# Watershed-level Policies to Implement Best Management Practices under Environmental Risk

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## Abstract

To meet environmental target, policies that coordinate nonpoint pollution control efforts within a watershed may result in higher total profits than policies that do not. That is, the greatest profits and most runoff reduction would be achieved with optimal combinations of BMPs. However, the uncertainty weather condition could pose some challenge in achieving environmental target. In this study, we use a bioeconomic model, Agricultural Policy Environment Extender (APEX) to simulate the environmental impacts of alternative cropping systems. Under safety-first constraints, the levels of environmental runoff and optimal net returns of alternative cropping practices are estimated, using GAMS.

## I. Background

According to US Environmental Protection Agency, Mississippi have a large number of 301D-listed streams and rivers, indicating that the quality of many of Mississippi's waterways is compromised for consumption and recreational activities. Many point sources of pollution have already been mitigated pursuant to the Clean Water Act, so that the potential for water quality improvement is now focused on agricultural nonpoint pollution. Total Maximum Daily Load standards (TMDLs) to reduce nonpoint pollution of surface water are soon to be in effect. However, the long run impact of the standards on agricultural producers' profits is not well understood. Furthermore, the way the standards will be implemented has not yet been determined. In order to meet more stringent water quality standards, producers may turn to best management practices (BMPs).

Exogenous factors, such as weather, create uncertainty as to weather environmental targets for agricultural nonpoint pollution will be met; in some periods, reductions will be higher, and in others lower than the efficient level. Since environmental standards are

unlikely to be fully met, safety-first plays significant role in environmental policies. Under safety-first criteria only restricted amount of run off is allowed to exceed targets or standards.

Researchers have used a number of stochastic models including chance-constraints. Target MOTAD, and Upper Partial Moment (UPM) to estimate the environmental and economic impacts of various cropping practices under uncertainty. To apply chance constraints, environmental variables are contained particular functional form, posing some model limitations. Target MOTAD, instead of specifying the distribution functional form, treats the sample of variables as an empirical distribution, and the results of the optimization are valid as long as the empirical distribution represents the true distribution. However, the environmental risk level is chosen exogenously. For this study, the UPM model is employed. Unlike the Target MOTAD model, the environmental risk level is endogenously determined after the desired compliance probability with the objective is specified.

Therefore, this study attempts to develop the watershed-level model of an economic optimization under environmental risk constraints. The model that results incorporates alternative conservation tillage practices, and the results are compared to the results of a baseline model that assumes conventional tillage.

It is hypothesized that policies that coordinate nonpoint pollution control efforts within a watershed may result in higher total profits than the policies that do not coordinate efforts. That is, the greatest profits and most runoff reduction would be achieved with optimal combinations of BMPs. However, producers closest to water bodies will contribute more loading of nutrients and sediment than other producers and would be required to implement more intensive use of BMPs than others, so that their profits would be more severely impacted. Use of watershed models should facilitate examination of the magnitude of profits under various as-

sumptions about pollution standards and combinations of practices. This study will examine the economic and environmental impacts of alternative tillage practices under various environmental policy scenarios. To meet this objective, an economic optimization model is developed that is constrained by environmental parameters that occur under different crop tillage practices and environmental risk in association with those practices, using UPM model. The extent to which TMDL regulations will change the current cropping patterns and tillage choices will also be revealed.

## II. Analytical Approach

To meet our objectives, we will first use Agricultural Policy Environment Extender (APEX). We develop the biophysical model in which we use APEX to estimate environmental runoff and yields under a number of scenarios. The outputs of interest from this model are expected crop yields and expected runoff of nitrogen and sediment. In addition we have developed scenarios in which filter strip practices are examined. In the second stage of analysis the optimal net return under safety-first constraint is calculated using the Generalized Algebraic Modeling System (GAMS) along with information on yields, crop prices, production costs and environmental parameters derived from APEX. Optimality of the system is determined by maximizing net returns across the entire watershed.

*Watershed Level Physical Model*

Site information such as cropping practices, soil types, topography and meteorological data has been collected over a number of years in the project, but in this paper, we focus on the year 1999 as the basis for our analyses. Traditional farm models assume that a farmer's production decisions are constrained by various factors such as amount of land, labor and

other available inputs. An extension of the traditional model that we use in our analysis is a bioeconomic model. Our model is developed for the Deep Hollow watershed, and we extrapolate the model results over a 25-year time period. The underlying physical simulation model incorporates nearby weather conditions in the watershed, nutrient uptake and the timing of planting and harvesting of crops.

The bioeconomic model uses the Agricultural Policy Environmental Extender, or APEX (Blackland Research Center, 1999; Williams et al., 2000), which was developed as an extension of the EPIC (Erosion-Productivity Impact Calculator) model to small watershed level by the US Department of Agriculture's Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Economic Research Service (ERS) in the early 1980's (Sharply and Williams 1990 (a and b)). APEX is designed to simulate biophysical processes and the interaction of cropping systems with management practices, soils and climates over long time periods. APEX captures timing of planting and harvesting and the use of cultural BMPs, and produces environmental parameters where water flows through small watersheds as surface, channelized and subsurface flow. APEX has flexibility in allowing for model calibration with existing data. In this study, we are interested in calibration of our model to correspond with onsite empirical measures of environmental parameters.

The watershed level model uses data inputs that replicate physical, meteorological and agricultural characteristics of the Deep Hollow Watershed. The watershed consists of 10 fields in which the primary crops grown have been cotton and soybeans. Within the watershed, there are 6 different soil types: Alligator, Arents, Arkabutla, Dubbs, Dundee and Tensas. In each field is a combination consisting of 2 to 3 soil types resulting in 22 subfields of unique soils (Table 1).

Approximately 20 inputs into the APEX model are needed for each subfield in order to perform simulations from which to obtain expected yields and nutrient and sediment run-off. The inputs include weather, soil type, soil erodibility factors, topography (as measured by average slope length and steepness), distance from fields to watercourses, relative geographic location of fields within the watershed, crop rotation, tillage practices and fertilizer and chemical use. As part of the MDMSEA project, the soils and topography of these fields have been measured to a high degree of accuracy.

The crops considered are continuous cotton and continuous soybeans under conventional tillage. We generated these outputs from the APEX model in order to use them as inputs to the economic optimization model described in the next section.

In our study, we will also calibrate our model to correspond with onsite empirical measures of environmental parameters. Uncertainty environmental impacts due to stochastic weather conditions will be simulated using APEX. Historical data of precipitation, collected from a nearby weather station (Greenwood Lefore Art), are divided up to a number of intervals, which correspond to the state of nature. The probabilities will be determined by dividing the number of observations in each interval by the total number of years.

*Optimization with Safety-first Constraint*

The optimal net returns of total watershed under safety-first constraints are estimated. The safety-first concept is applied to investigate economic decision under environmental uncertainty. Under safety-first rules, the decision maker concern with the probability of environmental variables falling below target values. The UPM model to evaluate environmental risk applied by Qui et al. (2001) can be written as

Maximize $E(z) = \sum_{j=1}^{n} c_j x_j$

Subject to $\sum\limits_{j=1}^{n} a_{kj} x_j \leq b_k \quad k = 1,....,K$

$$t - \sum_{j=1}^{n} \boldsymbol{n}_{rj} x_j + d_r \geq 0 \quad r = 1,....,s$$

$$\sum_{r=1}^{s} p_r d_r - \boldsymbol{q}(t) = 0$$

$$t + L^* \boldsymbol{q}(t) \leq G_e$$

for all $x_j$ and $d_r$ greater than zero, where t is an endogenously determined reference level for the environmental variable, $d_r$ is zero or deviation above t for state r, and $\boldsymbol{q}_t = \boldsymbol{q}(1,t)$

In our study, nutrient and sediment runoff are simulated using, which is then used in a mathematical optimization program using GAMS. Therefore, an economic optimization model and assess environmental risk of reduced nutrient and sediment runoff by incorporating the safety-first model constraints.

### III. Preliminary Results and Conclusions

Regarding uncertainty of environmental impacts (sediment and nitrate runoff) of cropping practices due to stochastic weather condition are simulated under 15 states of nature, using APEX. Information on variable costs is obtained from on site data. To calculate net returns, five years (1995-1999) average market prices of cotton and soybean in Mississippi are used.

For the baseline scenario, total watershed net returns along with amount of sediment and nitrate runoff are calculated. The optimal net returns of the whole watershed subject to land constraint are estimated, using mathematical program, GAMS. The environmental goals are to reduce sediment and nitrate runoff by 25% and 50% from the baseline levels (0% reduction in pollutants). Under UPM model, probability of achieving such goal as well as envi-

ronmental goals is incorporated to safety-first constraint. In this study, probabilities of compliance with environmental goals are set to 0.50, 0.75, 0.85, and 0.95. Even under the baseline scenario of 0% reduction in sediment and nitrate runoff, there are 4 possible compliance probabilities of 0.50, 0.75, 0.85, and 0.95. The environmental constraint becomes more restrictive as the reduction level and the probability of compliance increase. GAMS are used to solve the optimal net returns under the UPM environmental safety-first constraint.

For the baseline scenario, under conventional tillage practice, the net returns, sediment and nitrate runoff are $16,535, 12.6 tons, and 44 lbs, respectively. The environmental goal are 12.60, 9.45, and 6.30 tons for sediment and 44.40, 33.30, and 22.20 pounds for nitrate runoff, which correspond to a 0%, 25%, and 50% reduction in the baseline environmental reduction levels (Table 2 and 3).

Target value ($t$) of sediment and nitrate runoff, and sediment and nitrate risk levels $q(t)$ are also reported in Table 2 and 3. As the compliance probability to the sediment and nitrate runoff goals becomes higher the expected deviation $q(t)$ above the reference $t$ value becomes smaller. In other words, a less deviation from reference value is allowed when the compliance probability is higher. For instance, the expected deviation falls from 1.31 tons to 0.03 tons as compliance probability for achieving 25% sediment reduction increases from 0.50 to 0.95, which implies a reduction in the sediment risk level (Table 2). In this exercise, only conventional tillage practice is considered. For further study, conservation and no tillage practices will be included, which the optimal land allocation among the various tillage practices will be estimated.

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**Table 1:** Composition of Subfields in Deep Hollow Watershed, MS

| Field ID | Acres | Soil | % Soil |
|---|---|---|---|
| XP3A | 24.8 | Dubbs | 7.75 |
| XP3A | | Tensas | 3.11 |
| XP3B | 12.0 | Dubbs | 2.25 |
| XP3B | | Tensas | 1.55 |
| XP3B | | Dundee | 1.04 |
| XP3C | 12.4 | Dubbs | 0.66 |
| XP3C | | Dundee | 1.04 |
| XP10 | 37.1 | Tensas | 6.99 |
| XP10 | | Dundee | 8.30 |
| XP10 | | Dubbs | 1.80 |
| XP1 | 17.2 | Arkabutla | 12.27 |
| XP2W | 29.5 | Tensas | 14.09 |
| XP2W | | Alligator | 3.18 |
| XP2W | | Arkabutla | 1.24 |
| XP2E | 29.5 | Tensas | 14.50 |
| XP2E | | Alligator | 3.28 |
| XP2E | | Arkabutla | 1.24 |
| XP8 | 9.0 | Alligator | 2.36 |
| XP9A | 12.6 | Arkabutla | 6.04 |
| XP9A | | Arents | 2.10 |
| XP9B | 10.6 | Arents | 1.57 |
| XP9B | | Arkabutla | 3.64 |

**Table 2.** Upper Partial Moment Model for Sediment Reduction

| Prob. β | Sed. Goal (tons) | Net Returns $ | t (tons) | θ(t) (tons) |
|---|---|---|---|---|
| 0.50 | 12.6 | 16,275 | 9.31 | 1.65 |
| | 9.45 | 15,744 | 6.82 | 1.31 |
| | 6.3 | 15,212 | 4.33 | 0.99 |
| 0.75 | 12.6 | 15,930 | 10.46 | 0.54 |
| | 9.45 | 15,467 | 7.8 | 0.41 |
| | 6.3 | 15,004 | 5.13 | 0.29 |
| 0.85 | 12.6 | 15,771 | 10.86 | 0.26 |
| | 9.45 | 15,347 | 8.12 | 0.2 |
| | 6.3 | 14,919 | 5.36 | 0.14 |
| 0.95 | 12.6 | 15,533 | 12.56 | 0 |
| | 9.45 | 15,170 | 9.16 | 0.01 |
| | 6.3 | 13,407 | 5.79 | 0.03 |

**Table 3.** Upper Partial Moment Model for Nitrate Reduction

| Prob. β | Nitr Goal (lbs) | Net Return $ | t (lbs) | θ(t) (lbs) |
|---|---|---|---|---|
| 0.5 | 44.4 | 15,987 | 30.51 | 6.94 |
| | 33.3 | 15,482 | 21.06 | 6.12 |
| | 22.2 | 14,296 | 13.84 | 4.18 |
| 0.75 | 44.4 | 15,546 | 31.62 | 3.19 |
| | 33.3 | 14,769 | 26.11 | 1.8 |
| | 22.2 | 12,623 | 16.99 | 1.3 |
| 0.85 | 44.4 | 15,414 | 36.21 | 1.23 |
| | 33.3 | 14,487 | 26.98 | 0.95 |
| | 22.2 | 12,003 | 17.92 | 0.64 |
| 0.95 | 44.4 | 14,773 | 42.16 | 0.11 |
| | 33.3 | 13,373 | 32.15 | 0.06 |
| | 22.2 | 10,631 | 21.66 | 0.03 |