AN EXAMINATION OF NON-REGULATORY METHODS FOR CONTROLLING NONPOINT SOURCE POLLUTION

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CHAPTER I

INTRODUCTION

In recent years the problem of nonpoint source water pollution has become of greater concern for citizens, regulators, and environmentalists. In fact, the United States Environmental Protection Agency has declared that nonpoint source water pollution is the leading cause of impaired water bodies in the country (U.S. EPA 1997). This is also true for the Illinois River Basin, which feeds Lake Tenkiller. The Illinois River and Lake Tenkiller have seen an increase in eutrophication, i.e. algae blooms, in recent years which is believed to be caused by excessive amounts of phosphorus within the water. Popular opinion is that the source of these phosphates is directly related to the large number of animal feed operations, particularly poultry raising operations, within the Illinois River Basin. According to data from the United States Department of Agriculture, there are approximately 262 million chickens raised in the Illinois River Basin every year (U.S.D.A. 1997). It has been estimated that these chicken raising operations produce enough nitrogen and phosphorus waste to be equivalent to the waste generation of an additional 4.9 and 14.7 million people respectively (Meo et. al. 2000). This number is sizeable when one considers that the Illinois River Basin has a current population of approximately 400,000.

This dissertation will examine the problem of poultry waste generation and disposal within the Illinois River Basin and will propose possible solutions in two different essays that can be implemented into a “real world” policy. The essays are interrelated but have been written to be self-contained. The first essay encompasses a model for the entire Illinois River Basin and includes permit transfers between farmers and a point source discharger within the basin. The point source discharger is the wastewater treatment plant at Tahlequah, Oklahoma. There is a second wastewater treatment plant at Watts, Oklahoma, along with numerous poultry processing plants within the region, but due to a lack of reliable data they have been ignored. The growers/farmers with the region are treated as a single individual—as if there was one firm which owned or controlled all of the poultry raising and cropping activities within the entire region. The first essay will guide the model formulation and implementation for the second essay by establishing a starting point for some parameter values.

The second essay expands upon the results of the first and studies permit trading among growers. Because data is available at the county level only, each county included in the study is treated as an individual farm. The effect of permit trading on profits, runoff, and activity levels will be examined. Both of these investigate a region that crosses two political jurisdictions, making implementation of a policy more difficult. One state can institute various environmental policies and the other state can reap the benefits without paying any costs. Before examining the area of study in more detail it is necessary to gain some understanding of the operations of the poultry industry first.

Operational Structure of the Poultry Industry

The poultry industry is highly integrated and essentially consists of three types of economic agents: integrators, growers, and farmers. The integrators (or companies), such as Tyson Foods and ConAgra, contract the raising (called "growing out") of chickens, turkey, and other fowl to local growers. The integrators provide the growers with chicks to grow out to market weight but they retain ownership of the birds. In addition to supplying the growers with chicks, they provide technical support, medication, and feed to the growers. The growers feed and house the birds, remove and dispose of deceased birds in the flock, and apply medication as necessary. The process of growing out a flock varies, but the standard time frame is between 4 to 6 weeks depending upon the specific needs of the integrator.

The grower is responsible for hiring labor and providing a suitable environment for the birds to mature in. This includes heating the chicken houses in the winter and cooling them in the summer so as to attempt to maintain a temperature range between 18^{o} C and 24^{o} C (Rose 1997). The grower is paid a standard price for each pound of chicken he provides for the integrator plus a bonus, or loss, depending upon his performance relative to other growers in the area who have contracted with the same company within the same contract period. Typically, this bonus is a function of the settlement cost per pound of broiler raised where the settlement cost depends upon the conversion of feed into actual broiler weight. Therefore, a lower settlement cost is preferable since it indicates that less feed was used to generate a given weight of broiler (Knoeber and Thurman 1994; Vukina and Foster 1996).

Once the broilers have been marketed, the grower is left to clean out the chicken houses and dispose of the litter, which the grower owns. Broiler litter is a good fertilizer for various types of crops and has been shown to increase crop output (Govindasamy and Cochran 1995a; Xu and Prato 1995). However, recall that the growers and integrators are attempting to increase the weight of broilers by a large amount in a short span of time. In order to accomplish this, the broilers need strong bones to support their weight. Since integrators own the broilers and provide the growers with feed, they often place large amounts of phosphorus into the feed to aid the broilers in calcium retention. Since there is a substantial amount of phosphorus in the broiler diets, there is a substantial amount of phosphorus in broiler waste and hence large amounts of phosphorus available for runoff when litter is used in its present fashion.

Most growers also raise crops of various kinds. Growers clean out the litter from the poultry houses and spread it on local crops. Typically, the litter contains nitrogen and phosphorus in a 1:1 ratio, although it is possible that the litter has a 1:3 or even 1:4 ratio respectively[1]. The types of crops grown in the area require unequal amounts of nitrogen and phosphorus with the nitrogen needs being anywhere from 2.5 to 4 times that of their phosphorus needs. Most growers lay the litter according to the crops' need for nitrogen thereby placing excess phosphorus on the soil. Some phosphorus is taken up and used by the crops, and the remainder is stored in the soil or becomes available for runoff. It has been shown that the amount of phosphorus that becomes available for runoff increases as the amount of phosphorus within the soil increases (Sharpley 1995). Estimates of the amount of phosphorus within the soil needed by crops varies but is between 80-120 pounds of phosphorus per acre. Currently many acres in the Illinois River Basin exceed 300 pounds of soil test phosphorus per acre.

The problem then is to find a method of reducing the amount of phosphorus runoff that is entering the local water body. Past and current literature is replete with

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[1] Data indicates that the nitrogen content of litter can vary depending upon the cleanout frequency of the poultry houses (Xu and Prato 1995).

policies that claim to be able to reduce agricultural runoff of all sorts including nutrients, herbicides, pesticides, and topsoil. Proposed polices include diverse types of taxes placed at various stages on the production process, implementing best management practices by farmers, and transferable discharge permits. Although each of these might be able to reduce nonpoint pollution, it is important to find a policy that can be applied at a low cost and will not strain the resources of regulators or participants. A transferable discharge permit system can meet these requirements. It has the advantage of having relatively low information needs by the regulator and has already been tried in a multitude of circumstances. In fact, as future environmental standards become more stringent and as monitoring technology becomes more consistent and cost effective, the use of permit markets to control pollution is likely to increase (Hahn 1989).

The Relationship Between Litter, Phosphorus, and Pollution

Since broilers are feed a diet high in phosphorus, their litter also contains phosphorus. This phosphorus is in a combination of organic and inorganic form with generally 45 to 70 percent of broiler litter phosphorus being in the inorganic form. Inorganic phosphorus is in the orthophosphate form and is what is available for plant uptake. Most of the organic phosphorus is eventually broken down into the inorganic form in a process known as mineralization. Therefore, litter applications can be seen as both supplying vital phosphorus immediately and acting as a slow-release fertilizer (Zhang, Johnson, Fram 2000; Daniels et. al. 1998).

Agronomists can calculate the amount of phosphorus present in the soil through a analysis called soil test phosphorus (STP) which usually measures elemental phosphorus in the soil. (Animal manure phosphorus analysis is usually reported as phosphate, P_2O_5, since commercial fertilizers contain phosphate.) It takes 2.29 pounds of phosphate to be equivalent to 1 pound of phosphorus. Approximately 14 pounds of phosphate/acre is required to raise STP by 1 unit. Further research has shown that a STP level of 65 will be adequate for most crops. However, due to soil variability and other factors, there may not be enough phosphorus on every part of the field. A field that has a STP of 120 can ensure that 95 percent of the field has at least a STP of 65. Therefore, it should not be necessary to have a field test over 120 STP (Zhang, Johnson, Fram 2000; Daniels et. al. 1998). At the current time, a large percentage of the crop land in the area of study exceeds the 120 STP recommended limit. As an example, Adair County and Delaware County has 50.5 percent and 51.2 percent of crop land with a STP over 120, respectively. Furthermore, the average STP for these counties is 215 and 232 respectively[2]. In comparison the average STP level in Oklahoma is 57 and only 18 percent of fields test at a STP above 120 (Zhang 2000).

The fact that phosphorus can accelerate eutrophication is well known and documented (Pote 1997; Sharpley 1995). During a storm, phosphorus is transported to local surface water bodies in the form of dissolved and particulate phosphorus via the soil erosion that the storm has triggered. The dissolved phosphorus is immediately available for use by algae (Robinson, Sharpley, and Smith 1994), while the particulate phosphorus, phosphorus that is clinging to soil particles, takes longer to become available to algae and can be though of as a long term phosphorus reserve (Yli-Halla et. al. 1995). Therefore erosion control can be effective at reducing total phosphorus loadings into a local water

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[2] This data comes from personal correspondence with Hailin Zhang, Department of Plant and Soil Sciences, Oklahoma State University.

body, but dissolved phosphorus may still enter and cause eutrophication (Pote 1997; Sharpley 1995). Since dissolved phosphorus is harder to control than particulate phosphorus, one has to find a way to reduce all types of phosphorus loadings into the local water bodies. It has been shown that increases in litter applications cause increases in dissolved, particulate, and bioavailable phosphorus (Sharpley 1995). Therefore, it makes sense to instigate a policy that will reduce litter applications and hence phosphorus loadings into the Illinois River. This can best be accomplished via a permit system where the regulator sets the total amount of phosphorus emissions from each source and distributes permits accordingly.

The Area of Study

The area of study for this dissertation is the Illinois River Basin. The Illinois River begins in Washington County, Arkansas and flows in a southwesterly direction through Arkansas and Oklahoma. It enters Oklahoma near Siloam Springs, Arkansas and finally feeds into Lake Tenkiller, which is located in the southeastern portion of Cherokee County, Oklahoma. The Illinois River has two main tributaries which are Flint Creek and Baron Fork Creek. The river flows for 109 miles and drains an area of approximately 1,660 square miles in Northwest Arkansas and Northeast Oklahoma.

The Illinois River Basin includes in whole or in part the counties of Washington and Benton in Arkansas and Adair, Cherokee, Delaware, and Sequoyah in Oklahoma. Lake Tenkiller is located in both Cherokee and Sequoyah County (Oklahoma Water Resources Board 1987; Gade 1998). Only a small portion of the lake actually resides in Sequoyah County. Because of this, Sequoyah County is not included in the analysis.

Lake Tenkiller has a shoreline length of 130 miles and an average depth of 50.7 feet with a maximum depth of 152 feet. Its surface area is 12,900 acres and it has a capacity of 654,100 acre-feet during times of normal pool and a surface area of 20,800 acres with a capacity of 1,230,800 acre-feet during times of flood pool. Construction of the dam by the Army Corps of Engineers began in 1947 and was completed in 1952. Its purpose was to provide flood control and hydroelectric power. There are two 17,000 kilowatt generators located in the power pool (Oklahoma Water Resource Board 1990).

The Illinois River offers recreation and tourism benefits including float trips via canoe, raft, or kayak for an estimated 180,000 persons per year. An additional estimated 350,000 people enjoy swimming, camping, hiking, fishing, and hunting on the river. Lake Tenkiller also offers swimming, boating, skiing, and diving opportunities. In addition to recreation benefits, the Illinois River provides drinking water for the cities of Watts and Tahlequah, Oklahoma, is a habitat for several endangered and threatened species, and is used for irrigation of local farms and nurseries (Meo et. al. 2000).

All data collected and reported is at the county level or higher. The counties included in the study are Adair, Cherokee, and Delaware County in Oklahoma and Benton and Washington County in Arkansas. As stated earlier, a small portion of Sequoyah County lies within the Illinois River Basin, but it was felt that this portion was so small as to not be worthy of inclusion. Table I gives a brief profile of each county.

Table I

County Profile

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
Population	20,544	39,506	34,977	153,406	157,715
County Square ~~Mileage~~ acreage	368,450	480,696	474,080	539,718	608,156
Farms	1,090	1,154	1,303	2,323	2,476
Percent of Land in Agriculture	61.1	49.4	55.8	54.9	55
Average Farm Size In Acres	207	206	203	128	135
Poultry Operators	132	119	180	475	438
Average Poultry Operation Size—number of birds	92,028	28,033	158,299	238,174	233,669

CHAPTER II

POINT SOURCE – NONPOINT SOURCE TRADING TO REDUCE PHOSPHORUS POLLUTION IN A WATERSHED

Introduction

Thanks to the introduction of federal legislation such as the 1972 Clean Water Act and the 1974 Safe Drinking Water Act, the problem of point source water pollution has been greatly reduced. This pollution reduction is due in part to mandated regulations specifying the amount and nature of point source abatement methods and discharge limits. Despite the success that mandates have had at reducing pollution, economic theory predicts that permit trading can allow firms to meet the same environmental goals at a lower cost since pollution abatement is transferred from high to low cost firms. Although permits systems have been used in some areas for water and air pollution, their use has not been widespread for a variety of reasons. It now seems that further cost effective improvements in water quality must come from nonpoint source reductions; however, the problems of limiting and regulating nonpoint source water pollution can be substantial and the issue of how to effectively deal with nonpoint source pollution is a topic of growing concern for regulators (Leston 1992). This is partly due to the fact that nonpoint source pollution is now a growing proportion of total water pollution.[3] In addition, nonpoint source pollution is more difficult to control and monitor than point source pollution.

This chapter undertakes an investigation of a permit market on a regional level. The region under study is the Illinois River Basin, which spans Northeastern Oklahoma and Northwestern Arkansas. This watershed contains two wastewater treatment plants, a large number of poultry processing plants, and poultry farms, which produce significant amounts of phosphorus in plant discharges and runoff events. It is important to note that the Illinois River Basin stretches over two political jurisdictions. This has critical implications for our study. Since Oklahoma's environmental regulations can not be enforced in Arkansas and visa-versa, there is a need for any pollution reduction system, permit or otherwise, to be adopted in both states if it is to be efficacious and equitable.[4]

Each year approximately 262 million broilers are produced in the Illinois River region (U.S.D.A. Census of Agriculture 1997). These broilers are grown out in poultry houses which are lined with litter which consists of wood shavings and poultry feces. This litter is rich in nutrients such as nitrogen and phosphorus and is therefore an excellent fertilizer for the crops grown in the area. The nitrogen/phosphorus rate for litter is approximately 1:1 and typically farmers will apply litter to their crops to meet their nitrogen needs. This places an excess amount of phosphorus onto the cropland since most crops grown in the area need 2 ½ to 4 times more nitrogen than they need

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[3] This fact should not be entirely surprising since it has been previously noted that pollution from point sources has been declining over the past several years. Nevertheless, the fact remains that nonpoint source pollution, whether growing in absolute or relative terms, is still a problem.

[4] This need for cooperation, i.e. for some set of voluntary agreements, will be dealt with in other planned future work.

phosphorus (Daniels et al. 1998; Zhang et al. 2000). This excess phosphorus is available for runoff into local surface waters. The problem of leaching is not significant since the majority of the soil in the region is clay which does not exhibit the sort of leaching problems that a sandy soil would exhibit.

There have been several proposals for dealing with the problem of nonpoint source pollution that do not contain a form of pollution permit trading. Implementing a national or even statewide standard for pollution abatement for nonpoint source pollution control has been rejected by economists and agronomists due to the large variability of soils across the country (or the state). It is more cost effective to implement local solutions based on the soils' leaching and runoff potentials (VanDyke, Bosch, and Pease 1999; Qiu and Prato 1999). The most common solution is a tax to reduce the levels of nonpoint source pollution (Abrams and Barr 1974; Zhang et al. 1998; Shortle and Abler 1994; McSweeny and Shortle 1989). Economic theory demonstrates that if a regulator has full information, he will be able to place a tax on a product or input that is creating a negative externality and move the market towards the Pareto optimal solution. However, there is disagreement as to the size of the transactions costs and the level of ease in introducing a new tax on agriculture.

Some proponents state that taxes are a superior method of pollution control in that they might have the smallest transactions costs of many other pollution reducing programs (McCann and Easter 1999). Even though the tax may not be a first best solution, it is often impossible to achieve a first best solution, and economists should seek second-best solutions that are as close to the first-best solution as possible (Ribuado, Horan, and Smith 1999; McSweeny and Shortle 1989). This view of taxes though is not unanimous. First, taxes may not have the lowest transactions costs of other programs. In fact, their true cost can be substantially higher than other alternative programs (Jacobs and Casler 1979). There are other considerations as well. The most important of these is information. When dealing with nonpoint source pollution the information needed to obtain the correct tax size is often unknown or can only be discerned at considerable cost (Tietenberg 1973, 1974; Zhang et al. 1998). Regulators can respond to the lack of information on the true size of the tax by choosing a tax rate and then incrementally changing it until the optimal size is found. This is not a practical solution. Such a policy would introduce large degrees of uncertainty into the farmer's decision space making efficient input and output choices difficult at best. In addition, the time frame for many nonpoint source pollutants from discharge to an ambient concentration in groundwater or surface water bodies can be several years. The regulator would have to wait a considerable amount of time between incremental tax changes to determine if the current tax rate was optimal. During this time frame there would undoubtedly be many changes in land use, population, firm size, and market conditions, just to name a few, within the watershed making the regulator's previous analysis obsolete.

In economics, it is known that the polar opposite to a tax is a subsidy. Paying farmers to engage in abatement activities, i.e. rewarding them for doing something right and not punishing them for doing something wrong, has been recommended (Stranlund 1995). Since a greater proportion of the benefits of a water pollution reduction program accrue to urban areas while a greater proportion of the costs accrue to rural areas, it is not surprising that farmers are unwilling to engage in high levels of abatement (Park and Shabman 1982). These subsidy payments could be under a form of contract (Bystrom and Bromley 1998; DeVuyst and Ipe C. 1999) or could be a different form of incentive payment (Choe and Fraser 1998; Sharp and Bromley 1979; Wu and Babcock 1995). One of the problems with an incentive payment is moral hazard. It is in the farmer's best interest to receive payments for abatement that has not occurred.

Another solution to the problem of excessive phosphorus runoff from litter applications is to ship the litter to another less impaired region (Govindasamy and Cochran 1995a). The establishment of a litter bank, acting like a central clearinghouse, would greatly increase the efficiency of such a policy by reducing costs (Goodwin et al. 2000). At the present time the shipment of litter to other regions that are not phosphorus saturated is occurring only in very small amounts, if at all. There are two reasons: the price of litter is low and does not accurately reflect its true marginal value product (Govindasamy and Cochran 1995b; Xu and Prato 1995; Rainey et al. 1992), and transportation costs are high enough to make litter shipment unprofitable (Goodwin et al. 2000). This second problem would not exist to the degree that it does if a way to increase the price of litter could be found, i.e., to make its price more accurately reflect its marginal value product. A suitable way to increase the price of litter has not been found as of yet; however, the Oklahoma Legislature passed a law giving poultry producers a five dollar income tax credit for each ton of litter shipped outside of the Illinois River Basin and surrounding river basins which are also threatened due to excessive nutrient loadings.

One way around the high costs of the information needed to develop the aforementioned policies is to establish a pollution permit trading institution. The informational needs to build a successful permit trading program, although large, are not as substantial as other more farm and field specific programs. Since the individual firms and farms know their cost structure more intensively than a regulator would, they are in a better position to make pollution and abatement decisions. A permit program would allow them this freedom.

Woodward (2000) examines the use of such market-based solutions to solve pollution problems. He notes that the use of market based policies for nonpoint source pollution must overcome issues of nonuniformity, unobservability, and property rights. Specifically, the uncertainty surrounding nonpoint source pollution dictates that a trading ratio greater than 1:1 be used for point-nonpoint source trades. Although he concludes that the extensive use of some market based solutions is not likely to become law due to informational and enforcement issues, it does not invalidate the use of market based models to examine pollution reduction problems. The use of such models gives us valuable insights and allows economists to explore alternative market structures that might work better than existing ones.

Literature Review

Extensions in economic theory concerning permit trading among point source (ps) firms has proposed that point source and nonpoint source firms also be allowed to trade permits in an attempt to meet environmental goals at lower cost. The cost reducing theory of pollution permit trading institutions among firms is well known in the literature (Baumol and Oates 1988; Tietenberg 1980; Montgomery 1972; Hanley et al. 1997). Less well known are theories concerning trading between point source and nonpoint source polluters. Despite a lack of literature relative to simple ps-ps permit trading, ps-nps trading has been tried in the Dillion and Cherry Creek reservoirs in Colorado since 1984 and the Tan-Parmlico River Basin in North Carolina with limited success (Hahn, 1989; Leston 1992). A program of ps-nps permit trading seeks to reduce the total loading into a watershed at lowest cost. There are two groups of agents, the point source polluters like a wastewater treatment plant or some other polluting plant, and nonpoint source polluters such as farmers. There have been vast reductions in point source pollutants in the last few decades and very little reduction in nonpoint source pollutants. It is assumed to be more costly for point source polluters to reduce emissions than it is for nonpoint source polluters. Therefore, the theory of ps-nps trading has come about. It consists of letting nonpoint source polluters undertake a larger share of abatement, which they could do at lower cost, and letting point source polluters undertake less abatement. This would achieve a given environmental standard with smaller aggregate costs (Crutchfield et al. 1994; Malik et al. 1993). Nevertheless, the fact that nonpoint source abatement can be undertaken at a lower cost over point source abatement is not enough to guarantee the success of a ps-nps trading scheme. The regulatory agency must ensure that there is enough nonpoint source pollution that when abatement occurs, there can be a change in environmental quality. It must also ensure that the point source firms and the nonpoint source firms are trading in a manner that is efficacious towards the regulatory agency's goal.

Since nonpoint source emissions are assumed to be stochastic, theoretically they are more difficult to measure and hence it is more difficult to monitor enforcement activities. An answer to this problem has been found in the development of a trading ratio between point source and nonpoint source emissions. For example, the point source firm must buy 2 nonpoint source permits for every unit of pollutant it wishes to discharge in a river. This helps to ensure that the environmental standard will not be violated since nonpoint source pollution depends upon such random factors as weather. Finding the correct trading ratio is not merely an academic exercise. It is a serious and difficult issue (Leston et al. 1993). Whether a ps-nps trading scheme is effective, depends upon the trading ratio. It is also important to note that the point source firm and the nonpoint source firm must be discharging the same pollutant. If the trading scheme is based upon different effluents, it is not likely to be very effective (Leston 1992).

The uncertainty behind nonpoint source emissions has led some to propose to increase the trading ratio, however, setting the trading ratio too high to compensate for the lack of certainty most certainly will impede trade and keep the permit market from accomplishing the goal of environmental quality at lower cost. Solutions to the problem of the trading ratio have been to trade point source pollutants for nonpoint source best management activities. In other words, the point source polluter would be allowed to discharge a unit of effluent for every acre of land on which the farmer undertakes an erosion control management practice (Randall and Taylor 2000). This has the added problem of trading discharges for practices, i.e. apples and oranges, but it is a good place to start. Others have suggested giving the participants a trading schedule which is approximately defined by the expected damage constraint rather than having a solitary permit trading ratio (Malik et al. 1993). Shortle (1987) recommends placing an upper bound on the allowed expected flow of nonpoint source pollution to deal with the problem of nonpoint source uncertainty. Therefore the trading ratio between point source and nonpoint source firms will depend upon the proportionality of ps/nps loadings to the ps/nps ratio of expected damages.

Other considerations of a ps-nps trading scheme are similar to those raised in a "standard" permit scheme where point source firms are trading with other point source firms. Most of these include issues in the structure of a permit market and the effect that deviations away from the theoretical market structure will have on the workings of the market itself. One issue is concerned with ensuring that permit markets have enough, but not too many, participants. If there are too few firms, the permit market would be thin and might not work correctly. On the other hand, if there are too many participants, we could see the development of higher transactions costs as firms find it more difficult to locate a potential trading partner (Crutchfield et al. 1994). The issue of too few firms to establish a critical mass of firms for the proper functioning of the permit market is not likely in this study since there are a large number of growers in the Illinois River Basin. Even so, there is always the possibility of environmental groups entering a permit market and purchasing permits to lower pollution levels. This action helps to ensure competitive markets (Shrestha 1998) and this has actually been observed on several occasions in the permit market for sulfur dioxide emissions by electricity generating plants (Joskow et al. 1998). As far as having too many firms who wish to trade and thus driving up transactions costs, the regulator could easily establish a central clearing house where all trading takes place and thus reduce these transactions costs. The establishment of a central clearing house would also aid the regulator in the monitoring and enforcement of nonpoint source emission reductions.

Another important issue is whether growers and or point source polluters will able to pass the costs of abatement onto consumers or will they have to suffer with decreased profits. The issue is somewhat moot if firms are able to pass on these higher costs to consumers. However, if they can not pass on these costs, firms might have an incentive to not comply with the abatement requirements placed upon them through the permit system. Although there might be some ambiguity as to whether grower profits would decrease or stay relatively constant from increased abatement activities, in all likelihood, profits would decrease. Recall that growers are paid a fixed price for each pound of broiler produced and a bonus or loss depending upon settlement costs. Any activity that affects all of the grower's settlement costs in the same way will have no effect on their relative position and therefore the settlement payments will remain unchanged. Since the settlement cost is based on feed conversion ratios and not on abatement activities, it in not very likely that abatement activities will affect every grower the same.[5] Therefore, unless the integrator compensated growers for increased abatement activities in the fixed price or the settlement costs, it is unlikely that grower profits would stay constant.[6] Since growers would have an incentive to be noncompliant, the permit markets efficiency might be compromised (Malik 1990). The obvious solution to noncompliance is monitoring and enforcement by the regulatory agency. How much these additional

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[5] Salop and Scheffman (1983) have proposed that firms, especially when market power in the input, output, or permit market exists, can manipulate permit prices to raise a rival firm's costs. Although this undoubtedly is true, its application to this study is extraneous. Since there are so many growers in the region it is not likely that any one grower could either obtain this market power over permit prices or exercise said market power in a detrimental manner.

[6] The issue of changing the grower contracts to reflect abatement activities undertaken by the grower could be examined in the context of voluntary agreements. The integrator might begin to include these abatement payments to the grower if they believe that it will forestall possible regulation upon themselves.

monitoring and enforcement costs affect permit prices will determine how important the issue of noncompliance is to the functioning of the permit market.

Many of the criticisms of ps-nps permit markets are answered in the literature. Empirical results have shown that although permit markets do not work as well in practice as they do in theory, the participants in a permit market are almost always better off, despite issues of market power, uncertainty, different transfer coefficients, etc., under the permit scheme than any other regulatory structure (Ledyard and Szakaly-Moore 1994; Hahn and Hester 1989; O'Neil et al. 1983). This is not to suggest that the issues raised concerning ps-nps trading are not valid; quite the opposite. From a regulator's point of view, command and control policies might be easier to enforce and monitor; however, the power of permit markets to lower costs can overcome the increased difficulties from establishing and running a permit market. These problems can be overcome and will be easier to overcome in the near future as advances in technology and our understanding of biophysical models increase (Stephenson et al. 1998). In fact, Leston (1992) states, despite all of the difficulty of ps-nps trading, no other current policy exists which could reduce nonpoint source pollution on such a large scale at a reasonable cost.

The Point Source-Nonpoint Source Model

Design Issues

There are several design issues that need to be addressed before discussing the model in detail. One of these is where a pollution control instrument will be applied in the pollution stream. This is defined as the basis of the instrument. Obviously, the closer an instrument is based to actual pollution, the more effective it will be at reducing pollution. Theoretically, the ideal instrument would target the level of environmental damages; however, this is typically not practical in a real world policy due to a lack of viable information on the size and scope of said damages. In response to this, economists have devised other estimates of environmental damages such as the ambient concentration of a pollutant, the amount of pollutant that becomes runoff, and the use of polluting inputs. Each of these bases is respectively farther removed from the level of environmental damages so that an instrument based upon them will be less effective at controlling environmental damages (Ribuado, Horan, and Smith 1999). However, in the case of nonpoint source pollution, it is often necessary to use such measures, even if they are less effective at reducing damages, due to the large degrees of uncertainty that are inherent in a nonpoint source pollution problem.

The ideal goal for a regulator would be to find an instrument that can achieve Pareto optimality or economic efficiency, i.e. where the net social benefits, including environmental damages, are maximized. However, often he must settle for instruments that will obtain a stated environmental goal at least cost, i.e. policies that are cost effective or second-best. The difference between efficiency and cost effectiveness can be easily illustrated. Suppose that policy A reaches a stated environmental goal at a cost of $500 and obtains $1,000 in benefits while policy B achieves total benefits of $1,500 at a cost of $750. The amount of net benefits under policy A is $500 while the net benefits under policy B is $750. Therefore, policy A will be the cost effective policy whilst policy B is the Pareto optimal policy. Even though policy B would be the preferred policy choice, economists must often sacrifice Pareto optimality for second best policies. This necessary choice need not be overly cumbersome if the second best solution is arbitrarily close to the first best solution (Ribuado, Horan, and Smith 1999; Bare and Mendoza 1988; McSweeny and Shortle 1989; Onal, Isik, and Hornbaker 1998; Shortle and Abler 1994; Shortle and Dunn 1986).[7]

That being said, there are some general conclusions that can be drawn from the choice of an instrument base. Essentially instruments can be divided up into two classes—design based, of which market based programs are a subset, and performance based. Performance based approaches to nonpoint source water pollution are based on observable outcomes of a firm's actions whereas design based approaches seek to directly manipulate the behavior of the firm. An example of a performance based instrument would be one that targets ambient water quality or runoff whereas an example of a design based incentive would target inputs or technology choices.

Typically, performance incentives are not practical to implement due to the uncertainties in nonpoint source pollution even though their instrument basis is more aligned to the pollution problem (Ribuado, Horan, and Smith 1999). The reasons for the impractical nature of performance based instruments are many but include issues such as the uncertainty in measuring runoff, the informational requirements of both the regulator and of all of the farmers in the region that is necessary to derive an ambient standard, the additional risk that farmers would face, and monitoring and enforcement of ambient and runoff standards. One way to significantly reduce the administrative costs of a permit system based on ambient concentrations is to identify the location of the most polluted receptor and design the permit system so that trades improve the level of environmental quality at that receptor alone. Atkinson and Tietenberg (1982) refer to this design

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[7] See Mas-Colell, Whinston, and Green (1995) for an excellent but somewhat esoteric discussion of second best solutions.

structure as a Highest Ambient Permit System (HAP) whereby the HAP system is based on a scalar rather than a vector of different environmental receptors (and therefore reduces the number of permit markets to one).

The design based instruments lend themselves to practical policy applications even though they are only a second-best policy (Ribuado, Horan, and Smith 1999). One policy that has been proposed includes taxes on expected runoff. Mathematical models would be used to determine the expected level of runoff based upon the individual farmer's choices of technology, inputs, and other site-specific characteristics. Unfortunately, the informational costs of determining expected runoff given the plethora of different technology and input choices on each specific field would be enormous. However these informational requirements could be reduced by using general and limited site specific characteristics which might actually be more optimal when one weighs the costs of obtaining additional private information versus the incremental costs of making a modeling error. Nevertheless, a policy where farmers would face taxes for runoff that might occur and not for runoff that does occur is unlikely to gain acceptance in a political realm. Furthermore, enacted policies that are not politically acceptable with farmers will have higher transactions costs. If farmers find a pollution reduction policy more agreeable and reasonable, they are less likely to cheat and therefore regulator costs for enforcement and monitoring will be reduced (McCann and Easter 1999). Taxes of all kinds, whether they were based on manure applications, phosphorus content of fertilizers, or pollution leaving the farm, are perceived by farmers to be a very costly format for themselves to be placed under by a regulator and hence the regulator can likely expect have high levels of cheating and misreporting by farmers as to their true actions.

A more realistic approach would be to base the instrument on input use and technology choice (Shortle and Abler 1994). "Input- and technology-based incentives can be designed to achieve an efficient or any type of cost-effective outcome…The reason is that input choices, while not always equivalent to specific policy goals, are the means by which a resource management agency can achieve its goals." (Ribuado, Horan, and Smith 1999 pg. 45.) A permit market based on inputs has the advantage of being relatively easy to monitor and enforce by the regulator. Additionally, it is easier for a farmer to understand the information conveyed to him by the market and make an informed decision concerning input use. Farmers who must use complex mathematical models to determine the levels of runoff from their fields and how that might alter the ambient concentration of pollutants in a surface water body might not be able to fully understand the economic implications of their choices and elect to not participate in the market which would reduce the potential cost savings of the permit market. All the same, when considering instruments based on input and technology choices, one must cautiously design them in such a way as to diminish the impact that input substitution and changes to suboptimal technology choices might have on environmental quality.

Tahlequah Wastewater Treatment Plant

An important component of attaining an environmental goal at least cost in the regional trading model is the role that the Tahlequah wastewater treatment plant could play in the trading of permits. To understand this role in greater detail, it in necessary to delve into some of the characteristics of the plant and its treatment process.

The wastewater treatment plant at Tahlequah currently treats a flow of 2.601 million gallons per day of municipal wastewater of which the average concentration of phosphorus in the effluent discharge can not exceed 1 mg/L. The plant has a design flow of 5.27 mgd maximum. At the maximum flow rate and concentration level, the plant is allowed to discharge 44 lbs. of phosphorus per day.[8] Table II converts these phosphorus concentrations into tons discharged per year. The treatment process used for phosphorus removal is the activated sludge process. In this process the influent levels for a typical wastewater treatment plant for BOD, suspended solids, and phosphorus are 100 mg/L, 65 mg/L, and 11 mg/L respectively (Note et. al. 1975). Table III shows the average influent and effluent concentrations for BOD, phosphorus, suspended solids, and ammonia for the Tahlequah plant. The influent is pumped into an aeration tank which contains a bacterial biomass which consumes organic matter. Diffusers supply oxygen to the activated sludge, i.e. the biomass. The wastewater flows from the aeration tank to a settling tank where the activated sludge sinks to the bottom and a portion of it is recycled into the aeration tank while the remaining sludge is ultimately disposed of. In order for the activated sludge to perform correctly, the water temperature must be between 25-40^0 C. In addition, phosphorus and nitrogen are the primary nutrient requirements of activated sludge (Pavoni and Perrich 1977). At the end of the activated sludge process, the effluent from a typical wastewater treatment plant contains 15 mg/L of BOD, 15 mg/L of suspended solids, and 1.8 mg/L of phosphorus (Note et al. 1975).

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[8] My thanks to Bob Lynch of the University of Oklahoma's Health Services Center for providing this information along with other valuable information on the Tahlequah wastewater treatment plant.

Table II

Total Phosphorus Discharged by the Tahlequah Wastewater Treatment Plant for Various Levels of Treatment at 2.601 and 5.27 MGD, Tons/Year

	2.601 MGD	5.27 MGD
5 mg/L	19.81	40.15
2 mg/L	7.92	16.06
1 mg/L	3.96	8.03
.5 mg/L	1.98	4.02
.1 mg/L	0.4	0.8

Table III

Yearly Average of Influent and Effluent Concentrations for Pollutants at Tahlequah Wastewater Treatment Plant, Mg/L

	Influent	Effluent
BOD	129	2.12
Phosphorus	2.49	0.52
Suspended Solids	107.3	1.87
Ammonia	6.51	0.22

Although equations are available for both capital costs and operations and maintenance costs (O & M) for differing wastewater treatment process[9], these equations are written in terms of various waste flow levels and not in terms of differing concentration levels of influent and effluent (Note et. al. 1975; Pavoni and Perrich 1977).

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[9] My thanks to John Veenstra of the Department of Civil and Environmental Engineering at Oklahoma State University for guidance in finding these data sources.

However, Fraas and Munley (1984) derived a cost equation both in terms of capital costs and O&M costs for BOD removal for a wastewater treatment plant using the activated sludge process.[10] Their model accounted for changes in flow levels, capacity utilization, influent and effluent concentrations and allows one to measure the costs in terms of dollars per pound of BOD removed. Although this model does not directly address the problem of phosphorus removal from an influent stream, the removal of phosphorus is a complementary result of treatment for BOD (Rossi, Young, and Epp 1979). For example, the activated sludge process for the typical wastewater treatment plant reduces BOD from the influent stream to the effluent stream by 85%. The reduction in phosphorus, from 11 mg/L to 1.8 mg/L, represents an 84% decrease from the influent stream to the effluent stream. Given this, and the lack of a phosphorus removal cost equation, the model by Fraas and Munley has been adapted to reflect phosphorus removal costs and is presented in detail in Appendix A.[11]

The Model

Recall that the area under study crosses over two political jurisdictions; therefore, let z, where $z = 1, 2$, denote the separate political jurisdictions with 1 being equal to Oklahoma and 2 being equal to Arkansas. Also, there are i ($i = 1, \ldots, I$) crops that are produced on n ($n = 1, \ldots, N$) farms in k ($k = 1, \ldots, K$) regions. These regions are the five

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[10] My thanks to Vincent G. Munley, Department of Economics at Lehigh University, for providing an in-depth explanation of the Fraas-Munley model.

[11] Although I am somewhat confident that the adaptation of the Fraas-Munley model has yielded reliable estimates of the costs of various levels of phosphorus removal from an influent stream, the reader should be aware that these cost estimates are just that—estimates. Clearly, there is a gap in the literature on the costs of removal for pollutants other than BOD for wastewater treatment plants.

counties that are included in the Illinois River Basin. Finally, farmers and growers are able to produce crops using *t* ($t = 1, \ldots, T$) different types of technology.

There are several point source phosphorus polluters located in the watershed. In the introduction it was noted that there were both poultry processing plants and municipal wastewater treatment plants that discharged phosphorus into the Illinois River. Although inclusion of the poultry processing plants into the model would greatly increase the reliability of the results, there is inadequate information on their operation and discharge levels to do so. Therefore, only the municipal wastewater treatment plants are considered in the model. The two plants in the Illinois River are located at Watts and Tahlequah, Oklahoma. Both plants discharge into the Illinois River but only the plant at Tahlequah engages in phosphorus treatment of its effluent, consequently it is the only point source polluter in the model and is denoted as jth point source where j = 1. The Tahlequah wastewater treatment plant removes phosphorus with an activated sludge-contact stabilization process.

The regulator's problem is to maximize regional profits subject to a series of constraints. This is represented by the model below where equation (1) is the objective function and equations (2) through (8) are the constraints.

$$\begin{aligned}\max \pi = & \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{n=1}^{N} r_{1nk}^{z} V_{nk}^{z} + \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{t=1}^{T} m_{kint}^{z} L_{kint}^{z} \\ & - \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{n=1}^{N} b_{nk}^{z} Y_{nk}^{z} - \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{n=1}^{N} e_{kin}^{z} M_{kin}^{Z} - \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{n=1}^{N} \upsilon_{kin1}^{z} A_{kin1}^{z} \\ & - \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{n=1}^{N} \upsilon_{kin2}^{z} A_{kin2}^{z} - \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{j=1}^{J} C_{kj}^{z}\left(X_{kj}^{z}\right)\end{aligned} \tag{1}$$

subject to:

$$V_{nk}^{z} = f_{1kn}^{z} + f_{2kn}^{z} F_{kn}^{z} + f_{3kn}^{z} F_{kn}^{z2} \tag{2}$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$(n = 1, \ldots, N)$$

$$\eta^{z}_{nk} V^{z}_{nk} - Y^{z}_{nk} - \sum_{i=1}^{I} M^{z}_{kin} = 0 \tag{3}$$

$$(z = 1, 2)$$

$$(n = 1, \ldots, N)$$

$$(k = 1, \ldots, K)$$

$$Y^{z}_{nk} \leq \overline{Y}^{z}_{nk} \tag{4}$$

$$(z = 1, 2)$$

$$(n = 1, \ldots, N)$$

$$(k = 1, \ldots, K)$$

$$\sum_{i=1}^{I} \sum_{t=1}^{T} L^{z}_{kint} \leq \overline{L}^{z}_{kn} \tag{5}$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$(n = 1, \ldots, N)$$

$$\sum_{t=1}^{T} a^{z}_{kint1} L^{z}_{kint} = \alpha^{z}_{kin1} \left(A^{z}_{kin} + \theta^{z}_{kin1} M^{z}_{kin} \right) \tag{6}$$

$$(z = 1, 2)$$

$$(n = 1, \ldots, N)$$

$$(k = 1, \ldots, K)$$

$$(i = 1, \ldots, I)$$

$$\sum_{t=1}^{T} a_{kint2}^{z} L_{kint}^{z} = \alpha_{kin2}^{z}\left(A_{kin2}^{z} + \theta_{kin}^{z} M_{kin}^{z}\right) \qquad (7)$$

$$(z = 1, 2)$$

$$(n = 1, \ldots, N)$$

$$(k = 1, \ldots, K)$$

$$(i = 1, \ldots, I)$$

$$\sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{n=1}^{N} \beta_{kin1}^{z}\left(1 - \alpha_{kin1}^{z}\right)\left(A_{kin1}^{z} + \theta_{kin1}^{z} M_{kin}^{z}\right) + \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{j=1}^{J}\left(1 - X_{kj}^{z}\right) E_{kj}^{z} \le \overline{W} \qquad (8)$$

where the terms have the following meaning.

r_{kn}^{z} = profit margin for a unit of broiler output from a broiler production unit on farm n in region k

V_{kn}^{z} = number of units of broiler output from a broiler production unit on farm n in region k

m_{knti}^{z} = profit margin for crop i produced on farm n in region k using technology t

L_{knti}^{z} = total acres of land for crop i produced by farm n in region k using technology t

b_{kn}^{z} = disposal cost of a unit of poultry litter from a broiler production unit on farm n in region k

Y_{kn}^{z} = amount of poultry litter to be disposed of on farm n in region k

e_{kni}^{z} = cost of spreading a unit of poultry litter on crop i produced on farm n in region k with technology t

M_{kni}^{z} = amount of litter spread on crop i on farm n in region k using technology t

υ_{kni1}^{z} = cost of a unit of commercial phosphorus used on crop i on farm n in region k using technology t

A_{kni1}^{z} = quantity of commercial phosphorus used on crop i on farm n in region k using technology t

υ_{kni2}^{z} = cost of a unit of commercial nitrogen used on crop i on farm n in region k using technology t

A^{z}_{kni2} = quantity of commercial nitrogen used on crop *i* on farm *n* in region *k* using technology *t*

C^{z}_{kj} = Cost of phosphorus abatement by wastewater treatment plant *j* in region *k*

X^{z}_{kj} = Percent of phosphorus waste abated by wastewater treatment plant *j* in region *k*

q^{z}_{kn} = number of broilers in a broiler production unit on farm *n* in region *k*

W^{z}_{kn} = weight of an individual broiler in a production unit on farm *n* in region *k*

F^{z}_{kn} = amount of broiler feed that is feed to chickens on farm *n* in region *k*

η^{z}_{kn} = amount of litter generated per unit of broiler weight on farm *n* in region *k*

$\overline{Y}^{z}_{kn}$ = maximum litter disposal capacity of farm *n* in region *k*

$\overline{L}^{z}_{kn}$ = total available acres for farm *n* in region *k*

a^{z}_{knti1} = amount of phosphorus needed to produce a unit of crop *i* on farm *n* in region *k* using technology *t*

α^{z}_{kni1} = proportion of applied phosphorus from all sources that is available for use by crop *i* on farm *n* in region *k*

θ^{z}_{kni1} = amount of phosphorus in a unit of broiler litter applied to crop *i* on farm *n* in region *k* using technology *t*

a^{z}_{knti2} = amount of nitrogen needed to produce a unit of crop *i* on farm *n* in region *k* using technology *t*

α^{z}_{kni2} = proportion of applied nitrogen from all sources that is available for use by crop *i* on farm *n* in region *k*

θ^{z}_{kni2} = amount of nitrogen in a unit of broiler litter applied to crop *i* on farm *n* in region *k* using technology *t*

β^{z}_{kni} = proportion of phosphorus not used by crop *i* on farm *n* in region *k* that becomes runoff or is available for runoff

E^{z}_{kj} = amount of generated phosphorus waste from source *j* in region *k*

$\overline{W}$ = total amount of phosphorus from all sources that is allowed to enter the Illinois River

The growers receive revenue from selling broilers and crops which is represented by the first two sets of terms in equation (1). The raising of broilers produces litter which is spread on crops. Since litter is an excellent fertilizer providing nitrogen and phosphorus for crops, the raising of broilers and crops is a complementary endeavor. However, the excess phosphorus runs off the farm and become available for use by algae in the Illinois River and thus advances eutrophication. Since the regulator will be placing a limit on the amount of phosphorus that will be allowed to enter the Illinois River, the grower will now, in all likelihood, no longer be allowed to place all of his litter on cropland and will be forced to dispose of some portion of it. This disposal can take the form of storing litter in a storage shed for year round distribution,[12] burning it, or shipping it to other regions. Since a mature market for litter is assumed not to exist, shipping the litter to other regions is a questionable exercise. The most viable option for disposal is storage.

The remaining terms in equation (1) represent the cost of spreading litter and commercial fertilizers. The last term shows the abatement costs that the point source incurs to abate phosphorus waste where X_{kj}^{z} is the percent of phosphorus waste that is abated. Note that abatement costs are increasing at an increasing rate in X_{kj}^{z}. The reader will note that there is no term to capture the buying and selling of permits. The farmer's choice to buy or sell permits can be related to the value of b_{kn}^{z}, m_{knti}^{z}, and V_{kn}^{z}. As the farmer is required to reduce phosphorus runoff to meet an environmental standard, he can reduce this runoff through increased storage thus increasing storage costs, engaging in a more expensive abatement technology which would lower m_{knti}^{z}, or produce fewer

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[12] Goodwin et al. (2000) states that most litter is applied immediately after clean out which usually happens in the Spring and Summer. If litter were to be applied year round, there is some evidence that phosphorus loadings into local surface and groundwater bodies might be reduced (Pote 1997).

broilers, which would lower broiler derived revenue (Mitchell and Willett 2001). In other words, if the farmer were to sell a permit, this would reduce the amount of phosphorus that is allowed to runoff. He must therefore store the litter he would have laid down, reduce the amount of poultry grown, or lay the aforementioned litter and engage in a more costly abatement activity concerning his crops. This could be as simple as establishing a riparian buffer strip, digging drainage ditches, or tilling the litter into the soil.[13] Therefore, selling permits either raises costs or lowers revenue depending upon the farmer's actions.

The components of the constraint set can be divided into three logical components. The set of constraints (2) are concerned with broiler production. The set of constraints (3) – (7) are concerned with cropping activities and the disposition of poultry litter. The last set given by constraint (8) is concerned with tracking phosphorus available for runoff from point and nonpoint sources throughout the watershed.

The production of broilers in this model is based on the notion of a "broiler production unit" defined at the farm level. This definition includes a set number of birds produced in the unit along with a return per unit of weight. The weight gain for broiler production is usually stated in terms of a biological or growth response function. Examples of this include work by Miller, Arreas, and Pesti (1986) and Gonzalez-Alcorta, Dorfman, and Pesti (1994).

The model formulation for broiler production draws from the formulations reported in Gonzales-Alcorta et al. (1994) and is reported in detail in Appendix B. Equation (2) is a biological response function showing weight gain to be a function of

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[13] Zhang et al. (2000) state that litter that is tilled into the soil as opposed to just being laid on the ground will reduce soil test phosphorus and runoff.

feed intake. Feed intake is an implicit function of changes in metabolizable energy levels and protein levels in the broiler diet. Equation (2) is assumed to be characterized by positive but diminishing marginal returns.

The remaining components of the constraint set are concerned with cropping activities, poultry litter disposition, and the existence of phosphorus in runoff. Production regions within each state are based on political jurisdictions or other geographic characteristics. Constraint (6) represents restrictions on land availability. (It is also possible that this set of constraints could include other factors such as participation in the agricultural commodity programs.)

Constraints (6) and (7) are balance equations showing the relationship for phosphorus and nitrogen, respectively. The left-hand side of each equation shows the demand for each nutrient that is necessary to achieve the specified yield (and return) for a particular production technology. (The notion of a production technology is quite general in nature and may include particular management practices.) The right-hand sides of these equations show the sources of the respective nutrients, which include application of commercial fertilizer and poultry litter. These equations, along with other components of the model, play an important role in determining the demand and supply for nutrients, reflecting productivity and profitability considerations.

Constraint (3) is a balance equation reflecting the sources and disposition of poultry litter. The first term on the left-hand side of this constraint denotes the amount of litter generated from broiler production. The second term shows the litter to be disposed of (or put into storage). The third term shows the amount of litter spread on the different crops.

Equations (6) – (8) show a set of relationships that pertain to the supply and demand of the nutrients phosphorus and nitrogen applied to crops in the model as well as the amount of phosphorus lost to runoff. The nutrient formulations assume that a portion of the nutrient applied is used by the crops as uptake while the remaining portion is assumed to be carryover and lost to runoff.[14] The amount of the nutrient that is carryover is assumed to be proportional to the total amount of nutrient applied. This formulation is discussed in Kennedy (1981, 1986). Constraint (8) is concerned with tracking phosphorus from cropping activities as well as that which comes from the municipal treatment plants.

The features of equations (6) - (8) are as follows. First, equations (6) and (7) show the equality of the supply of phosphorus and nitrogen, respectively, and the corresponding demand for each farm in each region of the model. Essentially, these equations can be interpreted as "market clearing" or "market equilibrium" conditions for phosphorus and nitrogen on each farm in each production region. These equations show that the sources of the nutrients are derived from poultry litter and commercial fertilizer. The first set of terms shows that the amount of each nutrient available for each crop in the form of uptake is proportional to the amount of nutrient made available for the crop. The equations impose a limit on the amount of phosphorus that can be forthcoming from both nonpoint and fixed point sources.

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[14] Approximately 100 percent of the nutrients in a commercial fertilizer are immediately available for crop uptake.

Solution Characterization and Implications

The permit price for the discharge permits to be traded is derived on the basis of the optimization model outlined in the previous section. First, it is necessary to derive a set of optimality conditions and a corresponding set of marginal decision rules for poultry litter applications and also phosphorus applications. These are deduced from the Kuhn-Tucker conditions, which are derived from the appropriately defined Lagrangean function. The decision variables in the model are V^z_{nk}, L^z_{kint}, A^z_{kin1}, A^z_{kin2}, Y^z_{nk}, M^z_{kin}, X^z_{kj}, and F^z_{kn}. The Kuhn-Tucker conditions are shown in Appendix C.

The marginal decision rules for broiler production and the use of feedstuff for raising the broilers are derived first. These are as follows for feedstuff and broiler production, respectively.

$$\phi^z_{nk}\left[-f^Z_{2kn}-2f^z_{3kn}F^z_{kn}\right]=0 \qquad (9)$$

$$(z=1,2)$$

$$(n=1,\ldots,N)$$

$$(k=1,\ldots,K)$$

$$\Psi^z_{nk}r^z_{1nk}=\Gamma^z_{nk} \qquad (10)$$

where $\Psi^z_{nk}=\dfrac{1}{\eta^z_{nk}}$.

$$(z=1,2)$$

$$(n=1,\ldots,N)$$

$$(k=1,\ldots,K)$$

Consider equation (9), which represents the value marginal production of feedstuff used in producing broilers. In the model specifications, the amount of feedstuff is provided directly to the individual growers by integrators at no cost. It can then be concluded that feedstuff is used at a level where the value marginal product is zero. This implies that $\phi_{nk}^{z} = 0$.[15]

Now consider equation (10). The variable Γ_{nk}^{z} is the Lagrangean multiplier used for the poultry litter balance equation (3) in the constraint set of the optimization model. As shown in equation (10), this Lagrangean multiplier or shadow price is equal to the marginal return on broiler production adjusted for litter production by an individual broiler.

The primary concern and interest in this analysis is the use and disposition of poultry litter generated in production of broilers. There are two alternatives for disposing of poultry litter in this model: storage and application to crops as fertilizer. The optimal level of litter put in storage is based on the following marginal decision rule.

$$\Psi_{nk}^{z} r_{nk}^{z} = b_{nk}^{z} + \varepsilon_{nk}^{z}. \tag{11}$$

$$(z = 1, 2)$$

$$(n = 1, \ldots, N)$$

$$(k = 1, \ldots, K)$$

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[15] The reader should note that broiler contracts are not being modeled in this analysis. Total revenue from broiler production has both a fixed price and a bonus or loss payment which is based upon the grower's relative performance to other growers in feed management. If contracts were being examined, feed would not be used until its marginal value product was zero. My thanks to Ron Moomaw, Department of Economics, Oklahoma State University, for pointing this out.

The left-hand side of equation (11) is the marginal return for broiler production while the right-hand side is the marginal opportunity cost of storing litter. The first term on the right-hand side of this equation is the marginal cost of storing litter while the second term is the opportunity cost of a binding storage constraint. Note that if $Y_{nk}^{z} < \overline{Y}_{nk}^{z}$, then $\varepsilon_{nk}^{z} = 0$.

The nutrients used in the cropping activities can be derived from the application of commercial fertilizers or from poultry litter applications. Consider first the application of commercial fertilizers for phosphorus and nitrogen. The marginal decision rules for applications of commercial fertilizers for phosphorus and nitrogen are, respectively, as follows.

$$\Delta_{kin1}^{z} = \frac{\upsilon_{kin1}^{z}}{\alpha_{kin1}^{z}} + \frac{\beta_{kin1}^{z}\left(1-\alpha_{kin1}^{z}\right)\lambda}{\alpha_{kin1}^{z}} \tag{12}$$

$(z = 1, 2)$

$(i = 1, \ldots, I)$

$(n = 1, \ldots, N)$

$(k = 1, \ldots, K)$

$$\gamma_{kin}^{z} = \frac{\upsilon_{kin2}^{z}}{\alpha_{kin2}^{z}} \tag{13}$$

$(z = 1, 2)$

$(i = 1, \ldots, I)$

$(n = 1, \ldots, N)$

$(k = 1, \ldots, K)$

Consider first equation (12). The left-hand side is the marginal value of nutrient in production while the right-hand side shows the marginal opportunity cost of phosphorus from commercial fertilizer. The first term on the right-hand side shows the marginal cost of spreading commercial fertilizer with phosphorus while the second term shows the marginal opportunity cost of the phosphorus in runoff. The left-hand side of equation (13) shows the marginal value of nitrogen in production while the right-hand side shows the marginal value of spreading nitrogen.

As noted previously, poultry litter is also a source of nutrients for cropping activities. An important aspect of using poultry litter is that it embodies a joint production relationship that is clearly reflected in the marginal decision rule for applying poultry litter. This marginal decision rule is written as

$$\Psi^z_{nk} r^z_{nk} + \Delta^z_{kin} \alpha^z_{kin1} \theta^z_{kin1} + \gamma^z_{kin} \alpha^z_{kin2} \theta^z_{kin2} = e^z_{kin} + \lambda \beta^z_{kin1} \left(1 - \alpha^z_{kin1}\right) \theta^z_{kin1}. \tag{14}$$

$$(z = 1, 2)$$

$$(i = 1, \ldots, I)$$

$$(n = 1, \ldots, N)$$

$$(k = 1, \ldots, K)$$

The expression on the left-hand side of equation (14) shows the marginal return for poultry litter applications and reflects the existence of a joint production relationship. The first term on the left-hand side shows the marginal return from broiler production, the second term shows the marginal value of the phosphorus nutrient in the litter in production, and the third term shows the marginal value of the nitrogen nutrient in the litter in production. The marginal costs on the right-hand side include the marginal cost of spreading litter as well as the marginal opportunity cost of the litter in runoff.

The last decision is concerned with the optimal level of treatment in the fixed source treatment plants. The marginal decision rule is:

$$\frac{\partial C_{kj}^{z}}{\partial X_{kj}^{z}} = \lambda E_{kj}^{z} \qquad (15)$$

$$(z = 1, 2)$$

$$(j = 1, \ldots, J)$$

$$(k = 1, \ldots, K)$$

The left-hand side shows the marginal cost of treatment while the right-hand side shows the opportunity cost of untreated phosphorus.

The final task is to examine the nature of the cost-effective emission reduction credit design for phosphorus. The permit used in this analysis is an emission permit that is defined in terms of an allowable emissions rate of one ton of phosphorus per year. The emission permit system is initiated by defining the amount of emissions that will be allowed. It is assumed that allowable emissions are equal to $\overline{W}$, which is given in equation (8). The level of allowed permits will most likely cause the environmental constraint, equation (8), to be met as a strict equality.

If the environmental constraint holds as a strict equality and permits are issued, they will command a positive price as long as some sort of response is needed to meet the environmental target. Each decision-making unit will buy and sell permits as the markets allow the economic decision makers to move toward an equilibrium state.

Suppose that each source in the phosphorus permit market is issued an initial endowment of permits. Across all sources the initial endowment must be equal to the number of allowable permits in order to ensure compliance with $\overline{W}$. Thus the following condition must hold true.

$$\sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{n=1}^{N}\overline{G}^{z}_{nk} + \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{n=1}^{N}\overline{G}^{z}_{jk} = \overline{W} \tag{16}$$

where $\overline{G}^{z}_{nk} \equiv$ initial endowment of permits for farm *n* in production region *k* in political district *z*;

$\overline{G}^{z}_{jk} \equiv$ initial endowment of permits for wastewater treatment plant *j* in region *k*.

The decision-making problem for an individual farm in the presence of a phosphorus permit trading market is characterized as the following.

$$\begin{aligned} \max\ & r^{z}_{1nk}V^{z}_{nk} + \sum_{i=1}^{I}\sum_{t=1}^{T} m^{z}_{kint}L^{z}_{kint} - b^{z}_{nk}Y^{z}_{nk} - \sum_{i=1}^{I} e^{z}_{kin}M^{z}_{kin} \\ & - \sum_{i=1}^{I} v^{z}_{kin1}A^{z}_{kin1} - \sum_{i=1}^{I} v^{z}_{kin2}A^{z}_{kin2} + P^{-}S^{z}_{nk} - P^{+}D^{z}_{nk} \end{aligned} \tag{17}$$

subject to:

$$V^{z}_{nk} = f^{z}_{1kn} + f^{z}_{2kn}F^{z}_{kn} + f^{z}_{3kn}F^{z^{2}}_{kn}(D) \tag{18}$$

$$\eta^{z}_{nk}V^{z}_{nk} - Y^{z}_{nk}\sum_{i=1}^{I} M^{z}_{kin} = 0\ (\phi) \tag{19}$$

$$Y^{z}_{nk} \le \overline{Y}^{z}_{nk}\ (\varepsilon) \tag{20}$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} L^{z}_{kint} \le \overline{L}^{z}_{kn} \tag{21}$$

$$\sum_{t=1}^{T} a^{z}_{kint1}L^{z}_{kint} = \alpha^{z}_{kin}\left(A^{z}_{kin} + \theta^{z}_{kin1}M^{z}_{kin}\right)\quad (\Delta_{i}) \tag{22}$$

$$(i = 1, \ldots, I)$$

$$\sum_{t=1}^{T} a^{z}_{kint2}L^{z}_{kint} = \alpha^{z}_{kin2}\left(A^{z}_{kin2} + \theta^{z}_{kin}M^{z}_{kin}\right)\quad (\gamma_{i}) \tag{23}$$

$$(i = 1, \ldots, I)$$

$$\sum_{i=1}^{I} \beta_{kin1}^{z} \left(1 - \alpha_{kin1}^{z}\right)\left(A_{kin1}^{z} + \theta_{kin1}^{z} M_{kin}^{z}\right) \leq \overline{G}_{nk}^{z} + D_{nk}^{z} - S_{nk}^{z} \quad (\pi) \qquad (24)$$

The notation defined previously is used in the model formulation. Additional variables are defined as follows;

S_{nk}^{z} ≡ amount of permits sold by the farm,

D_{nk}^{z} ≡ amount of permits purchased by the farm,

P^{-} ≡ price received for selling a phosphorus permit, and

P^{+} ≡ price paid for purchasing a phosphorus permit.

The variables in parentheses to the right of each constraint are Lagrangean multipliers.

The structure of the optimization model as given by equations (17) – (24) is much the same as the model presented for the entire study region. Thus the following discussion will focus on the key differences in the model for the farm.

The key change in the model specifications at the farm level is the incorporation of activities that represent buying and selling activities in the regional market for phosphorus permits. The participation in the permit market is represented by modifications in the objective function and the environmental constraint equation (24). If the farmer finds it necessary to purchase additional phosphorus permits, then $D_{nk}^{z} > 0$ in equation (24) and the total cost to the farmer of the permits is represented by the expression $P^{+} D_{nk}^{2}$ in the objective function equation (17). If the farm has more permits than needed, the number of permits sold is given by S_{nk}^{z} and the farm receives a payment equal to $P^{-} S_{nk}^{-z}$, as shown in equation (17).

An important consideration in the development of a permit trading market for phosphorus is to account for transaction costs. If the market price for a permit is P, the actual price paid by the buyer of the permit, including the transaction cost, is P^+. If the farm sells permits, the existence of transaction costs reduces the actual amount received by the seller to P^-.

The objective for the phosphorus permit market is to bring about a cost minimizing solution that is similar to one implied in the regional model. A key concern in this exercise is to identify the permit price.

The decision variables in this model are the V^z_{nk}, F^z_{nk}, Y^z_{nk}, L^z_{kint}, M^z_{kin}, and A^z_{kin1}. The focus of the current analysis is confined to decisions related to applications of litter and commercial fertilizer for fertilizer and the related decisions to purchase or sell phosphorus permits. The marginal decision rule for applying litter on the *i*th crop is as follows:

$$\psi r^z_{1nk} + \Delta_i \alpha^z_{kin1} \theta^z_{kin} + \gamma_i \alpha^z_{kin2} \theta^z_{kin} = e^z_{kin} + \pi \beta^z_{kin1} \left(1 - \alpha^z_{kin1}\right) \theta^z_{kin1}. \qquad (25)$$

The managerial decision rule for applying phosphorus from commercial fertilizer is as follows:

$$\Delta_i = \frac{v^z_{kin1}}{\alpha^z_{kin1}} + \beta^z_{kin1} \frac{\left(1 - \alpha^z_{kin1}\right)}{\alpha^z_{kin1}} \pi. \qquad (26)$$

The variables γ_i, Δ_i, and π are Lagrangean multipliers associated with the various constraints as noted previously.

The optimal use of litter on crop *i* and the optimal application of phosphorus from commercial fertilizer is based on comparing equation (24) with equation (14) and equation (26) with equation (12). The applications of litter and commercial fertilizer with phosphorus will occur if

$$\lambda = \pi. \tag{27}$$

The institutional mechanism to bring this about is a phosphorus permit market. It has been shown by Montgomery (1972) and Tietenberg (1985) that this outcome will occur if:

$$\pi = P. \tag{28}$$

Now consider the possibility of permit trading activities. The relevant first-order conditions are as follows:

$$P^{-} - \pi \leq 0 \tag{29a}$$

$$\left[P^{-} - \pi\right] S_{nk}^{z} = 0 \tag{29b}$$

$$-P^{+} + \pi \leq 0 \tag{30a}$$

$$\left[-P^{+} + \pi\right] D_{nk}^{z} = 0. \tag{30b}$$

Now suppose that the farm finds that it needs additional phosphorus permits. It follows from equations (30) that $D_{nk}^{z} > 0$ and

$$P^{+} = \lambda. \tag{31}$$

The farm will then purchase the necessary number of permits to ensure compliance with the allowed level of phosphorus releases. Moreover, the farm's decisions will be consistent with the cost minimization decision throughout the watershed.

Next suppose that the farm has excess permits to sell. It follows from equations (29) that $S_{nk}^{z} > 0$ and

$$P^{-} = \lambda. \tag{32}$$

A similar set of discussions follows the reasoning presented above.

The final set of discussions are concerned with the municipal treatment plants and permit trades.

Results

Changes in Profits from a Tightened Environmental Constraint Without Trading

The results are found using the Generalized Algebraic Modeling System (GAMS). Since the level of data disaggregation is on the county level and data on individual farm structure is not available, each county is treated as a "farm" for the purposes of model implementation. Although a variety of crops are raised in each county included in the area of study, only the principal crops were chosen for inclusion. These crops are Bermuda grass, wheat for grain, native grass, soybeans, Alfalfa hay, and fescue pasture. Output per acre for each of these crops and their phosphorus and nitrogen demands are included in Table IV.

For purposes of analysis, it was necessary to establish a base case scenario. Growers earn income from both the raising of broilers and crops. Typically they will lay broiler litter on their crops both for its agronomic value and for disposal purposes. In the model, growers were allowed to lay excess litter on their crops to capture both of these effects. They were also allowed the option of purchasing and placing commercial fertilizers on crops. Determining the amount of runoff from excess phosphorus applications was important and a runoff coefficient of 8% was chosen, i.e. it is assumed that 8% of every ton of phosphorus that is not taken up by crops will actually become runoff.[16] Choosing

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[16] This estimate is based upon discussions with Phillip Moore, Department of Agronomy, University of Arkansas.

Table IV

Characteristics of Principal Crops

	Phosphorus (tons)	Nitrogen (tons)	Output per Acre	Net Return per Acre
Bermuda Grass	0.02	0.1375	2.5 tons	156.76
Wheat	0	0.028	29 bu	36.23
Native Grass*	0	0	1.38	6.29
Soybeans	0.015	0	29 bu	77.33
Alfalfa Hay	0	0	3.25 tons	128.5
Fescue Pasture*	0.02	0.09	0.7	39.95

Where ‘ * ‘ indicates only animal units are raised

a runoff coefficient eliminates the need to determine a trading ratio since the amount of phosphorus from agricultural activities is now known with certainty. This runoff coefficient is identical for both commercial and litter derived phosphorus. Knowing the runoff coefficient means that the permit system can be based on actual runoff and not predicted runoff. Therefore, each permit allows the holder to emit one ton of phosphorus runoff and these are distributed equally. In the regional model formulation, it is assumed that there is one firm which owns or controls all broiler raising and cropping activities.

If growers were to lay litter on crops that did not need any phosphorus, so that 8% of all litter derived phosphorus became runoff, and not engage in any storage, the Illinois River would receive approximately 709 tons of phosphorus per year. Adding the discharge from the Tahlequah wastewater treatment plant brings the total figure to approximately 711 tons per year. Since this represents a worst case scenario, a starting figure of 700 tons of phosphorus runoff per year was chosen. After this, reductions in allowed phosphorus runoff and discharges of 20, 50, 80, 90, and 95 percent were analyzed by GAMS for two different scenarios. The first of these assumes that the wastewater plant continues to treat 100% of its influent. The second assumes that the plant can vary its discharge by purchasing permits from growers.

Profits by county and total regional profits were derived for each of the phosphorus reduction levels. These profits are shown in Table V. Initial profits for the region are $95.459 million and steadily decrease to a level of $86.59 million for a 35 ton per year limit on phosphorus runoff. This translates into an opportunity cost of $8.869 million to reduce phosphorus runoff by 95%, or a reduction in profits of 9.29%. Previous work has estimated that an 80% reduction in current phosphorus runoff levels is necessary to return the Illinois River to its former condition (Meo et. al. 2000). This level of phosphorus runoff reduction represents an opportunity cost of approximately $7.058 million or a reduction in profits of 7.39%.

The reader will note that the level of profits for the 700 ton and the 560 ton runoff standards are identical. Growers were assumed to be able to store approximately 10% of their litter at a cost of $2.619 per ton in storage sheds. Since the cost of spreading litter on crops is $8.066 per ton, it is economically feasible for growers to store as much litter as they can. This storage reduced the initial amount of litter spread on crops and hence the level of phosphorus runoff. The initial level of phosphorus runoff from cropping activity is 547 tons per year. Adding the discharge from the treatment plant brings the total to 549 tons. Therefore, the environmental standard is not binding at either the 700 or 560 ton standard and therefore there is no incentive for growers to alter their behavior. Once the standard becomes binding, growers are forced to alter their behavior to meet the standard. Since they are prevented from building additional storage sheds in this analysis, they must alter the amount of litter that is laid on crops as the environmental standard is tightened. The only way to accomplish this is to reduce the amount of broilers raised to reduce litter production. These changes in behavior for each county are shown in Tables VI through X for the different environmental standards. Growers did not purchase commercial fertilizers in any of the model simulations. Nor did they produce any crops other than Bermuda grass and Alfalfa hay. Since these two crops have the highest net return, this behavior is not surprising. To aid the reader in understanding how growers alter their behavior, only the activities that growers initially engaged in and

Table V

Regional and County Profits for Various Levels of Allowed Discharge Standards

P Limit	Adair	Cherokee	Delaware	Benton	Washington	Region
700*	13,382,125	11,837,473	17,957,000	26,822,686	26,990,815	95,863,599
700	13,382,125	11,837,473	17,957,313	26,822,686	26,990,815	95,459,813
560*	13,382,125	11,837,473	17,957,000	26,822,686	26,990,815	95,863,599
560	13,382,125	11,837,473	17,957,313	26,822,686	26,990,815	95,459,813
350*	13,215,605	11,792,415	17,565,785	25,265,035	25,581,255	92,293,595
350	13,221,879	11,794,113	17,579,608	25,323,614	25,634,045	92,022,659
140*	13,046,695	11,746,711	17,168,316	23,684,766	24,152,270	88,672,257
140	13,052,969	11,748,409	17,182,139	23,743,457	24,205,058	88,401,432
70*	12,990,392	11,731,476	17,035,398	23,158,474	23,675,066	87,464,306
70	12,996,665	11,733,174	17,050,506	23,219,343	23,727,855	87,196,944
35*	12,962,240	11,723,859	16,969,582	22,894,685	23,437,107	86,860,973
35	12,968,514	11,725,556	16,983,405	22,953,377	23,489,896	86,590,148

Where ' * ' indicates that the Tahlequah Wastewater Treatment Plant can vary its treatment level changed as a result of strengthening the environmental standard have been included in the Tables.

The data in Tables VI through X assume that the Tahlequah wastewater treatment plant maintains a 100% treatment level for its influent. The scenario of allowing the plant to alter its treatment will be undertaken in a later section. As can be seen from Table XI, Benton and Washington county in Arkansas face the largest decrease in profits from a strengthening of the environmental standard. This should not be surprising since these two counties have the largest amounts of runoff for all of the phosphorus standards. For instance, when the standard is 560, Benton and Washington County have a combined phosphorus runoff of almost 455 tons. This represents 83% of all runoff from cropping activities and as the phosphorus standard is tightened, their proportional share of runoff from cropping activities does not change. Since the majority of runoff is coming from these two counties, the growers in these counties will have to undertake the largest change in their activity levels to reach any new environmental standard. The treatment plant's and each county's proportional share of runoff is shown in Table XII. With the Tahlequah plant's level of treatment fixed at 100%, there is not a large change in each county's relative contribution to runoff.

Table VI

Profits and Cropping Activity for Phosphorus Maximum of 560

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	27,598.40	7,467.69	64,936.40	258,180.00	233,570.00
ACRES					
Bermuda grass	974.19	263.85	2,292.10	9,120.71	8,251.19
Alfalfa Hay	99,025.81	90,736.16	127,710.00	160,880.00	166,750.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	126,680.00	114,600.00
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.00	238.77	216.00
GRAND TOTAL					547.176
Tahlequah Discharge					2.059
Total P from all sources					549.235
PROFITS	13,382,125	11,837,473	17,957,313	26,822,686	26,990,815
REGIONAL PROFITS					95,459,813

Table VII

Profits and Cropping Activity for Phosphorus Maximum of 350

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	19,148.06	5,181.16	45,053.56	179,130.00	162,050.00
ACRES					
Bermuda grass	619.25	167.80	1,456.95	5,800.21	5,247.26
Alfalfa Hay	99,380.75	90,832.20	128,540.00	164,200.00	169,750.00
LITTER					
Bermuda grass	8,600.64	2,330.60	20,235.46	80,558.43	72,878.54
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	16.21	4.39	38.14	151.84	137.36
GRAND TOTAL					347.941
Tahlequah Discharge					2.059
Total P from all sources					350.00
Profits	13,221,879	11,794,113	17,579,608	25,323,614	25,634,045
REGIONAL PROFITS					92,022,659

Table VIII

Profits and Cropping Activity for Phosphorus Maximum of 140

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	10,240.82	2,771.00	24,095.68	95,802.93	86,669.33
ACRES					
Bermuda grass	245.11	66.57	576.65	2,300.17	2,080.90
Alfalfa Hay	99,754.89	90,933.43	129,420.00	167,700.00	172,920.00
LITTER					
Bermuda grass	3,404.32	924.55	8,009.00	31,946.77	28,901.38
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	6.42	1.74	15.10	60.21	54.47
GRAND TOTAL					137.94
Tahlequah Discharge					2.06
Total P from all sources					140.00
Profits	13,052,969	11,748,409	17,182,139	23,743,457	24,205,058
REGIONAL PROFITS					88,401,432

Table IX

Profits and Cropping Activity for Phosphorus Maximum of 70

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	7,271.74	1,967.62	17,109.72	68,027.19	61,541.65
ACRES					
Bermuda grass	120.40	32.82	283.21	1,133.49	1,025.45
Alfalfa Hay	99,879.60	90,967.18	129,720.00	168,870.00	173,970.00
LITTER					
Bermuda grass	1,672.21	455.87	3,933.51	15,472.88	14,242.33
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	3.15	0.86	7.41	29.13	26.84
GRAND TOTAL					67.401
Tahlequah Discharge					2.059
Total P from all sources					69.460
Profits	12,996,665	11,733,174	17,050,506	23,219,343	23,727,855
REGIONAL PROFITS					87,196,944

Table X

Profits and Cropping Activity for Phosphorus Maximum of 35

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	5787.20	1565.93	13616.74	54139.31	48977.81
ACRES					
Bermuda grass	58.04	15.95	136.50	550.15	497.72
Alfalfa Hay	99941.96	90984.05	129860.00	169450.00	174500.00
LITTER					
Bermuda grass	806.15	221.53	1895.77	7640.93	6912.80
STORAGE	2570.00	692.00	6048.00	23943.00	21660.00
RUNOFF					
Bermuda grass	1.52	0.42	3.57	14.40	13.03
GRAND TOTAL					32.941
Tahlequah Discharge					2.059
Total P from all sources					35.000
Profits	12,968,514	11,725,556	16,983,405	22,953,377	23,489,896
REGIONAL PROFITS					86,590,148

Table XI

Percentage Decrease in Profits from the Base Case for Different Phosphorus Limits

P Limit	Adair	Cherokee	Delaware	Benton	Washington	Region
350	1.2	0.36	2.1	5.58	5.03	3.6
140	2.45	0.75	4.32	11.48	10.32	7.39
70	2.88	0.88	5.05	13.43	12.09	8.65
35	3.09	0.95	5.42	14.43	12.97	9.29

Table XII

Percentage Contribution to Total Phosphorus Runoff

P Limit	Adair	Cherokee	Delaware	Benton	Washington	Tahlequah
560	4.643	1.258	10.925	43.473	39.327	0.375
350	4.632	1.255	10.897	43.382	39.246	0.588
140	4.583	1.245	10.782	43.009	38.910	1.471
70	4.503	1.227	10.591	41.617	38.348	2.941
35	4.341	1.193	10.209	41.148	37.226	5.883

How is this change in behavior to reduce phosphorus runoff implemented? Table XIII shows the proportion of profits from both broiler and cropping activities for each of the phosphorus standards. As mentioned earlier, when the environmental standard is tightened and additional litter storage is not an option, growers must decrease the amount of broilers raised, and hence decrease the amount of potentially pollution generating litter in order to meet the new standard. A one ton reduction in broiler raising activity levels decreases profits by $22.4818; however, the reduction in broiler activity also decreases litter generation by .58 tons which translates into a cost savings of $4.70 since there is no need to incur the cost of spreading. Therefore, the overall reduction in profits from a one ton decrease in broiler production is only about $17.78. Nevertheless, since less litter is being produced for use on phosphorus demanding crops, substitution of Alfalfa hay for Bermuda grass must also take place. The net return for Alfalfa hay is less than the return for Bermuda grass so that crop substitution can also be expected to decrease profits. As the environmental standard is strengthened, the reduction in broiler raising activity and crop substitution become more acute. For instance, with a nonbinding environmental standard of 560 tons of runoff, Benton and Washington county derive 20% of their profits from broiler raising activity. As the standard is tightened, and these two counties are forced to undertake a more broad alteration of their profit generating activities than are the counties in Oklahoma. By the time the phosphorus standard has fallen to 35 tons,

Table XIII

Percent Contribution of Broiler Raising and Cropping Activity to Total Revenue for Different Phosphorus Standards

	Adair	Cherokee	Delaware	Benton	Washington
P = 560					
Broilers	4.636	1.418	8.130	21.640	19.455
Cropping	95.364	98.582	91.870	78.360	80.545
P = 350					
Broilers	3.256	0.988	5.762	15.903	14.212
Cropping	96.744	99.012	94.238	84.097	85.788
P = 140					
Broilers	1.764	0.530	3.153	9.071	8.050
Cropping	98.236	99.470	96.847	90.929	91.950
P = 70					
Broilers	1.258	0.377	2.256	6.587	5.831
Cropping	98.742	99.623	97.744	93.413	94.169
P = 35					
Broilers	1.003	0.300	1.803	5.303	4.688
Cropping	98.997	99.700	98.197	94.697	95.312

their proportion of profits from broilers falls to only 5%. This large degree of substitution is why the level of profits decrease much more dramatically for Benton and Washington county than they do for either Adair, Cherokee, or Delaware counties.

Changes in Profits from a Tightened Environmental Constraint With Trading

In this model, the transferable discharge permit is traded upon the basis of phosphorus runoff. Although, studies show that a model based upon actual damages is the most accurate, economists must often use other measures that try to approximate damages. In the terms of this model, that approximation can take the form of permits based on runoff or based on the polluting inputs. Since the model assumes that the runoff coefficients are known, phosphorus runoff was chosen for the permit base.

The permit is based upon one ton of phosphorus runoff that enters the Illinois River and it was assumed that trading could occur between growers and the Tahlequah wastewater treatment plant. The treatment plant is given an initial allocation of permits based upon its current discharge level of 2.059 tons of phosphorus with the remaining number of permits being distributed to the growers. (Recall, that in this model, it is assumed that there is just one grower who owns or controls all of the agricultural activities within the area, i.e. it is just as if there is one firm with five different production centers. Consequently, it does not matter to the grower where production is decreased or increased to meet an environmental standard since the effect on his profits is the same. This is done to understand in simplistic terms how the treatment plant will interact with the growers in the permit market. (In the next essay, this assumption is dropped.) The cost differential of treating 100% versus treating zero percent of the influent for the treatment plant is $404,032. Reducing treatment from 100% to zero percent resulted in 7.8 additional tons of phosphorus entering the Illinois River. The profit differential to growers of an additional 7.8 tons of phosphorus is approximately $134,550. Therefore, when the treatment plant was allowed to vary its discharge, results always indicated zero treatment with a total regional costs savings of $269,482. These increases in regional profits are shown in Table V.

Tightening of the environmental constraint always indicated a permit price of $17,250. This was true until the constraint was tightened to a level below 10 tons per year. At this level, the permit price increased to $20,780 and increased to a maximum of $2,099,000 when the constraint was set to 2.059 tons of phosphorus per year. This is the current level of discharge at the Tahlequah plant and was the assumed technological minimum phosphorus discharge limit. This increase in the permit price reflects the increasing cost of treatment at the wastewater treatment plant and of course the subsequent cost savings that can be achieved by relaxing the environmental constraint.

The consistency of the permit price is not surprising upon reflection. Since the treatment plant always treats zero percent of its influent when its treatment levels are allowed to vary, any reductions in phosphorus runoff must come from the growers. A one ton reduction in broiler raising always lowers profits by $22.48, regardless of the activity level of broiler production. The same is not true for the treatment plant. Economic theory predicts that if abatement costs are increasing at an increasing rate, as they are with the wastewater treatment plant, than tightening an environmental constraint will result in increasing permit prices (Mitchell and Willett 2001). Corollary to this is the case where abatement costs are constant and therefore permit prices are constant as an environmental constraint is tightened.

Examination of the data allows the reader to perceive why the permit price is immutable for the range of environmental standards. Assume initially that the environmental standard is 350 tons of runoff per year and that the treatment plant is allowed to vary its discharge so that it is treating zero percent of its influent, i.e. it is emitting 9.859 tons of phosphorus. Now increase the environmental standard to 349 tons per year. The one ton reduction in phosphorus runoff can come from two sources. Either the treatment plant can increase treatment by 12.8205% and reduce its discharge by one ton, or growers can alter their broiler raising, cropping, and litter application levels. When the treatment plant increases its treatment to reduce discharge by 1 ton, its costs increase by approximately $60,350. If the growers were to alter their behavior, their profits would decrease by approximately $17,250. Therefore, the treatment plant would be willing to pay growers up to $60,350 dollars to alter their behavior so that they could continue to operate at their present level of treatment. Similarly, growers would need to be compensated for the loss in profits from altering their behavior to meet the constraint and would need at least $17,250 in compensation payments. If an assumption of perfect competition among growers in the permit market is introduced into the analysis, the permit price will always be $17,250.[17] However, if we assume the existence of one grower who owns all of the broiler activity, than it is possible to have negotiations between the grower and the treatment plant and have the permit price vary depending

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[17] If the permit price were higher, the buyer would be better off altering his activities and reducing runoff by 1 ton. If the permit price were lower, the seller would not receive adequate compensation for the change in his profits that he would experience by having to alter his activity levels.

upon the relative strength of each agent in permit price negotiations. In this instance, the lower and upper bounds are $17,250 and $60,350.

Another example will show the upper and lower bounds of the permit price depend upon the initial level of treatment at the wastewater plant. Assume as before that the current standard is 350 tons per year and that the treatment plant is treating 100% of its influent so that it emits 2.059 tons of phosphorus per year. If the allowed standard is weakened to 351 tons per year, than either the growers can increase their activity levels and the treatment plant can continue its treatment level, or the treatment plant can reduce its treatment levels and the growers can continue their current levels of activity. When the treatment plant is treating 100% of its influent, it has a total cost of $1.531 million. By reducing its treatment 12.8205% to 87.1795%, it can lower its total costs to $1.345 million—a cost savings of $184,627.[18] Therefore, the plant would be willing to pay $184,627 to be allowed to increase its discharge by one ton. Since growers could have seen their profits increase by $17,250 if they had been allowed to emit another ton of phosphorus runoff, they would need to be compensated by at least that amount to keep their current activity levels. In this instance, if the permit market was not competitive, the permit price would vary between $17,250 and $184,627 depending upon the relative strength of each parties negotiation ability. It should be obvious by now that the permit price range will depend upon the initial starting treatment value for the treatment plant

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[18] These total costs and cost reduction figures were obtained by using the values obtained from the Fraas-Munley model. The cost estimates in the equation that was used in the GAMS model and in Appendix B, was not a perfect fit to the actual data. At levels above 50% treatment, variance between the actual costs and the predicted costs begin to appear. As treatment levels approached the 100% level, this variance became more acute, but not so much that I felt it necessary to throw out the estimated cost equation—of course, this was a judgement call and everyone may not agree with this approach. However, since the result was to underestimate the expected cost savings from a point source-nonpoint source trading model, I believe that the approach is valid. The actual level of cost savings is probably closer to $485,432. Table XIV uses the actual cost figures and not the cost figures derived from the cost equation.

and the degree of competitiveness within the permit market. Table XIV shows the cost savings for different increases in allowed discharges from the plant. These cost savings also represent the upper bounds for the permit price when that level of discharge is the starting point and the permit market does not exhibit perfect competition.

What is the effect on profits and runoff from the introduction of trading with the Tahlequah wastewater treatment plant? Tables XV through XIX show the effects on each county from a strengthening of the environmental standard. The results are similar to those undertaken in the previous section. Growers respond to the increased standard by decreasing broiler raising activity and by substituting Alfalfa hay for Bermuda grass in their cropping activities. However, as the environmental standard is tightened, growers must now engage in a larger amount of abatement activities than they did previously since the treatment plant is emitting 7.8 more tons of phosphorus than it was under the

Table XIV

Cost Savings for the Tahlequah Wastewater Treatment Plant for Different Allowed Phosphorus Discharge Levels

Discharge Allowed	Treatment Level	Cost Savings
3.059	87.18	485,432
4.059	74.34	116,792
5.059	61.51	65,361
6.059	48.68	45,263
7.059	35.85	33,909
8.059	23.02	27,105
9.059	10.19	22,483
9.859	0	15,486

Table XV

Profits and Cropping Activity for Phosphorus Maximum of 560 with Varying Plant Discharge

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	27,598.40	7,467.69	64,936.41	258,180.00	233,570.00
ACRES					
Bermuda grass	974.19	263.85	2,290.10	9,120.71	8,251.19
Alfalfa Hay	99,025.81	90,736.16	127,710.00	160,880.00	166,750.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	126,680.00	114,600.00
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.01	238.77	216.00
GRAND TOTAL					547.179
Tahlequah Discharge					9.859
Total P from all sources					557.038
Profits	13,382,125	11,837,473	17,957,000	26,822,686	26,990,815
REGIONAL PROFITS					95,863,599

Table XVI

Profits and Cropping Activity for Phosphorus Maximum of 350 with Varying Plant Discharge

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	18817.22	5091.64	44275.12	176040.00	159250.00
ACRES					
Bermuda grass	605.35	164.04	1424.26	5670.21	5129.65
Alfalfa Hay	99394.65	90835.96	128580.00	164330.00	169870.00
LITTER					
Bermuda grass	8407.64	2278.37	19781.34	78752.86	71245.10
STORAGE	2570.00	692.00	6048.00	23943.00	21660.00
RUNOFF					
Bermuda grass	15.85	4.29	37.28	148.43	134.28
GRAND TOTAL					340.141
Tahlequah Discharge					9.859
Total P from all sources					350.000
Profits	13,215,605	11,792,415	17,565,785	25,265,035	25,581,255
REGIONAL PROFITS					92,293,595

Table XVII

Profits and Cropping Activity for Phosphorus Maximum of 140 with Varying Plant Discharge

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	9909.98	2681.48	23317.24	92707.92	83869.39
ACRES					
Bermuda grass	231.21	62.81	543.95	2170.17	1963.29
Alfalfa Hay	99768.79	90937.19	129460.00	167830.00	173040.00
LITTER					
Bermuda grass	3211.31	872.33	7554.872	30141.189	27267.943
STORAGE	2570	692	6048	23943	21660
RUNOFF					
Bermuda grass	6.05	1.64	14.24	56.81	51.39
GRAND TOTAL					130.141
Tahlequah Discharge					9.859
Total P from all sources					140.000
Profits	13,046,695	11,746,711	17,168,316	23,684,766	24,152,270
REGIONAL PROFITS					88,672,257

Table XVIII

Profits and Cropping Activity for Phosphorus Maximum of 70 with Varying Plant Discharge

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	6,940.90	1,878.10	16,331.28	64,932.17	58,741.71
ACRES					
Bermuda grass	106.50	29.06	250.52	1,003.49	907.84
Alfalfa Hay	99,893.50	90,970.94	129,750.00	169,000.00	174,090.00
LITTER					
Bermuda grass	1,479.20	403.65	3,479.39	13,937.30	12,608.89
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	2.79	0.76	6.56	26.27	23.77
GRAND TOTAL					60.141
Tahlequah Discharge					9.859
Total P from all sources					70.000
Profits	12,990,392	11,731,476	17,035,398	23,158,474	23,675,066
REGIONAL PROFITS					87,464,306

Table XIX

Profits and Cropping Activity for Phosphorus Maximum of 35 with Varying Plant Discharge

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	5,456.36	1,476.41	12,838.30	51,044.30	46,177.87
ACRES					
Bermuda grass	44.15	12.19	103.80	420.15	380.11
Alfalfa Hay	99,955.85	90,987.81	129,900.00	169,580.00	174,620.00
LITTER					
Bermuda grass	613.15	169.31	1,441.64	5,835.36	5,279.36
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	1.16	0.32	2.72	11.00	9.95
GRAND TOTAL					25.141
Tahlequah Discharge					9.859
Total P from all sources					35
Profits	12,962,240	11,723,859	16,969,582	22,894,685	23,437,107
REGIONAL PROFITS					86,860,973

Table XX

Percentage Contribution to Total Phosphorus Runoff with Varying Wastewater Treatment Discharge

P Limit	Adair	Cherokee	Delaware	Benton	Washington	Tahlequah
560	4.578	1.240	10.772	42.864	38.776	1.770
350	4.528	1.227	10.653	42.410	38.367	2.817
140	4.323	1.174	10.171	40.579	36.710	7.042
70	3.983	1.087	9.368	37.527	33.950	14.084
35	3.302	0.912	7.763	31.424	28.430	28.169

Table XXI

Percentage Decrease in Profits from the Base Case for Different Phosphorus Limits with Permit Trading

P Limit	Adair	Cherokee	Delaware	Benton	Washington	Region
350	1.24	.38	2.18	5.80	5.22	3.31
140	2.50	.76	4.39	11.69	10.51	7.11
70	2.92	.89	5.13	13.66	12.28	8.37
35	3.13	.95	5.50	14.64	13.16	9.00

Table XXII

Percent Contribution of Broiler Raising and Cropping Activity to Total Revenue for Different Phosphorus Standards with Point Source Trading

	Adair	Cherokee	Delaware	Benton	Washington
P = 560					
Broilers	4.597	1.415	8.008	20.799	18.773
Cropping	95.403	98.585	91.992	79.201	81.227
P = 350					
Broilers	3.183	0.969	5.611	15.244	13.658
Cropping	96.817	99.031	94.389	84.756	86.342
P = 140					
Broilers	1.703	0.513	3.040	8.688	7.718
Cropping	98.297	99.487	96.960	91.312	92.282
P = 70					
Broilers	1.200	0.360	2.150	6.256	5.541
Cropping	98.800	99.640	97.850	93.744	94.459
P = 35					
Broilers	0.946	0.283	1.698	4.988	4.411
Cropping	99.054	99.717	98.302	95.012	95.589

fixed treatment scheme. This is evident by examining Table XX which shows the relative amount of total runoff decreases for the growers in each county as the environmental standard is tightened. This can only occur if the growers reduce their broiler activity levels and increase their crop substitution levels by an amount larger than is seen under the nontrading scheme. Although the size of these changes in minor when compared to the nontrading scheme, it does result in a slightly larger increase in the percentage of profits for the growers that are lost as a result of tightening the phosphorus runoff standard. Table XXI shows these profits in terms of the percentage of decline from the base case of 700 tons of phosphorus with allowed point source nonpoint source permit trading.

The reader will observe that under this scheme, the decline in profits for the growers is slightly larger than it was when trading was not allowed. This result warrants some explanation. The model was not configured to measure the revenue growers receive from selling their pollution permits to the treatment plant. As before, when the grower wants to decrease runoff by one ton, he must alter his behavior. This alteration results in a decrease in profits of $17,250. Since the growers must now reduce pollution by an additional 7.8 tons to offset the treatment plant's increased phosphorus discharge, his profits will subsequently fall by $134,550. However, under a workable policy, the grower would receive compensation for the selling of his permits to the treatment plant and would therefore see profits equivalent to the amount in the nontrading scheme for any particular environmental standard.

Of particular interest though is the slightly smaller decrease in regional profits under the trading scheme when the environmental standard is tightened. This is a result of the lower costs that the treatment plant incurs for not treating its waste. Since it is cheaper for the growers, rather than the treatment plant, to abate 7.8 tons, regional profits at all environmental standards are higher than under the nontrading scheme.

Permit Prices. The size of the permit price is somewhat larger than was initially expected. However, it must be remembered that the permits are for one ton of runoff and not for a ton of litter application itself. When the runoff coefficient is 8%, it requires an application of 500 excess tons of litter to produce a ton of phosphorus runoff. If the permit price were based on litter applications rather than phosphorus runoff, the permit price would be $34.50 per ton. In addition to this, a comparison of the permit price to the amount of runoff from the counties on a per farm basis is actually quite small. For instance, Cherokee County emits 6.91 tons of phosphorus runoff when the environmental constraint is nonbinding. Assuming that each of the 1,154 farms in Cherokee County is roughly identical in size and chosen farming activities means that each farm will emit about .00598 tons of phosphorus. For Cherokee county to reduce its phosphorus runoff by one ton means that the county as a whole would sell one permit to the treatment plant and receive $17,250. Each farm would have to reduce its own runoff by .00086 tons which would require altering its pollution production activities so that its own profits decrease by $14.94. Of course, each farm would receive $14.94 from the sale of the permit so that its profits would not decrease but its levels of runoff would.

Despite the small effect a trading scheme would have on the profits of an individual farm, GAMS was run again for several different values of the runoff coefficients to see how the permit price would change. Table XXIII shows the permit price for various sizes for the runoff coefficient of excess litter applications. The results at first may seem counterintuitive, but upon rumination the answer is somewhat clearer. When the runoff coefficient is 8%, it takes excess litter applications in the amount of 500 tons to produce one ton of runoff. In order for growers to reduce the amount of litter generation by 500 tons requires a large decrease in broiler production, approximately 857 fewer tons of broilers. If the runoff coefficient is 100%, growers must decrease litter production by 40 tons, i.e. decrease broiler production by 68 tons, which of course would have a smaller effect on profits than an 857 ton decrease in broiler production. It is interesting to note that if the permit price was based on a ton of litter application, that the price remains the same regardless of the value of the runoff coefficient. This tends to indicate that if a policy maker did not have adequate knowledge of the actual size of the runoff coefficient, and wanted to base a permit trading scheme on litter applications, a price of $34.50 would be the equilibrium price of the permit regardless of how much excess phosphorus actually becomes runoff.

Table XXIII

Permit Price for One Ton of Phosphorus Runoff for Different Sizes of the Runoff Coefficient

Runoff Coefficient	Permit Price	Litter Tons for One Ton of P Runoff
4%	$34,490	1,000
8%	$17,250	500
16%	$8,623	250
32%	$4,311	125
100%	$1,379	40

CHAPTER III

A FARM LEVEL ANALYSIS OF A TRANSFERABLE DISCHARGE PERMIT SYSTEM FOR PHOSPHORUS RUNOFF

Introduction

In recent years, the problem of water pollution has gained more prominence in the public's conscience. In fact, the EPA stated in a recent report that nontraditional sources of pollution such as urban and agricultural runoff, commonly called nonpoint source pollution, is the leading cause of impaired surface water bodies in the country (U.S. EPA 1997). This is especially true for the Illinois River which flows through Northwest Arkansas and Northeast Oklahoma and feeds into Lake Tenkiller. Recent data by the EPA suggests that the exceedence criteria for phosphorus, .1 mg/L, is violated more than 50% of the time in the Illinois River. Since there is such a large poultry industry in Oklahoma and Arkansas, the question of whether local poultry feed operations is a leading culprit in the degradation of the Illinois River Basin's water quality has been raised. Within the Illinois river Basin alone, approximately 262 million broiler are raised each year and the numbers for Oklahoma and Arkansas are much larger, 216 million and 1.02 billion broilers raised per year respectively (Willett et. al. 2000; Govindasamy et. al. 1994; U.S.D.A. Census of Agriculture 1997). It is believed that the impairment of local surface water bodies results more from the use and disposal methods of broiler waste than in the actual presence of feed operations in the river basin.

This chapter will address the set up and implementation of a trading scheme, based at the farm level, for poultry litter in an effort to reduce nonpoint source loadings into the Illinois River Basin. Since data is only available at the county level, each county will be treated as a single farm. It is assumed that the grower in each county is a profit maximizer who faces several constraints. One of these constraints will be on the amount of phosphorus in runoff that is assumed to derive from excess litter applications on crop land. This excess litter can be applied to one's own crops if the grower possess a permit to do so. Any excess permits can be sold to other growers in the region via the trading scheme. The use of runoff coefficients for nutrients resulting from fertilizer applications will be estimated and used as a rough guide to determine the amount of litter that can be spread.

Broiler litter often contains phosphorus and nitrogen in an approximate 1:1 ratio[19] (Daniels et. al. 1998; Zhang et. al. 2000). Nutrient analysis of litter produced within the Illinois River Basin indicates that phosphorus-nitrogen ratio is 1:1.2. Nevertheless, depending upon the particular crop, the needs for nitrogen are between 2 ½ to 4 times that of phosphorus (Daniels et. al. 1998). Therefore, when it is applied to land as a fertilizer, farmers lay it according to the nitrogen needs of the crops resulting in an excess of phosphorus being laid on the crops. Table XXIV shows the pounds of nutrients removed, nitrogen, phosphate, and phosphorus respectively, from the soil per ton of forage production for several typical crops within the area of study.

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[19] This figure is not universal in that some litter may contain as much as 3 or 4 parts of phosphorus to every part of nitrogen. Data indicates that the nitrogen content of litter can vary depending upon the cleanout frequency of the poultry houses (Xu and Prato 1995). Since the usual practice is to place litter on fields to meet the crop's demand for nitrogen, such a high ratio of phosphorus to nitrogen would greatly exacerbate the problem of phosphorus runoff.

Table XXIV

Pounds of Nutrients Removed Per Ton of Forage Dry Matter

	N	P_2O_5	P	N / P_2O_5
Alfalfa hay	58	14	6	4.14
Bermuda Grass	40	12	5	3.33
Fescue	36	14	6	2.57
Legume/grass	39	12	5	3.25
Wheat	36	13	6	2.77

This excess phosphorus can enter the groundwater and surface water system through runoff and leaching. Due to the soil type in Northeast Oklahoma and Northwest Arkansas, which is mostly clay loam, leaching of phosphorus into the groundwater is not a serious issue; however, runoff into surrounding surface waters is a serious issue. The presence of these phosphates leads to advanced eutrophication of the surface waters (Robinson, et. al. 1994) leading to a foul smell for drinking water, reduced oxygen levels leading to a greater probability of fish kills, losses of water recreation tourism dollars, and the like. It has been suggested that nitrogen and phosphorus concentrations as low as .3 mg/L and .01mg/L, respectively, are the critical values for advanced eutrophication (Pote 1997).

Such environmental problems, which are a form of a negative externality, have usually been handled in the past via direct regulation or some form of subsidy. Typically, the appropriate government entity would prohibit the use of a potentially polluting material. Other measures that are being examined are tax credits. In the example of litter, the Oklahoma Legislature has passed a bill allowing an income tax credit for growers who ship their litter outside of the affected region rather than spreading it on their crops. Despite the relative success of such heavy handed methods at controlling pollution, they typically impose such a high cost on society that the costs of implementing the regulatory measures are greater than the benefits to society from reducing the pollution. Because of inefficient results such as these, there has been a move to try more market based approaches (Hahn 1994) such as permit trading and voluntary agreements.

Literature Review

The problem of optimal levels of input application and pollution from agriculture and other nonpoint sources, and from poultry litter specifically, has been studied by several authors. One issue to address is the litter's marginal value of product to crop production. Estimates of this value have a wide variance and depend upon a variety of factors such as the nutrient content of litter, application rates, whether the litter is fresh or composted, and the type of crop it is applied to (Vervoort and Keeler, 1999; Govindasamy et. al. 1994). Estimates of litter's marginal value product have ranged from a low of $21 per ton to a high of $149 per ton (Xu and Prato 1995; Rainey et. al. 1992).

There is also the problem of reducing nutrient pollution once fertilizers and/or litter have been applied to the soil. The levels of phosphorus runoff from a field can be reduced through reductions in the amount of phosphorus initially laid on the soil or through abatement activity that the farmer engages in. These abatement activities can include the establishment of riparian zones, changes in tillage methods, drainage ditches, and the like. An examination of the literature finds that of all the different policies that have been proposed to reduce nutrient runoff, they are all simply a variation of one of three general policies: a tax, some form of a voluntary or mandated best management practice, or a transferable discharge permit system.

A variety of different taxes have been suggested for reducing nonpoint source pollution from agriculture. Some of the tax-based schemes that have been investigated include placing taxes on fertilizers directly, fertilizer application rates, or on nutrient/pesticide runoff (Abrams and Barr 1974; Zhang et. al. 1998; Shortle and Abler 1994; Tietenberg 1973 and 1974). Although theoretically taxes might be an easier method to reduce nutrient runoff than some other approaches, in that the tax could simply be levied on fertilizer purchases at the time of sale just like a sales tax, the effects of these taxes on income can be substantial. Income reductions for farmers on the order of $5,300 to $22,000, depending upon the structure of the tax, have been predicted (McSweeney and Shortle 1989). Nor is it at all clear that a system of taxes would be less costly than other tactics. Jacobs and Casler (1979) found that a tax system could have total costs that are between 2.7 to 13.3 times higher than a simple mandated reduction in nutrient use. Nevertheless, there is selected support for a tax based pollution reduction program on the grounds that the size of the program's transactions cost might be low (McCann and Easter 1999) but there is not complete agreement about this point. A tax that is placed on emissions which are stochastic probably will not have lower transactions costs than other methods. In addition to this, the question of how moral it is to tax nutrients which are necessary to all life at low levels but are a pollutant at high levels has been raised (Tomasi, Segerson, and Braden 1994).

A variety of different best management practices, where there is a change in the techniques or procedures that a farmer engages in, have also been proposed. These best management practices can be a change in land use to reduce pollution (Jacobs and Timmons 1974), changes in farming actions to reduce runoff and soil erosion (Shortle and Dunn 1986; VanDyke, Bosch, and Pease 1999; Choe and Fraser 1998), or simply placing limits on fertilizer applications (Schnitkey and Miranda 1993). These best management practices can be costly to farmers and it has been suggested that compensation in the amount of the reduced profits farmers incur from their implementing might encourage their more widespread use (DeVuyst and Ipe C. 1999; Sharp and Bromely 1979). Pecuniary compensation packages for best management practices though could introduce problems of moral hazard into the farmer's decision space and hence greatly obfuscate any solution. Moreover, the complete path nutrients take from the field to the local water body is both complex and not entirely under the farmer's control. There are other off-field opportunities, which do not involve any action by the farmer, for controlling nutrient runoff which might be cheaper than on-field management practices (Sharp and Bromely 1979). Shortle and Dunn (1986) discovered that in a comparison of different tax and best management practices, none of the policies was able to achieve a first best solution, although they noted that the execution of certain best management practices came closer to a first best solution than any tax policy.

Finally, there is the question of transferable discharge permit systems. The use of permit markets to reduce pollution at lowest cost is well known and understood in the literature. In theory, a transferable permit system is able to reach a given level of abatement at substantial cost savings over typical command-and-control policies by shifting the burden of abatement from all firms to firms with lower abatement costs (Baumol and Oates 1988; Tietenberg 1980; Montgomery 1972; Hanley et. al. 1997). This is true despite some of the drawbacks that accompany a permit systems implementation. In light of this, permit systems have been applied in theory and in practice to a variety of pollution problems. Some of these include hazardous waste (Opaluch and Kashmanian 1985), biological oxygen demand (Eheart et. al. 1987), water pollution (O'Neil et. al. 1983), and sulfur dioxide emissions from power plants (Schmalensee et. al. 1998; Stavins 1998).

The investigation of employing a permit system for phosphorus has been undertaken as well. David et. al. (1980) study how a permit market would be formed to control phosphorus loadings into Lake Michigan. In order for a permit market to be successful, they believe that the permit life must be staggered from 1 to 5 years. This allows the issuing regulatory body the authority to control total discharges into the lake since they can choose to not reissue permits once they expire. Having some permits that expire every year also ensures that the firm will enter the market every year to trade, thus avoiding the problem of having thin markets develop. It is also important for permit prices to be stable. This price stability helps to reduce the uncertainty in the manager's decision problem and should increase his willingness to participate in a permit market. Uncertainty in a permit market can induce firms to purchase additional treatment facilities to hedge against the possibility of extremely higher long run permit prices. A possible solution to this uncertainty, the analysis of which is beyond the scope of this paper, would be to sell permits in futures markets.

Govindasamy and Cochran (1995b; 1998) appraise a permit system for poultry litter and compare its results with several other policy options including quantity restrictions on litter applications, taxes on litter, and taxes on land that has received litter applications. The authors discovered that even though all of the policy options were capable of achieving the stated environmental goal, only the permit system could achieve it at the lowest cost and have the additional benefits of reducing uncertainty and adjustment costs, be introduced smoothly, and avoid the problem of economic growth and inflation that could drive up taxes beyond their intended levels. It is important to note that although the taxes on litter and/or land may be easier to enforce and monitor, there is opposition to their use because of their effects on output, prices, profits, and the difficulty in determining the efficient tax rate. Moreover, there is the additional consideration of losses in efficiency.

It is well known that efficiency requires the equalization of marginal benefits and marginal costs. Placing a quantity limit on litter applications or taxing litter applications over some determined standard would undoubtedly reduce efficiency. Since soils are different, whether in their composition or stock of nutrients, there will be some fields that can benefit from further litter applications, i.e. the marginal benefits of litter are not equalized. A limit on phosphorus applications to 300 pounds of phosphorus/acre, for instance, ignores these marginal benefits that are yet to be obtained. A permit system will allow the capture of these marginal benefits. The individual farmer has better information about the productivity of his fields than the regulator. Since the farmer will not purchase a permit to lay litter on his field if the marginal benefits of doing so are less than the permit price, a permit system helps to ensure the equalization of marginal benefits across all participating farms.

The details of setting up a permit system are many and can be of significant importance. One issue is how trading will occur (Ledyard and Szakaly-Moore 1994). For instance, will firms seek out each other when they desire to trade permits, or will permits be purchased from the regulatory agency through a regularly scheduled auction process? Will there be an initial allocation of permits that is issued for free on the basis of some measure of historical emissions or will the firm be forced to purchase all permits it uses? The answer to questions such as these has lots of implications for political viability, wealth redistribution, transactions cost, and efficiency in the permit market (Stavins 1995; Hoag and Hughes-Popp 1997; Loehman 1998; Atkinson and Tietenberg 1991).

A second issue is concerned with what exactly will be traded. In this case, will permits be issued for emissions, for an ambient environmental standard, or for polluting inputs? Issuing permits on the basis of an ambient environmental standard requires copious amounts of information since each individual receptor would in effect have its own unique permit market for the firms to trade in (Morgan, Coggins, and Eidman 2000). This could only lead to high transactions costs and a significant reduction in permit trading and therefore trading benefits. However, an emissions based trading program may develop local "hot spots" of pollution and fail to reach the desired level of environmental quality. Issuing permits on the basis of the polluting input saves on some informational problems that face the regulator concerning firm behavior; however, it is still necessary to determine the damage functions and the optimal level of issued permits (Shortle and Abler 1994).

Despite the potential economic and environmental benefits of a permit trading system over a more traditional pollution control system, some concerns exist. These include monopsony-like market power in the permit market among some firms, "thin markets" where there are not enough participants in the market for the establishment of efficient permit prices and trades, stochastic nonpoint source damages, and the presence of transactions costs (Godby 1997; Schmalensee et. al. 1998; Hoag and Hughes-Popp 1997; Shortle 1990; Stavins 1995; Hahn 1989; Hahn and Hester 1989). For the area of study, most of these concerns are not an issue. The product and input markets among growers can be considered perfectly competitive in that there are a large number of small firms who are all price takers in outputs and inputs.

The challenge of stochastic nonpoint source damages is a real issue. Shortle (1990) discusses the problems of improving water quality with the presence of stochastic nonpoint source emissions. The problem of nonpoint source emissions is not in reducing some scalar value but in changing the distribution of the stochastic emissions. If two firms engaging in permit trades change their emissions levels so that the firm with lower abatement costs is abating more, this does not necessarily mean that environmental quality has been improved—even if total emissions are reduced. One must consider the probability distribution of those emissions which might be adversely affected by the redistribution in firm abatement.

However, this view is not universal as evidenced by Stephenson et. al. (1998). Contrary to popular belief, point source loadings, what Shortle would call nonstochastic emissions, exhibit large degrees of measurement difficulty and stochasticity too. Consider the case of a retention basin for a wastewater treatment plant that floods local streams and lakes with raw sewage during periods of heavy rainfall. In short, measures of point source emissions suffer from error and uncertainty just like nonpoint source emissions. This fact has not stopped the successful implementation of several permit trading programs for point source loadings. Besides, even if point source loads were constant and accurately measurable, the water body's assimilative capacity is not.

The last issue is concerned with transactions costs. Even though economic theory predicts that permit systems will grant firms large reductions in costs, there has been only a few markets develop. Some in the literature attribute this failure to transactions costs (Hahn and Hester 1989). There are three types of transactions: information searching, bargaining, and monitoring and enforcement (Stavins 1995). The presence of transactions costs changes the firm's focus from the standard equalization among all firms of marginal abatement costs to a problem of equating the sum of marginal abatement costs plus marginal transactions costs. In addition, transactions costs reduce welfare by both using resources and suppressing otherwise beneficial trades. Although these transactions costs can reduce the potential cost savings of a permit program by 40 to 50 percent, they can be significantly reduced through the establishment of a central clearing house for permit traders (Woodward 2000).

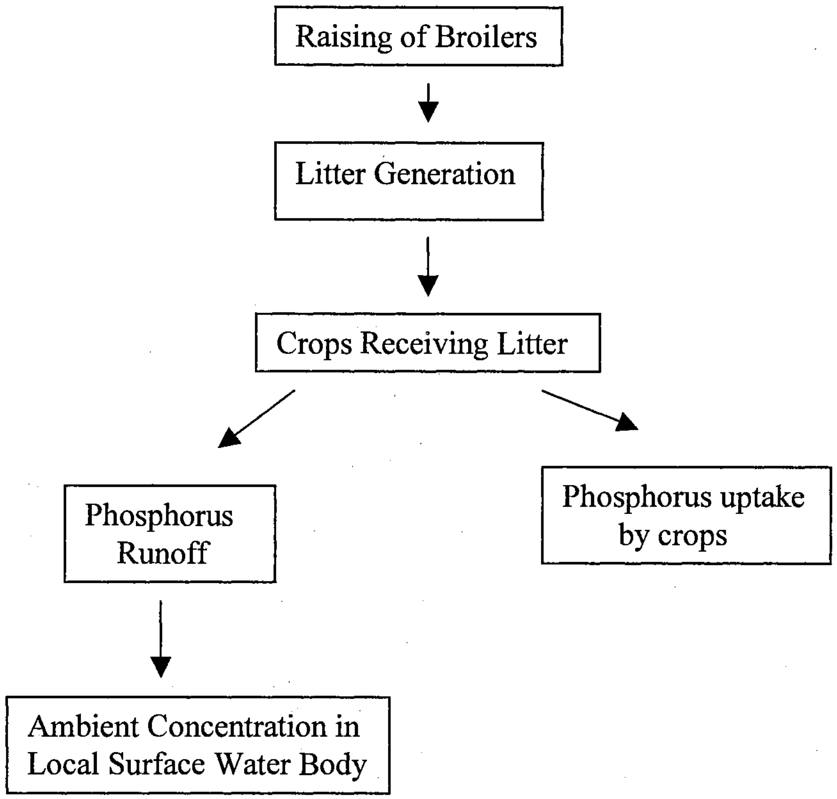
Despite all of the potential problems of a permit system, the best argument for their implementation is real world evidence of their economic and political viability. The U.S. Environmental Protection Agency's permit market for sulfur dioxide emissions has been extremely successful. There is no evidence of any downward biases in permit prices due to annual permit auctions or hoarding of permits by firms. In fact, the evidence seems to indicate that the permit market is acting very closely to a perfectly competitive market (Joskow et. al. 1998). Permit prices have been lower than predicted by forecasters, but this shows the difficulty in predicting prices in a market that has yet to exist. It is quite possible that future permit markets will be just as efficient as the sulfur dioxide emissions market if there is a lack of institutional barriers that impede trade within the market itself.

The Permit Trading Model

The permit scheme is based on a farm level model that maximizes the profits of growers and farmers. Since most growers in the region also raise crops, the growers problem is to maximize the profits that are derived from raising and selling broilers and crops. There are three essential components to the permit trading model: economic, physical, and agronomic. Figure 1 shows these relationships.

The agronomic component consists of identifying nutrient demands from crops. The physical component examines the relationship between litter and other fertilizer applications and how those translate into a pollutant's ambient concentration in the local water body. The last component is economic in nature and deals with such issues as profit maximization, the marginal value product of litter and its disposal costs, and the buying or selling of permits. It is important to have accurate data on each of these components in order to form a working model and to conduct sensitivity analysis. Each of these components is represented in the model.

Figure 1. The Physical and Agronomic Relationships



The grower is able to grow i crops ($i = 1,\dots, I$) with n nutrients ($n = 1, 2$). Denote phosphorus as $n = 1$ and nitrogen as $n = 2$. The problem for the grower is to choose the values of V, L_i, M_i, Y, A_{in}, S, and D that will maximize the following profit function, equation (1), subject to the constraints of equations (2) through (8)

$$\pi_j = rV + \sum_{i=1}^{I} (m_iL_i - e_iM_i) - bY - \sum_{i=1}^{I} \sum_{n=1}^{2} v_{in}A_{in} + P^- S - P^+ D \tag{1}$$

$$V = qW \tag{2}$$

$$W = \phi_1 + \phi_2 F + \phi_3 F^2 \tag{3}$$

$$\eta V - Y - \sum_{i=1}^{I} M_i \leq 0 \tag{4}$$

$$\mathrm{L} \geq \sum_{i=1}^{I} \mathrm{L}_i \tag{5}$$

$$\mathrm{a}_{i1}\mathrm{L}_i - \alpha_{\iota 1}\,(\mathrm{A}_{\iota 1} + \theta_{\iota 1}\mathrm{M}_\iota) = 0 \tag{6}$$

$$\mathrm{a}_{i2}\mathrm{L}_i - \alpha_{\iota 2}\,(\mathrm{A}_{\iota 2} + \theta_{\iota 2}\mathrm{M}_\iota) = 0 \tag{7}$$

$$\sum_{i=1}^{I} \mathrm{B}_{i1}(1 - \alpha_{\iota 1})\,(\mathrm{A}_{\iota 1} + \theta_{\iota 1}\mathrm{M}_\iota) \leq \mathrm{T} + \mathrm{D} - \mathrm{S} \tag{8}$$

where

r = the return per pound of broiler

V = the total weight of broilers sold
m_i = the net return per acre for crop *i*

L_i = number of acres used to grow crop *i*

e_i = the cost to spread litter on crop *i*

M_i = total amount of litter spread on crop *i*

b = disposal cost of litter

Y = amount of poultry litter to be disposed of

v_{in} = the cost of spreading commercial fertilizer containing *n* on crop *i*

A_{ni} = total amount of commercial fertilizer with nutrient *n* spread on crop *i*

S = amount of permits sold by the farmer over the initial allocation

D = amount of demanded by the farmer over the initial allocation

T = amount of initial permit allocation

P^+ = price farmer pays for permits

P^- = price farmer receives for permits

q = the number of broilers produced

W = broiler weight

F = feed for broilers

B = proportion of phosphorus that is available for runoff that actually does runoff

η = amount of litter generated per unit of broiler weight

L = total amount of cropland available

a_{i1} = amount of phosphorus needed to produce a unit of crop *i*

a_{i2} = amount of nitrogen needed to produce a unit of crop *i*

α_{i1} = proportion of applied phosphorus from all sources that is available for use by crop *i*

α_{i2} = proportion of applied nitrogen from all sources that is available for use by crop *i*

θ_{i1} = amount of phosphorus in a unit of broiler litter

θ_{i2} = amount of nitrogen in a unit of broiler litter

The first term in equation (1) is the profit resulting from broiler sales. The term in parentheses is the profit resulting from crop production, which is the net return from cropping activities less the costs of spreading litter. The third term shows the cost of disposing of excess litter that can not or will not be used as a fertilizer for the grower's crops. This could include shipping the litter to another region, burning it, or storing it for future use. The fourth term is the farmer's cost of commercial fertilizer applications while the last set of terms show the revenue or costs from selling excess permits or buying additional permits beyond the initial allocation. The reader will note that the price paid and received for permit is different. In short, these prices represented in equation (1) reflect the transactions costs that the grower must face in order to purchase or sell permits. It should be noted that if we assume the permit price to be P, that the true cost to the grower buying permits is P^+ which is greater than P, and the true price received from selling permits is P^- which is less than P. This form of analysis follows Tschirhart (1984) and is used to diminish the criticism from the literature that permit systems often ignore transactions costs.

The constraints in equations (2) and (3) show that total broiler weight sold depends upon the weight of each broiler times the number of broilers and that broiler weight is a quadratic function of poultry feed. Equation (4) states that all litter produced, the first term, must go somewhere, i.e., it can be spread on crops or disposed of in some alternative way. Equation (5) is a balance equation for land use while equations (6) and (7) are a balance constraint in that the amount of nutrients demanded by the crops equals the supply of nutrients. Finally, equation (8) states that the phosphorus available for runoff can not exceed the initial allocation of permits plus the net amount of permits purchased.

The permits are emission based in that it allows the grower or treatment plant to emit one ton of phosphorus runoff or discharge. The permits are valid for the entire period of simulation which in this model is one year. The model assumes that growers and the treatment plant are given an initial allocation of permits so that the aggregate of all permits will not allow the environmental standard of total phosphorus runoff/discharge into the Illinois River to be violated. It is assumed that the permit recipients receives their initial allocation of permits free and are able to purchase additional permits if they wish to emit or discharge more phosphorus runoff. Growers may also sell any excess permits that are not needed. The regulator begins by giving the treatment plant enough permits to cover its current level of phosphorus discharge. The remaining permits are distributed equally to all growers within the region.

Data and Methodology

Data for the permit model comes from a variety of sources including the 1997 Census of Agriculture and from budget generators from the Oklahoma State University and University of Arkansas Department of Agriculture Extension Offices. The census data was collected at the county level which was the limit of disaggregation. The included counties are Adair, Cherokee, and Delaware County in Oklahoma and Benton and Washington County in Arkansas.

The census data gave the total number of farms, farmed acres, total cropland acres, harvested cropland acres, pasture acres, and numbers of broilers raised for each of the counties. This data is represented in Table XXV by acres. In addition to this, there was data on the total number of acres used to produce a variety of crops in each county and the total amount of those crops produced. The aggregated county data for each of the crops and poultry raising operations was broken down into a countywide proportion of all cropping/raising activity within the county and that proportion was applied to the average farm size in the county. Using these cropping/raising activities proportionally allows the building of a model farm based on the average size of each farm in each county. Table XXVI shows the average farm size and the proportion, i.e. number of acres used to produce a crop, of the different cropping/raising activities for each of the 5 counties.

The budget generators include data on each of the different crops that are typically raised in the area of study. Since the soil variation within the Illinois River Basin itself is minor, it is assumed that the budget generators apply with equal validity regardless of which county the crops are grown. The budget generators are meant as a guide to local farmers and inform the farmer on a per acre basis for each type of crop as

Table XXV

County Land Use in Acres, 1997

	Adair	Cherokee	Delaware	Benton	Washington
Total County Acres	368,450	480,696	474,080	539,718	608,156
Farm Land	225,322	237,558	264,620	296,543	334,667
Cropland	99,857	90,943	129,230	168,089	174,878
Woodland	60,682	59,497	50,462	52,963	93,742
Other Land	64,783	87,118	84,928	75,491	66,047
Pasture, all types	149,647	164,251	169,653	173,589	183,995
Wetlands/ Conservation	1,977	1,641	699	1,377	606

to the expected variable and fixed costs of raising that crop, the amount of nutrients needed to cultivate a particular crop, etc. From these one is able to derive the amount of nutrients that will be necessary for the farmer to lay on each acre of the different crops raised in each county.

Table XXVI

Land Use in Acres on a Representative Farm, 1997

	Adair	Cherokee	Delaware	Benton	Washington
Total Cropland	91.61	78.81	99.18	72.36	70.63
Wheat	0.14	0.63	2.71	0.42	0.05
Soybeans	0	0.26	1.65	0.4	0
Corn	0.02	0	0	0.17	0
Sorghum	0	0	0.84	0	0
Vegetables	0.46	0.01	0.55	0.31	0.13
Orchards	0.1	0.59	0.15	0.21	0.24
Field Seed	0.1	0	0	1.83	0
Fescue Seed	0.1	0	1.06	1.83	0.36
Alfalfa Hay	0.41	0.68	0.46	0.97	0.41
Tame Hay	28.27	18.8	31.14	23.14	20.26
Wild Hay	6.44	6.74	6.26	6.57	8.47
Green Chop Hay	0.33	0.14	0.55	0.82	0.76
Corn for silage	0	0	0	0.27	0
Small Grain Hay	1.48	0.84	0.91	0.65	0.59
Hay	36.92	27.2	39.32	32.14	30.5
Idle Cropland	0.94	1.78	0.76	0.8	0.82
Total Woodland	55.67	51.58	38.73	22.8	37.86
Other Land	59.43	75.49	65.18	32.5	26.67

Results

The results were calculated using the Generalized Algebraic Modeling System (GAMS) and the model was set to maximize county profits. The previous chapter's results are used in this chapter to make the model more complete and realistic. Estimates of the permit price under the regional model gave a starting place for permit prices in this model. It is assumed that the regulator wants to reach a certain level of phosphorus runoff entering the Illinois River per year. A discharge permit is based upon one ton of runoff. Since the Tahlequah wastewater treatment plant currently discharges 2.059 tons of phosphorus per year, the regulator gives the treatment plant enough permits for its current discharge. He then distributes the rest of the permits to the five individual counties on an equal basis. For instance, if the environmental standard is 140 tons of phosphorus per year, the treatment plant receives 2.059 permits and the remainder, 137.941 permits is given equally to each county so that each county receives 27.5882 permits. Once the counties have received their runoff permits, they are free to do with them as they please. They can be sold to other counties or used for the counties own discharge.

As before, a base case had to be established. Results from the last chapter indicated that a worst case scenario would be approximately 711 tons of phosphorus runoff or discharge per year. The standard was reduced by 20, 50, 80, 90, and 95 percent after this. However, it was revealed that with a storage capacity of 10%, that the environmental standard would not become binding until the phosphorus limit was set at 350 tons per year. Profits, cropping and broiler activities, and runoff were identical with the phosphorus limit of 700 and 560. Therefore, in the interest of saving time and space, calculations were not run at the 700 ton level. In addition, estimates of cropping activity, broiler production, runoff, and profits were obtained in a no trading scenario. In this scenario, the individual counties were given their initial allocation or permits, after the treatment plant was given its initial allocation of permits, but trade was not allowed to occur. This was done to allow an estimation of the benefits of a permit trading system for each of the counties and for the region as a whole.

Transactions costs were initially assumed to be zero, and than increased to 5%, 15%, and 25% for both the seller and buyer of permits to study the effect that this would have on profits, cropping decisions, broiler activities, and runoff.[20] The price of permits without transactions costs is $17,250. Inclusion of transactions costs of 5% raises the purchase price to $18,111.50 and reduces the revenue from selling to $16,387.50. When transactions costs were increased to 15%, the purchase price rose to $19,837.50 and the price received the seller fell to $14,662.50. Finally, transactions cost of 25% raised the purchase price to $21,562.50 and lowered the revenue to the seller to $12,937.50.

The treatment plant is allowed to purchase additional permits from the counties to lower their level of abatement and hence increase their phosphorus discharge. In every circumstance, regardless of the phosphorus standard or the size of transactions costs, the treatment plant bought 7.8 permits so that its level of treatment for phosphorus was zero. This is not surprising since results from the previous chapter showed that phosphorus treatment at all levels was more expensive for the plant than buying permits. In fact, the plant is able to reduce its treatment costs by $404,032 when it is allowed to purchase permits. This cost savings does not include the purchase of permits. It was assumed that the treatment plant would face the same transactions costs as other buyers[21] so that they would pay the same price that growers would for their permits. Since the plant always purchased 7.8 permits, its permit expenditures were $134,550 when there were no

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[20] Estimates of transactions costs in the literature for water pollution range from 6% of market price (Colby 1990) to 11% of market price (Hearne and Easter 1995). The values of 5% and 15% chosen in this chapter are designed to mimic the literature. The value of 25% was chosen to represent an "upper bounds" of transactions costs.

[21] This may be an unrealistic assumption. It is quite possible that the treatment plant would have lower transactions costs than the individual growers. This possibility stems from the fact that once the individual growers realize that the treatment plant is always going to be a buyer of permits, they may in fact approach the plant about trading before they attempt to sell to other growers, i.e., the treatment plant may not need to "go looking" for permits to buy—the permits may come to them.

transactions costs and the plant saved $269,482 in costs. When transactions costs were 5%, the plant spent $141,269.70 on permits and saved $262,762.30; transactions costs of 15% resulted in permit expenditures of $154,732.50 and overall cost savings of $249,299.50. Finally, transactions costs of 25% meant that the plant must spend $168,187.50 on permits yielding cost savings of $235,844.50.

Effects of Increasing Environmental Standards and Transactions Costs on Profits

Tables 27 thru 38 show the effect of tightening the environmental constraint and the impact that transactions costs have on regional and individual county profits. As expected, increasing the environmental standard for any given level of transactions cost reduces profits in every instance. Also, the presence of transactions costs decreases profits for every environmental standard. Finally, as expected, when trade was allowed to occur, regional profits were higher for any given standard and for any level of transactions costs when compared to a scenario of non-tradeable discharge permits. Some of this higher regional profit is derived from the lower costs that the wastewater treatment plant experienced as a result of being able to shift abatement burden from itself to the growers. However, it was not always true that growers had higher profits in a tradeable permit scheme when compared to a market where permits were not allowed to be traded. Adair county, for instance, experienced slightly higher profits when trading was not allowed under the phosphorus standard of 70 tons per year, than it did when trade was permitted. It should be noted that Adair county profits were higher with trade than without for all of the other standards.

Table XXVII

Regional Profits for Various Levels of Phosphorus Limits and Transactions Costs

Transactions costs	35	70	140	350	560
0%	86,860,958	87,464,242	88,672,226	92,293,528	95,863,881
5%	86,834,078	87,411,355	88,567,296	92,032,468	95,450,913
15%	86,780,353	87,305,587	88,357,438	91,510,347	94,625,047
25%	86,726,628	87,199,819	88,147,580	90,988,226	93,799,202
No trade	86,591,535	87,117,474	88,010,589	90,016,747	91,282,293

Table XXVIII

Adair County Profits for Various Levels of Phosphorus Limits and Transactions Costs

Transactions Costs	35	70	140	350	560
0%	13,055,959	13,176,694	13,418,191	14,142,638	14,856,862
5%	13,051,273	13,167,377	13,399,616	14,096,286	14,776,619
15%	13,041,901	13,148,747	13,362,467	14,003,583	14,619,948
25%	13,032,529	13,130,117	13,325,317	13,910,879	13,910,879
No trade	13,055,931	13,215,204	13,382,125	13,382,125	13,382,125

Table XXIX

Cherokee County Profits for Various Levels of Phosphorus Limits and Transactions Costs

Transactions Costs	35	70	140	350	560
0%	11,831,999	11,952,742	12,194,245	12,918,737	13,632,974
5%	11,826,592	11,941,679	12,171,868	12,862,421	13,536,709
15%	11,815,778	11,919,552	12,127,115	12,749,789	13,362,784
25%	11,804,964	11,897,425	12,082,361	12,637,156	13,182,934
No trade	11,831,977	11,837,473	11,837,473	11,837,473	11,837,473

Table XXX

Delaware County Profits for Various Levels of Phosphorus Limits and Transactions Costs

Transactions Costs	35	70	140	350	560
0%	17,036,374	17,156,666	17,398,586	18,123,027	18,836,925
5%	17,033,018	17,150,602	17,387,073	18,095,167	18,786,439
15%	17,026,340	17,138,475	17,364,046	18,039,442	18,704,104
25%	17,019,663	17,126,349	17,341,019	17,983,718	18,615,866
No trade	17,036,068	17,156,458	17,398,523	17,957,313	17,957,313

Table XXXI

Benton County Profits for Various Levels of Phosphorus Limits and Transactions Costs

Transactions Costs	35	70	140	350	560
0%	22,818,613	22,939,726	23,180,686	23,904,959	24,618,723
5%	22,814,809	22,928,789	23,155,482	23,836,955	24,519,284
15%	22,807,202	22,906,914	23,105,074	23,700,948	24,299,912
25%	22,799,594	22,885,040	23,054,666	23,564,940	24,080,540
No trade	22,818,820	22,939,210	23,181,275	23,904,921	24,629,895

Table XXXII

Washington County Profits for Various Levels of Phosphorus Limits and Transactions Costs

Transactions Costs	35	70	140	350	560
0%	23,379,113	23,499,513	23,741,616	24,465,266	25,179,496
5%	23,376,213	23,490,736	23,721,084	24,409,466	25,099,689
15%	23,370,414	23,473,180	23,680,018	24,297,868	24,919,581
25%	23,364,614	23,455,625	23,638,953	24,186,269	24,739,474
No trade	23,379,320	23,499,710	23,741,774	24,465,496	25,006,068

Table XXXIII

Percentage of Regional Profits When Compared to the Base Case

Transactions Cost	35	70	140	350	560
0%	90.609	91.238	92.498	96.276	100.000
5%	90.581	91.183	92.389	96.003	99.569
15%	90.525	91.072	92.170	95.459	98.708
25%	90.469	90.962	91.951	94.914	97.846
No Trade	90.328	90.876	91.808	93.901	95.221

Table XXXIV

Percentage of Adair County Profits When Compared to the Base Case

Transactions Cost	35	70	140	350	560
0%	87.878	88.691	90.316	95.193	100.000
5%	87.847	88.628	90.191	94.881	99.460
15%	87.784	88.503	89.941	94.257	98.405
25%	87.721	88.377	89.691	93.633	93.633
No Trade	87.878	88.950	90.074	90.074	90.074

Table XXXV

Percentage of Cherokee County Profits When Compared to the Base Case

Transactions Cost	35	70	140	350	560
0%	86.790	87.675	89.447	94.761	100.000
5%	86.750	87.594	89.283	94.348	99.294
15%	86.671	87.432	88.954	93.522	98.018
25%	86.591	87.269	88.626	92.696	96.699
No Trade	86.789	86.830	86.830	86.830	86.830

Table XXXVI

Percentage of Delaware County Profits When Compared to the Base Case

Transactions Cost	35	70	140	350	560
0%	90.441	91.080	92.364	96.210	100.000
5%	90.424	91.048	92.303	96.062	99.732
15%	90.388	90.983	92.181	95.766	99.295
25%	90.353	90.919	92.059	95.471	98.826
No Trade	90.440	91.079	92.364	95.330	95.330

Table XXXVII

Percentage of Benton County Profits When Compared to the Base Case

Transactions Cost	35	70	140	350	560
0%	92.688	93.180	94.159	97.101	100.000
5%	92.673	93.136	94.056	96.824	99.596
15%	92.642	93.047	93.852	96.272	98.705
25%	92.611	92.958	93.647	95.720	97.814
No Trade	92.689	93.178	94.161	97.101	100.045

Table XXXVIII

Percentage of Washington County Profits When Compared to the Base Case

Transactions Cost	35	70	140	350	560
0%	92.850	93.328	94.289	97.163	100.000
5%	92.838	93.293	94.208	96.942	99.683
15%	92.815	93.223	94.045	96.499	98.968
25%	92.792	93.154	93.882	96.055	98.252
No Trade	92.851	93.329	94.290	97.164	99.311

Cherokee and Delaware county benefited from a scenario of tradeable permits. In fact Cherokee county had higher profits for every phosphorus standard and for every level of transactions costs, save two, when trading was allowed than when it was not. The two instances where profits were higher under a no-trade system was when the phosphorus standard was set to its most stringent and transactions costs were equal to or greater than 15%. Similarly, Delaware county experienced higher profits under a tradeable permit system for every environmental standard than when a tradeable system was not put in place. However, Delaware county profits proved to be more sensitive to the levels of transactions costs than they did for Cherokee county. When the environmental standard was set at either 35, 70, or 140 tons of phosphorus per year, every level of transactions costs equal to or above 5% resulted in lower profits. When the standard was set to 350 or 560, profits were higher regardless of the level of transactions costs.

Washington county and Benton county do not appear to benefit as much from trading as the counties in Oklahoma do. Like the counties within Oklahoma, Benton and Washington county experience a decrease in profits for any level of transactions costs when the environmental standard is tightened and a decrease in profits for any environmental standard when transactions cost increase. But, contrary to the behavior of profits for the Oklahoma counties when comparing trading versus non-trading permit plans, profits in Benton and Washington county tend to be lower when trading is allowed. In Washington county, profits are lower for every level of the environmental standard except for the standard of 560 tons per year. When Benton county is given permits but not allowed to trade them, their profits are slightly higher under the environmental standards of 560, 140, and 35 tons per year than in a trading scheme with zero transactions costs. Even though there is an increase in profits for Washington and Benton county when comparing the trading to the non-trading plan, the increase in profits is very small. In fact, the largest positive differential for Washington and Benton county is $230 and $11,172 respectively. The lowest profit differential is only $38. When one compares these numbers to the approximate $23 to $25 million in profit, depending upon the county and the existing phosphorus standard, these are certainly small.

One explanation for this behavior comes from the fact that Benton and Washington county were always buyers of permits when trading was allowed and never sellers. Therefore, they had to undertake additional expenditures for any excess phosphorus runoff above and beyond what they had been allotted in the initial allocation of permits. These permit expenditures of course reduce profits but allow the grower to engage in actions that will increase profits. The fact that the levels of profits are close to each other when trading is allowed versus when it is not indicates that a permit price of $17,250 is a fairly close estimate of the true price of the permits. In other words, if the permit price was significantly lower, than profits would be a lot higher under the trading scheme since the growers in Benton and Washington county could buy the right to emit additional tons of phosphorus. The ability to emit additional units of pollution means that broiler and cropping activities can expand. If the profits from this expansion were larger than the price paid for the permit to emit the additional phosphorus, than permit trading profits would be larger than non-trading profits. On the other hand, if the permit price was significantly higher than the value to marginal profits from being allowed to emit additional runoff, than non-trading profits would be significantly higher than trading profits. They are not. As stated earlier, the largest differential between higher non-trading profits and lower trading profits is $11,172 for Benton county and $230 for Washington county. In percentage terms this amounts to .045% and .000000094% respectively.

Of further interest is that for Benton and Washington county, profits from trading are always lower when transactions costs are at 5% or greater when compared to profit levels when there in no trading. Once again, the differential in profits is small but extant. For Benton county, the largest differential between profits from a non-tradeable scheme and profits when transactions costs are 25% is $549,355. As the phosphorus standard is tightened, the differential in profits from the no-trade case to the case of trading with 25% transactions costs falls to $19,226 when the standard is 35 tons per year. Similarly for Washington county, the profit differential begins as $266,594, increase slightly to $279,227 when the phosphorus standard is 350, and than falls to $14,706 when the standard is 35. This convergence of profit as the environmental standard is tightened, regardless of the level of transactions cost or whether trade is even allowed, occurs not only in Benton and Washington county, but in the Oklahoma counties as well. As the environmental standard is tightened for any given level of transactions costs, the largest impact on profits for the counties in Oklahoma appears to happen as the standard is first enacted. For instance, Adair, Cherokee, and Delaware county each experience an approximate 5% decrease in profits when the environmental standard is tightened from 560 to 350 and than again when it is lowered to 140. After that, further tightening in the environmental standard decrease profits about 1%. The effects of tightening the environmental standard in Benton and Washington county does not have as severe an impact on profits. When the allowed phosphorus loads are lowered from 560 to 350 and then to 140, each county sees profits fall by 2 to 3%. Further tightening of the environmental load decreases profits by a more modest one-half to 1%.

The explanation for this is somewhat obvious. As the environmental standard is tightened, each county receives fewer permits which for Adair, Cherokee, and Delaware county translates into fewer profit opportunities from permit sales. Similarly, since Benton and Washington counties are always buyers of permits, i.e. a majority of total runoff from cropping activities is derived from Benton and Washington county, a tightening of the environmental standard means less allowed runoff; but it also means that total expenditures for permits are reduced. Furthermore, when trading is not allowed, the environmental constraint is not even binding for the Oklahoma counties until it is greatly reduced. For instance, Cherokee county is not bound by the environmental constraint until it reaches 35 tons per year. Therefore, when trading is not allowed, the Oklahoma counties have a lot of "excess" permits which they can not sell. Continuing to use Cherokee county as an example, when the standard is 560 tons per year, Cherokee receives 111.5882 permits. It uses 6.91 of them leaving it an excess of 104.6782 permits. It can not use these permits for its own runoff since it can not reach the environmental constraint. If allowed to sell its permits, at the very minimum, it could continue to operate as is and sell these "excess" permits. When trading is allowed, this is in fact what Cherokee county, (Adair and Delaware county included) does. As the environmental constraint is tightened, not only are there fewer permits to sell to Benton and Washington county, there is less slack in the environmental constraint, i.e. the number of "excess" permits begins to decrease. By the time the environmental constraint has been reduced to

350 from 560, Adair, Cherokee, and Delaware counties are altering their behavior to reduce their own runoff and sell any remaining permits. Thus, by the time the environmental constraint is reduced to 35, profits under trading with any level of transactions costs, have converged to approximately their level that would exist under a non-trading standard, as evidenced by Tables 34 thru 38. This profit convergence is closest when comparing trading with zero transactions cost to no permit trading at all.

Effects of Increasing Environmental Standards and Transactions Costs on Activity Levels, Runoff, and Permit Trades

Activity Levels. Tables 39 and 40 show how the contribution to total revenue from broiler raising and cropping activity changes as the environmental standard and transaction costs change. It is interesting to note that there was no change in the levels of activity for a given phosphorus standard when transactions costs increase from zero to 25 percent. This is shown in Tables 41 through 65 which show the amount of broilers raised, cropping activity, runoff, permit transactions, and profits for each environmental standard at each level of transactions costs. When the environmental standard is tightened the level of broiler production, which indirectly determines the amount of litter and phosphorus generation, and its contribution to total revenue decreases. The proportion of Bermuda grass that is raised decreases and the amount of land devoted to Alfalfa hay increases since this crop does not need litter or commercial fertilizer applications. The decrease in profits experienced by each county as the phosphorus limit is lowered reflects this crop substitution. The decrease in broiler production lowers profits as does the crop substitution of Alfalfa hay for Bermuda grass since the net returns for the latter are higher.

Table XXXIX

Percentage Contribution of Broiler Raising and Cropping Activity to Total Agricultural Based Revenue for Different Phosphorus Standards for all Levels of Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
P = 560					
Broilers	4.597	1.415	8.008	20.799	18.773
Cropping	95.403	98.585	91.992	79.201	81.227
P = 350					
Broilers	3.183	0.969	5.611	15.244	13.658
Cropping	96.817	99.031	94.389	84.756	86.342
P = 140					
Broilers	1.703	0.513	3.040	8.688	7.718
Cropping	98.297	99.487	96.960	91.312	92.282
P = 70					
Broilers	1.200	0.360	2.150	6.256	5.541
Cropping	98.800	99.640	97.850	93.744	94.459
P = 35					
Broilers	0.946	0.283	1.698	4.988	4.411
Cropping	99.054	99.717	98.302	95.012	95.589

Table XL

Percentage Contribution of Broiler Raising and Cropping Activity to Total Agricultural Based Revenue for Different Phosphorus Standards with No Permit Trading

	Adair	Cherokee	Delaware	Benton	Washington
P = 560					
Broilers	4.597	1.415	8.008	12.731	11.370
Cropping	95.403	98.585	91.992	87.269	88.630
P = 350					
Broilers	4.597	1.415	8.008	9.666	9.096
Cropping	95.403	98.585	91.992	90.334	90.904
P = 140					
Broilers	4.597	1.415	4.547	6.364	5.849
Cropping	95.403	98.585	95.453	93.636	94.151
P = 70					
Broilers	2.838	1.415	2.965	5.206	4.711
Cropping	97.162	98.585	97.035	94.794	95.289
P = 35					
Broilers	1.786	1.360	2.153	4.615	4.131
Cropping	98.214	98.640	97.847	95.385	95.869

Table XLI

Profits and Cropping Activity for Phosphorus Maximum of 560 without Permit Trading

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	27,598.40	7,467.69	64,936.41	142,530.00	128,940.00
ACRES					
Bermuda grass	974.19	263.85	2,292.1	4,262.71	3,856.34
Alfalfa Hay	99,025.81	90,736.16	127,710.00	165,740.00	171,140.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	59,204.27	53,560.22
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.00	111.59	100.95
Total P from all sources					307.01
Profits	13,382,125	11,837,473	17,957,313	24,629,895	25,006,068
REGIONAL PROFITS					91,282,293

Table XLII

Profits and Cropping Activity for Phosphorus Maximum of 350 without Permit Trading

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	27,598.40	7,467.69	64,936.41	104,330.00	100,420.00
ACRES					
Bermuda grass	974.19	263.85	2,292.1	2,658.29	2,658.29
Alfalfa Hay	99,025.81	90,736.16	127,710.00	167,340.00	172,340.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	36,920.73	36,920.73
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.00	69.59	69.59
Total P from all sources					233.65
Profits	13,382,125	11,837,473	17,957,313	23,904,921	24,465,496
REGIONAL PROFITS					90,016,747

Table XLIII

Profits and Cropping Activity for Phosphorus Maximum of 140 without Permit Trading

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	27,598.40	7,467.69	35,457.35	66,131.91	62,218.52
ACRES					
Bermuda grass	974.19	263.85	1,053.88	1,053.88	1,053.88
Alfalfa Hay	99,025.81	90,736.16	128,950.00	168,950.00	173,950.00
LITTER					
Bermuda grass	13,530.43	3,664.52	14,637.20	14,637.20	14,637.20
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	27.59	27.59	27.59
Total P from all sources					117.23
Profits	13,382,125	11,837,473	17,398,523	23,181,275	23,741,774
REGIONAL PROFITS					88,010,589

Table XLIV

Profits and Cropping Activity for Phosphorus Maximum of 70 without Permit Trading

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	16,763.20	7,467.69	22,724.98	53,399.53	49,486.15
ACRES					
Bermuda grass	519.07	263.85	519.07	519.07	519.07
Alfalfa Hay	99,780.93	90,736.16	129,480.00	169,480.00	174,480.00
LITTER					
Bermuda grass	7,209.36	3,664.52	7,209.36	7,209.36	7,209.36
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	13.59	6.91	13.59	13.59	13.59
Total P from all sources					63.32
Profits	13,215,204	11,837,473	17,156,458	22,939,210	23,499,710
REGIONAL PROFITS					87,117,474

Table XLV

Profits and Cropping Activity for Phosphorus Maximum of 35 without Permit Trading

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	10,397.01	7,177.86	16,358.80	47,033.35	43,119.97
ACRES					
Bermuda grass	251.67	251.67	251.67	251.67	251.67
Alfalfa Hay	99,748.33	90,748.33	129,750.00	169,750.00	174,750.00
LITTER					
Bermuda grass	3,495.44	3,495.44	3,495.44	3,495.44	3,495.44
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	6.59	6.59	6.59	6.59	6.59
Total P from all sources					35
Profits	13,055,931	11,831,977	17,036,068	22,818,820	23,379,320
REGIONAL PROFITS					86,591,535

Table XLVI

Profits and Cropping Activity for Phosphorus Maximum of 560 with Zero Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	27,598.40	7,467.69	64,936.41	258,180.00	233,570.00
ACRES					
Bermuda grass	974.19	263.85	2,292.10	9,120.71	8,251.19
Alfalfa Hay	99,025.81	90,736.16	127,710.00	160,880.00	166,750.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	126,680.00	114,600.00
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.00	238.77	216.00
Total P from all sources					547.18
Permits Sold	85.492	104.087	50.992		
Permits Purchased				127.766	105.004
Profits	14,856,862	13,632,974	18,836,925	24,618,723	25,179,496
REGIONAL PROFITS					95,863,881

Table XLVII

Profits and Cropping Activity for Phosphorus Maximum of 350 with Zero Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	18,817.22	5,091.64	44,275.12	176,040.00	159,250.00
ACRES					
Bermuda grass	605.35	164.04	1,424.25	5,670.21	5,129.65
Alfalfa Hay	99,394.65	90,835.96	128,580.00	164,330.00	169,870.00
LITTER					
Bermuda grass	8,407.64	2,278.37	19,781.34	78,752.86	71,245.10
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	15.85	4.29	37.28	148.43	134.28
Total P from all sources					350.000
Permits Sold	53.741	65.294	32.304		
Permits Purchased				78.845	64.695
Profits	14,142,638	12,918,737	18,123,027	23,904,959	24,465,266
REGIONAL PROFITS					92,293,528

Table XLVIII

Profits and Cropping Activity for Phosphorus Maximum of 140 with Zero Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	9,909.98	2,681.48	23,317.24	92,707.92	83,869.39
ACRES					
Bermuda grass	231.21	62.81	543.95	2,170.17	1,963.29
Alfalfa Hay	99,768.79	90,937.19	129,460.00	167,830.00	173,040.00
LITTER					
Bermuda grass	3,211.31	872.33	7,554.87	30,141.19	27,267.94
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	6.05	1.64	14.24	56.81	51.39
Total P from all Sources					140.000
Permits Sold	21.536	25.944	13.349		
Permits Purchased				29.222	23.806
Profits	13,418,191	12,194,245	17,398,586	23,180,686	23,741,616
REGIONAL PROFITS					88,672,226

Table XLIX

Profits and Cropping Activity for Phosphorus Maximum of 70 with Zero Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	6,940.90	1,878.10	16,331.28	64,932.17	58,741.71
ACRES					
Bermuda grass	106.52	29.06	250.52	1,003.49	907.84
Alfalfa Hay	99,893.50	90,970.94	129,750.00	169,000.00	174,090.00
LITTER					
Bermuda grass	1,479.20	403.65	3,479.39	13,937.30	12,608.89
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	2.79	0.76	6.56	26.27	23.77
Total P from all sources					70.000
Permits Sold	10.8	12.827	7.03		
Permits Purchased				12.681	10.177
Profits	13,176,694	11,952,742	17,156,666	22,939,726	23,499,513
REGIONAL PROFITS					87,464,242

Table L

Profits and Cropping Activity for Phosphorus Maximum of 35 with Zero Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	5,456.36	1,476.41	12,838.30	51,044.30	46,177.87
ACRES					
Bermuda grass	44.15	12.19	103.80	420.15	380.11
Alfalfa Hay	99,955.85	90,987.81	129,900.00	169,580.00	174,620.00
LITTER					
Bermuda grass	613.15	169.31	1,441.64	5,835.36	5,279.36
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	1.16	0.32	2.72	11.00	9.95
Total P from all sources					35.000
Permits Sold	5.433	6.269	3.872		
Permits Purchased				4.41	3.362
Profits	13,055,959	11,831,999	17,036,374	22,818,613	23,379,113
REGIONAL PROFITS					86,860,958

Table LI

Profits and Cropping Activity for Phosphorus Maximum of 560 with 5 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	27,598.40	7,467.69	64,936.41	258,180.00	233,570.00
ACRES					
Bermuda grass	974.19	263.85	2,292.10	9,120.71	8,251.19
Alfalfa Hay	99,025.81	90,736.16	127,710.00	160,880.00	166,750.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	126,680.00	114,600.00
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.00	238.77	216.00
Total P from all sources					557.04
Permits Sold	85.095	103.691	50.595		
Permits Purchased				127.172	104.41
Profits	14,776,619	13,536,709	18,786,439	24,519,284	25,099,689
REGIONAL PROFITS					95,450,913

Table LII

Profits and Cropping Activity for Phosphorus Maximum of 350 with 5 Percent Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	18,817.22	5,091.64	44,275.12	176,040.00	159,250.00
ACRES					
Bermuda grass	605.35	164.04	1,424.26	5,670.21	5,129.65
Alfalfa Hay	99,394.65	90,835.96	128,580.00	164,330.00	169,870.00
LITTER					
Bermuda grass	8,407.64	2,278.37	19,781.34	78,752.86	71,245.10
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	15.85	4.29	37.28	148.43	134.28
Total P from all sources					350.00
Permits Sold	53.741	65.294	32.304		
Permits Purchased				78.845	64.695
Profits	14,096,286	12,862,421	18,095,167	23,836,955	24,409,466
REGIONAL PROFITS					92,032,468

Table LIII

Profits and Cropping Activity for Phosphorus Maximum of 140 with 5 Percent Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	9,909.98	2,681.48	23,317.24	92,707.92	83,869.39
ACRES					
Bermuda grass	231.21	62.81	543.95	2,170.17	1,963.29
Alfalfa Hay	99,768.79	90,937.19	129,460.00	167,830.00	173,040.00
LITTER					
Bermuda grass	3,211.31	872.33	7,554.87	30,141.19	27,267.94
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	6.05	1.64	14.24	56.81	51.39
Total P from all sources					140.00
Permits Sold	21.536	25.944	13.349		
Permits Purchased				29.222	23.806
Profits	13,399,616	12,171,868	17,387,073	23,155,482	23,721,084
REGIONAL PROFITS					88,567,296

Table LIV

Profits and Cropping Activity for Phosphorus Maximum of 70 with 5 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	6,940.90	1,878.10	16,331.28	64,932.17	58,741.71
ACRES					
Bermuda grass	106.50	29.06	250.52	1,003.49	907.84
Alfalfa Hay	99,893.50	90,970.94	129,750.00	169,000.00	174,090.00
LITTER					
Bermuda grass	1,479.20	403.65	3,479.39	13,937.30	12,608.89
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	2.79	0.76	6.56	26.27	23.77
Total P from all sources					70.00
Permits Sold	10.8	12.827	7.03		
Permits Purchased				12.681	10.177
Profits	13,167,377	11,941,679	17,150,602	22,928,789	23,490,736
REGIONAL PROFITS					87,411,355

Table LV

Profits and Cropping Activity for Phosphorus Maximum of 35 with 5 Percent Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	5,456.36	1,476.41	12,838.30	51,044.30	46,177.87
ACRES					
Bermuda grass	44.15	12.19	103.80	420.15	380.11
Alfalfa Hay	99,955.85	90,987.81	129,900.00	169,580.00	174,620.00
LITTER					
Bermuda grass	613.15	169.31	1,441.64	5,835.36	5,279.36
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	1.16	0.32	2.72	11.00	9.95
Total P from all sources					35.00
Permits Sold	5.433	6.269	3.871		
Permits Purchased				4.41	3.362
Profits	13,051,273	11,826,592	17,033,018	22,814,809	23,376,213
REGIONAL PROFITS					86,834,078

Table LVI

Profits and Cropping Activity for Phosphorus Maximum of 560 with 15 Percent Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	27,598.40	7,467.69	64,936.41	258,180.00	233,570.00
ACRES					
Bermuda grass	974.19	263.85	2,292.10	9,120.71	8,251.19
Alfalfa Hay	99,025.81	90,736.16	127,710.00	160,880.00	166,750.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	126,680.00	114,600.00
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.00	238.77	216.00
Total P from all sources					557.04
Permits Sold	84.421	104.028	50.932		
Permits Purchased				127.172	104.41
Profits	14,619,948	13,362,784	18,704,104	24,299,912	24,919,581
REGIONAL PROFITS					94,625,047

Table LVII

Profits and Cropping Activity for Phosphorus Maximum of 350 with 15 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	18,817.22	5,091.64	44,275.12	176,040.00	159,250.00
ACRES					
Bermuda grass	605.35	164.04	1,424.26	5,670.21	5,129.65
Alfalfa Hay	99,394.65	90,835.96	128,580.00	164,330.00	169,870.00
LITTER					
Bermuda grass	8,407.64	2,278.37	19,781.34	78,752.86	71,245.10
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	15.85	4.29	37.28	148.43	134.28
Total P from all sources					350.00
Permits Sold	53.741	65.294	32.304		
Permits Purchased				78.845	64.695
Profits	14,003,583	12,749,789	18,039,442	23,700,948	24,297,868
REGIONAL PROFITS					91,510,347

Table LVIII

Profits and Cropping Activity for Phosphorus Maximum of 140 with 15 Percent Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	9,909.98	2,681.48	23,317.24	92,707.92	83,869.39
ACRES					
Bermuda grass	231.21	62.81	543.95	2,170.17	1,963.29
Alfalfa Hay	99,768.79	90,937.19	129,460.00	167,830.00	173,040.00
LITTER					
Bermuda grass	3,211.31	872.33	7,554.87	30,141.19	27,267.94
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	6.05	1.64	14.24	56.81	51.39
Total P from all sources					140.00
Permits Sold	21.536	25.944	13.349		
Permits Purchased				29.222	23.806
Profits	13,362,467	12,127,115	17,364,046	23,105,074	23,680,018
REGIONAL PROFITS					88,357,438

Table LIX

Profits and Cropping Activity for Phosphorus Maximum of 70 with 15 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	6,940.90	1,878.10	16,331.28	64,932.17	58,741.71
ACRES					
Bermuda grass	106.50	29.06	250.52	1,003.49	907.84
Alfalfa Hay	99,893.50	90,970.94	129,750.00	169,000.00	174,090.00
LITTER					
Bermuda grass	1,479.20	403.65	3,479.39	13,937.30	12,608.89
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	2.79	0.76	6.56	26.27	23.77
Total P from all sources					70.00
Permits Sold	10.8	12.827	7.03		
Permits Purchased				12.681	10.177
Profits	13,148,747	11,919,552	17,138,475	22,906,914	23,473,180
REGIONAL PROFITS					87,305,587

Table LX

Profits and Cropping Activity for Phosphorus Maximum of 35 with 15 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	5,456.36	1,476.41	12,838.30	51,044.30	46,177.87
ACRES					
Bermuda grass	44.15	12.19	103.80	420.15	380.11
Alfalfa Hay	99,955.85	90,987.81	129,900.00	169,580.00	174,620.00
LITTER					
Bermuda grass	613.15	169.31	1,441.64	5,835.34	5,279.36
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	1.16	0.32	2.72	11.00	9.95
Total P from all sources					35.00
Permits Sold	5.433	6.269	3.871		
Permits Purchased				4.41	3.362
Profits	13,041,901	11,815,778	17,026,340	22,807,202	23,370,414
REGIONAL PROFITS					86,780,353

Table LXI

Profits and Cropping Activity for Phosphorus Maximum of 560 with 25 Percent Transactions Costs

	Adair	Cherokee	Delaware	Benton	Washington
BROILER (tons)	27,598.40	7,467.69	64,936.41	258,180.00	233,570.00
ACRES					
Bermuda grass	974.19	263.85	2,292.16	9,120.71	8,251.19
Alfalfa Hay	99,025.81	90,736.16	127,710.00	160,880.00	166,750.00
LITTER					
Bermuda grass	13,530.43	3,664.52	31,834.77	126,680.00	114,600.00
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	25.50	6.91	60.00	238.77	216.00
Total P from all sources					557.04
Permits Sold	84.483	103.997	50.902		
Permits Purchased				127.172	104.41
Profits	14,475,124	13,182,934	18,615,866	24,080,540	24,739,474
REGIONAL PROFITS					93,799,202

Table LXII

Profits and Cropping Activity for Phosphorus Maximum of 350 with 25 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	18,817.22	5,091.64	44,275.12	176,040.00	159,250.00
ACRES					
Bermuda grass	605.35	164.04	1,424.26	5,670.21	5,129.65
Alfalfa Hay	99,394.65	90,835.96	128,580.00	164,330.00	169,870.00
LITTER					
Bermuda grass	8,407.64	2,278.37	19,781.34	78,752.86	71,245.10
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	15.85	4.29	37.28	148.43	134.28
Total P from all sources					350.00
Permits Sold	53.741	65.294	32.304		
Permits Purchased				78.845	64.695
Profits	13,910,879	12,637,156	17,983,718	23,564,940	24,186,269
REGIONAL PROFITS					90,988,226

Table LXIII

Profits and Cropping Activity for Phosphorus Maximum of 140 with 25 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	9,909.98	2,681.48	23,317.24	92,707.92	83,869.39
ACRES					
Bermuda grass	231.21	62.81	543.95	2,170.17	1,963.29
Alfalfa Hay	99,768.79	90,937.19	129,460.00	167,830.00	173,040.00
LITTER					
Bermuda grass	3,211.31	872.33	7,554.87	30,141.19	27,267.94
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	6.05	1.64	14.24	56.81	51.39
Total P from all sources					140.00
Permits Sold	21.536	25.944	13.349		
Permits Purchased				29.222	23.806
Profits	13,325,317	12,082,361	17,341,019	23,054,666	23,638,953
REGIONAL PROFITS					88,147,580

Table LXIV

Profits and Cropping Activity for Phosphorus Maximum of 70 with 25 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	6,940.90	1,878.10	16,331.28	64,932.17	58,741.71
ACRES					
Bermuda grass	106.50	29.06	250.52	1,003.49	907.84
Alfalfa Hay	99,893.50	90,970.94	129,750.00	169,000.00	174,090.00
LITTER					
Bermuda grass	1,479.20	403.65	3,479.39	13,937.30	12,608.89
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	2.79	0.76	6.56	26.27	23.77
Total P from all sources					70.00
Permits Sold	10.8	12.827	7.03		
Permits Purchased				12.681	10.177
Profits	13,130,117	11,897,425	17,126,349	22,885,040	23,455,625
REGIONAL PROFITS					87,199,819

Table LXV

Profits and Cropping Activity for Phosphorus Maximum of 35 with 25 Percent Transactions Costs

	Adair	**Cherokee**	**Delaware**	**Benton**	**Washington**
BROILER (tons)	5,456.36	1,476.41	12,838.30	51,044.30	46,177.87
ACRES					
Bermuda grass	44.15	12.19	103.80	420.15	380.11
Alfalfa Hay	99,955.85	90,987.81	129,900.00	169,580.00	174,620.00
LITTER					
Bermuda grass	613.15	169.31	1,441.64	5,835.36	5,279.36
STORAGE	2,570.00	692.00	6,048.00	23,943.00	21,660.00
RUNOFF					
Bermuda grass	1.16	0.32	2.72	11.00	9.95
Total P from all sources					35.00
Permits Sold	5.433	6.269	3.871		
Permits Purchased				4.41	3.362
Profits	13,032,529	11,804,964	17,019,663	22,799,594	23,364,614
REGIONAL PROFITS					86,726,628

Of more interest is the fact that the levels of activity, and therefore runoff and permit transactions, does not vary when transactions cost increase. The only effect of increasing transactions costs is to decrease profits in all counties. This was an unexpected result. Stavins (1995) states the increases in transactions costs will not only lower profits, but the amount of permits traded, although it should be noted that he does not state how high those transactions costs have to be to affect the number of permit transactions in a market. Since there was no change in the activity levels of the growers as transactions costs changed, there was no change in runoff, and therefore no change in the amount of permits purchased or sold.[22]

One possible explanation for this behavior, which obviously has implications for runoff and the permit market, is that the demand for permits might be inelastic for certain ranges of permit price. The concept of inelasticity was observed in the regional model. Recall, that under the regional model, there was no change in the permit price when the environmental standard was tightened. In fact, the results from GAMS did not indicate any change until the constraint was lowered to approximately 11 tons of total phosphorus per year. It is likely that the same peculiarity that caused this observed result is responsible for the inelasticity of permit demand as transactions costs, and therefore permit price, increase. Whether this is something endemic to the poultry industry or to

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[22] This observation was initially of great concern. Upon discovery of this behavior, I incrementally increased the level of transactions costs. Only when the level of transactions costs reached 60% was there an alteration in activity levels and subsequently runoff and permit trading. At this level of transactions cost, only the Tahlequah plant and Benton county purchased permits, of which Benton county purchased 7.883 permits and the treatment plant purchased 7.8 permits. This was not included in the chapter's analysis because it was not felt that such a high level of transactions cost was a realistic outcome. Although this level of transactions costs could happen in a complex national market, a local market would probably not experience this for the simple fact that, at the very least, farmers could take out an ad in the local newspaper and advertise the amount of permits they are offering for sale or purchase. This result though has impressed upon me an interest in the effect that transactions costs will have on the viability of permit markets. An interest of which future research is planned.

industries characterized by constant returns to scale in general is not known, but definitely warrants future research.

There was a change in observed activity levels when growers were given non-tradeable permits in comparison to the case of tradeable permits. When the environmental standard is set at 560 tons per year, the effect when trading is not allowed is to lower the proportion of revenue from broiler production for Benton and Washington counties. The Arkansas counties would see the proportion of total revenue from broiler production fall from about 20% to approximately 12%. Since the environmental constraint was initially not binding for Adair, Cherokee, or Delaware counties, there was no observed change in their choice of broiler raising and cropping activity. Only as the environmental constraint was tightened, was there an observed change in the broiler/cropping activity mix. Note that as the environmental standard is tightened under the no permit trading scenario, the proportionality contribution to total revenue from cropping and broiler activities converges to the values given under a trading scheme for any particular level of transactions costs. In fact the difference in cropping and broiler activity's contribution to total revenue under a 35 tons of phosphorus per year standard is almost identical for both the trading and non-trading case for Washington and Benton county. Adair, Cherokee, and Delaware counties each see slightly more cropping activity under a permit trading scheme at an environmental standard of 35 than with a non-trading plan.

Runoff. As already mentioned in the previous subsection, there is no change in runoff and hence in permit transactions as transactions cost increase.

There is however changes in the relative contribution of runoff as the phosphorus standard is tightened as Tables 66 through 69 illustrate. When trading is not allowed, the percentage of phosphorus from the treatment plant increases as the environmental standard is tightened. This should not be surprising since the plant is discharging a constant amount for every environmental standard. Subsequently, the contribution of each county to total runoff converges to the same value. For Benton and Washington, this convergence takes the form of a decrease in the proportion of total runoff emanating from themselves. For the Oklahoma counties, the opposite occurs as their percentage contribution to total runoff increases.

The introduction of permit trading lowers Benton and Washington county's percentage contribution to total runoff from a combined level of 81.5% when the phosphorus standard is 560 down to 59.8% when the standard is set to 35 tons per year. Similarly, the contribution from Oklahoma counties falls from 16.4% to 11.9% when the standard is set to 35 tons of discharge and runoff per year. The treatment plant on the other hand assumes 28% of the phosphorus contribution to the Illinois River by the time the standard has fallen to 35.

When the treatment plant is not considered, the runoff from cropping activity is mostly from Benton and Washington county. These two counties account for 83% of all cropping related runoff when permit trading is allowed. When trading is restricted, their contribution falls to slightly over 66%. If permit trading is not allowed, than each county converges towards the same contribution to cropping related runoff. This is not surprising since each county faces the environmental constraint when the phosphorus standard is reduced to 35 tons per year. However, when trading is allowed, the relative

Table LXVI

Percentage Contribution to Total Phosphorus Runoff without Permit Trading

P Limit	Adair	Cherokee	Delaware	Benton	Washington	Tahlequah
560	8.307	2.250	19.544	36.347	32.882	0.671
350	10.915	2.956	25.681	29.784	29.784	0.881
140	21.753	5.892	23.533	23.533	23.533	1.756
70	21.460	10.908	21.460	21.460	21.460	3.252
35	18.823	18.823	18.823	18.823	18.823	5.883

Table LXVII

Percentage Contribution to Total Phosphorus Runoff with Permit Trading

P Limit	Adair	Cherokee	Delaware	Benton	Washington	Tahlequah
560	4.578	1.240	10.772	42.864	38.776	1.770
350	4.528	1.227	10.653	42.410	38.367	2.817
140	4.323	1.174	10.171	40.579	36.710	7.042
70	3.983	1.087	9.368	37.527	33.950	14.084
35	3.302	0.912	7.763	31.424	28.430	28.169

Table LXVIII

Percentage Contribution to Total Cropping Activity Runoff without Permit Trading

P Limit	Adair	Cherokee	Delaware	Benton	Washington
560	8.363	2.265	19.676	36.592	33.104
350	11.012	2.982	25.909	30.048	30.048
140	22.142	5.997	23.954	23.954	23.954
70	22.181	11.275	22.181	22.181	22.181
35	20.000	20.000	20.000	20.000	20.000

Table LXIX

Percentage Contribution to Total Cropping Activity Runoff with Permit Trading

P Limit	Adair	Cherokee	Delaware	Benton	Washington
560	4.661	1.262	10.966	43.636	39.475
350	4.659	1.262	10.961	43.639	39.479
140	4.651	1.263	10.942	43.653	39.491
70	4.636	1.265	10.904	43.679	39.516
35	4.597	1.269	10.808	43.747	39.579

contribution in percentage terms to cropping activity runoff stays fairly consistent, i.e. Benton and Washington county account for 83.3% of all phosphorus runoff. This would seem to indicate their preference for broiler raising and litter spreading as is evidenced by their overwhelming initial stake in these activities. Which is to say, that from the initial base case, Benton and Washington county produce 43% and 39% of all of the broilers raised within the Illinois River Basin. These numbers are identical to their initial percentage contribution to total cropping related phosphorus runoff.

Permit Trading. As has already been indicated, Benton and Washington county have the largest stake in broiler production within the Illinois River Basin. They therefore have the most to lose from restrictions on phosphorus loads into the Illinois River Basin. In fact, if it were not for the assumed larger storage capacity for litter, their broiler production would converge to levels equal to that of the counties in Oklahoma as the phosphorus standard is ratcheted downwards. With the introduction of tradeable permits, these counties are able to purchase the right to emit phosphorus runoff and to therefore increase broiler production above and beyond the levels that would exist if trading were not allowed.

Benton and Washington counties are always buyers of permits and the Oklahoma counties are always sellers of permits. Tables 70 and 71 show the relative contribution of each county to total permit supply and demand. There is a slight increase in the percentage of permits emanating from Delaware county and a subsequently slight decrease in the percentage of permits from Cherokee county. Nevertheless, notice that the Oklahoma counties tend roughly to supply the same percentage of permits to the total supply of permits available in the open market. The demand side, however, is a different story. The Tahlequah treatment plant always purchases permits, regardless of the phosphorus standard or the level of transactions costs, the same number of permits—7.8. Therefore, as the environmental standard is strengthened, the treatment plant consumes an ever growing percentage of permit demand. By the time the standard is lowered to 35 tons per year, the treatment plant is buying half of the available permits for sale.

Table LXX

Supply Contribution to Total Permit Sales for All Levels of Transactions Costs, Percentage

P Limit	Adair	Cherokee	Delaware
560	35.537	43.267	21.196
350	35.510	43.144	21.345
140	35.404	42.651	21.945
70	35.228	41.840	22.931
35	34.885	40.253	24.862

Table LXXI

Demand Contribution to Total Permit Demand for All Levels of Transactions Costs, Percentage

P Limit	Benton	Washington	Tahlequah
560	53.110	43.648	3.242
350	52.098	42.748	5.154
140	48.040	39.137	12.823
70	41.363	33.195	25.442
35	28.320	21.590	50.090

Table LXXII

Percent of Initial Permit Allocation Sold in Open Market

P Limit	Adair	Cherokee	Delaware
560	76.614	93.278	45.697
350	77.227	93.829	46.422
140	78.062	94.040	48.387
70	79.481	94.398	51.736
35	82.466	95.155	58.772

Table LXXIII

Percent of Initial Permit Allocation Purchased in Open Market

P Limit	Benton	Washington	Tahlequah
560	114.498	94.100	378.825
350	113.302	92.968	378.825
140	105.922	86.291	378.825
70	93.324	74.896	378.825
35	66.938	51.031	378.825

Also interesting to note is that as the allowed amount of phosphorus is lowered, the percent of the Oklahoma counties' initial permit allocation that is not used for local runoff but sold on the open market increases. As Tables 72 and 73 show, the increase for Cherokee county is slight—only 2%. But for Delaware and Adair county, the increase amounts to 13.1% and 5.8% respectively. Meanwhile, the percent of their initial permit allocation that is purchased by Benton and Washington county falls from 114% and 94% to 66% and 51% respectively as the environmental standard is lowered to its smallest allowed value. Since the treatment plant always purchases the same amount of permits, its permit purchases, as a percentage of its initial allocation, is always the same—378%. These changes in the percentage of initial permits that are sold or bought are undoubtedly due to the fixed buying of the treatment plant. As the environmental standard is lowered, the treatment plant requires a relatively larger percentage of the total permits allocated to the region as a whole. This means that the treatment plant is buying permits that otherwise would have been purchased by Benton or Washington counties. Although this behavior might be detrimental to the profits of the Arkansas counties, it is beneficial to the profits of the treatment plant and to regional profits as a whole since it is more costly for the treatment plant to abate one ton of phosphorus runoff than it is for the growers to abate one ton of runoff.

An examination of Tables 74 thru 78 shows that, as expected, the percentage contribution of permit sales to profits for the Oklahoma counties decreases as both the environmental standard is tightened and as transactions costs increase. As a corollary, the permit expenditures as a percentage of profits for the Arkansas counties increase as transactions costs increase and decrease as the environmental standard is changed to lower allowed phosphorus levels. This is not surprising. As the environmental standard is lowered, there are fewer permits to become available for sale in the open market, thus lowering the proportional impact that permits sales or purchases have on profits. Also, a lowering of the standard has the effect of decreasing the amount of "excess" permits that the Oklahoma counties posses and are thus willing to part with.

Table LXXIV

Total Permit Sales Revenue as a Percentage of Profit, Adair County

Transactions Cost	35	70	140	350	560
0%	0.718	1.414	2.769	6.555	9.926
5%	0.682	1.344	2.634	6.248	9.481
15%	0.611	1.204	2.363	5.627	8.574
25%	0.539	1.064	2.091	4.998	7.951

Table LXXV

Total Permit Sales Revenue as a Percentage of Profit, Cherokee County

Transactions Cost	35	70	140	350	560
0%	0.914	1.851	3.670	8.805	13.170
5%	0.869	1.760	3.493	8.402	12.601
15%	0.778	1.578	3.137	7.584	11.421
25%	0.687	1.395	2.778	6.751	10.215

Table LXXVI

Total Permit Sales Revenue as a Percentage of Profit, Delaware County

Transactions Cost	35	70	140	350	560
0%	0.392	0.707	1.323	3.075	4.670
5%	0.373	0.672	1.258	2.926	4.448
15%	0.333	0.601	1.127	2.626	3.997
25%	0.294	0.531	0.996	2.324	3.544

Table LXXVII

Total Permit Expenditures as a Percentage of Profit, Benton County

Transactions Cost	35	70	140	350	560
0%	0.333	0.954	2.175	5.690	8.952
5%	0.350	1.002	2.286	5.991	9.438
15%	0.384	1.098	2.509	6.599	10.430
25%	0.417	1.195	2.733	7.215	11.441

Table LXXVIII

Total Permit Expenditures as a Percentage of Profit, Washington County

Transactions Cost	35	70	140	350	560
0%	0.248	0.747	3.734	4.562	7.194
5%	0.260	0.785	3.924	4.801	7.577
15%	0.285	0.860	4.305	5.282	8.359
25%	0.310	0.936	4.688	5.768	9.152

CHAPTER IV

CONCLUSIONS

The previous two essays have examined the use of a market based permit system to reduce phosphorus runoff and discharge into the Illinois River in an attempt to reduce the eutrophication of the water and to restore it to its previous state. The primary source of this phosphorus runoff is believed to derive from the highly concentrated nature of broiler raising operations within the Illinois River Basin. These broiler raising operations produce litter as a by-product which is used by local farmers as a fertilizer and soil amendment. Since the litter has high concentrations of phosphorus, the runoff that occurs naturally in the region due to rain and soil erosion also contains large amounts of phosphorus. Past attempts to reduce the levels of phosphorus runoff have relied on tax credits to growers for shipping litter out of the region and placing limits on litter applications to fields which test positive for high levels of soil test phosphorus. Although the policies have only recently been implemented so that evidence for the efficaciousness of these policies in reducing phosphorus runoff is not yet extant, the two essays within this dissertation have attempted to explore another alternative that has to this date been overlooked.

This alternative policy involves establishing a transferable permit system for phosphorus runoff from fields and discharges from the Tahlequah wastewater treatment plant. Economic theory states that creation of a transferable permit system for pollutants will be able to reduce the amount of pollutants entering a waterbody or air shed at lowest cost. This is because the transferable nature of the permit allows abatement for the pollutant to be transferred from high cost firms to low cost firms. Theory predicts that permits can have significant cost savings, sometimes in the order of 50% or higher, over the cost of reaching an identical environmental goal with a command and control policy. The empirical evidence on permit systems has generally agreed with theory that permit systems do allow the attainment of an environmental standard at reduced cost, but that the cost savings are generally smaller than those predicted by pure theory.

Even though permit systems appear to be cost effective, they do have problems with their implementation. One of these, especially if the pollutant is a nonpoint pollutant, is the measurement and monitoring of actual pollutant loads. In the case of agricultural runoff, this can be very difficult. Other problems include the existence of transactions costs in permit trading, identifying the initial allocation of permits, and enforcement of firm behavior. Most of these issues were addressed in the model formulation. Some were not. This includes the enforcement of firm behavior to conform to the runoff requirements set forth by their participation in the permit market. This was not examined due to a lack in the theoretical literature concerning this behavior.

As previously stated, the first essay explored the workings and implications of a permit system on a regional level. It was assumed that there was one firm which owned all of the cropland and growing operations within the Illinois River Basin. Decreases in the environmental standard for allowed phosphorus were used to study the changes in growing and cropping activity within the region. After establishing a base case, trading of phosphorus permits was allowed to take place between the treatment plant and the grower, but not between counties. The model formulation of this was simple and served to establish whether inclusion of the treatment plant was warranted or not. It also helped to approximate the permit price for a ton of phosphorus runoff for the farm level analysis.

The second essay developed the permit market established in the first essay in greater detail. Here the idea was to maximize individual county profits, not regional profits, and to allow trading between both the counties and the treatment plant. This is different than the first essay which simply assumed trading between two economic agents, one firm which owned or controlled all agriculture related activities and the wastewater treatment plant. After the establishment of a base case scenario, the allowed levels of phosphorus were reduced and transactions costs in the trading of permits was introduced into the model to investigate their impact on permit trading and activity levels.

Since the two essays are have a lot of common ground in their investigation, conclusions were not included at the end of each essay but were saved for an individual chapter. The conclusions for both essays can be summarized below:

1. The implementation of permit trading system for phosphorus runoff was able to reach any of the examined runoff limits at lower cost than simply mandating that each economic agent reach the standard on their own. If each county and the treatment plant were given an individual but identical limit for phosphorus runoff, profits were generally lower. This is especially true at the regional level. In some instances, when the environmental standard was set to be sufficiently weak, the counties within Oklahoma did not even reach the allowed level of phosphorus runoff. To not allow these counties to sell their right to emit pollutants lowered profits, especially for the Oklahoma counties. However, it should be noted that as the environmental standard was tightened, the

profitability of engaging in a permit trading scheme was reduced for all of the nonpoint source polluters. This was due to decreasing slack in meeting the environmental constraint for each of the counties, especially the counties within Oklahoma. Whether this result would also affect other industries in an identical manner is not known.

2. Permit trading between point source polluters and nonpoint source polluters can allow an environmental standard to be meet at lower cost than if trading is not allowed. If this instances, the cost savings were in the hundreds of thousands of dollars regardless of the level of the environmental standard or the size of the transactions costs. Of course, it is important that the pollutant that is being traded in the permit market between the point source and nonpoint source polluters be identical. In this model it was.

3. Permit trading between firms who have identical costs may be cost effective, but the benefits from trade are likely to be small. This was shown through an examination of the effect that trades had on the profits of the individual counties. In some instances, especially for Benton and Washington county, trading would mean a small decrease in profits. This should not be surprising since the economic theory of permit trading is based upon the transfer of abatement from high cost polluters to low cost polluters. If all of the firms in the permit market face abatement costs that are identical, or at least very close to each other, than the benefits of trading are also likely to be small. It was for this reason that trading between growers and the treatment plant was so successful. The treatment plant is a high cost abater and the growers are low cost abaters, therefore, there is an opportunity to lower aggregate abatement costs and still obtain the stated environmental goal.

4. Transactions cost negatively affect profits and may negatively affect permit trades themselves. The supposition that higher transactions costs will lower profits was a predicted and confirmed result. What was not expected was that higher levels of transactions costs did not diminish the amount of permits traded. Although economic theory predicts this, this author is not aware of any empirical research that has examined this issue specifically. It is possible that economic agents will not be particularly sensitive to transactions costs in their decision making when those transactions cost are relatively low. Results did indicate that permit trading decreased when transactions costs were raised to about 60% of the permit price. Whether this is endemic to this particularly industry or can be generalized to other industries is not known.

These two essays have also brought up several questions which deserve future research. Some of these potential issues are listed below:

1. How exactly do transactions costs affect the formation and operation of a permit market? Is the demand for permits inelastic within a range of permit prices?

2. How would the model respond if it were to become dynamic? The model as it currently stands is a one-period model which shows the effect of a regulator switching from a mandated phosphorus runoff standard to a transferable discharge permit system. The ability of growers to store some of their litter allowed them to produce additional broilers which would not contribute to phosphorus runoff since the litter was never applied to crops. At the end of this one period, there was no excess storage capacity. How would growers respond to this in the next period? Would they build more storage sheds or decrease production?

3. How would the initial allocation of permit affect trading and profits within the region? Economic theory says that the initial allocation of permits should not affect the end allocation of permits, except that there might be some differences in aggregate profits and abatement costs. In this model, permits were distributed without discrimination to each county. Would permit distribution based on past runoff affect the final outcome?

4. How is an industry characterized by increasing or decreasing returns to scale impacted by the existence of a permit market? The growers in the model exhibited constant returns to scale. Would an industry with increasing or decreasing returns to scale find permit trading profitable? How would a ever tightening environmental constraint affect their participation in the market? How would transactions costs affect permit supply and demand for industries that are not characterized by constant returns to scale. Was the inelasticity of demand for permits as transactions costs increased atypical for the poultry industry alone, or do all industries with constant returns to scale behave this way?

5. What is the cost of changing the pollutant concentration for a wastewater treatment or a similar plant? Theory and this dissertation have shown that there are cost benefits to including point source polluters in a trading scheme with nonpoint source polluters. However, in order to better estimate the potential benefits of such a trading scheme, we need better data on the actual costs of treatment for many point source polluters.

6. What is the effect on pollution levels, profits, and permit trades if firms are noncompliant? In other words, if a firm buys 10 permits to emit 10 units of pollution and then actually emit 20 units, how will this behavior affect other firm's actions, profits, the amount of permits traded, and the permit price? Can monitoring reduce this behavior and if it can, does it increase costs enough to erase any gains realized by permit trading in the first place?

The answers to these questions are important, not only because they would aid in forming a sound policy for the Illinois River Basin, but because the knowledge that can be gained from answering them can benefit regulators, citizens, and industry in finding feasible solutions for other pollution problems in other parts of the country and the world.

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APPENDIX A

Appendix A

The Fraas-Munley model derives the total capital and total O & M costs for removal of BOD by a wastewater treatment plant. It has the following functional form

$$C = k\, F^{\alpha} I^{\beta} E^{\gamma} U^{\delta} \tag{A1}$$

where

C = costs

k = a constant

F = wastewater treatment flow in million gallons per day (MGD)

I = influent concentration in mg/L

E = effluent concentration in mg/L

U = capacity utilization of the plant

and α, β, γ, and δ are parameters to be estimated. Compiling data on construction costs and O&M costs from EPA documents and utilizing a log-log formulation yielded the parameter estimates listed in Table LXXIX.

Table LXXIX

Parameter Estimates from the Fraas-Munley Model

	Capital cost	O & M cost
Constant	11.28	10.17
Flow	0.89	0.79
Influent	0.24	0.24
Effluent	-0.16	-0.07
Capacity	-0.03	-0.46

For the Tahlequah wastewater treatment plant values for flow and capacity utilization were set at 2.601 mgd and 49.35%. Since the Fraas-Munley model estimates costs for BOD removal and not phosphorus removal, the influent and effluent concentrations were set at 129 mg/L and 2.12 mg/L respectively. The assumption that any given decrease in the percentage of BOD from the treatment process would lead to an equivalent decrease in phosphorus was used. In terms of the current model this means that for every 1.2689 mg/L decrease in BOD, phosphorus would decrease by .0197 mg/L.

The parameter estimates were obtained in a log-log form so that the final equation for estimation purposes of O & M and capital costs respectively is as follows:

$$\ln C = 12.416566 - .07 \ln(E) \tag{A2}$$

$$\ln C = 13.3182879 - .16 \ln(E) \tag{A3}$$

Taking the analog for any value of E, where E is BOD in mg/L, will allow an estimation of total O & M and total capital costs. It should also be remembered that the parameter estimate for E is a elasticity measure for changes in effluent levels and changes in costs.

The range of possible BOD amounts in .1 percent increments were entered into an Excel spreadsheet along with a corresponding .1 percent increment of percentage of waste treated. For example, treating 90% of the influent would result in a BOD measure of 13.5401 mg/L whereas treating 75% of the influent would result in a BOD measure of 32.5736 mg/L. The Excel spreadsheet was used to calculate capital, O & M, and total costs for each percentage level of treatment. This yielded the yearly capital and O & M costs. These costs were then divided by the current flow level times 365 days to derive costs in dollars per thousand gallons which is shown in Figure 2.[23] The total cost, total capital costs, and total O & M costs were entered into a SPSS spreadsheet along with the percentage of treatment. Curve fitting was used to estimate the parameter values of the costs and it was determined that a cubic function was the best fit with an R-squared value of .972 for total yearly cost. The resulting O & M, capital, and total cost equations, in dollars per year, are listed below in equations (A4) – (A6) respectively where X represents the level of treatment in percentage, i.e. 50% treatment is written as .50.

$$\text{O \& M Cost} = 442{,}150 + 126{,}045X - 300{,}681X^2 + 296{,}307X^3 \tag{A4}$$

$$\text{Capital Cost} = 684{,}399 + 573{,}506X - 1{,}000{,}000X^2 + 1{,}408{,}175X^3 \tag{A5}$$

$$\text{Total Cost} = 1126549 + 699550X - 2000000X^2 + 1704482X^3 \tag{A6}$$

Total cost is used in the estimation of regional profits in the objective equation and in the environmental constraint.

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[23] During my discussions with the water department at Tahlequah on June 15, 2001, they indicated that the approximate cost of treating 1,000 gallons was $2. The costs estimated in the Excel spreadsheet for the current treatment and flow levels was $2.10—a number which the author felt was a very good approximation.

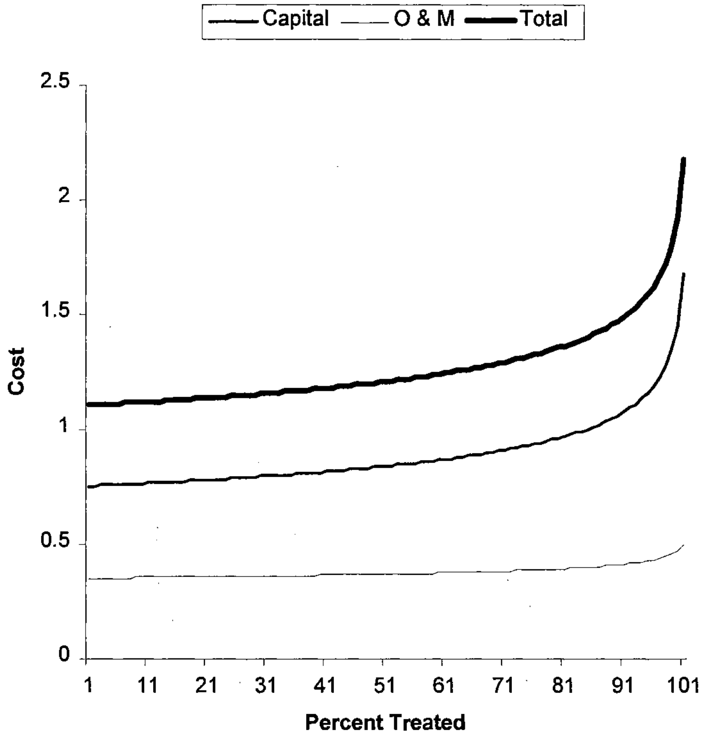

Figure 2. Costs of Different Treatment Levels, $ / 1,000 gallons

APPENDIX B

APPENDIX B

Since the amount of phosphorus runoff from cropping activity is indirectly related to the production of broilers and the type of diet used to feed them, it seems only appropriate to discuss the biological response function of the broilers and the constituent parts of their diet. Borrowing from Willet et. al. (2000) and Gonzalez-Alcorta, Dorfman, and Pesti (1994) the function relating weight gain to energy and protein levels is as follows:

$$W_k = B_{0k} + B_{1k}\ E_k + B_{2k}\ E_k^2 + B_{3k}\ Q_k + B_{4k}\ Q_k^2 \tag{B1}$$

where

E_k ≡ energy level of a production unit in region *k*;

Q_k ≡ protein in diet of a production unit in region *k*.

Equation (B1) needs to be rewritten to reflect a cost minimization solution which also reflects the necessary energy and protein content values for broiler growth. Assume that the amount of each ingredient within a cost minimizing diet can be stated as follows:

$$X_{kz} = \bar{x}_{kz}\ F_k \tag{B2}$$

where

$\bar{x}_{kz}$ ≡ fixed proportion of ingredient *z* in the diet for a broiler production unit in region (this is determined from the integrator's dietary cost minimization model);

X_{kz} ≡ amount of ingredient type *z* in the diet for a broiler production unit in region *k*;

F_k ≡ feedstuff intake for a broiler in a production unit in region *k*.

The energy and protein contents within a broiler diet can be stated as

$$\mathrm{E}_k = \sum_{z=1}^{Z} \varepsilon_{kz} X_{kz} \tag{B3}$$

$$\mathrm{Q_k} = \sum_{z=1}^{Z} \varphi_{kz} X_{kz} \qquad \text{(B4)}$$

where

$\varphi_{kz} \equiv$ protein content per unit of the *z*th ingredient in broiler diet for a broiler production unit in region *k*;

$\varepsilon_{kz} \equiv$ energy content per unit of *z*th ingredient in broiler diet for a broiler production unit in region *k*.

Equation (B2) can be used to rewrite equations (B3) and (B4) as

$$E_k = \Gamma_k \ F_k \qquad \text{(B5)}$$

$$Q_k = \Phi_k \ F_k \qquad \text{(B6)}$$

where

$$\Gamma_k = \sum_{z=1}^{Z} \varepsilon_{kz} \ \bar{x}_{kz}$$

$$\Phi_k = \sum_{z=1}^{Z} \varphi_{kz} \ \bar{x}_{kz} .$$

The parameters Γ_k and Φ_k have the interpretation as the "weighted average" of the energy content and protein content per unit of feedstuff.

Now we are in a position to rewrite equation (B1) using (B5) and (B6) as follows:

$$W_k = B_{0k} + \phi \, I_k \ F_k + \sigma_k \ F_k^2 \qquad \text{(B7)}$$

where

$$\sigma_k = B_{2k} \ \Gamma_k^2 + B_{4k} \ \Phi_k^2 .$$

$$\phi_k = B_{1k} \ \Gamma_k + B_{3k} \ \Phi_k$$

Empirical estimates of equation (B7) yield a biological response function for broiler weight gain that is used in estimating the amount of broilers raised in each county within the area of study. This equation is as follows and was estimated from data derived from Tables LXXX and LXXXI.

$$W_k = -0.2068 + 4.3219F_k - 2.0507F^2_k \tag{B8}$$

Table LXXX

Broiler Finisher Diet

Ingredient	Percent
Yellow Corn (NRC)	72.345
Soybean Meal (NRC)	18.782
Meat & Bone (NRC)	4.918
Poultry Oil (NRC)	2.513
Limestone	0.5833
Salt	0.3738
Broiler Vitamin (PWW)	0.2
Trace Mineral (PWW)	0.1
Threonine	0.082
DL Methionine 98	0.0528
Lysine HCL 98%	0.0499

Table LXXXI

Broiler Energy and Protein Values

Ingredient	Metabolizable Energy (kcal/kg)	Protein %
Yellow Corn (NRC)	3,350	8.5
Soybean Meal (NRC)	3,500	94.1
Meat & Bone (NRC)	2,150	50.4
Poultry Oil (NRC)	2,360	81
Limestone	—	—
Salt	—	—
Broiler Vitamin (PWW)	—	—
Trace Mineral (PWW)	—	—
Threonine	—	—
DL Methionine 98	3,606	57.52
Lysine HCL 98%	3,607	94.4

APPENDIX C

Appendix C

The optimization model is based on maximizing equation (1) subject to the constraint set (2)-(8). The decision variables in this model are V^z_{nk}, L^z_{kint}, A^z_{kin1}, A^z_{kin2}, Y^z_{nk}, M^z_{kin}, X^z_{kj}, and F^z_{kn}. The Kuhn-Tucker conditions for these decision variables are:

$$r^z_{1nk} - \phi^z_{nk} - \Gamma^z_{nk}\eta^z_{nk} \le 0 \tag{C1.a}$$

$$\left[r^z_{1nk} - \phi^z_{nk} - \Gamma^z_{nk}\eta^z_{nk}\right]V^z_{nk} = 0 \tag{C1.b}$$

$$(z = 1, 2)$$

$$(n = 1, \ldots, N)$$

$$(k = 1, \ldots, K)$$

$$-\phi^z_{kn}\left[-f^z_{2kn} - 2f^z_{3kn}F^z_{kn}\right] \le 0 \tag{C.2a}$$

$$\left[-\phi^z_{kn}\left(-f^z_{2kn} - 2f^z_{3kn}F^z_{kn}\right)\right]F^z_{kn} = 0 \tag{C.2b}$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$(n = 1, \ldots, N)$$

$$m^z_{kint} - \mu^z_{kn} - \Delta^z_{kin}a^z_{kint1} - \gamma^z_{nk}a^z_{kint2} \le 0 \tag{C3.a}$$

$$\left[m^z_{kint} - \mu^z_{kn} - \Delta^z_{kin}a^z_{kint1} - \gamma^z_{nk}a^z_{kint2}\right]L^z_{kint} = 0 \tag{C3.b}$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$(i = 1, \ldots, I)$$

$$(n = 1, \ldots, N)$$

$$(t = 1, \ldots, T)$$

$$\upsilon^{z}_{kin1} + \Delta^{z}_{kin}\alpha^{z}_{kin1} - \lambda\beta^{z}_{kin1}\left(1-\alpha^{z}_{kin1}\right) \leq 0 \qquad \text{(C4.a)}$$

$$\left[-\upsilon^{z}_{kin1} + \Delta^{z}_{kin}\alpha^{z}_{kin1} - \lambda\beta^{z}_{kin1}\left(1-\alpha^{z}_{kin1}\right)\right]A^{z}_{kin1} = 0 \qquad \text{(C4.b)}$$

$(z = 1, 2)$

$(k = 1, \ldots, K)$

$(i = 1, \ldots, I)$

$(n = 1, \ldots, N)$

$$-\upsilon^{z}_{kin2} + \gamma^{z}_{kin}\alpha^{z}_{kin2} \leq 0 \qquad \text{(C5.a)}$$

$$\left[-\upsilon^{z}_{kin2} + \gamma^{z}_{kin}\alpha^{z}_{kin2}\right]A^{z}_{kin2} = 0 \qquad \text{(C5.b)}$$

$(z = 1, 2)$

$(k = 1, \ldots, K)$

$(i = 1, \ldots, I)$

$(n = 1, \ldots, N)$

$$-b^{z}_{nk} + \Gamma^{z}_{nk} - \varepsilon^{z}_{nk} \leq 0 \qquad \text{(C6.a)}$$

$$\left[-b^{z}_{nk} + \Gamma^{z}_{nk} - \varepsilon^{z}_{nk}\right]Y^{z}_{nk} = 0 \qquad \text{(C6.b)}$$

$(z = 1, 2)$

$(n = 1, \ldots, N)$

$(k = 1, \ldots, K)$

$$-e^{z}_{kin} + \Gamma^{z}_{kn} + \Delta^{z}_{kin}\alpha^{z}_{kin1}\theta^{z}_{kin1} + \gamma^{z}_{kin}\alpha^{z}_{kin2}\theta^{z}_{kin2} - \lambda\beta^{z}_{kin1}\left(1-\alpha^{z}_{kin1}\right)\theta^{z}_{kin} \leq 0 \qquad \text{(C7.a)}$$

$$\left[-e^{z}_{kin} + \Gamma^{z}_{kin} + \Delta^{z}_{kin}\alpha^{z}_{kin1}\theta^{z}_{kin1} + \gamma^{z}_{kin}\alpha^{z}_{kin2}\theta^{z}_{kin2} - \lambda\beta^{z}_{kin1}\left(1-\alpha^{z}_{kin1}\right)\theta^{z}_{kin1}\right]M^{z}_{kin} = 0 \qquad \text{(C7.b)}$$

$(z = 1, 2)$

$(n = 1, \ldots, N)$

$(k = 1, \ldots, K)$

$(i = 1, \ldots, I)$

$$\frac{-\partial C_{kj}^{z}}{\partial X_{kj}^{z}} + \lambda E_{kj}^{z} \leq 0 \qquad \text{(C8.a)}$$

$$\left[\frac{-\partial C_{kj}^{z}}{\partial X_{kj}^{z}} + \lambda E_{kj}^{z}\right] X_{kj}^{z} = 0 \qquad \text{(C8.b)}$$

$(z = 1, 2)$

$(k = 1, \ldots, K)$

$(j = 1, \ldots, J)$

The variables ϕ_{nk}^{z}, Γ_{nk}^{z}, ε_{nk}^{z}, μ_{kn}^{z}, Δ_{kin}^{z}, γ_{kin}^{z}, and λ are Lagrangean multipliers for the broiler growth response balance equation, the poultry litter balance equation, the litter storage capacity constraint, the phosphorus balance equation, the nitrogen balance equation, and the phosphorus constraint, respectively.

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