WATER QUALITY VALUES OF WINTER-FLOODED RICE FIELDS: AN EXPERIMENTAL EVALUATION

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INTRODUCTION

Non-point source (NPS) pollution is a leading cause of surface water impairment in the United States (U.S. Environmental Protection Agency [USEPA] 1990; Olson 1993; USEPA 1994a, 1994b). An estimated 46%, 57%, and 44% of inland rivers, lakes, and estuaries, respectively, were designated impaired (i.e., not fully supporting intended uses) during a 1992 water quality inventory (USEPA 1994a, 1994b). NPS pollution derived from agricultural activities is of major concern. Sediments and nutrients derived from agricultural sources affected 72%, 56%, and 43% of U.S. impaired rivers, lakes, and estuaries, respectively. Several studies have identified NPS pollution problems in the Mississippi Delta. Estimates of sediment loss from agricultural lands in the Delta range from 2.23-7.88 tons/acre annually (Dendy 1981; Murphree and Mutchler 1981; Dendy et al. 1984; Murphree and Mutchler 1986). These lands typically have slopes of <2%; yet, frequent cultivation and exposed soils during winter contribute to erosion. Moreover, degradation of lakes and streams by NPS constituents, such as sediments and nutrients, have been reported at several sites within the Mississippi Delta (McHenry et al. 1982; Cooper and McHenry 1989; Cooper 1991). The abilities of our nation's water resources to support aquatic life, municipal and industrial needs, and provide recreational opportunities depend on our ability to reduce NPS pollution in the future. Farmers, the public, and ecosystems all stand to benefit from NPS pollution control.

Effective NPS pollution control techniques have been demonstrated in agricultural regions of the United States. For example, conservation tillage practices, such as reducing depth and frequency of soil disturbance and leaving crop residues to buffer rainfall events, have reduced NPS pollution (Barisas et al. 1978; Beasley et al. 1984; Schwab and Frevert 1985; Carter 1994; Tyler et al. 1994; Unger 1994). Additionally, impoundment of agricultural runoff in small flood-retention reservoirs provides an effective means of NPS pollution reduction (Gill et al. 1976; Rausch and Schrieber 1981; Cooper and McHenry 1989; Cooper and Knight 1990). Impoundment reduces major overland flow factors that affect sediment and nutrient delivery (Novotny et al. 1986; Novotny and Chesters 1989). Surface impoundment reduces rainfall impact, reduces overland flow energies, and allows additional time for sediments and attached nutrients to settle out of suspension (Figure 1).

There is a need to implement current methods and discover new means of reducing NPS pollution with a focus on techniques that maintain sediments and nutrients at their source (USEPA 1990; Baker 1993; USEPA 1994a, 1994b). Federal and State agencies are now taking a partnership approach to meet such needs (e.g., Management Systems Evaluation Areas). There is a growing consensus that NPS pollution control issues can best be solved at the basin or watershed level (USEPA 1994a, 1994b). Integrated approaches with multiple ecological and agricultural benefits would be most effective in solving today's NPS pollution and water quality challenges.

In response to these challenges, we propose to address NPS pollution and water quality problems relative to contemporary agricultural and wildlife conservation practices in the Mississippi Delta. Specifically, we propose to investigate NPS pollution abatement and water quality values of winter-flooded rice fields. Wildlife conservationists promote provision of shallow (<15 cm) wetlands on agricultural areas, particularly those farmed for rice and soybean production, to provide quality foraging and resting habitat for migrating and wintering waterbirds (Reinecke et al. 1989). Flooding harvested rice fields is particularly beneficial because rice seeds resist decomposition (Neely 1956; Shearer et al. 1969) and are nutritionally better for waterfowl than other crop seeds (Joyner et al. 1987; Loesch and Kaminski 1989).

Additionally, rice is grown in an aquatic environment with water-management systems facilitating impoundment.

Opportunities to winter flood croplands in the Mississippi Delta are significant. First, a survey of Mississippi Delta farmers revealed a significant interest in waterfowl management on private lands, and farmers did not perceive a problem with flooding their lands for wintering waterfowl (Zekor and Kaminski 1987). Secondly, rice and soybeans, often grown in single-year rotation, occupied 94% of the grain crop acreage harvested in the Mississippi Delta during fall 1993 (Mississippi Department of Agriculture and Commerce 1994). Lastly, of approximately 1.7 million acres of harvested soybean and rice crops in the Mississippi Delta during fall 1993, <2% (28,681 acres) were flooded for winter waterbird habitat (Uihlein et al. 1994). These statistics emphasize the apparent opportunity to manage additional cropland acreage for waterfowl and other waterbirds.

Besides offering quality habitat for migrating and wintering waterbirds, winter flooding of rice fields is believed to abate NPS pollution and yield other agricultural benefits. These benefits include increased sediment and nutrient retention, increased crop residue decomposition, increased soil moisture and tilth, decreased winter weed coverage, and decreased weed seed densities (Emory 1994; Muzzi 1994; Wesley et al. 1994).

Hypotheses regarding NPS pollution abatement, water quality, and winter flooding of rice fields for waterbirds have not been tested. A consensus exists among agriculturists and wildlife professionals that winter flooding of agricultural fields would be best justified by demonstrating positive effects on NPS pollution control, water quality, soil conservation, agricultural production, and wildlife habitat. Our broad objectives are to quantify ecological and agricultural values of winter-flooded rice fields. A specific objective is to test effects of winter flooding and post-harvest field manipulation on quality of rice-field runoff water. Results will provide an objective evaluation of winter flooding rice fields as an integrated conservation tool with multiple ecological and agricultural benefits. Additionally, results from this study will be useful to natural resource stewards and agriculturalists in other rice-growing regions of the Mississippi Alluvial Valley (MAV), Gulf Coast, and California.

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MATERIALS AND METHODS

Experimental Design

During winters 1995-97, 2 farms in each of 3 major rice growing counties (i.e., Bolivar, Washington, Sunflower) of the Mississippi Delta will serve as 6 replicate study areas. We will conduct our research in harvested rice fields which are routinely planted to soybeans the following spring/summer. Water management practices will include: (1) continuous winter flood (1 October-10 March) and (2) no flood (i.e., control). Inundation will be composed of rainfall and associated runoff. During winters 1993-95, aerial surveys of Mississippi rice fields managed for winter flooding revealed approximately 50% of the rice acreage was left with stubble standing and 36% was disked following harvest (W.B. Uihlein III, unpublished data). Therefore, post-harvest field treatments will include: (1) no treatment (i.e., stubble left standing), and (2) disking. Combinations of flooding regimes (n=2) and post-harvest field manipulations (n=2) will provide 4 experimental categories. One field of each experimental category will be established at each farm. All experimental treatments will be randomly assigned to fields within farms. Landowner interest and willingness to cooperate will be a deciding factor regarding farm selection.

Preliminary Soil Characterization

Prior to flooding, soils will be sampled and characterized for levels of total nitrogen, extractable phosphorus, and total carbon. These data will provide an objective measure of field similarity prior to experimental evaluation. These data can also serve as statistical covariates, allowing adjustment of water quality and NPS pollution data relative to preexisting levels present in the soil. Adjustments may be necessary to assure that quantities of water quality and NPS pollution variables clearly reflect responses to experimental manipulations and not preexisting field conditions.

Field Methods

Surface runoff volume will be measured in each field (n=24; 6 farms x 4 experimental categories) through drainage pipes using bubble gauge level recorders (ISCO Model 2870, Lincoln, Nebraska). Water samples from runoff will be collected using proportional flow composite samplers (ISCO Model 2910). Levels of each water quality variable will be measured from each runoff event between 1 October and 10 March. Water volumes and quantities of NPS pollution variables will be used to calculate exported NPS pollution for each runoff event and the entire winter season.

Laboratory Methods

Water quality variables include total suspended and dissolved solids, ammonium (NH_4^+), nitrate (NO_3^-), organic nitrogen, total phosphorus, and orthophosphates (PO_4^{3-}, HPO_4^{2-}, H_2PO_4). Water quality and soil samples will be processed at MSU School of Forest Resources' Soils and Hydrology Lab. Suspended and dissolved solids will be separated using standard filtration apparatuses and oven dried to obtain mass of sediment exported per volume of runoff. A Technicon II Auto Analyzer will be used for inorganic nitrogen and phosphorus analyses. A Fisons NA1500 CNS Analyzer will be used to measure total nitrogen. Laboratory procedures are currently being evaluated from samples collected during winter 1994-95.

Statistical Analyses

For each rice field (n=24/year), NPS pollution variables will be summed across all runoff events and divided by area (acres) of rice fields (i.e., response variable). All variables will be analyzed using analysis of variance in a randomized complete block design (Table 1). Farms will serve as blocks and experimental categories as fixed effects. Data will be tested for normality and homogeneity of variances; transformations will be applied, if necessary. Due to inherent variability of hydrological characteristics among agricultural fields, possible errors associated with estimations used to calculate water quality variables and costs of replication, all tests will be performed at α=0.10, followed by LSD mean separation procedures.

PILOT PROJECT

Applicability of instrumentation and flow measurement were assessed in a pilot study during winter 1994-95. Primary pilot-year objectives were to: (1) assess flow measurement accuracy using water level measures and the Manning formula (Manning 1891, 1895; Lanfear and Coll 1978; Grant 1992), and (2) develop a mathematical relationship between water level measures in, and flow rate from, drainage pipes to form a predictive equation using linear regression techniques (Grant 1992). Although the Manning formula is a widely accepted method of flow measurement, it is sensitive to numerous variables, such as depth of flow, pipe shape, length, slope, and roughness. In field situations, careful use of the Manning formula yields flow measurements which are accurate to within 10-20%. Using simultaneous measures of water level and flow rate to develop predictive flow rate equations for a particular pipe/flow stream has potential to reduce inaccuracies incurred from use of the Manning formula.

To assess accuracy of applying the Manning formula ($Q = 1.49(A)(R)^{2/3}(S)^{1/2}/N$); where Q=flow rate in cubic feet per second [CFS], A=cross sectional area of flow, R=hydraulic radius, S=slope, and N=roughness coefficient) and to develop the aforementioned mathematical relationship, we simultaneously measured water level in, and flow rate from, a 1.25-foot diameter drainage pipe using an ISCO 2870 bubble gauge recorder and a calibrated 1.00-foot diameter impeller meter. The drainage pipe was on a 2.1% slope, constructed of wrought iron, and affixed with a slotted-board riser. Sufficient water was impounded in the rice field to allow a range of flows which we manipulated using the slotted-board riser. The bubble gauge recorder tube was composed of 1/8 inch inside diameter stainless steel, placed 3.75 feet (3 x pipe diameter) upstream from the drainage pipe terminus, and oriented downstream from drainage pipe flow. The impeller meter was connected downstream, so as not to impede free flow from the drainage pipe.

Nine measurements were made along a flow rate continuum of 0.84-3.46 CFS. Using a slope of 2.1% and a roughness coefficient of 0.015 (i.e., tabular value for wrought iron from Grant 1992), the Manning formula underestimated all impeller flow rate estimates (Table 2). A combination of a nondiscernable roughness coefficient, variation in roughness coefficient over the range of flows, and other factors are likely responsible for significant discrepancies between calculated flow rates and those measured by the impeller meter. Our inability to define a correct roughness coefficient and the apparent variability of the roughness coefficient over our range of flows appear to render the Manning formula inadequate for measure of flow rates in this type of field application and for use in our experimental evaluation of effects of impoundment on surface runoff from rice fields.

An alternative method to measuring flow was tested by using the same data points and developing a predictive equation using regression techniques (Figure 2, [SAS Inc. 1988]). Approximately 98% of the variation in the flow rate measured by the impeller meter was explained by water level measured by the bubble gauge recorder (i.e.,

R^2=0.978). The equation yielded flow measurements which were accurate to within an average of 7% (range 1-17%). These results support the contention that flow rate can be predicted more accurately from regression equations for individual pipes and flow streams in question. These equations can be subsequently used to predict flow rates based on water levels determined by the bubble gauge recorder.

In summary, because pipes are likely to differ in hydrological characteristics, we are prepared to develop equations for each pipe used in our rice field research. We may reduce variation by selecting pipes constructed of the same materials, with identical diameters, and similar slopes. Additionally, we intend to develop equations along the continuum of flow rates indicative of Mississippi rice fields during winter; however, data are insufficient to identify this range presently. Equations should be validated by independent measures of flow rate, not those used to develop equations. Lastly, data from our impeller meter are assumed to be accurate measures of flow rates and we recognize any error introduced by this instrument will affect accuracy of our predictive equations.

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Table 1. Test for treatment effects using a randomized complete block design.

SOURCE		df
Total Corrected	([Treatment•Block]-1)	23
Blocks (Farms)	(Block-1)	5
Treatments	(Treatment-1)	3
Experimental Error	(Treatment-1)(Block-1)	15

Table 2. Data summary from flow measures obtained in winter 1994-95 pilot project.

TRIAL	IMPELLER (CFS)	WATER DEPTH (FEET)	MANNING (CFS)
1	0.84	0.077	0.06
2	1.03	0.123	0.17
3	1.59	0.159	0.29
4	1.65	0.197	0.45
5	2.09	0.223	0.57
6	2.19	0.232	0.64
7	2.48	0.248	0.71
8	2.79	0.300	1.03
9	3.46	0.350	1.39

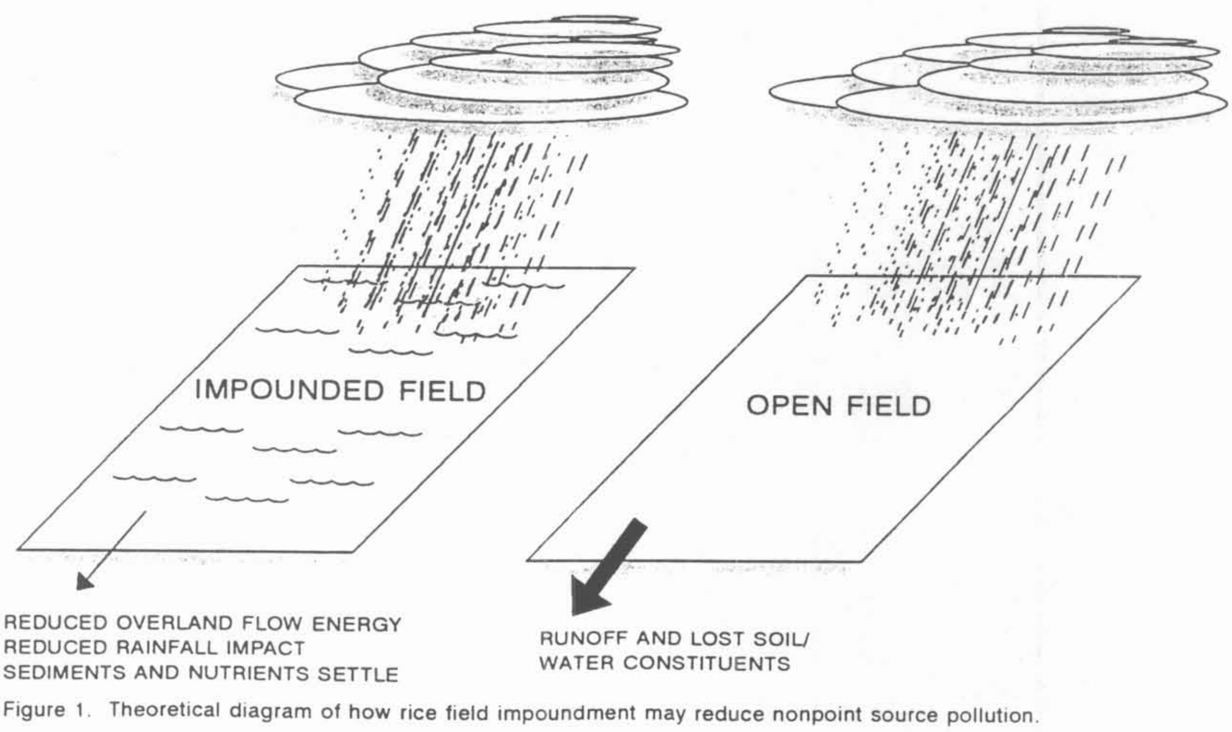

Figure 1. Theoretical diagram of how rice field impoundment may reduce nonpoint source pollution.

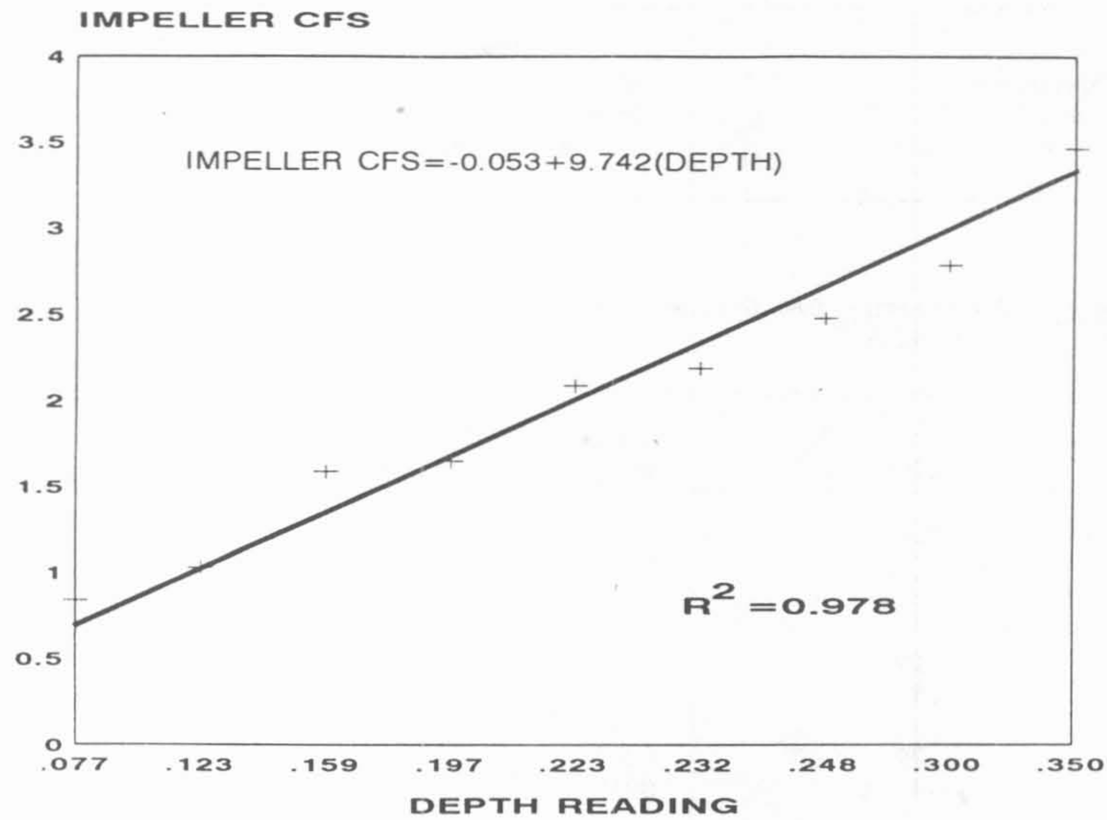

Figure 2. Mathematical relationship between depth measured by bubble gauge level recorder and flow rate measured by impeller meter.