nutrient level of 0.05mgP/lit and 0.3mgN/lit of water in the creek

Where,

C_i = Cost of i^{th} pollution reduction

C_{cr} = Marginal cost of crop land management practice required to reduce 1% level of pollutant

C_{pa} = Marginal cost of Pasture land management practice required to reduce 1% level of pollutant

C_{ls} = Marginal cost of livestock farm management practice to reduce 1% level of pollutant

C_{sw} = Marginal cost of swine farm management practice to reduce 1% level of pollutant

C_{pol} = Marginal cost of poultry farm management practice to reduce 1% level of pollutant

P_i = % age reduction of pollutant from i^{th} practices

i = 1, 2, 3, 4, 5 i.e. Cropland, Pasture land and Livestock farm, pig farm, and poultry farms.

$$\text{Min } L = 28828\, P_1 + 16241\, P_2 + 1200\, P_3 + 15547\, P_4 + 63290\, P_5 + \lambda\, (47.85 - P_1 - P_2 - P_3 - P_4 - P_5) \quad \text{-----------(ii)}$$

FOC

$$\partial L / \partial P_1 = 28{,}828 - \lambda = 0$$

$$\partial L / \partial P_2 = 16{,}241 - \lambda = 0$$

$$\partial L / \partial P_3 = 1{,}200 - \lambda = 0$$

$$\partial L / \partial P_4 = 15{,}547 - \lambda = 0$$

$$\partial L / \partial P_5 = 63{,}290 - \lambda = 0$$

$$\partial L / \partial \lambda = 47.85 - P_1 - P_2 - P_3 - P_4 - P_5 = 0$$

The lowest marginal cost of reducing nutrient loading in Tobesofkee creek is $1200. Thus, in the first case better management of animal waste can reduce required level of nutrient flow to maintain the Total Maximum Daily Load (TMDL). In order to reduce nutrient pollutant loading, beef and dairy management practices are seen as least cost solution. More than 50% of current nutrient pollution originates from the beef and dairy activities.

The study result reveals adopting the best management practices in livestock farms reduce more than 47.85% of nutrient pollution in the creek. Implementing environmental friendly feeding and animal waste management practices provides significant reduction on water pollution. Better water supply facility and excluding animals from shore also contributes on nutrition reduction in the creek. Thus the total cost of pollution reduction is estimated to be $ 57,420 with $P_2 = P_3 = P_4 = P_5 = 0$. None of other sectors are required to reduce their pollution emission if total livestock farm in the watershed will be managed properly.

In the second case, the constraint, which requires 72.56% reduction on current nutrient flow in the stream, is 0.3 mg N/liter and 0.05 mg P/liter of water. The least cost solution is obtained by following the same logic.

$P_3 = 50.10\%$, $P_4 = 1.93\%$, $P_2 = 16.08\%$, $P_1 = 4.45\%$, and $P_5 = 0$.

In order to comply with Georgia Environmental Protection Division (EPD) nutrient water quality standard, analysis suggest more than 50% of current nutrient loading can be reduced by spending around $ 60,120 on livestock management. 1.93% can be reduced by managing swine production and 16.08% can be reduced by using best management practices on pastureland. Implementing environmental friendly swine management activities costs $30,006 while, pastureland needs expenditure of $261,155 to reduce nutrient by 16.08% from current state. In addition, analysis suggests a spending of $128,285 on cropland to meet the desired pollution reduction. Environmentally friendly cost efficient management practices and associated cost are listed in Table 3.

Table 3. The cost-effective management practices and associated cost to achieve GAEPD water quality standard.

Water quality standards	Percentage reduction of nutrient loading by managing different agricultural practices				Total nutrient reduction (%) and cost ($) of compliance
	Livestock	Pig farm	Pasture	Crop land	
Reduction not to exceed TMDL	47.85	0	0	0	47.85
($) Cost of compliance	57,420	0	0	0	$ 57,420
Reduction Meet EPD nutrient quality	50.10	1.93	16.08	4.45	72.56
($) Cost of compliance	60,120	30,006	261,155	128,284	479,565.6

CONCLUSION

The most cost-effective nutrient reduction management practices consist of managing livestock production. Livestock waste management, fencing to avoid cattle to stream banks and stream and better water supply practices serves the least cost solution to reduce water pollution resulted from agricultural sectors. Total cost of $ 57,420 estimated to reduce nutrient emission less than or equal to TMDL of the creek. However, in order to reduce water pollution to meet Georgia EPD water quality standard of 0.05 mgP/lit and 0.3mgN/lit of water, total cost is estimated to be $479,566. Swine farms, crop farms pasture farms are also required to implement environmental friendly practices in addition to livestock farms.

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APPENDIX

Table 1. Total estimated cost of implementing best management practices on cattle, swine and poultry operations

Livestock management practices	Total cost		
	Cattle	Swine	Poultry
Fencing	$4,120	$1030	
HUA	$7,323		
Water supply	$17,613		
Waste collection and management	$28,556	$36480	$42,233
Heavy use area protection	$3,390		
Total	$61,002	$37510	$42,233

Table 2.Total estimated cost of implementing best management practices on Pasture land.

Land management activities	Unit	Amt	Cost	Total cost
Nutrient Mgt.	Ac.	10347	$10	$103,470
Pasture & Hay land Planting	Ac.	1034	$100	$103,400
Riparian Forest Buffer	Ac.	105	$190	$19,950
TOTAL				$226,820

Table 3. Total estimated cost of implementing best management practices on crop production process

Crop land management practices	Unit	Amt.	Cost	Total
Conservation Cover	Ac.	345	$100	$34,500
Conservation Croping Rotation	Ac.	3450	$10	$34,500
Cover & Green Manure Crop	Ac.	3450	$10	$34,500
Critical Area Planting	Ac.	206	$1,300	$267,800
Filter Strip	Ac.	131	$183	$23,973
Grasses & Legumes Rotation	Ac.	3450	$10	$34,500
Grassed Waterway	Ac.	13	$1,200	$15,600
Nutrient Mgt.	Ac.	3450	$10	$34,500
Residue Mgt., Seasonal	Ac.	3450	$35	$120,750
Riparian Forest Buffer	Ac.	131	$190	$24,890
Terrace	Ft.	1155600	$0.26	$300,456
Total				$925,969