Project Summary: CEEOT-LP
Modeling for Duck Creek Watershed, Texas

Keith Keplinger and Joju Abraham

PR0206
November 2002
Acknowledgments

The generous contributions and insights of many individuals are acknowledged, without which this report would not have been possible. They include Darrell Williams, Clyde Bohmfalk, Cary Betz, Catherine Nash, and David Lusk of the Texas Commission on Environmental Quality (TCEQ); John O’Connor, James Moore, and Steven Deiss of the Texas State Soil and Water Conservation Board (TSSWCB); Rick Leopold, Mike Lampe, Mike Stellbauer, and Dean Platt, USDA, Natural Resources Conservation Service; Philip Moore, USDA, Agricultural Research Service; Scott Radcliffe and Gregory Mullins, Virginia Tech.; Fraulene McKnight and Eric Eicher, BASF Corporation, and Karla Doremus-Tranfield, General Chemical, Inc. Our colleagues (all from TIAER) were also most helpful in the production of this report. They include Edward Osei and Ali Saleh who reviewed parts of the manuscript, Jim Vergura for providing regulatory expertise, Bill Ross for producing the graphic for the report, and Sarah Griffith and the Media Group for editing and formatting. In particular, the useful insights, overall direction, and reviews of this report by Larry Hauck and Ron Jones of TIAER are gratefully acknowledged.

The research upon which this report is based was financed by the U.S. Environmental Protection Agency, Office of Policy, cooperating agreement number CR 826807-01-1. For more information about this document or any other TIAER document, e-mail info@tiaer.tarleton.edu.

Mention of trademarks or proprietary products does not constitute a guarantee or warranty of the product and does not imply its approval to the exclusion of other products that also may be suitable.

Authors

Keith Keplinger, research economist, TIAER, keplinger@tiaer.tarleton.edu

Joju Abraham, senior research associate, TIAER, abraham@tiaer.tarleton.edu
Duck Creek project was initiated to determine potential economic and environmental impacts of broiler industry growth and alternative broiler litter best management practices (BMPs) within the watershed. Results of this analysis can also be generalized, to some extent, to larger geographic areas. The Comprehensive Economic and Environmental Optimization Tool - Livestock and Poultry (CEEOT-LP) modeling framework was employed to conduct economic and environmental evaluations of industry expansion and BMPs on ambient water quality measures. CEEOT-LP model results indicate that, in year 2000, phosphorus loading from the application of poultry litter to crop fields constituted only a small fraction of total phosphorus (P) loads in Duck Creek watershed. Applying litter at an agronomic nitrogen (N) rate over most available cropland, however, could result in in-stream P loads at more than twice year 2000 levels, with litter application being the major contributor to loads. Results indicate that ambient P loads from Duck Creek watershed can be substantially reduced by reducing the rate of litter application, hauling off litter, adding phytase to broiler feed, and amending broiler litter with alum. P rate scenarios are substantially more cost-effective than haul-off scenarios. The phytase and alum BMPs produce net economic benefits in addition to reducing P loads. The alum scenario results in reductions of ambient P approximately equal to a complete haul off of litter while producing net economic benefits to the broiler industry. Due to the highly integrated nature of the broiler industry and BMP specific requirements, full implementation of the phytase and alum BMPs may require the coordination and cooperation of poultry integrators.
## Contents

Project Summary: CEEOT-LP Modeling for Duck Creek Watershed, Texas ............ 11
- Background ............................................................................................................. 11
- Year 2000 Baseline .............................................................................................. 14
  - Baseline Regulatory Status ............................................................................... 14
  - Economic and Agronomic Considerations ......................................................... 16
  - Baseline Agricultural Practices ......................................................................... 17
  - Economic Baseline ............................................................................................ 19
  - Environmental Baseline .................................................................................... 20
- Litter Application Scenarios ... 21
- Expansion Scenarios ............................................................................................ 23
- BMP Scenarios ..................................................................................................... 24
- Research Methodology ......................................................................................... 26
  - Environmental Analysis .................................................................................... 26
  - Economic Analyses ........................................................................................... 27
- Research Results .................................................................................................. 28
  - Expansion Scenarios ........................................................................................... 28
  - BMP Scenarios ................................................................................................... 30
- Summary and Conclusions .................................................................................. 34

References ................................................................................................................ 37
Tables

Table 1  Nutrient Value of Broiler Litter, Duck Creek Region .............................................. 16
Table 2  Summary Statistics of Measured Concentration Data during Year 2000 ......................... 21
Table 3  Changes in Ambient Loads Resulting from Industry Expansion,
         Duck Creek Watershed ................................................................. 29
Table 4  Changes in Economic Activity Resulting from Broiler Industry Expansion,
         Duck Creek Watershed ................................................................. 29
Table 5  Fertilizer Prices, Application Rates, and Total Per Acre Fertilizer Expense for
         BMP Scenarios for Representative Pasture and Hay Operations, Duck Creek
         Watershed, Texas ................................................................. 30
Table 6  Annual Cost and Savings for a Phytase Supplemented Diet, Duck Creek Watershed ........ 31
Table 7  Annual Costs and Benefits of Alum Litter Treatment Per Broiler House,
         Duck Creek Watershed ................................................................. 32
Table 8  Annual Costs (Benefits) of Implementing BMP Scenarios for Representative
         Operations, Broiler Integrator, and Duck Creek Watershed ($) ......................... 33
Table 9  Cost-Effectiveness Ratios for Phosphorus BMPs, Duck Creek Watershed ................. 34
Figures

Figure 1  Duck Creek Watershed and Location of Broiler Operations ......................... 13
Figure 2  Comparison Between Measured and Predicted Average Nutrient and Sediment
           Concentrations, Year 2000 ................................................................. 22
Figure 3  Average Annual Phosphorus Loads for BMP Scenarios, Duck Creek .............. 34
This report summarizes major research findings of a detailed analysis of current conditions, industry expansion, and phosphorus best management practices (BMPs) for broiler operations in Duck Creek watershed, a small subbasin of the Navasota River watershed. Baseline environmental and economic conditions are more thoroughly treated in Keplinger and Abraham (2002a) while results of BMP and expansion scenarios are fully documented in Keplinger and Abraham (2002b). The regulatory environment pertaining to broiler operations in Texas is also summarized in this report and more thoroughly discussed in Keplinger (2001a). This study utilized the Comprehensive Economic and Environmental Optimization Tool - Livestock and Poultry (CEEOT-LP), a suite of linked economic and environmental models, to evaluate baseline economic and environmental conditions and the impacts of BMPs and industry growth.

Background

Nutrient pollution originating from agricultural operations has emerged as a leading source of nonpoint source (NPS) impairment in the nation’s waterways. The Environmental Protection Agency (EPA) identified nutrients as the most common pollutant in the nation’s surveyed lakes, and the second most common pollutant (after sediment) for surveyed rivers, while agriculture was cited as the leading source of impairment for both surveyed lakes and rivers (EPA, 2000). Excess nutrients washed into lakes, rivers, and estuaries often cause algal growth and eutrophication, which can lead to impaired biological integrity, unpleasant taste and odor, and diminished recreational opportunities.

Animal feeding operations (AFOs), in particular, have come under close scrutiny by regulators and the public as major sources of nonpoint source pollution. In many cases, large AFOs are designated and regulated as point sources. As such, BMPs are often implemented in production areas to eliminate or minimize point source discharges. The most common disposal method for animal manure, however, is application to crop fields. Once manure is removed from production areas and applied on cropland, it becomes a potential nonpoint source of nutrients. The nitrogen (N) to phosphorus (P) ratio typically found in animal manures exacerbates the potential of animal manures to impair surface waters. Application of manure or poultry litter at an agronomic N rate (a rate supplying crop the N needs) typically necessitates applying several times the crop P requirement. Many soils can partially absorb much of the excess P. Substantial loads of soluble and organic P, however, run-off into surface waters, primarily during heavy rainfall events. In addition, as P
builds up in soils, soils may become saturated and become a source of P. Since surface waters are typically P limited, algae and aquatic weeds often respond quickly to increased P loads, resulting in eutrophication and its consequences.

AFOs have become particularly problematic as a source of NPS pollution in recent years in part because of rapidly changing production techniques. First, individual operations have become ever larger as economies of scale and newer, less labor intensive, production techniques have been exploited. Secondly, production has concentrated in certain regions of the country due to logistical and climatic reasons. Although these efficiencies have resulted in lower prices to consumers, a by-product of the pattern of larger and more regionally concentrated animal production has been the concentration of large amounts of animal waste in production regions.

The transformation of the poultry industry in the United States has been especially compelling and is often cited as an industry model that may characterize much of US agriculture in the future. Prior to the 1950s, most farms raised chickens, but meat was a by-product of egg production (Perry, Banker, and Green, 1999). “Today, about 12,000 specialized farms produce more than 900 million birds for meat and 72 billion eggs per year…. All segments of the industry—producers, processors, hatcheries, geneticists, nutritionists, veterinarians, suppliers, marketing firms, and consumers—have combined to transform the industry from a minor sideline enterprise into a complex agribusiness.” (Perry, Banker, and Green, 1999). It is not unusual today for a single grower to raise in excess of 1.25 million 5 to 6-lb broilers while producing about 1,600 tons of broiler litter annually.

The concentrated nature of today’s broiler industry lends itself to the concept of cumulative impacts. The application of litter to a watershed from many broiler operations is much more likely to result in environmental impairment than the application of litter from a single operation, even though each operation may be implementing prescribed BMPs. Environmental regulatory authorities have typically prescribed regulation in an across the board fashion. The net effects of cumulative impacts, however, suggests that the extent and nature of regulation should take into consideration the density of operations and the ability of a watershed to assimilate wastes. The total maximum daily load (TMDL) approach to water quality, by focusing on ambient water quality, explicitly recognizes the importance of cumulative impacts. Because of the concentrated nature of today’s animal agriculture and the fact that ambient-based TMDLs have emerged as a prominent water quality control mechanism, cumulative impacts of animal waste applications have become a major water quality issue.

Sanderson Farms, Inc., a poultry integrator, commenced operation of a poultry processing facility just north of Bryan, Texas in Brazos County in the summer of 1995. Sanderson Farms initially processed broilers purchased from another poultry integrator, but soon contracted with farmers in a several county area in the proximity of its processing plant to grow broilers. The first Sanderson contract growers went into operation in the summer and fall of 1996. Seventeen operations located in Robertson County, nine of which are within Duck Creek watershed. Duck Creek watershed was selected as the focus of this study because its landscape is representative of the larger Middle Brazos and Navasota watershed, which is the
focus of a larger study of which this study is part, and because of the relatively high
density of broiler operations in the watershed.

Duck Creek is a small tributary of the Navasota River, which, in turn, flows into the
Brazos River, a major river system in Texas. The watershed, located in east central
Texas, covers a geographic area of 97,455 acres and measures approximately 21 miles
long by 12 miles wide (Figure 1). The watershed is situated almost entirely within
Robertson County and is almost entirely rural, with only two small communities,
Franklin and New Baden, lying partially or completely within the watershed (see
Figure 1). An estimated 1,105 people reside within the watershed.

Figure 1 Duck Creek Watershed and Location of Broiler Operations

Based on a GIS land use layer created from a Landsat image of the watershed and
other information, land use in Duck Creek watershed is estimated to be 28 percent
pasture, 9 percent hay, 45 percent range, 14 percent forest, 2 percent urban and other
hard surfaces, and 1 percent water. An estimated 53 percent of hay fields and 19 percent of pastureland is assumed fertilized with broiler litter. Keplinger (2001b) provides additional background and land use information.

Environmental and economic analyses described in this report were conducted within the CEEOT-LP (Comprehensive Economic and Environmental Optimization Tool – Livestock and Poultry) modeling framework. CEEOT-LP is a suite of integrated environmental and economic models used to promote the scientific investigation of environmental problems associated with livestock and poultry and to provide a scientific basis for environmental decision-making. The Soil and Water Assessment Tool (SWAT), a component of the CEEOT-LP framework, was employed to simulate environmental baseline measures and environmental implications of industry expansion and BMP scenarios.

Year 2000 Baseline

Year 2000 baseline conditions for broiler and water quality-related measures in Duck Creek watershed are documented to provide an assessment of current conditions that can be compared to hypothetical scenarios. The five key components of the baseline analysis are: 1) baseline regulatory status, 2) economic and agronomic considerations, 3) baseline agricultural practices, 4) the economic baseline, and 5) the environmental baseline. Baseline regulatory status and economic and agronomic considerations largely determine baseline agricultural practices which, in turn influence economic and environmental baselines.

Baseline Regulatory Status

Although the risk of water impairments from the production area of broiler operations is minimal because of their reliance on dry waste management systems, broiler litter is typically removed from houses and land applied, where there is potential for nutrients and other pollutants to run off fields and into streams. The Clean Water Act (CWA) is the primary source of federal water quality control. Although the CWA addresses nonpoint source pollution in a number of sections, its major regulatory mechanism, the National Pollutant Discharge Elimination System (NPDES), applies only to point sources. Federal regulations define concentrated animal feeding operations (CAFOs) as point sources subject to the NPDES permit program. The federal definition of CAFO, however, excludes virtually all broiler operations.

Broiler operations in Texas house large numbers of birds in confined situations and, thus, are considered animal feeding operations (AFOs). The criteria for determining whether an AFO is a CAFO include the number of animals confined and whether or not pollutants are discharged from the facility. An AFO can also be designated a CAFO on a case-by-case basis upon determining that it “is a significant contributor of pollution to the waters of the United States” (40 CFR § 122.23). For broiler operations, CAFO designation also depends on the type of manure system employed. For example, broiler operations are defined as CAFOs if more than 100,000 chickens are confined and the facility has continuous overflow watering, or more than 30,000
chickens are confined and the facility has a liquid manure system (40 CFR § 122, App. B).\(^1\) Although used more commonly in the past, few if any broiler operations in the United States (and in Texas) currently employ liquid manure systems or continuous overflow watering, and consequently avoid CAFO classification and regulation under the NPDES program. Most broiler operations today have adopted dry bedding to capture manure in lieu of liquid manure systems and utilize nipple or other “water on demand” systems instead of continuous overflow watering systems.

Although the Texas Commission on Environmental Quality (TCEQ) administers most state environmental regulations, Texas Senate Bill 503 (1993) designated the Texas State Soil and Water Conservation Board (TSSWCB) as “the lead agency in [Texas] for activity relating to abating agricultural and silvicultural nonpoint source pollution.” The TSSWCB is charged with developing a water quality management certification program, investigating complaints concerning violations of law relating to agricultural or silvicultural nonpoint source pollution, and, where warranted, developing and implementing a corrective action plan to address the complaint. Although the TSSWCB does not have regulatory authority, it is obligated to refer complaints or violations of a TSSWCB certified water quality management plan (WQMP) to the TCEQ if corrective action is refused. The TCEQ may then exercise its authority under appropriate state regulation. Broiler operations, thus, must either comply with TSSWCB certified WQMPs, or else risk being subject to state regulation.

An important aspect of Texas CAFO regulation is that its technical requirements also apply to all AFOs in Texas, unless the AFO is operating under a TSSWCB certified WQMP. The Texas Water Code authorizes the TSSWCB to develop and certify site-specific WQMPs for areas of the state that the TSSWCB “identifies as having or having the potential to develop agricultural or silvicultural nonpoint source water quality problems...” (§ 201.026(c)). TSSWCB certified WQMPs must “satisf[y] [TSSWCB] rules and criteria and compl[y] with state water quality standards established by the [TCEQ]” (Texas Water Code § 201.026(c)). WQMPs are very comprehensive, covering all land areas of an operation, including litter application fields. Their provisions are very similar to those required in pollution prevention plans and other technical requirements in Texas CAFO regulation since they are both based on Natural Resources Conservation Service (NRCS) practice standards.\(^2\) Almost all broiler operations in Texas have obtained TSSWCB certified WQMPs and are thereby exempt from Texas CAFO regulation as well as federal NPDES regulation.

Adoption of WQMPs by producers is completely voluntary from the standpoint of the TSSWCB and the state of Texas. Poultry integrators, however, strongly encourage and often require their growers to obtain WQMPs and lenders typically require them.

---

1. In addition, if pollutants are discharged into navigable waters, broiler operations are also considered CAFOs if more than 30,000 chickens are confined, and the facility has continuous overflow watering, or more than 9,000 chickens are confined, and the facility has a liquid manure system (40 CFR § 122, App. B).

2. WQMPs prescribe NRCS practice standards for each defined area or field of an operation. Practice standards that might typically apply to a combined poultry-beef operation include heavy use area protection, pest management, waste management system, compost facility, waste storage structure, forage harvest management, nutrient management, prescribed grazing, filter strip, waste utilization, upland wildlife habitat management, and riparian forest buffer.
An informal survey of agency personnel reveals that almost all broiler operations in Texas have obtained certified WQMPs. Other aspects of the regulation of broiler operations in Texas, including air quality considerations, worker safety, and nuisance and “right to farm” law, are discussed in Keplinger (2001a).

Regulatory aspects of greatest relevance to this research are those potentially influencing litter application rates. Maximum litter application rates are specified on a field by field basis in TSSWCB certified WQMPs. Most litter in Duck Creek and elsewhere in the region, however, is sold and applied to off-site hay fields and pastures, which are much less likely to be operating under WQMPs. In these situations, the only regulatory mechanisms that might apply would be those generally applying to nonpoint source pollution. Evidence suggests that economic and agronomic considerations, as described below, rather than regulation, are currently the major drivers governing off-site litter application in the Duck Creek region.

**Economic and Agronomic Considerations**

In addition to regulatory constraints, agricultural practices are the result of a multitude of other factors. These include current technology, beliefs and attitudes, availability of farm assistance programs, dissemination of information, industry structure, crop nutrient requirements, density of producers, prices of inputs and crops, and numerous other site-specific variables. Economic and agronomic considerations, as influenced by these factors, play major roles in determining the rate at which litter is applied.

Broiler litter, like other manures, contains valuable nutrients and, hence, is a beneficial soil amendment. Table 1 calculates the value of litter N, P$_2$O$_5$, and K$_2$O. Micronutrients and organic matter also add to the value of litter (Vogt, 2000) but placing values on these constituents is hampered by a lack of knowledge regarding their quantities and benefits. Table 1 indicates that the value of litter depends not only on how much of various nutrients are available in the litter but which nutrients are required. Economic theory suggests that farmers would pay up to $32.93/ton of litter if all three major nutrients (N, P, and K) were required, up to $26.33/ton if N and P were required, up to $15.32/ton if only N and K were required, and up to $8.72/ton if only N was required.

**Table 1** Nutrient Value of Broiler Litter, Duck Creek Region

Sources: nutrient content: NRCS; prices: National Agricultural Statistics Service, USDA

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Nutrients in Litter (lb/ton)</th>
<th>Price / Unit Nutrient ($/lb)</th>
<th>Value of Litter ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>$0.22</td>
<td>$8.72</td>
</tr>
<tr>
<td></td>
<td>P$_2$O$_5$</td>
<td>$0.26</td>
<td>$17.61</td>
</tr>
<tr>
<td></td>
<td>K$_2$O</td>
<td>$0.14</td>
<td>$6.60</td>
</tr>
<tr>
<td></td>
<td>Other$^b$</td>
<td>various</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>?</td>
<td>$32.93 $26.33 $15.32 $8.72</td>
</tr>
</tbody>
</table>

$^a$ Accounts for an assumed N volatilization of 20 percent after litter is land applied.

$^b$ Micronutrients and organic matter, unknown quantities and economic value.
Litter sales and prices in the region suggest that the price of litter averages around $25/ton and has been reported as high as $30/ton. This price range is consistent with the value of its N and P content and somewhat less than the fertilizer value of N, P, and K. At observed prices, economic theory would predict that litter would be applied at a rate that would substitute for commercial P (a P substitution rate). Professional judgment by NRCS field personnel indicates a litter application rate on hay land averaging 1.5 tons/acre. This observed rate is essentially a P requirement rate, i.e., it supplies the published P requirement for Coastal Bermuda grass hay. For definitions of rates, see Keplinger and Abraham (2002a), Appendix A.

The relatively high price of litter and resulting low application rates can be attributed to its relative scarcity in the region in relation to potential litter application sites (hay fields and pasture). This contrasts with other areas of the nation, where the density of broiler operations is much higher, and available land on which to apply litter is much less in relation to the amount of litter produced. If litter N were available at less than the price of commercial N (implying a litter price of less than $8.72/ton), there would be an economic incentive to replace commercial N with litter N, resulting in much higher application rates.

In summation, economic and agronomic considerations, rather than regulatory constraints, are presently driving the use of broiler litter and its price in the watershed. Potential demand for litter, based on crop requirements for N and P, is large relative to supply, causing high prices. High prices, in turn, limit the rate at which litter can be economically applied to essentially a P requirement rate. A significant expansion of broiler operations in the watershed would increase supply of litter, lower prices, and thereby create an incentive to apply litter at higher rates. Predicted cumulative effects of expansion scenarios are quantified later in the report.

Baseline Agricultural Practices

Broiler Production

As of year 2000, Duck Creek watershed contained 9 broiler-growing operations with a total of 52 broiler houses. Each grower operated 4, 6, or 8 broiler houses, which are typically 44 feet wide by 500 feet long. Contracts with Sanderson Farms allowed 27,500 broilers to be grown in each house, with finish weights averaging between 5 and 6 lb per broiler. While the number of flocks raised per year can vary, in 2000, Sanderson Farms growers averaged close to 6 flocks per year (Lampe, 2000). A typical growing cycle is about 50 days, while 1 to 2 weeks is generally allowed between flocks to prepare houses for the next flock. Under contract terms, the integrator (Sanderson Farms) supplies contract growers chicks, feed, wood shavings for bedding, veterinary services, and expertise. Growers return grown broilers to the integrator at the end of the growing cycle and are paid based on the live weight of grown broilers.

3 In these regions, litter is often given away, and there is an incentive to over-apply litter P because of the low, zero, or negative price of litter. High levels of soil test P and stream impairment attributable to high concentrations of ambient P are often found in these regions.
Litter Management

Partial clean outs of poultry houses, called “cake outs,” occur after each flock. Cake outs typically produce about eight tons of litter per house, which is often spread on growers’ hay fields or pastures immediately after the cake out, but is sometimes sold and transported to nearby hay fields or pastures. In the Duck Creek region, broiler houses are completely cleaned out by clean-out contractors about once a year. Clean outs produce about 160 tons of litter, which is typically sold to a clean-out contractor who hauls the litter directly to a buyer on a waiting list and land applies it at buyer-specified rates. Clean-out contractors currently offer growers in the region about $15/ton for litter, and receive up to $26/ton from buyers (Lampe, 2000). Approximately 200 tons of litter is produced per broiler house annually (40 tons from cake outs, and the remaining 160 tons from annual clean outs). Given that there are 52 broiler houses in Duck Creek watershed, an estimated 10,400 tons of litter are produced annually.

Crops

Although there is wide latitude in how any individual producer will manage his/her land, the following descriptions represent typical practices and average rates, which were used for model simulations in the analysis.

Hay Land

Coastal Bermuda grass is the primary hay variety grown in Duck Creek watershed. On average, 3 cuttings per year are made, producing average annual yields of 5.5 tons/acre. Hay fields not receiving litter receive commercial fertilizer, on average, at the rate of 300 lb N and 50 lb P$_2$O$_5$ per acre. On litter fertilized hay fields, litter is typically applied at a rate of three tons/acre every other year. During off years, commercial N is generally applied at the same rate as that for hay land not receiving litter. During years when litter is applied (on years), supplemental applications of commercial N are also typically made after the first and second cuttings so that the recommended annual N application of 300 lb/acre is achieved. We also assume that supplemental K$_2$O is applied such that total K$_2$O from litter and commercial fertilizer equals 100 lb/acre.

Pastureland

A variety of grasses are grown on pastureland in the Duck Creek region, bahia grass being the dominant species, followed by common Bermuda grass. One hay cutting is made on approximately 30 percent of pastureland in the watershed while the remainder is not hayed. Overall, a stocking density of a 0.2 cows/acre is assumed. For commercially fertilized pasture, both hayed and not hayed, application of 50 lb N and 25 lb P$_2$O$_5$ per acre every other year is typical, resulting in average annual

---

4 Fertilizer and litter application rates as well as other agronomic practices are based on expert opinion of NRCS personnel familiar with practices in the region (Leopold, 2000; Platt, 2000). To estimate the appropriate amount of broiler litter to apply on pastures and hay fields, NRCS assumes average nutrient content of broiler litter to be 40 lb N, 68 lb P$_2$O$_5$, and 48 lb K$_2$O per ton of litter if a nutrient analysis from a litter sample is not available. It is noted that there is a great variation in nutrient contents of broiler litter and that content analysis of broiler litter from other regions of the country often indicates higher levels of N and lower levels of P$_2$O$_5$ than those assumed herein.
applications of 25 lb N and 12.5 lb P₂O₅ per acre. For litter fertilized pastureland, both hayed and not hayed, an application is made, on average, every three years at the rate of two tons/acre. Typically, no supplemental commercial fertilizer applications are applied on pastureland receiving broiler litter.

Rangeland
Rangeland in the region consists of a variety of domestic and wild grasses and is not fertilized. Cows on range, however, require supplemental minerals and hay during winter months. On average, rangeland is stocked at the rate of about 0.1 cows/acre. Although rangeland is not considered potential litter application area in this study, with fertilization, either from commercial fertilizer or litter, rangeland can be converted to pastureland.

Economic Baseline
Most litter produced in Duck Creek watershed is sold and transported off-site where it is applied on hay fields and pastures. Consequently, baseline financial measures were developed for representative pasture and hay operations in addition to a representative broiler operation.

Representative Broiler Operation
In 2000, a typical 4-house operation was estimated to have produced approximately 3.3 million pounds of chicken which was sold to Sanderson Farms for an average of 4.5 cents/lb, resulting in annual gross revenue from broiler sales equaling an estimated $149,600. This analysis assumes that all litter (200tons/house) is sold and that growers received, on average, $14.31/ton of litter. Revenue from litter sales, thus, is estimated at $11,500 resulting in annual revenues totaling an estimated $161,100.

Electricity for fans and propane for heating are the two single largest expenses incurred by growers, followed by building repairs and maintenance. Other expenses include maintenance of equipment, property taxes, annual clean outs, the spreading of wood shavings, insurance, and supplies. Annual expenses for the representative broiler operation in year 2000 totaled an estimated $51,610.

Broiler operations are capital intensive. A 4-house operation in the Duck Creek region required an estimated initial capitalization of $705,000, the largest single expense being the construction of broiler houses ($600,000 for 4 houses). Other capital expenses include unimproved acreage, one 70-horsepower tractor, a poultry housekeeper, well drilling, and a wash-down unit. The majority of capital expenses are typically financed. Assuming typical down payments and loan terms, capital costs (loan payments) for the first 5 years of operation are estimated at $84,099 annually. These payments decline to $0 as loans are paid off. Thus, the representative broiler operation’s annual before-tax cash income varies between $25,300 and $109,400, depending of the stage of the capital cycle. It is here assumed that a poultry house has a lifetime of 30 years after which a new capital/financing cycle would begin. The average annual capital cost (real annuity equivalent) was estimated to be $48,531, resulting in an average annualized before-tax cash income of $60,912 for a
representation 4-house operation over the 30-year capital cycle. Detailed assumptions for all financial calculations are presented in Keplinger and Abraham (2002a).

**Representative Pasture Operations**

Revenue and expense statements were developed for representative pasture and hay operations that use only commercial fertilizer (commercial fertilizer operations) and for those using litter (litter operations). It is assumed that production, revenues, and expenses for commercial fertilizer and litter operations are identical in all respects except for fertilization expense. Annual revenues for representative 200-acre pasture operations, generated from the sale of cull cows, heifer calves, and steer calves, totaled as estimated $13,400. Estimated fertilizer expense was $2,300 for the pasture operation using commercial fertilizer and $3,300 for the operation using litter. Other expenses, most of which consist of supplemental feeding requirements, totaled $5,000. Annual capital costs for vehicles and equipment were estimated at $8,500. Thus, expenses and capital costs totaled $15,700 and $16,800, respectively, for the commercial fertilizer and litter pasture operations. Before-tax cash income was negative for both operations: -$2,300 and -$3,400, respectively, for the representative commercial fertilizer and litter pasture operations.

**Representative Hay Operation**

For a representative 100-acre hay operations, we assumed 11.5 tons annual production per acre, or approximately 144 80-lb bales. At $2.00 per bale, this generates revenues of $28,800. Fertilizer expense totaled approximately $9,800 for both the commercial fertilizer and litter operations. Other expenses, mainly for baling and hauling, totaled $15,600. Estimated annual capital costs, which totaled $2,600, are relatively small because custom baling and hauling are assumed, eliminating the need for harvesting and hauling equipment. Expenses and capital costs totaled $28,100 for both the commercial fertilizer and litter operations. Before-tax cash income is therefore small, but positive: about $700 for both types of operations. Revenues and expenses are similar for both operations suggesting that the type of fertilization chosen (commercial or litter) has little impact on farm profitability.

**Environmental Baseline**

The environmental baseline represents the status of key environmental indicators in the watershed for year 2000, particularly sediment and nutrient loadings, and serves as a reference for modeling expansion scenarios. To closely reflect year 2000 conditions, the baseline represents a 6-year period (1995 to 2000) corresponding to the length of time that broiler operations in the Duck Creek watershed have been in operation.

Statistics of measured sediment and nutrient concentrations, summarizing 46 days of stormwater data collected by the Brazos River Authority in 2000, are reported in Table 2. Target constituents had concentrations over a wide range, typical of storm runoff samples. Average concentrations of soluble P$_5$ (0.111 mg/L) and total P (0.315 mg/L) are below the TCEQ’s screening level of 0.5 mg/L and 0.8 mg/L, respectively, for
streams (TNRCC, 2001). Average nitrate-N concentration (0.590 mg/L) is also below the TCEQ's screening level of 2.76 mg/L for streams.

Table 2 Summary Statistics of Measured Concentration Data during Year 2000

<table>
<thead>
<tr>
<th></th>
<th>Mean (mg/L)</th>
<th>Percent of Total N, P</th>
<th>Minimum (mg/L)</th>
<th>Maximum (mg/L)</th>
<th>Counta</th>
<th>Total Countb</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids</td>
<td>91</td>
<td>0.710</td>
<td>358</td>
<td>46</td>
<td>144</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>Nitrate - N</td>
<td>0.590</td>
<td>0.100</td>
<td>0.800</td>
<td>43</td>
<td>151</td>
<td>0.187</td>
<td></td>
</tr>
<tr>
<td>Organic - N (TKN)</td>
<td>1.370</td>
<td>0.450</td>
<td>2.440</td>
<td>27</td>
<td>54</td>
<td>0.622</td>
<td></td>
</tr>
<tr>
<td>Total N</td>
<td>1.960</td>
<td>0.630</td>
<td>3.148</td>
<td>24</td>
<td>54</td>
<td>0.642</td>
<td></td>
</tr>
<tr>
<td>Soluble P</td>
<td>0.111</td>
<td>&lt; 0.050</td>
<td>0.330</td>
<td>42</td>
<td>151</td>
<td>0.071</td>
<td></td>
</tr>
<tr>
<td>Organic P</td>
<td>0.204</td>
<td>&lt; 0.050</td>
<td>0.753</td>
<td>27</td>
<td>54</td>
<td>0.218</td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td>0.315</td>
<td>&lt; 0.050</td>
<td>0.860</td>
<td>27</td>
<td>54</td>
<td>0.211</td>
<td></td>
</tr>
</tbody>
</table>

Source: Brazos River Authority

a. Total number of days with measurements
b. Total number of measurements

Simulated and measured concentrations of baseline constituents are compared in Figure 2. Figure 2 reveals that predicted average concentrations from the calibrated model closely matched measured concentration data for sediment, soluble P, organic P, and nitrate-N, while predicted average concentration of organic N underestimated measured values by more than 50 percent. Because impairment attributable to phosphorus is the most likely form of impairment, the simulation model was judged to have performed very well for the purposes of this report.

Litter Application Scenarios

Two types of litter application scenarios were simulated: 1) expansion scenarios and 2) BMP scenarios. Expansion scenarios simulate a hypothetical expansion of the regional broiler industry resulting in more land receiving litter and higher application rates. Because of relatively low rates of litter application in the region in 2000, the fact that the broiler industry had operated and litter had been applied in the region for only the past six years, and relatively low levels of soil P, it was hypothesized that litter application in the region may not be responsible for a large portion of ambient P loads in the creek. Research results indicated that year 2000 litter applications to watershed pastures and hay fields contributed less than 12 percent of total phosphorus loads. Application of litter at year 2000 rates and quantities, therefore, may not constitute a present or future water quality concern. Industry expansion, however, would produce more litter causing more land to receive litter at higher rates. Because of the potential environmental consequences of broiler industry expansion, scenarios representing industry expansion were simulated.

5 For this study, soluble P is considered to approximate dissolved orthophosphate-P.

6 Possible explanations for this under prediction are discussed in Keplinger and Abraham (2002a).
Because of the small percentage of total P loads attributed to the litter application practices in 2000, phosphorus control BMPs would also have relatively small impact on P loads. In addition, there may be little need for phosphorus control BMPs because of relatively low in-stream P loads. Under scenarios simulating higher rates on greater land areas, however, P loads are substantially higher and phosphorus control BMPs would make greater impacts and be more needed. Thus, a scenario representing an agronomic N rate of litter application on 75 percent of pastureland and hay fields in the watershed is used as a policy baseline. Phosphorus control BMPs are, thus, assumed to apply to the theoretical agronomic N rate policy baseline, which assumes that approximately 6.1 times the amount of litter is spread on watershed pastures and hay fields than was estimated to occur in 2000.

The following expansion and BMP scenarios were defined:

- Expansion Scenarios
  - Year 2000 conditions (1X)
  - Double the litter spread at current rates (2X)
  - Full expansion at current litter application rates (2.3X)
  - Full expansion at agronomic N application rates (6.1X) (agronomic N rate)
• BMP Scenarios
  □ P application rate (P rate)
  □ Double P application rate (Double P rate)
  □ Complete haul off of litter (Complete haul off)
  □ Haul off of clean-out litter
  □ Phytase addition to broiler feed (Phytase)
  □ Alum addition to broiler litter (Alum)

Expansion Scenarios

Expansion scenarios assume expansion of the regional broiler industry to multiples of year 2000 production levels, which are assumed to result in increases in the amount of litter applied to watershed soils by the same multiples.

Year 2000 Conditions (Expansion Baseline) (1X)

Broiler litter applications on watershed soils over a six-year period were simulated and model results were calibrated to measured data to replicate year 2000 agricultural practices, areas of land application, and environmental measures. Year 2000 litter application practices were then simulated for 30 years using historical weather data. Details are provided in Keplinger and Abraham (2002a). Because this scenario would likely prevail given current cropping practices and the amount of litter available in the region, it is considered the baseline scenario for a series of expansion scenarios.

Double the Litter Spread at Current Rates (2X)

The 2X scenario simulates a doubling of broiler production within Duck Creek watershed and in the region and, hence, assumes twice the litter applied on watershed soils as in year 2000. Because there is adequate land available for expansion of litter application, current application rates are maintained, while litter application areas expand. Hay and pasture acres employing litter do not expand in the same proportion. Because litter is already assumed applied on over 50 percent of hay land, hay land cannot accommodate a doubling of litter applied to it at current rates. In accordance with maximum adoption rate assumptions, litter is assumed applied at baseline rates on 75 percent of hay land, while the remaining litter is assumed spread on pastureland at baseline rates.

Full Expansion at Current Litter Rates (2.3X)

The 2.3X scenario assumes that litter is spread at year 2000 rates on 75 percent of watershed hay land and 75 percent of watershed pastureland resulting in 2.3 times the amount of litter being spread as in the baseline (1X) scenario. We assume that 75 percent is a maximum adoption rate for litter application to both pastureland and hay land due to limiting factors such as timing and odor control.
Full Expansion at N Rates (Agronomic N Rate) (6.1X)

Full expansion of litter application at the agronomic N rate simulates a 6.1-fold expansion of broiler production within Duck Creek watershed and, consequently, 6.1 times the amount of litter applied within the watershed as in year 2000. In accordance with the maximum adoption rate assumption, litter is assumed applied at the agronomic N rate on 75 percent of both hay land and pastureland within the watershed. Agronomic N rates are defined as those rate of litter application that meets crop N needs, taking soil N into consideration.\(^7\)

**BMP Scenarios**

The agronomic N rate scenario, in addition to being a 6.1X expansion scenario, serves as the baseline for the policy scenarios, which are described below. BMP scenarios can be classified into three categories: 1) reduced rate scenarios (P rate and double P rate), 2) haul-off scenarios (complete haul off and haul off of clean-out litter), and 3) amendment scenarios (phytase addition to broiler feed and alum addition to broiler litter).

**P Rate**

The P rate scenario assumes litter is applied at published crop requirement P rates\(^8\) on the same land areas receiving litter in the baseline (agronomic N rate) scenario. Excess litter generated as a result of moving to lower P application rates is assumed hauled out of the watershed.

**Double P Rate**

As its name implies, the double P rate scenario permits litter application at rates supplying twice the P crop requirement on the same land areas receiving litter in the baseline (agronomic N rate) scenario. Like the P rate scenario, excess litter generated as a result of moving to lower double P application rates is assumed hauled out of the watershed.\(^9\)

---

\(^7\) Agronomic N rates for pastureland and hay land were chosen to simulate the maximum rate at which an operator might apply broiler litter if it were available in large quantities at low prices. (Over application of N does not produce additional yields and can harm crops.) For a discussion and definitions of fertilizer application rates, see Keplinger and Abraham (2002), Appendix A.

\(^8\) Crop requirement rates are typically in excess of crop needs because crop requirement rates do not consider nutrients contributed by the soil. Definitions and discussion of fertilizer and litter application rates are provided in Keplinger and Abraham (2002a), Appendix A.

\(^9\) For both rate scenarios simulated in this analysis (P rate and double P rate), it is assumed permissible to apply litter at less than maximum allowable rates. Because agronomic N and P crop needs for pastureland are so much less than published crop N and P requirements, which do not take the buildup of soil nutrients into consideration, litter applications at agronomic N rates may be less than rates supplying published crop P requirements (or double crop P requirements). In such cases, baseline litter application rates are retained. Because no additional yield gains are anticipated if greater than agronomic levels of N are applied, a rancher would have no incentive to increase litter applications above baseline agronomic N rates if a P rate or double P rate were imposed.
Complete Haul Off

A complete haul off of litter from the watershed assumes that all broiler litter is transported off the watershed and that none is applied on watershed soils. In simulating this scenario, typical commercial fertilization schedules replace litter application on all pastures and hay field areas. The complete haul-off scenario also represents a 0X expansion scenario because no broiler litter application in the watershed would be expected in the absence of a regional broiler industry.

Haul Off of Clean-Out Litter

The haul off of clean-out litter scenario assumes that clean-out litter is hauled out of the watershed but that cake-out litter continues to be applied to watershed soils. Removal of litter from regional broiler houses occurs in two phases: cake outs and clean out. After each flock, houses are “caked out,” i.e., a poultry housekeeper removes the caked top layer of litter while leaving the remaining loose litter. Caked out litter is typically applied on broiler growers’ hay fields and pastures soon after it is caked out or is hauled a short distance to neighboring hay fields or pastures. It is estimated that each cake out produces 8 tons of litter per house resulting in 40 tons of cake-out litter annually. The remaining 160 tons of litter is typically cleaned out about once a year, and assumed hauled out of the watershed for this scenario. Because the application of only cake-out litter represents a great reduction of litter application in the watershed, litter is assumed applied at year 2000 rates in order to maximize its value. Simulated commercial fertilization schedules replace litter application on hay land and pastureland areas no longer receiving litter. The haul off of clean-out litter scenario simulates that only 20 percent of the litter produced in the watershed is applied, or an 80 percent reduction from that assumed for the baseline (agronomic N rate) scenario. This scenario is also consistent with a 1.2X expansion scenario, which represents a 20 percent increase in broiler production and litter application from year 2000.

Phytase Addition to Broiler Feed (Phytase)

Phytase is an enzyme that improves the digestibility of certain nutrients, particularly phosphorus, in simple stomached animals. Approximately two-thirds of total phosphorus in corn and soybean meal exists as phytate P, which is largely unavailable to broilers. The phytase enzyme breaks down phytate phosphorus molecules, thereby releasing phosphorus for absorption (Raboy, 1990). A large volume of research has shown that the addition of phytase to poultry diets can effectively substitute for supplemental dietary phosphorus (e.g. Kornegay, Denbow, and Zhang, 1998; Sohail and Roland, 1999; Huff et al, 1998; Waldroup, 1999). Research also indicates that broilers that consume phytase supplemented feed produce manure with a significantly lower P content (e.g., Ferguson et al., 1998; Yan et al., 2000).

---

10 For an operation growing six flocks of broilers per year, cakeouts would be performed after the first five flocks.
Alum Addition to Broiler Litter (Alum)

The addition of aluminum sulfate (alum) and other chemical amendments to broiler litter have been shown to reduce, sometimes dramatically, water soluble phosphorus levels in poultry litter (Moore and Miller, 1994). Laboratory studies by Moore, Jaynes, and Miller (1998) led these researchers to conclude that “aluminum phosphates can be considered geologically stable, at least in the pH range of 4-8, which covers most soils worldwide.” Because phosphorus is effectively “locked up,” alum addition to broiler litter is simulated by specifying a lower phosphorus content of litter.

Detailed descriptions of all expansion and BMP scenarios are found in Keplinger and Abraham (2002b).

Research Methodology

Baseline conditions and environmental and economic impacts of BMP adoption and industry expansion were simulated within the CEEOT-LP modeling framework. TIAER has previously utilized the CEEOT-LP framework to investigate the impacts of confined dairy operations in north-central Texas (Pratt, Jones and Jones, 1997) small dairy pasture operations in northeast Texas (McNitt et al., 1999), and hog, dairy, beef, and mixed operations in Iowa (Keith et al., 2000).

Environmental Analysis

The Soil and Water Assessment Tool (SWAT), a component of the CEEOT-LP framework, was employed to simulate environmental baseline measures and environmental implications of expansion and BMP scenarios. SWAT is a continuous-time, long-term, simulation model designed to predict the impact of management on water, sediment, and agricultural chemical yields in large ungauged basins (Arnold et al. 1998). The model operates on a daily time step and uses routing commands to route water, sediment, and agricultural chemicals through a watershed. SWAT has been successfully applied in watersheds of different sizes (e.g. Srinivasan et al., 1998; Saleh et al, 2000; Spruill, Workman, and Taraba, 2000) and has recently been incorporated in the EPA’s BASINS model system (version 3.0). Further description of the model components and model operation is provided in the SWAT User’s Manual (Neitsch, Arnold, and Williams, 2000) and in Arnold et al. (1998). A brief review of studies that have utilized SWAT is included in Spruill, Workman, and Taraba (2000).

Simulations of expansion and BMP scenarios were performed by modifying crop management data files to accommodate changes in land area and application rates, and modifying the nutrient coefficients in the fertilizer database to reflect changes in nutrient content for BMP scenarios. Land management regimes were specified on a hydrologic response unit (HRU) basis. HRUs are virtual subbasin units characterized by distinct soil and land use. Fertilizer management regimes for HRUs were specified to simulate either commercial fertilizer application or litter application. Simulated areas of litter application were based on the land area needed to accommodate the requirements for each BMP or expansion scenario. Supplemental commercial N
fertilizer was assumed applied on litter fertilized land to meet recommended levels when litter nutrients alone did not reach these levels.

For the phytase scenario, a litter P reduction of 25 percent was chosen as a conservative average value, when phytase is supplemented in broiler diets at recommended levels (Radcliffe, 2001). It is also assumed that both the organic and inorganic portions of litter P are reduced, but that organic litter P is reduced somewhat more than inorganic (soluble) litter P. The alum addition scenario simulates the addition of alum to broiler litter at rates designed to significantly reduce soluble phosphorus in broiler litter. Rates of alum addition recommended by Moore et al. (not dated) were used to estimate the amount and cost of alum used. Based on research findings, addition of alum to broiler litter was simulated by reducing the modeled total phosphorus content in alum treated litter to 20 percent of that specified for untreated litter. In addition, the soluble (inorganic) fraction of litter P was reduced from 50 percent to 5 percent, since alum has been shown to be particularly effective in reducing water soluble P. A third model adjustment was to increase the simulated N content of alum treated litter by 2.9 lb/ton to reflect research findings indicating greater N content in alum treated litter.

For all scenarios, 30 years of weather history were simulated. Development of data files used for economic and environmental modeling, and calibration and validation of the SWAT baseline model for Duck Creek watershed are fully described in Keplinger and Abraham (2002a) while full documentation of research procedures used to estimate environmental and economic impacts of BMP and expansion scenarios is provided in Keplinger and Abraham (2002b).

Economic Analyses

Economic Impact Analysis

Economic impact analysis of broiler industry expansion in Robertson County was conducted using industry multipliers developed with IMPLAN Professional 2.0 software using a Robertson County 1997 structural matrix supplied by the Minnesota IMPLAN Group. Type I and type II multipliers were used to calculate indirect effects, induced effects, and total impacts from initial direct effects of industry expansion. The economic impact of broiler industry expansion is calculated at the county rather than the watershed level because economic measures are not available for watersheds and because a county is a larger and more appropriate geographical area for estimation of economic impacts. A detailed explanation of impact analysis and definitions of various types of impacts and multipliers is presented in Keplinger and Abraham (2002a).

---

11 Field trials of phosphorus runoff by Moore et al. (1997) indicate that the increase from baseline in ambient P loads from fields fertilized with litter treated with alum at their recommended rates is only about 20 percent of the increase in P loads from fields fertilized with normal broiler litter.
Economic Impacts of BMP Scenarios

Economic impacts of BMP scenarios were estimated using partial budgeting analysis. Partial budgeting analysis quantifies changes in costs or benefits due to BMP implementation. Changes in quantities of commercial fertilizer, broiler litter, and amendments (alum and phytase), which were directly specified or induced by BMP scenarios, were multiplied by prevailing prices to estimate the economic implications of BMP scenarios on a per acre or per broiler house basis. Costs of BMP scenarios were calculated for representative operations (pasture, hay, and broiler) by multiplying per acre or per broiler house costs by the applicable number of acres or broiler houses for the representative operation. The P rate, double P rate, alum, and haul-off scenarios either directly simulate or imply removal of litter from the watershed; no additional hauling cost, however, was assumed for scenarios that either explicitly or implicitly involve hauling litter outside the watershed.\(^\text{12}\)

Costs of BMP scenarios at the watershed level were developed by multiplying per acre or per broiler house costs by the number of applicable acres or broiler houses in the watershed. Poultry integrator costs and benefits are also included in watershed estimates. Cost-effectiveness ratios, at the watershed level, were calculated by dividing the watershed cost for each BMP by its environmental effectiveness in terms of reducing simulated ambient P loads in Duck Creek.

Research Results

Expansion Scenarios

Economic Impact (Robertson County)

For year 2000, it was estimated that the broiler industry in Robertson County directly contributed $1,715,000 of value added.\(^\text{13}\) Another $988,000 of value added was estimated to have been generated from indirect and induced business activity related to broiler production. An estimated 47 jobs were generated directly within the broiler industry while another 47 jobs were created as a result of indirect and induced economic activity. At 2000 levels, the broiler industry was estimated to have constituted 0.9 percent of total economic activity in Robertson County and 1.4 percent of jobs in the county. Using multipliers developed in Keplinger and Abraham (2002a), the economic impact of broiler industry expansion is calculated and results are presented in Table 3.

\(^{12}\) Additional hauling expense for BMP scenarios involving removal of litter from the watershed would depend on the regional scope of BMP implementation. Hauling off clean-out litter from only the watershed, for instance, may involve little or no additional expense because many broiler operations are located very near watershed boundaries. On the other hand, a haul-off policy implemented over a 100 mile radius of Duck Creek watershed would involve significant additional hauling expense.

\(^{13}\) Value added consists of labor income (proprietors income and employee compensation), other property income, e.g., rental income, and indirect business tax.
A change in the direct impact is the additional income (value added) directly contributed by an assumed expansion of the broiler industry. Change in total impact includes changes in the indirect and induced effects related to an expansion in broiler production, in addition to the change in the direct impact. Table 3 indicates that a doubling of the broiler industry would produce an estimated additional $2.7 million of economic activity in the county and produce an estimated 94 additional jobs. Production at 6.1 times 2000 levels would produce an estimated additional $13.6 million in economic activity while producing an additional 478 jobs. At this level of expansion, the broiler industry would account for an estimated 5.4 percent of county economic activity, and 8.2 percent of county jobs.

### Environmental Impact

Expanding litter application in the watershed would also have environmental consequences. There is tremendous variation in annual nutrient and sediment loads depending largely on the amount, timing, and intensity of rainfall events. When these variations are averaged out over multiple years, trends in nutrient and sediments loads can be seen. Results of expansion scenario simulations over 30 years of weather history were used to calculate average annual phosphorus loads and percent increases from baseline, which are presented in Table 4. Soluble and organic P increase substantially for expansion scenarios. In-stream soluble and organic P loads more than double from year 2000 levels for the simulated 6.1X scenario.

Table 3 Changes in Economic Activity Resulting from Broiler Industry Expansion, Duck Creek Watershed

<table>
<thead>
<tr>
<th>Economic Measure</th>
<th>Expansion Factor [Baseline = 1X]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0X</td>
</tr>
<tr>
<td>Economic Activity</td>
<td></td>
</tr>
<tr>
<td>Change in direct impact ($1,000)</td>
<td>($1,715)</td>
</tr>
<tr>
<td>Change in total impact ($1,000)</td>
<td>($2,702)</td>
</tr>
<tr>
<td>Percent of county economic activity</td>
<td>0.0%</td>
</tr>
<tr>
<td>Jobs</td>
<td></td>
</tr>
<tr>
<td>Change in direct effect [jobs]</td>
<td>-47</td>
</tr>
<tr>
<td>Change in total Impact [jobs]</td>
<td>-94</td>
</tr>
<tr>
<td>Percent of county jobs</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 4 Changes in Ambient P Loads Resulting from Industry Expansion, Duck Creek Watershed

<table>
<thead>
<tr>
<th>Ambient Loads (kg)</th>
<th>Expansion Factor [Baseline = 1X]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0X</td>
</tr>
<tr>
<td>Soluble P</td>
<td>6,850</td>
</tr>
<tr>
<td>Organic P</td>
<td>13,070</td>
</tr>
<tr>
<td>Total P</td>
<td>19,920</td>
</tr>
<tr>
<td>Percent Change in Ambient Loads from Baseline</td>
<td></td>
</tr>
<tr>
<td>Soluble P</td>
<td>-11.2</td>
</tr>
<tr>
<td>Organic P</td>
<td>-12.2</td>
</tr>
<tr>
<td>Total P</td>
<td>-11.8</td>
</tr>
</tbody>
</table>
BMP Scenarios

BMP scenarios simulate the application of specified BMPs to the agronomic N rate (6.1X) scenario, which serves as the BMP baseline.

BMP Costs

For scenarios involving a change in the amount of litter applied (P rate, double P rate, and haul-off scenarios), the net cost of a scenario involves the additional cost of commercial fertilizer and its application required to substitute for reduced applications of litter. For the phytase and alum scenarios, product cost is the most important component of total cost; these scenarios also produce quantifiable benefits.

Costs of Additional Fertilizer

The BMP baseline (agronomic N rate) scenario simulates applications of litter that supply the N crop needs to pastures and hay fields, but which supply levels of P and K in excess of crop requirements. Application of litter at less than the agronomic N rate require applications of commercial N, and sometimes K, in order to meet crop needs. For the P rate and double P rate scenarios, this analysis assumes commercial N and K supplement litter applications to achieve the same N and K application rates as commercially fertilized land. The haul-off scenarios assume that litter is totally replaced by commercial N, P, and K fertilizer at rates observed in 2000. Table 5 presents changes in fertilization rates and per acre fertilizer expense of moving from the BMP baseline (agronomic N rate) scenario to one of the BMP scenarios, for representative pasture and hay operations.

Table 5 Fertilizer Prices, Application Rates, and Total Per Acre Fertilizer Expense for BMP Scenarios for Representative Pasture and Hay Operations, Duck Creek Watershed, Texas

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Phosphate</th>
<th>Potash</th>
<th>Fertilizer Application</th>
<th>Broiler Litter</th>
<th>Annual Fertilizer Expense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Fertilizer Price</td>
<td>$0.22/lb</td>
<td>$0.26/lb</td>
<td>$0.14/lb</td>
<td>$2.00</td>
<td>$8.73/ton</td>
</tr>
<tr>
<td>Alum Amend. Fert. Price</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BMP Scenario</th>
<th>Average Annual Application Rates</th>
<th>Total Cost</th>
<th>BMP Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(lb/acre)</td>
<td>(lb/acre)</td>
<td>(# appl.)</td>
</tr>
<tr>
<td>Hay Operations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline (agronomic N rate)</td>
<td>7.50</td>
<td>65.49</td>
<td></td>
</tr>
<tr>
<td>Alumb</td>
<td>6.99</td>
<td>65.49</td>
<td>0.00</td>
</tr>
<tr>
<td>Double P rate</td>
<td>182</td>
<td>2.0</td>
<td>2.94</td>
</tr>
<tr>
<td>P rate</td>
<td>241</td>
<td>29</td>
<td>2.5</td>
</tr>
<tr>
<td>Haul off</td>
<td>300</td>
<td>100</td>
<td>3.0</td>
</tr>
<tr>
<td>Pasture Operations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline, double P rate, P rate (hayed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P Rate (not hayed)</td>
<td>9.1</td>
<td>0.33</td>
<td>0.44</td>
</tr>
<tr>
<td>Haul off</td>
<td>25</td>
<td>12.5</td>
<td>12.5</td>
</tr>
</tbody>
</table>

a. The Phytase scenario is not included because it does not entail any changes in fertilizer or litter application rates.
b. The Alum scenario results in no additional fertilizer expense because an assumed slightly lower application rate (due to a slightly higher N content) is offset by an assumed slightly higher litter price.
Phytase Costs and Benefits

Because the enzymatic activity of phytase is compromised when subjected to the high temperatures, phytase must be sprayed over feed after it has been pelletized. Since most existing feed mills were not designed with post-pelletization spray equipment, installing this equipment requires costly retrofits, which may be the primary reason why the use of phytase supplemented broiler feed is not more widespread. Several feed mills, however, have added such equipment (McKnight, 2001).

Table 6 presents estimated cost and savings for a phytase supplemented broiler diet. The literature reports a range of rates for which phytase can be substituted for non-phytate P sources. A conservative interpretation of the literature suggests that 500 units of Natuphos® phytase can substitute for one gram of non-phytate phosphorus per kilogram of feed in broiler diets (Radcliffe, 2001). One gram of Natuphos® phytase contains 5,000 units and the product can be purchased for $14.95 per kilogram. Given this cost and application rate, one ton of feed can be treated for $1.36.

Table 6  Annual Cost and Savings for a Phytase Supplemented Diet, Duck Creek Watershed

<table>
<thead>
<tr>
<th>Per Ton Analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings from reduced dietary P requirement</td>
<td>$1.76</td>
</tr>
<tr>
<td>Cost of Natuphos phytase</td>
<td>$1.36</td>
</tr>
<tr>
<td>Net savings from feed ingredients</td>
<td>$0.40</td>
</tr>
<tr>
<td>Cost of spray equipment</td>
<td>$0.05</td>
</tr>
<tr>
<td>Net per ton savings</td>
<td>$0.35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Broiler House Analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed required for broiler growth (tons/house/yr)</td>
<td>783</td>
</tr>
<tr>
<td>Net savings per broiler house (yr)</td>
<td>$274</td>
</tr>
</tbody>
</table>

Utilizing phytase feed allows levels of dietary phosphorus to be reduced, resulting in cost savings. Dietary P in broiler diets can be reduced by 2 lb/ton of phytase treated feed, allowing a reduction of mono-dicalcium phosphate of 9.5 lb/ton feed. At an assumed price of $370/ton, reduction in mono-dicalcium phosphate in broiler feed results in savings of $1.76/ton feed. The capital service cost of spray equipment was estimated to at $0.05/ton feed. Savings, then, of supplementing broiler feed with phytase exceed costs by $0.35 per ton (Table 6). For production levels assumed for this analysis, one broiler house would require an estimated 783 tons of feed annually. Savings resulting from phytase supplementation of feed, thus, was estimated at $274 annually per broiler house. Additional details and assumptions are provided in Keplinger and Abraham (2002b).

Alum Costs and Benefits

In addition to providing environmental benefits, application of alum to litter has been shown to be effective in controlling ammonia levels in laboratory experiments (Moore et al., 1995, 1996) and in broiler houses (Moore, Daniel, and Edwards, 1997). The benefits of controlling ammonia levels in broiler houses include higher nitrogen

---

14 Natuphos® phytase is marketed by BASF Corporation. Other brands of phytase may require different application rates.
levels in litter, reduced heating and ventilating expense for growers, increased chicken weight gains, and reduced mortality (Moore, Daniel, and Edwards, 1999).

Costs and benefits of alum application to litter are presented in Table 7. Grower costs are comprised of the delivered price of alum and the extra labor required for its application. Grower benefits include reduced electricity and natural gas expense and higher payments based in increased bird weights and lower mortality. Despite these substantial benefits, grower costs are estimated to outweigh benefits by $2,625 per house annually. The integrator, however, also benefits from alum treatment due to a lower feed conversion ratio and lower mortality, which result in lower feed expense and a greater quantity of chicken. The magnitude of the benefit due to increased broiler production depends on integrator profits per pound of chicken sold and a number of cost factors that are not known. This analysis assumes the integrator achieves a one-cent profit per pound live weight produced, a level consistent with industry records. Based on these and other assumptions, integrator net benefits are estimated at approximately $3,600 per alum treated house annually. The combined benefit for both grower and integrator, thus, nets to about $1,000 annually per broiler house (Table 7). Additional details and assumptions are provided in Keplinger and Abraham (2002b).

Table 7  Annual Costs and Benefits of Alum Litter Treatment Per Broiler House, Duck Creek Watershed

<table>
<thead>
<tr>
<th>Integrator net benefits</th>
<th>$3,608</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grower net costs</td>
<td>$2,625</td>
</tr>
<tr>
<td>Net benefits (grower &amp; integrator)</td>
<td>$982</td>
</tr>
</tbody>
</table>

### BMP Costs and Benefits for Representative Farm Operations and the Watershed

Information presented in Tables 5-7 was aggregated to estimate annual BMP costs for representative pasture, hay, and broiler operations, for the broiler integrator, and for the entire watershed. Results are presented in Table 8. Table 8 indicates that the users of broiler litter (hay and pasture operations) incur the cost of implementing the double P rate, P rate, and haul-off scenarios. These costs result from the substitution of commercial fertilizer nutrients for litter nutrients and are due to the higher cost of commercial nutrients (Table 5).

This analysis indicates that substantial financial benefits accrue to the use of phytase in broiler diets, which were estimated at about $87,000 at the watershed level. These benefits result from reduced feed costs, since the cost of phytase is more than compensated for by lower dietary P requirements in broiler diets (Table 6). The broiler

---

15 Some growers are purchasing and applying alum at approximately one-quarter the phosphorus control rate to control atmospheric ammonia in broiler houses, suggesting that application of alum at an ammonia control rate is cost-effective for growers.

16 Sanderson Farms’ annual report for 2001 indicates net income of $27.8 million in 2001 from 1.2 billion dressed pounds of chicken processed and a net loss of 5.6 million in 2000 from 1.1 billion dressed pounds processed (Sanderson Farms Inc., 2002).
The integrator is here assumed to accrue all the benefits of phytase addition because the integrator controls and pays for the feed milling and feed ration formulation processes.

The addition of alum to broiler litter provides an interesting situation where broiler operators would incur net costs, assuming they were responsible for its purchase and application. Although the grower would benefit from greater production, reduced mortality, and reduced electricity (fans) and heating expense, the cost of alum and its application would more than offset these advantages, resulting in net costs of $10,500 for a representative 4-house broiler operation. The poultry integrator, however, would substantially benefit from higher feed efficiency, greater production, and reduced mortality rates. When the costs and benefits experienced by broiler growers and the integrator are aggregated, net benefits of $310,000 are estimated to accrue at the watershed level (Table 8).

### Environmental Measures

As depicted in Figure 3, all BMP scenarios result in reduced levels of soluble and organic P loads at the mouth of Duck Creek watershed. The relative magnitudes of these reductions are consistent with expectations. Sediment and NO₃ loads (not shown) exhibit very little variation across BMP scenarios. P loads, however, are progressively reduced moving from the agronomic N rate baseline, to the double P rate, to the P rate, to the haul off of clean-out litter, to the complete haul off. A simulated complete haul off of litter resulted in a 57 percent reduction of soluble P load. Phytase addition to feed yields a 13 percent reduction in soluble P loads while the alum scenario results in a 60 percent reduction in soluble P. Simulated organic P loads for all scenarios are approximately twice the levels of soluble P loads.

### Cost Effectiveness Analysis

Cost effectiveness ratios indicate the cost of achieving a one unit change in water quality. Cost effectiveness ratios were calculated for soluble and total P reduction for the six BMPs considered and are presented in Table 9. Cost effectiveness ratios are higher (less cost-effective) for haul-off scenarios than for reduced rate scenarios, because more litter nutrients must be replaced by commercial fertilizer nutrients per acre of land. Because the phytase and alum BMPs produce net economic benefits, their cost effectiveness ratios are negative. Both amendment BMPs produce cost effectiveness ratios of similar magnitude. The alum scenario, however, produces

<table>
<thead>
<tr>
<th>Table 8</th>
<th>Annual Costs (Benefits) of Implementing BMP Scenarios for Representative Operations, Broiler Integrator, and Duck Creek Watershed ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMP Scenario</td>
<td>Representative Operation</td>
</tr>
<tr>
<td>Pasture</td>
<td>Hay</td>
</tr>
<tr>
<td>Double P rate</td>
<td>0</td>
</tr>
<tr>
<td>P rate</td>
<td>70</td>
</tr>
<tr>
<td>Haul off of clean-out litter</td>
<td>587</td>
</tr>
<tr>
<td>Complete haulout</td>
<td>839</td>
</tr>
<tr>
<td>Phytase addition to feed</td>
<td>(86,603)</td>
</tr>
<tr>
<td>Alum addition to litter</td>
<td>10,501</td>
</tr>
</tbody>
</table>
about four and a half times the reduction of soluble P and about three times the reduction on total P as the phytase scenario. To summarize, for a given reduction in ambient P, haul-off scenarios are roughly four times more expensive to implement than P rate scenarios, while the phytase and alum scenarios produce net economic benefits.

Table 9 Cost-Effectiveness Ratios for Phosphorus BMPs, Duck Creek Watershed

<table>
<thead>
<tr>
<th>Rates</th>
<th>Haul Off</th>
<th>Amendments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Double P</td>
<td>P</td>
</tr>
<tr>
<td>Total Cost (Watershed)</td>
<td>$26,424</td>
<td>$69,306</td>
</tr>
<tr>
<td>Reduction in Ambient P Load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soluble P (kg)</td>
<td>5,400</td>
<td>7,685</td>
</tr>
<tr>
<td>Total P (kg)</td>
<td>16,020</td>
<td>22,085</td>
</tr>
<tr>
<td>Cost Effectiveness Ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soluble P ($/kg removed)</td>
<td>4.89</td>
<td>9.02</td>
</tr>
<tr>
<td>Total P ($/kg removed)</td>
<td>1.65</td>
<td>3.14</td>
</tr>
</tbody>
</table>

Figure 3 Average Annual Phosphorus Loads for BMP Scenarios, Duck Creek

Summary and Conclusions

Economic and environmental impacts of broiler industry expansion and phosphorus control BMPs were simulated for Duck Creek watershed, a small watershed located mostly in Robertson County, in east central Texas. The Soil and Water Assessment Tool (SWAT) was employed to simulate the impacts of various scenarios on ambient nutrient and sediment concentrations and soil phosphorus. The economic impact of broiler industry expansion was estimated using the Impact Planner (IMPLAN). Costs (or benefits) of BMP implementation for representative pasture, hay, and broiler operations, the broiler integrator, and for the entire watershed were also estimated.
Environmental and economic impacts of 0X, 1X, 1.2X, 2X, 2.3X, and 6.1X expansion scenarios were calculated, where 1X denotes the level of litter application estimated for year 2000. For the greatest expansion scenario considered (6.1X), Robertson County economic activity expands by five percent, jobs in Robertson County increase by an estimated seven percent, while simulated loads of soluble and organic phosphorus in Duck Creek approximately double.

Simulation of BMP scenarios utilized the 6.1X expansion scenario (agronomic N rate) as the baseline reference condition. BMP scenarios considered were double the P rate, P rate, haul off of clean-out litter, haul off of all litter, phytase addition to feed, and alum amendment of litter. The BMP analysis indicates that substantial reductions in watershed phosphorus loads can be accomplished by reducing the rates or areas to which broiler litter is applied. The P rate and double P rate scenarios are more cost-effective than the haul-off scenarios, although absolute reductions in ambient P levels are greater for the haul-off scenarios. The phytase and alum BMPs are new technologies that have not yet been widely adopted. Both of these technologies produce net economic benefits in addition to reduced P loads, and hence, are classic “win-win” solutions. The complete haul-off and alum amendment scenarios produce reductions in soluble P of similar magnitude. The complete haul-off scenario, however, is estimated to cost $334,000, whereas the alum amendment scenario produces estimated net economic benefits of about $310,000.

The win-win nature of the phytase and alum scenarios is an attractive feature for policy makers, integrators, and broiler growers to consider when assessing strategies to reduce phosphorus runoff from litter application areas. Due to technical aspects of these practices, unilateral implementation by growers of either practice is unlikely. To be effectively utilized, phytase must be added to feed when it is milled suggesting that any public action to increase the use of phytase in broiler feed would need to be directed at feed mills, which are often owned by integrators. Alum addition to litter at phosphorus control rates is not cost-effective for growers. Because integrators capture the majority of economic benefits attributable to alum use whereas broiler growers sustain net costs, it may be appropriate for poultry integrators and government agencies to help cost share alum use at the phosphorus control rate by growers.


Leopold, Rick. 2000. Personal communication. NRCS, Zone 4 - Bryan Office, Texas.

McKnight, Frauline. 2001. Personal communication. BASF Corporation, Inc.


Platt, Dean. 2000. Personal communication. NRCS, Franklin Field Office, Texas.


