Livestock and the Environment: A National Pilot Project

The Policy Space, Economic Model, and
Environmental Model Linkages

Livestock Series Report 4

Edward Osei, P.G. Lakshminarayan, Shannon Neibergs,
Aziz Bouzaher, and S.R. Johnson

Staff Report 95-SR 78
December 1995

LIVESTOCK AND THE ENVIRONMENT: A NATIONAL PILOT PROJECT

The Policy Space, Economic Model, and Environmental Model Linkages

Livestock Series Report 4

Edward Osei, P.G. Lakshminarayan, Shannon Neibergs,
Aziz Bouzaher, and S.R. Johnson

CARD Staff Report 95-SR 78
December 1995

Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011

Edward Osei was a CARD postdoctoral research associate; P.G. Lakshminarayan is a CARD associate scientist, Resource and Environmental Policy Division; Shannon Neibergs was a CARD postdoctoral research associate; Aziz Bouzaher was an associate professor of economics and head of the Resource and Environmental Policy Division, CARD; and S.R. Johnson is C.F. Curtiss Distinguished Professor and director of CARD.

The National Pilot Project on Livestock and the Environment is funded by the U.S. Environmental Protection Agency, under Cooperative Agreement #R820374010.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

The authors of this report have benefited from useful suggestions and input from colleagues. Worthy of specific mention are comments and suggestions from Ron Jones, Larry Beran, Larry Hauck, Anne McFarland, and Stacy Pratt of the Texas Institute for Applied Environmental Research; Larry Frarey of Shook, Hardy and Bacon, Attorneys at Law; Don Goss of the Texas Agricultural Experiment Station, Temple; Phil Gassman of the Center for Agricultural and Rural Development, Iowa State University, Ames; Lynn Shuyler of the Chesapeake Bay Program; Boyd Buxton of the USDA-ERS; Kathleen Segerson of the University of Connecticut; Jerry Hatfield of the National Soil Tilth Laboratory, Iowa State University, Ames; Clay Ogg of the Office of Policy, Planning and Evaluation, USEPA; William Ritter of the University of Delaware; and other members of the NPP Technical Review Committee.

LIVESTOCK AND THE ENVIRONMENT: A NATIONAL PILOT PROJECT
The Policy Space, Economic Model, and Environmental Model Linkages
Livestock Series Report 4

Assessing the effects of alternative policies that address nonpoint pollution sources from livestock operations requires insight into the interactions of livestock production practices, waste management technologies, and environmental impacts of these practices. Individual operations vary in size, cost structure, management expertise, attitudes toward risk, and willingness and ability to adopt new technologies. Usually a livestock producer's primary objective is to maximize net revenue, so the producer has to continuously adapt to changing external conditions. In strategic decision making at the farm level, environmental pollution is normally not considered because incentives or environmental regulations have not been implemented. This situation is rapidly changing.

Livestock operations can cause considerable environmental degradation and government programs are proposed to counter further decreases in environmental quality. Because farmers share the use of off-farm resources such as groundwater, surface water, and air with the rest of society, it is logical to expect society to develop policies that protect these resources. The question, however, is which instruments should be chosen as appropriate environmental policies for livestock operations: appropriate in the sense of reducing ecological stress within a reasonable period of time and without unnecessary income losses for the farm sector.

To address the growing problem of environmental degradation from livestock operations, the U.S. Environmental Protection Agency (USEPA) has sponsored a multidisciplinary project called Livestock and the Environment: A National Pilot Project (NPP). The NPP's *Detailed Problem Statement* (Jones et al. 1993) describes the project and the challenges facing the livestock production industry in general. This pilot project focuses on the dairy industry in Erath County, Texas.

This report details the linkages among the policy space, the dairy farm economic model, and the environmental fate and transport simulation models. A summary of the NPP's conceptual framework illustrates the overall model organization and linkages within the NPP. Following this a brief review of the policy space is provided. The report gives a detailed description of the dairy farm economic model information to set the foundation for a discussion of these linkages. A detailed description of the policy space is provided in the NPP report, *Review of Current Policies, Enforcement Mechanisms, and Compliance Strategies* (Frarey et al. 1993).

NPP Conceptual Framework Summary

The NPP's methodology is detailed in the Conceptual Framework Report (Bouzaher et al. 1993b). Research conducted under the auspices of the NPP involves scientific modeling, policy analysis, and policy implementation. The NPP's scientific modeling effort involves the development of an integrated system of interdisciplinary economic and environmental simulation models. The modeling system is designed to quantify the tradeoffs between economic returns and environmental quality resulting from alternative policy scenarios. Interdisciplinary integrated modeling has become a widely accepted conceptual framework for comprehensive economic-environmental analysis (Capalbo and Antle 1989). Such a holistic approach is a key to understanding the interactions between agricultural and environmental factors when determining the nature and intensity of pollution, as well as the policy implications for economic efficiency and environmental quality.

Figure 1 illustrates the basic NPP modeling framework. The initial step in the integrated modeling framework is to develop alternative polices to control the environmental impacts of livestock operations. These policies are then analyzed by the dairy farm economic model. Using alternative technologies and best management practices (BMPs), the economic model responds to a chosen policy and determines the farm-level economic impact and the associated nutrient loadings and odor emissions.

The nutrient loadings serve as input to environmental simulation models that determine the site-specific resource impact. Site-specific information is then aggregated across the entire watershed and fed back to the policy development module for analysis and policy refinement.

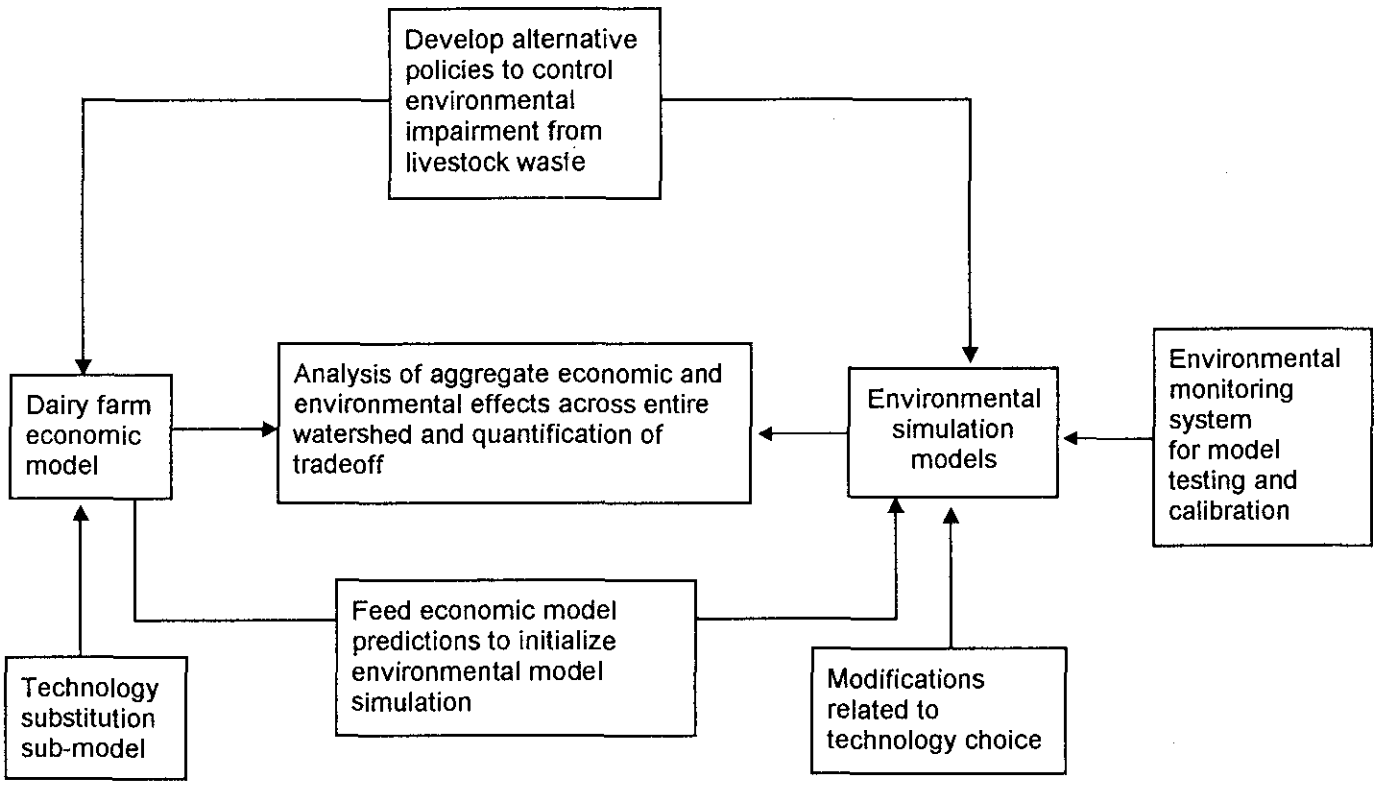


Figure 1. NPP Integrated modeling framework

Policy Space

A goal of the NPP is to demonstrate agricultural and environmental policy alternatives, supported by project research, to enable the livestock production industry to flourish while avoiding significant adverse effects on environmental quality. The NPP's policy objectives are clearly defined so that the research remains focused. The policy space can be divided into four categories. These categories and the associated policy space within each category are summarized in Table 1. Four published reports have addressed the NPP policy space (TIAER 1993; Frarey 1993; Jones et al. 1993 and Frarey et al. 1993).

Environmental accountability addresses the policy issues that link livestock operations to their impact on the environment. Implementing managerial and structural BMPs according to regulatory, voluntary, and economic incentives is believed to be the most efficient way to help regulate nutrient loading in the environment. It is perceived that implementing BMPs is key to successfully abating the negative environmental impacts of livestock production. One of the tasks of the NPP is to identify the combination of BMPs and policies that achieves environmental quality goals. It may be determined that too much manure is produced, so it cannot all be used on waste application fields. In that case, to conform to policies with high environmental quality goals, alternatives to land application of manure may need to be developed to reduce nutrient loadings. Alternative uses of manure may also convert livestock waste byproducts into an economic benefit, provided that there are enough incentives to make it economically feasible to process the waste byproduct. For example, processing of waste byproducts from the livestock meat processing and packaging industry has proven to be a profitable industry, producing commodities like high protein plasma and bone meal concentrates.

One of the most notable aspects of the NPP is that it examines the cross and extended media effects of livestock production on surface water, groundwater, and atmosphere. This ecosystem approach surpasses previous research on livestock waste and the environment that typically focused on only one environmental resource and one indicator. Analyzing the entire system is absolutely necessary when examining the cross effects of alternative BMPs on the environment. For example, incorporating manure into the soil when it is applied to a waste application field is a BMP designed to control surface runoff and odor, but knowledge about its effect on groundwater is rather limited. The NPP seeks to quantify both the cross effects of BMP implementation and their impact on environmental quality.

Table 1. Summmary of NPP objectives

	Categories			
	Environmental Accountability	**Cross and Extended Media**	**Institutional**	**CAFO Location Producer Structure**
Definition of Categories	Policies targeting the farm-level production of nutrient loadings to the environment that potentially create pollution.	Policies identifying the relationship between environmental resources and monitoring and enforcement policies at the farm and watershed levels.	Policies defining the role of institutions in implementing and monitoring CAFO policies.	Policies creating incentives for regional growth and producer size.
Kinds of policies used to correct problems	Policies in this category include regular incentives, voluntary incentives, and economic incentives. • Regulatory Incentives	The NPP examines the policy impact on all environmental resources: • Surface Water • Groundwater • Air Quality (Odor)	The roles of state and federal environmental regulatory agencies and farm service organizations are neither clearly defined nor coordinated.	Producer size is a policy issue related to permitting requirements and in the financial ability of farms to implement BMPs.
	Permitting Process EPA NPDES Permit TNRCC Waste Disposal and Air Quality Permits Technology Standards	The NPP will identify the intermedia trade-offs implicit in alternative policies and implementation of BMPs on the environmental resources.	The NPP will recommend new policies and possible new organization structures and relationships to address economic-environmental trade-offs and problems associated with livestock production.	Identification of policies that are responsible for growth patterns in producer size and regional growth.
	Nutrient Loading Standards • Voluntary Incentives Pride of Leadership • Economic Incentives Cost Share Price Subsidy Cross Compliance Input Taxes Discharge Fines Emission Trading Environmental Bonds	Policies that establish the level of monitoring and enforcement • Individual Farm Level • Microwatershed • Watershed	The coordination of institutions and policies can be described as: • Planned Intervention • Unplanned Intervention • Planned Nonintervention	Identification of the benefits and costs of the ongoing regionalization of livestock production.
	Policies that develop alternatives to land application of manure: Composting Pelletization Manure Burning Facility Centralized Waste Treatment Animal Feed Component			

Furthermore, the NPP examines a full set of nutrient parameters that can be modeled (Bouzaher et al. 1993a). Policies that focus on one indicator may result in pollution from a second indicator. For example, manure application to waste application fields that are based on agronomic rates for crop nitrogen requirements may result in an overapplication of phosphorus that easily runs off into the surface water. Preliminary monitoring results from the North Bosque watershed show 12 of 24 surface water monitoring sites with mean orthosphosphate levels above the recommended standard with a 95 percent degree of confidence (Jones et al. 1993).

The NPP's policy modeling framework is designed to model site-specific parameters and then aggregate impacts to microwatersheds and to the entire watershed. Alternative policies dealing with monitoring and enforcement can be targeted at each of these levels. This approach is consistent with the U.S. government's current environmental protection philosophy of looking beyond threatened individual components, to the entire ecosystem, while considering the trade-offs between ecosystem protection and economic growth. This holistic policy approach avoids the inefficiency of piecemeal decisions.

Institutional changes are being made to better deal with pollution problems from concentrated animal feeding operations (CAFOs). Both U.S.Department of Agriculture reorganization and state initiatives like those in Texas offer promise for merging voluntary and regulatory pollution abatement policies. The institutional goal for the NPP is to determine the ideal interface for farm service and regulatory agencies at the local, state, and federal levels to insure the greatest pollution abatement by CAFOs at the least cost (Jones et al. 1993). The NPP recommends new policies and possibly new organizational relationships to address the economic-environmental trade-offs associated with livestock production. Existing policies and institutions may have affected interregional shifts in livestock production, so the NPP conducts an in-depth review of how these policies are likely to affect future trends in the livestock industry.

Specific Policies Evaluated with NPP

The specific policies being considered in the NPP are detailed in "Livestock waste management policies for examination within the project's economic/biophysical process modeling framework." All proposed policies modify a baseline scenario termed "no discharge" from animal confinement and process areas (ACPA). This baseline, which combines existing EPA and TNRCC regulations controlling runoff from animal confinement and process areas, is described in that report as

> No waste discharge from animal confinement and process areas absent a chronic or catastrophic storm event exceeding the holding capacity of containment structures designed and maintained to contain a 25-year, 24-hour storm event. This policy applies to all dairies, regardless of size, that confine animals in a feedlot where crop or forage growth cannot be sustained due to animal activity.
>
> There are 17 proposed policies:

1. No discharge with nitrogen agronomic application rate.
2. No discharge with phosphorus agronomic application rate.
3. No discharge with relaxed phosphorus application rate.
4. No discharge with nitrogen agronomic application rate and incorporation of solid manure.
5. No discharge with phosphorus agronomic application rate and incorporation of solid manure.
6. No discharge with nitrogen agronomic application rate and filter strip.
7. No discharge with phosphorus agronomic application rate and filter strip.
8. No discharge with nitrogen agronomic application rate and cost shared filter strip.
9. No discharge with nitrogen agronomic application rate for lagoon effluent; solid manure transported to a central compost facility.
10. No discharge with nitrogen agronomic application rate for lagoon effluent; solid manure composted on site.
11. No discharge with nitrogen agronomic application rate for lagoon effluent; solid manure composted on site with 65 percent cost share for composting expenses.
12. No discharge with phosphorus agronomic application rate for lagoon effluent; solid manure composted on site.
13. No discharge with nitrogen agronomic application rate and two-stage lagoon technology adoption subsidized by milk price premium.
14. No discharge with manure application according to European Union nitrogen directive.
15. No discharge with nitrogen agronomic application rate and tax on purchased feed.

16. No discharge with nitrogen agronomic application rate and solids separator.

17. No discharge with nitrogen agronomic application rate and cost-shared solids separator.

Because of research by Trachtenberg and Ogg (1994) suggesting that livestock producers fail to account for the nutrient value of manure when it is applied to cropland, the following two policies are added to the 17 policies previously listed.

1. No discharge with nitrogen agronomic application rate and commercial N application at 100 percent of the agronomic rate on cropland.

2. No discharge with nitrogen agronomic application rate and commercial N application at 50 percent of the agronomic rate on cropland.

Limitations of NPP Policy Space and Modeling Framework

The NPP's modeling framework provides policymakers with critical information on which to base decisions affecting both environmental quality and CAFO profitability. However, the modeling framework is unable to incorporate all of the social costs and benefits involved in many policy decisions. No modeling effort has the ability to capture the entire real world process, but it must rather focus on specific segments and model those segments using the best available statistical design and technology. In this first round of the NPP modeling effort, the focus is on modeling the economic-environmental interactions at both the farm and watershed levels.

But the existing modeling framework does not estimate the benefits to society associated with improved environmental quality, nor does it estimate the public sector costs associated with policy implementation, institutional reorganization, and operation (Bouzaher et al. 1993a). Recognition of the policy transaction costs is crucial, particularly as public pressure to reduce government spending steadily increases. Any future modeling framework must be expanded to account for these costs, and to quantify and link environmental costs and benefits in the same way the NPP modeling framework currently links CAFO economics to environmental effects (Frarey and Jones 1993).

Dairy Farm Economic Model

There are many unresolved problems associated with the precise linkages of management choices and physical land characteristics and the generation of environmental contamination from dairy farms. A comprehensive effort is needed to identify the economic impact of alternative BMPs designed to reduce nutrient loadings and odor emissions. Developing sustainable policies to abate nonpoint source pollution requires that policymakers know the environmental effectiveness as well as economic impact of the policy options under consideration.

Historical Perspective and Context

Economic and environmental analysis of livestock waste management systems has generated extensive literature on the subject of efficient use of manure nutrients. Early studies typically considered manure as a resource in a mixed crop-livestock farming operation. A number of studies examined the efficient use of manure management systems and their associated nutrients (Huang 1979; Burney, Lo, and Carson 1980; Asraf and Christians 1974; Heimlich 1982; Stonehouse and Narayanan 1984). Many studies examined specific aspects of the economics of manure handling, such as economies of size (Lessley and Via 1976; Heimlich 1982), capital investment in waste management systems in response to water quality laws (Ashraf and Christensen 1974; Forster, 1975; Young et al. 1985) and manure as an integral part of overall farming systems and the uncertainty about crop response to nitrogen and the nitrogen content of manure (McSweeney and Shortle 1989).

Recent studies have shifted away from characterizing manure as a resource to viewing manure as a waste disposal problem. This can primarily be attributed to the increased specialization and concentration of livestock production systems creating excessive amounts of manure with very little crop acreage for waste application. Current studies are particularly concerned with the potential negative impact of livestock waste, which through runoff and leaching contaminates surface water and groundwater, and also causes odor problems. A number of these studies have used economic-environment simulation models to examine field-level losses of nutrients (Young and Crowder 1986; Heatwole, Diebel, and Halstead 1990). Schnitke and Miranda (1993) and Knisel (1980) have studied the long-term effects of phosphorus runoff controls on livestock production and manure application practices.

There are some important considerations that have been either ignored or given little focus in previous analyses. None of the previous studies examined the entire interconnected system of soil, water and air, and multiple nutrients. As society grapples with the complex problem of providing adequate food at affordable prices, providing adequate margins to livestock producers to keep them in business, and protecting the environment from livestock waste contamination, there is a clear need to evaluate the economic-environmental trade-offs of CAFOs. The intense policy debate surrounding dairy waste disposal focuses on the possibilities of cross-media transfers of waste application field runoff contaminating surface water, leaching of nutrients into the groundwater, greenhouse gas emissions into the atmosphere, and the odor problems associated with CAFOs.

An Overview of the Economic Model

Dairy production decisions generate a joint distribution of outputs, input usage, and nutrient loadings from livestock waste. For simulating the economic decision making process at the farm level, linear programming methods and their extensions are frequently employed. These methods represent the collection of relevant technical opportunities offered to the farm by separate activities in a process matrix. Programming methods are well suited for environmental-economic research because (a) many activities and restrictions can be considered at the same time; (b) an explicit and efficient goal seeking procedure is provided; (c) once formulated, results from changing variables can be calculated easily; and (d) new production techniques can be incorporated easily through additional activities. For this study, a mixed integer nonlinear programming (MINLP) model is developed to capture the complex interrelationships among policy options, economic variables, and nutrient loading parameters at the dairy farm level. The simulated dairy will maximize annual net revenue subject to constraining resources and exogenously determined environmental policies.

The success of the economic model depends largely on its ability to simulate and measure the reduction in nutrient loads associated with using alternative dairy production and waste management technologies. The model incorporates a complete set of all potential production systems, including the dairy facility, the manure management system, and the waste disposal fields. These are referred to as *technology systems*. Manure management technologies and best management practices are given considerable attention in the model design. A dairy operator can reduce pollution emissions from the feedlot in a number of ways, including by decreasing cow numbers or by introducing improved manure management technology systems.

The economic model effectively captures farm use of solid manure and waste water (liquid effluent). Naturally, the technology system dictates some manure use decisions such as whether the dairy waste lagoon is dewatered with a big gun or a center pivot and whether a solid separator is used to filter solid manure from the liquid effluent. The technology system also determines whether filter strips are used, and whether the solid manure is applied to waste application fields or hauled off-site. If the manure is hauled off-site, the model assumes that the nutrients generated by the farm are not removed from the watershed, but rather applied on nondairy land. This assumption is in contrast to a scenario where the manure is hauled to a composting facility outside the watershed, and the compost is then hauled out of the watershed to commercial outlets.

Most agricultural nonpoint source pollution occurs at the farm level. The farm determines the size and scope of its production practices and is the source of the nutrient loads into the environment. Policies that are designed to have a specific impact on average-sized dairy farms may be inadequate because this size probably does not represent many milk producers. Therefore, it is very important to examine the impact of proposed policies on differently sized dairy farms. The economic model simulates representative dairy farms in Erath County as small, medium, and large. Modeling the dairy economic system by herd size is important because of the economies of size and scale in milk production and waste handling systems. The herd sizes are defined as small (225 head, milking 185 head), medium (400 head, milking 350 head), and large (1,200 head, milking 1,000 head). Data used in the dairy economic model were collected for these three size categories.

There are three models representing the three farm sizes. The farm sizes and their associated operating and fixed costs differ across the size categories, enabling the model to capture important economies of size issues associated with dairy production.

Mathematical Representation of the Model

A mathematical representation of the dairy farm economic model is presented in Table 2. To ease interpretation of the variables, upper case variables represent technical coefficients, while lower case variables represent endogenous decision variables. For clarity we consider the complete model as consisting of four components: financial, technology choice, manure nutrient, and dairy cattle nutrition.

consisting of four components: financial, technology choice, manure nutrient, and dairy cattle nutrition. The basic equation system of the model is given below. The list includes all the equations necessary for the "no discharge" (ACPA) specification. A later section on policy linkages with the economic model introduces some modifications to the list to account for specific policy requirements and assumptions.

The primary objective of the dairy farmer is to maximize net returns, defined as

$$z^{NR} = z^{NCF} - z^{PMT} \tag{1a}$$

subject to the constraints in the four model components, where Z^{NE} is net returns after operating costs and debt service payments, Z^{NCF} is net cash flow returns, and Z^{PMT} is annual debt service payments. An alternative objective function is to maximize net returns to risk and management that already accounts for an annualized opportunity cost for the amount of equity invested (e^a) in the dairy enterprise. This objective function fully accounts for the cost to the dairy operator of investing in any fixed capital. A complete mathematical description of the model is given in Table 2.

Table 2. Mathematical description of the model

$$\text{Max} \quad z = z^{NCF} - z^{PMT} - e^a \tag{1b}$$

Subject to: Financial Component

$$\begin{aligned} z^{NCF} = & -V^{cd}h + P^m m + \sum_{cl} P_{cl}^l l_{cl} - \sum_{rl} V_{rl}^{LCR} b_{rl}^l a_{rl}^l - \sum_{rs} V_{rs}^{SCR} b_{rs}^s a_{rs}^s + \sum_q P_q^{fs} y_q^s \\ & - \sum_q P_q^{pfs} y_q^p - c^{TS} - C^{irrig} a^{el} - P^{nitr}(f_L + f_S) \end{aligned} \tag{2}$$

$$\begin{aligned} c^{INV} = & I^{land} + I^{herd} + \sum_i I_i^{lg} t_i^{lg} + \sum_i I_i^{irrig} t_i^{lg} + \sum_s I_s^{sep} t_s^{sep} + \sum_f I_f^{fs} t_f^{fs} + \sum_{com} I_{com}^{ccom} t_{com}^{ccom} + \\ & \sum_h I_h^h t_h^h + \sum_{inc} I_{inc}^{inc} t_{inc}^{inc} + \sum_{onc} I_{onc}^{ocom} t_{onc}^{ocom} \end{aligned} \tag{3}$$

Table 2 continued

$$d = (1 - U^{equity})c^{INV} \tag{4}$$

$$e = U^{equity}c^{INV} \tag{5}$$

$$d^{OPC} = U^{short}d \tag{6}$$

$$d^{R} = (1 - U^{short})d \tag{7}$$

$$z^{PMT} = \frac{d^{OPC}}{PVIFAO} + \frac{d^{R}}{PVIFAR} \tag{8}$$

$$d^{a} - \frac{d}{P^{l}_{cows}h + I^{herd} + I^{land}} = 0 \tag{9}$$

$$d^{a} \le MAXDA \tag{10}$$

$$c^{Feed} = \sum_{q} P^{PFS}_{q} y^{p}_{q} \tag{11}$$

$$h = S \tag{12}$$

$$m - Y^{M}h = 0 \tag{13}$$

$$l_{cl} - Y^{L}_{cl}h = 0 \tag{14}$$

$$\sum_{q} P^{fs}_{q} y^{s}_{q} - \sum_{rl} V^{LCR}_{rl} b^{l}_{rl} a^{l}_{rl} - \sum_{rs} V^{SCR}_{rs} b^{s}_{rs} a^{s}_{rs} \le 0 \tag{15}$$

Table 2 continued

Technology Choice Component

$$\sum_{i} t_{i}'^{\lg} = 1 \qquad (16)$$

$$t_{i}'^{\lg} - t_{i}^{\lg} = 0 \qquad (17)$$

$$\sum_{s} t_{s}'^{sep} = 1 \qquad (18)$$

$$t_{s}'^{sep} - t_{s}^{sep} = 0 \qquad (19)$$

$$\sum_{f} t_{f}'^{fs} = 1 \qquad (20)$$

$$t_{f}'^{fs} - t_{f}^{lfs} = 0 \qquad (21)$$

$$\sum_{com} t_{com}'^{ccom} = 1 \qquad (22)$$

$$t_{com}'^{ccom} - t_{com}^{ccom} = 0 \qquad (23)$$

$$\sum_{h} t_{h}'^{h} = 1 \qquad (24)$$

$$t_{h}'^{h} - t_{h}^{h} = 0 \qquad (25)$$

Table 2 continued

$$\sum_{inc} t'^{inc}_{inc} = 1 \qquad (26)$$

$$t'^{inc}_{inc} - t^{inc}_{inc} = 0 \qquad (27)$$

$$\sum_{onc} t'^{ocom}_{onc} = 1 \qquad (28)$$

$$t'^{ocom}_{onc} - t^{ocom}_{onc} = 0 \qquad (29)$$

$$h\left[\sum_i V_i^{\lg} t_i^{\lg} + \sum_s V_s^{sep} t_s^{sep} + \sum_f V_f^{fs} t_f^{fs} + \sum_{com} V_{com}^{ccom} t_{com}^{ccom} + \sum_h V_h^h t_h^h + \sum_{inc} V_{inc}^{inc} t_{inc}^{inc} + \sum_{onc} V_{onc}^{ocom} t_{onc}^{ocom}\right] - c^{TS} = 0$$

(30)

$$t'^{\lg}_{no\lg} = 0 \qquad (31)$$

Manure Nutrient Component

$$h\left[\sum_i \Delta_{i,j}^S t_i^{\lg}\right]\left[\sum_{com} \Delta_{com,j}^S t_{com}^{ccom}\right]\left[\sum_{onc} \Delta_{onc,j}^S t_{onc}^{ocom}\right] NMP_j + \left[1 - \sum_S \Delta_{S,j}^L t_S^{sep}\right] NLE_j - tnm_j = 0 \qquad (32)$$

$$h\left[\sum_i \Delta_{i,j}^L t_i^{\lg}\right]\left[\sum_s \Delta_{s,j}^L t_s^{sep}\right]\left[\sum_{com} \Delta_{com,j}^L t_{com}^{ccom}\right]\left[\sum_{onc} \Delta_{onc,j}^L t_{onc}^{ocom}\right] NLE_j - tne_j = 0 \qquad (33)$$

Table 2 continued

$$\sum_{rl} b_{rl}^{l} a_{rl}^{l} + a^{fsl} - a^{el} \leq AL \tag{34}$$

$$\sum_{rs} b_{rs}^{s} a_{rs}^{s} + a^{fss} + a^{el} \leq AS \tag{35}$$

$$\sum_{f} FILTERS_f t_f^{fs} + a^{fss} = 0 \tag{36}$$

$$\sum_{f} FILTERL_f t_f^{fs} + a^{fsl} = 0 \tag{37}$$

$$\sum_{rl} b_{rl}'^{l} = 1 \tag{38}$$

$$\sum_{rs} b_{rs}'^{s} = 1 \tag{39}$$

$$b_{rl}'^{l} - b_{rl}^{l} = 0 \tag{40}$$

$$b_{rs}'^{s} - b_{rs}^{s} = 0 \tag{41}$$

Dairy Cattle Nutrition Component

$$y_q^s + y_q^f - \sum_{rl} YLA_{q,rl} b_{rl}^{l} a_{rl}^{l} - \sum_{rs} YSA_{q,rs} b_{rs}^{s} a_{rs}^{s} \leq 0 \tag{42}$$

Table 2 continued

$$\left(RR_w([S-DRY]/S)+RRDRY_w(DRY/S)\right)h+RRBLL_wBULLS+RRHEIF_wHEIFERS$$
$$-\sum_q NIF_{q,dm}NIF_{q,w}(1-WASTE)\left[y_q^F+y_q^p\right]\leq 0 \quad (43)$$

$$\left(RR_{dm}([S-DRY]/S)+RRDRY_{dm}(DRY/S)\right)h+RRBULL_{dm}BULLS+RRHEIF_{dm}HEIFERS$$
$$-\sum_q NIF_{q,dm}(1-WASTE)\left[y_q^F+y_q^p\right]\geq 0 \quad (44)$$

$$totaldm=\left(RR_{dm}([S-DRY]/S)+RRDRY_{dm}(DRY/S)\right)h+RRBULL_{dm}BULLS+RRHEIF_{dm}HEIFERS \quad (45)$$

$$ex_w=\sum_q NIF_{q,dm}NIF_{q,w}(1-WASTE)\left[y_q^F+y_q^p\right] \quad (46)$$

$$ex_{dm}=\sum_q NIF_{q,dm}(1-WASTE)\left[y_q^F+y_q^p\right] \quad (47)$$

$$ex_w\leq BOUND_w totaldm \quad (48)$$

$$ex_{dm}\geq BOUND_{dm} \quad (49)$$

$$hMPI-y_{premix}^p\leq 0 \quad (50)$$

$$c\,hMFI-y_{alfalfa}^F-y_{coastal}^F-y_{silage}^F-y_{alfalfa}^p-y_{coastal}^p-y_{silage}^p\geq 0 \quad (51)$$

Sets or indices

i	=	alternative lagoon systems (i = nolg, onelg, twolg)
s	=	binary index for solid separator option
f	=	binary index for filter strip option
h	=	binary index for hauloff option
com	=	binary index for central composting option
onc	=	binary index for onsite composting option
inc	=	binary index for manure incorporation
j	=	nutrient parameters (n = nitrogen, nitrate nitrogen, ammonia nitrogen, phosphorus, sodium and potassium)
rl	=	liquid waste rotations (rl = cbh, cbww, sdww, ssu, cs)
rs	=	solid waste rotations (rs = cbh, cbww, sdww, ssu, cs)
w	=	nutrients required in rations (w = energy protein, calcium, phosphorus, vitamin A, vitamin D)
cl	=	culled livestock (cl = cows, bulls, calves)
q	=	feed (or crop) types (q = premix, alfalfa, coastal, silage, sorghum, wheat, mineral, cottonseed, brewers grain)

Variables

z	=	Net returns after operating costs and debt service payments, in dollars
z^{NCF}	=	Net cash flow returns in dollars
z^{PMT}	=	Annual debt service payments in dollars
h	=	Herd size: number of cows
b_{rl}^{l}	=	Dummy variable restricting liquid waste acreage to only one of the five rotations
b_{rs}^{s}	=	Dummy variable restricting solid waste acreage to only one of the five rotations
a_{rl}^{l}	=	Liquid waste acreage under cropping rotation rl
a_{rs}^{s}	=	Solid waste acreage under cropping rotation rs
a^{el}	=	Amount of extra liquid waste acreage taken out of solid waste acreage in acres

a^{fsl} = Amount of filter strip acreage across (taken out of) liquid waste fields in acres

a^{fss} = Amount of filter strip acreage across (taken out of) solid waste fields in acres

m = Total annual milk output and sales in cwt

l_{cl} = Number of livestock of type *cl* that is culled annually

y_q^s = Amount of raised feed q that is sold in cwt

y_q^p = Amount of fed feed q that is purchased in cwt

y_q^F = Amount of raised feed q that is fed in cwt

c^{TS} = Total operating cost of waste management technology systems in dollars

v = Dummy variable restricting proportion of solid manure hauled off to be zero unless all owned acreage is used up

p = Proportion of solid manure hauled out of dairy and applied on nondairy land within watershed

f^L = Amount of commercial nitrogen fertilizer applied on liquid waste fields in pounds

f^S = Amount of commercial nitrogen fertilizer applied on solid waste fields in pounds

c^{INV} = Total investment cost of dairy in dollars including capital outlay for waste management structures

t_i^{lg} = Dummy variable indicating number of lagoons on farm

t_s^{sep} = Dummy variable indicating whether a solid separator is used or not

t_f^{fs} = Dummy variable indicating whether a filter strip is used or not

t_{com}^{ccom} = Dummy variable indicating whether solid manure is sent to a central composting facility for composting

t_h^h = Dummy variable indicating whether the complete haul off option for solid manure is used

t_{inc}^{inc} = Dummy variable indicating whether solid manure is incorporated into the soil

t_{onc}^{ocom} = Dummy variable indicating whether solid manure is composted on the farm

d = Total debt of the dairy in dollars

e = Amount of investment cost financed through equity in dollars

d^{OPC} = Amount of debt in operating capital in dollars

d^{R} = Amount of debt in long term real estate (mortgage) in dollars

d^{a} = Debt asset ratio

c^{Feed} = Total annual cost of dairy cattle feed in dollars

tnm_j = Amount of nutrient j in solid manure at time of land application or haul off in pounds

tne_j = Amount of nutrient j in liquid manure at time of land application in pounds

tnm_j^a = Amount (at the time of land application) of nutrient j in solid manure that is applied on dairy land in pounds

tnm_j^b = Amount (at the time of haul off) of nutrient j in solid manure that is hauled off in pounds

ex_w = Total amount of nutrient w that is fed to dairy cattle annually in cwt

ex_{dm} = Total amount of dry matter that is fed to dairy cattle annually in cwt

$totaldm$ = Total amount of dry matter that is required by dairy cattle annually in cwt

Parameters

V^{cd} = Total variable cost of dairy per head, excluding waste management,s in dollars

P^{m} = Price of milk in dollars per cwt

P_{cl}^{l} = Price of culled livestock of type cl in dollars per animal

P_q^{sf} = Selling price of feed q in dollars per cwt

P_q^{pf} = Purchase price of feed q in dollars per cwt

V_{rl}^{LCR} = Annual operating cost in dollars per acre of liquid waste cropping rotation rl

V_{rs}^{SCR} = Annual operating cost in dollars per acre of solid waste cropping rotation rs

C^{haul} = Cost of hauling off all solid manure in dollars per head

C^{irrig} = Cost of expanding liquid waste (irrigated) acreage in dollars per acre

P^{nitr} = Purchase price of commercial nitrogen fertilizer in dollars per pound

I^{land} = Total investment in owned land in dollars

I^{herd} = Total investment in dairy herd establishment in dollars including buildings, initial herd of cattle, and feeding equipment

I_i^{lg} = Total investment cost of lagoon system *i* in dollars excluding irrigation facilities

I_i^{irrig} = Total investment cost of irrigation facilities accompanying lagoon system *i* in dollars

I_s^{sep} = Total investment cost of solid separator option *s* in dollars

I_f^{fs} = Total investment cost of filter strip option *f* in dollars

I_{com}^{ccom} = Total investment cost of central composting option *com* in dollars

I_h^h = Total investment cost of haul off option *h* in dollars

I_{inc}^{inc} = Total investment cost of solid manure incorporation option *inc* in dollars

I_{onc}^{ocom} = Total investment cost of onsite composting option *onc* in dollars

U^{equity} = Proportion of total investment cost financed by equity capital

U^{short} = Proportion of total debt that is held in short term operating capital

PVIFAO = Present value interest factor of annuity for debt held as operating capital

PVIFAR = Present value interest factor of annuity for debt held as long term capital

MAXDA = Maximum debt asset ratio: a constraint on borrowing

S = Maximum herd size given as number of cows

Y^m = Annual milk yield in cwt per head

Y_{cl}^l = Number of livestock of type *cl* culled annually for each cow on the farm

V_i^{lg} = Annual operating cost of lagoon system *i* in dollars per head excluding irrigation costs

V_s^{sep} = Annual operating cost of solid separator option *s* in dollars per head

V_f^{fs} = Annual operating cost of filter strip option *f* in dollars per head

V_{com}^{ccom} = Annual operating cost of central composting option *com* in dollars per head

V_h^h = Annual operating cost of haul off option *h* in dollars per head

V_{inc}^{inc} = Annual operating cost of solid manure incorporation option *inc* in dollars per head

V^{ocom}_{onc} = Annual operating cost of onsite composting option *onc* in dollars per head

$\Delta^{S}_{i,j}$ = Fractional change in solid manure nutrient *j* due to lagoon system *i*

$\Delta^{S}_{s,j}$ = Fractional change in solid manure nutrient *j* due to solid separator option *s*

$\Delta^{S}_{com,j}$ = Fractional change in solid manure nutrient *j* due to central composting option *com*

$\Delta^{S}_{onc,j}$ = Fractional change in solid manure nutrient *j* due to onsite composting option *onc*

$\Delta^{L}_{i,j}$ = Fractional change in liquid waste nutrient *j* due to lagoon system *i*

$\Delta^{L}_{s,j}$ = Fractional change in liquid waste nutrient *j* due to solid separator option *s*

$\Delta^{L}_{com,j}$ = Fractional change in liquid waste nutrient *j* due to central composting option *com*

$\Delta^{L}_{onc,j}$ = Fractional change in liquid waste nutrient *j* due to onsite composting option *onc*

NMP_j = Amount of nutrient *j* in solid manure in pounds at the time of land application or haul off without the effect of any waste management system

NLE_j = Amount of nutrient *j* in liquid waste in pounds at the time of land application without the effect of any waste management system

AS = Total solid waste acreage owned by dairy operator

AL = Total liquid waste acreage owned by dairy operator

$AGRATES_{j,rs}$: Agronomic application rate of nutrient *j* on solid waste cropping rotation *rs* in pounds per acre

$AGRATEL_{j,rl}$: Agronomic application rate of nutrient *j* on liquid waste cropping rotation *rl* in pounds per acre

$YLA_{q,rl}$ = Yield of crop or feed *q* on acreage of liquid waste cropping rotation *rl* in cwt per acre

$YSA_{q,rs}$ = Yield of crop or feed *q* on acreage of solid waste cropping rotation *rs* in cwt per acre

RR_w = Annual requirement of nutrient *w* in diet of lactating cows in cwt per lactating cow

$RRDRY_w$ = Annual requirement of nutrient *w* in diet of dry cows in cwt per dry cow

$RRBULL_w$ = Annual requirement of nutrient *w* in diet of bulls in cwt per bull

$RRHEIF_w$ = Annual requirement of nutrient *w* in diet of heifers in cwt per heifer

RR_{dm} = Annual recommended dry matter intake for lactating cows in cwt per lactating cow

$RRDRY_{dm}$ = Annual recommended dry matter intake for dry cows in cwt per dry cow

$RRBULL_{dm}$ = Annual recommended dry matter intake for bulls in cwt per bull

$RRHEIF_{dm}$ = Annual recommended dry matter intake for heifers in cwt per heifer

$NIF_{q,w}$ = Fractional content of nutrient w per unit crop or feed q on a 100% dry matter basis (Mcal per cwt for energy and 1000 IU per cwt for vitamins)

$NIF_{q,dm}$ = Fractional dry matter content of crop or feed q

$BOUND_{w}$ = Reasonable upper bounds on total intake of nutrient w by dairy cattle per unit of dry matter

$BOUND_{dm}$ = Reasonable lower bounds on dry matter intake of dairy cattle per unit of dry matter

$WASTE$ = Proportion of feed wasted on average during feeding

DRY = Average number of dry cows on the dairy farm at any point in time

$BULLS$ = Average number of bulls on the dairy farm at any point in time

$HEIFERS$ = Average number of heifers on the dairy farm at any point in time

MPI = Minimum recommended premix intake in cwt per head

MFI = Maximum recommended forage intake in cwt per head

SUBSIDY = Proportional increase in milk price by government policy

Model Description

Financial Component

This component contains the equations that determine the profitability of the dairy enterprise. In equation (1b) z, the net returns after variable costs, debt service payments, and annualized opportunity costs for the amount of equity investment, is calculated as the difference between net cash flow, debt service payments, and opportunity cost of equity. We assume that the primary objective of a typical dairy operator is to maximize net returns. Equation (2) shows the computation of net cash flow, z_{NCF}. The first term on the right hand side is the variable cost of the dairy, computed as variable cost per head, v^{cd}, multiplied by the herd size. The next two terms are milk sales revenues and returns from the sale of livestock. To these we add revenues from any crop sales and subtract the costs of cropping rotations on solid and liquid waste fields, cost of purchased feed and waste management systems, hauling costs, costs of expanding irrigated fields, and costs of nitrogen fertilizer. The result is the net cash flow of the dairy establishment.

Total investment cost is represented in (3) as c_{INV}. This consists of land costs, herd establishment costs (including buildings, feeding facilities, and initial cattle establishment), costs of any waste management systems in place, and costs of irrigation facilities. A given proportion, U^{equity}, of total investment costs is financed by equity as shown in (5). The rest is financed as debt (4). The total debt of the dairy is divided into short-term operating capital and long-term mortgage according to the proportion U^{short}, the short-term component of debt in (6) and (7). Thus the total annual debt payment is given in (8) where PVIFAO and PVIFAR are the present value interest factors of annuities on the short-term and long-term components of debt. Equation (9) evaluates the debt-to-asset ratio while (10) imposes a ceiling on this ratio.

Feed costs constitute a primary component of the operating costs of the dairy. Equation (11) computes feed costs for the sake of comparison with the other components of total variable cost. In this model, we constrain herd size to be exactly equal to the capacity of the farm, so there is no option for reducing herd size to help meet certain policy requirements. What is depicted in this model is, therefore, a short-run scenario. Milk production is represented in (13). Total milk output, m, is given as a constant yield coefficient times the herd size. Equation (14) is actually a set of three equations for each type of livestock sold. The number of animals of each of the three types in the set cl = {bulls, cows, calves} of culled livestock is given as a constant coefficient or proportion times the herd size. The final constraint in the financial component of the model is the inequality (15), which imposes a no-profit constraint on the cropping enterprise of the dairy farmer. This constraint is imposed in order to reflect the assumption that dairy farmers have no primary interest in cropping enterprises. The cropping rotations are primarily used for waste disposal purposes. Clearly, if we preclude crop sales by setting the selling price of all raised feed to zero, the no-profit constraint would be satisfied automatically.

Technology Choice Component

For the NPP farm-level economic model we assumed that the typical dairy farmer uses an open lot as herd management technology because most dairies in the study region are of that kind; there are very few freestall facilities in the area. Furthermore, it has been much easier to obtain data on open lot dairies.

few freestall facilities in the area. Furthermore, it has been much easier to obtain data on open lot dairies.

Another technology choice facing the farmer is that of waste management technologies. The model distinguishes seven structures or options that can be assembled into a waste management system.

Lagoons. Two types of lagoon systems are available: one-stage and two-stage. The farmer can choose to have either type of lagoon or none at all, unless otherwise constrained by the model in a given policy scenario. A one-stage lagoon system consists of an open earthen structure with adequate capacity to hold wastewater as well as runoff from animal confinement and process areas. According to current Texas regulations, the lagoon structures must also allow for enough volume to capture storm runoff from rain events of magnitudes of up to 25-year, 24-hour storms. In a one-stage lagoon system, the lagoon serves both for anaerobic digestion and for containment capacity to synchronize between wastewater generation and weather-contingent dewatering by irrigation.

In a two-stage lagoon system, the primary or first-stage lagoon serves primarily for anaerobic digestion while the secondary or second-stage lagoon is primarily, though not exclusively, for providing containment capacity to allow for infrequent dewatering that is driven by weather patterns and soil conditions.

Lagoons do not just store wastewater for infrequent dewatering. The process of anaerobic digestion ensures that the manure nutrients in the irrigated (lagoon) effluent are generally much smaller than the influent. This reduces the potential for excessive nutrient loadings into the ground and surface water media. One trade-off is that substantial volatilization off the lagoon surface results in more odor problems than would exist without lagoons. Another side effect of anerobic digestion is that the resulting lagoon effluent usually contains a lower level of nitrogen relative to phosphorus so that in order to maintain the appropriate nutrient ratio, commercial nitrogen costs to the farmer would be higher.

Solids Separators. These devices are used to separate manure solids from wastewater and runoff so that the total solids content in the portion of waste treated as liquid is minimized. This is primarily important if the dairy facility also has a lagoon system. A high solids content of liquid waste entering the lagoon would lead to more rapid build-up of sludge in the lagoon, making it necessary to scrape or clean the lagoon more frequently. Research results also show that the manure nutrient contents in the lagoon effluent are significantly lowered when a solids separator is installed.

Two major kinds of solids separators are used on dairy farms: gravity separators such as settling basins and mechanical separators such as the centrifugal or pressure-auger separators. In the economic model these types of separators are not distinguished. Manure nutrient reduction data represent an average over all kinds of separators. In the modeling framework, a typical dairy farmer may choose to have one separator or none, unless otherwise constrained in a specific policy scenario.

Filter Strips. Vegetative filter strips (also referred to as buffer strips, buffer zones, and filter strips) are vegetated regions that receive and purify runoff from upslope pollutant source areas (Chaubey et al. 1994). The use of filter strips results in no direct gains to dairy farmers. Farmers are therefore expected to adopt this technology only in response to a policy requirement. In the economic model the typical farmer has the choice of having a filter strip but is not required to, unless otherwise constrained in a specific policy scenario. The use of a filter strip entails committing some owned acreage to the strip. No manure can be applied on this land. Crop yields on the filter strip would be expected to be less than that of crops grown on land to which manure or other forms of nutrient have been applied. The economic model accounts for all these issues.

Manure Haul Off. Another waste management option in the economic model is that of hauling off all solid manure to nondairy land. We generally assume that only solid manure can be hauled off and spread over nondairy land. We also assume that there is an abundance of crop or pasture acreage over which solid dairy waste can be applied in accordance with policy specifications. It is assumed that manure has to be hauled an average distance of one mile to appropriate nondairy land. The cost of hauling and spreading all solid manure has been estimated as $10 per cow per year.

In addition to the complete haul off option, we also allow for hauling off excess manure if the dairy operator applies some solid manure on his own acreage but needs extra land to meet policy specifications. In that case, the cost of hauling is simply a proportion of the cost attributed to the complete haul off option, that proportion being the fraction of total solid manure that has to be hauled off.

Manure Incorporation. Just as with filter strips manure incorporation entails no direct, perceived benefits to the dairy farmer. Its benefits are to society in better waste management. Incorporating manure leads to less nutrient loss through surface flow. Like the haul off option, incorporation is assumed to be practical only for solid manure. Of all the crops accounted for in the model, only coastal bermuda hay is incompatible with this technology option. It is assumed that, in the case of a policy option specifying solid manure incorporation, coastal bermuda fields are exempt. An alternative assumption would be to enforce incorporation and thereby preclude all rotations involving coastal bermuda hay. Dairy farmers have the option of either incorporating manure or not incorporating it unless they are constrained by a particular policy scenario.

Central Composting. The central composting option consists of hauling off solid manure to a central composting plant where it is processed for a fee. It is assumed that, under the policy scenarios involving composting, all solid manure is composted. Even though the model could account for composting of only a portion of the manure, in general it is currently set up to deal with composting all or none of the manure. It is assumed that the product of the composting process is essentially a full substitute of commercial fertilizer so that composting practically brings an end to the problem of solid manure disposal. Unlike all the noncomposting options, the choice of the central composting option means that the level of each nutrient disposed into the environment is practically zero. Furthermore, we assume that the dairy farmer pays for the full cost of composting, unless otherwise subsidized by a government cost share in a given policy scenario.

On-site Composting. Very similar to the central composting option is the option of on-site composting. With this option all solid manure is composted on the dairy farm. Apart from the absence of any solid manure hauling, the assumptions here are basically the same as for the central composting option. Even though this option does not entail any hauling costs, it may lack the advantages of scale economies possible with central composting. A dairy farmer may choose to compost all solid manure on-site, but is not required to do so, unless otherwise constrained in a given policy scenario. Furthermore, the dairy farmer pays for the full cost of composting. While it is primarily an issue of variable cost with central composting, on-site composting might involve installing a composting facility, which would involve some overhead costs.

The choice of waste management technology is represented by equations (16) through (29). For each type of waste management system component, a binary variable t' ($t'^{\lg}$ for lagoons, t'^{sep} for solid separators, and so on) is used to indicate which option was chosen. For example, if $t'^{\lg}_{one\lg} = 1$ it means a one-stage lagoon was chosen. The constraint (16) ensures that only one option within each component is chosen: $t'^{\lg}_{one\lg} = 1$ implies that $t'^{\lg}_{two\lg} = 0$ and $t'^{\lg}_{no\lg} = 0$ as well. Similarly, (18), (20), (22), (24), (26), and (28) ensure that only one option within each of the other waste management system components is chosen.

The GAMS solver used for the optimization problem does not handle binary variables in nonlinear constraints. Transfer equations (17), (19), (21), (23), (25), (27), and (29) were used to create continuous variables that take on the same values as their binary counterparts. These continuous dummy variables could then be used in place of the binary ones in other constraints, particularly those that are nonlinear. Finally, equation (30) computes the total variable cost of the waste management technology systems, c^{ts}, which is in turn used in equation (2) to calculate net cash flow.

The last equation in this component of the model is (31), which imposes the no discharge specifications. This prohibits the discharge of wastewater or other dairy waste from animal confinement and process areas. Because of the difficulty inherent in monitoring discharges, such regulations are usually implemented by requiring the adoption of technologies that would in general prevent any violation of the regulation. In this case, constructing an earthen pond or lagoon is regarded an effective way to contain any runoff or discharge from animal confinement and process areas. Thus the no discharge stipulation is incorporated into the basic model by requiring that all dairies should have lagoon systems sized appropriately to contain wastewater from dairy areas. This is essentially the same as saying that the "no lagoon" option is not viable. Equation (31), therefore, imposes the no discharge requirements on the modeling framework. This, along with the other technology constraints, ensures that the dairy farmer would choose either a one-stage lagoon or a two-stage lagoon system. In either case the lagoons modeled in the NPP are sized in accordance with the regulatory requirements so that any violation of the no discharge rule is unexpected.

Manure Nutrient Component

The total amount of manure nutrients released into the environment is calculated in equations (32) and (33). In these equations, Δ^S and Δ^L represent the percentage changes in manure nutrients due to the given system. Equations (34) and (35) are acreage constraints. Again, b_{rl}^{l} and b_{rs}^{s} are variables that ensure that only one cropping rotation is chosen in any given policy scenario. According to equation (34) the total acreage used for irrigated crop production plus the area taken up by filter strip requirements must not exceed the total owned land available for liquid waste application augmented by any extra acreage taken out of solid waste fields. In equation (35) we see a similar constraint for solid waste application. Equations (36) and (37) compute the filter strip acreages taken out of solid and liquid waste application fields, depending on the choice of a filter strip option. Equations (38) through

(41) define the dummy variables b_{rl}^{l} and b_{rs}^{s} mentioned above. These dummy variables ensure that only one cropping system is chosen in any given policy scenario in order to simplify the requirements of the environmental modeling process.

Dairy Cattle Nutrition Component

This component of the model contains the constraints that ensure that an adequate diet is fed to the dairy cattle and that an appropriate accounting is done for crops raised as opposed to those fed so that the full benefit of feeding raised crops is reflected in the model. The first constraint suggests that the total amount of crop fed or sold from on farm crop enterprises cannot exceed the amount produced. Some amount of waste is permitted as (42) is an inequality. However, in an optimization framework this is expected to hold as an equality at the optimal solution.

Equation (43) is the dairy cattle nutrition constraint requiring that the ration fed to the cattle must meet all the nutrient requirements. The nutrients are indexed by w where w = {energy, protein, calcium, phosphorus, vitamin A, and vitamin D}. Furthermore, for the ration to be balanced it must be contained in the amount of dry matter the cattle can consume in any given time period. This latter requirement is imposed by inequality (44). Equation (45) computes the total dry matter recommended for the cattle. Equation (46) computes the total amount of each nutrient that is contained in the chosen ration while equation (47) does the same for dry matter. Then equations (48) and (49) impose reasonable bounds on these in order to avoid a ration that provides lethal amounts of any given nutrient.

The last two constraints are less demanding. Inequality (50) requires at least a minimum level of premix to be included in the chosen ration while equation (51) imposes a ceiling on the proportion of the ration that is composed of forage items.

This model is adequate to meet the specifications of the no discharge rule. As mentioned, the model has been augmented to deal with the various policy options being analyzed. These are discussed in the section dealing with economic model–environmental policy linkages. The model's results will provide needed information to aid policymakers in designing and developing future environmental policies to guide the livestock industry toward economic and environmental sustainability.

Economic Model Assumptions

In order to perform any meaningful analysis with the economic model, it is necessary to make specific assumptions of behavioral, technological, or other nature to be sure that the model responds in a way that is close enough to reality. Furthermore, specific assumptions are needed to analyze any policy scenario since it is crucial that we specify exactly what each policy implies. Specific policy requirements are outlined briefly in another section, where we deal with the linkages between the policy space and the economic model. The more general assumptions underlying the economic model are listed in Appendix B.

Data Requirements, Description, and Sources

The results of the mathematical programming model depend largely on the values of the coefficients used. These coefficients reflect the response of model constraints and solution values to changes in the respective variables. The various types of coefficients capture among others, dairy farm costs and returns, nutrient loadings into the environment by waste management system, crop yields and feed values, nutrient requirements of dairy cows, and specific policy parameters. A complete description of all the model coefficients and their sources is given in Appendix C.

Explicit Linkages Between Policy Space and the Dairy Farm Economic Model

The economic model does not model every option within the policy space, but it accounts for all the 17 specific policy options plus the two additional scenarios. This section of the report provides the detail necessary to understand the role of the dairy farm economic model, and its ability to model the specific policies proposed for the NPP. It explains how the basic model is augmented to account for the specifications of the environmental policy options being analyzed. The basic model outlined above meets the no discharge stipulation, which in itself is required in all the policy options.

Policy 1: No discharge with nitrogen agronomic application rate: Current Policy Scenario.

This policy requires, in addition to the no discharge stipulation, that the agronomic rate for nitrogen should not be exceeded. To incorporate this in the model, we introduce constraints in the manure nutrient component, that require that manure be applied at rates not exceeding the nitrogen agronomic rate for the crop(s) grown on the waste application fields. These constraints would be:

$$tnm^{a}_{nitr} - \sum_{rs} AGRATES_{nitr,rs} b^{s}_{rs} a^{s}_{rs} \leq 0 \text{ for solid fields and}$$

$$tne_{nitr} - \sum_{rl} AGRATEL_{nitr,rl} b^{l}_{rl} a^{l}_{rl} \leq 0 \text{ for liquid fields.}$$

In case there is insufficient owned land to apply the manure according to the nitrogen agronomic rate, the liquid waste acreage may be expanded, the excess land, a^{el}, assumed to be taken out of solid waste acreage. Any excess solid manure may be hauled off. A positive proportion, p, of solid manure hauled off implies an additional cost to the farmer evaluated as $C^{haul}ph$, where C^{haul} is the cost per head of hauling all solid manure out of the dairy. To avoid the problem of some manure being hauled off even though some owned land is available, we constrain the proportion hauled off to be positive only when all owned acreage has been used and excess solid manure exists. To achieve this, we calculate an indicator variable v such that

$$v = 0 \text{ when } \sum_{rs} a^{s}_{rs} + a^{fss} + a^{el} - AS \geq \varepsilon$$

$$v = 1 \text{ otherwise}$$

where ε is a positive number close to zero. Then in the model, the product vp is used instead of p wherever the proportion of manure hauled off is needed. Furthermore, we suppose that farmers would normally apply manure at the highest rate possible. Thus in this policy scenario we assume they would apply it at the nitrogen agronomic rates. Therefore, the additional constraints required for policy 1 are:

$$vp \leq 1 \tag{52}$$

$$vp \geq 0 \tag{53}$$

$$v = 1 + (1/\varepsilon)\left\{\max\left[\min\left(\sum_{rs} a^{s}_{rs} + a^{fss} + a^{el} - AS, 0\right), -\varepsilon\right]\right\} \tag{54}$$

$$tnm^{a}_{j} - \sum_{rs} AGRATES_{j,rs} b^{s}_{rs} a^{s}_{rs} = 0 \tag{55}$$

$$tne_j - \sum_{rl} AGRATEL_{j,rl} b_{rl}^{l} a_{rl}^{l} = 0 \tag{56}$$

$$tnm_j^a + tnm_j^b - tnm_j = 0 \tag{57}$$

$$tnm_j^b = vptnm_j \tag{58}$$

In addition we would need to modify equation (2) to include hauling costs and costs of expanding the liquid waste fields. The new equation would be (59). Furthermore, inequalities (34) and (35) would be replaced by inequalities (60) and (61) which account for the expansion of liquid waste acreage. The new constraints are

$$\begin{aligned} z^{NCF} = & -V^{cd}h + P^m m + \sum_{cl} P_{cl}^{l} l_{cl} - \sum_{rl} V_{rl}^{LCR} b_{rl}^{l} a_{rl}^{l} - \sum_{rs} V_{rs}^{SCR} b_{rs}^{s} a_{rs}^{s} + \sum_{q} P_q^{fs} y_q^{s} \\ & - \sum_{q} P_q^{pfs} y_q^{p} - c^{TS} - C^{haul} vph - C^{irrig} a^{el} \end{aligned} \tag{59}$$

$$\sum_{rl} b_{rl}^{l} a_{rl}^{l} + a^{fsl} - a^{el} \le AL \tag{60}$$

$$\sum_{rs} b_{rs}^{s} a_{rs}^{s} + a^{fss} + a^{el} \le AS \tag{61}$$

It is worth mentioning, though, that in general liquid waste acreage expansion is expected within a phosphorus agronomic rates policy scenario, rather than a nitrogen agronomic rates policy situation.

Policy 2: No discharge with phosphorus agronomic application rate.

With this scenario, farmers are expected to apply all solid manure and lagoon effluent at the phosphorus agronomic application rate for plant growth on manure application fields. Generally the nitrogen/phosphorus ratio in crop nutrient uptake is higher than the nitrogen/phosphorus ratio of nutrients available in the applied manure. It is assumed that farmers would apply commercial nitrogen fertilizer to bring the nitrogen/phosphorus ratio up to the level required for plant growth. To accomplish this scenario we begin with the equation system for policy 1 and adjust equation (2) to account for the cost of commercial nitrogen fertilizer. Similarly we replace equations (55) through (58) with equations (63) through (68) in which phosphorus agronomic rates are explicitly imposed and commercial nitrogen is applied as a supplement to meet accompanying nitrogen agronomic application rates. The additional constraints are as follows.

$$z^{NCF} = -V^{cd}h + P^{m}m + \sum_{cl} P^{l}_{cl} l_{cl} - \sum_{rl} V^{LCR}_{rl} b^{l}_{rl} a^{l}_{rl} - \sum_{rs} V^{SCR}_{rs} b^{s}_{rs} a^{s}_{rs} + \sum_{q} P^{fs}_{q} y^{s}_{q}$$
$$- \sum_{q} P^{pfs}_{q} y^{p}_{q} - c^{TS} - C^{haul} vph - C^{irrig} a^{el} - P^{nitr}(f^{L} + f^{S}) \qquad (62)$$

$$tnm^{a}_{nitr} + f^{S} - \sum_{rs} AGRATES_{nitr,rs} b^{s}_{rs} a^{s}_{rs} = 0 \qquad (63)$$

$$tne_{nitr} + f^{L} - \sum_{rl} AGRATEL_{nitr,rl} b^{l}_{rl} a^{l}_{rl} = 0 \qquad (64)$$

$$tnm^{a}_{phos} - \sum_{rs} AGRATES_{phos,rs} b^{s}_{rs} a^{s}_{rs} = 0 \qquad (65)$$

$$tne_{phos} - \sum_{rl} AGRATEL_{phos,rl} b^{l}_{rl} a^{l}_{rl} = 0 \qquad (66)$$

$$tnm^{a}_{j} + tnm^{b}_{j} - tnm_{j} = 0, j = \{\text{nitrogen, phosphorus}\} \qquad (67)$$

$$tnm^{b}_{j} = vptnm_{j}, j = \{\text{nitrogen, phosphorus}\} \qquad (68)$$

Policy 3: No discharge with relaxed phosphorus application rate.

This policy scenario augments the no discharge policy by allowing manure application at rates exceeding phosphorus agronomic application rates by up to 50 percent and 100 percent. We model this in the MINLP framework by modifying the equations restricting manure application to the agronomic rates. The equation system used for policy 2 is used here, with slight modifications in (65) and (66), which are replaced by (69) and (70).

$$tnm^{a}_{phos} - (1 + RELAX) \sum_{rs} AGRATES_{phos,rs} b^{s}_{rs} a^{s}_{rs} = 0 \qquad (69)$$

$$tne_{phos} - (1 + RELAX) \sum_{rl} AGRATEL_{phos,rl} b^{l}_{rl} a^{l}_{rl} = 0 \qquad (70)$$

Policy 4: No discharge with nitrogen agronomic application rate and incorporation of solid manure.

This policy is modeled by adding a technology standard to the equation system used for policy 1. By this technology choice restriction, we impose the constraint that all dairies must incorporate into the soil, all solid manure applied to cropland. This is equivalent to adding the constraint

$$t'^{inc}_{incorp} = 1 \tag{71}$$

to the equation system used for policy 1.

Policy 5: No discharge with phosphorus agronomic application rate and incorporation of solid manure.

The requirements of this policy are met by adding equation (71) to the equation system used for policy 2.

Policy 6: No discharge with nitrogen agronomic application rate and filter strip.

To account for nitrogen agronomic application rate policy with a filter strip requirement, we augment the model used for policy 1 with the following constraint:

$$t'^{fs}_{filter} = 1 \tag{72}$$

Policy 7: No discharge with phosphorus agronomic application rate and filter strip.

This policy is modeled by adding equation (72) to the equation system used for policy 2.

Policy 8: No discharge with nitrogen agronomic application rate and cost shared filter strip.

This policy augments the no discharge policy by requiring operators to apply all solid manure and lagoon effluent at the nitrogen agronomic application rate for plant growth on manure application fields, as well as to maintain a vegetative filter strip at least 15 feet wide along the entire lower edge of manure application fields. There is a government cost share that covers 65 percent of the cost of establishing filter strips on all dairies. Government cost sharing is modeled by including a cost share term in equation (3), which then becomes

$$c^{INV} = I^{land} + I^{herd} + \sum_i I_i^{\lg} t_i^{\lg} + \sum_i I_i^{irrig} t_i^{\lg} + \sum_s I_s^{sep} t_s^{sep} + \sum_f (1 - C_f^{share}) I_f^{fs} t_f^{fs} + \sum_{com} I_{com}^{ccom} t_{com}^{ccom} + \sum_h I_h^h t_h^h + \sum_{inc} I_{inc}^{inc} t_{inc}^{inc} + \sum_{onc} I_{onc}^{ocom} t_{onc}^{ocom} \tag{73}$$

where $C_{nofilter}^{share} = 0$ and $C_{filter}^{share} = 0.65$.

Thus policy 8 is analyzed by adding equation (73) to the model used for policy 6.

Policy 9: No discharge with nitrogen agronomic application rate for lagoon effluent; solid manure transported to a central compost facility.

With this scenario the lagoon effluent is applied at the nitrogen agronomic rate. In addition dairy operators are required to transport all solid manure to a central compost facility. This entails a processing cost to the farmer per unit of manure composted. This policy is modeled by adding constraint (74) to the model specifications used for policy 1.

$$t_{compost}^{\prime\, ccom} = 1 \tag{74}$$

Policy 10: No discharge with nitrogen agronomic application rate for lagoon effluent; solid manure composted on-site.

The basic difference between this policy and the previous one is that while the other required centralized composting, this requires on-site composting. As with the previous policy, we model this scenario by adding to policy 1's model specifications, a new constraint that forces all dairy operators to compost all solid manure on their farms:

$$t_{onsite}^{\prime\, ocom} = 1 \tag{75}$$

The cost features characterizing on-site composting are different from those true in the case of central composting. These differences are captured in the model coefficients.

Policy 11: No discharge with nitrogen agronomic application rate for lagoon effluent; solid manure composted on-site with 65 percent cost share for composting expenses.

This policy promises a 65 percent government cost share to accompany the threefold requirements of policy 10: no discharge, nitrogen agronomic rate for liquid waste application, and on-site composting. Thus the model for policy 10 is used with equation (3) being replaced by equation (76), which includes a cost share term for on-site composting.

$$c^{INV} = I^{land} + I^{herd} + \sum_i I_i^{\lg} t_i^{\lg} + \sum_i I_i^{irrig} t_i^{\lg} + \sum_s I_s^{sep} t_s^{sep} + \sum_f I_f^{fs} t_f^{fs} + \sum_{com} I_{com}^{ccom} t_{com}^{ccom} + \sum_h I_h^h t_h^h + \sum_{inc} I_{inc}^{inc} t_{inc}^{inc} + \sum_{onc} (1 - C_{onc}^{share}) I_{onc}^{ocom} t_{onc}^{ocom} \tag{76}$$

where $C_{noonsite}^{share} = 0$ and $C_{onsite}^{share} = 0.65$.

Policy 12: No discharge with phosphorus agronomic application rate for lagoon effluent; solid manure composted on-site.

In its specifications, this policy differs from policy 10 only in requiring that the lagoon effluent be applied at the phosphorus agronomic rates rather than the nitrogen agronomic rates. It is modeled by adding equation (75) to the model structure for policy 2.

Policy 13: No discharge (ACPA) with nitrogen agronomic application rate and two-stage lagoon technology adoption subsidized by milk price premium.

For this policy scenario we analyze the implications of alternative milk price subsidies accompanying the threefold requirements of no discharge, nitrogen agronomic rates, and two-stage lagoon system. To model this policy we introduce a constraint which forces farmers to have two-stage lagoon systems:

$$t_{two\lg}^{r\lg} = 1 \tag{77}$$

Furthermore, we modify equation (59) by including a milk price subsidy term. The new equation defining net cash flows then becomes

$$z^{NCF} = -V^{cd} h + (1 + SUBSIDY) P^m m + \sum_{cl} P_{cl}^l l_{cl} - \sum_{rl} V_{rl}^{LCR} b_{rl}^l a_{rl}^l - \sum_{rs} V_{rs}^{SCR} b_{rs}^s a_{rs}^s + \sum_q P_q^{fs} y_q^s - \sum_q P_q^{pfs} y_q^p - c^{TS} - C^{haul} vph - C^{irrig} a^{el} \tag{78}$$

Policy 14: No discharge with manure application according to European Union nitrogen directive.

The model structure for this is the same as for policy 1. The difference between this policy and policy 1 is that rather than allowing manure application rates to be determined by crop needs, a fixed rate of 152 pounds per acre (170 kg/ha) is stipulated. Thus all dairy operators apply solid manure and liquid waste at the rate of 152 pounds per acre. This policy is modeled by replacing the agronomic liquid waste at the rate of 152 pounds per acre. This policy is modeled by replacing the agronomic application rates tables of coefficients, *AGRATEL* and *AGRATES* by a table, EU, of the constant nitrogen rate of 152 pounds per acre (across all crop types) in equations (55) and (56). Appropriate crop yield adjustments are made to correspond with the fixed nitrogen application rate.

Policy 15: No discharge with nitrogen agronomic application rate and tax on purchased feed.

This policy augments the specifications of policy 1 by imposing a proportional tax on all purchased feed. We model this policy by introducing a tax term in equation (59), which then becomes

$$\begin{aligned} z^{NCF} = & -V^{cd}h + P^m m + \sum_{cl} P^l_{cl} l_{cl} - \sum_{rl} V^{LCR}_{rl} b^l_{rl} a^l_{rl} - \sum_{rs} V^{SCR}_{rs} b^s_{rs} a^s_{rs} + \sum_{q} P^{fs}_q y^s_q \\ & - \sum_{q} (1 + TAX) P^{pfs}_q y^p_q - c^{TS} - C^{haul} vph - C^{irrig} a^{el} \end{aligned} \quad (79)$$

For this policy we thus use the equation system from policy 1, but equation (79) is used in place of (59).

Policy 16: No discharge with nitrogen agronomic application rate and solids separator.

This policy requires all dairy operators to install or construct solid separators for use on their farms. Modeling this policy requires the equation system used for policy 1 and an additional technology constraint,

$$t^{t\,sep}_{separat} = 1. \quad (80)$$

Policy 17: No discharge with nitrogen agronomic application rate and cost-shared solids separator.

This policy differs from the previous policy only in providing a 65 percent government cost share for the construction of a solids separator. As with the other policies involving government cost sharing, we augment equation (3) and use instead:

$$\begin{aligned} c^{INV} = & I^{land} + I^{herd} + \sum_i I^{lg}_i t^{lg}_i + \sum_i I^{irrig}_i t^{lg}_i + \sum_s (1 - C^{share}_s) I^{sep}_s t^{sep}_s + \sum_f I^{fs}_f t^{fs}_f + \\ & \sum_{com} I^{ccom}_{com} t^{ccom}_{com} + \sum_h I^h_h t^h_h + \sum_{inc} I^{inc}_{inc} t^{inc}_{inc} + \sum_{onc} I^{ocom}_{onc} t^{ocom}_{onc} \end{aligned} \quad (81)$$

where $C_{nosep}^{share} = 0$ and $C_{separat}^{share} = 0.65$.

In addition to these policies, two more scenarios are being considered because they reflect what many dairy operators are doing now, according to several studies (see, for example, Trachtenberg and Ogg 1994). These scenarios are based on the assumption that farmers think manure has little or no crop nutrient value. Thus, after applying the animal waste at the given policy specifications, they apply commercial nitrogen as if little or no nutrient was provided by the manure. Based on the current policy scenario (policy 1), these additional scenarios are also modeled.

Scenario 1: No discharge with nitrogen agronomic application rate and commercial N application at 100 percent of the agronomic rate on cropland.

For this scenario, we use the model specifications for policy 1 except that equation (62), which accounts for commercial nitrogen costs is used in place of equation (59) and we have the following additional equations:

$$f^{S} - \sum_{rs} AGRATES_{nitr,rs} b_{rs}^{s} a_{rs}^{s} = 0 \tag{82}$$

$$f^{L} - \sum_{rl} AGRATEL_{nitr,rl} b_{rl}^{l} a_{rl}^{l} = 0 \tag{83}$$

Scenario 2: No discharge with nitrogen agronomic application rate and commercial N application at 50 percent of the agronomic rate on cropland.

This scenario is modeled by using the same equations as for scenario 1 with modifications. The AGRATES and AGRATEL terms in equations (82) and (83) are multiplied by 50 percent (or half) to reflect the fact that commercial nitrogen is applied at half the crop agronomic rates in this scenario. As in the previous scenario, manure is applied at the nitrogen agronomic rate.

Cross and Extended Media—Institutional—CAFO Location and Producer Structure

The role of the dairy farm economic model in cross and extended media, institutional, and CAFO location and producer structure policy issues is limited. The dairy farm economic model provides nutrient loading information to the environmental simulation models, which capture the cross effects on environmental resources. It has no role in evaluating monitoring/enforcement policies, and institutional issues. The dairy farm economic model analyzes producer size through the model formulation that incorporates the small, medium, and large size classifications, but has no role in analyzing polices influencing the regionalization of livestock production.

Dairy Farm Economic Model—Environmental Simulation Model Linkages

Environmental pollution in dairy farming can be caused by the loss of nutrients and objectionable odor levels from the dairy site and its associated waste application fields. The potential impact of dairy waste on surface water quality is primarily due to phosphorus loadings. Phosphorus is usually the limiting nutrient for algae blooms that impair water uses directly and contribute to reduced dissolved oxygen content in surface water. Decreased dissolved oxygen has been attributed to five fish kills in the North Bosque River Watershed. Nitrogen percolating below the root zone in the form of nitrates poses a potential threat to groundwater quality. Objectionable odor, particularly when waste is being applied on the application fields, is a potential problem. The extent of dairy environmental pollution depends on implemented BMPs and site-specific characteristics such as meterorological conditions, receiving water flow, water temperature and depth, sunlight, distance to receiving waters, soil type and slope, and the magnitude of other point and nonpoint source emissions. Therefore, it is worth noting that modeling such a complex dairy nonpoint source pollution problem requires tremendous skill and thorough understanding of all the underlying processes.

It is important to note that the dairy farm economic model does not provide adequate measures to assess environmental impacts. The economic model provides information on the implementation of BMPs, the crop rotation, and the magnitude of nutrient loadings. This information serves as partial input to the Erosion Productivity Impact Calculator (EPIC) which serves as the field level environmental simulation model to determine the amount and nutrient concentration of surface edge-of-field runoff and bottom of the soil profile leaching. For the purpose of modeling fate and transport of nutrients from dairy waste application a more tailored EPIC model for whole farm analysis called APEX (Agricultural Policy EXtender) was developed by the Blackland Research Center in Temple, Texas, for use in our current NPP policy evaluation.

APEX was developed by the USDA Agricultural Research Service in Temple, Texas, to extend the capabilities of EPIC for simulation of large complex farming systems. It has features that account for the routing of water, sediment, nutrients, and pesticides across landscapes of different topographies. It's major advantage over EPIC is that it allows for routing over multiple fields. It is thus more capable of handling dairy farm situations as the latter more often than not include multiple waste application fields.

APEX receives, as its input, output from the economic model. This output includes manure nutrient application on waste application fields, acreages under various cropping rotations, and the waste treatment facilities used. Economic model output to APEX is created as a GAMS "put" file in ASCII format. This put file is read into APEX by an automated APEX input file builder. Through its simulation capabilities APEX produces as its output, the edge-of-field nutrient contents and other soil and water parameters. This then serves as input to another model, the Soil and Water Assessment Tool (SWAT), which is a basin or watershed level aggregator of the environmental parameters obtained from APEX. The edge-of-field loadings from APEX are routed into SWAT on a daily time step basis to measure surface water impacts at the microwatershed/ watershed level. Thus, beginning with nutrient loadings onto the waste application fields, the APEX and SWAT models enable us to capture the fate and transport of these environmental parameters at the watershed level and also at disaggregated levels. A detailed review of these models and their linkages will be provided in the NPP's task report 3.1. The objective of this section of the report is to detail the dairy farm economic model's role in providing input to the environmental models.

NPP Project Task 1.4 (Bouzaher et al. 1993a) identified a number of parameters that will be monitored as environmental indicators. A summary of the recommended indicators is provided in Table 3, and the second column indicates whether the modeling system will account for the indicator. Table 3 identifies ten indicators, of which the environmental modeling system accounts for five. The dairy farm economic model determines the production of these nutrient indicators in the manure and lagoon effluent. The acres of filter strip used and the crop rotation complete the direct information linkages between the economic and environmental simulation models.

Table 3. Environmental Indicators

Indicator	Model
Coliforms	NO
TKN	YES - EPIC/APEX
Nitrate - Nitrogen	YES - EPIC/APEX
Ammonia	YES - EPIC/APEX
Total Phosphorus	YES - EPIC/APEX
Orthophosphorus	YES - EPIC/APEX
Sodium	NO
Chloride	NO
pH	NO
BOD	NO

The economic model is based on an annual time frame. EPIC/APEX can be run on a daily, monthly or annual time frame, and requires as input the timing of nutrient applications to the waste fields. The distribution of nutrient load application levels throughout the year will be determined exogenously. This distribution can be varied to examine the effect of policies that regulate the timing of waste applications. These types of policies are in effect in northern climates where waste cannot be applied to frozen application fields.

Potential future refinements that would further enhance the linkages between the economic and environmental simulation models are possible. For example, currently a fixed crop yield is used by the economic model. It is conceivable that APEX's crop yield estimates could be used by the economic model to estimate a variable yield response. However, at this point in time, the focus is on quantifying the environmental impact in response to alternative policies that influence the implementation of managerial and structural BMPs at the dairy farm level. Future refinements will be adopted as necessary.

Summary

The design of economically sound policies for reducing nutrient losses for dairy farms requires consideration of how farmers may respond to alternative policies, the farmers' costs of nutrient control, and the resulting environmental benefits. This report details the linkages between the policy space, the dairy farm economic model, and the environmental simulation models. The policy simulation results from these models identify farm-specific economic and environmental impacts and resulting tradeoffs. This information serves as a base to aggregate the impacts to microwatersheds and to the entire watershed and make regional assessments.

These are some of the limitations to this modeling system. The economic model is annual so that seasonal changes in behavior or model parameters are not considered explicitly. Issues that relate to distribution of key variables across months or days in a given year are not explicitly considered. The environmental simulation models, on the other hand, are capable of handling such dynamic issues. Finally, the accuracy of the coefficients of the economic model is limited to some extent by data availability. In some cases it is possible to construct reasonable confidence intervals to reflect the most likely value range of the relevant parameters. We did this for the nutrient loading coefficients, because these vary so much by information source.

Despite these limitations, the current model captures to an appreciable extent most of the relevant issues for the environmental considerations for livestock feedlots. Furthermore, model calibrations and refinements are underway to enhance the model's usefulness in analyzing current and future policy issues.

APPENDIX A.

DAIRY FARM ANNUAL ECONOMIC BUDGETS

	Small 225 milking 185	Medium 400 milking 350	Large 1,200 milking 1,000
REVENUE			
Milk Production (cow)	166.95 cwt	189.0 cwt	195.3 cwt
Milk Production (herd)	37,564 cwt	75,600 cwt	243,360 cwt
Milk Sales[a]	$475,933	$957,852	$2,969,341
Cull Cow	68 head $43,875	120 head $78,000	360 head $234,000
Cull Bull	3 head $3,000	8 head $8,000	30 head $30,000
Calf Sale	166 head $16,600	243 head $24,300	1069 head 106,900
TOTAL REVENUE	$539,408	$1,068,152	3,340,261
Operating Costs			
Feed[b]	$225,716	$497,420	$1,220,359
Replacements	49,178	68,750	495,300
Promo. Haul Coop	41,320	83,160	257,796
Operating	58,033	106,990	413,833
Hired Labor	68,420	117,508	241,522
Farming[c]	14,428	0	0
TOTAL OPERATING	$457,096	$873,828	$2,628,809
Capital Cost			
Total Investment	$480,000	$1,026,000	$2,790,000
Annual Debt Cost	$46,642	$125,706	$331,353
Net Returns	$35,670	$68,618	$380,098
Net Returns (per cow)	$159	$172	$317

Notes: [a] Price of milk can be varied within the model, $12.67/cwt assumed here.
[b] Feed costs are determined endogenously within the economic model.
[c] Farming Costs are for small, medium and large sizes haul manure offsite.

SOURCE: Pagano, Amy, John Holt, Robert B Schwart, Kristin A. Gill, and Heather Haedge Jones. Profiles of Representative Erath County Dairies, Livestock and the Environment: A National Pilot Project, Project Task 1.3a, TIAER, Stephenville, Texas, November, 1992.

APPENDIX B.

MAJOR ASSUMPTIONS OF THE ECONOMIC MODEL

1. The farmer gains additional benefits from crop farming by means of the harvested forage or crop which can be fed to the cattle. However, no crop or forage sales are allowed in the model.

2. The dairy farmer is entitled to choose one waste treatment structure. The feedlot operator need not choose from any or all of the previously mentioned waste treatment options unless otherwise obliged to do so because of some specific policy stipulations.

3. Each waste management system results in various levels of N (including NH3, N03, and organic N), P, K, and other nutrients, microbial compounds and organisms in liquid waste as well as solid manure.

4. In case the size of the application fields is inadequate to contain manure at the rate stipulated by regulations, the dairy farmer may haul off any excess solid manure. Since it is less practical to haul off liquid waste, it is assumed that if necessary, the liquid waste acreage will be expanded, the additional acreage being taken out of the solid waste acreage.

5. In accordance with the above assumption, we permit solid manure to be hauled out of the dairy feedlot assuming abundant acreage in the watershed for waste disposal. However, the model is structured to permit haul off only when all owned acreage has been used for manure disposal and there is extra solid manure. Thus even though the farmer might find it more profitable to haul off manure rather than apply it on his land, we do not permit any haul off that is solely based on profit maximization.

6. As the nutrient ratios in manure are different from those required in regulations governing manure application (as in the case of agronomic rates), it is often necessary to apply mineral (commercial) fertilizer. Mineral forms of the limiting nutrients are applied to bring the nutrient ratios up to par with the stipulated levels. The limiting nutrient is the one whose crop use (agronomic need) to manure content ratio is highest. In general we assume this to be nitrogen rather than phosphorus.

7. Mineral fertilizer is applied for the sole purpose of meeting stipulated (agronomic) nutrient ratios. Once these ratios have been reached, no further mineral fertilizer application is done. The possibility is entertained for there to exist excess acreage if manure nutrient production is not large enough to cover all available crop land.

8. We assume that the agronomic rates stipulated in the policies refer to the levels of nutrients available for plant uptake rather than the levels at the time of land application. Thus in calculating the amount of manure to be applied, the farmer considers pre-land application losses (due to waste treatment systems and barnlot losses), surface losses after land application, as well as 'losses' due to the fact that some portion of the nutrient is not available for plant uptake even though it resides in the soil. We have used the SCS numbers for surface loss rates and plant availability proportions of nitrogen. No such losses were assumed for phosphorus. Thus even though the actual levels of surface losses and plant availability proportions of nitrogen depend on other factors such as climate, time and management practices, we have assumed the fixed SCS rates in the model. This seems reasonable since this is typically what the farmers also anticipate on average. However, the APEX runs will take all the other factors into account and allow for variability in the levels of nutrient available to the crop. Hence, while the SCS assumptions enable us to calculate how much manure the farmer would apply on the land, the APEX model estimates how much is actually used up and the fate of any remainder.

9. In computing filter strip acreages we have assumed a square configuration for all waste application fields. We have also assumed that there is only one downslope side.

10. We assume that dairy enterprises can be adequately categorized into three classes based upon herd size.

APPENDIX C.

COEFFICIENTS OF THE DAIRY FARM ECONOMIC MODEL

Coefficients of dairy farm economic model: Financial Component

Price of livestock sales (per animal)

Livestock	Price
Cows	650
Bulls	1000
Calves	100

Source: Profiles of Representative Erath County Dairies, June 1994.

Yield per cow of cull livestock (animals per cow)

	Small	Medium	Large
Cows	0.3022	0.3000	0.3000
Bulls	0.0133	0.0200	0.0250
Calves	0.7378	0.6075	0.8908

These coefficients are used so that the number of animals sold for each livestock type would be the same as implied by the Profiles of Representative Erath County Dairies, June 1994. In the Profiles, the number of cull livestock by type for the small (225 cow), medium (400 cow) and large (1200 cow) dairies were recorded as follows:

Number of cull livestock

	Small	Medium	Large
Cows	68	120	360
Bulls	4	8	30
Calves	166	243	1069

Operating cost per acre of liquid waste crop rotations (dollars per acre)

Cropping Rotation	Cost
Coastal bermuda hay	114.68
Coastal bermuda-winter wheat	176.05
Sorghum double cropped with winter wheat	221.01
Sorghum/Sudan	123.94
Corn silage	126.07

Source: Enterprise Budgets 1993, Central Texas District, Texas A&M Extension Service.

These costs do not include irregation costs, which are accounted separately.

Operating costs of solid crop waste rotations were the same, except that the costs of land application of solid manure are accounted separately.

Purchase price of feedstuffs per cwt

	Small	Medium	Large
Premix	8.25	8.25	6.70
Alfalfa	6.00	6.00	6.00
Coastal	3.00	3.00	3.00
Silage	1.35	1.35	1.35
Sorghum	3.00	3.00	3.00
Wheat	3.89	3.89	3.89
Mineral	17.50	17.50	17.50

Source: Profiles of Representative Erath County Dairies, June 1994

Scalar Coefficients

Coefficient	Description	Small	Medium	Large
VCD	Variable cost of dairy per cow	973.44	936.02	1161.21
FCD	Fixed cost of dairy facility	365,500	930,000	2,360,000
PM	Price of milk per cwt	12.67	12.67	12.67
S	Herd Size: total # of cows	225	400	1200
YM	Annual milk yield per cow in cwt	166.95	189	195.3
EQUITY	Proportion of equity	0.55	0.55	0.55
IRATE	Interest rate on debt	0.11	0.11	0.11
BUILDING	Value of buildings and feeding equipments	140,500	530,000	1,160,000
MAXDA	Maximum debt to asset ratio	0.8	0.8	0.8
HAULCOST	Cost of manure hauling per cow	10	10	10
IRRIGEXP	Cost of liquid field expansion per acre	169.67	121.08	117
NPRICE	Cost of nitrogen fertilizer in dollars per pound	0.2	0.2	0.2
LANDCOST	Total cost of owned acreage	112500	225000	200000
PVIFAO	Present value interest factor for loan	3.6048	3.6048	3.6048
PVIFAM	Present value interest factor for mortgage	9.8226	9.8226	9.8226
SHORT	Proportion of debt in operating capital	0.65	0.65	0.65
SUBSIDY	Milk price subsidy for adoption of two-stage lagoon	0.0025	0.0025	0.0025
TAX	Tax rate on purchased feed	0.02	0.02	0.02
SHARE	Fraction of government cost share	0.65	0.65	0.65

The coefficients in the above table were obtained as follows:

Variable cost of dairy per cow: Calculated from Profiles of Representative Erath County Dairies, June 1994, by dividing total variable cost by herd size. These costs do not include manure hauling costs, operating costs of crop farming, or of the waste treatment systems as they are accounted for elsewhere in the model.

Fixed cost of dairy facility: Obtained from Profiles of Representative Erath County Dairies, June 1994. Includes cost of buildings, feeding equipments and livestock purchases involved in initial herd establishment.

Price of milk per cwt: Obtained from Profiles of Representative Erath County Dairies, June 1994.

Herd Size: total number of cows: Obtained from Profiles of Representative Erath County Dairies, June 1994.

Annual milk yield per cow in cwt: Obtained from Profiles of Representative Erath County Dairies, June 1994.

Proportion of equity: Obtained from Profiles of Representative Erath County Dairies, June 1994.

Interest rate on debt: Obtained as prevailing interest rate on debt in study area.

Value of buildings and feeding equipments: Calculated from Profiles of Representative Erath County Dairies, June 1994.

Maximum debt to asset ratio: Chosen by modeler.

Cost of manure hauling per cow: Calculated by considering manure hauling cost in profiles and recent dairy farm data in Erath County.

Cost of liquid field expansion per acre: Calculated by dividing irrigation facility expenses by the number of acres involved. This figure will help us capture added cost of expanding liquid waste acreage. Irrigation facility expenses were obtained through communications with an irrigation facility expert in Erath County.

Cost of nitrogen fertilizer in dollars per pound: Price of commercial nitrogen fertilizer obtained from crop enterprise budgets in Texas A & M Extension Bulletin.

Total cost of owned acreage: Calculated from Profiles of Representative Erath County Dairies, June 1994, by multiplying land cost per acre by total owned acreage.

Present value interest factor for loan: Obtained from financial tables in Brigham and Gapenski, 1991. Using the Profiles as our basis, we assumed that the dairy pays 12percent interest on a 5-year operating capital.

Present value interest factor for mortgage: Obtained from financial tables in Brigham and Gapenski, 1991. Based on the Profiles, the typical dairy has a 25-year mortgage with an interest rate of 9 percent.

Proportion of debt in operating capital: Obtained from Profiles of Representative Erath County Dairies, June 1994.

Milk price subsidy for adoption of two-stage lagoon: A policy parameter introduced for a price subsidy policy.

Tax rate on purchased feed: A policy parameter introduced for a feed tax policy.

Fraction of government cost share: A policy parameter introduced for a government cost share policy.

Coefficients of Dairy Farm Economic Model: Technology Component

Total cost of construction (fixed costs) of technology systems

	Small	Medium	Large
One-stage lagoon	21,120.15	39,971.95	114,153.01
Two-stage lagoon	23,909.60	45.183/01	129,050.53
Primary lagoon	12,200.03	23,081.96	65,935.32
Secondary lagoon	11,709.57	22,101.05	63,115.21
Filter strip ($/acre)	62.23	62.23	62.23
Solid separator	14,500	14,500	22,500
Incorporation	0	0	0
Centralized composting	0	0	0
On-farm composting	200,000	300,000	500,000

All the above cost figures represent total investment costs, except for filter strip figures which are in dollars per acre of filter strip. The cost for the solid separator reflects the total cost of purchasing and installing an AgKone mechanical separator, which is representative of the solid-liquid separators used in Erath County. These figures assume a maximum pump capacity of 450 gallons per minute and that all dairy feedlots are of the dry lot type as opposed to a freestall.

Filter strip construction costs were calculated from Camacho (1991) as cited in EPA-840-B-92-002 (January 1993). The equivalent annual cost cited in Camacho (1991) was $7.31/acre/year. Using the suggested practical life span of 5 years we obtain a total investment cost of $27.71/acre. However, if we account for a 20 year lifespan (in order to match up with the lifespan of the other waste treatment structures), we will have $62.23/acre. This assumes an interst rate of 10 percent.

On-farm composting investment was estimated from costs cited in the On-farm Composting Handbook published by the Northeast Regional Agricultural Engineering Service (NRAES, 1992).

Investment costs for lagoons were obtained by multiplying the volumes of the lagoons by a cost per unit volume of construction. Lagoon design volumes are presented below. Lagoon construction costs per unit volume vary depending on the type of lining material and the pedological features of the site.

Some unit cost estimates are presented in the following table. For this study, we used the $1.90 per cubic yard figure from a local contractor in Erath County, Texas.

Lagoon unit construction costs from various sources

Source	$/cubic ft	$/cubic yd	$/acre-ft
USDA May 1992: without liner	0.13	3.50	5609
USDA May 1992: with soil liner	0.20	5.37	8667
USDA May 1992: with HDPE liner	0.34	9.28	14964
USDA May 1992: with reenforced concrete	0.50	13.62	21970
NRCS, Stephenville, TX[a]	0.04	1.05	1694
Local Contractor: Erath County, TX[b]	0.07	**1.90**	3065
EPA-840-B-92: 241 cubic ft pond	2.58	69.66	112385
EPA-840-B-92: 2678 cubic ft pond	1.24	33.48	54014
EPA-840-B-92: 28638 cubic ft pond	0.60	16.20	26136
EPA-840-B-92: 267123 cubic ft pond	0.31	8.37	13504
ISU Ag. Eng. Extension (1 cent per gallon)[c]	0.07	2.02	3259

a: From personal communication. These figures reflect an average over cost estimates reported by local dairy operators. NRCS sources indicate that prices cited by contractors are usually higher.

b: These figures include the costs of lagoon excavation, and berm and liner construction as reported by a local contractor in Erath County, TX. These costs assume that the material is onsite.

c: From personal communication.

Technology system operating cost per head (dollars per cow)

	Small	Medium	Large
Solid manure spreading	18.50	16	12
One-stage lagoon	11	9	5
Two-stage lagoon	11	9	5
Filter strip	0	0	0
Solid separator	6.50	5	3
Incorporation	2	2	2
Centralized Composting	75.15	75.15	75.15
On-farm composting	57.33	57.33	57.33

Technology system operating costs include an allowance for maintenance. Solid manure spreading includes cost of broadcasting or surface applying the solid manure. One-stage and two-stage lagoon system operating costs include insurance, repairs, taxes, fuel and lubrication, and electricity. They do not include labor costs as these are accounted for elsewhere in the model. The operating costs tabulated above are extrapolations of the estimates obtained from USDA (1992), as tabulated below. Centralized composting operating costs consist of a $10/cow/year hauling cost for manure and a composting fee which comes to about $65.15/cow/year. This figure was obtained by using a $5.50/ton estimate given for poultry in Biocycle August 1992, page 90. We adjusted this figure for the difference in percent solids between dairy cows and poultry.

On-farm composting operating cost were estimated from cost figures cited for swine composting in Wilkinson and Amick, 1993.

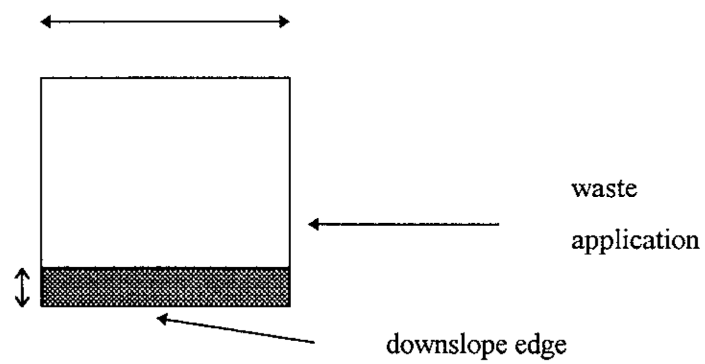
Waste treatment system operating costs from USDA 1992

System/Cost Category		**Herd Size**	
Practice	100	200	300
Manure spreading (daily)			
Insurance, repair, taxes	946	1253	1510
Labor cost (@ $4/hour)	980	1816	2672
Labor cost (@ $6/hour)	1470	2724	4008
Fuel and lubrication	1421	2460	3551
Electricity ($0.03/kWh)	0	0	0
Lagoon flush			
Insurance, repair, taxes	958	1124	1277
Labor cost (@ $4/hour)	440	880	1320
Labor cost (@ $6/hour)	660	1320	1980
Fuel and lubrication	543	1087	1622
Electricity ($0.03/kWh)	20	41	61

Lagoon flush and separator			
Insurance, repair, taxes	1847	2013	2166
Labor cost (@ $4/hour)	804	1608	2412
Labor cost (@ $6/hour)	1206	2412	3618
Fuel and lubrication	584	1169	1745
Electricity ($0.03/kWh)	210	420	631
Cost per cow for separator only	11.2	6.75	5.27

Filter strip dimensions:

The filter strip is constructed on the downslope edge of the field as illustrated below.



We assume a square configuration for the waste application fields. Let A be the acreage of the field and l the length (or breadth) of the field in feet. Suppose w is the minimum required width in feet of the filter strip according to a regulatory policy. Then the area of the filter strip in square feet is wl. Thus the area of the filter strip in acres would be given as $f = w\sqrt{A/k}$ where k equals 43,560, the number of square feet in an acre. Thus, if A_L and A_S are the liquid and solid waste application acreages respectively, then the liquid and solid waste filter strip acreages would be given respectively as

$$f_L = w\sqrt{\frac{A_L}{k}} \text{ and } f_S = w\sqrt{\frac{A_S}{k}}.$$

Summary of lagoon design volumes using TAEX Manure Spreadsheet for a 500 Cow dairy

All the capacities given below are in acre-feet. They were adjusted so that total capacities were as close as possible to the figures representative of the study area.

One Stage Lagoon System

	Small	Medium	Large
Total Treatment Volume	2.23	4.74	13.81
Sludge Storage	0.95	2.02	5.81
Freeboard	1.38	2.61	7.45
Design runoff volume (minimum)	2.33	3.67	10.09
Total Capacity of one-stage system	**6.89**	**13.04**	**37.24**

Two Stage Lagoon System

Primary Lagoon

	Small	Medium	Large
Total Treatment Volume	2.23	4.22	12.07
Sludge Storage	0.95	1.80	5.14
Freeboard	0.80	1.51	4.30
Total Capacity	3.98	7.53	21.51

Secondary Lagoon

	Small	Medium	Large
Minimum Design wastewater storage volume	0.54	1.29	4.03
Design runoff volume (minimum)	2.33	4.13	11.37
Additional capacity	0.76	1.44	4.12
Freeboard	0.19	0.35	1.08
Total Capacity	3.82	7.21	20.59
Total Capacity of two-stage system	**7.80**	**14.74**	**42.10**

Coefficients of Dairy Farm Economic Model: Nutrition Component

The dairy cattle nutrition component of the economic model consists of a set of constraints and definitions that ensure that the optimizing ration fed to the cattle meets their nutrient requirements adequately. Nine types of feed are used in selecting the optimizing ration in the economic model. These are premix, alfalfa, winter wheat, coastal bermuda hay, corn silage, sorghum and mineral, cottonseed and brewers grain. The task of nutrition component of the model is to obtain the profit maximizing combination of purchased feed and raised feed that would meet the nutrient requirements of the cattle. All feed raised on the farm is fed to the cattle. Sale of any feed raised on the farm is disallowed. Crop yields are assumed as follows: coastal bermuda hay 120 ctw per acre; sorghum, winter wheat, sudan 80 cwt per acre; corn silage 260 cwt per acre. Crop yields are not differential between solid manure and liquid manure fields.

The first task in the nutrient component is to estimate the nutrient requirements of the mature dairy cattle on the farm. Nutrient requirements for mature dairy cows and bulls are estimated from the National Research Council's "Nutrient Requirements of Dairy Cattle" (NRC, 1989). Recommended levels of energy, crude protein, calcium, phosphorus, vitamin A, and vitamin D must be satisfied by the chosen ration. Furthermore, for it to be a balanced ration, the required nutrients must be contained in the amount of dry matter consumed in the given period. Thus the probable dry matter intake (DMI) of dairy cattle is also estimated and accounted for in the choice of ration.

Nutrient Requirements for Lactating Cows

Dry Matter Intake

To obtain the DMI for a 1400 lb lactating cow, we first estimate the amount of 4 percent Fat Corrected Milk (FCM) produced by the cow as a sum of 0.4 pounds of milk and 15 pounds of milk fat. If we assume that the proportion of fat is 4%, then the 4% FCM is the same as the milk yield of the cow. From the Profiles of Erath County dairy farmers, the milk yields and hence the 4% FCM are: 53 pounds per cow per day for the small dairy, 60 pounds per cow per day for the medium-sized dairy and 62 pounds per cow per day for the large-sized dairy. Assuming an average weight gain of 0.055% liveweight per day, the recommended DMI as a percent of liveweight is obtained from Appendix Table 1 of NRC (1989) as 3.07% for the small dairies, 3.2% for the medium-sized dairies and 3.26% for the large-sized dairies. This means a DMI of 42.98 pounds per cow per day, 44.8 pounds per cow per day and 45.64 pounds per cow per day for the small, medium, and large-sized dairies respectively, which translate to 156.877 cwt per cow per year, 163.52 cwt per cow per year, and 166.586 cwt per cow per year respectively.

Lactating cow requirements for major nutrients:

The economic model accounts for the following major nutrients of all dairy cattle: protein, calcium, phosphorus, vitamin A, and vitamin D. Using the tables in NRC (1989), we obtained annual requirements per lactating cow, of the above nutrients as follows. The required level of a given nutrient is the sum of the requirements for maintenance, milk production and weight gain, computed from Appendix Table 3 of NRC (1989). The requirement for milk production differs across the three dairy herd size groups in accordance with the different milk yields reported in the Profiles of Representative Erath County Dairies, for the representative dairy herds. Milk output per year assumes 315 lactaating days in a year. The steps involved in calculating the nutrient requirements for lactating cows are shown in the following tables.

Small Dairy

Milk output per year: 166.95 cwt per cow   Dry Matter Intake per year: 156.88 cwt per cow

	NEL	Crude Protein	Calcium	Phosphorus	Vitamin A	Vitamin D
	Mcal/ cow	lb/cow	lb/cow	lb/cow	1000 IU/cow	1000 IU/cow
Maintenance requirement	10.12	1.37	0.06	0.04	48	19
Requirement per lb of milk	0.33	0.086	0.003	0.002	0	0
Total requirement for Milk production	17.49	4.56	0.17	0.11	0	0
Requirement per lb body wt. gain	2.32	0.32	0	0	0	0
Weight gain requirement	1.79	0.25	0	0	0	0
Total daily nutrient requirement	29.40	6.17	0.23	0.15	48	19
Total annual nutrient requirement per cow	10729.69	2253.29	82.71	53.29	17520	6935

Medium Dairy

Milk output per year: 189 cwt per cow   Dry Matter Intake per year: 163.52 cwt per cow

	NEL	Crude Protein	Calcium	Phosphorus	Vitamin A	Vitamin D
	Mcal/cow	lbs/cow	lbs/cow	lbs/cow	1000 IU/cow	1000 IU/cow
Maintenance requirement	10.12	1.37	0.06	0.04	48	19
Requirement per lb of milk	0.33	0.086	0.003	0.002	0	0
Total requirement for Milk production	19.80	5.16	0.19	0.12	0	0
Requirement per lb body wt. gain	2.32	0.32	0	0	0	0

Weight gain requirement	1.79	0.25	0	0	0	0
Total daily nutrient requirement	31.71	6.78	0.25	0.16	48	19
Total annual nutrient requirement per cow	11572.84	2473.02	90.89	58.40	17520	6935

Large Dairy

Milk output per year: 195.3 cwt per cow Dry Matter Intake per year: 166.59 cwt per cow

	NEL	**Crude Protein**	**Calcium**	**Phosphorus**	**Vitamin A**	**Vitamin D**
	Mcal/cow	lb/cow	lb/cow	lb/cow	1000 IU/cow	1000 IU/cow
Maintenance requirement	10.12	1.37	0.06	0.04	48	19
Requirement per lb of milk	0.33	0.086	0.003	0.002	0	0
Total requirement for Milk production	20.46	5.33	0.20	0.12	0	0
Requirement per lb body wt. gain	2.32	0.32	0	0	0	0
Weight gain requirement	1.79	0.25	0	0	0	0
Total daily nutrient requirement	32.37	6.95	0.26	0.16	48	19
Total annual nutrient requirement per cow	11813.74	2535.80	93.22	59.86	17520	6935

In addition to lactating cows, each dairy in the study region also has dry cows, heifers and mature bulls. The nutrient requirements for these animals were also accounted for in the nutrition component of the economic model. These requirements were estimated as follows.

Nutrient requirements for dry cows

Based on communications with a dairy nutritionist, the daily dry matter intake (DMI) for dry cows was assumed to be 2.5 percent of liveweight. This translates to 35 lbs of DMI/cow/day or 127.75 cwt/cow/year based on 1400 liveweight per dry cow. Using this DMI figure, we obtained recommended nutrient levels from Appendix Table 5 of NRC (1989), using figures corresponding to dry pregnant cows. The recommendations on a per DMI basis are 0.57 Mcal per lb of DMI for NEL, 12 percent DMI for crude protein, 0.39 percent and 0.24 percent DMI for calcium and phosphorus respectively, and 1800 and 540 IU per lb of DMI for vitamins A and D, respectively.

Nutrient requirements for heifers

To calculate the nutrient requirements for heifers we assumed an average liveweight of 1000 lbs and a weight gain of 1.7 lbs per day. Thus the nutrient requirements per heifer on a daily basis are obtained from Appendix Table 2 (Daily Nutrient Requirements of Growing Dairy Cattle and Mature Bulls: Large-breed growing females) of NRC (1989) as 23.68 lbs DMI, 8.45 Mcal NEM, 2.84 lbs crude protein, 0.063 lbs calcium, 0.046 lbs phosphorus, 19.23 1000IU vitamin A, and 2.99 1000IU vitamin D.

Nutrient requirements for mature bulls

The nutrient requirements for the maintenance of mature breeding bulls listed in Appendix Table 2 of NRC (1989) were used. Assuming a 1400 lb bull, these are 20.82 lbs DMI, 10.88 Mcal NEM, 2.08 lbs crude protein, 0.057 lb calcium, 0.035 lbs phosphorus, 26.93 1000IU of vitamin A and 4.19 1000IU of vitamin D on a daily basis for a 1400 lb bull.. The following table summarizes the nutrient requirements of dry cows, heifers and bulls.

Nutrient requirements of dry cows, heifers and bulls

Nutrient/animal/year	Dry Cows	Heifers	Bulls
Energy, mega cal.	7281.75	3084.25	3971.20
Protein, cwt.	15.33	10.37	7.59
Dry matter, cwt.	127.75	86.43	75.99
Calcium, cwt.	0.4982	0.230	0.2080
Phosphorus, cwt.	0.3066	0.168	0.1278
Vitamin A, 1000 IU	22995	7018.95	9829.45
Vitamin D, 1000 IU	6898.5	1091.35	1529.35

As stated above, the nutrition component of the economic model ensures that adequate amounts of all nutrients are contained in the feed ration chosen by the model. Another issue considered is the implication of choosing a ration that contains lethal amounts of any nutrient. This might be a cost-minimizing diet but would not be practical since it would not reflect what dairy farmers do in real world situations. In order to prevent the economic model from choosing a feed ration that contains excessively large quantities of any given nutrient, we imposed upper bounds on the amounts of each nutrient fed to the dairy cattle. Bounds for calcium, phosphorus, vitamin A and vitamin D were obtained from Appendix Table 5 of Nutrient Requirements of Dairy Cattle, NRC (1989). These bounds are on a per DMI basis. The bounds for calcium and phosphorus are in cwt per cwt of DMI, while those of the vitamins are in IUs per lb of DMI.

Bounds on nutrients fed to cattle.

Nutrient	Upper Bound
Energy	100
Protein	0.20
Calcium	0.02
Phosphorus	0.01
Vitamin A	3000
Vitamin D	450

Finally, to prevent the model from choosing a ration that has too little dry matter a lower bound on DMR equal to 80 percent of requirement is imposed. The following table lists the nutrient contents of the various types of feed considered in the economic model.

Nutrients in feedstuffs as fed

Feedstuff	Energy	Protein	Dry Matter	Calcium	Phosphorus	Vitamin A	Vitamin D
Premix	109.1	0.144	0.94	0.00338	0.00442	226.8	2.8
Alfalfa	64.41	0.20	0.90	0.0154	0.0029	2542.4	90.8
Coastal	54.43	0.165	0.91	0	0	0	0
Silage	55.79	0.059	0.31	0.0038	0.0031	272.16	0
Sorghum	56.70	0.08	0.91	0.0055	0.003	1088.64	0
Wheat	58.97	0.085	0.88	0.0015	0.002	1542.24	68.04
Mineral	0	0	0.97	0.3011	0.1414	368.0	80.0
Cottonseed	101.24	0.25	0.90	0.0012	0.0054	0	0
Brewer's grain	68.1	0.254	0.21	0.0033	0.0055	0	0

The nutrient contents above were obtained from Tables 7-1 and 7-2 of Nutrient Requirements of Dairy Cattle, NRC (1989). Energy is in Mcal per cwt, vitamins in 1000IU per cwt and the rest are in cwt per cwt. The specific types of feedsuffs assume are as follows. The entry numbers in NRC (1989) are also given below.

Feedstuff	Common Name	Botanical Name	Specific Description	Entry No.
Premix				
Alfalfa	Alfalfa	*Medicago sativa*	Hay, sun-cured, late vegetative	006
Coastal	Bermudagrass, Coastal	*Cynodon dactylon*	Hay, sun-cured, late vegetative	032
Silage	Corn, Dent Yellow	*Zea mays indentata*	Silage, aerial part without ears, without husks (stalkage, stover)	083
Sorghum	Sorghum, Sudangrass	*Sorghum bicolor sudanense*	Hay, sun-cured, full bloom	207
Wheat	Wheat	*Triticum aestivum*	Hay, sun-cured	249
Mineral				

Cottonseed	Cotton	*Gossypium* spp.	Seeds, without lint	089
Brewer's grain	Brewers grains		Wet	044

Other coefficients used in the nutrition component of the model are listed in the following table.

Scalar Coefficients

Coefficient	Description	Small	Medium	Large
MPI	Minimum premix intake as fed basis in cwt per head	50.0	50.0	47.74
MFI	Maximum forage intake as fed basis in cwt per head	999	999	999
BULLS	Number of bulls on the dairy farm	8	8	30
WASTE	Proportion of cattle feed wasted	0.07	0.07	0.07
DRY	Number of dry cows at any given time	40	50	200
HEIFERS	Total number of heifers on the farm (replacements)	36	81	0
TOTALDM	Total recommended dry matter intake for all dairy cattle	37800.42	71228.27	194220

Source:

Premix intake as fed basis in cwt per head: Calculated from Profiles of Representative Erath County Dairies, June 1994.

Forage intake as fed basis in cwt per head

Number of bulls on the dairy farm: From Profiles of Representative Erath County Dairies, June 1994.

Proportion of cattle feed wasted: From communications with dairy nutritionists.

Number of dry cows at any given time: From Profiles of Representative Erath County Dairies, June 1994.

Total number of heifers on the farm (replacements): From Profiles of Representative Erath County Dairies, June 1994.

Total recommended dry matter intake for all dairy cattle: Calculated from nutrient requirements of all types of dairy cattle.

Coefficients of Dairy Farm Economic Model: Manure Component

Scalar Coefficients

Coefficient	Description	Small	Medium	Large
AL	Available acres for lagoon effluent	8.34	14.82	44.45
AS	Available acres for solid waste	37.55	66.75	200.22
LW	Waste water generated per cow in acre feet	0.03409	0.03375	0.03454
CA	Containment acres for apex	6.25	8.75	21.5
RELAX	Factor by which phosphorus agronomic rate is relaxed	0.50	0.50	0.50
PANLOSSL	Proportion of liquid nitrogen not plant available	0.20	0.20	0.20
PANLOSSS	Proportion of solid nitrogen not plant available	0.50	0.50	0.50
VOLATILL	Proportion of liquid nitrogen lost through volatilization	0.20	0.20	0.20
VOLATILS	Proportion of solid nitrogen lost through volatilization	0.20	0.20	0.20

The scalar coefficients in the above table were obtained as follows:

Available acres for lagoon effluent: This was taken as the average acreage of the liquid waste application fields of all dairies of a given class, rounded up to the nearest whole number.

Available acres for solid waste: This was taken as the average acreage of the solid waste application fields of all dairies of a given class, rounded up to the nearest whole number.

Waste water generated per cow in acre feet: Obtained from SCS Dairy Manure Spreadsheet
Containment acres for apex: Obtained from SCS Dairy Manure Spreadsheet

Factor by which phosphorus agronomic rate is relaxed: A policy parameter for relaxed Phosphorus agronomic rates policy.

Proportion of liquid nitrogen lost through volatilization: Based on NRCS assumptions.

Proportion of solid nitrogen lost through volatilization: Based on NRCS assumptions.

Proportion of liquid nitrogen not plant available: Based on NRCS assumptions.

Proportion of solid nitrogen not plant available: Based on NRCS assumptions.

Solid waste monthly application schedule: proportions of annual solid waste applied during each month.

Month		cbh	cbww	sdww	ssu	cs
1	January					
2	February					
3	March					1.0
4	April	0.25	0.33	0.5	1.0	
5	May					
6	June	0.25				
7	July		0.33			
8	August	0.25				
9	September		0.34	0.5		
10	October	0.25				
11	November					
12	December					

cbh: coastal bermuda hay
cbww: coastal bermuda overseeded with winter wheat
sdww: Sorghum double cropped with winter wheat
ssu: Sorghum or sudan
cs: Corn silage

The numbers in this table represent the proportions of solid manure applied during each month. These proportions reflect current assumptions of manure application schedules practiced by dairy farmers in Erath County.

APPENDIX D.

A REVIEW OF DAIRY MANURE NUTRIENT LOADING COEFFICIENTS

Edward Osei and P.G. Lakshminarayan

The role of the dairy farm economic model is to obtain the economic and environmental impacts of various policy scenarios. Environmental issues arise out of the farmers' decisions primarily because of the generation of manure from the dairy cows on a daily basis. Assessment of the environmental impacts of farmer's decisions then involves a careful estimation of how much manure is produced under alternative scenarios and what happens to the manure. Key environmental indicators of concern to public safety and health are embodied in the manure.

The environmental indicators are accounted for by manure nutrient coefficients, usually engineering estimates measured on a per cow per annum basis. Changes in the levels of various indicators thus result from changes in herd size or technology choices. Since the accuracy of these nutrient coefficients is essential for the reliability of any model results, careful revisions of the nutrient loading coefficients have been made. In this revision, attention has been given to incorporating as much information from as many studies as possible on the subject. The fate of manure nutrients from production to land application as reported in the literature was reviewed with the intent of obtaining system specific estimates of manure nutrient composition at land application This report contains a summary of the findings and an explanation of how these were used to arrive at the estimates for the current NPP. As the wide range of values for a given coefficient is apparent from the various studies, we have chosen not only to report most likely values (means), but also reasonable ranges (confidence intervals) within which these coefficients might be expected to fall. In subsequent analyses we will use both the means and the confidence intervals. This will give us an idea of the degree of precision we can attach to the corresponding results.

The beginning of the environmental problem is the production of manure at the feedlot. Manure generated in a feedlot is handled as solid and liquid waste. Solid waste results from scraping operations in the feedlot. Liquid waste results from flushing or washing operations in the feedlot or milking parlor. Usually the solid waste component is piled and then spread over an application field.

The liquid waste is usually stored in a lagoon or earthen pond and then applied to a field. The nutrient composition of waste applied on the land depends on the entire waste management process.

Manure Production and Characteristics

The amounts and nutritional compositions of manure produced have been tabulated in the ASAE Standards (1993) for various livestock species. Other studies such as Overcash et al. (1983) also provide summaries of a wide range of studies on manure characteristics and management. However, for the purposes of obtaining the nutrient loading coefficients we used the manure nutrient production characteristics in the ASAE standards. These standards probably reflect the results of a wider range of studies than most other sources. ASAE estimates of daily fresh manure nutrient production for TKN, NH_3, P, K, and Na per 1000 lb liveweight were converted to dairy manure nutrient production estimates per 1400 lb liveweight, which is regarded as the typical liveweight of a dairy cow (ASAE 1993), (Table D.1). Fresh manure contains neither nitrates nor nitrites (Merkel 1981). Nitrification produces nitrates in both solid and liquid components of excreted manure. An estimation of the amount of nitrates in both solid and liquid manure is needed for us to know how much nitrate ends up in the manure that is applied to the land. Nitrate composition in solid manure piles prior to land application has been estimated in a few studies including Randall et al. (1975). An arithmetic mean from these studies was used as an estimate of how much nitrate exists in solid manure as a percentage of TKN, (Table D.2). Table D.3 contains estimates of liquid waste nutrient composition. Figures obtained as concentrations were converted to lb/cow/year using appropriate conversions. For instance, mg/L (parts per million) figures were multiplied by volume of waste water per cow per year in liters and then by 4.536×10^{-4} lb/mg to convert to lb/cow/year. Mean solid manure nutrient compositions are shown in Table D.4. With the exception of nitrates the solid manure composition of a given nutrient was computed as the difference between total manure nutrient production and the estimated liquid manure content of that nutrient. For the level of nitrate in solid manure, we multiplied the average proportion in Table D.2 by the level of TKN in Table D.4. Thus Tables D.3 and D.4 contain the amounts of various nutrients produced annually by each cow in liquid and solid waste.

Waste Management Process Impacts on Nutrient Loading Coefficients

Solids separation and lagoon storage and treatment of liquid wastes are the two primary on-farm waste management processes that significantly impact the levels of nutrients in dairy waste applied on land. In the ensuing sections we briefly discuss the impacts of these two processes.

Solid Separation

On farms with solid separation devices, which are usually a gravity separator (e.g. settling basin) or a mechanical separator, liquid waste from the feedlot and milking parlor is passed through these devices to separate the solid fraction from the liquid waste. Studies on solid separation device efficiencies show that the separator effluent is considerably cleaner (has lower waste content) than the separator influent. Solid separation generally reduces the solid content of liquid waste and also affects the nutrient composition of the resulting separated solids and the liquid component. We assume that the separated solid is added to the solid manure pile. The reduction in lagoon affluent nutrients is thus assumed to be balanced by an equal increase in solid manure nutrient composition. Percentage reductions of nutrients in liquid waste due to the use of solid separators are reported in Table D.5. We computed mean reductions for all the six nutrients based on the studies cited.

Lagoon Treatment

Many dairy farms have lagoons for liquid waste storage and treatment prior to land application. Some have single-stage lagoon systems while others have multiple-stage (usually two-stage) lagoon systems. Although the primary purpose of lagoons is for waste storage to prevent unchecked discharge of waste into the environment, the nutrient composition of lagoon effluents is significantly different from that of wastewater flowing into the lagoon. We report in Tables D.6 and D.7 the percentage reductions in various nutrients attributable to single-stage and two-stage lagoon systems. Means and 95 percent confidence intervals are also reported.

Nutrient Losses in Solid Manure Pile

Another factor that affects the nutrient content of manure at land application is the change that occurs in the solid manure pile. A few studies have documented losses of N, P, K, Na and NH_4-N on feedlot surfaces (see Table D.8). For want of a direct estimate the percentage reduction suggested for NH_4-N from the studies was imputed to NO_3 as well. Such reductions were accounted for in order to obtain the nutrient loadings on solid application fields. All nutrient loading coefficients are in lb/1400 lb/cow/year. Except for P, Table D.9 contains the levels of nutrients in solid manure at the time of land application. For phosphorus, we used the SCS estimate rather than the estimate computed from the above procedure. The figures in Table D.9 are for solid manure that is applied on land after being left to stand in a pile for a while. Alternative, solid manure could be composted. We assume that composting brings an end to the solid waste problem because there is ready market for the end product.

Waste Management Technology Systems and Nutrient Loading Coefficients

Using the estimates shown in Tables D.1 through D.9, we calculated mean percentage reductions of the nutrients for selected combinations of the above waste treatment structures as well as the composting option. This is tabulated in Table D.10. Using the percentage reductions reported in Table D.10 we calculated the amounts of various manure nutrients applied on land when each of the alternative waste treatment systems is in place. The percentage reductions in Table D.10 were applied to the liquid waste figures of Table D.3 for liquid waste nutrient levels at the time of land application. Similarly, the solid waste nutrient levels of Table D.9 were used in conjunction with the figures of Table D.10 to obtain solid waste nutrient levels at the time of land application. These figures are tabulated in Table D.11.

Table D.1. Characteristics of fresh dairy manure from various studies

Source	TS	TKN	NH_4	TP	TK	Na
			pounds			
ASAE	6132	229.95	40.369	60.298	148.19	26.57
Overcash et al. 1983	5467.7	260.61				
Overcash et al. 1983	8176	270.83		56.21	214.62	38.84
Van Horne et al. 1994	5837.00	229.07	96.92	39.65	90.31	41.85
Van Horne et al. 1994		270.93	123.35	48.46	149.78	
Van Horne et al. 1994	4380		40.20	48.24	147.93	26.53
Van Horne et al. 1994				70.48		
Sweeten, TAES	5320	210		84	168	

Table D.2. Nitrate content of solid manure at time of land application

Source	TKN	NO_3-N	NO_3-N as % of TKN
Randall et al. 1975	13230.00	4.00	0.03
Randall et al. 1975	9360.00	2.00	0.02
Staley et al. 1971	3598.00	18.00	0.50
MEAN	8729.33	8.00	0.18

Table D.3. Liquid waste nutrient composition

Source	TS	TKN	NH_3-N	NO_3-N	Organic N	Total P	Total K	Sodium
			pounds per cow per year					
Sweeten & Wolfe 1993	944.05	44.26	42.27	0.10	4.12	14.48	74.11	32.88
Sweeten & Wolfe 1993	655.65	37.40	33.04	0.07	3.25	5.01	37.21	14.29
Sweeten & Wolfe 1993	421.01	23.39	21.81	0.07	1.75	3.33	26.18	s9.11
Overcash et al. 1983	613.20	32.70	15.37	0.85		34.24	47.01	
Mean	658.48	34.44	28.12	0.08	3.04	14.26	46.13	11.70
Size	4.00	4.00	4.00	3.00	3.00	4.00	4.00	3.00
Standard Deviation	216.03	8.76	11.93	0.02	1.20	14.19	20.50	3.67
Precision	211.70	8.59	11.69	0.02	1.36	13.91	20.09	4.15
Lower confidence limit	446.77	25.85	16.43	0.06	1.68	0.36	26.04	7.55
Upper confidence limit	870.18	43.03	39.81	0.10	4.40	28.17	66.22	15.85

Table D.4. Mean solid manure nutrient production

TS	TKN	NH_4-N	NO_3-N	P	K	Na
5473.52	195.51	12.25	0.36	54.38	102.06	14.87

Table D.5. Separator efficiency for dairy waste from various sources

Source	TKN	NH_3-N	NO_3-N	N-Org	Total P	Total K	Sodium
Auvermann & Sweeten 1992	-4.90				-11.30	1.30	
Auvermann & Sweeten 1992	3.10				7.30	0.80	
Auvermann & Sweeten 1992	13.30				18.40	7.60	
Auvermann & Sweeten 1992	0.00				0.00	-2.80	
Auvermann & Sweeten 1992	2.70				5.40	2.80	
Auvermann & Sweeten 1992	0.00				6.00	3.00	
Moore 1989	25.00				20.00	20.00	
Käck et al. 1994	23.70				37.30		
Käck et al. 1994	8.60				14.90		
Sweeten & Wolfe 1994	14.20				1.50	10.80	
Sweeten & Wolfe 1994	24.31	14.31	63.83	20.66	-6.11	7.15	13.99
Sweeten & Wolfe 1994	78.00				25.00		
Sweeten & Wolfe 1994	25.00				49.00		
Graves et al. 1971		30.00	-62.50	75.63	-13.33		
Graves et al. 1971		57.63	6.25	80.34	8.00		
Graves et al. 1971		34.29	-50.00	85.58	-6.67		
Graves et al. 1971		45.31	-52.27	79.72	17.24		
Van Horne et al. 1994	8.80				3.40		
Van Horne et al. 1994	30.00				12.00	15.00	
Graves et al. 1971		18-33		33-52			
MEAN	16.79	36.31	-18.94	68.39	9.90	6.57	13.99

Table D.6. Single-stage lagoon efficiency for dairy waste from various sources

Source	TKN	NH_3-N	NO_3-N	Total P	Total K	Sodium
Sweeten & Wolfe 1993	-4.00			-18.30	-19.20	
Sweeten & Wolfe 1993	33.90	35.00	-162.70	38.10	33.90	22.90
Sweeten & Wolfe 1993	7.34	12.69	-272.96	4.28	-7.02	-3.18
Sweeten & Wolfe 1993	27.80	26.80	2.60	9.60	14.00	-3.70
Moore & Gamroth 1994	70.00			60.00	40.00	
Safley & Westerman 1992	70.36	44.15				
Safley & Westerman 1992	78.87	60.27				
Safley & Westerman 1992	77.52	55.08				
MWPS-18, 1975	84.67			77.19	32.93	
Lyman et al. 1970		52.70	40.20	58.80	2.90	
Lyman et al. 1970		88.60	-575.00	83.30	11.70	
Lyman et al. 1970		60.10	9.30	51.00	10.00	
Nordstedt et al. 1975			-7.14	31.62		
MWPS-1 1987	70-80					
White 1977	60-85			70-95		
USDA-SCS 1992	65-80			50-65	35-50	
Mean	49.61	48.38	-137.96	39.56	13.25	5.34
Size	9.00	9.00	7.00	10.00	9.00	3.00
Standard deviation	33.71	22.07	223.66	33.00	19.73	15.21
Precision	22.03	14.42	165.68	20.46	12.89	17.21
Lower confidence limit	27.58	33.96	-303.64	19.10	0.36	-11.87
Upper confidence limit	71.63	62.80	27.73	60.01	26.13	22.55

Table D.7. Two-stage lagoon efficiency for dairy waste from various sources

Source	TKN	NH3-N	NO3-N	Total P	Total K	Sodium
USDA-SCS 1992	70.00			85.00		
USDA-SCS 1992	60.00			75.00		
Sweeten & Wolfe 1993	73.10	52.80	-431.10	91.00	32.50	-9.80
Sweeten & Wolfe 1993	54.90	53.00	-693.30	54.10	34.50	24.20
Sweeten & Wolfe 1993						
Lyman et al. 1970		79.50	55.50	-58.00	-13.80	
Lyman et al. 1970		99.00	75.30	96.20	23.20	
Lyman et al. 1970		84.00	-500.00	61.00	8.00	
Van Horne et al. 1994	69.00			47.00		
Mean	65.40	73.66	-298.72	56.41	16.88	7.20
Size	5.00	5.00	5.00	8.00	5.00	2.00
Standard deviation	7.63	20.28	346.08	49.49	20.09	24.04
Precision	6.69	17.78	303.35	34.30	17.61	33.32
Lower confidence limit	58.71	55.88	-602.07	22.12	-0.73	-26.12
Upper confidence limit	72.09	91.44	4.63	90.71	34.49	40.52

Table D.8. Nutrient losses in solid manure pile prior to land application

Source	TKN	NH_3-N	NO_3-N	Total P	Total K	Sodium
MWPS-18 1975	48.67			18.52	6.10	
Safley et al. 1984	23.00			-2.00	10.00	
USDA-SCS 1992	20.00					
Safley et al. 1984	52.32	29.45	29.45	55.39	51.69	49.64
USDA-SCS 1992	15-45			5-15	5-15	
Gilbertson et al. 1971	45-58					
Mean	36.00	29.45	29.45	23.97	22.60	49.64
Size	4.00	1.00	1.00	3.00	3.00	1.00
Standard deviation	16.85	0.00	0.00	29.08	25.27	0.00
Precision	16.51	0.00	0.00	32.91	28.60	0.00
Lower confidence limit	19.48	29.45	29.45	-8.94	-6.00	49.64
Upper confidence limit	52.51	29.45	29.45	56.88	51.19	49.64

Table D.9. Mean solid manure nutrient content at the time of land application

TKN	NH_4-N	NO_3-N	P	K	Na
		pounds per cow per year			
125.13	8.54	0.25	54.38	79.00	11.51

Table D.10. Percentage reductions in liquid waste nutrient levels

Selected System	TKN	NH_3-N	NO_3-N	Total P	Total K	Sodium
	Percentage reductions in liquid waste nutrient levels					
Single-stage lagoon	49.61	48.38	-137.96	39.56	13.25	5.34
Single-stage, separator	58.07	67.12	-183.03	45.54	18.95	18.58
Two-stage lagoon	65.40	73.66	-298.72	56.41	16.88	7.20
Two-stage, separator	71.21	83.22	-374.24	60.73	22.34	20.18
Single-stage, separator, compost	58.07	67.12	-183.03	45.54	18.95	18.58
Two-stage, separator, compost	71.21	83.22	-374.24	60.73	22.34	20.18

Table D.11. Mean nutrient contents at the time of land application under various systems

Selected System	TKN	NH_3-N	NO_3-N	Total P	Total K	Sodium
Solid manure nutrient application						
		pounds per cow per year				
Single-stage lagoon	125.13	8.54	0.25	54.38	79.00	11.51
Single-stage, separator	128.04	13.81	0.21	55.23	81.63	13.06
Two-stage lagoon	125.13	8.54	0.25	54.38	79.00	11.51
Two-stage, separator	127.13	11.23	0.19	55.00	81.52	13.03
Single-stage, separator, compost	0.00	0.00	0.00	0.00	0.00	0.00
Two-stage, separator, compost	0.00	0.00	0.00	0.00	0.00	0.00
Liquid manure nutrient application						
Single-stage lagoon	17.35	14.52	0.19	8.62	40.02	11.08
Single-stage, separator	14.44	9.24	0.23	7.77	37.39	9.53
Two-stage lagoon	11.92	7.41	0.32	6.22	38.34	10.86
Two-stage, separator	9.92	4.72	0.38	5.60	35.82	9.34
Single-stage, separator, compost	14.44	9.24	0.23	7.77	37.39	9.53
Two-stage, separator, compost	9.92	4.72	0.38	5.60	35.82	9.34

APPENDIX D REFERENCES

Agriculture Canada. 1979. *Canada Animal Manure Management Guide.* Publication 1534. Ottawa: Agriculture Canada.

American Society of Agricultural Engineers. 1993. *ASAE Standards.* 40th Edition. St. Joseph, MI:ASAE.

Auvermann, Brent W. and John M. Sweeten. 1992. *Solids-separation systems for livestock manure and wastewater.* College Station: Texas A & M University.

Gilbertson, C. B., T. M. McCalla, J. R. Ellis, and W. R. Woods. 1971. Characteristics of manure accumulations removed from outdoor, unpaved, beef cattle feedlots. *Livestock Waste Management and Pollution Abatement*: Proceedings of the International Symposium on Livestock Wastes, April 19-22. Center for Tomorrow, The Ohio State University, American Society of Agricultural Engineers, 56-9.

Graves, R. E., J. T. Clayton and R. G. Light. 1971. Renovation and reuse of water for dilution and hydraulic transport of dairy cattle manure. *Livestock Waste Management and Pollution Abatement*: Proceedings of the International Symposium on Livestock Wastes, April 19-22. Center for Tomorrow, The Ohio State University, American Society of Agricultural Engineers. 341-44.

Käck, M., J. Beck and T. Jungbluth. 1994. Low emission dairy waste management by separating and composting. *Dairy Systems for the 21st Century*: Proceedings of the Third International Dairy Housing Conference, 2-5 February. Orlando, FL: American Society of Agricultural Engineers. 443-52.

Lymann Edwin D., Melville W. Gray, and John H. Bailey. 1970. A field study of the performance of waste stabilization ponds serving small towns. *International Symposium for Waste treatment lagoons*, June 23-25. Kansas City, Missouri. 387-404.

Merkel, James A. 1981. *Managing Livestock Wastes.* Avi Publishing Company, Inc., Westport, Connecticut. (68).

Midwest Plan Service. 1975. *Livestock Waste Facilities Handbook.* MWPS-18. Ames: Iowa State University.

_______. 1983, 1987. *Structures and Environment Handbook.* MWPS-1, 11th edition. Ames: Iowa State University.

Moore, James A. and Michael J. Gamroth. 1994. Pathways of nitrogen movement from land spread manures. *Dairy Systems for the 21st Century*: Proceedings of the Third International Dairy Housing Conference, 2-5 February. Orlando, FL: American Society of Agricultural Engineers. 760-68.

Nordstedt, R. A., L. B. Baldwin, and C. C. Hortenstine. 1975. Multistage lagoon systems for treatment of dairy farm waste. *Livestock Waste Management.* 77-80.

Overcash, Michael R., Frank James Humenik, and J. Ronald Miner. 1983. *Livestock Waste Management.* Volumes 1 & 2, CRC Press.

Randall G. W., R. H. Anderson, and P. R. Goodrich. 1975. Soil properties and future crop production as affected by maximum rates of dairy manure. *Managing Livestock Wastes*, Proceedings of the Third International Symposium on livestock wastes, April 21-24. American Society of Agricultural Engineers. 611-13, 621.

Safley, L. M. and P. W. Westerman. 1992. Performance of a dairy manure anaerobic lagoon. *Bioresource Technology.* 42 (1) 43-52.

Staley, L. M., N. R. Bulley, and T. A. Windt. 1971. Pumping characteristics, biological and chemical properties of dairy manure slurries. *Livestock Waste Management and Pollution Abatement*, Proceedings of the International Symposium on livestock wastes, April 19-22. American Society of Agricultural Engineers. 142-45.

Sweeten, John and Mary Leigh Wolfe. 1993. *The expanding dairy industry: Impact on ground water quality and quantity with emphasis on waste management system evaluation for open lot dairies.* Texas Water Resources Institute, Texas A & M University. August.

_______. 1994. *Final Report, Animal Waste Management System Evaluation.* USEPA Section 319 Agricultural Nonpoint Source Pollution Project. July.

U.S. Department of Agriculture, Soil Conservation Service (USDA-SCS). 1992. *Agricultural Waste Management Handbook.* National Engineering Handbook. Washington, D.C.: U.S. Government Printing Office.

Van Horn, H. H., A. C. Wilkie, W. J. Powers, and R. A. Nordstedt. 1994. Components of dairy manure management systems. *Journal of Dairy Science* 77: 2008–30.

White, R. K. 1977. Lagoon systems for animal wastes. In *Animal Wastes.* ed. E. Paul Taiganides. London: Applied Science Publishers Limited.

REFERENCES

Ashraf, Muhammad and Robert L. Christensen. 1974. "An Analysis of the Impact of Manure Disposal Regulations on Dairy Farms." *American Journal of Agricultural Economics* 56(2)331–36.

Bohm, Peter, and Clifford S. Russell. 1985. "Comparative Analysis of Alternative Policy Instruments." *Handbook of Natural Resource and Energy Economics*, I:10 395–460. Edited by A.V. Kneese and J.L. Sweeny. Elsevier Science Publishers.

Bouzaher, Aziz, P.G. Lakshminarayan, Stanley R. Johnson, Ron Jones, and Tim Jones. 1993a. *The Economic and Environmental Indicators for Evaluating the National Pilot Project on Livestock and the Environment.* Livestock Series Report 1. Card Staff Report 93-SR 64. Center for Agricultural and Rural Development (CARD). Ames: Iowa State.

Bouzaher, Aziz, Stanley R. Johnson, Shannon Neibergs, Ron Jones, Larry Beran, Larry Hauck, and Larry Frarey. 1993b. *The Conceptual Framework for the National Pilot Project on Livestock and the Environment.* Livestock Series Report 2. Card Staff Report 93-SR 67. Center for Agricultural and Rural Development (CARD. Ames: Iowa State University.

Bullard, Steven H. and Thomas J. Straka. 1988. "Structure and Funding of State-level Forestry Cost-share Programs." *Northern Journal of Applied Forestry* 5(2):132–35.

Burney, J.R., K.V. Lo, and W. M. Carson. 1980. "Dairy Waste Management System Selection by Network Analysis." Canadian Agricultural Engineering 22:41–47.

Capalbo, S. M. and J. M. Antle. 1989. "Incorporating Social Costs in the Returns to Agricultural Research." *American Journal of Agricultural Economics* 71:458–63.

Epp, D.J. and J.S. Shortle. 1985. "Agricultural Nonpoint Pollution Control: Voluntary or Mandatory?" *Journal of Soil and Water Conservation* 40 1:111–14.

Forster, D. Lynn. 1975. "Simulated Beef Feedlot Behavior Under Alternative Water Pollution Control Rules." *American Journal of Agricultural Economics* 57(2): 259–68.

Frarey, Larry, Ron Jones, Heather Jones, Aziz Bouzaher, Stanley Johnson, Edward Osei, and Shannon Neibergs. 1993. *Critical Review of Current Policies, Enforcement Mechanisms, and Compliance Strategies.* Stephenville: Texas Institute for Applied Environmental Research (TIAER).

Frarey, Larry. 1993. Summary: Second Meeting of NPP Policy Working Group. Washington D.C., April 12–13. Unpublished report. Stephenville: Texas Institute for Applied Environmental Research (TIAER).

Frarey, Larry, and Heather Jones. 1993. "Development of Baseline Regulatory Policies for an Economic-Environmental Modeling Framework: Policies Affecting Erath County, Texas Dairy CAFOs." September. Stephenville: Texas Institute for Applied Environmental Research (TIAER).

Heatwole, C.D., P.L. Diebel, and J.M. Halstead. 1990. "Management and Policy Effects on Potential Ground Water Contamination From Dairy Waste." *Water Resources Bulletin* 26:25–34.

Heatwole, C.D., A. B. Bottcher, and L. B. Baldwin. 1987. "Modeling Cost-Effectiveness of Agricultural Nonpoint Pollution Abatement Programs on Two Florida Basins." *Water Resource Bulletin.* 23(1):127–31.

Heimlich, Ralph E. 1982. "Economics and Environmental Effects of Manure Handling Systems for Northeastern Dairy Farms." *Journal of Northeastern Agricutural Economic Council* 11(2):45–56.

Huang, Wen-yuan. 1979. "A Framework for Economic Analysis of Livestock and Crop Byproducts Utilization." *American Journal of Agricultural Economics* (1):91–96.

Jones, Ron, Larry Frarey, Aziz Bouzaher, Stanley R. Johnson and Shannon Neibergs. 1993. *Livestock and the Environment: A National Pilot Project—Detailed Problem Statement.* June. Stephenville: Texas Institute for Applied Environmental Research (TIAER), Tarleton State University.

Lessley, Billy V. and James E. Via. 1976. "Economic Analysis of Alternative Manure Handling Systems by Size of Dairy Herd." Journal of the Northeastern Agricultural Economic Council 5:(1)113–24.

Liroff, Richard A. 1986. Reforming Air Pollution Regulation: The Toil and Trouble of EPA's Bubble. *The Conservation Foundation.*

Logan, T.J. 1991. "Agricultural Best Management Practices: Implications for Groundwater Protection." *Groundwater and Public Policy* 5:6–7.

McSweeny, William T., and James S. Shortle. 1989. "Reducing Nutrient Application Rates for Water Quality Protection in Intensive Livestock Areas: Policy Implications of Alternative Producer Behavior." *Northeastern Journal of Agricutural and Resource Economics* 18(1)1–11.

Metcalf, Gilbert E., Daniel J. Dudek, and Cleve E. Willis. 1984. "Cross-Media Transfers of Hazardous Wastes." *Northeastern Journal of Agriculture and Resource Economics* 13(2)203–09.

Pagano, Amy Purvis, John Holt, Robert B. Schwart, Jr., Kristin A, Gill, and Heather Haedge Jones. 1994. Profiles of Representative Erath County Dairies. June. Stephenville: Texas Institute for Applied Environmental Reserach (TIAER), Tarleton State University..

Richardson, R.M., C.C. Adams, K.C. Deville, C.A. Kraenzie, J.E. Penn, and J.W. Stutzman. 1990. "Cooperative business volume and net income up in 1988: Shares of marketing and purchasing activities stable." *American Cooperation.* 202–8.

Schnitkey, Gary D., and Mario J. Miranda. 1993. "The Impact of Pollution Controls on Livestock—Crop Producers." *Journal of Agricultural and Resource Economics* 18:25–36.

Stonehouse, D. Peter, and A. V. S. Narayanan. 1984. "The Contributions of Livestock Manure to Profitability and to Self-Sufficiency in Plant Nutrients on Mixed Farms." *Canadian Journal of Agricultural Economics* 32:201–10.

Sweeten, John M. and Maritza Rodriguez-Akabani. 1994. Approaches to Odor Measurement for Dairies and Cattle Feedlots: A State of the Art Review. In Final Report: Preliminary research concerning the character, sources and intensity of odors from dairy operations in Erath County, Texas. Stephansville and College Station: TIAER and Texas A&M University Extension Service.

TIAER. 1993. "Summary: Initial Meeting of NPP Policy Working Group." Dallas, Texas. January 13. Stephenville: Texas Institute for Applied Environmental Research (TIAER).Tarleton State University.

Tietenberg, Thomas H. 1985. Emissions Trading: An Exercise in Reforming Pollution Policy. Resources for the Future. Washington, D.C..

Trachtenberg, Eric and Clayton Ogg. 1994. "Potential for reducing nitrogen pollution through improved agronomic practices." *Water Resources Bulletin.* Volume 30 December:1109.

U. S. General Accounting Office (USGAO). 1988. "Milk Marketing Orders: Options for Change." *GAO/RCED.* (3)88–9.

U.S. Environmental Protection Agency (USEPA). "Guidance for Water Quality-based Decisions: The TMDL Process." Assessment and Watershed Protection Division, U.S. Environmental Protection Agency, Washington, D.C.

Young, C. Edwin, and Bradley M. Crowder. 1986. "Managing Nutrient Losses: Some Empirical Results on the Potential Water Quality Effects." *NJARE*:15(2)130–36.

Young, C. Edwin, Bradley M. Crowder, James S. Shortle, and Jeffrey R. Alwang. 1985. "Nutrient Management on Dairy Farms in Southeastern Pennsylvania." *Journal of Soil and Water Conservation.* 40(5):443–45.