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MODELING COST-EFFECTIVENESS OF AGRICULTURAL NONPOINT POLLUTION ABATEMENT PROGRAMS ON TWO FLORIDA BASINS[1]

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ABSTRACT: A model was developed to evaluate the cost-effectiveness of alternative "best management practice" (BMP) implementation schemes on two agricultural basins in Florida. The model selectively applies BMPs throughout the basin on a field by field basis, estimates the associated costs, and predicts the relative water quality improvement (reductions in nitrogen and phosphorus). The water quality model links field scale simulation (for detailed BMP evaluation) with basin delivery and attenuation functions to predict the basin-wide effects of any combination of BMPs. Fifteen BMP scenarios were evaluated to aid in prioritizing BMPs for implementation in these basins. Applying the maximum level of BMPs is estimated to cost around $1.2 million (annually), while the four most cost-effective BMPs would cost only one quarter as much, yet are projected to provide approximately 90 percent of the water quality improvement.

(KEY TERMS: water quality; best management practice (BMP); nitrogen; phosphorus; Coastal Plain; Lake Okeechobee.)

INTRODUCTION

The Lower Kissimmee River (LKR) and Taylor Creek-Nubbin Slough (TCNS) basins lie in the "flatwoods" region of Florida, an area characterized by very flat sandy soils and a high water table that fluctuates from the surface to two meters deep. Ranching and dairying are the primary land uses of these basins which lie on the north side of Lake Okeechobee (Figure 1). They contribute about 35 percent of the water flowing into the lake but discharge a disproportionate amount of phosphorus (P) into the lake. The TCNS basin, in particular, accounts for 25 percent of the lake P budget while supplying only 4 percent of the water (Federico, *et al.*, 1981).

Concern over the P load to Lake Okeechobee has focused attention on the Taylor Creek-Nubbin Slough basin. Reduction of nutrient loads is being tackled at the upland source areas through the use of appropriate best management practices (BMPs). Both state and federal funds have been allocated for cost-sharing the implementation of BMPs for nutrient load reduction (Ritter and Allen, 1982). The desire of any such program is to achieve maximum benefit for the dollars spent. To design a program where this will be accomplished, the most appropriate BMPs must be selected, and some idea of their effectiveness is needed. A list of BMPs applicable to Florida conditions has been compiled (Bottcher and Baldwin, 1983), but quantifying the effects of BMPs is a much more difficult task.

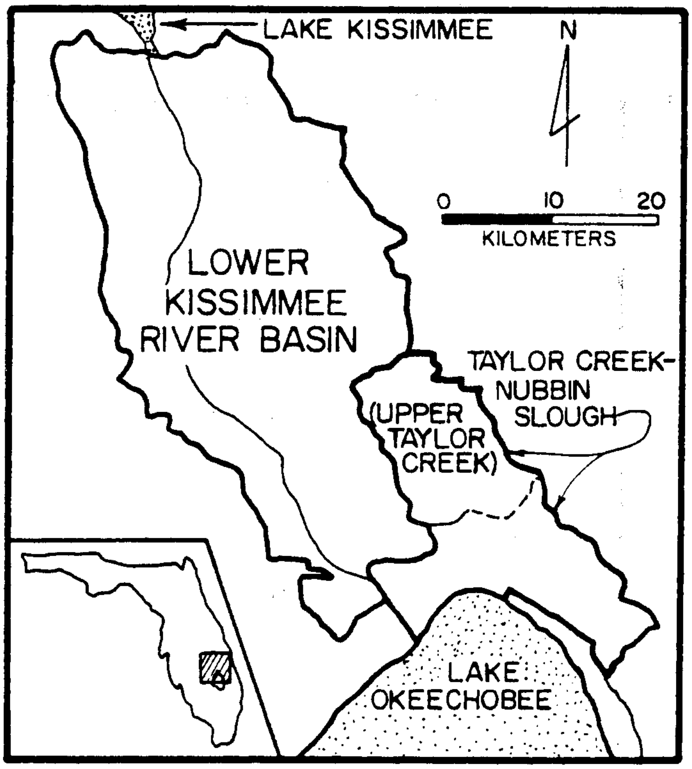

Figure 1. Location of the Lower Kissimmee River and Taylor Creek-Nubbin Slough Basins.

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Detailed hydrologic-water quality models provide the primary means of evaluating BMP effectiveness (Beasley, *et al.*, 1982). In practice, BMPs are applied on a field by field basis; thus, the most accurate assessment of the effectiveness of a BMP can be obtained with field-scale simulation. However, it may also be desirable to evaluate the effects of a BMP implementation program over a basin. Including a cost analysis with the water quality predictions enables comparison of the cost-effectiveness of different BMP implementation programs. This combination of field/basin scale water quality predictions and cost analysis provides information for evaluating broader planning, funding, and water quality objectives. The purpose of this study was to develop a model for estimating the cost-effectiveness of different BMP application scenarios on these two large agricultural basins in Florida.

WATER QUALITY MODEL

The water quality model developed for this cost-effectiveness analysis is a combination of two models. The first is CREAMS-WT, a modified version of the CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) model (Knisel, 1980), which predicts nutrient [nitrogen (N) and P] and water yield for individual field-sized areas. Average annual yields are passed to the second model, BASIN, which integrates the field scale predictions over the entire basin.

The U.S. Army Corps of Engineers has developed an extensive geographic database of the LKR and TCNS basins. Using a 200 by 250 meter grid, 50,165 five-hectare (12.35 acre) cells have been defined in the two basins. Data for each cell include basin and sub-basin codes, hydrologic soil group (A/B/C/D), presence of a stream in the cell, and land use (Table 1). This 'cell' is the basic land unit used by the model for applying BMPs and in water quality modeling. Each cell is considered a homogeneous "field" for the CREAMS-WT simulation. The BASIN model takes the CREAMS-WT nutrient yield predictions for each cell and predicts nutrient delivery to the edge of the nearest stream and at selected sub-watershed outlets in the basins. This modeling approach utilizes all the information available at the cell level and enables prediction for each cell and for the entire basin.

Objectives in the design of CREAMS were that the model should: 1) simulate major physical processes that control water balance, ~~erosion, sediment yield, and movement of plant~~ nutrients and pesticides; 2) use physically based parameters that can reflect changes in management systems; 3) be computationally efficient – operate on a daily time step; and 4) be field scale, since this is the common base for BMP selection (DelVecchio and Knisel, 1982). Because the parameters of the model are physically based, they can be estimated from site visits, maps, county soil survey reports, and the CREAMS manual. An additional advantage of physically based parameters is that the need for calibration is minimized.

TABLE 1. 1980 Land Use in the Lower Kissimmee River (LKR) and Taylor Creek-Nubbin Slough (TCNS) Basins as Coded in the Five-Hectare Cell Database of the Area.

Land Use	LKR		TCNS	
	Cells	Percent	Cells	Percent
Row Crops	5	0.0	161	1.4
Citrus	113	0.3	156	1.4
Dairy (barn and lot)	4	0.0	345	3.0
Dairy Pasture	758	2.0	1963	17.3
Irrigated Pasture	1141	2.9	455	4.0
Improved Pasture	10129	26.1	3670	32.3
Semi-Impr. Pasture	2555	6.6	496	4.4
Range Land	10183	26.3	1072	9.4
Wetlands	9162	23.6	847	7.4
Forest	1389	3.6	788	6.9
Other Agr./Idle	977	2.5	349	3.1
Urban	1697	4.4	1005	8.8
Water	678	1.7	67	0.6
TOTALS	**38791 (1940 sq km)**		**11374 (570 sq km)**	

The CREAMS-WT version of CREAMS was developed for the South Florida flatwoods (Heatwole, *et al.*, 1984). CREAMS-WT has the added capability of following the fluctuating water table which strongly influences the hydrologic processes of this area. This improves the model conceptually, and yields better estimates of annual runoff and evapotranspiration.

To assure that the simulated results represented a long-term average, simulations were run using 20 years of actual rainfall data. The first two years of the simulation were used to assure stable initial conditions, with the final 18 years used to obtain average annual values of runoff, and N and P yield for each cell.

physically ? based ?

The simulation of BMPs with CREAMS-WT involves changing the model parameters (such as curve number and soil properties) to reflect the new practice. One of the most important BMPs in this study, fencing, is not reflected directly in any of the CREAMS-WT parameters. Fencing results in the animal waste, which previously would have been deposited in the stream or wetland, being deposited instead on the pasture. Fencing is modeled by distributing animal waste (which CREAMS-WT considers as a 'fertilizer' application) between the pasture and the wetland or stream which it borders. The fraction of waste distributed to each depends on the percentage of area fenced.

The BASIN model performs the following functions: 1) models the effects of BMPs that cannot be simulated in CREAMS-WT (fencing, detention and retention basins); 2) Provides background loading for forests, native range, and other non-agricultural land use; 3) attenuates the nutrient loads in overland flow to compute edge-of-stream loadings; and 4) computes nutrient loads due to cattle in streams and wetlands, and for wetlands, attenuates those loads in flow through the wetland to a stream. The implementation of these functions along with the calibration and verification of the BASIN model are discussed in detail by Heatwole, *et al.* (1986). The most important parameters for BASIN are the attenuation factors needed for the functions mentioned above. These factors were initially obtained by summarizing the results of nutrient studies in controlled marshes and natural wetlands in South Florida (Bottcher, *et al.*, 1984) but were calibrated further against observed data from the basins.

The primary model output is the predicted edge-of-stream N and P load. This value is compared with that of other simulations to indicate the relative improvement in water quality that may be expected as a result of various changes in the watershed data when simulating different BMPs. Instream attentuation, to predict nutrient loads delivered to the basin outlet, is not considered at the present due to the lack of data on the drainage network. This function may be added in the future, but with the primary focus being on the relative differences between management practices, edge-of-stream predictions are assumed to be adequately representative.

BMP SELECTION AND COSTS

BMPs for the LKR and TCNS basins must be oriented to keeping livestock away from drainageways, dispersing wastes for soil assimilation and plant uptake, proper fertilization and water management, and impounding runoff for nutrient attenuation. Specific BMPs used in this study were fencing of cattle from streams and wetlands that border pasture, runoff detention basins, and runoff impoundment from dairy barn lots for application to pasture and cropland.

A file specifying the BMPs for each cell in the watershed must be created for use by the water quality model. While this file could be created by hand, this would be tedious for all but the smallest watershed, and is certainly not feasible for simulation of the LKR and TCNS basins. A BMP application model has been developed which creates the BMP file based on specified selection criteria (Bottcher, *et al.*, 1984). Some of the relationships used in applying BMPs to particular cells are discussed below.

The model's assignment of BMPs to a particular cell is not to be taken as a field guide for actual implementation of a BMP program. The model only indicates the criteria for BMP application and an estimate of the total amount of BMPs applied in the basin. Nonetheless, this will be a very helpful guide for field personnel who ultimately must determine the proper location of the BMPs.

BMPs were assigned by considering the land use, cattle density (for pasture land), hydrologic soil group, and the distance of the cell from a stream or wetland. Cells neighboring a stream cell would be expected to deliver greater amounts of N and P to streams than those not bordering the stream. Thus BMP application levels were decreased with increasing distance of a cell from a stream or wetland. For fencing of pasture from wetlands, decreasing amounts of fencing were applied as the distance of the adjoining wetland from a stream cell increased.

For cells identified as 'dairy,' a method for estimating cattle density was needed. The number of milking cows at each dairy was known, but additional subdivision of the 'dairy' land into pasture or hayland was not available. Dairy cells were divided into three groups of decreasing cattle density ('cow pasture,' 'dry cow pasture,' and 'hayland'), based on distance from the barn cell. Cattle density was then computed as a function of the assigned dairy land use group and the size of the milking herd.

Costs (1984 base) of installing and maintaining the different BMPs were obtained from contactors and the USDA-SCS. Capital costs were amortized (10 percent annual interest) over the expected life of the BMP to determine the effective annual cost. Adding the estimated annual maintenance cost gives the total annual cost of the BMP. This total annual cost estimate was then used with the predicted average annual rediction in nutrient loading to give the cost-effectiveness in terms of kilograms of N or P reduced per dollar cost.

RESULTS AND DISCUSSION

Fifteen different BMP scenarios were evaluated and are listed in Table 2 along with their relative cost-effectiveness. In addition to the scenarios in Table 2, a 'do nothing' scenario was simulated as the 'base line' for comparative evaluation of the other BMP scenarios. A variety of individual BMPs and combinations of BMPs are included in Table 2 as applied to both the LKR and TCNS basins. Because of the interaction among BMPs, the results from individual scenarios cannot be added to estimate the response of combinations of BMPs. To determine the response of a particular group of BMPs, that combination of BMPs must be evaluated independently.

Several interesting relationships can be observed in Table 2. First, as the level of BMP application increases, the cost-effectiveness decreases (scenarios 1-3 and 13-15). Second, fencing is one of the most cost-effective practices. This is especially significant since fencing also results in the greatest reduction in nutrient load (Heatwole, *et al.*, 1986). Third, cost-effectiveness values for the TCNS basin are generally higher than the LKR basin due to the higher intensity of land use in the TCNS basin. Higher nutrient loads will generally result in a higher percentage reduction, thus higher cost-effectiveness. Note, however, that the residual nutrient load may still be higher than acceptable standards. Cost-effectiveness, of itself, does not imply adequate treatment.

Since streams are the primary pathways of mass transport of nutrients, the proximity of a cell to a stream has a dramatic effect on the actual nutrient delivery to the stream and, therefore, its potential nutrient reduction. Thus, high nutrient producing activities, such as dairy barns, will have much less impact on water quality if located in 'upland' areas away from streams. The apparent reason for the relative ineffectiveness of pasture impoundment (scenarios 4

TABLE 2. BMP Scenarios and Their Cost-Effectiveness for the Taylor Creek-Nubbin Slough (TCNS) and Lower Kissimmee River (LKR) Basins.

Scenario	Description	Cost Effectiveness LKR Nitrogen (kg/$)	Cost Effectiveness LKR Phosphorus (kg/$)	Cost Effectiveness TCNS Nitrogen (kg/$)	Cost Effectiveness TCNS Phosphorus (kg/$)
1	All BMPs Applied – High Rate	0.42	0.11	0.67	0.15
2	All BMPs Applied – Medium Rate	0.54	0.14	0.75	0.17
3	All BMPs Applied – Low Rate	1.10	0.26	1.10	0.25
4	Dairy Pasture* Runoff Impoundment	0.06	0.03	0.04	0.02
5	Dairy Barn Lot Impoundment	2.00	0.47	3.60	0.24
6	Dairy Pasture* Fencing	1.90	0.51	2.60	0.55
7	Beef Pasture Impoundment	0.01	0.02	0.02	0.02
8	All BMPs in Dairy Barn Area (includes fencing of cow pasture)	0.19	0.04	1.40	0.33
9	Fencing of All Pastures (excluding cow pasture around barns)	1.40	0.33	1.70	0.38
	Beef Pasture Fencing:				
10	– Intensively Managed Pasture	6.90	1.70	6.90	1.50
11	– Improved Pasture	1.50	0.36	1.90	0.41
12	– Semi-Improved Pasture	0.43	0.11	1.90	0.40
	Row Crop and Citrus Impoundment:				
13	– High Rate	0.39	0.18	0.08	0.06
14	– Moderate Rate	0.63	0.30	0.13	0.10
15	– Low Rate	1.90	0.86	0.18	0.14

*All pasture in dairy ownership. Includes cow (milking herd) pasture, dry cow pasture, and some calf and beef pasture.

and 7) in comparison with pasture fencing is that impoundment does not treat the nutrient load directly deposited in streams and wetlands. The difference between the basins in row crop and citrus runoff impoundment effectiveness is likely due to the location of those areas relative to streams.

An interesting observation, and one important to an implementation program, is the decrease in cost-effectiveness with increasing levels of application of a particular BMP. Even though a BMP may be the most cost-effective at one level of analysis, it may not be desirable to apply only that BMP in greater and greater amounts to meet some water quality goal. Rather, a point may be reached where a different BMP will become more cost-effective than continued use of the first BMP.

Using the cost-effectiveness data, the individual BMPs can be ranked. Considering both basins together (not a simple average of Table 2 values because of the differing areas involved), the BMPs in order of decreasing effectiveness are:

1. Fence dairy cows from streams and wetlands.
2. Fence intensively managed beef pasture and dry cow pasture from streams and wetlands.
3. Retain runoff from dairy barn holding lots and distribute on low density pasture or crop land.
4. Fence beef cattle on improved unirrigated pasture from streams and wetlands.
5. Impound (detain for nutrient attenuation) runoff from dairy cow pastures.
6. Impound runoff from intensively managed beef pasture and dry cow pasture.
7. Impound runoff from citrus and row crop land.
8. Impound runoff from unirrigated improved beef pasture.

The first four, if fully implemented, could potentially reduce loadings at the edge-of-stream by 60 percent for N and 60 percent for P in TCNS, and 35 percent for N and 40 percent for P in the LKR basin. Note that these reductions cannot be directly projected to the basin outlet. The actual percent reduction downstream would be less because of the natural background nutrient concentrations. Implementing all BMPs (scenario 1) in both basins would have a capital cost of $5.2 million, and an effective total annual cost of $1.2 million. In comparison, the four most cost-effective BMPs provide about 90 percent of the maximum load reductions found in scenario 1, but at a capital cost of only $1.3 million with a total annual cost of $0.3 million. The potential benefit of this type of analysis is apparent.

SUMMARY

A computer model was developed as a tool for evaluating the cost-effectiveness of different BMP programs in the LKR and TCNS basins. For a proposed BMP implementation program, the relative N and P load reductions can be determined, and the cost of installing and maintaining those BMPs estimated. The cost-effectiveness of this particular BMP program can then be compared with other BMP options. However, a final decision on a BMP strategy must depend on more than just cost-effectiveness. A specified level of improvement in water quality may be desired, and also, there will generally be a limit on the available funding. The CREAMS-WT/BASIN model can aid in the selection of a BMP implementation program for these basins, taking into consideration BMP cost-effectiveness, water quality goals and financial constraints.

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